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Generator Gas

The Swedish Experience from 1939–1945

Translated by the Solar Energy Research Institute

Solar Energy Research Institute
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GENERATOR GAS

The Swedish Experience -Gas 1939-1945

3rd Edition with Index

A translation of the Swedish book GENGAS, which describes the conversion of the Swedish motoring fleet and stationary engines to the use of gas generated from wood or charcoal during the Second World Was.

Originally published in Swedish by the Ingneiorsvetenskapsakademien (Swedish Academy of Engineering) and printed by the Generalstabens Litogrfiska Anstaits Forlag, Stockholm 1950.

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FOREWORD

This book "Generator Gas" (in Swedish Gengas) summarizes the scientific, technical and Commercial information developed during World War II when Sweden, cut off from fossil fuels, converted 40% of its entire motor vehicle fleet to burning wood. Again we face a period when fossil liquid fuels are increasingly scarce and expensive and when we will have to find substitutes. We have translated this book because we believe the information contained will save the enormous cost of rediscovering the data and experience gained by Sweden, and will enable scientists and engineers engaged in gasifier projects to build upon what is already known.

The gas generator for motor vehicles was developed at an astonishing speed during the war years. It is quite possible that we may never need to use gas generators for vehicles because we may develop electric cars or synthetic alcohol or gasoline fuels for portable use. Nevertheless, we feel that the gas generator has a new important role for retrofitting existing gas/oil boilers to biomass fuels, for operation of stationary engines for irrigation and power generation, and possibly for operation of turbine engines. We believe that the information in this book will speed development of these alternatives.

We would like to thank Prof. Gunnar Hambraeus and the Swedish Academy of engineering for permission to translate GEWNGAS, and for additional information that thy have supplied from more recent Swedish work. We would also like to thank Maria Geuther of Boulder, Colorado, for translating the Swedish book into English. We have enjoyed our share of the scientific editing of this very interesting chapter of technological history and feel that our overall program in gasification at SERI is greatly strengthened by our knowledge of the details found in this book.

Thomas B. Reed and Dan Jantzen January 1979

PREFACE TO 3RD EDITION

This is the 20th anniversary of the publication of GENERATOR GAS and we are including a history of its publication and more recent gasifier developments for historic interest. A Mr. Agua Das (later my co-author on other books) learned of the existence of our first edition in 1979, but could not find it in libraries - until he learned it was in Government Documents files and there was no ISBN number. When he finally found a copy he decided to publish it in his TIPI (Technology in the Public Interest) Press. He was in bed with the flu when he read it, so decided to make an index. He printed 500 copies, reduce to 5 1/2 X 8 in size for handy pocket reading (and to save printing costs). We have included his index in this volume, but returned it to its original size.

In 1979 I met Prof. Dick Bailie at the University of W. Virginia. He was the proud owner of a 75 hp Swedish WWII gasifier which he bought for $150 (and shipped to the U.S. for $900). SERI/NREL gave him a contract to operate this gasifier on the new wood pellets and also on oxygen. We were amazed to discover that the gasifier could operate quite well on pellets and even more amazed that it would operate on 100% oxygen with only a 50°C rise in hearth temperature! Later he gave that gasifier to SERI/NREL and it was used in half a dozen projects.

In 1985 I met a Dr. Harry LaFontaine who had formed the Biomass Energy Foundation (BEF). He had manufactured gasifiers during WW II as a cover for his Danish Underground activities. Harry owned the JENSEN CIRCUS for several years before he came to the U.S. and appreciated the value of showmanship. The limousine shown on the cover was initially intended for the Shah of Iran, but when the Shah died, Harry purchased it to demonstrate gasification at Eastern Universities and lecture on alternate energy.

I joined the BEF and started reprinting books under the BEF Press name. Harry died in 1994 and left the BEF to me to continue his work in this field. We now list 12 books in our catalogue (see end pages) and will be adding more. We have also given our books ISBN numbers and this is ISBN 1-890607-01-0.

Based on our oxygen gasifier work SERI/NREL permitted me to design a high pressure oxygen gasifier to make synthesis gas for synthetic methanol, and Prof. Graboski (Colorado School of Mines) and I invented and developed a new type of gasifier, the "stratified downdraft gasifier" (a straight cylinder with no choke plate as shown in this book). A principle advantage was that air entered the top of the bed, so the gasifier could be scaled to any size. Not true with side nozzles. He eventually scaled this gasifier to 25 tons/day, 30 inch diameter and 75 tons/day, 50 inch diameter.

Since then I have continued to work on gasifiers and am currently writing a "Survey of Biomass Gasification" in two volumes to detail the changes in the field since the publication of this first book in 1979. Meanwhile, Dan Jantzen works at a high level in the Winrock Foundation. We believe that gasifiers have a great future, as well as the great past detailed in this book.

Thomas B. Reed, February 1998

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*This chapter is a summary of the original material published in Swedish.

**Chapter 13 has been omitted as not relevant to present-day American interest in gas generators.

Chapter 1

HISTORY

Up to the Outbreak of the War in 1939

Generator gas has been used extensively since the middle of the 19th Century in the iron working industry for the firing of furnaces. A Swedish design which first attracted attention was the gas generator invented by Gustaf Ekman at Lesjofors and named "Ekman's Coal Shaft Furnace." [21] It was described in Jernkontorets Annaler 1843 (Annals of the Swedish Ironmasters Association, 1843). The "downdraft principle" (gases passing down through the firebed) of this generator is, on the whole, the same as that used for most gas generators for fueling engines. The first proposal for the use of generator gas for engines appeared in 1877 and the engine was run for the first time around 1881. It was used for stationary operation, and because the gas is sucked by the engine through the generator, the gas was usually called "suction gas." The first gas generator specifically constructed for stationary engine operation did not come into existence until the beginning of the 20th Century. Something similar, however, was described in an English patent as early as 1859.

With the outbreak of war in 1939, the use of generator gas for vehicular operation increased, and the head of the Swedish Board of Trade, Axel J. Enstrom, proposed the Swedish name "GENGAS,"* which soon was accepted in this field. Gas for firing industrial furnaces, however, is still usually called generator gas.

Not until around 1920 were there portable gas generators worth mentioning which could be used for motor vehicles although experiments had been carried out much earlier. [55] At this time, portable gas generators were attached to trucks as well as to tractors. There was interest in France in this development, and the firm of Panhard & Lavassor manufactured the first gas generator for practical use. Another French design was the Gohin-generator, which can be considered the forerunner of generators not enclosed in brick and with water vapor added. In Germany there was also great interest in generator gas operation; the best known is Imbert's gas generator for wood.

In 1918 Axel Swedlund of Sweden designed an updraft charcoal generator, and in 1924 the first of his downdraft designs was manufactured. [58] During 1923 and 1924, a few Austrian charcoal gas generators of Julius Heller's design were imported to Sweden and tried on trucks, buses, and railcars. These updraft gas generators produced a gas with a rather high tar content, which was difficult to remove. Although the best available beech charcoal was used, during the first long drive (625 kilometers) [50] the truck motor used for the experiment had to be taken out after about 300 kilometers and thoroughly cleaned of tar. Trial runs during 1925 to 1926 showed that starting and driving using only charcoal gas was possible, but not convenient. For example, starting directly on coal gas was time consuming and troublesome even when the fire in the gas generator had been lit

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*In English, approximately "wood gas," "generator gas," or "manufactured gas," but there is no exact equivalent.

beforehand. In those cases where there was a starting fan it was hand operated and not sufficiently effective. Generally, no modifications had been made to the engines, which had relatively little power even when run with gasoline; and when run on generator gas, down-shifting of the gears was required on even moderate inclines. Therefore, gasoline was preferred for starting and warming up the engine; gasoline was also used to increase the climbing ability of the car when necessary.

By the end of the 1920s the first charcoal gas generators were made in Sweden. They used a downdraft design and were mainly intended for farm tractors, and were soon followed by designs for trucks and cars. At the same time, an interest developed in wood as a gas generator fuel, and the first wood gas generator in Sweden was designed by the Widegren brothers and A. B. Svenska Flaktfabriken (The Swedish Fanfactory, Inc.). This gas generator used a downdraft fire and was double jacketed with the rectangular section enclosed in brick. This wood burning gas generator was tried out on trucks in the early 1930s, but there was considerable tar residue deposited in the motor and corrosion of the crankshaft necks. Since the results of the experimental operations did not match expectations and there was a lack of consumer interest, the work was not pursued.

At the Swedish Riksdag (Parliament) in 1930, bills were introduced to support generator gas operation of motor vehicles; and in the following year a government committee was appointed on the initiative of Ingeniorsvetenskapsakademien (The Swedish Academy of Engineering Sciences) to perform scientific and practical experiments with generator gas driven vehicles. The committee received a government grant of 15,000 kronor*, and experiments were carried out with three different types of gas generators.

In 1932 the Riksdag (Parliament) appropriated 200,000 kronor ($53,600 U.S.) for a loan fund for car owners who wished to install gas generators. In addition, the vehicle tax was reduced to half that imposed for operation on liquid fuel. The vehicle tax reduction amounted in practice to 33%, due to the weight of the gas generator. These measures led to a rapid increase of generator gas operation in 1932, and the total number of generator gas operated cars in Sweden during the first half of 1933 reached about 250; practically all of these cars were equipped with charcoal gas generators. This increase, however, was followed by a drastic decrease mainly due, on the one hand, to the fact that many hastily produced gas generators were introduced on the market by inexperienced manufacturers and proved to be seriously defective; and on the other hand, to the fact that in the transition to generator gas operation, insufficient attention was paid to whether the vehicle and type of traffic in question were actually suited for generator gas operation. To this must be added the shortage of personnel knowledgeable in generator gas technology, imperfect service, and the difficulty of obtaining suitable charcoal for which there was no organized distribution.

The disappointment with generator gas operation was undoubtedly justified in many cases because the technical conditions for satisfactory operation were not met. But even in cases where the conditions for good results existed, the generator gas operation met with resistance among most consumers. It was quite natural, of course, that to those concerned with driving and car upkeep, the more convenient and cleaner operation with

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*The exchange rate (January 4, 1932) was one kr equalled $0.268.

liquid fuel was more attractive than was generator gas operation. It was also understandable that the big oil companies did not welcome new competition.

Another factor of importance was that the generator gas operation was not necessitated by an obvious emergency but was supported by motives less apparent to the average man—reasons that had to do with military preparedness, forestry, and national economy. However, a small number of car owners, who either drove their own generator gas cars or encouraged their hired chauffeurs with bonuses, continued with generator gas operation and had good results, especially when they were able to solve the fuel problem by burning charcoal from their own forest.

Military authorities showed an interest in generator gas as early as 1925 by buying the first Swedish truck adapted to such operation, which was tested with both charcoal and wood gas generators. In 1933, at the initiative of the Generator Gas Committee of the Academy of Engineering Sciences, thorough experiments on a large scale were started by the Army on a number of different types and sizes of trucks equipped with modern (for that time) types of gas generators. Civilian interest does not seem to have been particularly stimulated by these tests. A contributing factor which was particularly unfavorable for generator gas operation was the relation between gasoline and charcoal prices in Sweden; the approximate ratio between gasoline price per liter and charcoal price per kilogram in Sweden was 2:8; but in France, 4:3; in Austria, 6:4; and in Italy, 11:4 (as of 1937).

The increased interest for military preparedness caused the head of the Royal Ministry of National Defense to engage three experts from the government to assist with an investigation concerning generator gas operation of motor vehicles. Under the name "The Gas Generator Committee of 1937" the investigators started their work in February 1937 and delivered partial reports on December 9, 1937, [55] and a final report on July 8, 1939. [57]

When wood gas operation was still considered to be in the experimental stage the Committee initially planned on generator gas operation based on charcoal. It was established that the gas generators had been significantly improved since the experiments in 1931 to 1932. Among other things the heat of combustion had risen from 550-580 kcal/Nm^3* (66-70 Btu/scf) since the early tests to 620-650 kcal/Nm^3 (75-79 Btu/scf). The starting time had been reduced considerably by addition of an electric starting fan and a central air nozzle into the gas generator. Thus direct starting on generator gas without the use of liquid fuel became possible and practical. Improvement in the design of gas exhausts had brought about greater dependability, and interference by slag formation or carbonization was minimized. Also, better nozzle designs eliminated the slag formation on the hearth sides. Motor operation with generator gas was improved; idling characteristics were almost equal to gasoline operation, and engine power per liter of cylinder capacity had been improved. Generator gas operation was considered most suitable for long nonstop driving, but the experiments had shown that satisfactory results also could be obtained in very intermittent operation. With regard to the engines, the opinion was that relatively large cylinder capacity and low rpm were of considerable importance for obtaining favorable results.

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*1 kcal/normal m^3 = 0.121 Btu/scf

After the fall of 1937, a somewhat greater interest in generator gas operation could be sensed in Sweden. Prior to the outbreak of the war, some 20 to 30 gas generators were sold in the country, and the number of generator gas operated civilian and military vehicles in Sweden probably was somewhat more than a hundred when the war broke out. Before the war the price of automotive charcoal was very low in Sweden, 0.07 kr to 0.08 kr per kilogram. This price probably did not give the correct value of the wood, which consisted of waste wood without real value. An even lower price could be obtained by buying uncrushed charcoal and crushing it at home. The prime cost then was often less than 1 kr per hectoliter, or about 0.05 kr per kilogram of hardwood charcoal.

The Outbreak of the War in 1939

As background for the development of generator gas operation during the Second World War, I would like to introduce some data concerning the growth of the Swedish car fleet during the years 1935 to 1939 (i.e., during the economic boom before the war).

Table 1. INCREASE OF AUTOMOBILE VEHICLES IN SWEDEN DECEMBER 31, 1935 - DECEMBER 31, 1939

Dec. 31	Cars	Buses	Trucks	Total
1935	109,096	3,914	41,803	154,813
1936	119,303	4,165	44,575	168,043
1937	134,296	4,558	53,093	191,947
1938	156,573	4,894	57,734	219,201
1939	180,717	5,109	63,028	248,854
% Increase 1935-39 . .	66	30	50	60

The growth of the car fleet might have continued during the following years if the war had not interfered. It is therefore natural that the automotive transportation system experienced great difficulties caused by the outbreak of the war on September 1, 1939, and by the accompanying commercial blockade, which created shortages in the supply of liquid fuel to Sweden. Because of this, the right to drive motor vehicles powered by liquid fuel and the right to buy such fuel were severely restricted as early as the first days of September 1939. Further restrictions and even total prohibition seemed conceivable.

As mentioned in the preceding section, the final report of the Gas Generator Committee of 1937 became available just before the war broke out and showed comparatively advantageous and positive results, while at the same time about one hundred generator gas operated motor vehicles were in practical use in the country. An inventory of alternatives to gasoline and diesel oil pointed to generator gas as the only possible path. Thus, generator gas was placed in a good position. When the war broke out there were Swedish charcoal gas generators already tested and fabricated.

As early as September 6, the head of the Royal Swedish Ministry of Supply appointed experts to advise on questions concerning generator gas, to follow the developments in the field, and to prepare and submit to the government proposals to hasten a transition to generator gas operation. The experts were named "The Government Generator Gas Committee."

With the intention of furthering a transition to generator gas operation with sound methods, the Generator Gas Committee recommended that the government take certain measures similar to those proposed by the Gas Generator Committee of 1937. Among other things, they recommended control over production, installation, and use of gas generators including approval of design and construction, and licensing of construction in assembly plants.

The Generator Gas Committee also proposed a provision for instruction courses for drivers and mechanics working with generator gas vehicles, provision for the production and supply of charcoal, facilitation of loans and an increase of the loan fund (see below), and finally, government acquisition of a number of generator gas operated tractors.

On November 10, the charter for the Generator Gas Committee, subordinate to the National Swedish Industry Commission, was confirmed. According to the charter it was the duty of the Committee to undertake necessary investigations and experiments to perfect gas generator operation; to work for the production of technically excellent generator gas units; and, through advice and directions, to ensure that the installation of the units was managed satisfactorily. The same day, the government authorized the National Swedish Testing Institute for Agricultural Machinery, together with the Generator Gas Committee, to promptly investigate the possibility of adapting farm tractors to generator gas operation.

As early as March 20, 1933, the Inspector of Explosive Substances issued a bulletin of precautionary measures for generator gas operation of motor vehicles. On October 10, 1939, the Inspector of Explosive Substances issued a new bulletin containing instructions on the use and maintenance of gas generators. These instructions were soon replaced by joint instructions issued by the Generator Gas Committee and the Inspector of Explosive Substances on November 28, 1939. The instructions were completed on April 23, 1940, by the Generator Gas Committee, at which time advice was also given to assembly shops. Complementary additions and revisions were made through the years by the successor of the Generator Gas Committee, the Generator Gas Bureau, within the Government Fuel Commission. (See Chapter 13.)

In September 1939, former producers of gas generators as well as certain automobile manufacturers started large-scale production of gas generators after they had secured licenses from the designers. Intensive work on new designs began in many places, mainly for charcoal gas but also for wood gas generators. There was a high demand for gas generators even though many people were skeptical and pursued a wait-and-see policy. The charcoal gas generator market was initially controlled by three brands: Svedlund, Greygas, and Volvo.

Indisputably, the early gas generators were not fully developed and had some technical deficiencies. Also, the installation and service turned out to be less than satisfactory due to the shortage of trained personnel. There was also a lack of drivers familiar with generator gas operation and aware of the necessity of systematic cleaning and care of the generator gas apparatus, as well as the adaptation of driving techniques to the characteristics of generator gas. Added to this were the great difficulties in many places of acquiring charcoal at a reasonable price, since charcoal distribution was still not satisfactorily arranged. Finally, the fire and poisoning risks associated with generator gas operation became apparent.

Under these circumstances it is easily understandable that the generator gas operation in the beginning was a source of miscalculation and loss for many people. This was true especially in the professional trucking business, where the early expectations of generator gas were not met, resulting in serious economic consequences.

Steps to remedy these shortcomings were undertaken immediately. In September 1939, the Generator Gas Committee (in cooperation with the Army, a car company, and workers' organizations) began educational courses for drivers and mechanics, which laid the foundation for the furthering of generator gas operation. These study courses expanded considerably during 1940, and training was given to around 15,000 drivers and mechanics during the first generator gas years. Many were also trained by private initiative. The Generator Gas Committee instituted a generator gas license for generator gas vehicle drivers, proving that the person in question had passed a test in front of an inspector and was a competent driver of a generator gas vehicle.

To the extent that the Generator Gas Committee had experts available, they gave much advice; and in spite of many difficulties during the early period, they tried to make the best of the generator gas operation. Undoubtedly, this work was of great importance to car owners, who for one reason or another could not handle the generator gas operation.

Funds were provided to the Generator Gas Committee for testing of existing types of gas generators and for investigating their installation on different types of cars. During September 1939, the Gas Generator Committee began testing various types of gas generators and issuing certificates of approval. This testing was not obligatory, but boosted the sales of a manufacturer because it provided a guarantee of construction and performance to the buyer of a gas generator. In connection with the testing the Generator Gas Committee also had an opportunity to give advice to the manufacturers. During the latter part of December 1939, the first 18 approval certificates were issued: 17 for charcoal gas and one for wood gas. Of the first 100 approval certificates, 64 were for charcoal gas and 36 for wood gas. By the end of 1940 the number of certificates had grown to 177; by December 1941, to 370; and by December 1943, to 489, of which about 130 had, for different reasons, been revoked. In November 1945, there were 503 types approved, distributed among 53 different companies, manufacturers, or designers. The approval certificates were divided approximately equally between charcoal gas operation and wood gas operation. (See Chapter 13 for testing standards.) Later, testing of different auxiliary parts of generator gas operation was established; e.g., motor heaters, fire shields, fire extinguishers. This was done partially in cooperation with other authorities and the insurance companies.

The Generator Gas Committee considered an adequate supply and distribution system for reasonably priced charcoal to be one of the most important conditions for effecting a transition to generator gas operation. (See Chapter 3.)

One question that the Generator Gas Committee addressed early was whether the market for gas generators should be left uncontrolled or should be subjected to some form of government regulation and standardization. The latter alternative would have as its goal to ensure that, as far as possible, only satisfactory types of gas generators would be produced, thus protecting the buyers. On the other hand, the alternative of free development would encourage private work on inventions and private initiative, which in turn would regulate prices and promote further development in the field.

In the fall of 1939, legal provisions were proposed to forbid the installation of gas generators on motor vehicles without a permit. This idea, however, was abandoned and the market was left uncontrolled with the resulting advantages and disadvantages. Only for obtaining loans from the Generator Gas Fund was it required that the gas generator be of an approved type. In addition, restrictions concerning the installation and use of gas generators were introduced in order to reduce the risks of fire and poisoning. Anyone had the right to freely manufacture and sell a gas generator, as well as use it after a motor vehicle inspector had inspected and approved the mounting. The disadvantage of the free market approach was that a variety of poorly designed generators were produced, and many buyers suffered great losses not only in the form of poor gas generators but also in the form of ruined motors. The number of different untested gas generators, the so-called handicraft units, was indeed very large. Without a doubt, much material and work could have been saved if from the beginning development had been aimed at a limited number of types of gas generators with far reaching standardization.

Many times the related question has been raised regarding the possibly legally binding character of certain of the instructions and precautionary directions of the Generator Gas Committee (later, the Government Fuel Commission's Generator Gas Bureau). The authorities, however, did not choose this policy, and therefore these instructions and precautionary directions have only been found binding by a court of law to the extent that failing to adhere to them could be considered negligence or recklessness, punishable by law (i.e., causing fire, poisoning or other damage).

When the war broke out, close to 200,000 kr were available in the Generator Gas Loan Fund. According to the regulations, loans of a maximum of 1,000 kr could be obtained, to be paid over 5 years at 4% interest. The Gas Generator Committee of 1937 had proposed that loans should be granted up to 80% of the cost of purchase and installation, up to a maximum of 2,000 kr. The Generator Gas Committee brought out these proposals on September 11, 1939, and also proposed that the fund should be increased to 2 million kr. On November 10, 1939, the Government confirmed the various conditions and provisions of the loan fund according to the Generator Gas Commission proposal. No installments were required during the first year, after which one-tenth of the loan was to be paid off every half year, at an interest rate of 3%.

At first the loan fund was not used a great deal. During the second half of 1939, 107 loans were granted, of which 88 were for trucks; during the first half of 1940, 250 loans were granted, of which 217 were for trucks. The loan terms were not considered especially attractive, as long as collateral was required. Therefore, the Generator Gas Committee proposed on March 9, 1940, an improvement of the loan terms by substituting for the requirement of collateral a control of the borrower's solvency over a period of time. On October 11, 1940, new loan provisions were confirmed by the government with no payments due during the first six months and thereafter an installment of one-tenth of the principal every four months. The requirement of collateral for the loan was handled by the Royal Swedish Board of Commerce in consultation with the Emergency Committee.

During the second half of 1940 no less than 4,460 loans were granted; an additional 4,010 were granted during the first half of 1941. After that the number of loans decreased rapidly. In 1942 a total of 21.7 million kr were invested in the fund; and by January 1, 1942, the outstanding loans amounted to 15 million kr. By January 1, 1943, the outstanding loans amounted to only 10.25 million kr and by January 1, 1944, to about 5,375,000 kr.

During the budget year 1940/1941, a grant was also given to a government loan fund for the acquisition of generator gas units for certain vessels. Only 12 loans were granted from this fund, for a total of 59,190 kr. During the same budget year grants were also given for the acquisition of gas generators for fishing boats. Only 7,000 kr was used for this purpose, which was given partly as grants, partly as loans, for five generator gas installations.

By the end of November 1939, the number of generator gas vehicles had risen to about 800, and by the end of 1939 the estimate is about 1,500, mainly large and medium sized trucks in addition to about 100 buses and a few private cars and tractors.

Around the end of 1939, generator gas installations declined because of the increased opportunity to acquire rations of liquid fuel, mostly for the heavy trucking traffic. A comparatively large amount of liquid fuel was imported, and the shortage of storage facilities forced an increased distribution of fuel. Under these circumstances and due to the difficulties related above for generator gas operation, many generator gas cars were gradually taken out of use and many gas generators were dismantled. The manufacturers, who under the influence of the great rush in September had developed the production of generator gas units on a large scale, suddenly saw their market threatened and orders cancelled. Many farseeing owners of generator gas operated cars realized, however, that the increased supply of liquid fuel was temporary and continued operating with generator gas. According to the producers' information, over 3,100 gas generators had been produced by April 1, 1940. However, the number of generator gas cars in use at this time had hardly reached 1,000.

By the end of 1939, and during the first quarter of 1940, the matter of further measures to improve and stimulate the generator gas operation gave rise to proposals and requests from different organizations and individuals, among them the National Swedish Industry Commission, the Chambers of Commerce of Stockholm and Gothenburg, the unions, and professional truck drivers. Among other things, many craftsmen requested increased authority and grants from the Generator Gas Committee. The craftsmen also proposed subsidies for the designers of gas generators, and government assistance for the buyers in the form of lower costs. It was also pointed out that the conditions for obtaining generator gas loans were not very attractive (see above), and government intervention was once again requested for the supply of charcoal.

In view of these requests, the Generator Gas Committee proposed several measures, including government purchase of 1,000 gas generators for government vehicles and for military preparedness, improvement of the loan terms, tax exemption for generator gas cars or equivalent subsidies, free educational courses, and increased grants for consulting work by the Generator Gas Committee.

The change in the war situation in April 1940, and the shortage of liquid fuel rations which followed, rekindled interest in gas generators. The generator gas cars returned to use, dismantled gas generators were once again installed, production was renewed, and installations increased rapidly. By mid-1940 the number of registered generator gas cars reached about 3,000 and after that there was a rapid increase. In the beginning of November 1940, all gasoline rations for civilian traffic were stopped. By the beginning of March 1941, there were 40,000 registered generator gas cars; by the beginning of May 1941, 50,000; and by the beginning of July 1941, 60,000. Then the increase subsided rapidly; not, however, due to the lack of demand but to the restriction of the right to operate a car, necessitated by shortages of lubricating oil and later of rubber tires. Not until November 1941 were there 70,000 generator gas cars in service, with a peak of 71,500 in mid-December 1941.

On April 1, 1942, generator gas vehicle statistics were changed to include only the registered civilian generator gas cars (i.e., to exclude the military vehicles). During the three years between April 1, 1942, and April 1, 1945, the expansion and composition of the car fleet did not change rapidly. The change of the car fleet during the crisis period is demonstrated by Figure 1 and Tables 2 and 3.

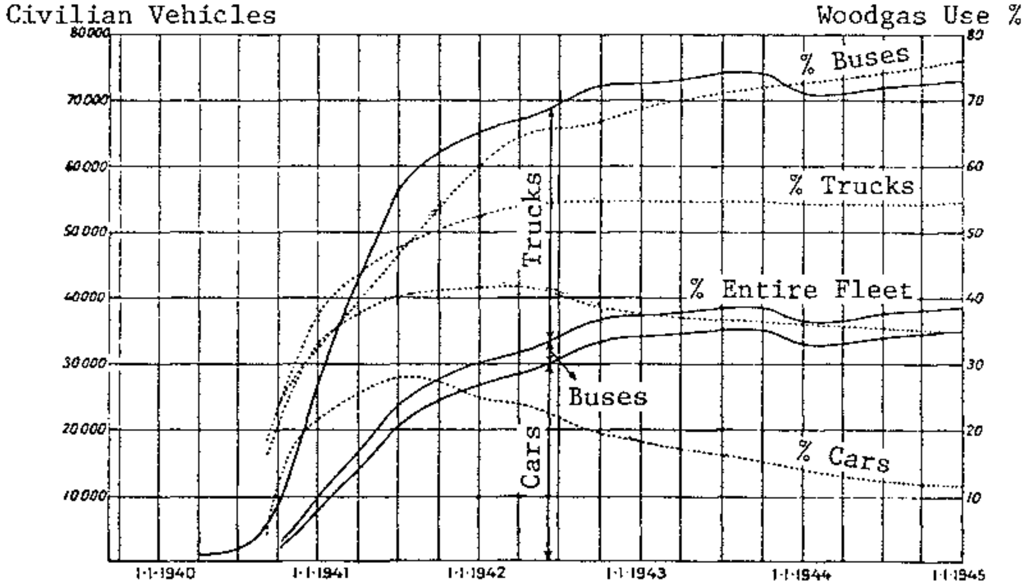

Figure 1. Civilian Generator-Gas Vehicles During the Crises Years

One government action of 1940 was the establishment of Svenska Gengas AB (Swedish Generator Gas Co.) with government funds. The task of the company was to stimulate the production of generator gas units and to conduct experiments. The generator gas company organized large-scale production of wood gas units and devoted considerable attention to units for farm tractors, stationary engines, and boats. The company was also to support and stimulate the production of generator gas fuel and organize its distribution. The company started work in the middle of 1940.

Table 2. WOODGAS OPERATION IN PERCENT OF ACTIVE GENERATOR-GAS CAR FLEET

Date	Private Cars	Buses	Trucks	Average Mean
1 Oct. 1940	13.0	24.0	24.0	22.0
1 April 1941	25.5	40.0	44.0	38.0
1 Oct. 1941	27.0	54.0	50.0	41.0
1 April 1942	23.5	64.5	54.0	41.5
1 Oct. 1942	19.2	66.6	54.5	38.1
1 April 1943	17.0	70.0	54.6	36.9
1 Oct. 1943	15.1	73.3	55.4	36.3
1 April 1944	12.6	73.0	54.0	35.6
1 Oct. 1944	11.8	74.9	54.4	34.9
1 April 1945	11.1	77.0	54.9	34.7

Table 3. THE GROWTH OF THE FLEET OF GENERATOR GAS CARS DURING THE TIME PERIOD OCTOBER 1, 1940 - APRIL 1, 1945

Date	Cars	Buses	Trucks	Total
1 Oct. 1940	2,045	864	6,232	9,141
1 April 1941	14,356	2,904	27,988	45,248
1 Oct. 1941	27,199	3,638	38,035	68,872
1 April 1942[a].	28,479	3,404	35,274	67,157
1 Oct. 1942	33,395	3,416	35,367	72,178
1 April 1943	34,306	3,502	35,096	72,904
1 Oct. 1943	35,068	3,533	35,252	73,853
1 April 1944	32,962	3,526	34,439	70,927
1 Oct. 1944	34,716	3,531	34,416	72,663
1 April 1945	34,854	3,539	34,199	72,592

[a] From April 1, 1942, changed method of statistics. On Figure 1, there is a certain leveling of the curves because of this.

As ordered by the Government on June 14, 1940, the Government Fuel Commission started its work on July 1, 1940; the Generator Gas Committee was made part of the Commission as the Commission's Generator Gas Bureau. During the summer of 1940 the Generator Gas Bureau, together with the National Swedish Industry Commission, the National Swedish Board of Crown Forests and Lands, and the National Swedish Testing Institute for Agricultural Machinery, arranged long-term experiments using various wood gas generators mounted on different types of trucks. The testing program was aimed at investigating the practical problems of wood gas operation, including the preparation of wood fuel in machines of different kinds, air drying of the wood, the suitability of different sizes and shapes of wood, fuel consumption with different wood fuels, maximum driving speeds on different types of roads, etc.

A trend from charcoal gas operation toward increased wood gas operation was very striking during the initial period but decreased and changed to the opposite trend. A somewhat stabilized condition was reached when opinion formed that charcoal gas operation was most suitable for discontinuous driving of private cars and smaller trucks (e.g., delivery vans) in urban traffic where fuel economy was not so important, and that wood gas operation, on the other hand, was more suitable for constant heavy loads where fuel economy was of great importance. In Table 2 the distribution between charcoal and wood gas operation does not include, after April 1, 1942, the military vehicles which were mainly driven with charcoal gas (about 10,000 at the end of the statistical period).

Farm tractors were converted to generator gas operation, which was very important for the Swedish national food supply. Because the supply of motor kerosene and similar fuels was scarce, it became necessary to gradually eliminate liquid fuel rations for tractors, which could most easily be adapted to generator gas operation. In the fall of 1941 over 7,000 farm tractors were shut off from a supply of liquid fuel. Practically the entire transition to generator gas operation for tractors was based on wood gas operation, for which the fuel could be rather easily produced by the farmers themselves from their own forests. The farmers could buy the government subsidized units for a price of 1,000 to 2,000 kr, not including installation. At the beginning of 1942, about 6,000 farm tractors had been converted to wood gas operation. By the end of 1944, the number had reached about 15,000. The entire number of tractors at this time has been estimated to be about 27,500, of which 5,000 were of simple design.

To a lesser extent, small seagoing cargo vessels and fishing boats had also been remodeled for generator gas operation, although only in cases where refueling could be done frequently. Stationary engine generator gas operation had been initiated to some extent, for instance, for stone-crushers, mills and portable sawmills in the forest areas. In the latter case the fuel was made up of waste wood from the premises. Some industrial hearth and forge furnaces, as well as heating furnaces for other purposes, had also been successfully converted to wood-firing, partially with practically unchanged car units and partially with special units.

Among many private initiatives for the promotion of generator gas, two generator gas contests arranged by the Royal Automobile Club deserve mention. In September 1940, the club arranged an economy contest for generator gas cars, with no less than 127 participating private cars and trucks. In one big winter contest in February 1941, 129 private cars and trucks participated in a long distance contest. Both contests gave remarkable results.

Although outside the scope of generator gas operation, it is of interest to note other car fuels in use after the end of the 5-1/2 year war period, indigenous as well as imported. On April 1, 1945, 240 cars were driven with acetylene gas, 531 with coal gas or methane gas, 1,180 with electrical power, and 6,612 with liquid fuels of different kinds. Acetylene gas operation reached its peak during the first part of the war with 769 cars on November 1, 1941, then decreased to 240 cars on April 1, 1945. The entire number of civilian heavy motorcycles decreased by April 1, 1945, to 10,778, of which 939 were driven with generator gas and 1,417 driven with electrical power.

The exceedingly rapid rate of development in the area of generator gas during the two first years of crisis was succeeded by a quieter period characterized by some consolidation, standardization, and inner development. The large number of different types of gas generators underwent the "natural selection" which is normal for new designs. Together with most of the "handicraft units," many approved types gradually disappeared, whereby a needed thinning out among approved types was achieved.

By July 1, 1943, about 73% of the charcoal gas generators and about 81% of the wood gas generators were of an approved type. Only seven types of charcoal gas generators and two types of wood gas generators had over 1,000 generators in operation. About 59% of the approved charcoal gas generators belonged to two types, Svedlund and Kalle. About 74% of the approved wood gas generators belonged to the Imbert or similar type. As late as October 1, 1943, 35% of the private cars were equipped with gas generators of a non-approved type; for busses, the percentage was only about 8%; and for trucks, about 16%. It is easy to understand why the figure for private cars is comparatively high. It is more reasonable to experiment with a "handicraft unit" on one's own private car than on a truck or a public bus. It is remarkable that the wood gas, to a much greater extent than charcoal gas, stimulated private car owners to use homemade units. Thus, in the fall of 1943, less than 47% of the wood gas driven private cars had gas generators of a non-approved type.

Concerning the practical and technical possibilities of generator gas, I would like to add the following to the above history.

A characteristic of gas generators is to produce a gas-air mixture with lower thermal value than a gasoline-air mixture. During the earlier phase of generator gas operation, this characteristic led to the observation that one of the conditions for a practical and satisfactory result with generator gas operation was a comparatively large cylinder volume and a low engine rpm. To allow an increase of the motor compression ratio in order to regain part of the lost motor power, the motor must be strongly built especially in the bearings. Furthermore, the motor must have a well dimensioned inlet manifold and a large range of ignition regulation.

Further, the load capacity of the vehicle should be sufficient, so that the weight of the generator gas unit would not excessively diminish the load capacity. Thus, generator gas operation was best suited for larger vehicles, with long daily routes and continuous driving without long interruptions. A further condition was that the gas generator should be mounted on the car in such a way that the use of the vehicle would not be impaired.

During the last years of the war it was observed that the use of generator gas had expanded to such an extent that it could be regarded as an adequate substitute for liquid fuels—if economic factors were not considered. Generator gas operation had been used on practically all kinds and sizes of motor vehicles with either four-cycle or two-cycle engines, designed for either gasoline or diesel engines. Generator gas had been used on rail-buses, on tractors with crude oil and kerosene engines, on boats of different size categories, in stationary designs, and in heating furnaces of different kinds (e.g., hearth furnaces).

Due to technical improvements the requirement that the generator gas engine must have a large cylinder volume has been largely modified; the same may be said about the rpm of the generator gas engine. Small, relatively high rpm engines as well as large slow running engines have been driven with generator gas. The requirement remains, however, that the engine must be strongly built in those cases where an increase of compression takes place. Through such an increase in compression ratio the decrease of power can be limited under certain circumstances.

Through various measures, among other things the elimination of the ceramic casting, the generator weight has been brought down, in some cases to a considerable extent, especially in small charcoal generators. Therefore, the requirement of comparatively large load capacity of the vehicle has been moderated. The incentive to make the generator gas apparatus less expensive led to reduction of weight which was further motivated by the scarcity of larger tires. Mounting of the generator on the front of the car was done so one did not have to reduce the permitted load or the number of passengers.

The requirement of continuous driving was diminished, because methods had been developed for an easy, dependable, and relatively fast start even after a comparatively long driving interruption.

Finally, during the last years, progress had been made in the adaption of gas generators to the vehicles both in function and appearance. Gas generators no longer detracted from the fitness of the vehicles for use but were integrated as parts of the vehicles to a greater extent than before.

The use of generator gas has been tested in Sweden on ship engines of up to 150 horse power. Most suitable for generator gas operation are the two-cycle engines, which retain their full capacity in such operation. One circumstance which initially reduced the attractiveness of generator gas operation for ships is that dependability is of critical importance for maneuverability in rough weather and in narrow passages. In the present state of technical knowledge, however, practically 100% dependability and fully satisfactory maneuverability can be achieved in generator gas operation of a sea vessel.

It can therefore be said that generator gas operation from a technical and practical point of view is well adapted for use in practically all types of vehicles, including tractors. Furthermore, it is well adapted for use on boats and for stationary engine operation.

It has also been observed that the fuel supply for this operation, even on a large scale, does not have to be a great problem, at any rate not if one uses the fuel saving wood gas operation (rather than charcoal). In general, there is plenty of waste wood and thinned out wood available from forestry operations.

Chapter 2

THE THEORY OF GAS GENERATION

Types of Gas Generators

The devices used for the production of generator gas are called gas generators. They may be designed to operate according to two somewhat different principles: upward burning (updraft) with the gas carried from the bottom upward (Figure 2); and downward burning (downdraft) with the gas carried from the top downward (Figures 3 and 4). Generators with horizontal burning (crossdraft, Figure 5) and the Kalle generator (Figure 6) work somewhat differently from the main types.

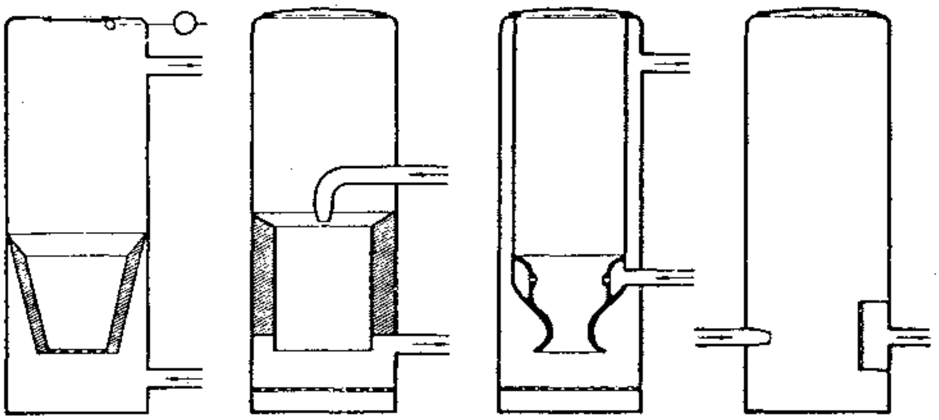

Fig. 2—5.

Updraft Gas Generator	Downdraft Gas Generator with a Central Air Nozzle	Downdraft Gas Generator with Nozzles in a Ring	Crossdraft Gas Generator

The type first used was the updraft generator, as illustrated in Figure 2. The air is taken in through a grating in the bottom of the fuel container. Immediately above this grating a burning zone is created. The gas obtained in this burning is reduced in the adjacent reduction zone, and finally the fuel is freed from vapors and dried in the uppermost cool part of the container.

Generator gas produced for motor propulsion should as far as possible be free from tars, etc. The updraft generator yields tar-free gas only from fuels very poor in gas such as coke, anthracite, and possibly charcoal. However, fuels rich in gas are suitable for the operation of furnaces, particularly if subsequent combustion is carried out close to the generator, where the gas need not be cooled and the tar mist and the tar drops can be burned in the furnace.* In order to obtain gas as free from tar as possible, downdraft

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*This operation is called "close-coupled" and yields a higher energy gas for retrofitting existing gas- and oil-fired boilers. It also eliminates the need for cooling and filtering. - Ed.

generators, as shown in Figures 3 and 4, are used. The air is brought in through a central nozzle* shown in Figure 3 or through a number of nozzles in the annular arrangement shown in Figure 4. The burning area is formed near the nozzles, and from there the gases travel downward through the reduction zone. When wood is used as generator-gas fuel, a degassing and carbonization (pyrolysis) zone is created above the burning zone where the wood is charred due to the heat from the burning zone. Gases, tar vapor, and water vapor are formed in the pyrolysis zone, and charcoal is obtained. The main components of these pyrolysis products enter the burning zone, where they are either consumed or cracked into more volatile components, from which a charcoal residue is also obtained. Charcoal, when heated, may frequently emit small amounts of tar, which may require downdraft operation. In wood gas generators, where the amount of pyrolysis products from the fuel is very large, a restriction of the gas flow has usually been arranged to achieve a partial mixing of the gases and to force those pyrolysis products that have not been a part of the burning process into a zone with high temperature, so that the remaining tar mist will be cracked. In the horizontal burning shown in Figure 5, the air is taken in through a horizontal nozzle, and the gas taken out through a vertical grate on the opposite side. The burning zone is formed next to the nozzle and the reduction zone adjacent to the burning zone.

The principle of the Kalle generator is demonstrated in Figure 6. Here the air is taken in through a central pipe together with a certain amount of cinders, smoke, and gases with a content of carbon dioxide. The burning zone is formed around the lower end of the pipe, and the reduction takes place immediately outside and above the burning zone. The generator gas formed is sucked into a pipe, which encloses the air feed pipe.

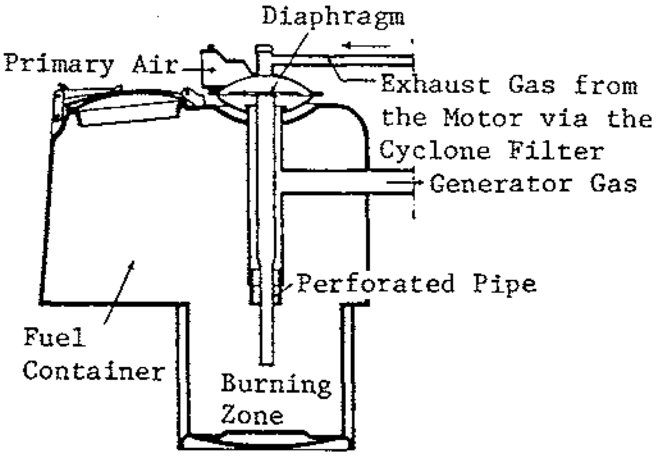

Figure 6. Kalle Generator

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*Often called "Tuyerres" (French) - Ed.

Principal Reactions

The production of generator gas, which is a "gasification" or partial combustion of a solid fuel, is, like the total combustion of solid fuel, a reaction at a high temperature between the oxygen of the air and the solid fuel. In total combustion there is usually a surplus of air or oxygen; in gasification there is a surplus of the solid fuel. The combustion products from complete combustion consist mainly of nitrogen, water vapor, and carbon dioxide, as well as a surplus of oxygen. However, if there is a surplus of solid fuel, water vapor and carbon dioxide may pass through a glowing layer of charcoal and be reduced into the combustible gases, carbon monoxide (CO) and hydrogen (H_2). The degree of reduction is dependent on the chemical and physical conditions.

The combustible substance of a solid fuel is usually composed of the elements carbon, hydrogen, and oxygen. In addition, there may be nitrogen and sulfur, but since these are present only in small quantities they will be disregarded in this context. In complete combustion, carbon dioxide is obtained from the carbon in the fuel, and water is obtained from the hydrogen, usually as steam. The oxygen in the fuel will, of course, be a part of the combustion products, and therefore the amount of oxygen needed for complete combustion is decreased.

The following chemical reaction formulae describe this burning:

$$C + O_2 = CO_2 \tag{1}$$

$$H_2 + 1/2\ O_2 = H_2O \tag{2}$$

The quantity of heat generated by the burning of the coal is to some extent dependent upon the origin of the coal. Thus, the following quantities of heat are obtained from the burning of 1 gram atom, i.e., 12.00 g coal, into carbon dioxide.

Graphite	393.5 kJ (94.0 kcal)
Black coal coke	401.9 kJ (96.0 kcal)
Brown coal coke	409.4 kJ (97.8 kcal)

A heat quantity of 241.1 kJ (57.6 kcal) results from the burning of 1 mole, i.e., 2.016 g, hydrogen into water vapor.

The main combustible components of generator gas are carbon monoxide, hydrogen, and methane. In addition, there may be small amounts of other hydrocarbons and tar vapor. These, however, are not generated in the generator gas process itself but originate from the products that are formed when the solid fuel is heated and decomposed (pyrolyzed). In addition to the combustible gases, generator gas also contains a great deal of nitrogen as well as carbon dioxide and water vapor. A gas containing a very small amount of nitrogen may be obtained in some processes such as the production of "water gas" by reduction of water vapor with carbon, or by gasification with oxygen instead of air. These processes, however, are of no importance for producing generator gas for motor propulsion.

The most important reactions that can take place in the reduction zone and between the gases formed are given below. The stated heat quantities are in kJ (kcal) per mole, where the burning of the carbon has been assumed to yield 401.9 kJ (96.0 kcal). A plus sign indicates that heat is generated in the reaction; a minus sign, that the reaction requires heat.

$$C + CO_2 = 2\ CO \quad -164.9\ (-39.4) \tag{3}$$

$$C + H_2O = CO + H_2 \quad -122.6\ (-29.3) \tag{4}$$

$$CO_2 + H_2 = CO + H_2O \quad -42.3\ (-10.1) \tag{5}$$

$$C + 2\ H_2 = CH_4 \quad +83.3\ (19.9) \tag{6}$$

$$CO + 3\ H_2 = CH_4 + H_2O \quad +205.9\ (49.2) \tag{7}$$

Equations (3) and (4), the main reactions of reduction, show that the reduction requires heat. Therefore, the gas temperature will decrease during the reduction--unless a corresponding quantity of heat is supplied from the outside.

Chemical Equilibrium*

The composition of the gas produced by a generator depends on the degree of equilibrium attained in the various reactions. The ratio of reactants in a reaction at equilibrium is usually expressed by the so-called equilibrium constant, k, which can be derived in the following way.

If in a given space there are molecules of two gases that can react with each other, not only will molecules of the same kind collide but molecules of different kinds as well. The reaction velocity, (the change in concentration per unit of time in the substances participating in the reaction) is dependent upon the number of molecules present. If we assume that n_A molecules of the substance A and n_B of the substance B will react with one another and yield $n_{A'}$ molecules of a substance A' and $n_{B'}$ of a substance B', we can write the following reaction equation:

$$n_A \cdot A + n_B \cdot B \rightleftarrows n_{A'} \cdot A' + n_{B'} \cdot B' \tag{8}$$

The speed of this reaction is the product of the amount of A, the amount of B, and a factor k, which is < 1, since not every molecular collision, but only a fraction of them, bring on a reaction. The condition for two molecules to react with each other is that they must have greater energy than the average molecule. We then arrive at the following reaction velocity,

$$v = k \cdot C_A^{n_A} \cdot C_B^{n_B} \tag{9}$$

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*The following derivation of the equilibrium constant, k, is similar to that found in any modern thermodynamic textbook. (TBR) where C_A and C_B are the molar concentrations of the substances A and B. At the same time, however, as demonstrated in Equation (8), the substances A' and B' may react with each other so that the reaction will go to the left. Analogously the velocity for this reaction will be

$$v' = k' \cdot C_{A'}^{n_{A'}} \cdot C_{B'}^{n_{B'}} \tag{10}$$

The two opposite reactions are striving toward equilibrium, and when equilibrium has been reached, the two velocities v and v' must be equal, thus,

$$v - v' = k \cdot C_A^{n_A} \cdot C_B^{n_B} - k' \cdot C_{A'}^{n_{A'}} \cdot C_{B'}^{n_{B'}} = 0 \tag{11}$$

From this equation we derive the following equilibrium constant

$$K_c = \frac{k}{k'} = \frac{C_{A'}^{n_{A'}} \cdot C_{B'}^{n_{B'}}}{C_A^{n_A} \cdot C_B^{n_B}} \tag{12}$$

In place of the molar concentrations, the partial pressure of the gases p may be introduced, provided that the laws for ideal gases apply. Then the equilibrium constant will be defined as

$$K_p = \frac{p_{A'}^{n_{A'}} \cdot p_{B'}^{n_{B'}}}{p_A^{n_A} \cdot p_B^{n_B}} \tag{13}$$

The connection between the two equilibrium constants is

$$K_p = K_c \cdot (R\ T)^{\Sigma n} \tag{14}$$

where R is the gas constant, T the absolute temperature, and Σn is the algebraic sum of the mole numbers of the substances participating in the reaction according to Equation (15).

$$n = n_{A'} + n_{B'} - (n_A + n_B) \tag{15}$$

If $\Sigma n = 0$ and the same mole number appears on both sides of the reaction sign, the reaction is independent of the pressure. If, for example, the mole number is bigger on the right side, this means that the reaction is connected with a volume increase. A pressure increase will then force the reaction back to the left.

The equilibrium constant K_p is a function of the temperature; its value for various reactions may be experimentally determined. The equilibrium constants of several reactions have been determined directly from measurements of the partial pressures of gases at different temperatures. However, the direct method suffers from the weakness that a relatively long time is required for equilibrium to ensue. It is now possible, however, to calculate the equilibrium constants from spectroscopic measurements. [17]

The Equilibrium State of the Generator-Gas Reactions

The equilibrium state of the reaction described in Equation (3) is expressed by the equilibrium constant

$$K_{pB} = \frac{p^2_{CO}}{p_{CO_2}} \tag{16}$$

The subscript B refers to Boudouard, who was the first to study this equilibrium thoroughly.

If the reacting substances are carbon and pure carbon dioxide only, the partial pressure of the two gases can then be calculated by means of the value of the equilibrium constant according to Equation (16).

In gas generation with air, however, the nitrogen of the air must be taken into account. The primary combustion equation for carbon may then be written

$$C + O_2 + 3.76\ N_2 = CO_2 + 3.76\ N_2 \tag{17}$$

and the reduction

$$C + CO_2 + 3.76\ N_2 = 2\ CO + 3.76\ N_2 \tag{18}$$

If the total pressure of the gases is denoted by p, the volumes of the various gases will be

$$v_{CO_2} = \frac{p_{CO_2}}{p}; \quad v_{CO} = \frac{p_{CO}}{p}; \quad v_{N_2} = \frac{p_{N_2}}{p}$$

Then

$$K_{pB} = \frac{p^2_{CO}}{p_{CO_2}} = \frac{p^2 \cdot v^2_{CO}}{p \cdot v_{CO_2}} = p \cdot \frac{v^2_{CO}}{v_{CO_2}}$$

or

$$K_{pB} = p \cdot \frac{v^2_{CO}}{v_{CO_2}} \tag{19}$$

Further

$$v_{CO_2} + v_{CO} + v_{N_2} = 1 \tag{20}$$

and, as a consequence of O_2 always being equivalent to 3.76 N_2,

$$v_{CO_2} + \frac{1}{2}\ v_{CO} = \frac{1}{3.76}\ v_{N_2} \tag{21}$$

With the help of Equations (19), (20), and (21) we can calculate the composition of the gas at equilibrium, if we know the value of K_{pB}. In Table 4 the equilibrium constant and composition are given for various temperatures for a pressure of 1 atmosphere (760 mm Hg).

Table 4. EQUILIBRIUM CONSTANT K AND GAS COMPOSITION FOR GAS GENERATION FROM CARBON AND AIR AT A PRESSURE OF 760 mm Hg

Temperature °C	K_{pB} %	v_{CO} %	v_{CO_2} %	v_{N_2} %
500	0.00469	3.00	19.18	77.82
600	0.09610	11.59	13.99	74.42
700	1.061	24.90	5.93	69.17
800	7.42	32.38	1.41	66.21
900	37.40	34.19	0.31	65.50
1000	146.2	34.61	0.08	65.31
1100	468.7	34.71	0.02	65.27

According to the table at 1100°C, at equilibrium practically complete reduction of CO_2 to CO occurs.

If we combine Equations (1) and (3) we get

$$C + \frac{1}{2}\ O_2 = CO \quad + 118.4 \quad (28.3) \tag{22}$$

This equation corresponds to the final result of the generator gas production from charcoal. Thus, there is a heat release of 118.4 kJ (28.3 kcal), equivalent to 118.4/401.6 = 0.295 of the combustion heat of the carbon. The heat generated would produce a gas temperature of about 1300°C, neglecting heat losses. If the hot generator gas is used immediately for combustion, all the heat of the carbon could theoretically be available. If, on the other hand, the gas must be cooled without utilizing the sensible heat before combustion, some heat loss will occur because of the cooling. Apart from other losses, if the gas is chilled to room temperature the efficiency of the generator will be only about 70%, which would then be equivalent to the heating value of the gas.

To better use the energy of the carbon and also to limit the maximum temperature of the generator, one may add for example, coke, anthracite, or completely dry charcoal, or large or small quantities of water, which is best fed into the generator as steam with the primary air. One may also, as in the Kalle generator of Figure 6, bring back exhaust gases from the motor, which contain carbon dioxide but practically no oxygen.

When wood is used as a generator-gas fuel, normally no water needs to be added, since the wood contains sufficient quantities of both physically absorbed water and chemically combined water—frequently even unnecessarily large quantities. The situation is similar for charcoal with a suitable moisture content—the heat-demanding reduction of water vapor occurs as a consequence of the water mixture, and carbon monoxide and hydrogen are formed as shown in Equation (4). If exhaust gases are added, heat will be absorbed by the reduction of the carbon dioxide, according to Equation (3).

If water vapor is present in generator-gas production, the gas composition will depend upon the so-called water-gas reaction expressed by Equation (5). The corresponding equilibrium constant (independent of the pressure), is

$$K_v = \frac{p_{CO} \cdot p_{H_2O}}{p_{CO_2} \cdot p_{H_2}} \qquad (23)$$

Methane may conceivably be formed according to Equation (6) or (7). As a rule, however, the formation of methane is of minor importance. The most favorable temperature for methane formation is between 300°C and 400°C, and at higher temperatures the equilibrium is shifted toward rapidly decreasing quantities of methane. For the reaction of Equation (6) the equilibrium constant may be written

$$K_{pM} = \frac{p_{CH_4}}{p^2_{H_2}} \qquad (24)$$

The formation of methane can also be represented by Equation (7). It is of little importance which equation is used since Equation (6) may be obtained from Equations (7) and (4); the latter reaction also takes place in the gas generator. For the reaction of Equation (7) the equilibrium constant will be

$$K_M = \frac{p_{CH_4} \cdot p_{H_2O}}{p_{CO} \cdot p^3_{H_2}} \qquad (25)$$

The values of the equilibrium constants for the various reactions are compiled in Table 5 (mainly according to Gumz [17]).

In Figure 7, the equilibrium constants are shown graphically. In this graph we have chosen 1/T as abscissa, where T is the absolute temperature (°K), and log K as ordinate. With this system of coordinates we get practially straight lines for the equilibrium constants.

Table 5. EQUILIBRIUM CONSTANTS FOR GENERATOR GAS REACTIONS

	Boudouard	Water Gas	Methane	
Temperature °C	K_{pB} Eq. (16)	K_V Eq. (23)	K_{pM} Eq. (24)	K_M Eq. (25)
500	0.00469	0.2047	2.731	119.
550	0.0233	0.2872	1.152	14.2
600	0.0961	0.3881	0.5363	2.17
650	0.3399	0.5060	0.2713	0.404
700	1.061	0.6404	0.1472	0.0888
750	2.936	0.7889	0.08477	0.0228
800	7.421	0.9514	0.05140	0.00660
850	17.27	1.125	0.03259	0.00212
900	37.40	1.308	0.02148	
1000	146.2	1.695	0.01029	
1100	468.7	2.100	0.00549	

The values of the equilibrium constants over a temperature range of 600 to 900°C are shown in Figure 8.

Reaction Velocities and Reaction Processes

Calculations concerning the process taking place in a gas generator have been carried out primarily on the basis of material balances, heat balances, and equilibrium equations. However, one necessary condition for reaching correct results by this method is that equilibrium is indeed obtained in the generator. Opinions differs as to whether that is the case.

A great many laboratory experiments have been conducted to determine the reaction velocity for the reduction of carbon dioxide or water vapor with carbon. Figure 9 shows the result of an experiment by Rambush [11] on the reduction of carbon dioxide with carbon in the presence of nitrogen for various reaction times. The experimental equilibrium curve in these experiments is equivalent to the time $t = \infty$. A curve representing the values according to Table 4 has been drawn in the graph. The dashed curve represents the probable equilibrium curve. The deviation between the two curves for $t = \infty$ indicates that Rambush did not attain the states of equilibrium at the lower temperatures, when the reaction velocities are low. According to Rambush's experiment, as shown in the graph, considerable time is required for the carbon dioxide reaction, even if the temperature is fairly high. It hardly seems probable to attain equilibrium with the gas velocities normal for a gas generator.

According to Traustel's [47] experiments one can arrive at values in good agreement with real experimental values by calculation of the gas composition in the gas generator using the equilibrium equations. It is Traustel's opinion that the reaction velocities cannot be applied directly, since they are determined in laboratories and are frequently obtained from carbon and carbon dioxide in tubes, which are heated from the outside where the heat transfer will not be very good. In practice, combustion takes place directly

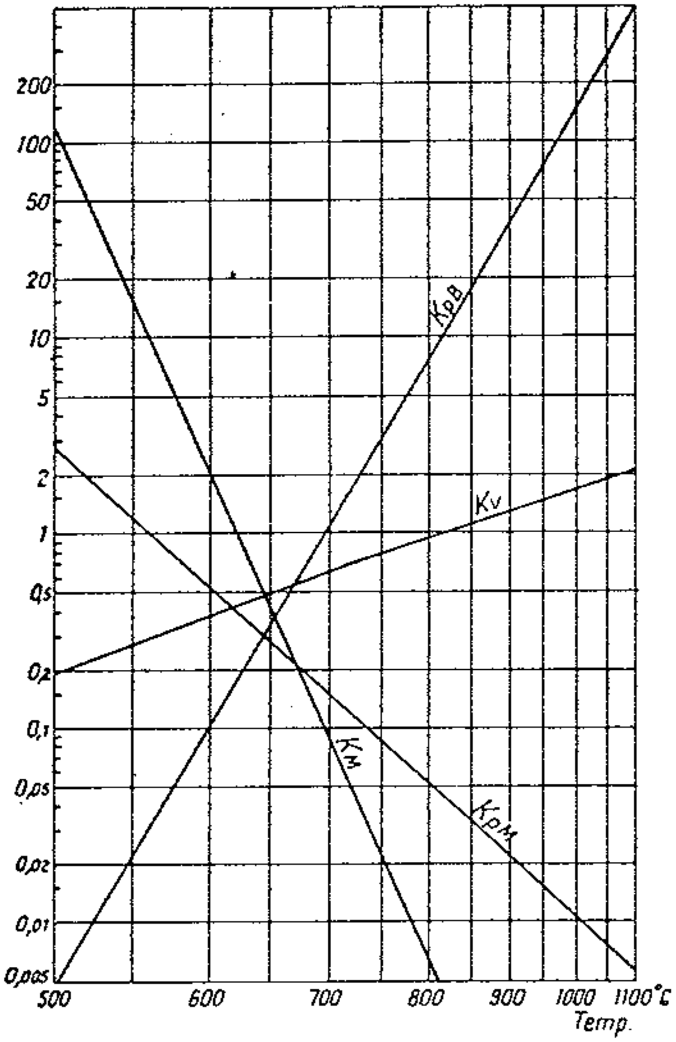

Figure 7. Equilibrium Constants for Generator Gas Reactions

$$K_{pB} = \frac{p^2_{CO}}{p_{CO_2}};\ K_v = \frac{p_{CO} \cdot p_{H_2O}}{p_{CO_2} \cdot p_{H_2}};\ K_{pM} = \frac{p_{CH_4}}{p^2_{H_2}};\ K_M = \frac{p_{CH_4} \cdot p_{H_2O}}{p_{CO} \cdot p^3_{H_2}}$$

followed by the reduction; and through this burning, as well as through the catalytic influence of ashes, a more rapid reduction occurs.

Experiments carried out in large industrial coke generators also show that equilibrium is not attained in the reactions. [19] The main reactions take place in the hot layer immediately above the slag zone. The experiments also show that there is no combustion into exclusively carbon dioxide, which would give a very high temperature. Instead, a mixture of carbon dioxide and carbon monoxide is formed during combustion, after which the carbon dioxide is in part reduced with the coal into carbon monoxide. This latter experience corresponds with what has been found in the burning of carbon in oxygen at a very low pressure. [16] According to experiments on the reaction between graphite and oxygen, two different reaction processes occur depending upon the temperature.

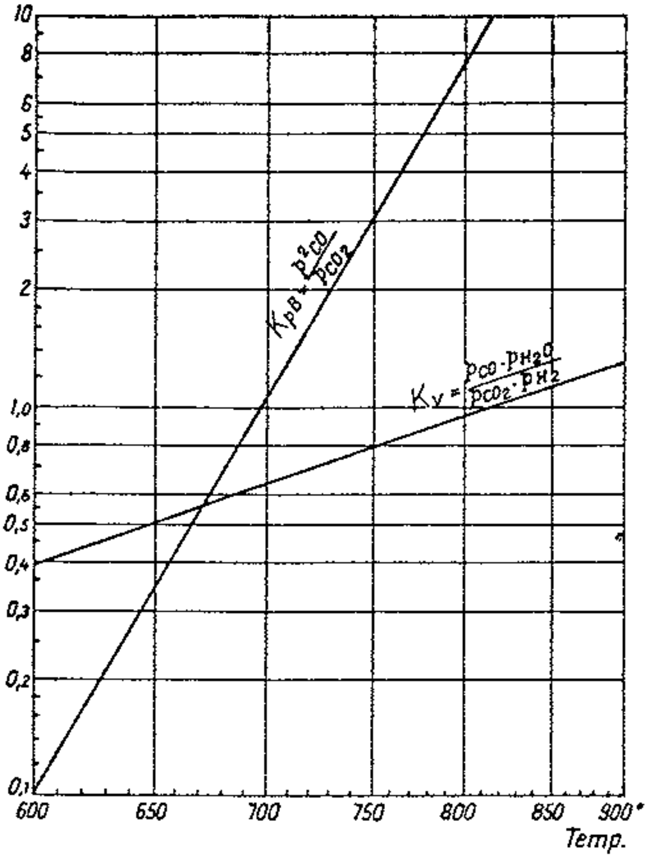

Figure 8. Equilibrium Constants over the Temperature Range 600-900°C

At temperatures between 900°C and 1300°C the theory suggests that the oxygen molecules penetrate the graphite lattice according to Figure 10. The oxygen molecules 3-4 and 5-6 are between the first and second atom layers of the graphite, and molecules 1-2 react from the gas space outside. The oxygen molecules 1 and 4 react with carbon atom 8, and 2 and 5 react with carbon atom 9 to form two molecules of CO_2; while oxygen atoms 3 and 6 react with carbon atoms 7 and 10 to form two molecules of CO. The reaction is then expressed by

$$4\ C + 3\ O_2 = 2\ CO_2 + 2\ CO \qquad (26)$$

The reaction does not occur at edges and corners but on the best developed surfaces.

At temperatures above 1500°C the course of reaction is different. The solubility of the oxygen in the graphite is then so small that the reaction from within does not occur; and, therefore, the reaction cannot occur on the surfaces. However, because of the increased temperature, the edges of the lattice are loosened and the oxygen can react there. According to Figure 11, the suggested mechanism is that two oxygen molecules react together with three carbon atoms, so that the reaction process will be

$$3\ C + 2\ O_2 = CO_2 + 2\ CO \qquad (27)$$

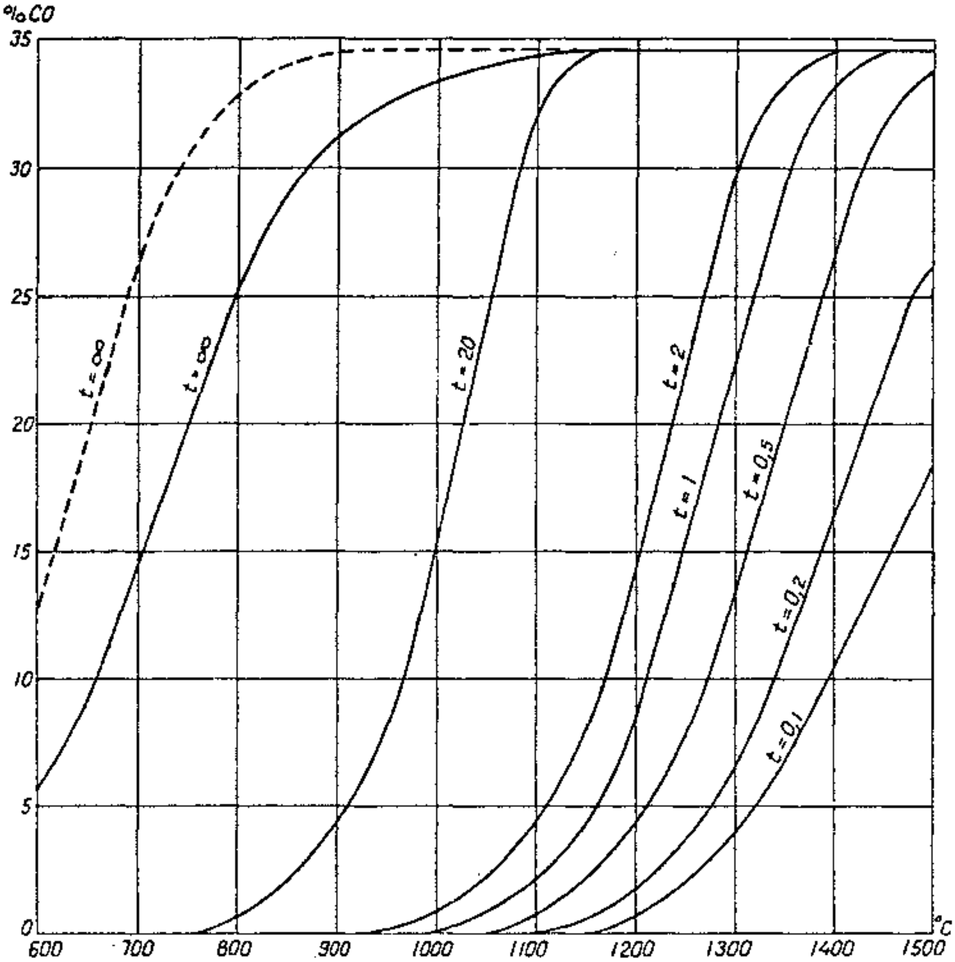

Figure 9. Reduction of Carbon Dioxide with Carbon, According to Rambush. (The reaction time t is stated in seconds. The dashed curve refers to the equilibrium according to Table 4.)

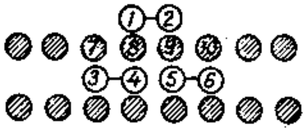

Figure 10. Diagram of the Combustion of Carbon at Temperatures Between 900 and 1300°C

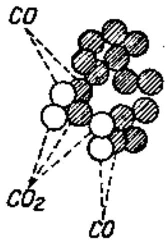

Figure 11. Diagram of the Combustion of Carbon at Temperatures Above 1500°C

The reaction is with oxygen which has been absorbed on the surface, and not with oxygen molecules hitting from the gas space. Within the range from 1300°C to 1500°C there is no active mechanism for the burning of carbon.

In an ordinary combustion process, where there is a surplus of oxygen, there is a subsequent burning of the carbon monoxide; while in gas generation there is a reduction of the carbon dioxide formed initially.

Thus, there are different views as to the possibilities of reaching the state of equilibrium in a gas generator during gas production. Since this question is quite important for the theoretical estimation of generator gas production, it will be discussed further.

If the reaction velocity during combustion or gasification could be infinitely great, the reaction could then be concentrated to an infinitely thin layer; and chemical equilibrium would be attained immediately. This would cause the generator gas formed initially at a high temperature to adopt, at every moment during cooling, the composition corresponding to the temperature. Experience proves, however, that combustion as well as gasification requires a certain amount of time. In reality, a finite, sometimes fairly long time, is required for the combustion or the gasification; therefore a corresponding volume is required, such as the volume of a gas flame or the flames in a furnace.

If in this context we disregard the ignition process, where special factors may come into play, the process of combustion and gasification is made up first of a physical transport of oxygen, carbon dioxide, or water vapor to the fuel; then the real reaction between the gas in question and the fuel, which is a chemical process; and finally a transport away of the products formed. The time requirement for the entire reaction is then the sum of the time required for the physical processes and the reaction time of the chemical process. If these times differ considerably, the slowest process will on the whole determine the reaction time.

In general it may be said that the reaction time is directly proportional to a driving force, and inversely proportional to a reaction resistance. If the reaction resistance is denoted by W, it will be composed of the physical resistance, W_{phys}, usually the diffusion resistance, and the chemical reaction resistance W_{chem}, according to Equation (28).

$$W = W_{phys} + W_{chem} \tag{28}$$

The driving force may be expressed as a concentration difference. It may be made proportional to the difference between the concentration c in the reacting gas at a great distance from the reaction zone and the equilibrium concentration a at the reaction surface. We may then write the reaction equation

$$\frac{dx}{dt} = \frac{c - a}{W_{phys} + W_{chem}} \cdot f \tag{29}$$

where x is the rate of the reaction, t is the time, and f is a dimension constant dependent upon the units chosen.

If the physical resistance is a clear diffusion resistance, the reaction rate should be inversely proportional to the diffusion constant. This occurs when the flow to the fuel surface is laminar. If the flow is turbulent, the physical resistance decreases when the flow velocity increases and becomes inversely proportional to a mixing coefficient. The physical resistance is generally not to a great extent dependent upon temperature.

The chemical resistance, on the other hand, is highly dependent upon the temperature, so that the reaction resistance rapidly decreases when the temperature rises. When catalysts influence the reaction rate, as a rule only the chemical resistance is influenced;

therefore, catalysts are not very important at high temperatures, as in burning processes. At the temperatures encountered in the reduction process of gas generation and where the chemical reaction resistance is relatively large, catalysts may, however, influence the progress.

Both the physical and the chemical reaction resistances are on the whole inversely proportional to the surface of the solid substance, and therefore, as is well-known, a large reaction surface increases the reaction velocity. The reaction is shown graphically in Figure 12, where the temperature is assumed to be the only factor influencing the reaction velocity. The gas velocity and other factors which could influence the process are consequently assumed to be constant.

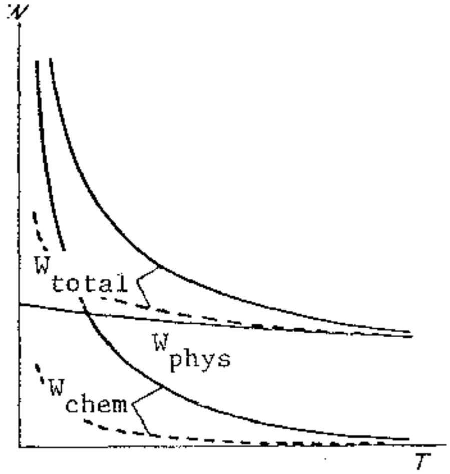

Figure 12. Reaction Resistance, W, as a Function of Temperature, T. (The dashed curves show the resistance when a catalyst is used.)

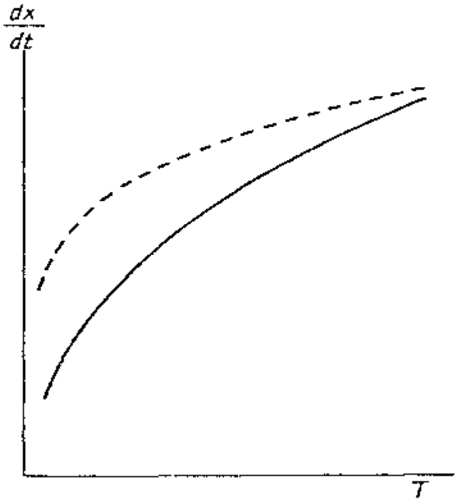

Figure 13. Reaction Velocity dx/dt as a Function of the Temperature, T. (The dashed curve shows the velocity when a catalyst is used.)

The reaction velocity, which according to Equation (29) is inversely proportional to the reaction resistance, will then depend upon the temperature, as shown in Figure 13. If the chemical reaction resistance can be brought down by a catalyst to, for example, 1/5 at all temperatures, as shown by the dashed curve in Figure 12, the total resistance will also be decreased and the reaction velocity increased. Figure 13 shows that the increase of the reaction velocity manifests itself primarily at lower temperatures. Even if the chemical resistance could be brought down to zero by means of catalysis, unlimited velocity of reaction could still not be achieved because of the remaining physical resistance.

It also appears from Equation (29) that the reaction velocity will go toward zero when the concentration c approaches the equilibrium value a. This fact and the occurrence of the reaction resistances make it impossible to attain the state of equilibrium theoretically in a finite time.

These discussions, however, give no indication as to whether it is practically possible to reach the state of equilibrium in a reaction. Experimental determinations are needed to decide this question; many have already been carried out, and the results of such experiments are shown in Figure 9.

In an experiment by H. Edenholm and T. Widell [12] on the catalytic effect of soda on the reduction of carbon dioxide with charcoal, the reaction resistance during the various tests has been estimated. The experiments were carried out with pure carbon dioxide and charcoal and briquettes in an electric furnace. The incoming carbon dioxide was preheated to the reaction temperature before it was passed over the charcoal layer. The temperature was measured with thermocouples inside the reaction layer in two places, to insure accurate measurement of the temperature actually present during the reaction. The gas, having passed the reaction layer, was taken out for analysis through a water-cooled probe. The carbon monoxide content values obtained in tests with charcoal without a catalyst at various gas velocities are shown in Figure 14. The gas velocity is given in m^3/s of added carbon dioxide, calculated at 20°C and per m^2 cross-section area of the reaction pipe, disregarding that part of the area which is occupied by the charcoal. The length of the reaction layer was 200 mm. If the volumetric efficiency of the briquettes in the pipe is assumed to be 0.6 and that of the gas 0.4, then the reaction time at, for instance, 0.015 m^3/m^2s and at 1000°C will be:

$$\frac{0.2 \cdot 0.4}{0.015} \cdot \frac{273 + 20}{273 + 1{,}000} = 1.2 \text{ seconds}$$

At 0.104 m^3/m^2s the reaction time will be 0.18 second, if the temperature is 1000°C.

The influence of soda as a catalyst is shown in Figure 15. The equilibrium curve drawn in Figures 14 and 15 has been calculated with the help of values in Table 2 and Equation (16). In the graphs it is shown that the states of equilibrium have not been reached at all during the tests, not even with a catalyst.

The reaction resistance has been calculated for the tests without catalysts and for the tests with a 4.2% soda mixture. The result is shown in Figure 16. The continuous curves, which give the total resistance, show that the reaction resistance at a constant temperature is decreased with increasing gas velocity.

At a single temperature the chemical reaction resistance should remain unchanged; thus, the reduction of the reaction resistance should depend upon a reduction of the physical resistance. From the tests we deduce that the physical resistance is approximately inversely proportional to the 0.65th power of the gas flow. With the help of this relation we can calculate the total reaction resistance at an infinitely great gas velocity, with the physical resistance fixed at zero. This reaction resistance, which is shown with dashed curves in Figure 16, then represents the chemical reaction resistance. The physical resistance is obtained as the difference between the total resistance and the chemical resistance. Figure 16 also shows that adding the catalyst does not seem to affect the physical resistance. The chemical reaction resistance on the other hand is greatly changed, and this is particularly prominent at low temperatures. Even with maximum catalytic action, however, the reaction resistance increases rapidly when the temperature falls below 900°C. Hence, the reaction resistance is about five times as great at

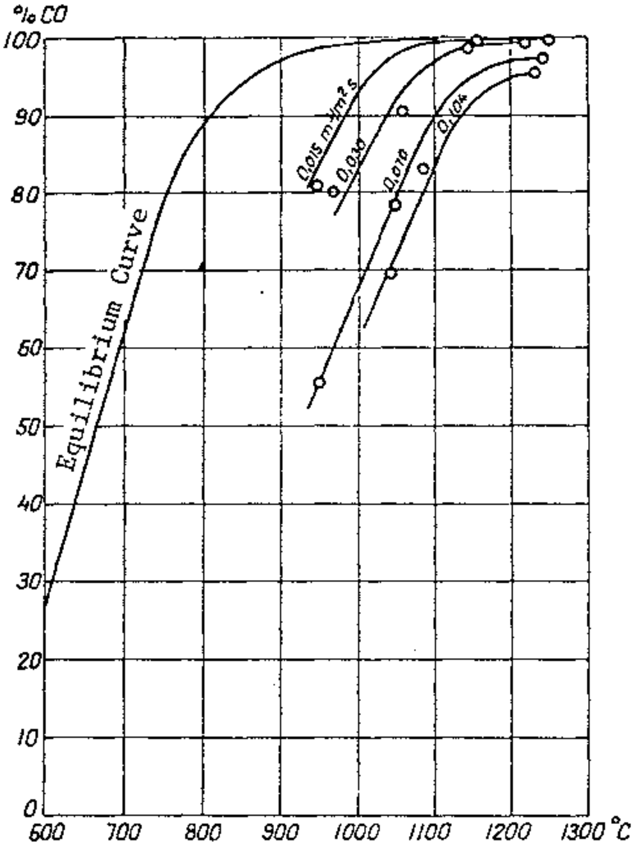

Figure 14. Reduction of Carbon Dioxide with Charcoal at
Various Temperatures and Various Gas Velocities

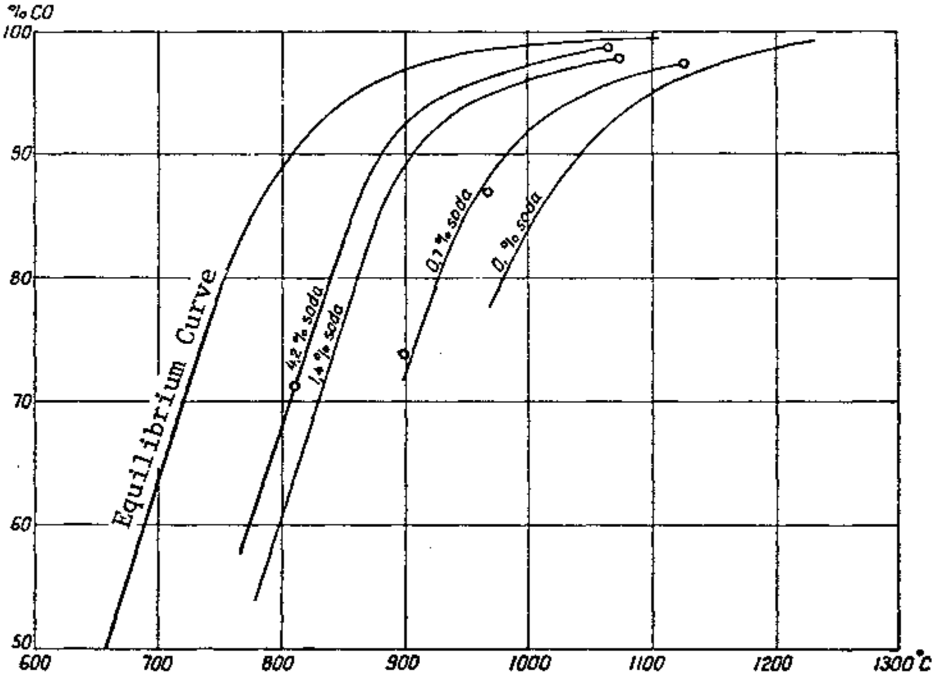

Figure 15. Reduction of Carbon Dioxide with Charcoal, using
Soda as a Catalyst

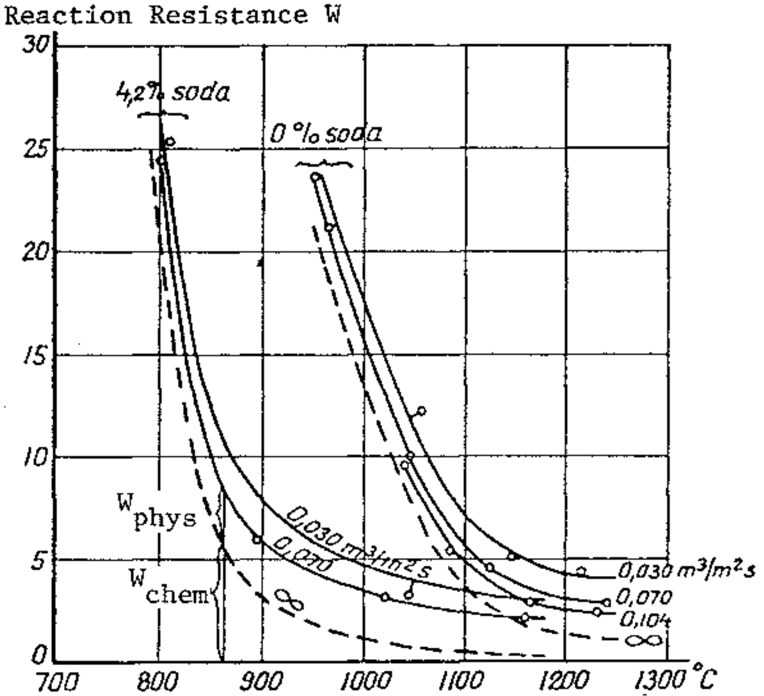

Figure 16. Reaction Resistance, W, in the Reduction of Carbon Dioxide with Charcoal, with or without Soda as a Catalyst

800°C as at 900°C for a gas velocity of 0.07 m^3/m^2s. This velocity is approximately equivalent to a gas velocity of 0.4 m^3/m^2s in a gas generator, which is a very low value. (0.14 Nm^3/cm^2h)

According to this experiment, some reaction resistance remains even in the presence of a catalyst at the velocities encountered in a real gas generator. Thus, it is impossible for equilibrium to occur.

When water vapor is reduced with carbon, the circumstances are similar to those that occur when carbon dioxide is reduced with carbon. The effects of temperature and time upon the decomposition of water vapor are shown in Figure 17 according to the experiments of Clement and Adams. Figure 17 is reproduced from the work of Lutz, [35] who did not, however, define the quality of carbon used in the tests at different temperatures. In both cases a solid substance participates in the reaction. The analysis of the gas obtained with water vapor present is, however, as mentioned earlier, dependent on the water-gas equilibrium. Only gaseous substances can participate in the water-gas reaction; therefore, the prospects are greater that one would get closer to the state of equilibrium here.

Control Over the Reduction

It is possible to get an idea of how close to equilibrium a gas generator is, by taking gas samples from different parts of the reaction zone and at the same time measuring the temperature at these points. The gas samples are analyzed and from the resulting

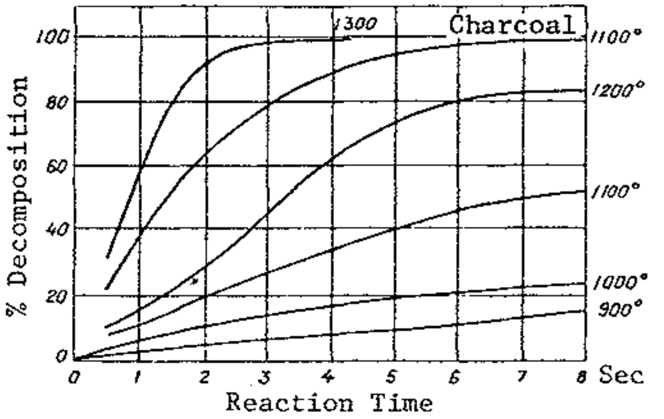

Figure 17. Decomposition of Water Vapor with Coal, According to Clement and Adams

analyses the equilibrium constant can be calculated; then, from Table 5 or Figures 7 and 8, the corresponding temperature can be determined. A comparison of the temperature determined in this way and the measured temperature will show to what extent one is approaching the state of equilibrium. In determining these values it is very important to choose the sampling point so as not to have the gas temperature lowered by heat dissipation after the reaction is finished. It is also important to know the water vapor content of the gas, which may be determined either directly or through fuel analysis and analysis of dry gases using the process described in the section "Calculation of Gas Quantity and Generator Efficiency from Fuel and Gas Analysis."

The application of the method mentioned above is best demonstrated by an example. In an experiment with a wood-gas generator, gas samples were extracted immediately underneath the hearth, where the reaction was practically complete and where the temperature was measured to be approximately 930°C. By calculating from the wood analysis and the analysis of dry gas, the amount of water vapor was determined--10% by volume of the dry gas. The analysis of the dry gas and the analysis of the moist gas as calculated from this were the following:

		Dry Gas	Moist Gas
CO_2	%	11.0	10.0
O_2.	%	0.1	0.1
CO	%	19.0	17.3
H_2.	%	18.8	17.1
$C_n H_m$.	%	0.1	0.1
CH_4.	%	0.8	0.7
N_2.	%	50.2	45.6
H_2O.	%	----	9.1

Thus, according to Equation (23), for the water-gas reaction the equilibrium constant will be:

$$K_V = \frac{p_{CO} \cdot p_{H_2O}}{p_{CO_2} \cdot p_{H_2}} = \frac{v_{CO} \cdot v_{H_2O}}{v_{CO_2} \cdot v_{H_2}} = \frac{0.173 \cdot 0.091}{0.100 \cdot 0.171} = 0.92$$

The equilibrium temperature corresponding to this value is approximately 790°C; this temperature is 140°C below the measured temperature.

For the Boudouard equilibrium according to Equation (16), if the total pressure of the gas is assumed to be 760 mm Hg, we obtain:

$$K_{pB} = \frac{p^2_{CO}}{p_{CO_2}} = \frac{(0.173)^2}{0.100} = 0.30$$

The equilibrium temperature corresponding to this is approximately 640°C; i.e., 290°C below the measured temperature.

Thus, the calculated equilibrium temperatures are considerably below the measured temperature, which shows that equilibrium has not been reached. For the water-gas reaction the temperature difference is smaller than for the carbon monoxide reduction, which indicates that the water-gas reaction is faster. This may be a consequence of the fact that the water-gas reaction is a homogeneous reaction, where only gases participate, while the carbon dioxide reduction is a heterogeneous reaction, where a solid substance also participates.

Temperature in the Reduction Zone

It is also interesting to know at what temperature the reduction process takes place. The curves in Figure 14 show for instance that if the gas velocity values are moderate, a temperature of from 1000°C to 1100°C is needed to achieve a fairly complete reduction. To obtain a reduction to 90% carbon monoxide, which according to the equilibrium curve would require a temperature of 800°C, 980°C was required according to the tests at the lowest gas velocity and 1140°C at the highest. The curves in Figure 9 also indicate that the temperature should be within this range in order to obtain a satisfactory reaction velocity.

The graphs above, however, refer to laboratory tests, which is the reason that some uncertainty exists when they are applied in practical cases. For instance, in Traustel's opinion, considerably greater reaction velocities would occur in practical cases than in laboratory tests; therefore, in practice temperatures as high as required in the laboratory tests would not seem to be necessary.

At the request of the Swedish Generator Gas Co., a series of measurements of the temperature in different parts of the charcoal layer in a wood-gas generator was conducted at the Steamheat Institute of the Academy of Engineering Science by Torsten Widell. The gas generator used in the measurements was an Imbert generator, type GMR-S 130-50-16; during the tests the original hearth was exchanged for a V-hearth from the Swedish

Generator Gas Co. The tests were conducted with hearths of various sizes, from 100 to 145 mm diameter. Tests were also carried out with Imbert's original hearth, using air nozzles of various sizes. The generator was stationary and connected to a car with the rear wheels on a dynomometer to measure the power at the rear wheels. The car engine had six cylinders with side inlet valves, a cylinder capacity of 3.67 liters, and a compression ratio of 5.9.

The temperature was measured with sliding horizontal thermocouples in that part of the charcoal bed situated between the hearth and the jacket of the generator, and also with a vertically sliding thermocouple close to the center line of the generator. In all the tests, which were carried out at car velocities of 35 and 70 km/h and maximum power, about the same temperature distribution was obtained in the generator. In Figure 18 the results of the measurements at 70 km/h are shown and in Figure 19 the results at 35 km/h. For an Imbert generator with the original hearth, similar temperature curves were obtained and are shown in Figure 20.

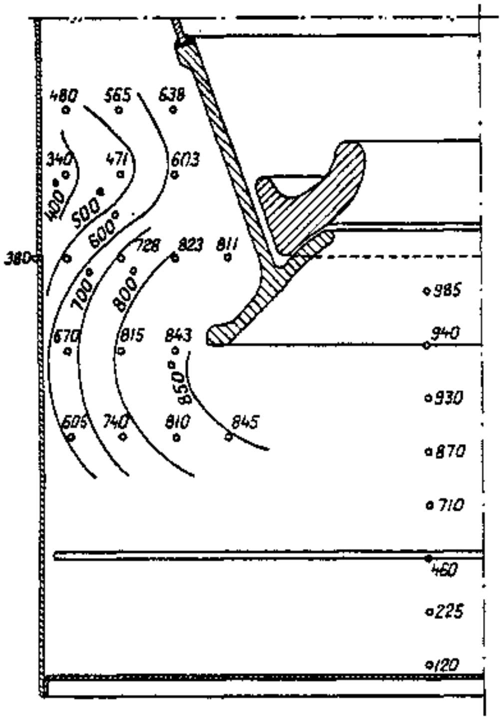

Figure 18. Temperatures in an Imbert Generator with a 130-mm Minimum Diameter V-Hearth; Car Velocity, 70 km/h; 23 hp at Rear Wheels

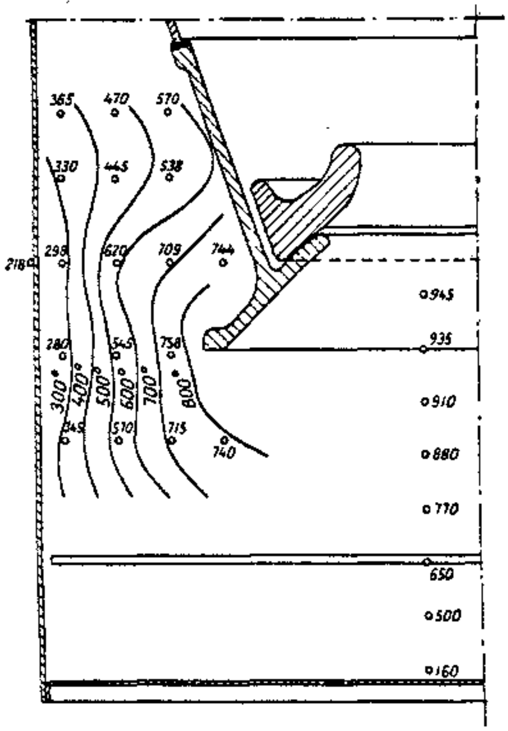

Figure 19. Temperatures in an Imbert Generator with a 130-mm Minimum Diameter V-Hearth; Car Velocity, 35 km/h; 14.5 hp at Rear Wheels

The temperature curves in Figures 18-20 are, on the whole, parallel to the outer mantle of the generator. This indicates that the outer charcoal bed (a layer of relatively fine charcoal, placed below and around the lower part of a wood gas generator to serve as a gas-transmitting heat insulation, as a filter, and a bed for the charcoal in the hearth) only serves as heat insulation; thus no extensive reduction occurs here. If a more extensive reduction were to occur here, a more pronounced decrease in temperature in the path of the gas flow would occur. The temperature is below 850°C in almost all of this part of the generator. The concavity of the curves obtained in the upper part of the outer charcoal bed is due to cooling the generator mantle by blowing cold air over it.

Measurements were also made without the outer charcoal bed and without the main part of the coal bed normally situated below the hearth, as shown in Figure 21. In this test nearly the same power was obtained at the rear wheels, indicating that the gas reaction was completed when the gas left the hearth, where a temperature of 820°C was measured.

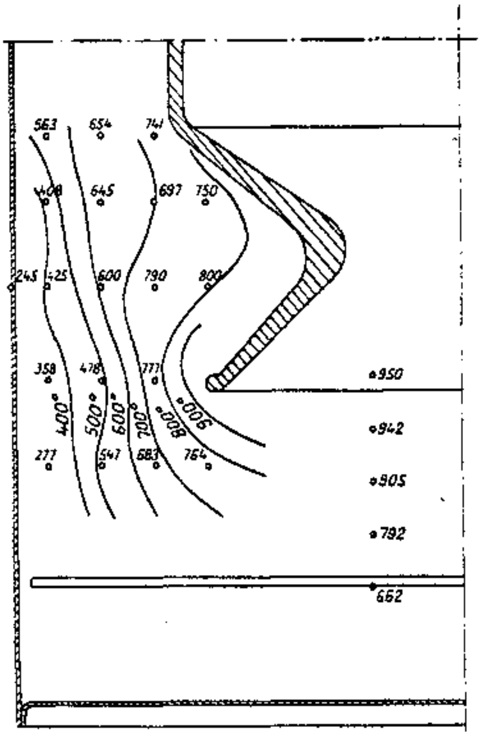

Figure 20. Temperatures in an Imbert Generator with Original Hearth; 70 km/h

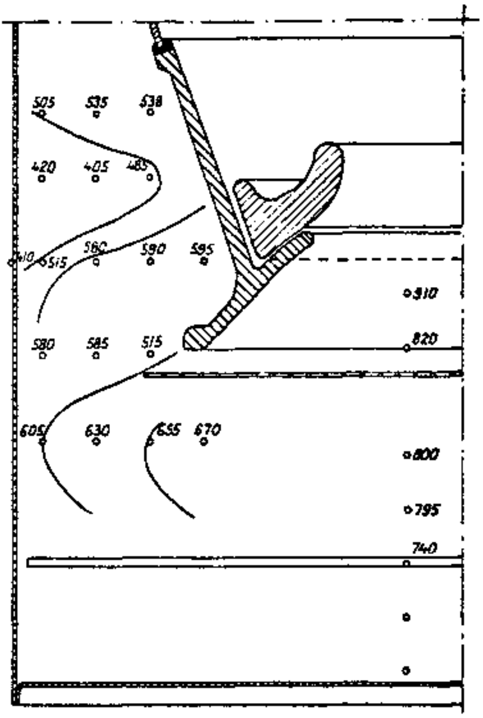

Figure 21. Temperatures in an Imbert Generator with a 130-mm Minimum Diameter V-Hearth Without an Outer Coal Bed; Velocity, 70 km/h; 22.9 hp at Rear Wheels

In the tests represented by Figures 18 and 19, gas samples were taken immediately below the hearth as well as after the generator, and the results are shown in Table 6.

As shown above, in the test with an outer charcoal bed, practically the same analysis was obtained immediately below the hearth as at the outlet of the generator. This shows that no significant conversions occur in the outer charcoal bed or in the charcoal bed below the hearth. Thus, we may conclude from the temperature measurements that the reduction must be completed at temperatures of 900°C. The two analyses carried out in the test without an outer charcoal bed are almost exactly equal, which shows that the cooling of the gas has been fast enough to prevent a change of its composition.

Table 6. TESTS WITH AN IMBERT GENERATOR WITH A V-HEARTH

	With Outer Coalbed Fig. 18		Without Outer Coalbed Fig. 21	
	Immediately Below the Hearth %	After the Generator %	Immediately Below the Hearth %	After the Generator %
Analysis: . . .				
CO_2	11.0	11.8	12.0	12.0
O_2.	0.1	0.1	0.2	0.2
CO.	19.0	19.2	18.2	18.6
H_2.	18.8	19.3	17.4	17.3
$C_n H_m$	0.1	0.1	0.2	0.2
CH_4	0.8	0.8	0.8	0.8
N_2.	50.2	48.7	51.2	50.9

As mentioned above, practically the same power was obtained in the test without an outer charcoal bed, and Table 6 shows that the gas analyses in both tests were nearly equal. The somewhat poorer result obtained in the test without an outer charcoal bed may be explained in that the heat losses may have been somewhat greater in this case than in the test with an outer charcoal bed, since the outer charcoal bed to some extent serves as heat insulation.

The tests with hearth rings with diameters of 90, 100, 115, and 145 mm gave on the whole the same measured temperatures. The power was greatest for the 130-mm hearth.

In the tests with the Imbert hearth the 12-mm standard nozzles as well as 8.5-, 17-, and 24-mm nozzles were used. The power proved to be the highest with the original nozzles. The temperature distribution was about the same with the various nozzle diameters. To sum up the various tests with the generator, it may be said that the function of a generator may be affected by the choice of various nozzle diameters and hearth-ring diameters (or the smallest bore of the hearth.) In the tested generator, the gas was almost completely developed within the hearth at a temperature above 850°C to 900°C. This temperature limit for the reduction is about 100°C lower than what one would assume on the basis of laboratory experiments on the reaction velocity. The tests with the generator do not indicate that no reduction of practical importance takes place below 850°C to 900°C, but only that the reduction may be regarded as practically completed at these temperatures.

Another similar experiment has been carried out with a wood gas generator. [51] In this experiment the air flow of the gas generator was obtained with a fan which sucked the gas through the generator, radiator, and filter. The gas flow was measured with an orifice flowmeter. As in the experiment previously mentioned the temperature was measured at various points in the charcoal layer, but, in addition, the gas was sampled immediately below the hearth as well as in the gas exit on top of the generator. The generator and the gas filters were placed on a stand which was vibrated by a motor-driven eccentric device, so that the conditions of road operation would be simulated. The gas extracted by the fan was flared.

The temperature curves obtained were rather like those shown in Figures 18-20, and Figure 22 shows the results of measurements at a flow of generated gas of 1.7 Nm^3/min (64.7 scf/min). The shape of the hearth is shown in this picture. The outer mantle of the generator had a diameter of 500 mm, and the smallest diameter of the hearth was 100 mm.

The dependence of the temperature curves upon the power developed by the generator is shown in Figure 23, where curve I refers to the center of the lower edge of the hearth, curve II to the area below the lower outer edge of the hearth, and curve III to the gas exit on top of the generator. This graph shows that the temperature of the coal bed at first rises fairly rapidly when the power increases from the generator, but remains comparatively constant at higher power outputs.

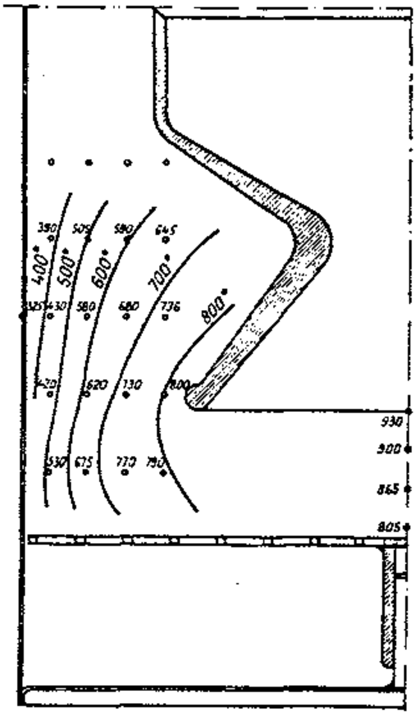

Figure 22. Temperature Graph for Wood Gas Generator, Flowrate 1.7 Nm^3/min

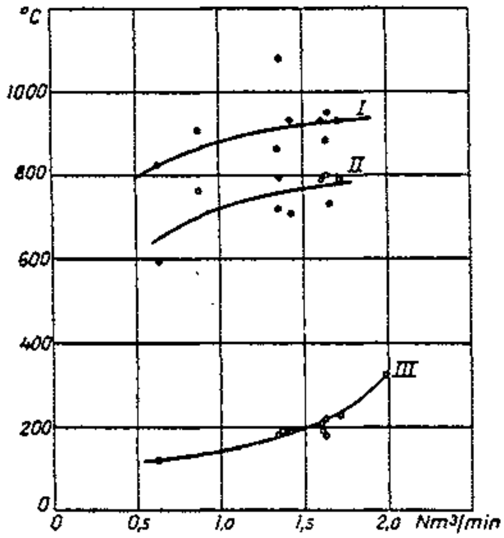

Figure 23. Temperature as a Function of the Power Output for a Wood Gas Generator. (I - In the center of the lower edge of the hearth; II - below the edge of the hearth; III - in the gas outlet on top of the generator)

The analyses in Table 7 are converted into air-free gas. No measurable amount of methane could be noticed in the tests. The table shows that CO_2, $C_n H_m$, and N_2 increased whereas CO and H_2 decreased, and that also the heat value of the gas decreased while passing through the outer coal bed. For the individual tests, greater differences are usually obtained than these mean values; there are also tests where the gas has been somewhat improved compared to these analyses.

Hence, it may be observed that on an average the gas quality is made somewhat worse when the gas passes through the outer part of the coal bed. Thus, no reduction takes place there. The damaging effect of the outer coal bed upon the reduction process itself is most likely compensated for, however, by its function as heat insulation for the hearth.

Table 7. MEAN VALUES OF GAS ANALYSES IN TESTS WITH A WOOD GAS GENERATOR

Analysis	Gas Below the Hearth	Gas Exhausted from the Top of the Generator	Increase (+) or Decrease (-) when Gas Passes through the Outer Coalbed
CO_2 . . . . %	10.92	11.06	+0.14
C_nH_m . . . . %	0.26	0.32	+0.06
CO . . . . %	21.86	21.24	-0.62
H_2 . . . . %	20.52	19.22	-1.30
N_2 . . . . %	46.44	48.16	+1.72
Effective Heat Value			
MJ/Nm^3	5.133	4.948	-0.185

Through this heat insulation, the hearth may be kept at a high temperature so that the reduction will proceed rapidly.

If the equilibrium temperature is calculated from the gas analyses,it appears again that the state of equilibrium is not attained. To sum up, the reaction at temperatures below 900°C goes so slowly that in a generator for practical use there is no noticeable change in the composition of the gas.

Consequences of Not Attaining Equilibrium

As shown previously, one cannot count upon attaining equilibrium during the reduction. What does this mean? If the composition of the gas in a generator is calculated and these calculations are based upon heat balance, chemical balance, and equilibrium equations, the final temperatures calculated would be considerably below the measured temperature, 850°C to 1000°C, at which the reduction occurs. In a series of essays by Hubendick and co-workers, [22-25] calculations of gas compositions and "reduction temperatures" (i.e., the final temperature after the reduction) have been carried out on the basis of the equilibrium equations. For example, in the reduction of charcoal containing 20% moisture, values of the "reduction temperature" have been obtained between 860°C and 660°C, if the heat losses from the generator have varied between 0 and 20%. For wood with 20% moisture, the corresponding temperature values are 630°C and 570°C.

If such a relatively low final temperature is made the basis for calculations of the composition of the gas, there will be a higher heat value found in the gas per quantity of fuel used, than if a higher temperature had been chosen in connection with the test results for use in the calculations. The heat quantity corresponding to the cooling of the gas from 900°C to 700°C, for example, would then be lost together with the heat quantity lost in the cooling of the gas from the assumed equilibrium temperature of 700°C to the temperature at which the gas enters the motor. In reality, the situation does not have to be that unfavorable, since the generators usually are designed with the intention of partially using the heat from the hot gases for drying and preheating of fuel and perhaps even preheating of air.

The Use of Catalysts

Since the limited reaction velocity must be considered in general to give poorer results than a higher reaction velocity, efforts have been made to speed up the generator gas reaction. The influence of catalysts has been touched upon in the foregoing sections. In Figure 15 it was shown how addition of soda influenced the reduction process. According to what has been observed in this context, the state of equilibrium cannot be attained with the use of catalysts either, but the reactions may in some cases be speeded up considerably.

Also, a great number of other salts may act as catalysts in the reduction process. If adding a catalyst is to be of any practical importance, the catalyst must be inexpensive. Soda normally is an inexpensive chemical. In a time of crisis, when the generator gas operation of motor vehicles would be especially important, there may be, however, a shortage of chemicals as well; therefore one can hardly count on using catalysts to a large extent. In Sweden not very many tests have been carried out with catalysts.

In one case, however, there was an experiment by S. Perlstrom in Gothenburg, who added saltpeter ($NaNO_3$) to charcoal intended for generator gas operation. This charcoal was used for generator gas operation of a Mercedes-Benz car with a 38 hp motor. The power increased in relation to regular charcoal by an estimated 10% to 20%. After 1-1/2 years' operation, no salt or other deposits could be observed in the intake manifold, the cylinders, or the exhaust manifold; and in a chemical analysis the oil was found to contain no residues of the saltpeter. For practical use of the method on a large scale, according to Perlstrom, it would be necessary to make the charcoal into briquettes mixed with saltpeter.

Conceivably, the saltpeter improves the gas generation by emitting oxygen as well as by serving as a catalyst in the reduction of the carbon dioxide and water vapor. In the experiment 0.5 kg of saltpeter was added to 10 liters of charcoal. The charcoal weight being 1.4 kg/liter, the saltpeter will constitute 3.6 weight percent of the charcoal. The decomposition of saltpeter takes place according to the formula

$$\begin{array}{lll} 2\ NaNO_3 = 2\ NaNO_2 + O_2 & & \\ 170\ kg & & 22.4 Nm^3 \end{array} \qquad (30)$$

Thus, 0.13 Nm^3 oxygen is obtained from 1 kg saltpeter. This amount of oxygen is infinitesimally small in comparison with the amount of oxygen required for gas generation and can hardly be of any importance. As a comparison it may be mentioned that 0.93 Nm^3 oxygen is needed to burn 1 kg pure carbon (C) into carbon monoxide (CO); i.e., 200 times the amount of oxygen emitted by the saltpeter per kg charcoal. The improvement of the power must therefore be attributed to the catalytic influence of the saltpeter.

If a catalyst directly mixed with the charcoal could be used, there should be no insurmountable economic obstacles. If, however, the charcoal must be made into briquettes—which would probably be the case—one would have to expect an increase in the price of the fuel. Charcoal made into briquettes has certain great advantages, however (especially for vehicular operation), so a higher price may be justified.

Besides, the reaction rate of charcoal is so high that the improvement by using a catalyst is of minor importance. When fuels with low reaction rates, such as anthracite and coke, are used the importance of catalysts increases. Eight different substances have been tested in experiments in England, [26] and the best results were obtained with soda. The proportion needed to attain maximum catalytic effect was about 1% for anthracite; at this level a relatively large improvement of the properties of the fuel for generator gas use occurred.

The Properties of Generator Gas

Generator gas intended for motor operation, as shown in the preceding chapters, contains combustible gases as well as noncombustible nitrogen and water vapor, and usually also a small quantity of oxygen. All gases except water vapor are usually called "dry gases" and then one speaks of "quantity of dry gases", the "heating value of the dry gas" etc. In most gas analyses only dry gases are obtained. The water vapor content may be determined by condensation and absorption, or by the determination of the dew point of the gas; it may also be calculated through gas and fuel analyses. If a gas has passed free water surfaces or contains water vapor which has condensed, it may be considered to be moisture saturated, and its content of water vapor is then unambiguously determined by the temperature. The sum of the quantity of dry gas and water vapor is usually called the total gas quantity or quantity of "wet" gas.

The following laws apply for a gas when the temperature or pressure changes, provided that the gas is not close to the saturation point and may be considered to be an ideal gas. If a gas is heated at constant pressure, its volume will increase in direct proportion to the increase of the absolute temperature of the gas. The absolute temperature is stated in degrees Kelvin (°K). If the temperature in °C is denoted t and the absolute temperature T, $T = 273 + t$. If, on the other hand, the temperature is kept constant and the pressure increased, the volume of the gas will decrease inversely in proportion to the pressure, which means that the product of the volume and the pressure is constant. If the volume is denoted V and the pressure p, the ideal gas law states that

$$\frac{p \cdot V}{T} = \text{constant} \qquad (31)$$

It is customary to refer to a gas quantity at a standard temperature and a standard pressure. The "normal state" is usually chosen to be at the temperature 0°C and the pressure 760 mm Hg. A quantity of gas which has a volume of 1 m^3 at 0°C and 760 mm Hg, is defined as a "normal" cubic meter, denoted Nm^3. The heating value of the gas is usually stated in kJ per Nm^3 dry gas.*

If a gas quantity at an absolute pressure of p mm Hg and a temperature of t°C has the volume V m^3, the standard volume, V_o, is obtained in Nm^3 from the formula

---

*In English units, the "standard state "is defined as 70°F and 760 mm (1 atmosphere), and measured in standard cubic feet, scf. To convert Nm^3 to scf multiply by 38.03.

$$V_o = V \cdot \frac{p}{760} \cdot \frac{273}{273 + t} \tag{32}$$

The quantity of water vapor accompanying a certain amount of dry gas may be determined from the saturation pressure of the water vapor and its relative humidity. If the saturation pressure of the water vapor at a certain temperature is denoted p' and the relative humidity ϕ, the real pressure of the water vapor is $\phi p'$. If the total pressure of the gas is p, the partial pressure of the dry gas will then be $p - \phi p'$. In 1 Nm^3 of dry gas, the fraction of the water vapor, Φ, will then be:

$$\Phi = \frac{\phi\, p'}{p - \phi p'},\ Nm^3/Nm^3 \tag{33}$$

If the gas is saturated with water vapor, there is a special case:

$$\Phi = \frac{p'}{p-p'} \tag{34}$$

The saturation pressure of the water vapor (p') at various temperatures and the water-vapor volume proportional to the volume of dry gases, Φ, are shown in Table 8. The value of Φ is calculated here for a pressure of p = 760 mm Hg.

Table 8. DATA FOR WATER VAPOR

Temperature °C	p' mm Hg	 mbar	Φ at ϕ = 1
0	4.58	6.11	0.0061
5	6.54	8.72	0.0087
10	9.21	12.28	0.0123
15	12.79	17.05	0.0171
20	17.54	23.38	0.0236
25	23.76	31.67	0.0322
30	31.82	42.42	0.0437
35	42.18	56.23	0.0587
40	55.32	73.75	0.0785
45	71.88	95.83	0.104
50	92.51	123.3	0.139
55	118.0	157.3	0.184
60	149.4	199.2	0.245
65	187.5	250.0	0.328
70	233.7	316.9	0.443
75	289.1	385.4	0.614
80	355.1	473.4	0.876

If we know the dew point of the gas (i.e., the temperature at which water starts to condense from the mixture of dry gas and water vapor), we may determine the volume of water vapor proportionate to the volume of dry gas with the help of Table 8.

Table 9 is a survey of the gases that are of importance for generator gas production. The last two columns of the table contain information about the air requirement for a complete combustion of respective gases in Nm^3/Nm^3 and the heating value for a stoichiometric mixture in $kcal/Nm^3$. The last value is obtained by division of the effective heat value of the gas by the sum of the gas quantity and the air requirement; i.e., 1 + the value of the air requirement as stated in the table.

Table 9. GAS TABLE

Gas	Chemical Symbol	Molecular Weight	Molecular Volume	Density	Effective Heat Value		Stoichiometric Air Ratio	Heat Value of Stoichiometric Mixture
			$Nm^3/kmol$	kg/Nm^3	kcal/kmol	$kcal/Nm^3$	Nm^3/Nm^3	$kcal/Nm^3$
Carbon monoxide	CO	28.00	22.40	1.250	67,700	3,020	2.38	895
Hydrogen. . . .	H_2	2.016	22.43	0.0899	57,590	2,570	2.38	760
Methane	CH_4	16.03	22.36	0.717	191,290	8,550	9.52	812
Ethane.	C_2H_6	30.05	22.16	1.356	340,530	15,370	16.66	871
Acetylene . . .	C_2H_2	26.02	22.22	1.171	302,240	13,600	11.90	1,053
Ethylene. . . .	C_2H_4	28.03	22.24	1.261	318,490	14,320	14.28	937
Oxygen.	O_2	32.000	22.39	1.429	--	--	-4.76	--
Nitrogen, pure	N_2	28.02	22.40	1.251	--	--	--	--
Nitrogen mixed with argon as in air . .	--	(28.16)	22.40	1.257	--	--	--	--
Air	--	(28.97)	22.40	1.293	--	--	--	--
Carbon dioxide	CO_2	44.00	22.26	1.977	--	--	--	--
Water vapor . .	H_2O	18.016	(22.4)	(0.804)	--	--	--	--

For combustion of the various gases with air the following equations apply.

$$CO + 0.5\ O_2 + 1.88\ N_2 = CO_2 + 1.88N_2 \tag{35}$$

$$H_2 + 0.5\ O_2 + 1.88\ N_2 = H_2O + 1.88N_2 \tag{36}$$

$$CH_4 + 2\ O_2 + 7.52\ N_2 = CO_2 + 2\ H_2O + 7.52\ N_2 \tag{37}$$

$$C_2H_6 + 3.5\ O_2 + 13.16\ N_2 = 2\ CO_2 + 3\ H_2O + 13.16\ N_2 \tag{38}$$

$$C_2H_2 + 2.5\ O_2 + 9.4\ N_2 = 2\ CO_2 + H_2O + 9.4\ N_2 \tag{39}$$

$$C_2H_4 + 3\ O_2 + 11.28\ N_2 = 2\ CO_2 + H_2O + 11.28\ N_2 \tag{40}$$

If the analysis of the gas mixture is known, the heating value and density of the mixture can easily be calculated with the help of the values in Table 9 by simple proportioning. The procedure is shown in Table 10 or Figure 24.

Thus the result of the calculation is an effective heat value of 1139.7 $kcal/Nm^3$ (4.77 MJ/Nm^3; 119 Btu/scf) and a density of 1.111 kg/Nm^3 (0.064 lb/scf).

When the generator gas is intended for motor operation it is also interesting to know the heat value of a mixture of the gas with the quantity of air needed for burning: after all, this value is one of the basic factors determining the power obtainable from the motor.

Table 10. CALCULATION OF THE EFFECTIVE HEAT VALUE AND SPECIFIC GRAVITY (g/L) OF A GAS MIXTURE

Analysis		Effective Heat Value (kcal)	Density (g/L)
CO_2	11.0%		0.110 · 1.977 = 0.2175
O_2	0.1%		0.001 · 1.429 = 0.0014
CO	19.0%	0.190 · 3,020 = 573.8	0.190 · 1.250 = 0.2375
H_2	18.8%	0.188 · 2,570 = 483.2	0.188 · 0.090 = 0.0169
C_nH_m[a]	0.1%	0.001 · 14,320 = 14.3	0.001 · 1.261 = 0.0013
CH_4	0.8%	0.008 · 8,550 = 68.4	0.008 · 0.717 = 0.0057
Residue			
N_2	50.2%		0.502 · 1.257 = 0.6310
	100.0%	1,139.7	1.1113

[a] C_nH_m denotes so-called heavy hydrocarbons, which are determined in the analysis by absorption in fuming sulfuric acid. In calculations, the values for ethylene (C_2H_4) are commonly used.

In calculating this mixed gas heat value one may, as in Table 9, allow for the air quantity theoretically needed for complete combustion, the so-called stoichiometric air quantity. This value may then be called the theoretical mixed heating value. Frequently, however, in practice the combustion occurs with some excess air, so that a lower mixed heating value than the theoretical is obtained. In calculating the mixed heat value the water-vapor content of the gas or the air is usually not taken into account, since it normally is no greater then about 2% to 3%. Since dry air contains 21% oxygen and 79% nitrogen (including 0.9% argon) 1 mole oxygen in air is associated with 3.76 moles of nitrogen or 4.76 moles air.

Using the gas analysis from Figure 10 and the stoichiometric air ratios from Table 9, we can then calculate the total air requirements for combustion, as follows:

CO	0.190 · 2.38 = 0.452
H_2.	0.188 · 2.38 = 0.447
C_2H_4	0.001 · 14.28 = 0.014
CH_4	0.008 · 9.52 = 0.076
O_2.	-0.001 · 4.76 = -0.005
	0.984

Thus, the air requirement is 0.984 Nm^3 per Nm^3 dry generator gas with the analysis given above. The total volume of generator gas plus air is then 1 + 0.984 = 1.984 Nm^3; consequently the theoretical mixed heat value is 2406 kJ/Nm^3 (575 $kcal/Nm^3$).

$$\frac{1140\ \text{kcal/Nm}^3}{1.984\ \text{Nm}^3/\text{Nm}^3} = 575\ \text{kcal/Nm}^3$$

The flue-gas quantity and composition may be calculated in a similar way. Equations (35), (36), (37), and (40) are used for this. If a surplus of air has been supplied in the combination, an equivalent air quantity becomes a part also of the flue gas.

In the example above the oxygen content of the gas was only 0.1%; under these circumstances the oxygen plays only a minor role. Frequently, however, analyses show a considerably higher oxygen content. Usually this is due to the fact that air has entered the gas sample during or after the sampling; therefore it does not necessarily indicate a high oxygen content in the gas. If, however, the heat value of the gas is calculated after such an analysis, the results are frequently misleading. In that case, of course, not only the oxygen content but the nitrogen content as well become too high. In order to use such gas analyses with abnormally high oxygen contents, the analysis may be converted to "airfree" gas, which is done in the following manner.

Assume that the oxygen content of the gas entirely originates from air that has a nitrogen quantity 3.76 times as large as the oxygen quantity which must then be subtracted. The percentages of the remaining residue gas are then adjusted, so that the sum of the remaining gas percentage values will be 100. The following example demonstrates the procedure. Under circumstances which make it probable that air has entered the gas sample, the following analysis is obtained:

CO_2	8.6%
O_2.	4.6%
CO	14.8%
H_2.	14.6%
N_2 (residue).	57.4%

The nitrogen content equivalent corresponding to the oxygen content is 4.6 x 3.76 = 17.3% and the total air content consequently 4.6 + 17.3 = 21.9%. After this quantity has been subtracted there remains 78.1% airfree gas. The nitrogen quantity of this gas will be 57.4 - 17.3 = 40.1%, calculated on the original gas. Divide this value and the above given values for CO_2, CO and H_2 by 0.781, the following analysis of the airfree gas is obtained:

CO	11.0%
CO_2	19.0%
H_2.	18.7%
N_2.	51.3%

In this context it may be of interest to state the limits within which the gas analyses for generator gas usually fall. The common analyses of coal gas and wood gas according to Tobler [45] are shown in Table II. The values are calculated for airfree gas; the real air content of generator gas is usually 1% to 2%.

For estimates of the effective heat value of generator gas and the theoretical air quantity for complete combustion, one may use the nomographs in Figures 24 and 25. In these nomographs the lines of calculation for the analysis given in the calculation example on the preceding page have been drawn as an example. It should be observed that in the

Table 11. RANGE OF THE MOST COMMON ANALYSES OF DRY, AIRFREE GENERATOR GAS

Fuel	Charcoal	Wood with a 12-20% Moisture Content
Analysis:		
CO_2 %	1-2	10-15
C_nH_m%	0-0.1	0.2-0.4
CO %	28-31	17-22
H_2 %	5-10	16-20
CH_4 %	1-2	2-3
N_2 %	55-60	45-50
Effective Heat Value, kcal/Nm^3	1,100-1,350	1,200-1,400
Effective Heat Value for a Stoichiometric Mixture, kcal/Nm^3	590-620	590-620

calculation of the heat value the sum $CO + 5 \cdot C_nH_m$ is used; in the calculation of the theoretical air quantity, the sum $CO + 6 \cdot C_nH_m$ and the difference $CH_4 - 0.5\ O_2$ are required.

The air quantity needed for combustion is approximately proportional to the effective heat value of the generator gas; thus, the change of the theoretical mixed heat value will be considerably smaller than the change of the effective heat value of the generator gas. It has been shown by Rosin and Fehling [39] that a straight-line relationship between the effective heat value and the theoretical air quantity may be approximately established; and for generator gas a good correlation is obtained by using the formula given by H. Lundberg, [34]

$$\ell_t = 0.98 \cdot \frac{H_i}{1000} - 0.13 \quad Nm^3/Nm^3 \tag{41}$$

where ℓ_t is the theoretical air quantity and H_i the effective heat value in kcal/Nm^3.

With Equation (39), the relation between the effective heat value of generator gas and the mixed heat value may be calculated for a stoichiometric mixture with the air factor n=1 as well as at an arbitrary air factor n. The air factor is the ratio between the actual and the stoichiometric air quantity, and the air excess may be expressed by the value n-1. Thus, for the calculation of the mixed heat value we get the expression:

$$\text{Mixed Heat Value} \approx \frac{H_i}{1 + n(0.98 \cdot \frac{H_i}{1000} - 0.13)} \tag{42}$$

When using Equation (42), one must remember that this is not exact but is based upon an approximate relationship. With Equation (42) the mixed heat value has been calculated for a stoichiometric mixture (n=1), and also for a 20% air surplus (n=1.2) See Figure 26.

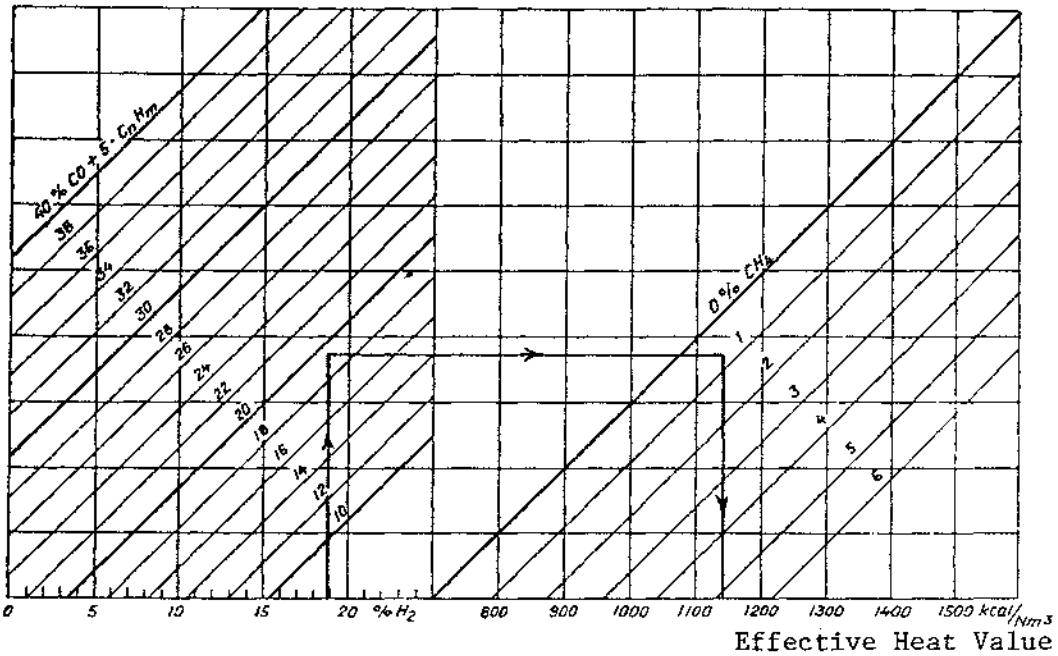

Figure 24. Nomograph for Determining the Effective Heat Value for Generator Gas. (Example 18.8% H_2; 19.0% CO; 0.1% C_nH_m; 0.8% CH_4; 0.1% O_2.)

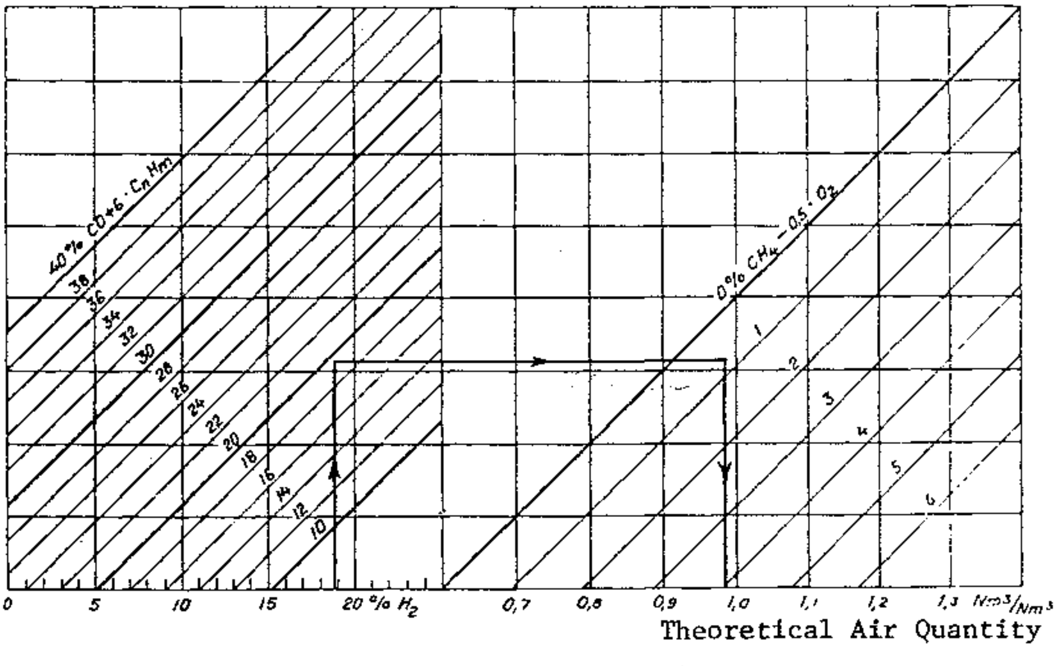

Figure 25. Nomograph for Determining the Theoretical Air Quantity for the Combustion of Generator Gas. (Example as in Figure 24)

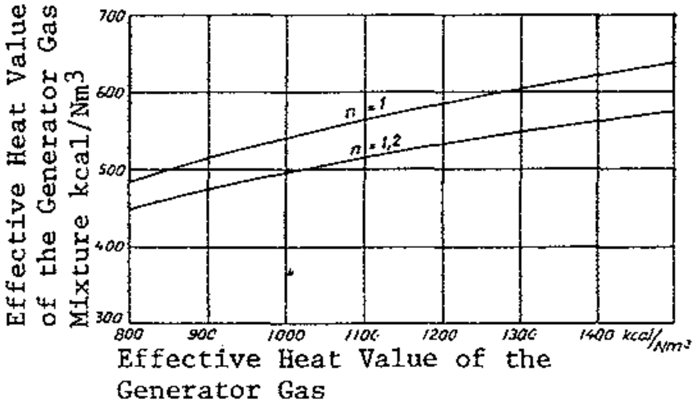

Figure 26. Approximate Relationship Between the Effective Heat Value of Generator Gas and a Stoichiometric Gas Mixture (n = 1); Also for a 20% Air Surplus (n = 1.2)

As mentioned above, the term "mixed heat value" usually means the effective heat value of the generator gas-air mixture at 0°C and at 760 mm Hg. In calculating the heat quantity which must be supplied to the motor, one must take into account the pressure and temperature of the mixture. The actual volume V at a pressure of p and a temperature of t may be converted to an equivalent volume V_0 for a pressure of 760 mm Hg and a temperature t°C with the help of Equation (32). The volume V_0 obtained in this way is then multiplied by the mixed heat value for a calculation of the heat value. In order to supply a large heat quantity and with it a high motor power, one should strive to obtain the highest pressure and lowest temperature possible in the gas mixture sucked into the motor. A low temperature is obtained by effective cooling of the generator gas, and in order to obtain the highest possible pressure, the pressure losses in the generator gas device must be kept low. One method of considerably increasing the pressure of the gas mixture and the motor power is by the use of a supercharger.

Ignition Velocity

In addition to the heat value, the burning velocity of the generator gas is important for its use, especially in engine operation. The higher the burning velocity, the more complete the combustion will be. The burning velocity has different values for each gas and it also changes with the air-gas mixture. The ignition velocities of various gases have been determined experimentally by Bunte using escape tests with gas at room temperature. A few of Bunte's results are shown in Figure 27 (according to Gumz [17]).

Figure 28 shows (according to Finkbeiner [15]) the burning velocity of a few different gas mixtures whose analyses are given in the following table:

Gas	a	b	c	d
CO_2 . . . . %	1.6	4.5	0.2	4.4
C_nH_m . . . . %	3.6	2.4	--	--
O_2. . . . . %	1.0	0.2	0.4	--
CO . . . . %	5.5	20.8	47.0	29.1
H_2. . . . . %	54.2	51.8	50.5	10.2
CH_4 . . . . %	27.2	14.9	--	--
N_2. . . . . %	6.9	5.4	1.9	56.3

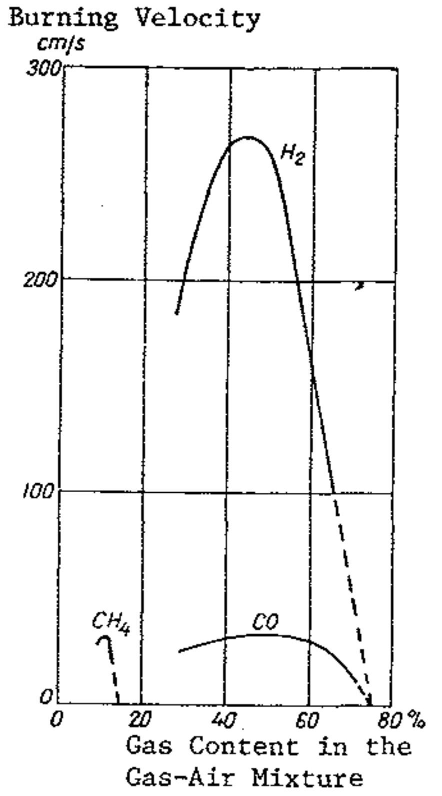

Figure 27. Burning Velocity for the Most Important Combustible Gases in Generator Gas, According to Bunte

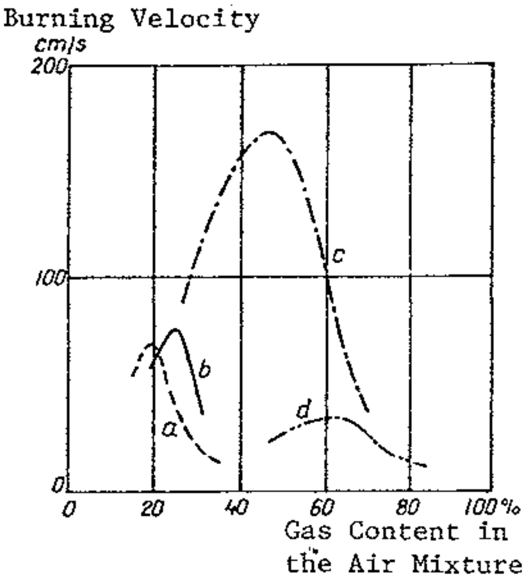

Figure 28. Burning Velocity for Various Gas Mixtures in a Mixture with Air

Naturally, it is not possible to apply the values measured by Bunte directly to the combustion of generator gas in an engine. Other experiments have shown that the ignition velocity increases with rising temperature within the temperature range in question. The flow conditions of the gases are also very important. (See for example W. Unger [48]). Figure 27 shows that hydrogen has a burning velocity nine times higher than carbon monoxide and methane. A gas containing only carbon monoxide as a combustible component has a low burning velocity and is therefore fairly difficult to burn effectively. If the gas also contains a fairly large quantity of hydrogen, the ignition velocity increases considerably.

Calculation of Gas Quantity and Generator Efficiency from Fuel and Gas Analyses

The gas quantity generated from a given fuel quantity and the generator efficiency may be calculated from the heat value of the fuel used and the gas analyses. These calculations are based upon element balances. The accuracy of the results depends on the accuracy of the analyses which have been conducted. If the duff or soot quantity from the generator is large, one must also take this into account. During normal operation of a generator which is functioning satisfactorily, the duff and soot quantities will be relatively small; thus, these losses can be neglected, at least in estimates.

The analyses of the charcoal and wood fuels commonly in use seem to show hardly any differences in the values of combustible substance. As an average value for charcoal the following analysis may be adopted:

C	89%
H	3%
O	8%
	100%

The effective heat value of this charcoal amounts to approximately 7880 kcal/kg. (33 MJ/kg) (14,200 Btu/lb). In the calculations one must allow for the ash content and moisture content of the fuel. If the effective heating value is denoted H_i and is calculated on the basis of combustible substances with H_{ib}, the ash content denoted by A and the moisture content F, we get

$$H_i = (1 - A - F)\, H_{ib} - 585F \tag{43}$$

in which the number 585 represents the heat of vaporization of water at 20°C in kcal/kg.

For dry wood (allowing for the ash content) the following analysis may be considered typical:

C	50.5%
H	6.2%
O	42.8%
Ash	0.5%
	100.0%

The effective heating value is 4540 kcal/kg (dry substance of wood), which is the mean value for birch, spruce, and pine. For a moisture content of F we get the effective heat value:

$$H_{i\ \mathrm{wood}} = 4540\ (1-F) - 585F = 4540 - 5125F \tag{44}$$

The calculation method is shown in the following example, in which wood with a moisture content of F has been assumed as fuel. Per kg wood we get the following composition in kg:

C: $(1-F)\ 0.505$

H: $(1-F)\ 0.062 + \frac{1}{9} F = 0.062 + 0.049\ F$

O: $(1-F)\ 0.428 + \frac{8}{9} F = 0.428 + 0.461\ F$

Ashes: $(1-F)\ 0.005$

If the number of molecules of the various gases is taken into account, the following expressions give the yield:

$$\frac{22.4}{12}\,(1\text{-}F)0.505 = 0.943\,(1\text{-}F) \quad \text{Nm}^3 \text{ gases containing C}$$

$$\frac{22.4}{2}\,(0.062 + 0.049F) = 0.694\,(1 + 0.79) \quad \text{Nm}^3 \text{ gases containing H}$$

$$\frac{22.4}{32}\,(0.428 + 0.461F) = 0.299(1 + 1.076F) \quad \text{Nm}^3 \text{ gases containing O}$$

In addition to this there is the oxygen supplied to the generator by the primary air.

If the volume fractions of the various gases contained in the dry generator gas are denoted v_{CO_2}, v_{O_2}, v_{CO}, etc., the following formula applies:

$$v_{CO_2} + v_{O_2} + v_{CO} + v_{H_2} + v_{C_2H_4} + v_{CH_4} + v_{N_2} = 1 \tag{45}$$

The so-called heavy hydrocarbons, usually denoted C_nH_m are here counted as C_2H_4, which would seem to correspond to the real conditions.

If the primary air quantity supplied to the generator per kg wood is denoted L Nm^3, the quantity of dry generator gas obtained per kg wood V Nm^3, and the water-vapor quantity per kg wood in the generator gas V_{H_2O} Nm^3, and if the air composition is assumed to be $0.21\,O_2 + 0.79N_2$, we get the following element balances:

$$\text{C:} \quad 0.943\,(1\text{-}F) = V\,(v_{CO_2} + 2\,v_{C_2H_4} + v_{CO} + v_{CH_4}) \tag{46}$$

$$H_2\text{:} \quad 0.694\,(1 + 0.79F) = V(2v_{C_2H_4} + v_{H_2} + 2v_{CH_4}) + V_{H_2O} \tag{47}$$

$$O_2\text{:} \quad 0.299\,(1 + 1.076F) + 0.21\,L = V\,(v_{CO_2} + v_{O_2} + \frac{1}{2}\,v_{CO}) + \frac{1}{2}\,V_{H_2O} \tag{48}$$

$$N_2\text{:} \quad 0.79L = V \cdot v_{N_2} \tag{49}$$

Losses of carbon, for example by duffing, have not been taken into account. These losses are fairly small, as mentioned earlier.

In the four equations above, (46-49), there are only three unknowns, namely V, V_{H_2O} and L. If all measurements were exact, all equations could be satisfied by the measured values of these quantities. In most cases, however, agreement would hardly be obtained for all four equations, because of the difficulties involved in making exact measurements and in obtaining representative samples. Taking into account the accuracy possible in the various determinations and the build-up of the equations, it appears most suitable to determine V from Equation (46) and V_{H_2O} from Equation (47), in which the value of V obtained from the former equation is put into Equation (47). If a determination of the air quantity L also is desirable, it would probably be obtained most reliably from Equation (49).

After V has been calculated, the generator efficiency may be calculated by knowing the effective heat values of the gas and the wood. If the effective heat value of the dry gas is denoted $H_{i,gas}$ and the dry gas quantity is V Nm^3 per kg wood, the generator efficiency is determined from the expression:

$$\eta = \frac{V \cdot H_{i,gas}}{H_{i,wood}} \tag{50}$$

It may also be of interest to calculate the losses. In this case, the heat value of the gas that corresponds to the losses may be calculated. The relative size of the losses is $1-\eta$, and their quantity per kg wood amounts to

$$H_{i,wood} - V \cdot H_{i,gas}$$

Since the total gas volume is $V + V_{H_2O}$, the heat content of the gas corresponding to the losses will be:

$$i_{gas} = \frac{H_{i,wood} - V \cdot H_{i,gas}}{V + V_{H_2O}} \text{ kcal/Nm}^3 \tag{51}$$

The heat content of the gas according to Equation (51) is, as shown above, an imaginary quantity only, which corresponds to the temperature at which the generator gas leaves the generator, if the generator has no heat losses.

In order to carry through the calculation above fairly exactly, the mean value of the gas analysis during the combustion of the entire fuel supply must be known. As shown next, the composition of the generator gas may vary considerably during the combustion of the fuel load.

The calculation method given above may, of course, be used for other fuels as well, (e.g., peat, anthracite or coke); in which case, however, the analysis of the fuel must be known. An average analysis may be used in the calculation for wood, however, and generally for charcoal as well.

Variations in the Composition of Generator Gas

The gas obtained from a generator may under various conditions show considerable variation of the analysis. The factors especially affecting the gas analysis are, in addition to the moisture content of the fuel, the degree of combustion of the fuel load, the output of the generator (i.e., gas quantity taken out per time unit), and rapid changes of the load.

Especially in wood gas generators, the gas composition varies according to the degree of combustion. When the generator is first filled, the largest quantities of water vapor are emitted from the wood and as a consequence the poorest gas is obtained. As fuel is consumed the gas improves, and the heat value reaches a maximum when the generator charge is almost completely burnt.

Figure 29 shows how the heat value of the gas changes in a wood gas generator during the burning of the fuel load, according to Hedlund. [20] The heat value of the gas as a function of the load and as a function of the moisture content of the fuel as well is shown in Figure 30. [20] The curves in Figures 29 and 30 show the results of a test with a

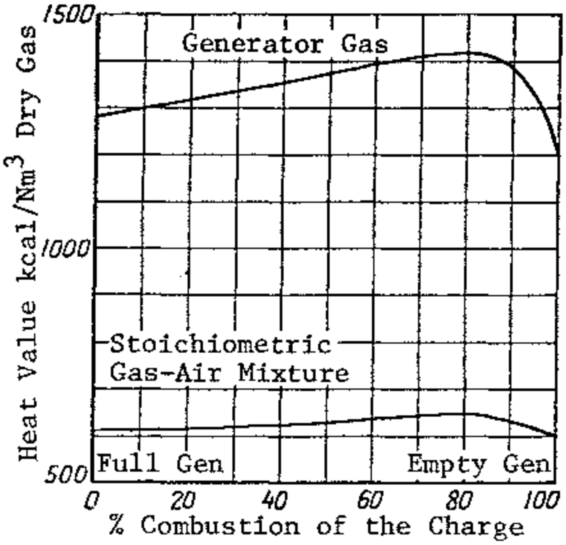

Figure 29. Heat Values of Wood Gas as a Function of the Degree of Combustion

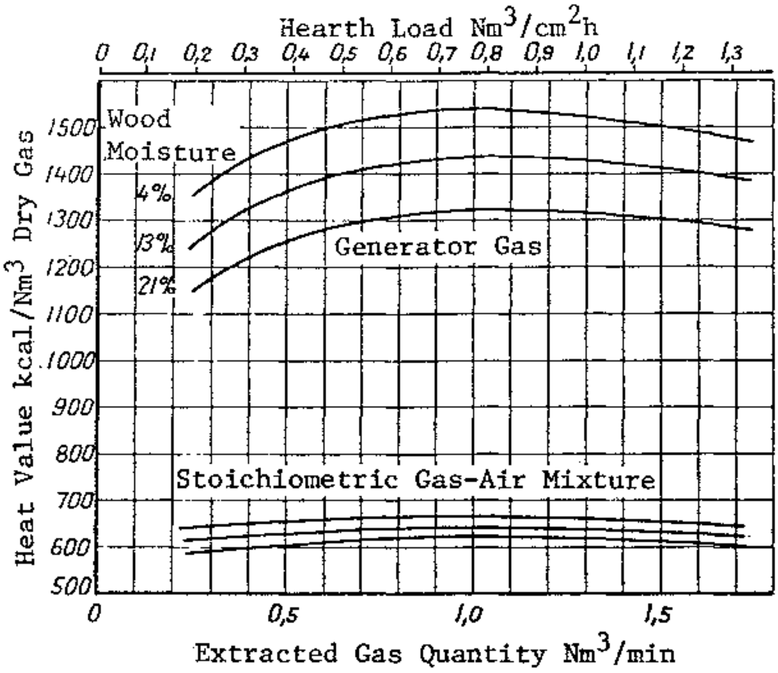

Figure 30. Heat Values of Wood Gas as a Function of the Load in a Special Heat-Insulated Generator at 50% Combustion of the Charge

wood-gas generator with a small hearth opening of 100 mm diameter. A quantity of gas of 1 Nm^3/min corresponds to a hearth loading of 0.77 Nm^3/cm^{2}hr. The curves in Figure 30 were obtained in a heat-insulated generator; in the standard generator somewhat lower heat values were obtained.

Figure 30 shows that the generator gas becomes considerably lower in heat value with increased moisture content of the wood. Figure 31 shows analyses obtained at 4% and 21% moisture content of the wood respectively, during various degrees of combustion. In this graph the two curves beginning at 100% show the percentage of the original moisture remaining in the wood. In order to achieve the best possible operation one should, according to the tests, use as dry wood as possible and add new wood at the latest after approximately 70% of the wood filling has burned.

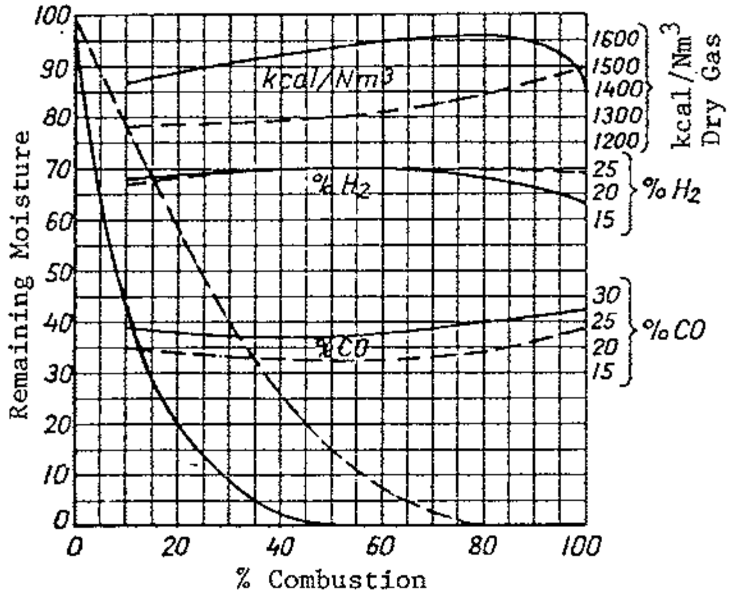

Figure 31. H_2, CO Content and Heat Value of Wood Gas as a Function of the Degree of Combustion

—— Moisture Content of Wood 4%

--- Moisture Content of Wood 21%

Great changes in the gas composition occur in wood gas generators during rapid load changes. Figure 32 shows how rapidly the heat value of the gas may rise during engine idle. If the load on the generator is rapidly decreased after a continuous high load to a value of approximately the idling requirement of the engine, the primary-air quantity sucked into the generator will be very small. Since the generator temperature still is fairly high, however, the degassing of the wood will continue for a few minutes, and the generator gas emitted during this period will have a very high heat value. Therefore, when the engine is loaded again, more secondary air than normal must be supplied for a short time to achieve complete burning and to avoid engine failure. During operation with charcoal, changes in the heat value of the gas may also occur, but as a rule these changes are less pronounced than those in wood gas generators.

Drying and Charring of Wood in a Gas Generator

As mentioned previously, when wood is used as a generator-gas fuel a degassing and charring zone is created above the burning zone in the gas generator; the wood is degassed or charred there with the help of heat supplied from the hot burning zone. Such

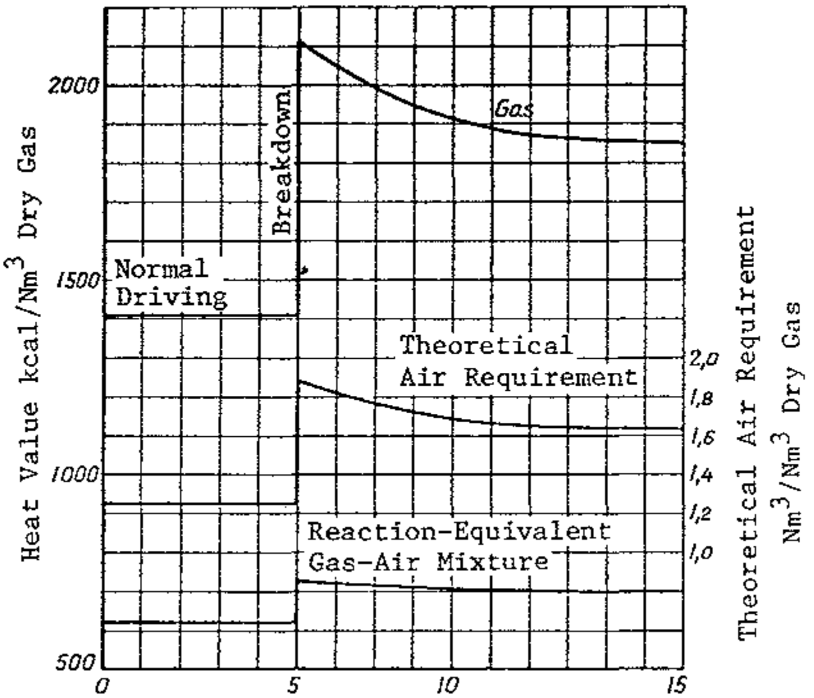

Figure 32. Change in Heat Value of Wood Gas at Engine Idle

decomposition through heat is also called pyrolysis. A more or less sharply defined drying zone is usually situated above this charring zone.

In the heating of wood without access to air, the following characteristic factors may be discerned: During the first stage of heating the moisture of the wood is released; this happens mainly (at least in slow heating) at approximately 100°C and somewhat above that. When the temperature rises further, a chemical decomposition of the wood substance is started during which only water vapor is emitted at first. This continues to approximately 170°C to 200°C, at which temperature gases containing oxygen (at first carbon dioxide, then also carbon monoxide and acid-condensable products) start separating.

At approximately 270°C to 300°C an exothermic reaction is started, the so-called self-charring reaction during which the main part of the condensable as well as gaseous reaction-products are emitted. On the basis of previously published data one can conclude that the exothermic reaction would seem to be confined to the temperature range 300°C to 400°C. If the heating is sufficiently slow, this is indeed the case; but if the heating is faster the conditions will probably be different. According to an experiment by T. Widell [52] at the Steamheat Institute of the Academy of Engineering Science, the exothermic reaction will be shifted toward a higher temperature during faster heating of the wood. Furthermore, the reaction has been proved to require several hours, even if the temperature is as high as approximately 600°C. A series of experiments on the weight loss of the wood for various charring times and temperatures from 250°C to 400°C have been carried out by J. Tobler. [46] The experiments were made with wood blocks, sizes 4x4x4 and 2x2x2 cm respectively, which were immersed in a metal bath kept at the desired temperature. The experiment time was 40 minutes at 250°C and 300°C and 10 minutes at 350°C and 400°C. In addition, tests with experimental times as short as 2.5 minutes were made. The measured weight losses were at most 20% to 30% in wood with a moisture content of 19%. The weight losses arise from the drying and beginning charring of the material. The exposure time was not long enough to realize a fairly complete charring of the wood. In ordinary charring of wood in a furnace, a charcoal gain of approximately 36% is obtained at 400°C, calculated from dry substance wood. This corresponds to a weight loss of 71%, a moisture content of 19% of the wood; i.e., more than double what was obtained in Tobler's short experiments.

According to the experiments cited above it is hardly possible that the charring in a wood gas generator—where the wood stays for 1 to 2 hours—takes place at such low temperatures as furnace charring; the charring most likely takes place at considerably higher temperatures. In spite of this fact, it may be interesting to study the results obtained in charring experiments that have been carried out with longer experimental times. Figure 33 shows the results of such charring experiments according to Bergstrom. It shows that charcoal formation decreases with increasing temperature at the same time that carbon content of the charcoal increases and hydrogen content decreases. Charring in a wood gas generator will in all probability be similar to the results shown in Figure 33; but probably considerably higher temperatures are required in order to obtain the same values of formation and analyses.

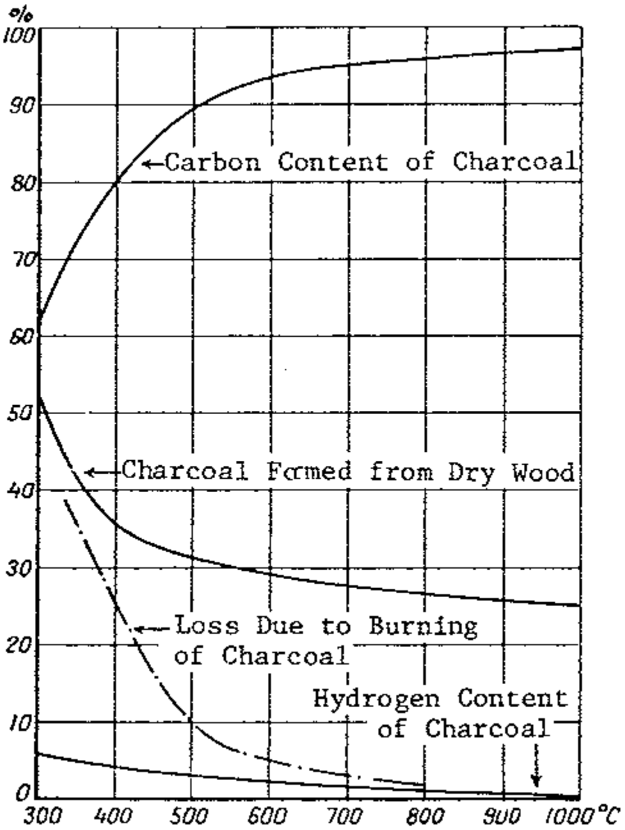

Figure 33. Charring of Wood at Various Temperatures

A so-called Geipert analysis of the wood may also be of interest. It consists of degassing a wood sample in a quartz tube at 1100°C. Only a 15% to 16% charcoal formation was obtained from such samples while the gas quantity emitted was high, 0.52-0.57 Nm^3 per kg wood. The heat value of the gas was also high: 4600-4900 kcal/Nm^3 (19.25-20.50 MJ/Nm^3). The gas contained heavy hydrocarbons, approximately 40% carbon monoxide, approximately 20% hydrogen, approximately 15% methane and only approximately 11% to 14% carbon dioxide. The heat that must be transferred to the wood in order to drive off the main part of its volatile substances is fairly substantial. A graph of the amount of heat needed to heat dry wood to various temperatures is shown in Figure 34 according to the cited experiments. [52] In the graph the amount of heat required for the heating is shown by solid lines. The left curve shows slow heating, during which a temperature of 400°C is reached after 9 hours, and the right curve shows a faster heating to 500°C to 600°C, at which an average temperature of 500°C was reached after 1.5 hours. In the latter case the self-charring occurred at about 400°C and the exothermic heat developed caused the total added heat to decrease. The dashed lines in the graph show how far the exothermic reaction has advanced at various times after the experiment was started. The graph shows further that, at most, approximately 130 kcal/kg (544 kJ/kg) must be supplied at the slower heating rate and approximately 200 kcal/kg (837 kJ/kg) at the faster heating rate. That a larger heat quantity is required during faster heating is due to the fact that the exothermic reaction requires considerable time, so that it cannot be completely accomplished during fast heating.

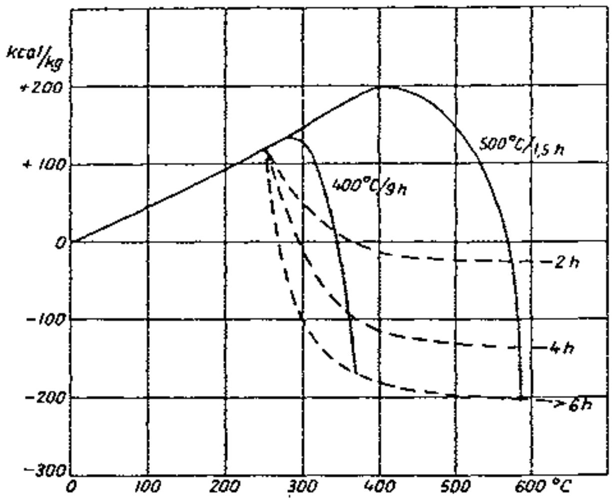

Figure 34. Graph of Absorbed (+) and Emitted (-) Heat Quantity in Charring of Dry Pine Firewood

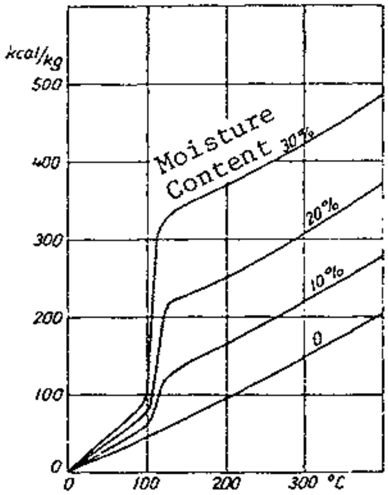

Figure 35. Maximum Heat Supply for Charring of Pine Firewood with Various Moisture Contents

When moist wood is used the heat requirement increases, of course, since heat is required to vaporize the water. Figure 35 shows the heat supply required for various moisture contents of the wood. For dry wood the right curve in Figure 34 was observed. For example, for wood with a 10% moisture content, approximately 300 kcal/kg (1.25 MJ/kg) is required for heating up to 400°C.

In a gas generator the time available for charring of the wood is relatively small; thus, the heating rate will most likely be considerably higher than in the cited tests. It seems probable then, that the heat supply needed for charring will be higher than shown in Figures 34 and 35, possibly 400 kcal/kg (1.67 MJ/kg) at a 10% moisture content of the wood. In the case of a higher moisture content probably a higher drying temperature will be required, and then a higher charring temperature will be required for the process to take place sufficiently fast.

When using wood with a high moisture content it would be advantageous to use a generator designed such that at least part of the moisture may be removed from the wood before it enters the charring zone.

When wood is charred the volume of the wood decreases. The volume of the charcoal obtained from the charring is 50% to 70% of the volume of the wood used.

Fuel Analyses

Standard methods for fuel analyses are used to rate generator gas fuels, but other special methods are used as well. In many cases simplified methods may be used because the accuracy requirements are not as great as, for example, in the delivery of large fuel quantities. Besides the usual fuel analyses there are, however, analyses determined by the special requirements of the fuels with reference to the operating conditions of the generator. Information about some analytical methods developed for generator-gas fuels is presented in the following paragraphs.

Wood

For generator-gas wood it has usually been considered sufficient to determine the moisture content. This has been done either in the usual way by drying in a drying cabinet; by distillation with xylol; or with an electric moisture-content meter (Figure 36), based on the fact that the electric conductivity is dependent upon the moisture content. The accuracy of the electric moisture-content meter is relatively low, approximately ± 1% moisture content, but is quite sufficient for most cases.

Charcoal

Methods of analysis for charcoal have been described by Bergstrom and Jansson; [3] they deal with methods for the control of charcoal deliveries in the iron industry as well as special methods for generator-gas charcoal.

The exact moisture content is hard to determine during drying in a drying cabinet at 110°C, due to the fact that the charcoal may absorb oxygen and also emit carbon dioxide when heated in air. A more reliable and accurate method is distillation with xylol, which is carried out in a special device. The ash content and calcination loss may be determined with standard methods. The Charring Laboratory, [28] however, has worked out a simplified method for determining the moisture content and calcination loss of charcoal. In this method an ordinary kerosene stove is used to heat the samples. This makes it possible to use the method in small laboratories with simple equipment.

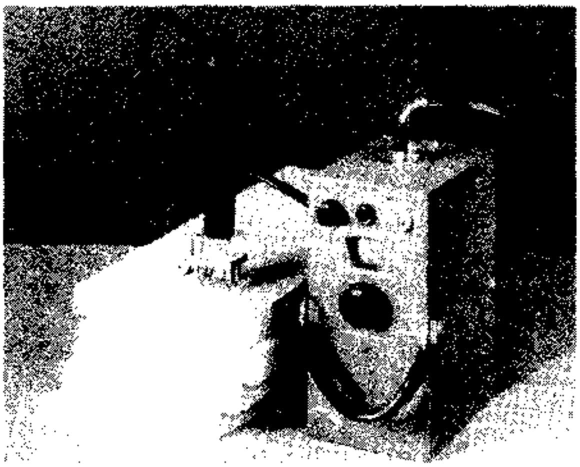

Figure 36. Electric Meter for Measuring Moisture Content, 8-24% Measuring Range

Even if the loss due to burning is satisfactorily low for a sample of generator-gas charcoal, there may be a risk of charring, if the charcoal bulk consists of well charred and badly charred charcoals. Bergstrom and Jansson [3] have described a method used in Sweden for determining the tar quantity emitted during the heating. The sample (100-125g) is placed in a one-liter stainless steel retort and is heated to 500°C, while a weak flow of nitrogen is passed through the retort; the emitted tars are condensed in a condensation system attached to the retort. The tar quantity is determined by extraction with ether. Similar methods are used in England, [8] where smaller sample quantities are used and the tar is collected in a different way. The samples are heated to 600°C in the English method.

The tendency of charcoal to duff* is also a factor that must be taken into account in the quality grading. A device for determining this property is mentioned by the Charring Laboratory. [27] The device consists of a cylindrical drum having a diameter of 300 mm and a length of 250 mm, which is rotated around the horizontal axis. A 150-mm high radial metal sheet is attached inside the drum as a carrier for the charcoal sample. A 500-g charcoal sample with a piece size of 20-60 mm is put into the drum and rotated a total of 500 revolutions with a velocity of 20-40 rpm. After this, the duffing loss is determined by sifting through a 10-mm mesh screen. After the duffing loss, the charcoal may be classified into five different hardness grades according to Table 12.

One property of generator gas fuels of special importance is the reaction ability. In Sweden charcoal has been used almost exclusively rather than coal; for this fuel the reaction rate is so high that it has not been considered necessary to determine it. When wood is used as fuel there is even less gas produced than with charcoal; therefore, wood does not cause any troubles either in this respect. In other countries, however, anthracite and bituminous-coal coke are used to a large extent as generator-gas fuel. These fuels have a relatively poor reaction rate, which is why determining this property

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*"Duff" means to give off fine powder during handling.

Table 12. THE TENDENCY OF CHARCOAL TO DUFF (POWDER) ACCORDING TO THE CHARRING LABORATORY

No.	Type of Charcoal	% Duffing Loss
1	Very Loose	30
2	Loose,	25-30
3	Average	15-25
4	Hard	10-15
5	Very Hard	10

frequently is desirable. It is also valuable to determine the reaction rate in order to estimate, for example, the influence of catalysts and various coking temperatures upon the suitability of a fuel for generator-gas fuel.

A method of directly determining the reaction velocity by the reduction of carbon dioxide with charcoal has already been mentioned, but this method can not be used in operation or routine analyses.

A method better suited for such purposes as well as certain scientific experiments has been developed in England, namely the critical air blast test (C.A.B.). This test is carried out with a fuel bed in a cylindrical vertical pipe with an internal diameter of 40 mm. The thickness of the fuel bed should be at least 25 mm and the fuel sample should be crushed so that it may be sifted through a 14-mesh B.S. screen (1.41-mm mesh width), after which the amount that passes through a 25-mesh B.S. screen (0.71-mm mesh width) is sifted away. In the crushing one should avoid getting too fine a powder. The fraction 0.71-1.41 mm is used for testing the reaction ability. The fuel sample is ignited with an electric heating element while an air flow of 0.07 L/s (0.150 cu ft/min) is blown through. As soon as the fuel starts glowing, the current is switched off and at the same time the air supply is reduced to a value calculated to be immediately above the critical air supply and is kept constant for 20 minutes. After this time has passed, the air supply is increased again to 0.07 L/sec (0.150 cu ft/min) and the fuel bed is observed.

If, after 20 minutes with this increased air supply, no glowing is obtained, the air supply used earlier was below the critical value. By repeating the tests with new fuel samples one may find the critical value. The air supply used in this test and measured in cu ft/min is called the CAB value. Thus, a low CAB value corresponds to a high reaction ability and vice versa. Table 13 gives the CAB values of a few different fuel samples.

An experiment on the reaction rate of various types of coke and also of mixtures of various types of coke has been run in the Netherlands. [29] For example, the CAB value 0.004 was obtained for peat coke made at a low temperature, whereas 0.024 was obtained for peat coke manufactured at 1050°C to 1100°C. For "wood-coke" manufactured at the same high temperature, 0.026 was obtained. These figures show the high degree of dependence of the reaction rate upon the coking temperature. As a comparison, it may be mentioned that the value 0.055 is recommended for coke intended for central heaters, although there is a tendency to lower the value to 0.040. Coke with a CAB value of 0.070 is not sufficiently reactive for this purpose.

Table 13. REACTION RATE OF VARIOUS FUEL SAMPLES

The figures are not general, but merely examples of values obtained. A low CAB value indicates a high reaction rate.

Fuel	CAB Value
Charcoal	0.003
Low-Temperature Coke	0.018
Anthracite	0.035
High-Temperature Coke (gas works). . .	0.057
High-Temperature Coke (coke oven). . .	0.070

Chapter 3

GENERATOR GAS FUELS

Overview

The fuels suitable for generator gas operation in Sweden consist of products from forests and peat moors. Before they can be used for generator gas production, the raw materials must be more or less extensively processed, depending on the type of gas generator for which the fuel is intended, as well as the type of raw material. The processing is complicated not only by the purely technical demands on the quality, selection, and greatest possible utilization of the generator gas fuels manufactured from the raw materials, but also by special circumstances prevailing during times of crisis due to shortages of labor and transportation. Added to this is the necessity of conserving the raw material, particularly if, as is the case with forests, it normally has other uses in the national economy.

To produce suitable generator gas fuels while observing these restrictions is a factor equally as important for generator gas operation as is the production of gas generators fit for operation. These circumstances are touched upon by Hilding Bergstrom, one of the authors of the report "Utilization and Processing of Inferior Lumber, Waste, and By-Products in the Forest Industry," published in 1942 under the name "The Norrland Investigation,"* by the Swedish Industrial Institute for Economic and Social Research.

Hilding Bergstrom gives the following summary:

> When wood is used for motor operation, only a half or third as much is needed as when the wood is processed first to charcoal for motor operaton. This difference in consumption represents large quantities of wood and during a time of crisis it must be considered decisive, since no efforts must be spared to save fuel, transportation, and labor. There are good opportunities through continued technical development to overcome the inconveniences that still affect generator gas operation with wood. In estimating the future prospects for using wood waste for generator gas, one should, therefore, count upon using wood directly.

The continuous development of wood gasification since 1942 supports these views, although charcoal gas operation may still be justifiable for purely technical reasons in a few special cases. New progress in gas generator design under more tranquil circumstances and the benefit of past experience would undoubtedly create a better basis for generator gas operation in the case of a future embargo on imported fuel. The authorities must see to it that such development work is indeed carried out during normal times, although it may not be required until times of future crises or war. Technical progress of this kind would be, for instance, the design of gas generators which would be as independent as possible of the type, size, shape, or moisture content of the fuel. Devices for

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*Norland is roughly the northern half of Sweden, having large forests but a comparatively small population.

continuous drying of the wood gas fuel in the generator itself would greatly decrease the cost of manufacture, storage, and distribution of the fuel. A general changeover to wood gas operation only, would mean a substantial resolution of the entire generator gas problem and make standardization possible for gas generators as well as their fuels.

Supplies of Raw Materials for Production of Generator Gas Fuel

In Sweden we are, as mentioned, obliged to resort mainly to peat and wood for raw materials in manufacturing generator gas fuel. Our peat moors are not completely explored and there are different views as to how big they are. According to one report [49] they contain six billion tons of dry material; consequently, they could become very important for the manufacture of generator gas fuel, if fully satisfactory operation of gas generators could be achieved with peat or peat coke.

Since peat contains considerably more ash than wood, and since peat ash in many cases is relatively fusible (and therefore easily causes slag formation), practically all generator gas fuel in Sweden has been manufactured from wood as a raw material up to the present. The gas generators that have been built have been designed specifically for wood or charcoal. If large-scale generator gas operation once again is required, the wood resources of the country would be used first.

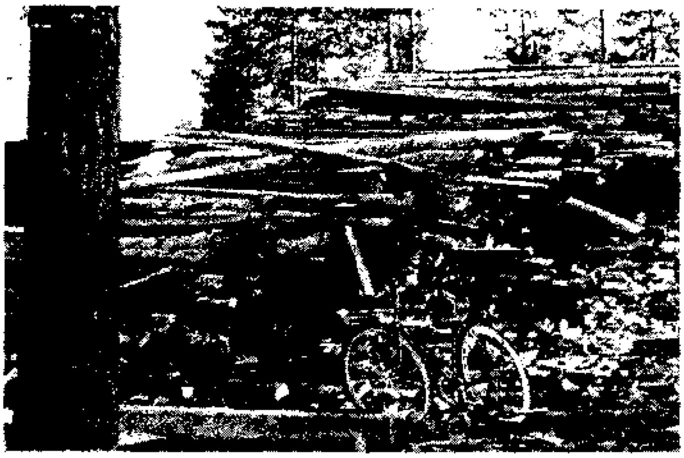

Figure 37. Waste Wood at a Lumber Mill

In this context it is generally recommended that forest and lumber mill so-called waste (Figures 37 and 41) should be used first for generator gas operation. Certain objections may be made to this generalization. Because of the recent enormous progress in the area of wood processing, particularly in the sulfate and wallboard industries, hardly any waste wood exists which, from a purely technical point of view, is useless for industrial processing. The determination of what is still called waste wood in felling are based on factors such as transportation (floating possibilities, forest roads, etc.), wages, market prices, etc.; and therefore the limits vary a great deal. According to the Norrland Investigation in 1942 it is estimated, for the Norrland area, that in felling with the proposed minimal dimensions, approximately 20% to 25% waste is generated that cannot be profitably processed for paper and lumber. Such waste consists of tops, branches, thinning material, partly decayed wood, etc.

Due to transportation costs, etc., most of this "waste" is also, from an economic viewpoint, unsuitable for car wood. What was earlier called waste unfit for use in lumber mills, i.e., edgings, etc., shingles and splinters (amounting to approximately 30% and 13% respectively of the so-called wood balance), is now (1950) practically 100% used, the former for sulfate and wallboard industries, the latter for heating the drying ovens in lumber mills.

The use of available wood raw material for generator gas production in the case of a general forced changeover to generator gas operation in Sweden would depend, irrespective of the kind, shape, and dimensions of the raw material, upon conditions related to the general situation of crisis; for example, transportation conditions and availability, availability of labor, military demands, civil defense demands, storage and distribution possibilities, etc. Although the use of good wood for fuel purposes should be avoided, generally under these special circumstances it may be necessary and sometimes even economical to use first grade industrial wood for production of generator gas fuel. Where local conditions permit, however, branches, tops, thinning material, stumps, etc., should of course be used; for example for tractors on farms with wood supplies. Therefore, it is very important that gas generators be made useable for operation with as many available fuels as possible; and also, on the other hand, that generator gas fuels be standardized in as few grades as possible, so that they can easily be manufactured from various existing types of raw material.

For transportation to meet the present requirements of towns, fishing, small industries, etc., the need for raw wood for generator gas operation is estimated to be approximately five million solid cubic metres (m^3) per year; this is equivalent to approximately 100 million hectolitres (hL) of bulk generator gas wood chips, or approximately 800,000 tons of gasoline. If operation is only with charcoal, the same amount of raw wood would produce less than half this amount of motor fuel. In 1944 approximately 25 million hL of car wood and as much car charcoal was manufactured, the total corresponding to approximately 3.75 million m^3 wood raw material. For a comparison see the tabulation below by the Central Bureau of Statistics of the total felling in Sweden during 1937.

1.	Industrial Lumber, etc.	42.3 million m^3
2.	Prime Fuel Wood (including household wood)	11.4 million m^3
3.	Wood for Charcoal	1.6 million m^3
	Total	55.3 million m^3
	of which 10% is birch.	

Under all circumstances a relatively small amount of charcoal should be reserved to be used as charcoal beds in the generators. Such charcoal, which must have fairly high mechanical strength, may be obtained, for example, from charring-stacks or from charcoal furnaces.

Large quantities of stumps originate from wood cutting in the forests; however, nowadays such stumps consist mainly of root wood, since the felling is done as close as possible to the ground surface. The use of stump and root wood is mainly a question of transportation possibilities and labor availability. Old pine stumps and trunks (so-called tore*), are an exceedingly useful raw material for manufacturing tar products, motor fuel, lubrication oils, turpentine, etc. Such manufacturing is usually done in retort furnaces. However, these products may also be produced directly by extraction with suitable solvents; for example, sulfite alcohol. In this way no carbon is created as a byproduct. In the investigation mentioned above, the supply of economically workable tore in Norrland amounted to approximately one million or more cubic meters. From this quantity of raw material may be produced approximately 110,000 tons of lubrication oils; approximately 20,000 tons of turpentine; great quantities of methanol and motor fuels; and approximately 160,000 tons of small size charcoal of a good but fairly brittle quality suitable for operating, for example, small private car generators. The charcoal quantity corresponds to approximately 75,000 tons of gasoline. In better designed retort furnaces and charring furnaces, so-called A-tar may be produced as a byproduct of the charring; this tar may be used, for example, for operating glow plug engines (surface ingition engines) in fishing boats and the like.**

Technical Considerations for Combustion

As was shown in Table 11, the combustible components in generator gas consist primarily of carbon monoxide, hydrogen, and methane. The effective heat value of generator gas when charcoal is used as fuel varies between 1,100 and 1,350 kcal/Nm^3 (4.60 - 5.65 MJ/Nm^3; 133 - 163 Btu/scf); and with wood as fuel, between 1,200 and 1,400 kcal/Nm^3 (5.02 - 5.86 MJ/Nm^3; 145 - 170 Btu/scf). For well designed gas generators and fuels with a moderate moisture content 1,300 kcal/Nm^3 (5.44 MJ/Nm^3; 157 Btu/scf) could be considered an average for both charcoal and wood gas. For this heat value there will be a heat value of approximately 600 kcal/Nm^3 (2.51 MJ/Nm^3; 67 Btu/scf) in the stoichiometric gas mixture as shown in Figure 26. For gasoline the corresponding theoretical mixed heat value would be 850 kcal/Nm^3 (3.55 MJ/Nm^3; 95 Btu/scf); consequently, generator gas has only 70% of the heating value for gasoline, which corresponds to a 30% loss of power in generator-gas operation relative to gasoline operation.

The effective heat value for the most important gas generator fuels in Sweden is given in Table 14.

As shown in the table an effective heat value of 4540 kcal/kg may be calculated for a mixture of spruce and pine as well as for birch. At a moisture content of F, the following effective heat value is obtained according to Chapter 2, Equation (44):

$$H_{i,wood} = 4540\ (1 - F) - 585\ F = 4540 - 5125\ F$$

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*Old pine stumps are especially rich in turpentine and rosin. We have no equivalent English word.

**This may refer to a semidiesel type operation using pyrolysis oil from the stumps.

Table 14. EFFECTIVE HEAT VALUES OF VARIOUS FUELS (APPROXIMATE VALUES)

	Effective Heat Value kcal/kg	Basis
Spruce Wood.	4570	Dry Substance
Pine Wood.	4520	Dry Substance
Birch Wood	4540	Dry Substance
Beech Wood	4370	Dry Substance
Alder Wood	4510	Dry Substance
Aspen Wood	4340	Dry Substance
Charcoal from Stacks	7950	Combustible Substance
Furnace Charcoal	7850	Combustible Substance
Peat	5000	Combustible Substance
Peat	3400	5% Dry Basis Ash Content and 25% Moisture Content

If, for the comparison between wood and charcoal, the average moisture content of wood is assumed to be 20% and that of charcoal 10%, the effective heat value of wood will be 3520 kcal/kg as shown in Equation (44), whereas 6600 kcal/kg may be assumed for charcoal. The relation between these two values, approximately 1.85, will be the relation between wood and charcoal consumption at equal efficiency. As shown in Chapter 11, approximately this value has also been obtained in practical operation, which shows that about the same efficiency is obtained from wood as from charcoal.

The specific fuel consumption b (in kg/hp · hr) may be calculated according to the formula

$$b = \frac{632.3}{\eta_g \cdot \eta_{mot} \cdot H_i} \tag{52}$$

where η_g is the efficiency of the generator; η_{mot}, that of the motor; and H_i, the effective heat value of the fuel. Assume as an average the efficiencies $\eta_g = 0.8$ and $\eta_{mot} = 0.22$; then the specific fuel consumption with the average heat values above will be:

For wood. . . . . approximately 1000 g/hp · hr

For charcoal . . . . approximately 550 g/hp · hr

With the same assumption, we get on an average

From 1 kg wood . . . . . . approx. 2.2 Nm^3 wood gas of 1300 kcal/Nm^3

From 1 kg charcoal . . . approx. 4.0 Nm^3 charcoal gas of 1300 kcal/Nm^3.

In gasoline operation the specific fuel consumption at constant motor efficiency will be approximately 275 g/hp · hr if the effective heat value is 10,500 kcal/kg. If the gasoline density is 730 kg/m^3, the effective heat value per litre will be 7665 kcal/L. Then one litre gasoline theoretically corresponds to approximately 2.7 kg wood or approximately 1.45 kg charcoal. (One gallon of gasoline corresponds to 22.5 lb of wood or 12.1 lb of charcoal.)

Operation with generator gas has considerable disadvantages relative to gasoline, due to increased driving in lower gear, fuel consumption when standing still, firing and starting up the generator, etc. In ordinary varied highway driving it has been calculated that one litre of gasoline corresponds to approximately 3 kg of wood or 1.65 kg of charcoal in practical operation. (One gallon of gasoline corresponds to 25 lbs of wood or 14 lbs of charcoal.)

The comparison figures in Table 15 have been calculated on the basis of these values.

Table 15. COMPARISONS BETWEEN VARIOUS GENERATOR GAS FUELS AND GASOLINE

Fuel	% Moisture	Weight kg/hL	Litres Gasoline per Hectolitre Fuel	Price in 1945 kr/hL	Equivalent Price for Gasoline kr/L
Car Wood					
Hardwood	20	33	11.0	3.50	0.32
Softwood	20	25	8.3	2.50	0.30
Mixed Wood 50/50	20	29	9.7	3.10	0.32
Car Charcoal					
Hardwood Charcoal. . . .	10	20	12.1	5.50	0.46
Softwood Charcoal. . . .	10	16	9.7	4.50	0.46
Mixed Charcoal 50/50 . .	10	18	10.9	5.--	0.46

The table, as well as experience, shows that in general the same motor performance is obtained from one hL wood as from one hL charcoal, which is approximately 55% more expensive to buy. The price of gasoline in 1947 was 0.37 kr/L and in 1948 0.68 kr/L.

In comparing various fuels it is also important to take into account the consumption of raw materials in their production. If on the average 80 kg of charcoal or 375 kg of wood are obtained from one cubic metre of charcoal wood, the raw-material consumption for charcoal in relation to the raw-material consumption for wood (using the values given above) will be:

$$\frac{375 \cdot 1.65}{3 \cdot 80} = \text{approx. } 2.5$$

Thus, the raw-material consumption for charcoal will be approximately 2.5 times as great as wood for generator gas production.

Car Wood

Raw Wood

The wood felled in the forest to be used for purposes of heating or fuel for power consists mainly of so-called firewood, which is sawed into one-metre lengths and split lengthwise (Figures 38 and 39). The cross section usually is a circle segment or sector shape and varies considerably in size. On the average there are 50 to 80 wood pieces per stacked cubic metre, which is the basic measurement for such lumber. Wood of smaller diameter is only cross-cut, i.e., not split lengthwise, with approximately 80 to 200 wood pieces per m^3. Wood of even smaller dimensions (so-called clearing or thinning wood) and branches and tops which have fallen down during cutting (Figures 40 and 41) are usually cut as long round logs. In all cases, after further processing of the raw material to car wood, approximately 11 hL of car wood may be obtained per m^3 of raw material, in reality. Besides firewood and logs, so-called slabs (edgings) and other wastes from the lumber industries may be used for the production of car fuel (Figure 37). In today's generator designs such wood is more likely to bridge (hold up in the generator). In addition, much waste occurs as splinters and splits, which cannot be used at all in these generators. The same is true for rough bark (so-called crust bark); cones, however, can be used. Due to their greater density, beech and birch in particular are somewhat heavier per volume unit than softwood with the same moisture content; likewise, fir and pine are somewhat heavier than spruce.

The greater porosity of softwood (coniferous wood) probably causes somewhat faster reactions in generators than do the denser hardwoods; and this is also true for the various types of charcoal. Oak is hardly suitable for generator use, and since this high grade wood is needed almost entirely for other purposes, it should, of course, not be used.

Green wood felled in the winter has a moisture content of approximately 30% to 35%; wood felled in the summer, 40% to 55%. In favorable weather during spring and summer, air-dried firewood has a moisture content of 15% to 25%. If the wood is cut into short lengths when green, the drying takes place much faster. The shorter the individual wood pieces, the more rapidly they dry (down to lengths of approximately 5 cm), whereas lengthwise splitting is of minor importance in this respect. According to tests, where air-dried car wood of 20% moisture content was immersed in water for 12 hours, the moisture content increased to approximately 42%. Another eight days' immersion did not cause any measurable increase of the moisture content. Thus, it is important to protect finished and dried car wood from rain and humidity.

Manufacture of Commercial Car Wood

Wood used as generator gas fuel comes in three basic forms, car blocks, car billets, and car chips, as shown in Table 16 and Figures 42 to 44.

Shorter lengths of car wood of the same thickness produce—at an increased manufacturing cost--a greater percentage of solid mass; in other words, the space in a one-hectolitre sack will be better used in this way, which is of importance, since this product is sold by the hectolitre. It should be determined whether generator gas fuel, like

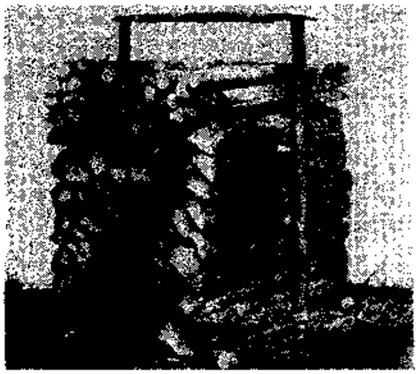


Figure 38. One Stacked Cubic Meter of Firewood

Figure 39. Piles of Firewood Along a Highway

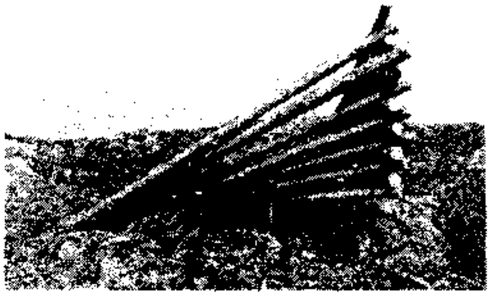


Figure 40. Log Stacking in the Forest

Figure 41. Log Thinnings in a Forest Being Selectively Cut

Table 16. TERMS, GRADES, ETC., OF COMMERCIAL CAR WOOD

Commercial Term	Raw Material	Production Method	Approximate Dimensions	Approximate Solid Mass
A. Car Blocks				
1. Thick Blocks	Sawed and Split Firewood	Crosscut and Split	8 cm X 25 cm^2	50%
2. Thin Blocks	Sawed, Round Firewood	Crosscut and Split	6 cm X 20 cm^2	48%
B. Car Billets				
1. Thick Billets	Thin, Round Firewood, Thick Round Logs	Crosscut with Saw	8-9 cm X 25-75 mm dia.	54%
2. Thin Billets ("stick firewood")	Thinner, Round Logs (clearing wood in general)	Crosscut with Saw	6 cm X 25-50 mm dia.	52%
C. Car Chips				
1. Thick Chips	Same as B.1	Squared	8-9 cm X 25-75 mm dia.	46%
2. Thin Chips	Same as B.2	Squared	6 cm X 25-50 mm dia.	44%

virtually all other solid materials or products, should be sold by weight or by volume. In selling by weight, moisture controls would be necessary. This requires a simple, reliable, and rapid method for moisture analysis.

Generator gas wood is produced partly on a small scale for household use, partly on a large scale with special machines and at central storage yards.

Production of Car Wood for Household Use

Due to the high cost of transportation to a central storage yard and the high cost of dry storage for extended periods, household production is frequently advantageous from an economical point of view, in spite of all the manual work involved.

For the calculation of the production cost of car wood on a small scale the following average output of work by two men with a crosscut saw and an axe may be cited:

Crosscutting with a circular saw:

Firewood. . . . . approximately 1.5 m^3 hr

Thin round wood. . . . . . . approximately 1.0 m^3 hr

Splitting with an axe:

Easily split . . . . approximately 0.25 m^3 hr or
approximately 2.5 hL/hr car wood

Of average difficulty. . . . . approximately 0.20 m^3/hr or
approximately 2.0 hL/hr car wood.

When the car wood is split lengthwise or crosswise, the various pieces must be completely separated and not allowed to hang together with splinters, knots, etc., which could cause bridging in the generators. If the splitting work is done while the wood is

Figure 42. Car Blocks

Figure 43. Car Billets

Figure 44. Car Chips

Figures 42-44. Commercial Types of Generator Gas Wood. (Note matchbox for scale.)

moist, the smallest waste occurs. Losses due to waste may be estimated on the average of approximately 5% sawdust and 5% splitting waste (splinters, etc.), or 10% at the most. The production of round billets and car chips is more economical than the production of car blocks; in addition, round billets contain a larger percentage of solid mass (see Table 16) than other types of car wood and present less risk of bridging in the generator.

Large-Scale Production of Car Wood [42]

In large-scale production of car wood, machines are used to split the wood (Figure 45). Cutting machines with one or two steel blades are used to produce car chips from thin round wood, saplings, or fairly straight branch wood; i.e., the normal waste from forestry thinning or felling operations. The diameter of the thicker end should not exceed approximately 10 cm. The cut is done either at an oblique angle or at a right angle (Figure 46). In the former case the wood dries out faster but the waste is somewhat greater. Such chopping machines are also called "wood eaters" (chippers) and operate at 2 to 3 hp with a working capacity of 20 to 50 hL/hr of car chips with approximately 5% waste. The solid mass of the wood is approximately 45%.

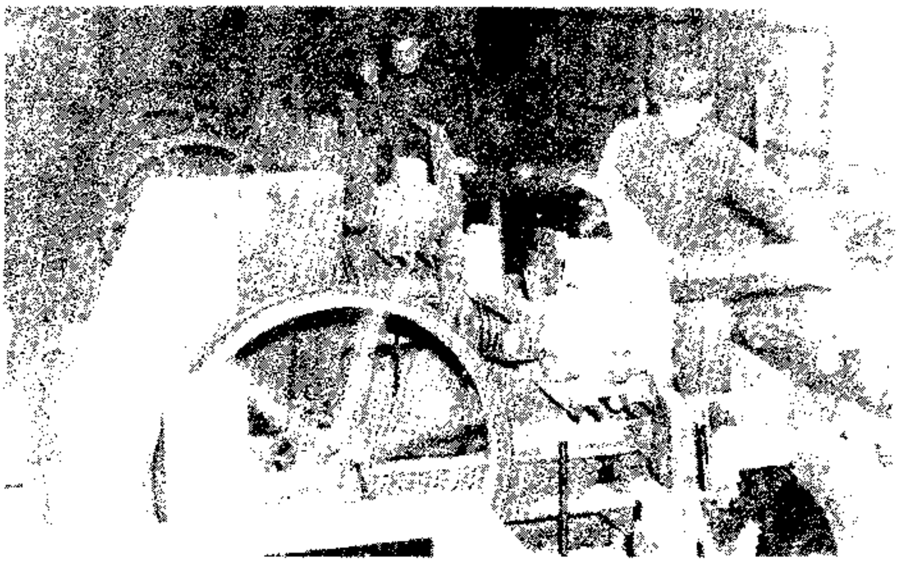


Figure 45. Crosscutting and Chopping Machine for Production of Generator Gas Wood.

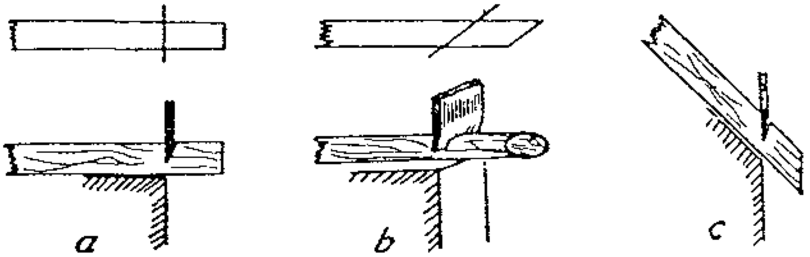


Figure 46. Various Methods for Cutting Wood Chips.
a) The wood is cut at a right angle to the longitudinal grain. b) The wood is cut at a right angle to the longitudinal grain, but with an oblique cutting angle.
c) The wood is cut at a 30° - 45° angle to the longitudinal grain.

A combined sawing and splitting machine is used to produce car blocks. In this case, firewood is used as raw material, but the machines may also be used in the production of car chips from round wood or saplings. The power consumption varies between 3 and 9 hp and the work efficiency between 10 and 35 hL/hr of car chips. Approximately 15% of the firewood goes to waste. The machines may also be equipped with shaking screens for a careful separation of the waste and a fan for removing the sawdust.

The energy consumption of various machines making finished car wood is estimated to be approximately as follows:

For chopping machines. . . . approximately 0.05 kWh/hL

For crosscutting and
splitting machines. . . . . . approximately 0.15 kWh/hL

If the wood gas generators could be made more "omniverous" and less sensitive to the bridging and clogging caused by sawdust, splinters, etc., it would be possible to make the production of car wood less expensive.

The number of car-wood mills in Sweden was greater than 4,000 on January 1, 1945. The total quantity of manufactured car wood during 1943 to 1945 amounted to approximately 25 million hL per year, corresponding to 200,000 tons of gasoline. The experience from the production of generator gas wood on a large scale is given in the appendix.

Car Charcoal

Raw Charcoal

When wood is charred, most of the volatile components are removed. The charring process is shown graphically in Figure 33 (Chapter 2), and the change of the chemical composition in Table 17, below. During charring in a retort furnace the valuable volatile components are collected, which is not the case during charring in stacks or, as a rule, in charring furnaces.

Table 17. CHANGE IN CHEMICAL COMPOSITION OF SOFTWOOD DURING CHARRING

	Softwood	Partially Charred	Normally Charred	Heavily Charred
C	49.6%	82.9%	89%	93.6%
H	6.2	4.0	3	1.8
O	44.2	13.1	8	4.6
Volatile Substances	87%	20%	10%	6.7%

Air-dried wood (15%-25% moisture content) is used as a basic material when the wood is charred to "raw charcoal," for subsequent use as commercial car charcoal. The wood may consist of fire wood, logs, small pieces, branch wood, stumps, etc., but it is important for the charring that all the wood being processed is of the same type (hard or soft), and that the pieces are of similar shape and size. The charring should not proceed rapidly. At excessively high temperatures brittle material is obtained, and at too low temperatures the charring is incomplete and uneven (calcines). From one m^3 of firewood approximately 4.5 hL of car charcoal are obtained as an end product; i.e., less than half of the car wood that may be obtained from the same quantity of raw material (11 hL). When the raw charcoal is crushed to car charcoal, approximately 20% to 30% fine charcoal and charcoal dust (duff) is obtained. Of this, the fine charcoal in particular is valuable for gas generator operation, where it is used for special types of charcoal gas generators (for example Kalle generators).

The charcoal dust frequently must be considered a loss. Charcoal produced from hardwood is denser, heavier, and more mechanically resistant than softwood charcoal; the latter also emits more charcoal dust. However, softwood charcoal reacts somewhat faster in the generator and this is advantageous, especially during intermittent operating conditions.

The weight of various kinds of charcoal per hL is shown in Table 18.

Table 18. WEIGHT PER hL OF CAR CHARCOAL (WITH 10% MOISTURE CONTENT)

Type of Charcoal	kg/hL
Beech Charcoal	21-23
Birch Charcoal	18-20
Softwood Charcoal (forest charcoal)	15-17
Softwood Charcoal (Slabs)	13-15
Mixed Charcoal (60 hardwood 40 softwood)	17-19

Incompletely charred wood (calcines) causes breakdowns in gas generators, since these generators, in spite of downdraft burning, are not designed for cracking possible tar products into useful components; therefore, the motor or the filtering apparatus runs a risk of being gummed up by tar.

In charring wood three principal methods are used: (1) charring in stacks; (2) charring in charring furnaces; and (3) charring in car-type and retort furnaces.

Charcoal burning in stacks has taken place for centuries in Sweden and is used nowadays mainly to produce charcoal for the ironworks. In earlier times it was also used for rock-blasting. About 2 million m^3 are still used annually for these industries. The charring takes place nowadays in charring-stacks with chimneys (Figures 47 and 48), which are in some ways more advantageous than older types of charring stacks. (In addition, see Bergstrom [2]). The quality of charcoal from stacks as a rule is good, but the charcoal is fairly often mixed with sand, soil, etc. Such impurities do not cause great inconvenience in industrial use, but, in the production of generator gas, may cause a breakdown in motor operation due to slag formation. This kind of charring demands great skill and takes a long time to learn. Charring in stacks is also highly seasonal, which is a great disadvantage from the standpoint of military preparedness.

Charring in metal or brick charring furnaces does not demand as great skill and is faster than charring in stacks. [1,2] The furnaces are usually simple, made either of brick or metal using the principle of the charring-stack with a chimney (Figures 49 and 50). In most cases tar products are not collected; this is particularly uneconomical in a large-scale production, when the wood resources of the country are considered. Only as an exception are there arrangements for collection of tar products (raw tar, etc.); and this, mainly in large plants.

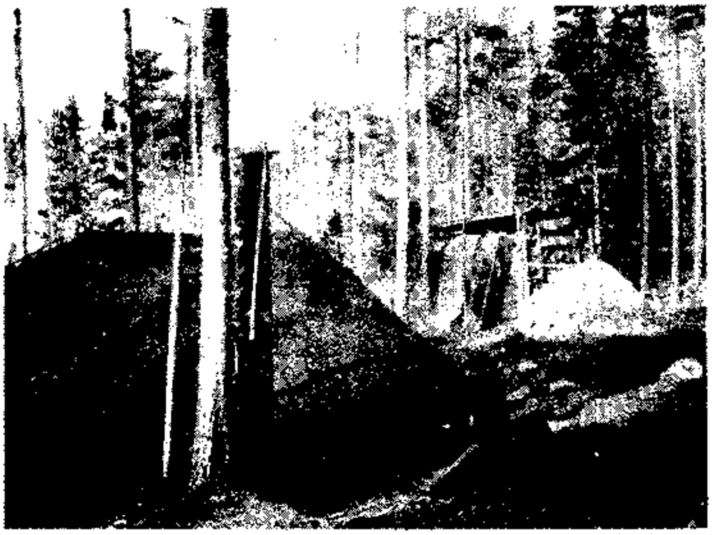
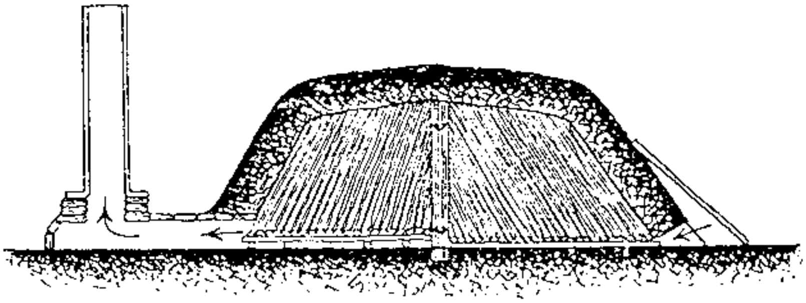


Figure 47. Typical Charring Stack with Chimney



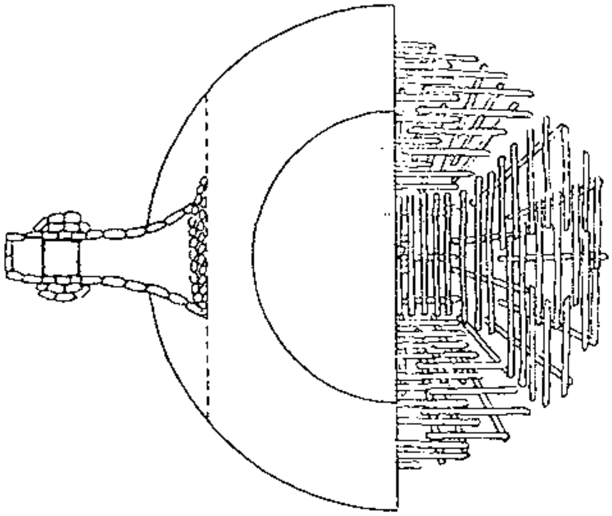


Figure 48. Cross Section and Top View of Charring Stack with Chimney

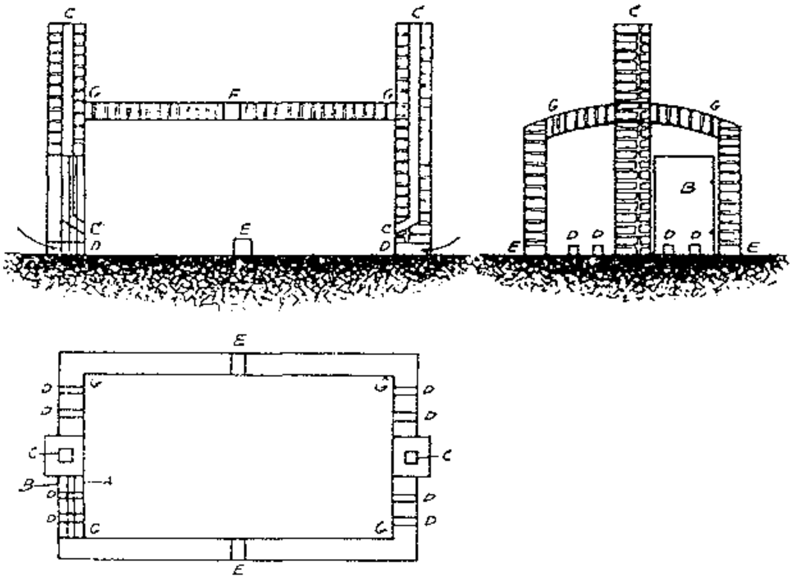


Figure 49. Schematic of Brick Charring Furnace

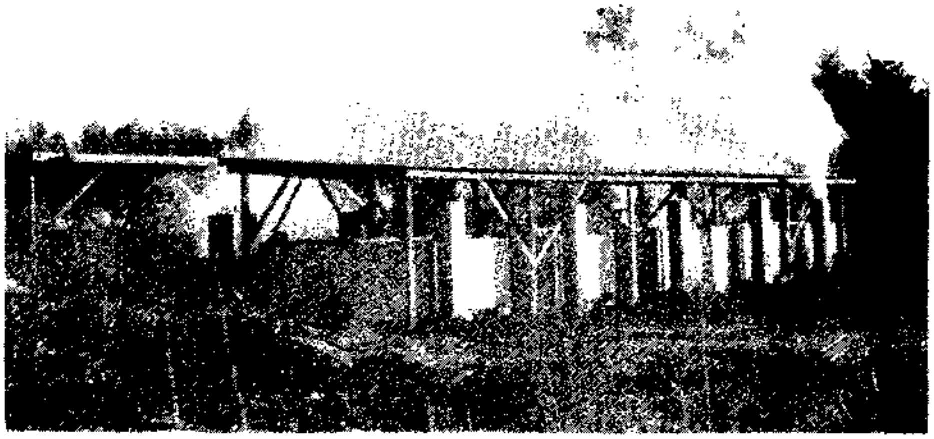


Figure 50. Charring Furnace of Brick

The extraction of tar and byproducts in wood charring may be done following various principles. Descriptions of furnace types and methods have been given by, among others, Bergstrom. [1,2] A great number of memoranda concerning experiences of operation with various structures and with more recent furnace designs have been given at pyrolysis conferences, arranged by the Swedish Academy of Engineering Sciences from 1941 to 1944. [60,61,62]

Furnaces may be classified in two groups: smaller furnaces, built for extracting tar from decayed stumps (tore), usually called retort furnaces; and larger industrial plants for charring regular wood, car-type furnaces, or retort furnaces. In charring of tore, relatively little charcoal is obtained and it is considered to be a byproduct; whereas in the larger plants charcoal is frequently of about the same importance as the liquid products. As shown in Table 21, only a minor quantity of raw charcoal is obtained from the tore furnaces. Therefore these furnaces will not be examined further.

According to a report by A. Hellstrom [62] which makes a comparison of various types of furnaces for charring tore, a recent type of furnace, the so-called "smoke spout," or AVI-Ramen furnace, produces about double the output per m^3 of furnace volume per day as is obtained in other types of furnaces. A short report on this type of furnace is given below.

The principle of the furnace, which is a combination of downdraft and charring, is described by T. Widell and K.V. Wiberg. [54] Reports on the design of the Steam Heat Institute, and on results have been given by O. Stenberg and K.E. Lagerstrom. [43] The design of a furnace with two brick shafts, each with a volume of 6.5 m^3, is shown in Figure 51. The furnace charge is put in from above, and gas burners are placed at the top as well. The charcoal is taken out at the bottom. The charge is ignited with generator gas from a smaller wood gas generator; when the uppermost fuel layer is ignited, the hot flue gases which result heat the material below, so that it is charred. For combustion, air is blown in by a fan. When the charring process is started, the gas that has not condensed will burn; this gas is brought back by the circulation fan to the shaft through the burner. The cooler for the pyrolysis gas mixed with flue gases is a scrubber type. The cooling liquid consists of tar water, cooled by water in a special cooler. The condensation from the cooler is carried with the cooling liquid solution to a collecting tub, to which a condensate separated in cyclones is also carried. The furnace is relatively inexpensive to build and very safe to operate because, among other reasons, it does not contain any high-temperature heat exchangers, which constitute highly sensitive components in prevalent types of construction. The furnace has also been successfully used for charring peat.

Several older types of construction of large charring furnace facilities are in use; for example, "car-type" furnaces with fans for internal gas circulation, from which tars are obtained, which are particularly suitable for motor operation. A car-type furnace of another kind, the "Aminoff furnace" is shown diagrammatically in Figure 52. This furnace has outside gas circulation and heating of the gas in a special device. The wood is loaded onto cars which are brought through a sluice and slowly pulled through the charring space. After charring is finished the charcoal and the cars are cooled in a charcoal cooler. A furnace type with vertical retorts and outer gas circulation has long been used, for example, at the Skanska Vinegar Factory, Inc., in Perstorp (Sweden), and furnaces of the same design have been constructed during the crisis in other places as well.

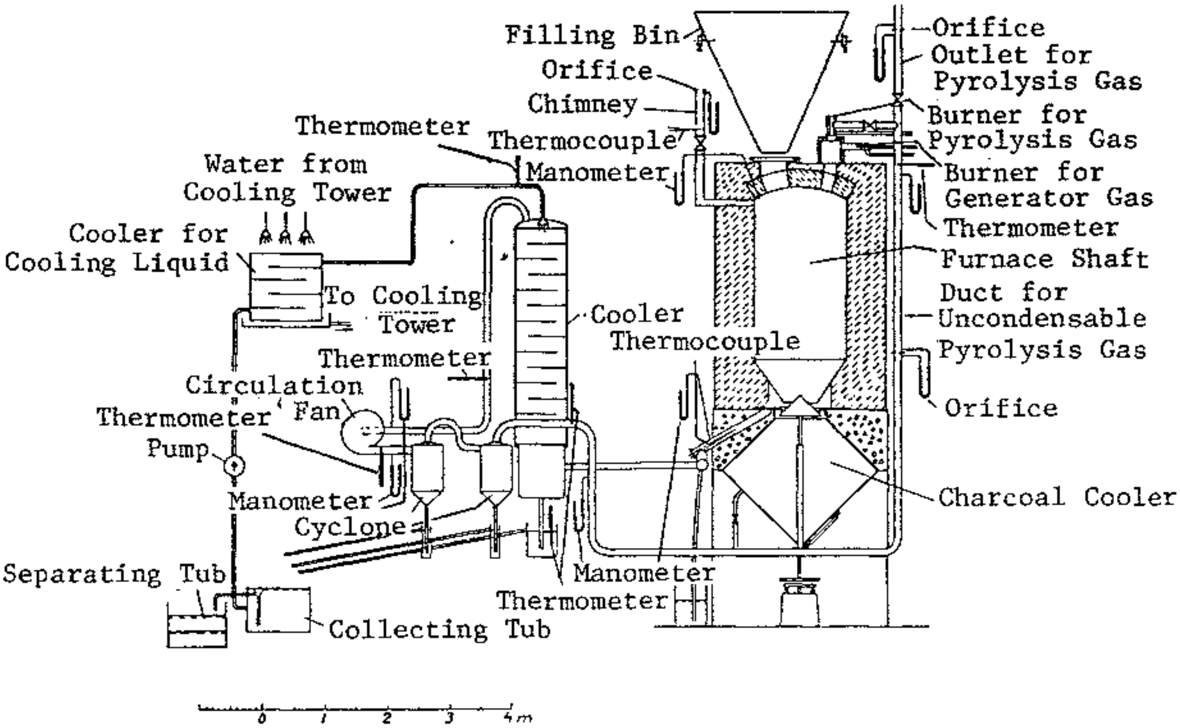


Figure 51. Diagram of an AVI-Ramen Furnace

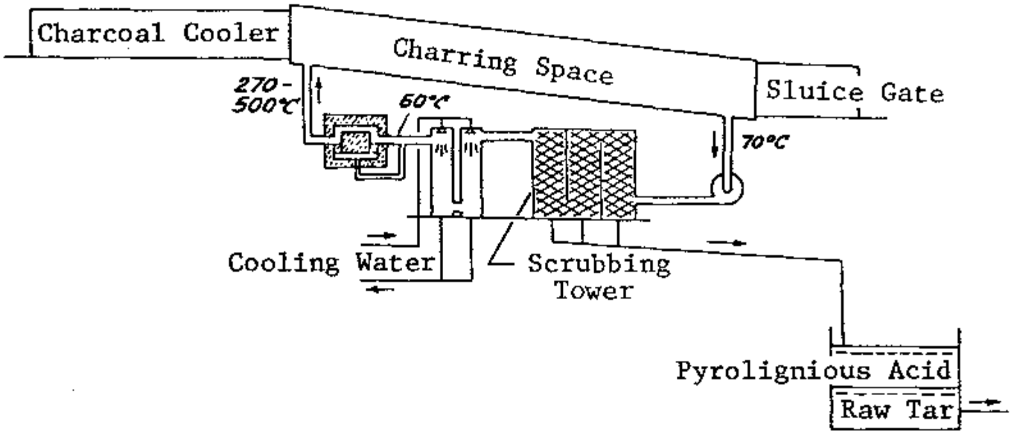


Figure 52. Diagram of an Aminoff furnace. (7-8 car loads of 10 m^3 each are charred in one furnace unit per 24 hours.)

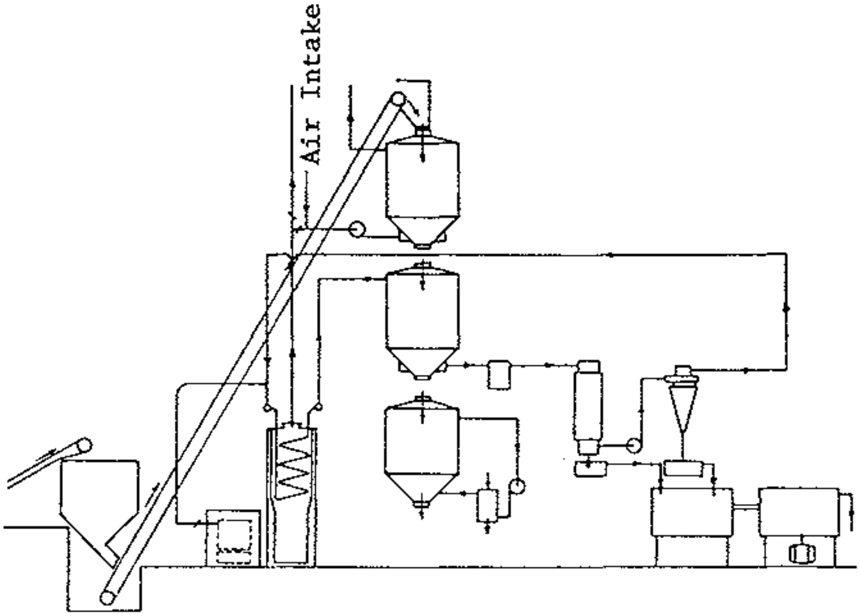


Figure 53. Diagram of the Swedish Generator Gas Co. Charcoal Furnace.

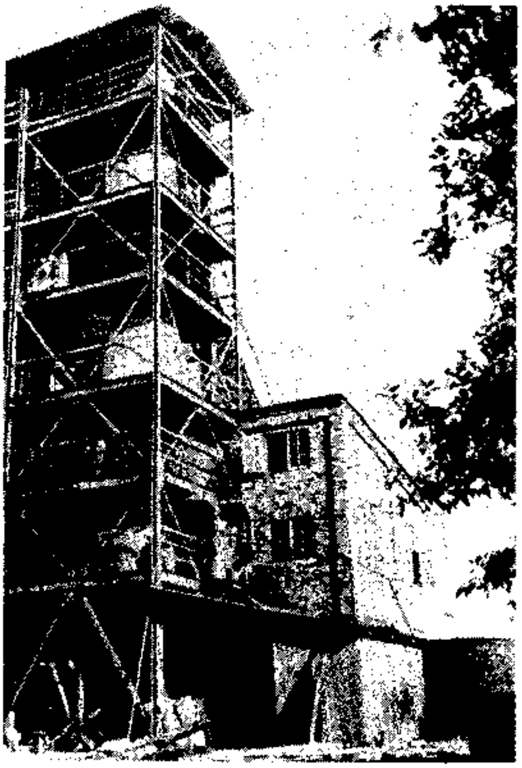


Figure 54. Large Modern Charcoal Furnace Plant. (The Swedish Generator Gas Co.)

A new type of charcoal furnace has been designed by the Swedish Generator Gas Company. [60,61] The principle for this is illustrated in Figure 53, and a picture of one given in Figure 54. This furnace is specifically intended for the charring of wood which has been broken up into small pieces beforehand. Therefore, the charcoal does not have to be crushed into smaller pieces as is required for furnaces which work with larger pieces of wood. The additional cost of breaking up the wood is compensated by decreased charcoal-dust loss and elimination of the cost of crushing. The furnace consists of three retorts vertically arranged: the uppermost for drying the wood, the second for charring, and the lowest for cooling the charcoal. The charring retort, containing 16.5 m^3 generator gas wood, works with outside gas circulation; the tar products are extracted in the condensor connected to the gas path. The gain has been 90 to 95 hL charcoal and 270 to 350 kg tar per retort, and three to four charring cycles have been completed in 24 hours.

Car-type furnaces and retort furnaces produce tar oils, turpentine, motor tar, raw methanol, and other important products; the charcoal obtained as a byproduct is somewhat brittle, but of high quality. These furnaces usually work with softwood as raw material in order to obtain tar products suitable for motor operation. There are, as mentioned above, suitable small furnace types for utilizing stumps (tore) and such waste; the number of these increased considerably toward the end of the crisis, whereas the number of charring furnaces decreased (see Table 19).

Table 19. NUMBER OF CHARCOAL FURNACES 1940-1945

	Retort Furnaces	Charring Furnaces
1 Jan. 1940	19	200
1 July 1940	19	220
1 April 1941.	38	2,570
1 Jan. 1942	55	2,490
1 Jan. 1943	106	2,780
1 Jan. 1944	approx. 260	approx. 2,500
1 Jan. 1945	269	1,975

Of the retort furnaces operating in 1945 no less than 186 were so-called "stump furnaces." It should be noted that at times over 5,000 privately owned charring furnaces were in operation at the same time. The total charcoal consumption during the years 1938 to 1944 according to information from the National Swedish Fuel Commission is shown in Table 20.

Approximately 17% waste has been estimated for burning raw charcoal into car charcoal, corresponding to a conversion figure of raw-charcoal/car charcoal of 1.2:1.0. The quantity of charcoal produced in 1943 is shown in Table 21. The iron industry probably used approximately 40% and vehicular traffic approximately 60% of this charcoal.

Table 20. CHARCOAL CONSUMPTION 1938-1944

Year	Raw Charcoal in 1,000 m^3			Car Charcoal in 1,000 hL
	Industrial Charcoal	Car Charcoal	Total	
1938	2,126	--	2,126	--
1939	1,954	24	1,978	200
1940	2,249	410	2,659	3,420
1941	1,843	2,580	4,423	21,507
1942	1,857	2,990	4,847	24,883
1943	2,042	3,160	5,202	26,322
1944	2,043	2,970	5,013	24,754

Table 21. PRODUCTION OF RAW CHARCOAL IN 1943

Manufacturing Method	Percentage
Charcoal from Stacks	approx. 39%
Charcoal from Charring Furnaces.	approx. 39%
Charcoal from Large Charcoal Furnaces.	approx. 17%
Charcoal from Retort Furnaces.	approx. 5%

Production of Commercial Car Charcoal

Charcoal obtained from charring wood that has been cut into small pieces may be used directly as generator gas charcoal, but as a rule the raw charcoal from charring-stacks and furnaces is crushed into suitable sizes; thus, commercial car charcoal may be obtained in various sizes. The various grades are shown in Table 22.

Table 22. COMMERCIAL TYPE CAR CHARCOAL

Type	Manufactured from	Manufacturing Method	Dimensions
Coarse grade car charcoal.	Charring-stack and furnace charcoal	Crushing and screening	1-6 cm
Fine charcoal	" "	" "	1-3 cm
Charcoal dust (duff). .	Waste in the charring process, crushing, transportation, and distribution	Taking out, screening, manual gathering	Powder

To utilize the considerable quantities of charcoal dust (duff) from generator gas production, specific generators have been designed and briquettes produced on a small scale. Charcoal dust is created not only during the production of the common charcoal grades and during transportation, etc., but also during long-term storage because of changes in weather conditions; charcoal of more porous consistency emits the most charcoal dust.

Production of Car Charcoal in Machines

Machines for crushing raw charcoal into commercial car charcoal are as a rule crushers combined with sorting devices such as screens, fans for charcoal-dust sucking, etc. (Figure 55). In order to decrease the charcoal-dust waste the crushing must be done in several stages. Power consumption may be estimated as approximately five to six kW at 80-120 hL/hr. On an average the grades of such machines will be approximately 78% coarse charcoal, 12% charcoal granules, and 10% charcoal dust. Sometimes, due to demand, it has been advantageous to concentrate on the production of fine charcoal at the expense of coarse charcoal. In that case the charcoal-dust fallout will be much greater, 35% or more.

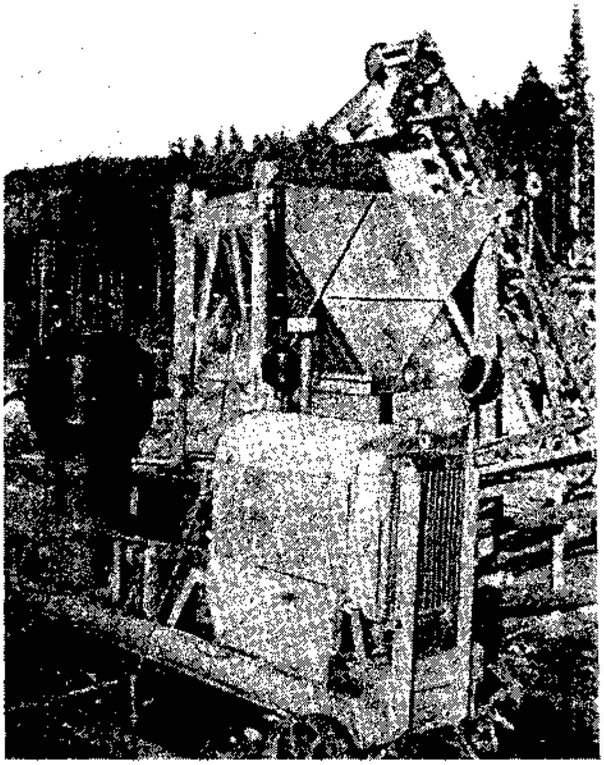


Figure 55. Charcoal Crusher Operated by a Generator Gas Motor for Production of Car Charcoal.

Semicharred Wood

So-called semicharred wood may be considered to fall somewhere between wood and charcoal. It is produced by having the wood dried and heated at approximately 250°C in a furnace. The gain from the raw material is then approximately 80% calculated from the dry substance of the wood. The wood undergoes a chemical change as shown in Table 23; also see Figure 33 in Chapter 2.

Table 23. THE CHANGE IN BIRCH WOOD DURING SEMICHARRING

	Wood before Processing	Semicharred Wood
Combustible Substance		
C . . . . %	51.0	55.6
H . . . . %	6.2	5.9
O . . . . %	42.8	38.5
Effective Heat Value kcal/kg	4565	4915
Moisture Content. . . . . %	24.5	10.5

The semicharred material is brown and does not emit soot. However, due to cost, such wood is of no importance for practical generator gas operation.

Peat and Peat Coke

Peat and peat coke for generator gas operation should be of especially low ash content and suitable piece size. Naturally, a low moisture content is also a valuable property.

The production of peat for fuel purposes may be done by several different methods. In Sweden, the most important are the machine-peat method and the cutter-milling peat method in combination with subsequent briquetting. [32,49]

The machine-peat method produces, after semidrying, irregularly shaped pieces of peat approximately 25 cm long and with an approximately 5 X 8 cm cross section. (See Figure 56.) These pieces of peat are too large to be used in gas generators and have to be crushed or divided in some other way into smaller pieces, which creates additional costs as well as dust losses that must be screened away. The generator gas fuel must be of a uniform size (see Figure 57).

The briquettes, which are manufactured by pressing the machine-cut peat, do not seem to be very suitable for generator gas operation since they have shown a tendency to fall apart or stick to each other. Some peat briquettes are shown in Figure 58.

One kind of peat fuel that probably could be used as generator gas fuel is Klint's peat pellets, which are made from raw peat directly shaped into dried pellets of suitable sizes.

Manufacturing peat coke is considerably more difficult than charring wood, since greater heat must be supplied for the charring of peat. Many furnaces intended for charring wood are, however, also suitable for charring peat, particularly furnaces in which hot gases circulate.

Operation results with peat briquettes and peat coke are given in Chapter 10.

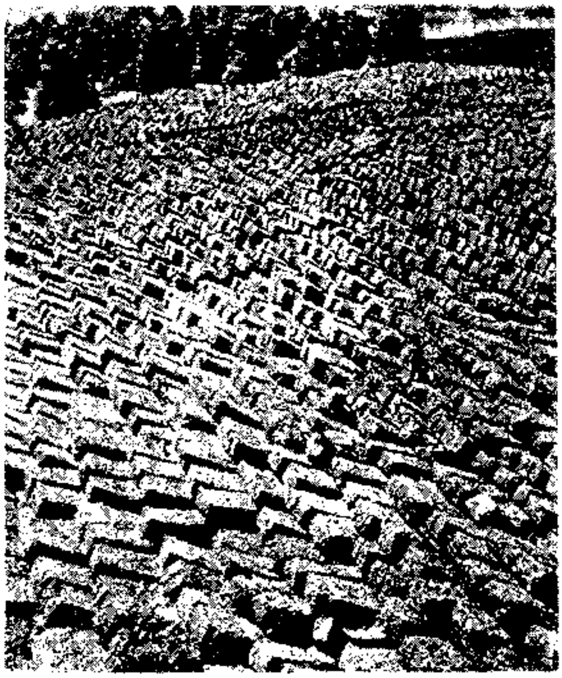


Figure 56. Sun-drying of peat. (Peat stacks in the background)

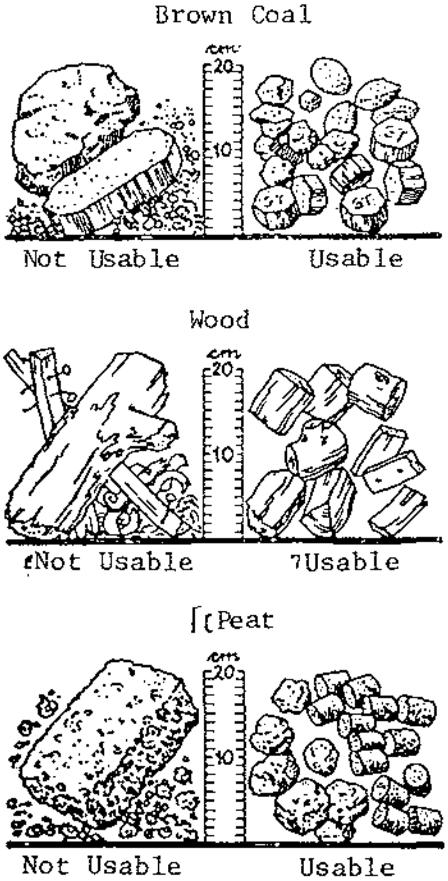


Figure 57. Sketch of Suitable and Unsuitable Generator Gas Fuel of Brown Coal, Wood, and Peat. (The piece sizes of the wood and briquettes of peat coke are about the same.)

Figure 58. Peat Briquettes

Briquettes

The production of various kinds of briquettes for gas generator use is relatively expensive, but, as a rule, the fuel is excellent with high heat value, little ash content, and high weight per unit volume. The difficulty in briquetting is to find a suitable binding agent. Dried sulfite lye has proven to be unsuitable since it is soluble in water; thus the briquettes, which in this case contained charcoal dust as raw material, could not tolerate dampness. Briquettes of charcoal and wood in equal parts have been tried with some success. Briquettes of peat were mentioned above. Briquettes of charcoal dust (duff) with tar as a binding agent have proved to be usable. Pressed briquettes of brown coal, of the same type used in Sweden for central heating of houses, were used in other countries to a large extent in wood gas generators. The production of charcoal briquettes has been kept especially secret, and little has been published. The technical development in this area could probably be said to be far from finished.

Car-Fuel Packing

Car wood as well as car charcoal was packed mainly in paper sacks (Figure 59). Other types of packing, such as net sacks of paper yarn, were used occasionally. The sacks were filled manually by the small producers, whereas the big producers frequently had special filling machines. The sacks, when filled, were closed with a soft metal wire which was twisted together with a drill shaft. The sacks were chiefly of three sizes, containing 1 hL, 1/2 hL, and 1/3 hL. The last-mentioned small sack was used mostly for charcoal for Kalle generators. Sacks for 1 hL of generator gas wood were made of three sheets of 80-g sulfate bag paper, whereas the other sacks were made of two sheets of 80-g paper.

Figure 59. Packing Generator Gas Charcoal

The sacks were made with either glued, sewn or stapled bottoms (Figure 60). They usually were furnished with advertising prints in one or two colors. The small producers of generator gas fuel, however, used sacks without print, since the printing would be too expensive for the small quantities in question.

The paper sacks were usually manufactured in special sack machines and their durability was controlled by several different special tests, such as bursting tests (Figure 61), falling tests, dampness tests, heat and cold tests.

The total deliveries of paper sacks for generator gas fuel in Sweden is stated in approximate figures in the list below, according to information given by Sture Andre, President of the Stromsnas Mill.

Year	Number in Millions	Value in Million kr
1940	21.9	3.0
1941	47.8	6.7
1942	55.2	7.7
1943	48.5	6.8
1944	40.8	5.7
1945	36.5	5.0

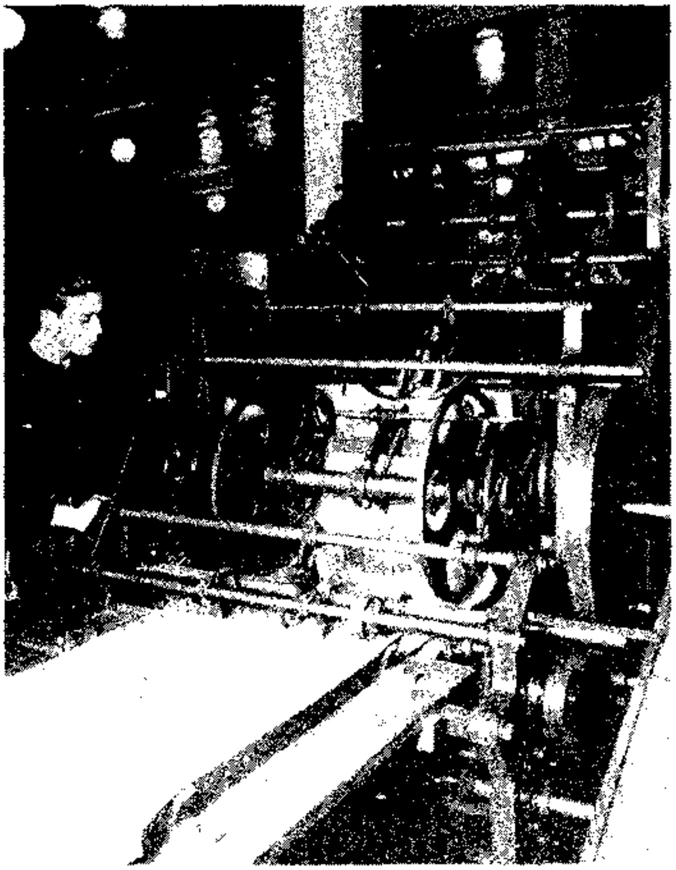


Figure 60. Machine for Producing Canister Sacks with Wide Bottoms (Stromsnas Mill, Inc.)

Paper sacks of the type described above cannot, however, be burned up in the generators, due in part to ash formation and in part to their possibly causing bridging of the fuel. A suitable packing, one that burns rapidly without considerable ash formation and does not interfere in the process, would be a substantial improvement--also esthetically, since the innumerable generator gas fuel sacks on the roads are not attractive. Such packings have been tested, but the results have not been sufficiently good for commercialization. One method would be to use sacks with a durable outer cover and a thinner inside sack that can go with the fuel into the generator. The outer sacks would not be thrown away, but returned when fuel is bought next time.

Distribution and Storage Problems for Generator Gas Fuels

Distribution of generator gas fuel to consumers is effected mainly by gasoline stations along the roads. These stations bought their supplies from large wood and charcoal firms, which also delivered directly to big consumers. Some businesses such as certain industries, railroad companies, etc., were self-supporting. Since most distributors lack sufficient storage facilities for the bulky fuel and an even and continuous supply frequently is difficult to maintain from the standpoint of production as well as transportation, it is desirable to arrange large buffer storages of generator gas fuel in densely

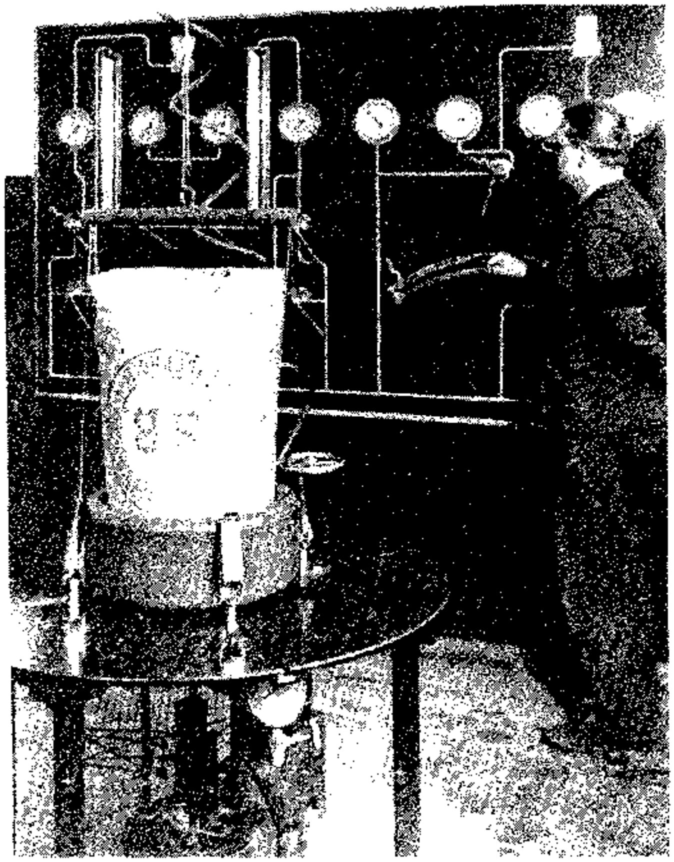


Figure 61. Bursting Tests in a Specially Made Testing Device (Stromsnas Mill, Inc.)

populated areas. Private initiative in such situations cannot be relied upon, due to relatively great investment risks, etc. Since it is in the interest of society that the traffic system is not thrown into confusion, it is desirable for generator gas fuel to be produced, stored, and distributed under government auspices during times of crisis. This was the case to a large extent during the past time of crisis (see Chapter 1). In this context it should be observed that the rayon regulations, which were passed for motor traffic with the intention of saving rubber and lubrication oil, have proven to be an impediment as well as an extra expense for the distribution of generator gas fuel.

Car charcoal has less resistance to mechanical strains and has greater flammability and sensitivity to impurities (gravel, soil, etc.), and hygroscopic properties compared to car wood. Thus the direct costs of storage, distribution, quality control, etc., will be considerably higher for car charcoal than for car wood, as well as additional indirect costs due to material losses, time losses, etc.

Distribution and Storage of Car Charcoal

The mechanical durability of raw (i.e., not crushed and packed) charcoal is poor. Through transportation, transshipments, and storage during its way from the charring stack or the charcoal furnace to the consumer, up to 40% to 50% of the raw charcoal might be converted to dust. This charcoal dust was utilized only to a small extent. The charcoal dust losses may be kept to about 20% to 25% if the charcoal is packed at the place of production, the charcoal furnace. Charcoal from stacks in the forest generally contain soil and sand impurities, which must be carefully separated. Thus, such raw charcoal must be transported to places where there are sorting devices and then charcoal dust losses cannot be avoided.

By transferring the entire charcoal production process, from raw wood to charcoal ready for sale, to large plants within typical forest and wood industry areas the following advantages are gained.

1. Better utilization of the raw material and decreased charcoal-dust loss;
2. More even and purer quality;
3. More regular supply (not seasonal); and
4. Better opportunities to utilize the charcoal-dust waste.

After car charcoal has been packed, the possibility of maintaining quality control until it is used in the generator is small and, as a rule, can only take place through spot checks. The difficulties in this respect brought about a rather strong competition between car-charcoal producers and the creation of special brands, [38] which was, of course, an advantage for the consumers, who had an opportunity to obtain regular and assured supply of a guaranteed quality product.

Car charcoal absorbs humidity from the air (see Figure 62) and gives off charcoal dust due to changes in temperature, especially under the pressure that is created by stacking in the storage facilities. Storage in these facilities should be on a wooden, not cement, floor; in the latter case the lowest layer of charcoal sacks have their contents ruined by dampness. Provided that crosswise stacking is used, car charcoal can tolerate a considerable stacking height, up to 50 layers of sacks.

Distribution and Storage of Car Wood

Car wood should also be stored in as dry a place as possible, although it is far less hygroscopic than car charcoal. Its greater mechanical strength relative to charcoal makes distribution and storage a relatively simple problem from a technical point of view.

Control methods for generator gas fuels were discussed in Chapter 2.

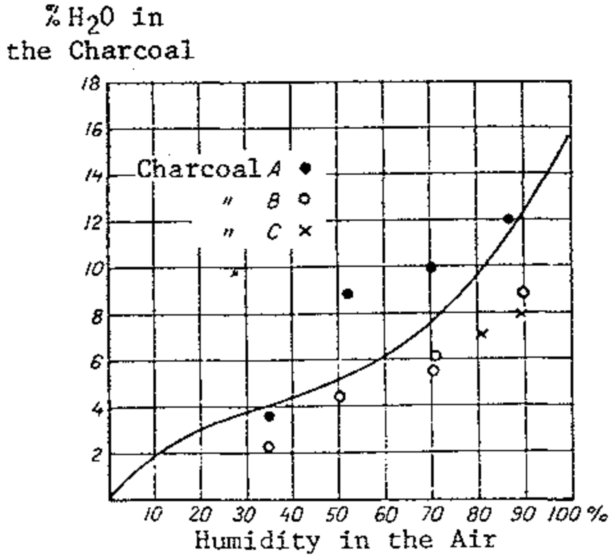


Figure 62. Graph Showing Variation in Moisture Content of Charcoal with Relative Humidity of the Air.

Government Measures for the Production of Generator Gas Fuel

It was mentioned in Chapter 1 that the Generator Gas Committee from its inception considered the question of the supply and distribution of charcoal suitable for generator-gas operation at reasonable prices to be one of the most important conditions for a successful changeover to generator gas operation. (This question had also earlier caught the attention of government authorities. Thus the 1938 Parliament had appropriated 30,000 kr for measures to support the production of generator gas charcoal.) In the Committee's letter of September 11, 1939, to the government, measures were proposed in this regard. Immediately after war broke out, the government set up the National Swedish Wood Committee, which was to direct the wood and charcoal supplies during the coming crisis. The Wood Committee was later incorporated in the National Swedish Fuel Commission. In the beginning of the crisis, a highly increased demand for charcoal arose due to expected import difficulties for foreign fuels. Besides the charcoal needs of the iron works, the charcoal needs of the generator cars had to be satisfied. The generator cars had just started to come into use and most of them were designed for charcoal operation. It was difficult to meet the increased demand, because the charring season had already started, and no large quantities of wood for charring were available above what was needed for the planned charring for normal needs. Furthermore, there was a shortage of skilled charcoal-burners.

In order to stimulate production the prices of charcoal were increased. The government appropriated funds as subsidies for the construction of small charcoal furnaces in order to rapidly increase charcoal production. To further the development of charring in furnaces, the Government Fuel Board later had drawings made for charring furnaces of various sizes, units for utilizing by-products from charring furnaces, and a few types of small retort-furnaces. Furthermore, the government appropriated grants for arranging courses in charcoal manufacturing technique. Widespread course activities were achieved in this way, especially in the north. Due to these measures, there was a considerable increase in charcoal production.

In a letter of December 14, 1939, the Generator Gas Committee petitioned the government to make arrangements to create a financially strong commission to be in charge of the charcoal trade and its regulation. However, as early as November 1939, an association named "Car Charcoal Association, Inc.," had been created after deliberation between various interested parties, with shareholders mainly from the car- and generator gas manufacturers. The object of the association was to oversee the production and distribution of adequate car charcoal at a reasonable price. The association cooperated closely with the government bodies and received government loan guaranties, which made it easier for the association to attain its ends. In January 1940, quality standards for car charcoal were drawn up. These were later revised by the National Swedish Fuel Commission and were expanded to contain more detailed requirements for car charcoal and car wood. (Technical Memoranda from the National Swedish Fuel Commission, No. 9, May 1941.)

When a general changeover to generator gas operation came into question in April-May 1940, government authorities discussed proposals for, among other things, measures to satisfy the country's need for generator gas fuel. One measure was the creation of the Swedish Generator Gas Co., which took over the business of the Car Charcoal Association and devoted itself to the production and sales of generator gas fuel on a large scale.

The unexpectedly rapid growth of generator gas operation put the supply of generator gas fuel to the test. During the spring and summer of 1940 it could hardly have been foreseen that the number of generator gas cars in operation would grow by about 30,000, of which two-thirds were charcoal gas operated.

The rapid increase toward the fall of 1940 therefore caused a concern for the winter and the needs for generator gas fuel together with an estimated great need of wood for households and industries. In September 1940, the Fuel Commission estimated the need for generator gas fuel (car charcoal and car wood) which would arise in case of an unrestricted changeover to generator gas operation, paying due attention to the most important traffic needs and certain other purposes within the agriculture and road systems, as well as other areas where generator gas could easily replace liquid fuel. An annual quantity of over 50 million hL was estimated; this need, however, could not be expected to arise until the latter part of 1941. For an assumed wood gas operation averaging 40%, a consumption of car charcoal and car wood could be assumed in an approximate proportion of 50/50 taking into account the larger consumption of trucks and buses. Approximately 3.3 million m^3 raw charcoal would be needed for the production of the car charcoal. The estimate for the entire car fuel quantity was that approximately 8.2 million m^3 of wood would be consumed. Since the iron industry during the period 1915 to 1919 had used on an average of 4.2 million m^3 charcoal per year, and around 1940 was estimated to use only 2 million m^3, the charcoal needed for the generator gas operation did not seem alarmingly great; at any rate, not if the car fuel would consist of wood to a large extent. Possibly a shortage of personnel skilled at charring in stacks could be expected, but on the other hand, furnace charring had made great progress during the last years. Charring courses were arranged. In addition, charcoal could be produced from hardwood, which had previously not been used for this purpose. Therefore, it was the opinion of the Fuel Commission that there was no reason, in the long run, to object to a free development of generator gas operation from the viewpoint of fuel acquisition.

It should be mentioned that, among other measures, the National Swedish Forest Industries, Inc., was created with government assistance.

The Generator Gas Bureau's Standards for Generator Gas Fuels

Quality Regulations for Car Wood (Generator Gas Wood)

1. Wood fuel, ready to burn in gas generators for motor operation, shall be sold under the term "car wood."

2. Car wood shall be sold with information about the kind of wood (see instructions, Item 1):

    a. Hardwood

        (1) Beech (other heavy kinds of hardwood, except for oak)
        (2) Birch
        (3) Alder, aspen (other light kinds of hardwood and oak)

    b. Softwood
    c. Mixed wood, with information about mixing proportions

3. Car wood shall be sold with information about manufacturing method:

    a. Sawn wood, car blocks (see Instructions, Item 2)
    b. Wood cut with an axe or a chopping machine, car chips (see Instructions, Item 3)

4. Car wood shall be sold in two grades:

    a. Fine grade, length 2-5 cm, largest cross section 25 cm^2
    b. Coarse grade, length 3-8 cm, largest cross section 30 cm^2

5. Car wood shall be practically free from sawdust and splinters. Splitting must be complete, so that the pieces are completely separated (see Instructions, Item 4).
    Car wood shall be free from rough bark (see Instructions, Item 5).
    Car wood shall be practically free from decay (see Instructions, Item 6).
    Car wood shall be dry:

    The moisture content of general samples taken from car wood must not exceed 25% (see Instructions, Item 7).

    Car wood whose moisture content in general samples does not exceed 17% is considered to be <u>extra dry</u>.

    The limit values of the moisture content above are valid with a permissible variation of two units.

6. The following data shall be given on packages of car wood: Car wood, volume in hL, kind of wood and mixing proportions, manufacturing method and assortment, degree of dryness, and manufacturer.

Example of Designation

1 hL Car Wood
Dry Car Chips
Birch and Softwood
70% 30%
Coarse Grade
Manufacturer:
A. Johansson, Backdala

1 hL Car Wood
Extra Dry Car Blocks
Birch

Manufacturer:
A. Johansson, Backdala

<u>Quality Regulations for Car Charcoal</u> (Generator Gas Charcoal)

1. Charcoal ready to burn in gas generators for motor operation shall be sold under the term "car charcoal."

2. Car charcoal shall be sold with information about the kind of wood (see Instructions, Item 8):

   a. Hardwood Charcoal

      (1) Charcoal of beech (other heavy kinds of hardwood except for oak)
      (2) Charcoal of birch
      (3) Charcoal of alder, aspen (other light kinds of hardwood and oak)

   b. Softwood charcoal
   c. Mixed charcoal, with information about the mixing proportions

3. Car charcoal shall be sold with information about the charring method:

   a. Charcoal from charring stacks
   b. Charcoal from charring furnaces
   c. Charcoal from retort furnaces

4. Car charcoal shall be sold in two grades:

   a. Fine grade—1-3 cm
   b. Coarse grade—1-6 cm. In the coarse assortment no more than 10% may be of 1-2 cm dimensions.

5. Car charcoal shall be dry, solid and as far as possible free from charcoal dust. It shall be thoroughly charred, free from calcines, and practically free from foreign substances such as soil, sand, rocks, metal particles, and other impurities.

a. The quality shall correspond at the least to the following analysis values (see Instructions, Item 9). Moisture content—18%, ash content—5%, loss due to burning—20%.

b. Car charcoal is considered as prime with at least the quality shown in the following analysis values (see instructions, Item 9). Moisture content—10%, ash content—3%, loss due to burning—15%.

c. Loss due to burning means the weight loss in a dry sample when heated without air supply to 800°C to 850°C. An analysis of car charcoal shall be made on general samples. The following permissible variations on the above-mentioned percentages are then valid. Moisture content—2 units, ash content—1 unit, and loss due to burning—3 units.

6. The following data shall be shown on packages of car charcoal. Car charcoal—volume in hL (when packed), kind of wood and mixing proportions, charring method and assortment, and manufacturer (see Instructions, Item 10).

Example of Designation

1 hL Car Charcoal
from Charring Stack
Birch and Softwood
70% 30%
Coarse Grade
Manufacturer:
A. Johansson, Backdala

1 hL Car Charcoal
Prime Charring Furnace
Hard (Birch 70%)

Fine Grade
Manufacturer:
A. Johansson, Backdala

Instructions

1. When information is given on the packing about the kind of wood, the following rules should be observed.

Unmixed wood is indicated by the name of the kind of wood. For pure softwood, however, the term soft may be used. Mixed hardwood shall, if the mixture is of various kinds of wood, be named hard, to which may also be added the approximate proportion of the most valuable kind of wood, for example Hard Beech 30%. If only two kinds of hardwood are part of the mixture, these should be named with their respective percentages, for example Beech 30%—Birch 70%. When hardwood and softwood are mixed, the approximate mixture proportions shall always be stated, for example, if only one kind of hardwood is used Birch 40%—soft 60% and if several kinds of hardwood are used for example, Hard 40%—Soft 60%. Oak wood must not be more than 1/3 of the entire quantity, unless so stated.

2. As for the manufacturing method, sawn wood is called car blocks, by which is meant sawn and split wood, sawn unsplit roundwood, as well as a mixture of both assortments. Sawn unsplit wood is sometimes called round billets. If more than 3/4 of the car wood consists of such wood it is suitable to give the wood a special term, namely car blocks (billets) or only car billets. Car blocks may contain a small amount of car chips (see below); however, no more than 1/3.

3. Wood cut with an axe or chopping machine is called car chips. Car chips may contain car blocks.

4. The wood pieces shall be completely separated from each other. A few pieces sticking to each other is permissible, however, if the wood otherwise is of the recommended quality.

5. Car wood shall, according to the regulations, be free from rough bark. Thus, there must be no crust-bark or other rough bark; for example, the kind of rough bark frequently occurring on loose-grained spruce. Removal of the bark under all circumstances is advantageous and makes the wood dry faster and more easily, especially when it is the kind of wood, such as aspen, that is difficult to dry.

6. Car wood must not be decayed. However, rotten knots in hardwood are permissible.

7. In summer-dried wood, the moisture content rarely exceeds 25%. Such wood is called dry.

   The degree of dryness required for wood to be called extra dry is a maximum moisture content of 17%. It is obtained during the best drying time (April-July) through air drying of cut up pieces over a long period, under cover; but during other times of the year only through artificial drying. Because of air humidity, however, the moisture content of such wood may increase again, under certain circumstances up to 20% to 22%, even if protected from rain. This means that extra dry wood must be stored in dry facilities or be protected in some other way. "Percentage" in this context means weight percentage when nothing else is stated; i.e., the gross weight of the fuel.

8. For car charcoal, the kind of wood is stated just as for car wood; car charcoal is considered to be a mixture of hard and soft wood only if the hardwood portion amounts to at least 25%.

9. Charcoal complying with the minimal requirements of the regulations in Item 5 for car charcoal (moisture content, ash content, loss due to burning), is obtained from a charring process that has been carefully carried out with suitable wood, independent of the charring method. Charcoal is considered to be solid charcoal when, in a given manufacturing method, it is obtained from careful and not too rapid charring of suitable wood.

Car charcoal manufactured by furnace charring frequently has lower moisture content and ash content than those stated. Charcoal from charring-stacks usually has low loss due to burning.

The loss due to burning is a measure of the volatile substances contained in the charcoal. Low loss due to burning consequently means, among other things, a decreased risk of tar formation.

In order to obtain and keep the quality necessary for prime grade car charcoal, special care is required in the charring process as well as in transportation and storage of the charcoal. To reach this quality in charring in furnaces it is important that the charring process is not rushed, and that the charring temperature is kept sufficiently high. During charring in stacks it is necessary to prevent the charcoal from being contaminated by sand, etc., or from becoming wet. Charring with a chimney and cold extinguishing (damming the charring stack) would seem to be the best method for obtaining good charcoal.

"Percentage" means weight percentage based on the gross weight of the fuel, unless otherwise stated.

A simple method for analyzing charcoal has been worked out by the Charring Laboratory and is described in publications by the Swedish Ironmaster's Association, "Charring in a Furnace," and "Manufacturing of Charcoal for Generator Gas Operation."

10. "Manufacturer" means whoever finishes and packs car charcoal.

Charcoal or Wood?

The question of generator gas from charcoal or wood has been heatedly debated during the generator gas epoch (especially in its beginning), and experience has gradually brought forth the more correct position of charcoal and wood. Both kinds of fuel are justified in Sweden; rationally, they must really only be limited to the appropriate area of use for each, so that each may be done justice. Chapter 2 shows that wood gas operation means better fuel economy for the car. During the war the prices of car charcoal and car wood resulted in 60% greater cost for charcoal gas operation then for wood gas operation.

Opposing opinions have been heard concerning other factors affecting the operating cost estimates (rate of interest and maintenance). Among other things it has been said that wood gas operation would result in greater service costs than charcoal gas operation; a detailed study of available statistics concerning this detail makes it clear, however, that such a statement is, on the whole, exaggerated. In reality, many reliable operators are of the opinion that wood gas operation is also superior from the viewpoint of service. Thus it could rightfully be said that, with skilled maintenance, both charcoal gas and wood gas operation are practically equal in this respect; if there should be, in a few rare cases, some small difference to the disadvantage of wood gas, it would not be so great as to counterbalance the fuel economy advantages of wood gas operation.

From a politico-economic point of view the situation is more complicated.

On one hand, wood gas operation does save forest resources (see Figure 63), as was shown in the preceding paragraphs. During the latter part of the generator gas epoch about as much car charcoal as car wood was consumed in Sweden, approximately 25 million hL per year of each kind. But as the charcoal gas operation consumed approximately 50% of the generator gas fuel, it made use of approximately 70% of the wood needed for the entire quantity of generator gas fuel. If our entire generator gas operation had been based upon wood gas, the quantity of wood needed for motor fuel production would have decreased by more than 40%. A corresponding decrease of workhours for felling and chopping and transportation would have been the result. At the same time the work of charring the generator gas fuel would have been eliminated. These opportunities for saving are important factors in a critical situation with a shortage of labor, especially skilled labor, and transportation.

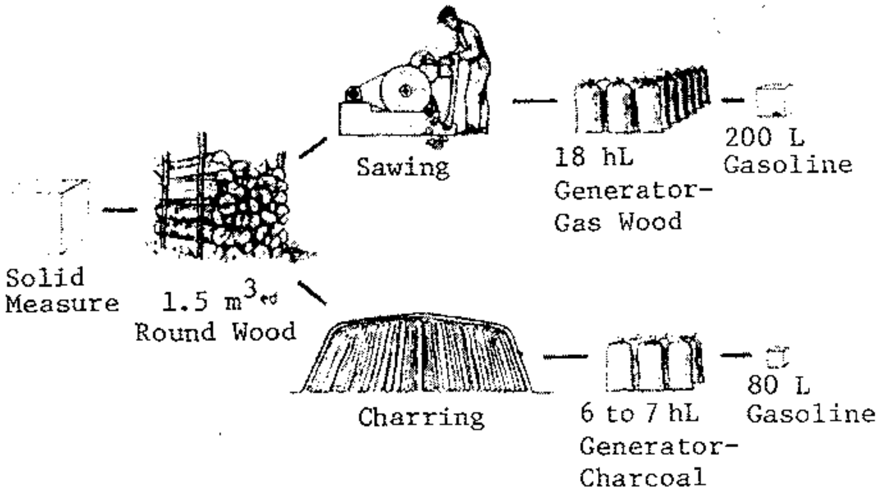


Figure 63. Comparison between the Quantities of Car Wood and Car Charcoal Manufactured from 1 m^3 Solid Raw Wood.

On the other hand, it has been pointed out that rational charring, utilizing all byproducts, yields large quantities of byproducts that are valuable for the nation's economy, so that charcoal operation is well justified and useful for the nation, in spite of its larger wood consumption.

Thus the applications of car wood and car charcoal become clearly defined. In the case of an oil embargo, however, other factors involving organization seem to make wood gas operation more advantageous (labor supply, transportation, storage, distribution conditions, etc.).

To this may be added that the quality of car wood is not very dependent upon the wood raw material and the manufacturing method, whereas the quality of car charcoal is highly dependent upon the manufacturing method in respect to the combustible substance as well as impurities causing functioning difficulties. It is often said that charcoal operation means faster adaptation to changes of load than wood gas operation; this, however, is not due to the kind of fuel, apart from the fact that a smaller piece size and more porous fuel increases the reaction surface. This is why fine charcoal and charcoal dust, in generators designed for this purpose, have certain advantages in this respect. As a matter of fact, the so-called slow response of generator gas operation to changes of load and the relation between maximum power and idling characteristics are mainly due to the quality of design of the gas generator (for example, hearth size, hearth insulation, resistance in pipes and filters, etc.), and the adaptation of the design to the fuel and the conditions of operation, in wood gas as well as charcoal gas operation.

Chapter 4

SHAPE AND DESIGN OF THE GAS GENERATOR

From a technical viewpoint the gas generator is a device in which a solid fuel is transformed into a gaseous fuel, usually without the use of an outside artificial heat source. It is desirable that this transformation take place with as little loss of the energy content of the solid fuel as possible.

From the viewpoint of use, the ideal gas generator should be suitable for all solid fuels and thus be universally usable. Attempts have been made to design such gas generators, but the results have not been satisfactory for fuels specifically distinct from each other. This is due to the fact that the fuels used for gas generation may be classified into two main categories: (1) "tar free," i.e., prime grade charcoal and coke; (2) "tar emitting," i.e., wood, peat, and, to some extent, incompletely charred charcoal. A gas generator for category 1 is mainly only a space in which charcoal is burned to CO_2 with an immediate reduction of CO_2 to CO by means of glowing charcoal. On the other hand, a gas generator for category 2 must contain not only the combustion-reduction space just mentioned but, in addition, a space in which the basic fuel is dried and pyrolyzed through heating into charcoal that is continuously fed out and is suitable for combustion. Furthermore, the combustion must take place under such circumstances that the volatile tars created in the fuel container may be utilized by being rendered harmless during their passage through the combustion zone.

A "universal generator" must be of the latter type; and, in addition, be so designed that during operation with tar-free fuel the entire "primary" part of the production process may be passed over without altering the temperature conditions in the hearth to an extent detrimental to the function of the generator. This has proved to be a very difficult, and from a practical standpoint, perhaps an unsolvable problem.

Therefore, the development of generators has proceeded along separate paths for the main groups of fuels—in Sweden's case mainly charcoal and wood. (In other countries, especially where the forest resources are limited, the gas generators have been designed for more abundant fuels such as anthracite, brown coal, brown-coal coke, peat, pressed straw, etc.)

The simplest design of a gas generator is feasible, as pointed out above, when fuels are used whose volatile components have been removed beforehand. The difference in design between charcoal and wood gas generators is primarily in the gas generator itself; but there are also some differences in secondary devices such as gas cleaners and gas coolers, depending upon, for instance, the unequal moisture contents of wood gas and charcoal gas. (See Chapter 5).

In designing a gas generator, one must take into account the circumstances under which it is to be used. Greater demands with respect to combustion properties and cleanliness are made on a gas generator for motor operation than on a gas generator for heating purposes. Furthermore, the demands made on a gas generator for vehicular operation are generally higher than for stationary motors, where weight is of minor importance.

In Sweden gas generators have been used mainly for operating motorized vehicles. The features of gas generators desirable for such operation may be summarized as follows:

1. Simple design and use of suitable materials to ensure safety of operation
2. Low weight
3. Simple and inexpensive installation
4. Simple maintenance with the various parts easily accessible for inspection and cleaning
5. Capability of easily changing damaged or worn parts
6. Good energy economy, without neglecting the other requirements
7. Great flexibility during load variations with respect to both gas production and the requirement of clean and tar-free gas during all load conditions as well as during prolonged idling
8. Small pressure drop, so that the best possible motor efficiency is obtained (For two-cycle motors this is of particular importance.)
9. High heat value of the gas produced, and easy ignition in a suitable mixture with air
10. Insensitivity to inferior quality fuel
11. Easy adaptation to various motor efficiencies and operating conditions
12. Adequate protection against fire and poisoning accidents
13. Short startup time.

To facilitate driving and to prevent damage to the gas generator or the motor it is also desirable that the gas generator be equipped with instruments that indicate pressure, temperature, and fuel supply. Since the stresses on various parts of a gas generator vary to a great extent, it is important to design the generator to make it easy to replace parts which are rapidly worn or damaged; especially to replace welded connections with bolted connections, etc. Maintenance should be facilitated by making drain cocks and drain plugs, ports, etc., easily accessible.

Thus the designer of a perfect gas generator for vehicular operation must consider many factors and must have intimate knowledge of the physical and chemical processes which determine the function of the gas generator. Systematic cleaning and maintenance as well as a driving technique adapted to the fuel are required to make the gas generator function well.

The manner in which these requirements are to be met is highly dependent upon the fuel used. A charcoal gas generator, which usually is not designed to give total combustion and decomposition of tar gases from incompletely charred charcoal, is sensitive to the quality of the charcoal,. depending on the shape of the hearth. In addition, the high combustion temperature may make strong demands on the material used in the most exposed parts, especially the primary air nozzles. The most critical parts of a wood gas generator are the fuel container and the hearth.

Due to the properties of charcoal, the fuel container of a charcoal gas generator may be made from thinner material. Also, since the cleaning and cooling of charcoal gas (due to the insignificant moisture content of the gas) are comparatively simple and require less cooling surface than in the case of wood gas, a charcoal gas generator can be more easily designed for light weight than a wood gas generator.

The greatest advantages of a wood gas generator are to be found in lower fuel costs and greater opportunities for the owner to prepare his own fuel. On the other hand, a wood gas generator seems to require more extensive maintenance during intermittent operation. As for operational properties, no difference in efficiency has been shown to exist between charcoal and wood gas during brake tests. In practical operation, however, wood gas has been found to be somewhat superior for steady power; this may be of importance in heavy traffic and for stationary motors with peak loads.

In comparing the suitability of charcoal gas and wood gas for motor operation one must also determine if there is a difference in motor wear and oil consumption. The determining factor is the degree of purity of the generator gas and the secondary air.

Gas from a charcoal gas generator is relatively free of water and corroding components, but it generally contains a considerable amount of ash and charcoal particles, which may cause mechanical wear and thickening of the lubrication oil if allowed to enter the motor. Thus the cleaning problem in charcoal gas operation is of a purely mechanical kind and may be satisfactorily solved by means of cyclone and cloth filters coupled in series. (Until about 1940 only cloth filters were used.)

At the gas outlet the wood gas contains a considerable amount of ash and soot, as well as water vapor and possibly distillation products from the pyrolysis in the fuel container (if these have not been cracked in the combustion and reduction zone). These impurities in the form of gas or vapor made it necessary to use a more complicated cleaning process than for charcoal gas.

If the dimensions of the gas cleaning devices and the gas generators are adequate, wood gas operation may be considered as harmless as charcoal gas operation for motors. When the war started, however, the charcoal gas technique was more advanced, and it is quite natural that wood gas operation was generally considered dangerous for motors, and indeed it was in many cases.

In this context one must not disregard a circumstance that does not directly concern the gas generator but that nevertheless has greatly contributed to abnormal motor wear; namely, inadequate cleaning of the secondary air. This has probably caused most of the motor damage that has been blamed on generator gas operation. This assumption is supported by the fact that generator gas-driven stationary and marine motors generally have shown quite insignificant wear and that the effective air cleaners later used in generator gas-driven ground vehicles contributed to a significant decrease in motor wear and oil consumption.

Parallel with the qualitative equalization between charcoal and wood gas generators during the war years, there has also been a quantative equalization. Table 24 shows the distribution of civilian motorized vehicles in various categories by the end of 1944.

Table 24. THE NUMBER OF CHARCOAL AND WOOD GAS GENERATORS BY THE END OF 1944

Generator Gas Category	Private Cars	Truckload Capacity, kg		Buses[a]	Large Motor-Cycles	Agricultural Tractors	Total
		Up to 2,000	Over 2,000				
Charcoal Gas . . .	30,496	7,095	8,547	1,625	855	approx. 300	approx. 48,920
Wood Gas	4,072	1,909	16,774	3,121	4	approx. 15,000	approx. 40,880

[a] The number of buses includes all gas generators mounted on trailers and those few used for operating passenger cars.

The table shows that charcoal gas operation was predominant for private cars, light trucks, and motorcycles, whereas wood gas operation accounted for the majority of the other categories. If the number of wood gas generators for stationary motors, heating purposes, ships, etc., is included, the total number of wood gas generators in Sweden would seem to be as great as the number of charcoal gas generators. The total number of gas generators in Sweden reached about 100,000 by the end of the war, involving a considerable capital investment, including the cost of adapting motors, installation, and service facilities. It would seem to be of great importance to choose a few types of gas generators for large-scale standardized production in case of any future general change-over to generator gas operation. Thus previous experience may be used and, in case of a fuel embargo, the most suitable fuel may be used at the same time that costs of manufacture, operation, and maintenance are minimized.

The gas generators described below, which are categorized according to the fuel required, represent the types in most common use. In addition, a few other designs of special interest are discussed.

Charcoal Gas Generators

In Sweden, the technical development of charcoal gas generators has been greatly influenced by the nature of the available fuel and by the requirement of minimum weight for use in private cars, due to strain on the vehicle tires. The obvious advantages of charcoal generators, which require a carefully specified charcoal quality, have resulted in production of the desired quality charcoal.

Charcoal gas generators may be grouped into three main categories based on the type of combustion: (1) up-draft, (2) down-draft, and (3) cross-draft. The Kalle generator may be considered a fourth type. (See Figures 2-6, Chapter 2.)

1. In an up-draft gas generator the combustion air enters underneath the fuel bed. The generated gas rises upward in the fuel container and is sucked through a gas outlet above the combustion zone.

   Advantages: Small pressure drop, good thermal efficiency, relatively high power during motor operation, little tendency toward slag problems.

   Disadvantages: Great sensitivity to the tar and moisture content of the charcoal; relatively long time required for start-up; risk of "burning out" the charcoal (i.e., poor reaction capability) through heavy load, especially if the gas outlet is high up.

2. In a down-draft gas generator the combustion air enters the fuel bed through one or several nozzles above the combustion zone, and the generated gas is sucked downward through and out of the hearth close to the bottom of the generator.

   Advantages: Rather flexible adaptation of gas production to load; no influence on the reaction capability of the charcoal through preheating; relatively low sensitivity to charcoal dust, slag formation, and tar content of the charcoal.

   Disadvantages: Design tends to be tall.

3. In a cross-draft gas generator the combustion air enters the fuel bed through a nozzle at approximately the level of the combustion zone, and the generated gas is sucked out of the hearth opposite the nozzle at about the same level. The cross-draft is characterized by very high speed of the air flowing from the primary-air nozzle; therefore, this type of generator has a very concentrated reaction zone with extremely high temperature.

   Advantages: Short design height; relatively independent of the reaction capability of the charcoal; generally no need for brick casing; particularly flexible gas production.

   Disadvantages: Very high sensitivity to slag formation, fairly high pressure drop.

Before and during the import restrictions of liquid fuel, charcoal was produced in Sweden mainly through charring in stacks. This charcoal was intended almost entirely for the iron industry, and irregularity in the degree of charring, piece size, and moisture was not of great importance. However, when this charcoal was used in gas generators for vehicular operation, the disadvantages of uneven quality (especially in the degree of charring) became obvious. For satisfactory operation the gas generators had to be adapted to the irregularities of the charcoal quality. When the advantages and disadvantages of the three main categories of charcoal gas generators are considered, it is clear that only the down-draft system was suited to the circumstances; the other two systems experienced difficulties due to their sensitivity to the tar content of incompletely charred charcoal and to excessive and uneven moisture content of the charcoal.

Thus it is understandable that during this time down-draft charcoal gas generators, namely, the Swedlund and Gragas types, were used almost exclusively. An effort was made to introduce cross-draft charcoal gas generators on a large scale during the first part of the war, but it failed because of the unsuitability of Sweden's charcoal for this system. It was not tried again, although Sweden's improved charring furnaces later produced enormous quantities of good quality charcoal. This excellent fuel made possible the use of gas generators of an entirely new type (Kalle) with very low weight (down to 45 kg) and short start-up time (approximately 30 seconds). This new type was designed for a charcoal size of about 10 mm, whereas the charcoal size of traditional generator types was usually from 20 to 40 mm for average size models and up to 60 mm for the very largest truck generators having a hearth diameter of 275 to 310 mm.

The war years, however, did not produce a gas generator especially designed for using briquette fuel. Such a gas generator would considerably increase the distance travelled per litre of fuel and make it possible to utilize the considerable quantities of charcoal dust resulting from crushing charcoal for generator gas operation.

The Swedlund System

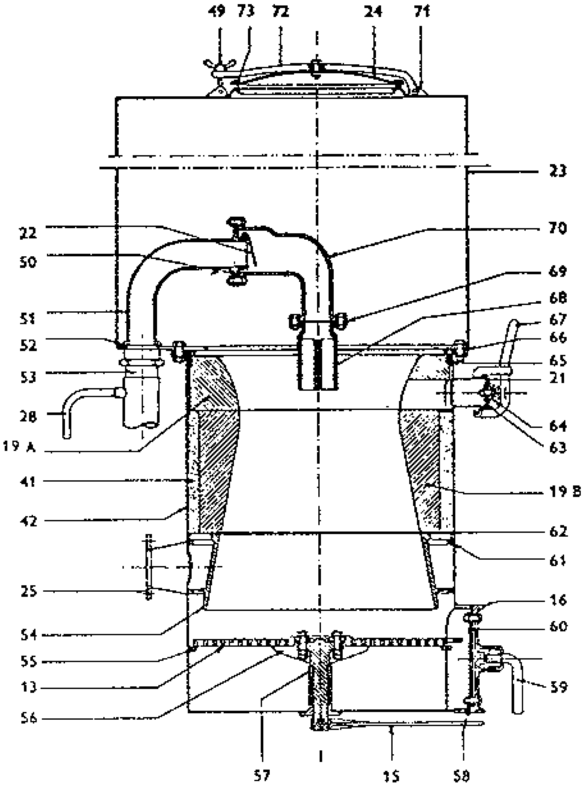
The majority of the charcoal gas generators used in Sweden were of the Swedlund System design (Figure 64), manufactured by the Gas Generator Co. in Orebro or by some of its licensees.

The upper part of this gas generator is a fuel container; the lower part, a hearth with ashbin. The fuel container is made of iron plate and shaped to accommodate various installations: usually the section is square or, for trunk adaptation on private cars, rectangular.

In the top is a round fuel port, usually of pressed sheet metal, equipped with a resilient locking device to function as a safety valve during positive pressure operation of the generator; e.g., during ignition of the generator gas in the container, after the port has been opened and air has entered. A seal between the port and the container is effected by packing with asbestos twine or rubber.

The hearth section of the generator consists chiefly of a cylindrical iron-plate case with the bottom welded on. The ceramic hearth, located in the upper half of this case, rests on the gas ring. This ring is an inverted, somewhat acute-angled L-section whose nearly vertical shank constitutes a continuation of the hearth cone and goes down so near the grate that coarse pieces of charcoal cannot pass through the narrow opening and be carried by the gas flow. The gas ring is made of heat-resistant material. The cast grate, also of heat-resistant material, is made in four parts to eliminate thermal stress. It is center mounted on a shaft which goes through the bottom of the hearth case, and can be turned from the outside by means of a shaker arm attached to the shaft.

The primary-air intake consists of a pipe joint in a bottom corner of the fuel container. During heating, the primary air flows through a pipe (bent in two 90° elbows and containing a check valve) upward-inward-downward to a central primary-air nozzle screwed onto the inner end of the pipe. The nozzle, made of kanthal or ferrochrome, extends downward into the upper part of the ceramic insert; the insert expands upward in a trumpet shape. The distance between the nozzle orifice and the grate varies, according to the size of the generator, between 414 and 468 mm.



13. Grate sectors. 15. Shaking arm. 16. Ash port. 19A. Upper brick. 19B. Lower brick. 21. Inspection port. 22. Damper. 23. Fuel Container. 24. Fuel port. 25. Gas outlet. 28. Steampipe. 41. Asbestos insulation. 42. Generator mantle. 49. Ringbolt with wingnut. 50. Asbestos gasket. 51. Pipe with damper. 52. Ring gasket. 53. Pipe sleeve. 54. Gas ring. 55. Grate ring. 56. Grate holder. 57. Grate-holder bearing. 58. Packing screw on the grate port. 59. Angular bolt. 60. Copper-asbestos gasket. 61. Support ring for the gas ring. 62. Asbestos ring. 63. Asbestos gasket. 64. Conical coil spring. 65. Asbestos twine. 66. Asbestos twine. 67. Inspection port handle. 68. Air nozzle. 69. Asbestos gasket. 70. Air-nozzle pipe. 71. Fuel clamp attachment. 72. Fuel clamp. 73. Rubber gasket on the port.

Figure 64. Downdraft Charcoal Gas Generator, the Swedlund System. (Brick hearth)

An ignition tube on the approximate level of the air nozzle orifice passes through the hearth case and the ceramic insert. It is closed during operation by a spring-loaded lid. Through this ignition tube the fire may be inspected. In the side of the hearth case, near the bottom edge, is a large, square hole through which the space inside the narrow opening between the grate and ring may be reached for raking out ashes and fuel residue. The ash hole is covered by a hinged ash port equipped with an asbestos gasket and a stretching device for sealing purposes.

A device has sometimes been used with the Swedlund generator for producing water which mixes with the primary air and, while passing through the hearth, is reduced to hydrogen and carbon monoxide thus increasing the hydrogen content, heat value, and ease of ignition of the generator gas. This device consists of a small low-pressure boiler, which is heated by the hot generator gas flowing through a jacket from the gas generator. Water runs to the boiler from an elevated container, and the water level in the boiler is kept constant by means of a float in the boiler intake. Water vapor produced in the boiler is carried through a thin pipe into the primary-air conduit immediately before the primary-air intake of the gas generator.

The Swedlund generator is characterized by its relatively great insensitivity to the tar content of the charcoal: Because of the ceramic casing, such high temperatures may be maintained over the entire highly constricted passage area below the primary-air nozzle, that possible tar vapors are decomposed. The generator gas does not have to pass through the grate on its way to the gas outlet, so that temporary clogging of the grate by charcoal dust and ashes does not involve a significant fall of pressure in the generator. The gas is removed at a high temperature, which is important because of the reduced risk of re-creation of CO_2.

The Gragas System

The Gragas generator (Figure 65) was designed by Graham Lundquist, Inc., before the war and was produced during the war in significant numbers by many licensees. The fundamental idea was to develop a charcoal gas generator not encased in brick and with as little tendency as possible toward bridging of the fuel during its movement downward in the generator.

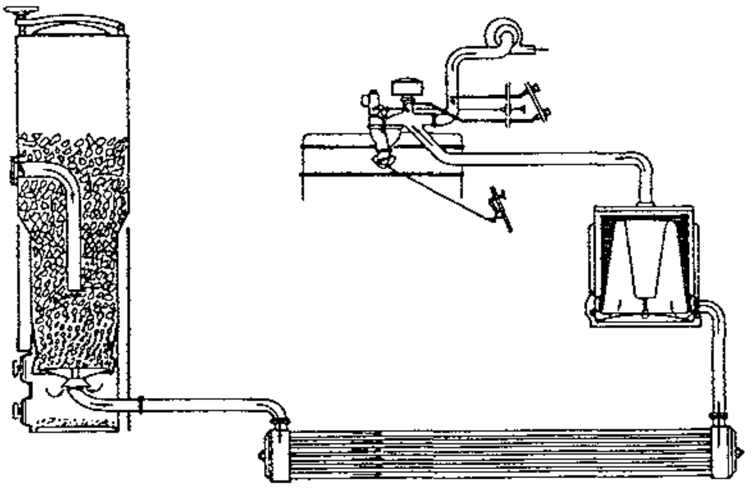


Figure 65. Gragas System: Downdraft Charcoal Gas Generator (Iron-plate hearth)

The upper part of this type of generator is a fuel container, generally of rectangular cross section. The fuel container tapers to a funnel shape, which in turn becomes cylindrical. A flat base is welded to it. Both upper and lower sections are made of black sheet metal. A one-piece grate, located at some distance from the base, rotates on a tripod-mounted central shaft. An inspection port opens to the space immediately above the grate; an ash port, to the ashbin below.

The primary-air intake, fitted with a check valve and flame arrestor, is located fairly high on the side of the fuel container. From the intake, the air flows through a pipe bent 90° downward to a kanthal nozzle screwed onto the pipe end.

A gas outlet is located in the ashbin wall. The upper end of the outlet pipe is under the center of the grate; a cover protects the orifice from falling combustion residues. Below the grate the pipe extends downward, then out through the wall. The gas passes through the grate as well as through the narrow opening between it and the mantle; the movement toward the outlet pipe takes place under a distinct direction change which involves some separation of coarse dust particles. The gas is emitted at a high temperature, thus reducing the risk of re-forming CO_2.

The Gragas generator may be considered to lack a hearth in the strickest sense. To protect the mantle plate around the gasification zone from high temperatures, the fuel itself is used as insulation: The lower part of the generator must be dimensioned such that there is always a layer of charcoal, sufficient for a satisfactory temperature decrease, around the high temperature gasification zone. The system has functioned satisfactorily, but the Gragas generator is relatively sensitive to the tar and moisture content of the charcoal, which may cause operational disturbances particularly during startup. Tars may find their way down through the relatively cool insulating charcoal mantle, and thus get into the gas.

The Kalle System

The Kalle generator, which was designed during the war, works with finely crushed charcoal and is in many respects radically different from other systems for producing charcoal gas. [33] The principles of this generator are shown in Figure 6; Figure 66 is a diagram of the entire gas generator system. The gas produced in the generator is taken out upward through the fuel container countercurrent to the inflowing primary air and through a ring mantle which is concentric to the primary-air pipe. The generator is further characterized by the fact that charcoal particles carried out by the gas are brought back to the generator by the exhaust flow during motor operation, part of which is made to participate in the generator gas production. The Kalle generator is designed in the following manner.

The generator case consists of two functional parts: a wide, somewhat streamlined upper section that serves as a fuel container and has a filling port at the top; and a smaller, cylindrical, lower section constituting an extension of the bottom of the upper section and having a flat base. The interiors of the two sections are continuous. The lower part serves, in a way, as a hearth and is equipped with heat insulation on the inside. In the base is a threaded port for raking out slag.

A "gas-mantle pipe" is inserted through a fitting in the generator roof; its upper orifice is connected to the lower basin of a diaphragm case containing a large-diameter, horizontal metal diaphragm; the diaphragm is equipped with an indicator pin, with a knob on top.

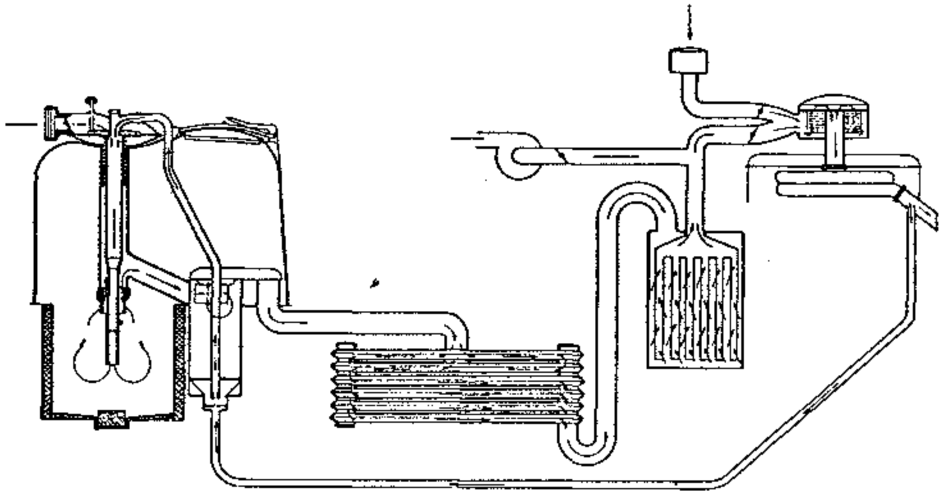


Figure 66. Charcoal Gas Generator for Fine Charcoal (Kalle System).

The mantle pipe extends into the generator almost to the bottom of the upper section, and is equipped at the lower end with a small flange with a circular opening directed toward the center; a branch of this pipe passes through the generator case and serves as the gas outlet.

The center part of the diaphragm consists of a rigid metal plate with a fairly large center hole, which opens out into the primary-air pipe attached to the plate. The primary-air pipe extends into the aforementioned gas-mantle pipe and is dimensioned so that a cylindrical ring mantle is created between the two pipes. On the somewhat reduced lower end of the primary-air pipe is attached a cylindrical grating with a diameter large enough that an annular space is created between the inner side of the grating and the primary-air pipe, while the outer side of the grating extends with a working fit into the gas-mantle pipe. The nonperforated bottom of the grating is supported by the primary-air pipe shoulder, which is created at the upper end of the reduced section. Finally, the primary-air nozzle is pushed onto the primary-air pipe until it is supported by the bottom of the grating, after which the grating and the nozzle are locked to the pipe with a radial locking screw. The nozzle is made of kanthal. Around the upper part of the primary-air pipe a coil spring is attached with the upper end supported by the central disk of the diaphragm and the lower end placed on the edge of an inward-flanged cuff and set into the gas-mantle pipe. Thus the diaphragm and the primary-air pipe "float" in resting position on the coil spring, and the respective design lengths are adapted so that a large part of the grating is covered by the gas-mantle pipe.

The primary-air intake, equipped with a protective cover, flame arrestor, and check valve, opens out into the upper basin of the diaphragm case from which the air may flow to the primary-air pipe through an opening in the center of the diaphragm disk. Through part of this opening a vertical nozzle (whose upper end, reaching out into the open, is covered by a screw cap) extends into the primary-air pipe. This nozzle is used during ignition of the generator fire and, in addition, it has a fundamental function for operation of the generator. The nozzle is connected by a short pipe socket to a pipe running from a cyclone cleaner specifically designed for the Kalle gas generator (the so-called wind screen) through which coarse charcoal particles, separated from the generator gas and mixed with exhaust gases from the motor operated by the gas apparatus, are fed into the gasification zone of the generator. This flow of CO_2 from the exhaust is required to order to keep the generator temperature down to an acceptable level, so that the nozzle does not burn up and the charcoal brought back with the exhaust improves the operating economy.

Since the wind screen in the Kalle generator participates in gas generation, it will be discussed within that context. The wind screen is basically an ordinary cyclone cleaner with a reversed conical bottom section, equipped with a sharp-edged strainer plate against which larger pieces of charcoal are ground up during screening. In addition, its dimensions are such that very small particles of dust that should not be brought back to the generator, remain in the gas and are carried by it to the cloth filter/cleaner of the gas generator.

The Kalle generator works as follows: charcoal is loaded until the fuel container is nearly full. The charcoal should have an individual piece size of from 4 to 20 mm and, if the generator is to function without disturbances, must fulfill the following minimal requirements: moisture content, 10% maximum; ash content, 3% maximum; loss due to burning, 15% maximum. After the starting fan has been turned on, an ignited generator-gas match is dropped down through the ignition hole, whose lid is then screwed on. A few pumpings with the indicator hasten the heating. When the fan has been running for 30 to 40 seconds, it is shut off and the motor is turned over with the automatic starter, with the ignition switched on, while the secondary-air valve slowly is opened. Not until the motor ignites and runs smoothly and a certain amount of exhaust gas containing carbon dioxide is fed through the primary-air nozzle has the Kalle generator reached its normal state of operation. If this gas admixture does not develop, the primary-air nozzle and the grating will burn up within a few minutes.

This is due to the fact that the reaction zones of the generator are very efficiently insulated by the charcoal around them and the reacting volume is small because of the small size of the fuel, so that only an extremely concentrated reaction zone is created. During the reaction between air and dry charcoal, a considerable heat surplus results, which would produce too high a temperature. In order to obtain heat equilibrium, the primary air is mixed, as mentioned, with about 25% exhaust gas brought back from the motor; during reduction of the carbon dioxide in the exhaust gas so much heat is absorbed that an acceptable temperature is maintained automatically. Since the return gas also conveys the charcoal grains separated in the cyclone cleaner back to the generator, the fuel economy of the Kalle generator is very good.

The fact that the grating can be moved vertically plays a very important role in the function of the generator. When the generator is used for car operation, the negative pressure in the gas outlet, and thus in the lower diaphragm basin, will vary constantly and the center disk of the diaphragm, to which the grating is attached, will move vertically. Because the grating moves, it is constantly scraped clean, so that it cannot clog up. It also acts to regulate itself according to the momentary gas requirement: When the gas pedal is let up, the grating is pulled into the primary-air pipe; when the gas supply is increased, the grating automatically creeps forward in proportion to the negative pressure, depending on the speed of the motor. The charcoal particles which are loosened from the grating in the scraping process are fed down into the oxidation zone below. There they are caught by the blast from the primary-air nozzle and are carried away by the circulating gas flow, while their surface temperature rapidly increases. Some do stick on the grating, while others go into circulation until they have been more or less transformed into gas. The main part of the charcoal mass contained in the reaction zone is in constant motion in a cavity which automatically changes shape and size according to the velocity of the gas flow. When, for instance, the gas requirement is increased and the grating, as well as the nozzle, consequently goes deeper into the charcoal mass, the nozzle blasts up more charcoal which also starts moving. A large part of it gets stuck on the now exposed grating surface, where an exceedingly effective reduction zone is formed because the reduction efficiency of this clean-blasted charcoal reaches an optimum level. The circulation of the charcoal particles also contributes to keeping the generator free from slag; assuming, of course, that the charcoal does not contain any impurities such as soil, rocks, etc. The fine slag powder formed during combustion is blown out through the grating and is finally caught in the cloth filter.

The principles of the Kalle generator make it the most interesting charcoal gas generator designed so far, and its great flexibility makes it useful for motors of greatly varied sizes. It was manufactured during the war in three types: "junior" for motors with up to 2-litre cylinder volume, "standard" for 2 to 4-litre cylinder volume, and "senior" for 4 to 6-litre cylinder volume. It is very light; for instance, the entire "standard" generator model weighs no more than 50 kg. Provided that the fuel fulfills the previously mentioned minimal quality requirements, and that the return-gas delivery is properly adjusted, the Kalle generator has proven to be extremely safe in operation and easily maintained, and its fuel economy has been very good. During intermittent operation the fast start with the Kalle generator has been of very great importance as well as the fact that it keeps the fire burning during an interval of several hours of standby operation. Thus after such an interval one does not have to re-ignite the generator but can just fan it directly into operation. Finally, the generator has one valuable quality from the viewpoint of safety; when the gas delivery from the generator is shut off, no positive pressure is developed in the system (provided that the charcoal is of the prescribed quality); therefore the Kalle generator, unlike other gas generators, is not dangerous for approximately 20 minutes after having been shut off.

The two disadvantages of the Kalle generator have already been touched upon: (1) It cannot function without problems on inferior quality fuel. (2) If the return-gas system does not function properly or is adjusted incorrectly, the nozzle and the grating will soon be ruined. The former disadvantage may be eliminated through carefully controlled charcoal production—actually the Kalle generator necessitated production of such "Kalle charcoal" during the war; the latter may be avoided through proper and careful assembly according to the directions of the manufacturer.

The Mako System

Charcoal gas generators of the Mako brand were manufactured by Stockholm's Metal Industry, Inc. The main purpose of the design was to produce a simple and reliable lightweight charcoal gas generator.

The first Mako type (about 1940) was designed on the same principle as the Gragas but with an added inverted conical sheet-metal hearth, and with a gas outlet from the ring space between this hearth and the cylindrical case. However, the blasting effect from the central nozzle opening out only 250 mm over the grate caused thermal stresses too great for the generator grate and bottom, especially in the case of low filling. Therefore, in 1941 an entirely new Mako "S" was designed, which became very popular during the latter half of the war, especially for operation of private cars.

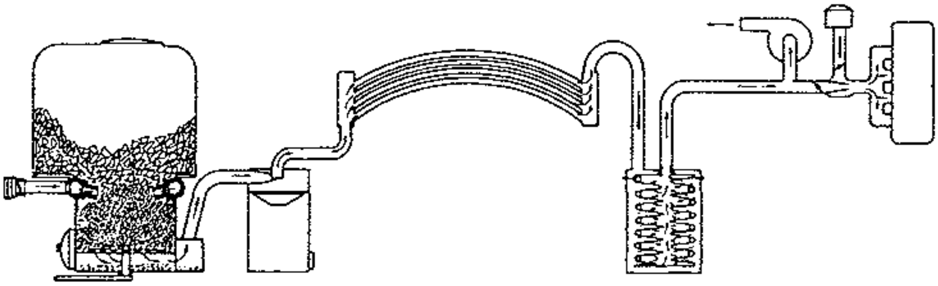


Figure 67. Mako S1 Type Charcoal Gas Generator (Cast-iron hearth and four kanthal nozzles for air intake.)

Mako S1 (Figure 67), which was intended for front installation, has the generator, cyclone cleaner, cooler, and cloth filter built together in one unit. The generator case consists of two main parts: the upper egg-shaped fuel container of 1.25-mm ordinary iron plate, and a lower cylindrical (365 mm diameter) "hearth" of 4-mm ordinary iron plate (with no surface treatment of any kind). The bottom of the hearth consists of 3-mm iron plates. Approximately 80 mm above the bottom, a flat ring of 5-mm iron plate is welded in as peripheral support for the circular grate. The grate (250 mm diameter) is cast iron with 7% chrome, and turns around a vertical center bolt of the same material. At the top the bolt is shaped as a triple-armed support with an extending square center pin, corresponding to a square hole in the middle of the grate. The center bolt is stored in a stainless steel pipe (Uddeholm stainless No. 5), positioned and welded into the bottom of the generator, and it can be turned with a shaker arm under the base. The gas is emitted through a rectangular hole in the side of the ashbin to a gas outlet box welded to the case, from which a pipe rises to the intake of the cyclone cleaner.

At the top, the hearth side is reinforced with a 2" X 3/16" flat iron bushing, bent in a ring along the inside of the hearth. At the upper edges of the hearth side and the bushing ring, a ring pipe of 1-1/4" gas pipe is welded on. A welded intake pipe for primary air leads to the ring pipe, obliquely from the front. This intake pipe is equipped at the orifice with a flame arrestor and a check valve. Four 14-mm air nozzles of kanthal are evenly distributed around the periphery, going from the ring pipe toward the hearth axis. The nozzles are screwed into heads welded onto the ring pipe and inclined a few degrees downward. Finally, the top of the ring pipe is welded onto the bottom of the fuel container.

Fire is ignited in the generator through a pipe socket equipped with a screw plug in the side of the fuel container near the bottom. For raking out slag, there is an ash port with the center approximately at grate level; refilling is done through an ordinary filling port equipped with a strong sealing ring of reinforced rubber.

Mako Sl is intended for motors with 2.5-4 litre cylinder volume; the entire gas generator weighs 75 kg. A smaller type was also manufactured, Mako S Junior, for 1-2.5 litre motors with a total weight of only 45 kg; as well as a larger model for 4-5 litre motors.

The Mako Sl works satisfactorily with charcoal of various sizes from dust to 60 mm; however, it runs best on the 20-40 mm size, which was produced during the war specifically for this type of generator. It is also relatively insensitive to somewhat inferior quality charcoal, and it requires very little maintenance.

Wood Gas Generators

As was mentioned in the introduction to this chapter, the wood gas generator is actually a charcoal gas generator plus a charring furnace. The heat released in the wood gas generator originates, first, from the burning of charcoal, tars distilled from the wood and incondensable gases; and second, from the exothermic reaction during charring in the fuel container. This heat (apart from the losses) is used for heating the wood in the fuel container; charring the wood; evaporating the water in the wood; and overheating the water vapor, which is allowed to pass through the hearth, for decomposing miscellaneous distillation products; and finally, for reducing carbon dioxide and water vapor. Because of this dual function of the wood gas generator there are more complicated and intricate problems to solve in its design than in that of the charcoal gas generator. Not until the last part of the war can science be said to have clarified the working process of a wood gas generator so completely that the designer would be on solid scientific ground. It has been shown that earlier assumptions concerning the extension of the reduction zone were incorrect, and that a charcoal bed may have a damaging influence on the quality of the gas by promoting to some extent the re-formation of CO_2 from the CO contained in the gas. The problem touched upon above in connection with charcoal gas generators, namely, the reduction of acid or tar products in the generator gas, is intensified for the wood gas generator and may be considered the deciding factor for the dimensioning and design of the hearth. In a charcoal gas generator one may use up-draft or cross-draft with good quality charcoal and thus do without a hearth in the strict sense. In a wood gas generator, however, one must use down-draft as well as a hearth with some constriction of the passage area, in order to obtain the high temperature at which distillation products harmful to motor operation are completely burned or rendered harmless through decomposition. The development of a hearth design, one that fulfills this condition at low gas velocity without causing an abnormally high pressure drop at a high gas velocity and can also endure high temperature without the use of high alloy materials, has been one of the greatest problems of the wood gas technique. Swedish designers have contributed to the solution of this problem in a highly satisfactory way.

The exceedingly complicated chemical process in a wood gas generator was discussed in detail in Chapter 2. As mentioned there, the processes completed in the generator are briefly the following:

(1) Drying of the wood with or without separating the water;

(2) Charring of the wood with extraction of chemically bound water, carbon dioxide, carbon monoxide and other gases, tars, acetic acid, etc.;

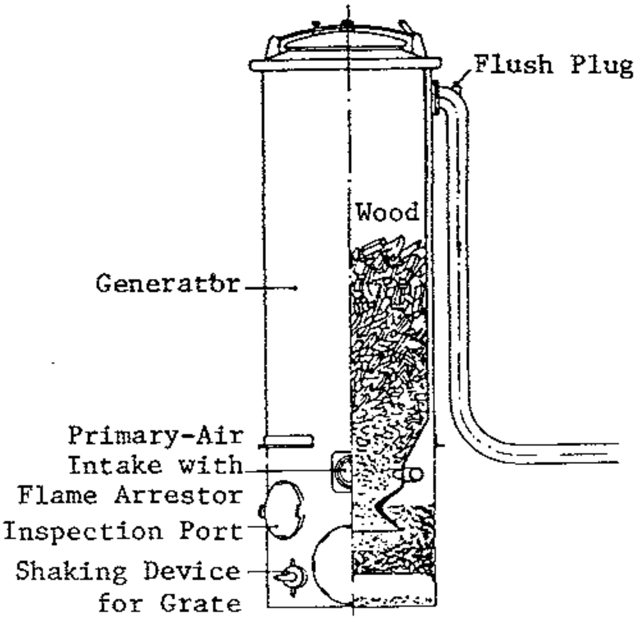


Figure 68. Wood Gas Generator. Imbert Type, Hesselman Motor Corporation, Inc.

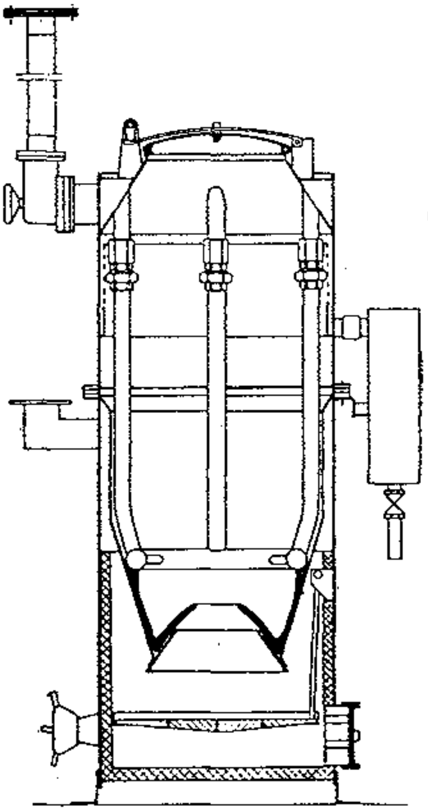


Figure 69. Wood Gas Generator for Boats, Swedish Generator Gas Co. (with the first sheet metal V-hearth, inside air pipes, condensation-water conveyor with a tank, and removable fuel store)

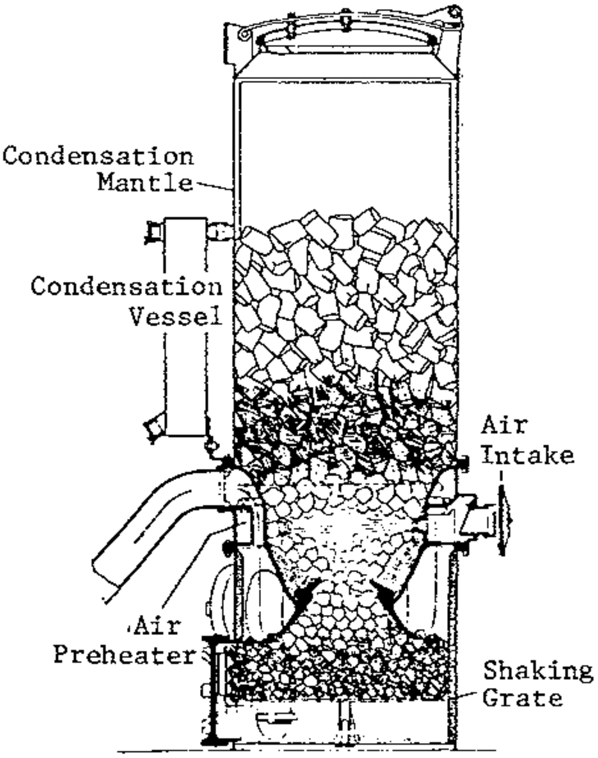


Figure 70. Wood Gas Generator for Boats, Swedish Generator Gas Co. (with air intake and the other part of the hearth cast in one piece of ordinary iron with a removable hearth ring)

(3) Burning of combustible distillation gases and charcoal, gradually fed down into the hearth; and

(4) Decomposition of tar products, etc., reduction of water vapor and carbon dioxide formed during the burning.

Theoretically, after these processes have been completed, only an insignificant quantity of ash remains as a waste product. In practice, however, this ash is more or less mixed with charcoal residues from the reduction zone.

From a functional point of view, the wood gas generator consists of three principal components: (a) an upper section, the fuel container, in which processes 1 and 2 take place; (b) a lower section containing the hearth in which processes 3 and 4 are carried out, a gas-collecting space, and an ashbin space; and (c) a device for supplying primary air to the burning zone. These devices are usually located in the lower part of the generator (the ring-nozzle device). In a few types (e.g., Lion, Beram) the air supply comes through a central primary-air nozzle with an intake through the roof of the fuel container.

This functional division into an upper and lower section relates to the construction in certain cases (e.g., Swedish Generator Gas Co.), where the two parts usually are joined with flanges which have been bolted together, and the gas outlet is located in the lower part. In most wood gas generators used so far in Sweden (Imbert), such a constructional division is not followed because the fuel container does not also serve as an outer case. Instead, the generator is surrounded by an outer jacket in which the generator gas flows up through the annular space between the container and the outer mantle, and the gas outlet is placed near the top of the generator. In this type the fuel container, the conical lower part, and the hearth with the ring-nozzle device create a welded unit inserted into the outer mantle (see Figure 71). The double-jacketing of the upper part of the generator was considered advantageous from the viewpoint of heat economy; later research seems to indicate that generator gas with a higher heat value may be obtained without the heavy double-jacketing, through condensation of the water content of the wood with the help of a fuel container specifically designed for this purpose (see Figure 70). If such condensation is effective, it would be possible to use wood with a moisture content up to approximately 50% (i.e., completely undried wood), whereas in a "traditional" wood gas generator the moisture content must not exceed approximately 25%. It should be clearly emphasized, however, that the moisture of the wood is mainly dead weight, which lowers the heating value of the gas and the efficiency of the gas generator. Condensation of this moisture may make it possible to use very moist wood; but, even equipped with such a device, a generator produces better gas with dry wood.

Design Considerations for Wood Gas Generators

Fuel Container

The size of the fuel container usually determines the weight of the generator. For car operation low weight is always desirable for the gas generator; therefore, the size of the fuel container must be limited. For private cars, the volume of the fuel container for

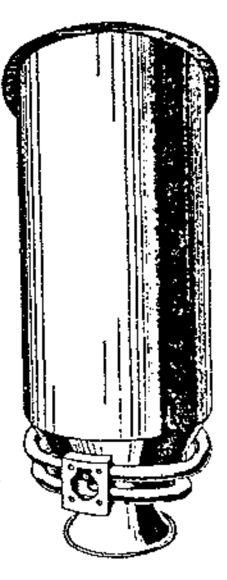


Figure 71. Hearth Inset with Fuel Container and Air-Pipe Rings, the Imbert System. (Note the many welding spots.)

charcoal gas was usually under 1.5 hL and for wood-gas between 1 and 2 hL. Wood gas generators for trucks usually had 2-3 hL fuel container volume; those for buses, 3-6 hL. If, as is frequently the case for buses, the gas generator is installed in a trailer intended for this purpose, the strict weight limitation requirement is alleviated to some extent. The same is true, of course, for stationary generators.

The inside of the fuel container, including the lid, contacts the generator gases. These gases contain acids, particularly acetic acid; therefore, the inside surface must consist of some material which is not easily corroded and rapidly destroyed by these acids. Stainless steel has proven to be the best material for these parts; it shows hardly any corrosion damage even after several years of use. Aluminum, on the other hand, has in some cases proved to be less suitable, due to the ammonium hydroxide content of the wood gas. [40]

If the fuel container is equipped with a condensation pocket, the lower part of the pocket should not be separated from the inside of the container by a dense wall, preventing gas circulation between the wood space and the pocket. The dividing wall should be perforated part way up from the bottom. (Figure 70). The pocket should be equipped with an effective drain to a condensate container placed outside the generator, and the perforation of the condensation-water mantle must not extend all the way to the bottom of the pocket, so that condensate may run back into the wood space through the lowest holes in the mantle. The condenser may be made of stainless steel, aluminum, or copper. In a generator without a condensation pocket, a special precondenser may be installed afterward.

Devices for drying the wood in the fuel container have proven to be of fairly low efficiency during operation of the generator under load. On the other hand, they have been able to counteract the disadvantages of the water condensation during idling and periods of rest, and thus prevent the charcoal bed from getting wet, which in turn makes starting easier. The Monorator, designed in Finland, was another step in this direction. [31] This device has an expanded fuel store, which has only one simple sheet metal wall, as opposed to the usual double-jacketed wall of the generator, so that the fuel along the inside wall of the mantle is positioned outside the upward heat radiation of the oxidation zone; thus it stays comparatively cool and is not charred. (See Figures 72 and 73.)

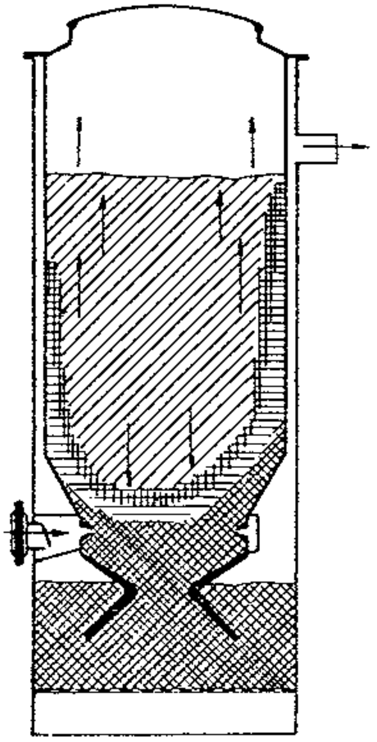


Figure 72. Ordinary Wood-Gas Generator

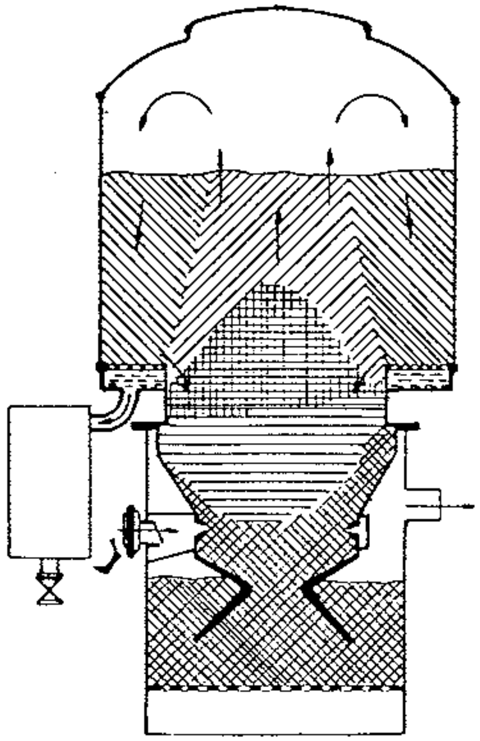


Figure 73. Monorator

A comparison between the gasification processes in an ordinary wood gas generator and one equipped with a Monorator. Oblique lines downward to the right (\\\\ ): wet wood. Oblique lines upward to the right (////): ordinary wood (20-25% moisture content). Horizontal/vertical checks (###): very dry wood (approx. 10% moisture content). Horizontal lines (≡): semi-charred wood. Oblique checks (XXX): prepared charcoal.

Heavy condensation takes place on the walls; the condensate is collected in the usual manner by means of a corrosion-free, ring-shaped condensation conduit at the bottom of the fuel container, and is carried outside the generator to a container equipped with a drain cock. As the fuel is charred and pyrolized in the center of the generator, the wood on the sides gradually falls toward the center to be dried and charred, in its turn entering the gasification process.

The Hearth

During operation the wood is gradually dried out and moves slowly downward through the fuel container toward the hearth, passing first through the usually cylindrical oxidation area, then through a conical transition area where charring takes place. In the oxidation or combustion zone, several air nozzles are usually directed radially toward the center from a ring-shaped chamber. The real hearth begins with this zone, which is constricted below the air intake to obtain a sufficiently high temperature for total combustion and cracking of the tar gases. Beyond the constriction, there is frequently an expansion through which the lower part of the hearth becomes hourglass shaped.

The conical passage for the wood, which is constricted downward, is important for the function of the gas generator. Charring takes place very rapidly and within a comparatively small volume due to the high temperature close to the oxidation zone. Ideally, charring should keep pace with fuel consumption, so that the quantity of prepared charcoal in the generator remains constant; under such circumstances, the charcoal bed of the generator does not need to be supplemented or reduced during extended operation. Through selection of a suitable cone angle the cross-section reduction of the charring funnel corresponds to the volume reduction during the charring, and the fuel is just charred through when entering the oxidation zone, but not charred at too early a stage of fuel passage; this is important for gas quality.

Heat resistant alloy is the desirable choice of material for the lower conical part of the fuel container, the charring zone. In both single- and double-jacketed wood gas generators it is, as a rule, surrounded by generator gas with a temperature ranging from 500°C to 600°C and, consequently, has a high wall temperature.

As mentioned earlier, the oxidation and reduction processes take place within the hearth. In the oxidation or, as it is frequently called, the combustion zone, combustible gases and part of the charcoal produced are burned with the primary air. In addition, decomposition of distillation gases that are damaging to the motor takes place in the combustion zone. These decomposition processes require a high temperature, which is obtained by intensifying combustion in the constricted part of the hearth in the lower part of the combustion zone. The more pronounced the cross section reduction, the greater the temperature increase, within certain limits; thus the tendency is to make the opening relatively small. This, on the other hand, creates a greater flow resistance in the hearth with a subsequent pressure drop, which decreases the efficiency of a generator-driven motor during full speed, and thus the maximum motor power output.

The problem to be solved by the designer is therefore to make the minimum passage area of the hearth as large as possible without allowing the temperature in any part of the passage opening to drop below the value needed for satisfactory decomposition. For this purpose it is necessary to minimize the heat emission from the hearth outward; therefore, it is disadvantageous to use the hearth wall as an inside wall in a ring mantle in which the primary air is preheated, because the heat needed for this must be taken from the combustion zone.

Logically, the outside of the hearth should be heat insulated and the metal material of the hearth should be protected from thermal stress as much as possible; therefore, the insulation should be placed on the inside of the hearth plate. Ceramic hearth inserts are not very suitable for this purpose from a practical standpoint, because they can easily be damaged by stirring in the hearth. A good solution to the heat-insulation problem is the V-hearth, described in a later section, in which ashes formed during combustion and collected in a ring pocket in the hearth are used as insulation. The hearth may then be made of nonalloyed or low-alloy iron.

A hearth that is not insulated on the inside makes very high demands on the material, since the temperature in the hottest spot of the combustion zone normally is over 1300°C and under some circumstances may rise to between 1400°C and 1500°C.

In the lower part of the hearth below the constriction, reduction of carbon dioxide and water vapor takes place. To prolong the time during which the gas remains in the reduction zone, it is desirable to decrease the gas velocity there by gradually increasing the cross-section area. The processes in the reduction zone use up heat and therefore cause a decrease of temperature in the direction of the gas flow. The dimensions of the reduction part of the hearth should be designed so that the temperature at the lower hearth opening does not go below approximately 800°C, even during low load.

Various solutions have been tried, to obtain a foundation for the glowing charcoal in the reduction zone. The oldest solution, and until recently, the most commonly used, is to place the lower hearth opening 10 to 15 cm above the bottom of the generator (or an ash-separating grate), filling the space under and around the lower part of the hearth with charcoal of individual piece sizes such that the gas can easily pass through the charcoal layer. It was believed that an advantageous so-called outer reduction was gained, the size of which was automatically varied to fit the load. Swedish tests, however, have shown that there is no foundation for this opinion and that the charcoal bed, through its relatively low temperature, may actually make the generator gas poorer by promoting some reaction to CO_2.

These tests indicate that the gas, while passing through the ring space around the hearth, should be kept either at a high temperature or be rapidly cooled; the space may therefore be free and equipped with heat insulation at the outer wall. The bottom of the generator should be heat insulated. Porous concrete of suitable piece size may be advantageously used as a foundation for the reduction charcoal; this porous bed allows gas to pass through without abnormal pressure drop.

In Russia, they have to a large extent done without any kind of bed underneath the hearth, with good results; instead a grate has been placed approximately 20 mm under the hearth opening. This design would seem to make very high demands on the heat resistance of the grate material as well as on the lower part of the hearth, if special measures are not taken to distribute the gas flow over the periphery of the opening.

In all wood gas generators an asymmetric outflow of gas from the hearth occurs, based on the law of least resistance, by which the gas has flowed out preferentially over some part of the periphery of the opening; this causes a "bend" of the reduction cone in the main direction of the flow. Once this deformation has started, the bending effect then intensifies. Even hearths of extremely strong materials may, in this way, be ruined relatively quickly. (See Chapter 10, Figures 252 and 254.) Such an oblique load on the hearth is neutralized to some extent if the gas, after leaving the hearth, must overcome a resistance evenly distributed over the flow area; for instance, during passage through a bed of charcoal or porous concrete.

The requirements on the materials of the hearth are, of course, highly dependent upon the temperature at which the hearth works. Hearths without inside insulation (e.g., the prevalent Imbert type) must be made of high-alloyed ferro-material to be reasonably durable. The pre-war Imbert hearth contained over 20% chrome and 20% nickel. These hearths proved to be durable enough for approximately 20,000 km of bus operation during predominantly high load. Since the circumstances of crisis made it necessary to eliminate the nickel admixture altogether and to limit the chrome content to 6%, the durability of the hearth was decreased to approximately 2,000 km. However, during operation of private cars with generally low load, the durability was several times greater and, on the whole, satisfactory..

The unsatisfactory durability of the hourglass-shaped alloyed hearths is caused by the following:

1. A shape that causes thermal stress in the material and during uneven and varied heating causes cracks and deformation.

2. The poor heat conductivity (approximately half of the ordinary castings), which causes the hearth to warp during uneven heating; i.e., in case of local overheating due to air leaks in the cleaning doors, pipes to the air nozzles, or at connection flanges.

3. Uneven mixing of the components contained in the casting. Special, rotating furnaces are required to provide even mixing.

One very obvious disadvantage from the viewpoint of operating economy is that any serious defect in the hearth makes it necessary to replace the entire hearth, which is both expensive and time consuming. To get around this disadvantage it would be better to design the hearth in several parts so that parts that are easily damaged can be removed and replaced. This is one of the thoughts behind the V-hearth, designed by V. Blomquist of the Swedish Generator Gas Co., which was installed toward the end of the war in existing generators to replace wornout original hearths.

In its simplest design, the V-hearth (see Figures 18 and 74) consists of a hearth mantle welded together of two truncated plate cones with the points directed toward each other, so that the point of the lower cone penetrates that of the upper cone, thus creating a ring-shaped conduit in which a cast-iron ring is loosely placed. The hearth mantle was, in the beginning, made of 5-mm aluminized black plate with its upper edge welded onto the nozzle ring of the generator. When the generator was used, a protective wall of ash and charcoal particles was built up in a few minutes around the inside of the hearth mantle. This insulation wall, which was soon packed together to a relatively solid consistency and was maintained during operation, protected the hearth mantle from severe thermal stress. The only metal part more exposed, especially around the opening, is the hearth ring. Thus the hearth ring will inevitably be subject to damage. When cast with "normal care" it lasts for 400 to 500 hours of driving during normal full load. It is very inexpensive and may be replaced without the use of tools, in a minute or so while cleaning the generator; therefore, the cost of replacement is of no importance. The good heat conductivity of the nonalloyed cast iron contributes considerably to the relatively great durability of the hearth ring; thus it may be debated whether anything is gained by manufacturing the ring of alloyed material, which is more heat resistant but possesses poorer heat conductivity.

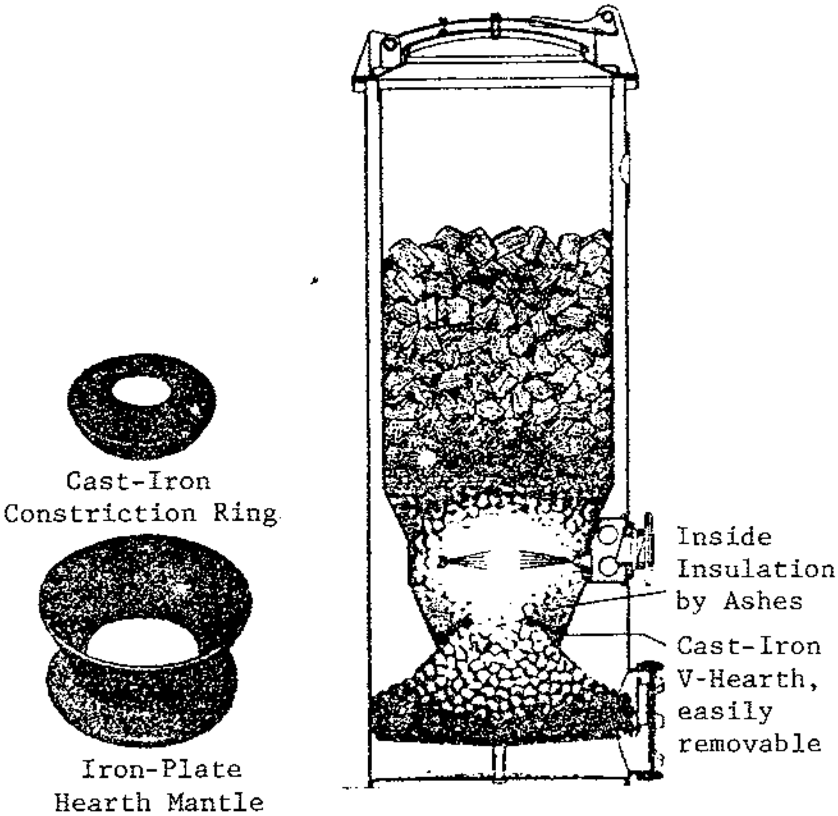


Figure 74. V-Hearth of Sheet Metal with a Cast Hearth Ring of Nonalloyed Iron for Installation in Generators of Various Makes.

In the designs with a welded hearth mantle, there was sometimes a tendency toward descaling on the inside of the lower cone of the hearth mantle, after extended heavy driving. To secure long life, the mantle was later manufactured of metal plate alloyed with 6% chrome, and finally of cast steel with a 6% chrome content. In the latter case the V-hearth was supplemented with an upper part, consisting of a nozzle ring fitting the hearth, with a funnel for direct connection to the lower end of the fuel store and with dimensions to fit the store. Such a hearth is virtually indestructable, apart from the easily removable hearth ring. Since hearth rings of various inner diameters may be put into the hearth mantle, one and the same generator can easily, through ring changes, be adjusted to various hearth loads. (See Chapter 6, Figure 118.)

Figure 76 shows a German generator for wood, peat, or brown coal, which, like the V-hearth, has a removable hearth ring. [7]

Insulation of the Wood Gas Generator

The following may be added to the above views on the insulation of the wood gas generator. A wood gas generator has a thermal efficiency of about 80%; i.e., a fifth of the heat value of the fuel is lost, partly through radiation, partly with heat physically bound in the generator gas. Efforts have been made to decrease these losses through various designs; e.g., through insulation of the fuel storage to prevent heat radiation from the outside walls of the generator, through leading the hot gas up around the fuel storage between the outer and inner mantles, through preheating the primary air, etc. With the exception of the last method, however, these measures do not appear to be useful. The reaction ability of charcoal is impaired by very high charring temperature and long charring time in the generator, which may be observed, for instance, in up-draft generators. As mentioned in the preceding section, it may be more advantageous to promote condensation and dehumidification through extreme cooling of the walls of the fuel storage. As shown in Chapter 2, for instance in the tests by the Steam Heat Institute, it is the heat-consuming reduction zone of the generator that, by insulation, should be prevented from unnecessarily emitting its heat. In keeping the temperature there as high as the design and the properties of the hearth material permit, the velocity of the reduction process is increased as is the heat value of the gas at a given gas velocity. Experimental tests have shown that the reduction process in normal generators may be considered completed at a temperature of approximately 850°C to 900°C. To maintain the gas quality, the gas should be cooled fairly rapidly; i.e., immediately after leaving the hearth the gas should be conducted out of the generator via the shortest path, and cooled down ("frozen in equilibrium") to prevent the decomposition of CO to CO_2 and carbon.

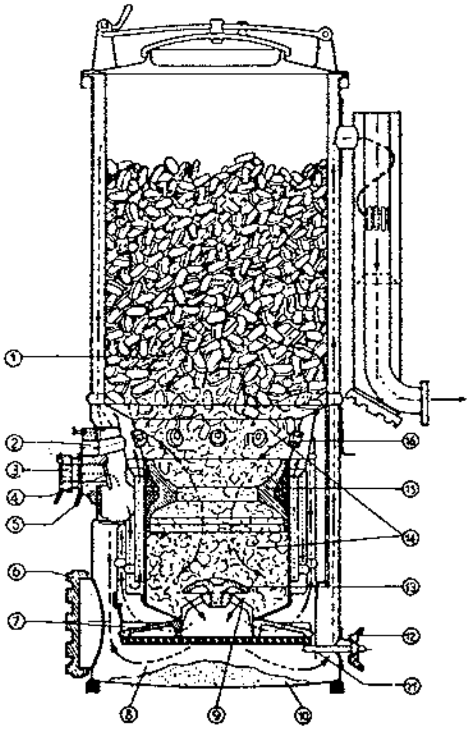


Figure 75. Imbert Generator for Wood, Brown Coal, and Peat, without Outer Charcoal Bed.

(The numbers are not explained in the Swedish text; therefore no explanations are given here.--Ed.)

Figure 75 is a picture of a generator intended for wood and brown coal; the figure shows that the incoming primary air is conducted past the heavily insulated hearth and that the emitted gas goes out between the outer wall of the generator and the air intake, which is arranged concentrically around the hearth. In this way, the gas is cooled off and the primary air heated. Particularly in stationary generators where there is no forced air available for cooling the generator gas, such cooling by incoming air is of great advantage. The picture also shows that the outer charcoal bed has been completely removed, and the generator fuel is carried directly by a grate. It has been determined that no reduction takes place outside the lower edge of the hearth; on the other hand, there is a risk of re-creation of carbon dioxide and free charcoal in an outer bed, which is why such a design is suitable from this point of view.

To protect the hearth material and further improve the local hearth insulation, ash-keeping hearth designs are highly advantageous. The V-hearth has such a design, as does the Zeuch gas generator shown in Figure 76. These designs also have easily removable hearth rings, whereby the specific hearth load of the generator may easily be adjusted within certain limits for various operating conditions.

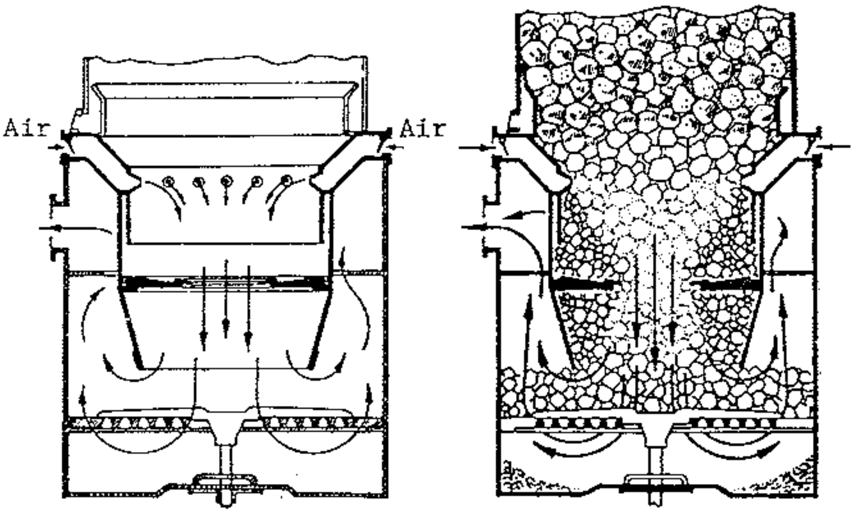


Figure 76. Zeuch Wood Gas Generator with a Removable Cast-Iron Hearth Ring.

Hearth Load

The concept of hearth load plays a very important role in dimensioning a wood gas generator hearth. The hearth load is the quantity of prepared generator gas, reduced to normal cubic meters per hour, divided by the smallest passage area in cm^2 of the hearth (Nm^3/cm^2-hr). Thus the hearth load is dimensionally a velocity although it is customarily expressed as a numerator and a denominator. The hearth load expressed in this way is called B_h and the imaginary velocity of the prepared gas, in its normal state, through the smallest passage area of the hearth v_h (m/s). The following relations are obtained from the definition of the hearth load.

$$B_h = 0.36\ v_h Nm^3/cm^2hr \tag{53}$$

$$v_h = 2.78\ B_h\ m/s \tag{54}$$

Practically, the load range for all wood gas generators is fairly narrow between an upper limit $B_{h\ max}$, above which the gas quality is made poorer due to charcoal dusting in the combustion zone, and a lower limit $B_{h\ min}$, below which the gas, due to too low a temperature in the hearth or in certain parts of it, will contain unacceptably large quantities of tar. The relation between $B_{h\ max}$ and $B_{h\ min}$, which could be called the flexibility of the generator, is of great importance in operation with widely varying load (e.g., car operation). As great a flexibility as possible is desirable in such a case, and the numerical value of the flexibility becomes, to a certain extent, an operating quality parameter.

In Imbert wood gas generators and other similar types, the $B_{h\ max}$ reaches about 0.9 in continuous operation and the $B_{h\ min}$ stays within a range of 0.3 to 0.35. This gives a flexibility between 2.6 and 3.0. Tests on V-hearths have given practically the same values of $B_{h\ max}$, whereas $B_{h\ min}$ has been less than 0.2. An eight-hour test with $B_h = 0.05$ on a V-hearth wood gas generator from the Swedish Generator Gas Co. (with a heat-insulated lower part) during operaton of a 2-cycle engine, has been carried out without abnormal tar content in the gas. The V-hearth has thus given the generators a flexibility of at least 4.5 as opposed to the maximum value of 3.0 for a hearth designed with metal only. For the test with $B_h = 0.05$, a flexibility of 18.0 was obtained, which is a unique value.

It is possible to attribute the very good idling properties of the V-hearth exclusively to the good heat insulation of the combustion zone, but there is still one other factor involved. The ash mantle, which is continuously recreated, extends to the same height as the nozzle openings, and creates between these openings local "insulation cushions" in the hearth, whose passage cross-section thus becomes, as it were, an "n-gon" (where n is the number of nozzles). Thus, the creation of cool zones between the nozzles is prevented, and this seems to contribute considerably to the fact that no tar escapes through the hearth even at a very low load.

The great adaptability of the generator is a very important property from an economic viewpoint, particularly during intermittent car operation and during generator gas operation of fishing boats, which sometimes must remain for hours with the motor idling. Only with a V-hearth has idling, in the strict sense, become possible in wood gas operation without decrease of the continuous maximum power. Thus, wood gas operation with widely varying load may be said to have taken a rather large step forward.

Devices for Primary Air Delivery

As mentioned in the introduction, in a few cases primary air has been delivered from above through a central air nozzle. This method, however, has a tendency to cause hanging of the wood around the air pipe and the nozzle. There have been a few exceptions where the primary air has been fed into the combustion zone from below through a central pipe running through the hearth; the pipe is capped by a nozzle part with a closed top end and equipped with a number of radial nozzle holes. The object of this device was to preheat the air intensely; the principle of this procedure is, however, incorrect, in that the heat is taken from the heat-consuming reduction zone.

In most wood gas generators the primary air is fed in through a ring of nozzles, evenly distributed over the periphery at or immediately below the lower opening of the charring funnel, and directed radially inward toward the hearth axis (Figures 68-76). This system is probably most suitable. As for conducting the air from the primary air intake to the nozzles, various solutions have been tried. In an Imbert generator the intake leads to a distribution chamber, from which air pipes, bent in an arch around the hearth, run individually to each nozzle except for one which is directly connected to the distribution chamber. This method is hardly ideal; the air is not evenly heated and distributed. Welding a distribution mantle onto the outside of the hearth either with one air intake through the generator case or with two opposite intakes, has also been tried. It has been difficult in practice to prevent cracking, due to thermal stress, in this design. A third method has been tried experimentally in connection with a V-hearth: air intake, distribution ring, and hearth mantle were all cast in one piece. This design gave good results but is relatively heavy. All the systems mentioned take more or less heat from the hearth, which is incorrect in principle. In the last mentioned design, however, the quantity of heat carried off is fairly insignificant. Preheating of the air is not sufficiently effective in any of the types mentioned. This could be improved by passing the primary air through a heat exchanger before the intake.

Figure 69 shows a design for primary air delivery used in one of the stationary generators of the Swedish Generator Gas Co., made so that parts may be replaced without welding. The air intake is placed at the top of the generator and opens out into an upper distribution ring, from which four primary-air pipes, evenly distributed around the periphery, go downward near the inside of the generator to a nozzle ring, which is supported by a ring-shaped shoulder on the inner mantle. The lower half of the fuel storage is double-jacketed. The emitted gas flows through the ring space, which results in a certain amount of heat insulation. In the upper part of the generator is a ring-shaped condensation-water pocket which drains to an outside collector.

The upper distribution ring stimulates the condensation of water vapor derived from the wood. No dangerous thermal stress occurs in the air-feeding devices, and the peripheral primary-air pipes promote practically no hanging of the wood in the fuel container. One disadvantage is that the design is relatively heavy and, therefore, suitable only for stationary or marine purposes.

There is no solid, scientifically documented basis for the choice of the most suitable number, diameter, and placement of the nozzles. Unfortunately, a systematic investigation of these questions has been neglected and in the practical design one has had to try to apply, at random, certain findings from experience. The operational results of generators designed in this way have been satisfactory in many ways, which seems to indicate that the range for the best device does not have narrowly drawn limits. This is very fortunate, because a narrow optimal range would certainly involve a very high sensitivity of the generator to variations in load, moisture of the wood, etc.

Total Nozzle Area

The relation between the total nozzle area (A_m) and the smallest passage area of the hearth (A_h) varies in generators with good operational properties within very wide limits, between about 3% and 14%. It is customary to use high values for this ratio for small hearth diameters and low values for large ones. This procedure is based on the opinion that there should be a greater air velocity in the nozzles of large hearths, and then greater penetrating ability of the air streams towards the hearth center. Whether the change of air velocity in this way is really desirable or necessary has never been satisfactorily investigated, but for the time being is merely an unproven assumption. In reality, this procedure may be seen as a result of the simple and inexpensive method of using the same nozzle device for several greatly different hearth diameters.

The Imbert generators, which were used during the war in very great numbers and which, on the whole, had very good properties, used the nozzle devices shown in Table 25. In Table 26 corresponding data for the Swedish Gas Generator Co.'s SGB 600 model generator, with a V-hearth, are given.

Table 25. NOZZLES IN IMBERT GENERATORS

Type	Hearth Diameter, mm	Nozzle Diameter, mm	Number of Nozzles	$100\frac{A_m}{A_h}$
Sport	60	10	5	13.9
	80	10	5	7.8
	90	10	5	6.2
	100	10	5	5.0
500/16	100	12	5	7.2
	115	12	5	5.5
	130	12	5	4.3
550/17 and 550/21	139	12	5	4.3
	150	12	5	3.2
650	170	--	--	--
PAS (for cars)	80	12	5	11.2
	100	12	5	7.2
	130	12	5	4.3

Table 26. NOZZLES OF SWEDISH GENERATOR GAS CO.'s MODEL SGB 600 GENERATOR WITH A V-HEARTH

Type	Hearth Diameter, mm	Nozzle Diameter, mm	Number of Nozzles	$100\frac{A_m}{A_h}$
SGB 600	90	12	8	14.2
	100	12	8	11.5
	115	12	8	8.7
	130	12	12	10.2
	145	12	12	8.2
	160	12	12	6.8

The data of the tables are shown graphically in Figure 77, where the "theoretical" air velocity V_m is given at 0°C and 760 mm Hg in the nozzles with no regard to the design, valid for a hearth load of 0.9 Nm^3/cm^2hr on the condition of the primary-air consumption being 0.6 Nm^3 per Nm^3 prepared gas. The table and figure values are based on the following formulas:

$$V_h = 2.78\ B_h \tag{54}$$

$$100\ \frac{A_m}{A_h} = 100\ \frac{{d_m}^2}{{d_h}^2} \cdot n \tag{55}$$

$$V_m = \frac{0.6 \cdot V_h}{A_m/A_h} \tag{56}$$

where

A_h = the smallest passage area of the hearth in cm^2

A_m = the total nozzle area in cm^2

d_m = the nozzle diameter in mm

d_h = the minimum diameter of the hearth in mm

V_h = the "theoretical" gas velocity at 0°C in the minimum hearth cross section, with no regard to the volume of the charcoal, in m/s

V_m = the "theoretical" air velocity at 0°C in the air nozzles, with no regard to contraction, in m/s

n = the number of nozzles

B_h = the hearth load in Nm^3/cm^2hr

At an assumed maximum hearth load of 0.9 Nm^3/cm^2hr we get

$$V_{h_{max}} = 2.5\ m/s$$

$$V_{m_{max}} = \frac{150}{100\ A_m/A_h}$$

As shown in Figure 77, the air velocity of the SGB600 is considerably lower than that of the Imbert. The former was designed and used in operation of slow two-cycle engines, in which the gas was sucked out in a pulsating manner; however, in operating four-cycle engines the gas withdrawal hardly shows noticeable pulsation. It has been proven by

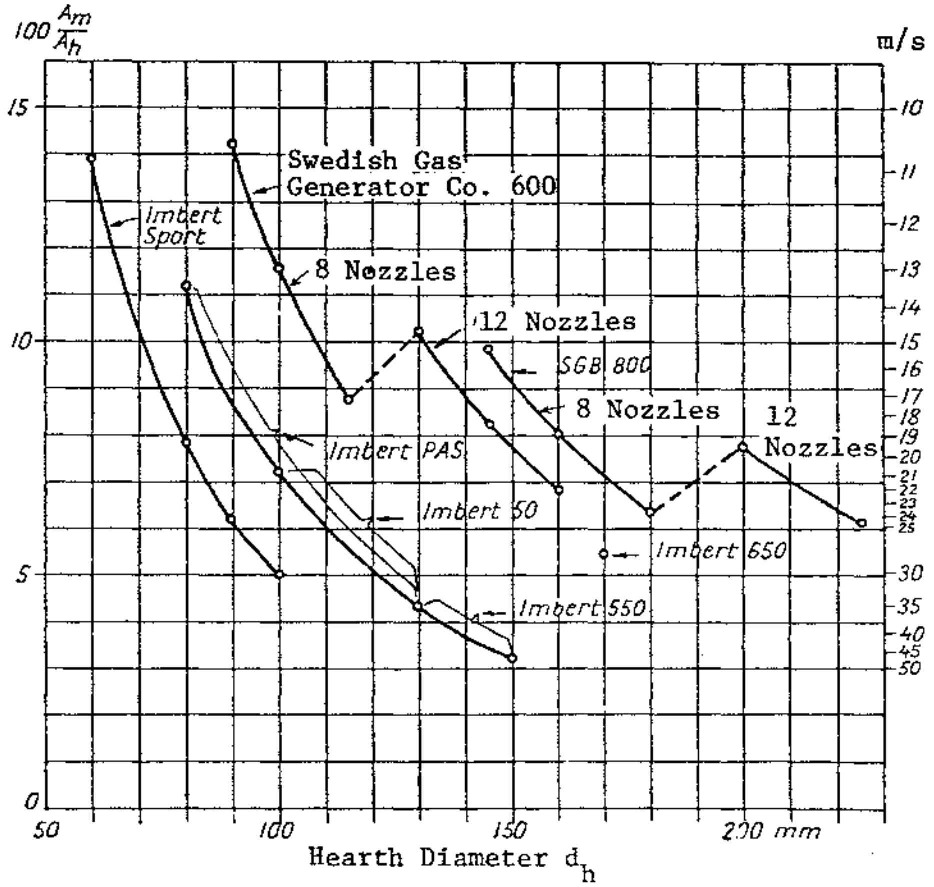


Figure 77. Graph Showing the Relation between the Total Nozzle Area and the Smallest Hearth Section, Air Velocity, etc., as a Function of Hearth Diameter at a Hearth Load of 0.9 Nm^3/cm^2hr.

practical operation that, for such two-cycle operation, a considerably lower air velocity than in four-cycle operation may be used without impairing combustion.

The great variation shown in the graph, of V_m with the hearth diameter of Imbert type generators, could probably be reduced considerably. Table 27, drawn up on the basis of a proposal from Hesselman Motor Corporation Ltd., bears upon nozzle devices for Imbert generators and is characterized by an even, moderate increase of the air velocity in the nozzles with the hearth diameter.

The values of the two columns to the right in Table 27 are shown in the graph of Figure 78. The values measured for the system evidently differ insignificantly from the continuous curve.

The nozzle devices of this system are suitable for an Imbert type wood gas generator with an original hearth, which is used for operating four-cycle engines with many cylinders. Such generators have been tested in operation where the original hearth has been replaced by a V-hearth; good results have been obtained without changing the nozzles; thus a dimensioning similar to that shown in the table is certainly also suitable for V-hearths during operation of four-cycle engines with several cylinders.

Table 27. SUITABLE NOZZLES FOR WOOD GAS GENERATORS FOR FOUR-CYCLE ENGINES WITH SEVERAL CYLINDERS--WITHIN PARENTHESES SUITABLE VALUES FOR OPERATING SLOW TWO-CYCLE ENGINES

d_h = Diameter of the hearth constriction
d_m = Nozzle diameter
A_h = Area of the hearth constriction
A_m = Total nozzle area
$v_{m_{max}}$ = "Theoretical" air velocity in the nozzles during a hearth load of 0.9 Nm^3/cm^2hr

d_h mm	d_m mm	n	$100\frac{A_m}{A_h}$	$v_{m_{max}}$ m/s
70	10.5 (10)	3 (5)	6.7 (10.2)	22.4 (14.7)
80	9 (11)	5	6.3 (9.5)	23.8 (15.8)
90	10 (12)	5	6.2 (8.9)	24.2 (16.8)
100	11 (13)	5	6.05 (8.5)	24.8 (17.6)
120	12.7 (15)	5	5.6 (7.8)	26.8 (19.2)
130	13.5 (16)	5	5.4 (7.6)	27.8 (19.8)
150	15 (18)	5	5.0 (7.2)	30.0 (20.8)
170	14.3 (18)	7	4.95 (7.8)	30.5 (19.2)
190	16 (20)	7	4.95 (7.8)	30.3 (19.2)
220	18 (22)	7	4.7 (7.0)	32.0 (21.4)
270	22 (24)	7 (9)	4.65 (7.1)	32.3 (21.2)
300	24 (26)	7 (9)	4.5 (6.8)	33.5 (22.1)

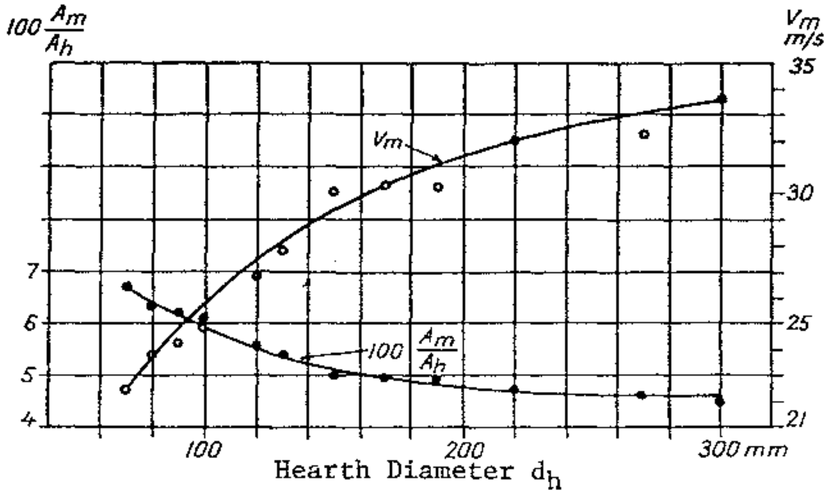


Figure 78. Graph of Suitable Nozzles for Operating Four-Cycle Engines with Several Cylinders.

On the other hand, in operating slow two-cycle engines with few cylinders, it is desirable to increase the nozzle diameter so much that V_m is decreased to approximately two-thirds of the values given for the four-cycle engines. The values suitable for two-cycle engines and corresponding nozzle diameters are given in Table 27 within the parentheses.

Concerning the influence of air velocity on temperature in the combustion zone of the generator, it may be said that a decrease of v_m by using larger nozzles causes a decrease of the maximum temperature in the hearth; and that a hearth, well insulated toward the outside, functions satisfactorily with a lower V_m than an uninsulated hearth.

As for the diameter of the nozzle ring (d_r) in relation to the diameter of the hearth construction (d_h), a series of values from good generators are dotted into the graph of Figure 79; on the basis of this dotted scale, a continuous mean curve is drawn. In a similar way, the diagram demonstrates the relation between the diameter of the nozzle-opening circle (d_{r_1}) and the smallest hearth diameter d_h. The mean curve for this relation is dashed.

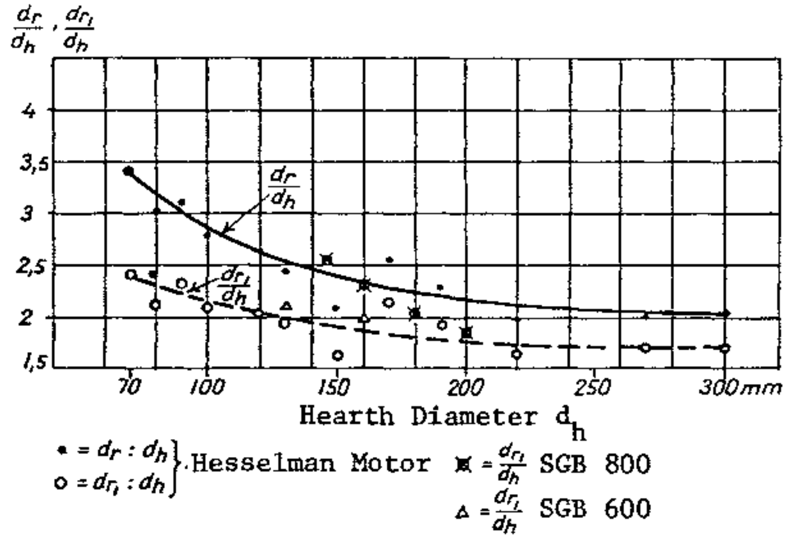


Figure 79. Diameter of Nozzle Ring and Nozzle Opening in Relation to Hearth Constriction, as a Function of Hearth Diameter, for Various Generator Makes.

Similarly, in Figure 80 there is a dotted scale elaborated for the relation between the height above the hearth construction of the nozzle plane (h) and the diameter in the hearth construction (d_h). A mean curve is also drawn for this.

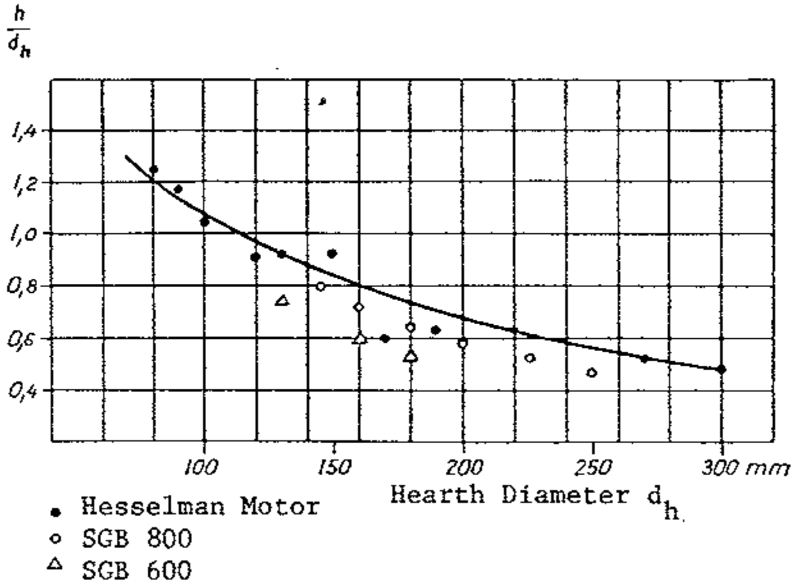


Figure 80. Height of the Nozzle Plane above the Hearth Constriction for Various Generator Sizes.

Both these diagrams are based upon generators of the Imbert type. If, from the two mean curves, the volume of the effective combustion space is calculated, consisting of a truncated cone with the height h and the areas $\pi d^2_{rl}:4$ and $\pi d^2_h:4$, respectively, of the two parallel surfaces, and if this volume is divided by the gas volume produced at a certain hearth load, the result for the entire generator family will be a time constant.

If, for instance, the generally assumed maximum hearth load of 0.9 Nm^3/cm^2hr is chosen to be the denominator, the result of the division determined by the mean curves will be 0.11 second for all generators. This time is calculated, however, on the assumption that the space in question does not contain any solid substances and that the temperature is 0° C. If, for example, it is assumed that charcoal takes up 0.6 of the total volume and the gas then 0.4, and that the temperature is 1200° C, the real time will be merely approximately 0.01 s. Consequently, this means that the dwell time of the gases in the space above the hearth construction is 0.01 s.

To date, no general rule for dimensioning of the hearth has been given in the specialist literature. The dimensioning system put forth here—with the mean curves in Figures 79 and 80 as bases—is intended to make up for this lack. The system is based on an empirical foundation and gives satisfactory results. That does not mean, however, that a hearth with dimensions differing from the system must be, or probably will be, a poor hearth. On the contrary, the system appears to allow for fairly significant deviations without obviously unfavorable consequences; it does seem, however, that the ratio h/d_h should not be made greater than as shown in the mean curve of Figure 80.

The part of the hearth below the narrowest section should be made a truncated cone, with height d_h and the opening diameter 2.5 d_h. The increased passage area downward is intended to cause a considerable gas velocity decrease, and thereby an increase of the time that the gas spends in the presence of charcoal at a temperature higher than approximately 800°C. This is advantageous for producing maximum reduction. On the other hand, the expansion must not be so great that the temperature at the opening goes below about 800°C, since the lower temperature to some extent seems to stimulate a re-formation of CO_2. The norms given above for dimensioning are values which have given good results from experience.

Due to the considerble drop in temperature, practically no reduction takes place outside the hearth (see Chapter 2). Due to this fact, it is unimportant whether the space below the hearth opening is filled with a bed of charcoal or some other porous material (e.g., porous concrete) or whether it is filled with any material at all. In practically all wood gas generators in Sweden a bed of charcoal or porous concrete, resting on a shaking, grate, is placed at approximately the distance d_h below the hearth opening and approximately 0.5 d above the bottom of the generator. The spaces above and below this grate are made accessible from the outside by a relatively large ash port. It is vital for proper operation of the generator that this port be tightly sealed.

Peat Gas Generators

No special generator designs for peat gas operation were produced in Sweden during the war. In practical tests which were carried out on generator gas operation with peat, peat charcoal, or peat coke (briquettes) as fuel, regular gas generators for charcoal or wood were used. Various operational disturbances were quite common due to tar and slag formation. The main reason for the inferior results was that the peat used was of unsuitable quality with too great ash content, and the tests seem to indicate that a satisfactory generator gas operation with peat as a fuel is not possible if the ash content of the peat significantly exceeds approximately 2%. In addition, the fuel must be relatively free from peat dust, charcoal dust, and foreign substances.

Judging from tests carried out by government authorities in Germany during the war, it appears that peat with low ash content could give satisfactory operation in wood gas generators provided that the diameters of the primary-air nozzles are increased so much (on the order of 50%) that the temperature in the combustion zone will stay below the fusing point of the ashes, approximately 1250°C. This test was carried out in an Imbert generator with the smallest hearth diameter at 130 mm and with five standard 12-mm air nozzles. The gas cleaning system was the usual one with wet cleaners and cork cleaners; the cooler was a standard type with 1.17 m^2 cooling surface.

This gas generator was first run for two hours on an Opel-Blitz truck whose motor had a 3.5-L cylinder volume and a 68-hp engine developing peak efficiency on gasoline at 3400 rpm. The peat size was 40-60 mm and the water content of the peat 20% to 22%. With the 12-mm air nozzles intended for wood, the hearth temperature became very high (over 1400°C) at which the peat coke formation became too small and the coke burst into pieces. By increasing the nozzle diameter to 20 mm (which involved a lowering of the temperature in the combustion zone to 1100°C) these disadvantages were eliminated; according to the reports the generator rendered a practically tar-free gas, and the peat-coke formation was so good that no charcoal had to be fed into the reduction zone through the ports, even during extended operation. The composition of the gas was about the same as in wood operation. The series of tests was completed with long distance tests with a 3.5-ton Magirus truck, equipped with a 7.4-L diesel motor with 90-hp peak efficiency during oil operation. The peat consumption with a 3-ton load on the truck was approximately 10 kg/10km. The operational properties of the truck when using peat gas proved to be good throughout, and the maintenance requirement was, on the whole, the same as in wood gas operation. The gas cooler had to be flushed every 1000 km and the grate shaken each morning in order to remove dust and ashes from the reduction chamber. Particularly interesting is the information that, during the tests (which included highway driving: Cologne-Hamburg-Lubeck-Berlin), no slag formation was observed in the generator. Peat fuel with an ash content of approximately 2% and 20% to 25% moisture was used.

Unfortunately, no tests have been made in Sweden with a similarly reduced temperature in the hearth, and therefore slag formation has not been overcome. In exceptional cases, where peat coke very low in ash was used as fuel in charcoal gas generators, the slag formation was so insignificant (somewhat more than 1% of the coke weight) that satisfactory continuous operation could be maintained.

Figure 75 shows a generator intended for peat, and the generator in Figure 76 is also suitable for this fuel.

Chapter 5

COOLING AND CLEANING OF GENERATOR GAS

General Conditions

Motor: Technical Considerations

The gas produced in the generator has a high temperature and is mixed with impurities, solid as well as vapors, which are harmful to the engine. Therefore, the gas temperature and the impurities content must be reduced to values suitable for motor operation. The main function of cooling is to prevent the volumetric efficiency of the engine from decreasing too much, and the power from being reduced because of too high a gas temperature. Corrosion, wear, and fouling of the engine are prevented, as far as possible, by gas cleaning. In connection with gas cleaning, cooling frequently has another function; namely, to condense water vapor present in the gas (especially in wood gas) and at the same time precipitate solid dust particles.

The cooling and cleaning system must not cause too great a flow resistance, either through its construction or its function. Thus the impurities separated from the gas should be automatically collected in a space where gas flow is not obstructed and which is easily accessible to be drained and emptied out periodically.

The influence of gas temperature and pressure upon engine power may be estimated on the basis of the general-state equation of gases:

$$\frac{N_i}{N_{i_o}} = \frac{p}{p_o} \cdot \frac{T_o}{T} \;;$$

N_i = indicated power at p and T
N_{i_o} = indicated power at p_0 and T_0

Thus, heating the gas mixture by 10°C would cause a power loss of about 3%, and a pressure drop of 100 mm water would cause a loss of about 1%. The mean value of the temperature of the generator gas in practical operation, after cooling and before mixing with secondary air, is approximately 40°C.

The impurities of motor fuels or impurities originating in fuel combustion in the cylinders may be classified in two main categories: those that affect the engine construction directly, either mechanically by abrasion or chemically by corrosion (rust, acids); and those that cause thickening of the lubrication oil, and thereby cause damage indirectly by disturbing the lubrication process. The so-called mechanical impurities consist mainly of iron particles originating mostly in abrasion between the sliding surfaces of the engine during operation on liquid fuels, and in the case of generator gas operation probably also originating in the gas; and silica, which probably causes the most direct abrasion of the engine. The latter originates mainly in dust sucked in with the air and is always highly mixed with minerals containing quartz. In generator gas operation however, particularly in the case of charcoal gas, a substantial part of the impurities would seem to come from the fuel and possibly from the primary air as well. The importance of the air cleaner is obvious for generator gas operation. The air may contain considerable quantities of dust, as shown in Table 28.

Table 28. DUST CONTENT OF AIR

Air in	mg/m^3
Rural areas and suburbs	0.5 – 1
Cities.	≃ 2
Industrial centers.	≃ 4
Streets with heavy traffic.	≃20
Dusty highways, excavation and graveling work, farm work with tractors, etc. .	over 200

In the case of 200 mg dust per m^3 air, a car with a 2-L engine would, when driving 100 km without an air cleaner, suck in 26 g dust. If the main part of this dust enters the crankcase oil, this corresponds to about 1% by weight of the oil.*

The question as to the extent that these impurities in the crankcase oil originate in the gas generator poses a very difficult problem and has not been thoroughly investigated.

Carbon dioxide and sulfur oxides can form corrosive acids in the engine cylinder in the presence of condensed water, but these gases are harmless as long as the water remains a vapor. (The minimum temperature for preventing corrosion in the motors is 60°C to 70°C.) Wood and charcoal do not contain sulfur, as opposed to fossil fuels. On the other hand, small quantities of acetic acid, carbolic acid formed by phenols (aromatics) and carbonic acid formed by carbon dioxide sometimes are found in the pipe system of the gas generator. Due to the high alkali content of the gas during normal operating conditions with generator gas, these acids usually react. (In the condensate-cooler container of a wood gas generator there are significant quantities of ammonia as well, 4-10 g/L.) Therefore, they are of little consequence for motor corrosion. Wood gas, however, affects aluminum, copper, etc.

Unlike liquid fuel operation, generator gas operation does not produce crankcase oil dilution, which is, of course, a considerable advantage. This fact frequently means that the oil thickening and lubrication oil consumption during generator gas operation seem greater than is really the case. The higher rotation speed during generator gas operation involves an increase of the oil consumption.

During operation with liquid fuels the "nonmechanical" impurities in the crankcase oil consist mainly of soot (carbon) and resins. The resins originate in cracked fuel in the cylinders, and also from oxidation products from poor lubrication oil. Lead and iron oxides are also to be found to a considerable extent, from the antiknock agents in the gasoline. During generator gas operation the impurities are, according to numerous analyses, composed mainly of alkali compounds (70%-80% of the total ash content). In both cases it is these impurities that cause thickening of the oil, thereby disturbing the lubrication process. The lubricating ability of the oil, which is dependent on its molecular structure, is not altered by these impurities. After the used lubrication oil has been

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*Cartechnical Manual 1941 (Automobiltechniches Handbuch 1941).

filtered, whereby particles as small as 0.1 μ (i.e., of colloidal size) are retained with the help of modern devices, the oil is as good as new. Gradually, it will become saturated with such substances, which can then no longer be dissolved in it and then are precipitated. Recent research in the field (Coordinating Research Council, USA) also indicates that impurities are also precipitated earlier in the presence of condensation water, especially in modern lubrication oils with additives intended for heavy operation.

Deposition takes place everywhere that the oil goes in the engine and where there are "cold walls" on which the omnipresent water vapor is condensed. The deposits are slimy at first, since they contain much oil and water, but dry out and become harder and harder during periods of full load and high operational temperature of the engine. Intermittent operation with many cold startings is, therefore, a significant cause of engine fouling for gasoline or generator gas operation. Since generator gas operation involves higher operational temperatures of the engine, and since drivers generally are reluctant to shut off the engine during occasional stops and prefer to keep a high idle speed, the formation of condensation water is likely to be smaller during generator gas operation, even if some water vapor accompanies the gas.

In this context it should be pointed out that when 1 kg gasoline is burnt in the cylinders, about the same quantity of water is formed. However, in the crankcase system for generator gas driven two-cycle engines, where the gas is sucked into the relatively cold crankcase, much fouling takes place during operation. It should be possible to keep the thickening of the oil by solid impurities during generator gas operation of cars, below 0.5% by weight for a driving distance of 100 to 150 km. [46]

There are many divergent opinions as to the acceptable content of solid dust particles in the gas after cleaning. French regulations allow 5 mg/m^3 for charcoal gas operation and 20 mg/m^3 for wood gas operation; other specifications are: 50 mg/m^3 for both charcoal and wood gas [15]; 20 mg/m^3 (H. Lutz & E. Kuhl, "Examinations of Gas-Cleaning Devices," Berlin 1942), among others. In practice the dust content is much higher, as indicated by many tests, ranging from 50-200mg/m^3, with the lowest values found when cloth filters are used and the highest for baffle-plate cleaners, which at the same time act as coolers (see below).

Provided that the air cleaner for the secondary air is functioning properly, an average dust content in the mixer pipe of 10 to 20 mg/m^3 is quite satisfactory. When a high content of silicon and iron compounds are involved, the above-mentioned maximum figure should probably be divided in half.

General Conditions for Cooling of Generator Gas

Depending on the design and type of generator, the temperature of the gas leaving the reduction zone is decreased from about 800°C to about 300°C to 400°C during wood gas operation and to 400°C to 500°C during charcoal gas operation; this temperature decrease takes place immediately outside the gas outlet at a full hearth load. Wood gas contains more water vapor than charcoal gas; thus its dewpoint is higher. On an average, the dewpoint may be set at 40°C to 60°C for wood gas and at 30°C to 35°C for charcoal gas at the gas oulet. In the generator a significant heat quantity is associated with the water vapor of the gas. Thus, during cooling, more heat must be transported away by a moisture saturated gas than by a dry gas for a given decrease of temperature, as shown in Figure 81. The moisture content, measured in g/m^3, is determined by the dewpoint (see Figure 82); thus, cooling devices of a wood gas generator should have a significantly greater capacity than those of a charcoal gas generator. When measuring the moisture in volume units, for example as a percent of the volume of dry gas, the total gas pressure must be taken into account. (See Chapter 2 and Table 8.) The pressure in the gas affects the dewpoint. Figure 83 shows that the dewpoint becomes lower at lower pressure and vice versa.

Knowledge of the moisture proportions of generator gas is needed for designing both cooling and cleaning devices. Condensation of water in the wood gas may be considered to be cleaning as well, since large quantities of dust particles are precipitated, the dust grains constituting condensation nuclei for the water droplets. In cleaning charcoal gas, where cloth-filter cleaning is prevalent, it is important that the gas not be cooled down too much before entering the cloth cleaner, producing condensation on the cloths. Cooling between the generator and the engine must be well adapted to this purpose. These facts will be discussed in more detail in connection with the cleaning problem.

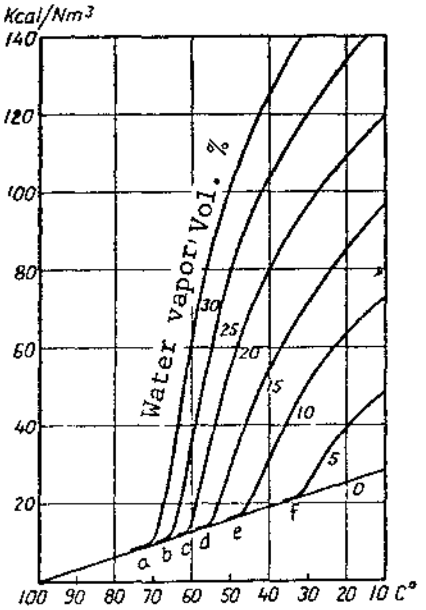
General Conditions for Cleaning the Gas

Impurities in the generator gas which may be considered harmful to the engine are tar mists with acetic acid, acids formed by phenols and carbon dioxide, surplus water vapor, and solid dust particles of all kinds. In addition to these, valuable components such as carbon monoxide and hydrogen, and the neutral component nitrogen are found in the gas.

Deposits of tar mists after the gas outlet in wood gas generators can be caused by an insufficiently high temperature in the reduction zone due to poor insulation or poor hearth design, by too great moisture content in the fuel, or by incorrectly adapted (too large) hearth diameter in relation to the dimensions of the engine and the operating conditions, etc.; these deposits are most abundant at a low hearth load. Tar in the gas during charcoal operation is caused by insufficiently charred fuel, so-called calcines, and is related to the hearth dimensions and the method used for the primary air supply. Gas from pure charcoal is practically tar free. The risk of damage to the engine due to tar, is, at this stage of design development, rather insignificant for generator gas operation. The small quantities of tar mists carried with the gas during unfavorable operating conditions are condensed in a container designed for this purpose; they practically never reach the engine. In laboratory tests by the Swedish Steam Heat Institute in October 1944 on a Volvo passenger car equipped with an Imbert generator with a V-hearth and using hardwood fuel of 13.5% moisture content, the following results were obtained:

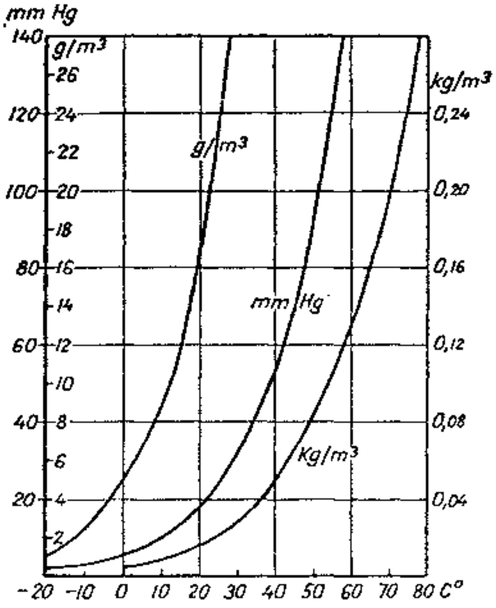
> Test 1 at 70 km/hr: Tar content in gas leaving the gas outlet—Approximately 0.34 g/m^3
>
> Test 2 at 30 km/hr: Tar content in gas leaving the gas outlet—Approximately 0.64 g/m^3

At 70 km/hr a sample was also taken in the generator immediately below the hearth, where the tar content was found to be 0.47 g/m^3; this indicates that part of the tar had been separated in the generator since, at the same load, the tar content outside the



(a - f Various dewpoints)

Figure 81. Heat Quantity per Nm^3 to Be Removed When Cooling from 100°C. (When below the dewpoint, this heat quantity increases considerably; i.e., the curves move upward.) Total Pressure 680 mm Hg.



(Dewpoint)

Figure 82. Pressure and Maximum Density in Moisture Saturated Gas at Various Temperatures.

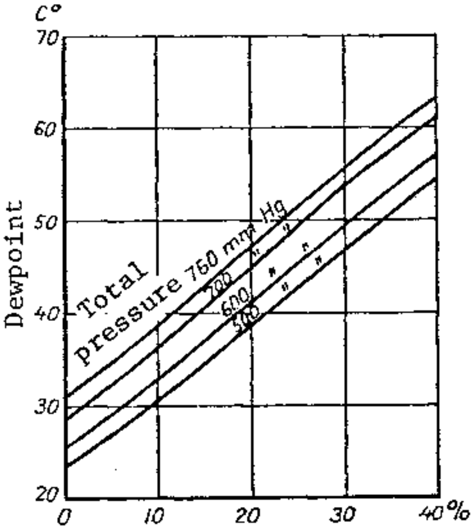


Figure 83. Dewpoint of Wood Gas at Various Total Pressures Calculated for Dry Primary Air. (The abscissa gives the moisture content of the wood, corrected for water obtained in the precondenser.)

generator at the gas outlet was only 0.34 g/m^3. Tests by Professor H. List ("Examinations of Vehicular Generators during Softwood and Hardwood Operation," Vienna, 1940) indicate that the average tar content in the gas conduit before the cleaners is approximately 1 g/m^3, a rather high value that would be much lower with modern generator designs. Thus, under normal circumstances there is no risk that engines equipped with modern devices would get clogged with tar. Deposits that may be caused by the cooling effect of the secondary air in the mixer or intake pipe by the engine, and that are sometimes considered to contain tar, consist in reality of soot and ashes mixed with water which have been deposited due to condensation caused by the cooling. The tar-like odor originates in the phenols present in the gas (aromatics arising during dry distillation of wood, which give tar its characteristic smell). The acid content from phenols and carbon dioxide as well as from possible small quantities of acetic acid during wood gas operation is small; thus the gas and the condensation water practically always become alkaline (as mentioned above), which is important for the choice of material for the cooling and cleaning system, but is absolutely harmless to the engine.

When the gas is cooled, water is condensed; this is true especially for wood gas. If the dewpoint of the wood gas is, for instance, 60°C at the gas outlet, it will contain approximately 130 g water per m^3 as shown in Figure 82. If we assume that 1 kg wood will give 2.5 Nm^3 wood gas, this moisture content will correspond to about 325 g water per kg wood; for air-dried wood (20% moisture content) this corresponds to approximately 400 g water per kg of dry wood. In terms of volume, the water vapor in this case constitutes approximately 25% of the dry gas (compare Table 8). If cooling goes down to 40°C, the moisture content will be approximately 150 g/kg dry wood; i.e., about 250 g water per kg wood is condensed. If the temperature is lowered to 20°C, approximately 350 g/kg is condensed. For charcoal gas, at a dewpoint of 35°C, about 100 g water per kg dry charcoal material is obtained if the charcoal is assumed to have a 12% moisture content (i.e., only a few percent water vapor by volume). Condensation caused by the secondary air is given in Figure 84, where the gas is considered to be moisture saturated and to have a temperature of 40°C, while the air temperatue is 20°C. The mixing proportion is 1:1 and the temperature of the gas/air mixture is consequently 30°C. Water is then always condensed as soon as the humidity of the air exceeds 62%. In order to prevent such condensation, the secondary air may be preheated. Figure 85 shows a device for this.

In this way, however, a theoretical power loss of 6% (decreased volumetric efficiency) occurs in the engine, in addition to which the unprecipitated dust accompanies the gas on its way into the engine. If the wood gas, before the mixer, cannot be cooled down another 20°C, which corresponds to a further water condensation of 100 g per kg wood according to the estimates above, it would probably be better to arrange a chamber for the condensate caused by the cooling effect of the secondary air, rather than to preheat the air. It is not advisable to keep the old intake manifold with a functioning hotspot, from carburetor engines which are redesigned for generator gas operation, due to the pressure drop which occurs through the intake manifold of the carburetor engine.

In addition to condensing surplus water in the generator gas, the main function of the cleaning apparatus is to separate the solid dust particles. When leaving the reduction zone in the generator the gas contains considerable quantities of dust. The main portion of the dust has already been separated in the generator through suitable generator construction (low gas velocity through an enlarged gas area, change of the gas flow

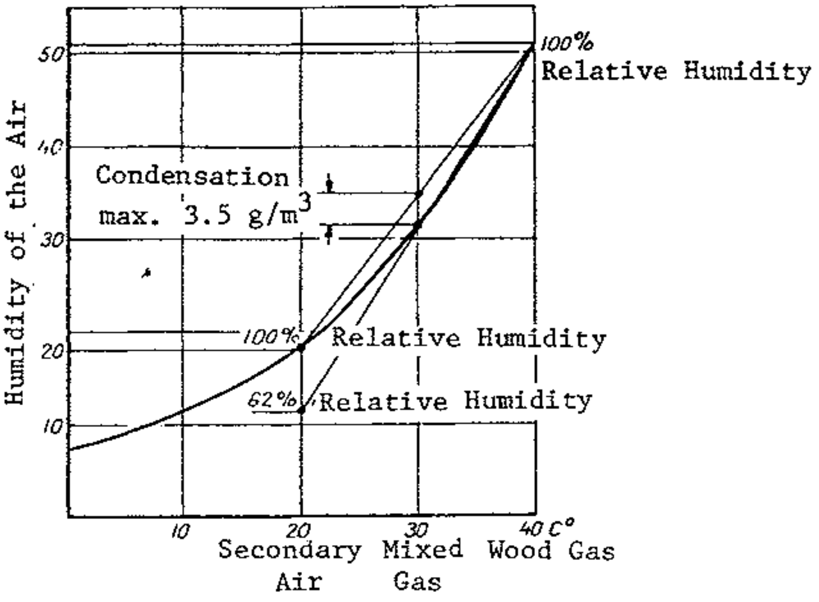


Figure 84. Condensation in the Mixer Due to Mixing with Secondary Air. (From Nils Gustafsson,"Car Engines and Engine Fuels")

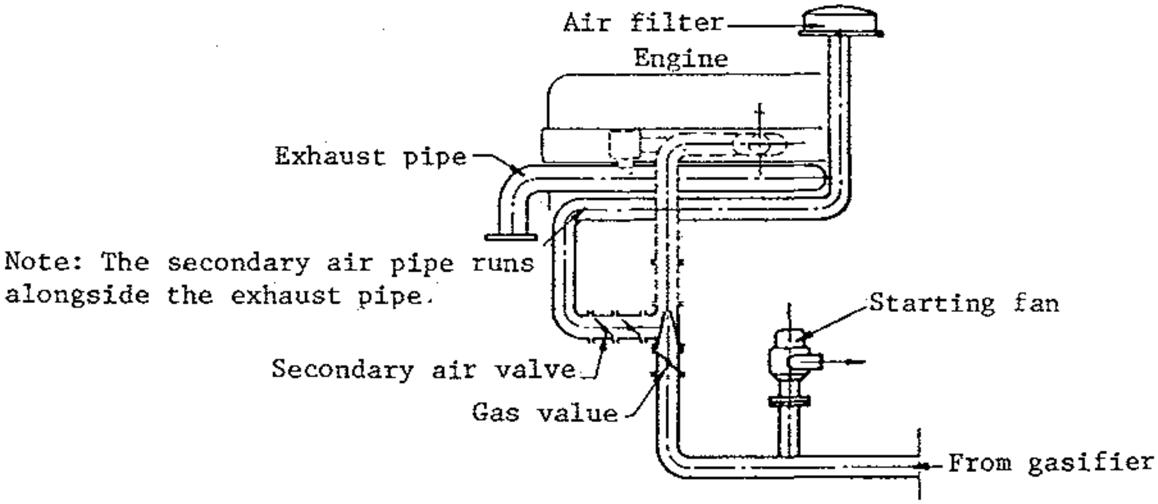


Figure 85. Heating of Secondary Air by Exhaust Gas Heat from the Engine (Hesselman).

direction, perforated plates, etc.) and the filtering effect of the charcoal or concrete bed. For collecting these ashes and the charcoal dust there is an ashbin, as a rule with a shaking grate. The dust content of the gas outlet varies with the load of the generator. The greater the gas velocity, the more dust is carried along. There are some test results concerning the size and variation of dust quantity with gas velocity. Figure 86 shows results from tests with charcoal gas and wood gas generators. Due to the difference in design of the generators, these curves cannot be directly compared. As a rule, a somewhat greater dust content is to be expected in charcoal gas generators, where the gas is generally taken the shortest way from the reduction zone. In the case of wood gas generators, the gas frequently is brought upwards through the wood store for heating the

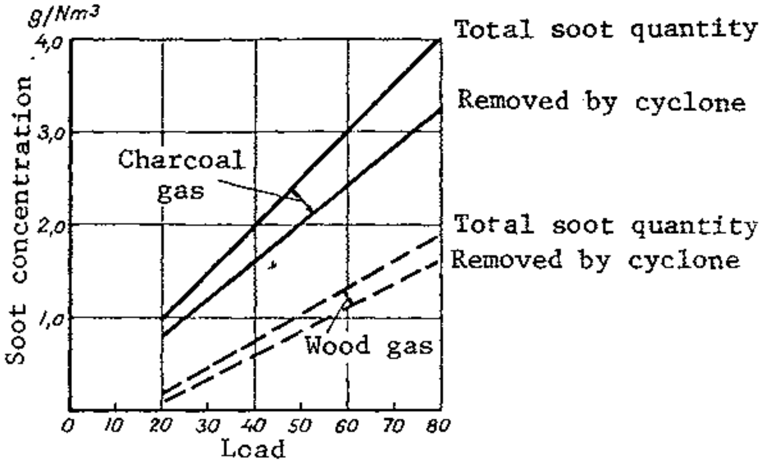


Figure 86. Dust Concentration Related to the Load in Wood and Charcoal Gas Generators. Full load on the generator corresponds to 80 Nm^3/hr (Gas Generator Co, Orebro)

fuel (which as a matter of fact is inappropriate and does not increase the generator efficiency), or through a heat exchanger for heating the primary air. A mean value for generator gas in general is 3-5 g/m^3 of dust at a load of 100 Nm^3/hr and about half of that at 50 Nm^3/hr. Figure 87 shows a graph listing measured quantities of dust at the gas outlet from wood gas generators of various makes, in which the measured soot quantities fall within the dashed area and are stated in g per m^3 gas. The abscissa of the graph gives the generator load in Nm^3/hr. Table 29 gives the particle size measured by means of screening tests on wood gas soot from an Imbert type generator, conducted by the Charring Laboratory, Stockholm. In Figure 88 the dust residue is shown as a function of the particle size.

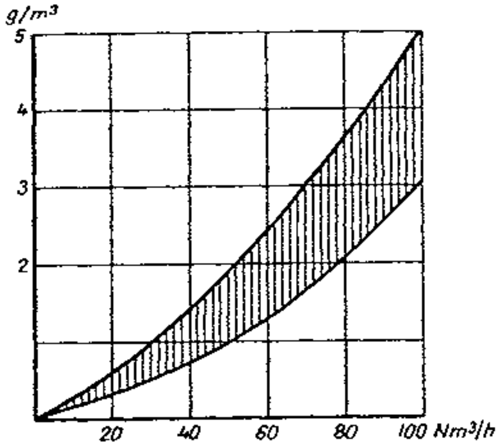


Figure 87. Dust Concentrations for Wood Gas Generators of Various Makes as a Function of Load. Full load on the generator corresponds to 100 Nm^3/hr. (Nordberg, Orebro)

Table 29. ANALYSIS OF WOOD GAS SOOT

	%
Over 1000 μ (1 mm screen)	1.7
1000 - 250 μ	24.7
250 - 102 μ	23.7
102 - 75 μ	7.1
75 - 60 μ	8.3
Under 60 μ	30.3
Losses	4.2
	100.0
Water content	3.2
Ash content, dry sample	10.6
Loss due to burning, dry sample	15.7
Content of Fe_2O_3 in the ashes	11.0
Content of SiO_2 in the ashes.	7.7

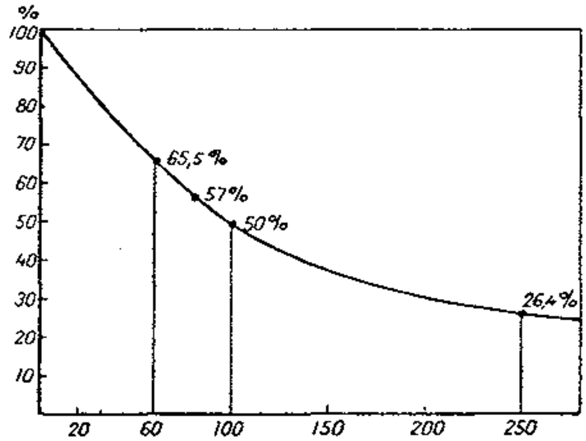


Figure 88. Residue Curve for the Screening of Generator Gas Dust.

Approximately 80% of the soot, especially the coarser and heavier particles, are separated in the cyclone cleaner nearly always found in current designs of gas generators for both charcoal and wood. The remaining 20%, mostly with a particle size below 60 μ, is then separated by the rest of the cleaning system. In tests, two cyclones have been connected in series but the result was less than satisfactory, due to the fact that the fine soot remaining in the gas after the first cleaner is affected only to a small degree by the second. As shown in Figure 86, if the raw gas at a generator load of 100 Nm^3/hr contains 5 g soot per m^3 gas, an estimated 4 g/m^3 will be separated by the cyclone cleaner, after which the rest of the system must separate as much as possible of the remaining 1,000 mg/m^3 with a particle size mostly below 60 μ. This gas cleaning is most thorough with a cloth filter (except for electrostatic precipitators which would hardly seem to be of practical importance for generator gas operation). Through such filtering, dust down to 0.5 μ may be separated. However, the cloth filters are very sensitive to moisture and mechanical impact and they frequently require special design in order to function satisfactorily (large dimensions, heating devices). It is especially important that the intervals between the necessary cleaning of the collected impurities from the filters are long enough, and that damage to the cloths does not mean damage to the engines. Therefore, the cloths must always be used in combination with suppression or safety filters.

Figure 89 schematically shows various cooling and cleaning equipment for wood gas operation—motor vehicles, stationary motors and boats—as well as for charcoal gas operation of motor vehicles. Also included is a device for the use of cloth filters for wood gas operation with secondary heating of the gas before the cloth cleaner, using the engine exhaust gases. Before that, the wood gas has passed a cyclone cleaner and a condensation-water cooler. The various standard cooling and cleaning systems developed by practical operating experience will be discussed later. In general it may be said that there is room for significant technical progress in this area.

Design and Shape of the Generator Gas Cooler

Heat Transfer

Cooling of generator gas involves heat transfer from the hot gas to the surrounding colder air. The condition for having heat transmitted from one point to another is that there is a temperature difference between the points. In this way, there is always a tendency toward an equalization of this difference in temperature. Heat may be transmitted in different ways, by conduction, convection, and radiation.

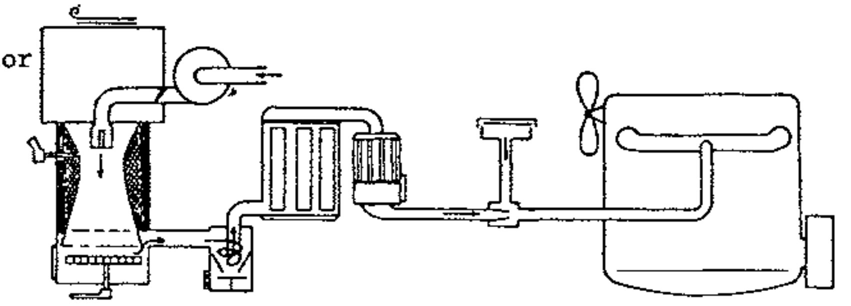
Heat conduction is heat tranmission from one part to another within the same body or between two bodies attached to each other. Heat conduction may take place in solid and liquid substances as well as in gases.

Convection is heat tranmitted due to inner movements in a gas or liquid. If the movement is solely a consequence of density differences due to temperature differences, it is free convection; if the movement is imposed by external means, it is forced convection.

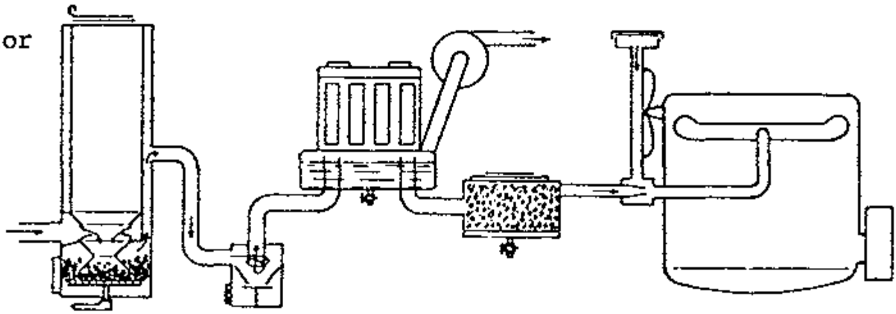
Heat radiation occurs because a body always radiates heat, and the heat flow is determined by the temperature and properties of the surface. The higher the temperature, the greater the radiation intensity and thus the heat flow. A hotter surface will emit greater heat to a cooler surface than the cooler radiates to the warmer, whereby heat will be transmitted to the cooler body. Most important is the radiation from solid bodies, but certain gases such as carbon dioxide and water vapor (but not oxygen and nitrogen) also may emit heat through radiation, so-called gas radiation.

In general the transmission of heat is composed of various elements and frequently comprises both conduction and radiation as well as convection. In a generator gas cooler consisting of a pipe through which the gas is carried, heat transmission from the gas to the inside of the pipe takes place virtually exclusively through convection and only to a very small extent through radiation. For gas radiation to be of importance, very high temperatures are required as well as a great concentration of gas, as, for instance, in furnaces. Heat is transmitted through the pipewall by conduction, and if the pipe is

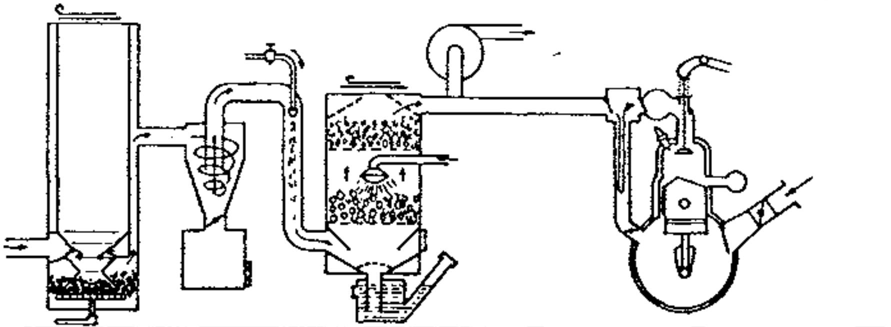
A. Charcoal gas apparatus for motor vehicle.



B. Wood gas apparatus for motor vehicle.



C. Wood gas apparatus for 2-cycle ignition bulb motor with pulsator for boat.



D. Wood gas apparatus with cloth cleaner and preheating of gas for motor vehicle.

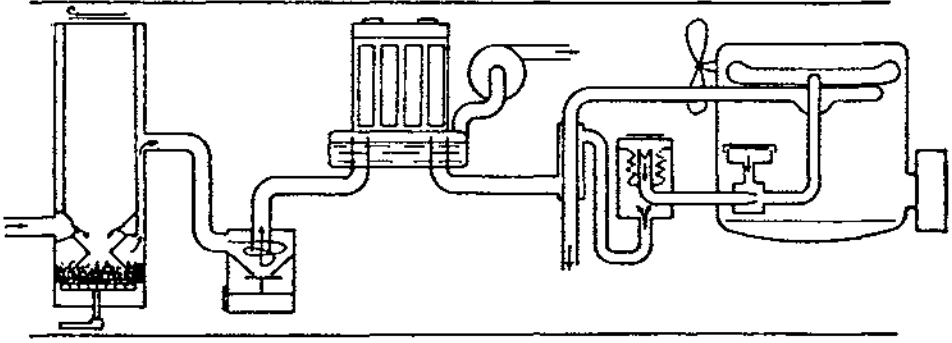


Figure 89. Schematics of Generator Gas Devices.

covered by soot or dust, the heat must also be transmitted through this layer. Finally, heat is transmitted from the outside of the pipe to the surrounding air by convection. Heat radiation to the surroundings is also of some importance, especially at high temperatures. If the cooler is installed in a car for instance, forced convection takes place due to the motion of air relative to the car, whereby the car's speed determines the heat transfer coefficient.

The heat transfer coefficient, usually written α, denotes the heat quantity transmitted per surface unit and time unit at a temperature difference of 1°C. If the heat quantity is calculated in kcal, the surface in m^2 and the time in hours (hr), the dimension for α will be kcal/m^2hr°C. The heat conductivity, λ, of a material denotes the heat quantity per surface unit and time unit, passing through a wall of the material at a temperature difference of 1°C/m of wall thickness. The dimension for λ is then kcal/m^2hr°C/m= kcal/mhr°C.

The temperatures produced by heat transmission through a wall with a dust covering are shown schematically in Figure 90. The entire temperature fall $t_g - t_\ell$ is, then divided into a temperature fall on the gas side, one in the wall, one in the dust coating and one on the air side. For the heat quantity transmitted per time unit, Φ, i.e., the heat flow, we have generally

$$\Phi = kA\,(t_g - t_\ell) \tag{57}$$

where k is the heat transfer coefficient and A is the area of the heated surface. The dimension for k is the same as for α, i.e., kcal/m^2hr°C.

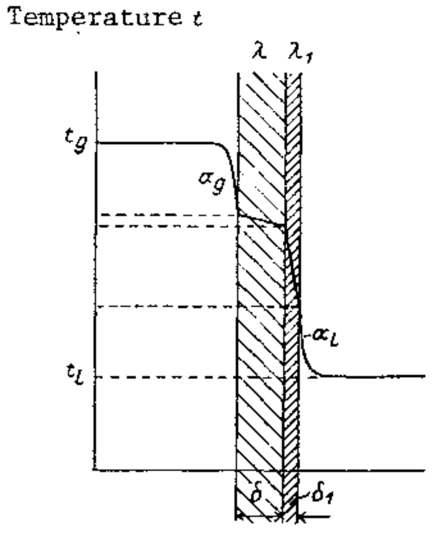


Figure 90. Heat Transmission from Gas to Air through a Wall of Thickness δ with a Dust Film of Thickness δ_1. (Boundary layers of A_g on the gas side and A_1 on the air side.)

Using the same notation for the heat transfer coefficient, etc., as in Figure 90 we obtain the following expression:

$$\frac{1}{kA} = \frac{1}{\alpha_g A_g} + \frac{}{\lambda A_g} + \frac{1}{\lambda_1 A_\ell} + \frac{1}{\alpha_\ell A_\ell} \tag{58}$$

If the wall is a plane, we obtain $A_g = A_\ell = A$ and may then write

$$\frac{1}{k} = \frac{1}{\alpha_g} + \frac{\delta}{\lambda} + \frac{\delta_1}{\lambda_1} + \frac{1}{\alpha_\ell}, \tag{59}$$

This expression may also be used with sufficient accuracy for cylindric pipes, if the heat surface is calculated for the side where the heat resistance is the greater; i.e., the heat transfer coefficient the lower.

Fins may be used to improve the heat transmission, so that the surface is enlarged on one side, usually the air side, where the heat transfer coefficient generally is the lowest. In such cases Equation (59) cannot be used, but Equation (58) must be used in the calculation.

Equation (59) shows that the heat transfer coefficient k is reduced when the terms on the right side become greater. The greatest influence is, of course, exerted by the larger term; i.e., the lowest value of α and λ/δ. In order to improve the value of k, one should try to improve the lowest value of α and λ/δ.

Heat conductivity is high for metals; e.g., for copper 330, aluminum 175, iron 45, alloyed steels 10-30 kcal/mhr°C. For wood the heat conductivity varies between approximately 0.1 and 0.3; heat insulation materials have even lower values, such as asbestos 0.13 and glass wool 0.03. For charcoal the value is approximately 0.05 and for a loose dust layer one could calculate with 0.03 kcal/mhr°C. These values are valid at room temperature. For iron the conductivity decreases somewhat at an increasing temperature, whereas it rises for heat-insulation materials. Thus, the heat conductivity for glass wool at 100°C is 0.045; at 200°C, 0.062; and at 300°C, 0.09 kcal/mhr°C.

The heat transfer coefficient during convection is, as mentioned, highly dependent upon the gas or air velocity and, in addition, upon the shape of the heated surface. (See, for example, Schack, "Industrial Heat Transfer," 2nd ed., Dusseldorf, 1940.)

For smooth, plane surfaces, with α expressed in kcal/m^{2}hr°C, we obtain

$$\text{at velocity } \omega \leq 5 \text{ m/s,} \qquad \alpha = 4.8 + 3.4\omega \tag{60}$$

$$\text{at velocity } \omega > 5 \text{ m/s,} \qquad \alpha = 6.12 \cdot \omega^{0.78} \tag{61}$$

where ω is the air velocity over the surface.

The magnitude of the heat transfer coefficient at various air velocities is shown in Figure 91, calculated with the help of Equations (60) and (61).

During gas flow inside pipes, not only the gas velocity and temperature are of importance, but also the pipe diameter. If the gas velocity in m/s is denoted ω_0, converted to 0°C, 760 mm Hg, and the pipe diameter in meters is denoted d, for air in turbulent flow

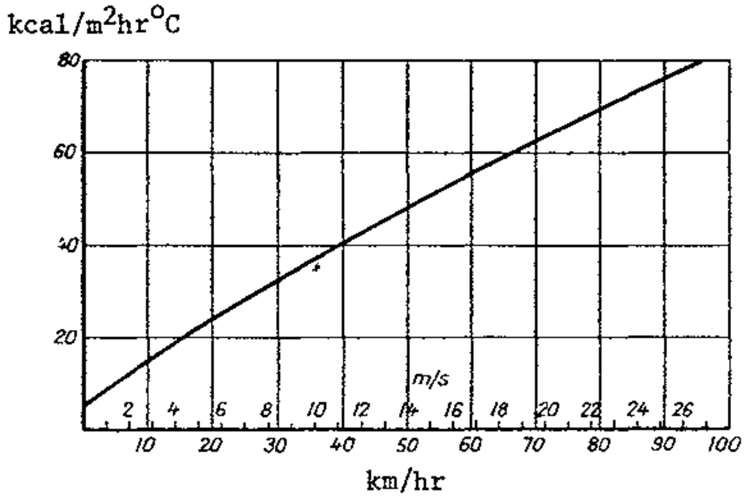


Figure 91. Convective Heat Transfer Coefficients for a Level Surface as a Function of Air Velocity.

we obtain (according to Schack) the following expression for the heat transfer coefficient:

$$\alpha = \left(3.55 + 0.17\,\frac{t}{100}\right)\frac{\omega_0^{0.75}}{d^{0.25}}\ \text{kcal/m}^2\text{hr}^\circ\text{C} \qquad (62)$$

Somewhat higher values are obtained for generator gas than for air, but this difference is of minor importance; therefore, we may also use Equation (62) for generator gas, and be on the safe side in sizing the cooling surfaces. In Figure 92 the heat transfer coefficient is given for air at 20°C, for a few different cases. At a higher temperature the heat transfer coefficient is obtained by using Equation (62). Thus an increase of the temperature to 100°C leads to a 4% increase of the heat transfer coefficient; an increase to 300°C leads to a 13% increase.

The heat transfer coefficients, calculated according to Equations (60) to (62) refer to air with no condensation of water vapor. If water vapor is condensed at the same time as the gas is cooled, which happens as soon as the dewpoint of the gas is reached, a considerably greater heat transfer takes place. In a generator gas cooler such a high heat transfer coefficient is obtained that the corresponding heat resistance usually does not have to be taken into account, being much smaller than the heat resistance at the air side.

The heat transfer coefficient at the air side is highly dependent upon the shape of the cooling surface. For plane surfaces or surfaces with a great radius of curvature, Equations (60) and (61) may be used in the calculation. Frequently the cooler is made in the shape of pipes between which the air flows. For such a pipe arrangement, the heat transfer coefficient may be calculated according to Equation (63). It is valid for air at 20°C and pipes in a row, the spacing between the pipes being as large as the pipe diameter d; ω is the air velocity at 20°C. In Figure 93 the heat transfer coefficient is given according to Equation (63) for a few different cases.

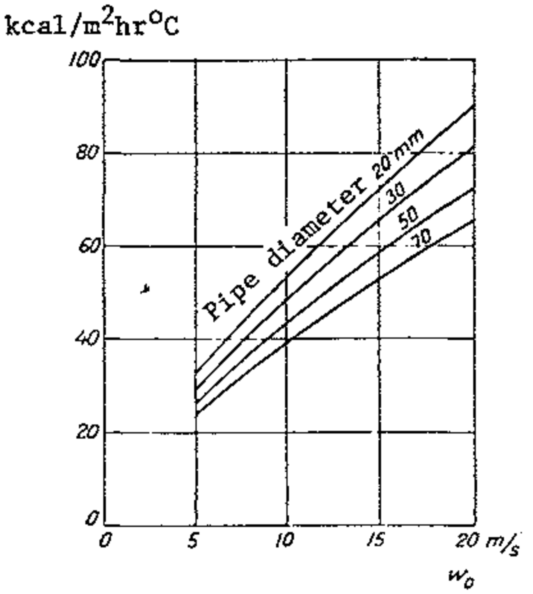


Figure 92. Heat Transfer Coefficient for Air at 20°C during Flow in Pipes as a Function of the Velocity ω_0 at 0°C, 760 mm Hg.

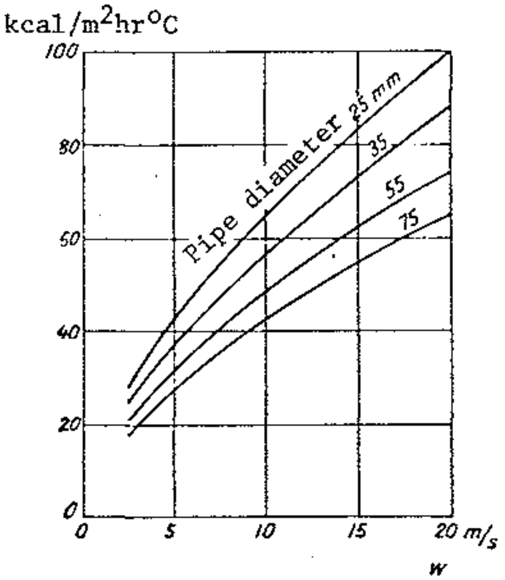


Figure 93. Heat Transfer Coefficient(s) for Air at 20°C Flowing Across Pipes in a Row with the Spacing between Pipes Equal to the Pipe Diameter; ω is the Air Velocity at 20°C.

$$\alpha \approx 3.8\,\frac{\omega^{0.61}}{d^{0.39}}\ \text{kcal/m}^2\text{hr}^\circ\text{C} \tag{63}$$

Figures 91 to 93 show how great is the influence of velocity on the heat transfer coefficient. In order to have small heat surfaces, high velocities are necessary. However, the velocity cannot be chosen at random. If there is no arrangement for a special fan, on the air side we must depend on the velocity of the vehicle; and on the gas side the velocity must be limited due to pressure losses. To achieve high engine power the pressure losses must be small on the gas side so that the volumetric efficiency of the engine will be high. We may assume that the pressure loss is approximately proportional to the square of the velocity. When installing the generator gas radiator in front of the ordinary radiator of a car, so that the engine fan may be used to suck the air through the generator gas cooler, the corresponding increase of fan work must be taken into account. The heat resistance in the wall of the radiator may be neglected in comparison with the heat resistances occuring at the gas side and air side. For an iron radiator with a wall thickness of 1 mm we get:

$$\frac{\lambda}{\delta} = \frac{45}{0.001} = 45,000$$

This value cannot, of course, affect the calculation of the heat transfer coefficient according to Equation (59). Thus there is no reason from a technical viewpoint to choose materials with higher conductivity. If there is a thick dust film on the radiator, however, the effect may be decreased considerably; this is the case particularly if the radiator is designed for high gas velocities and consequently high heat-transfer coefficients, as shown in Figure 94.

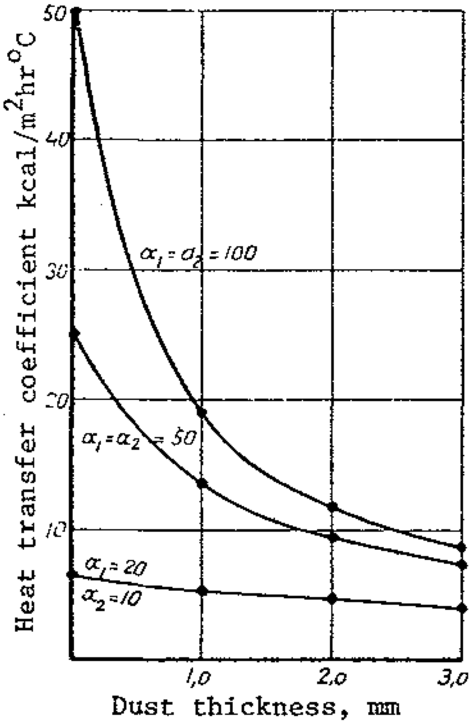


Figure 94. The Influence of a Dust Film on the Heat Transfer Coefficient of Cooling Surfaces. (a_1 and a_2 are heat-transfer coefficients at the gas and air sides, respectively.)

The heat quantity transmitted per hour by radiation from a body with absolute temperature T_1, to a body with absolute temperature T_2, may be expressed by the equation

$$\Phi = 4.96\ \varepsilon\ \phi\ A \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \right] \text{kcal/hr} \tag{64}$$

Here ε denotes the emissivity factor, ϕ the angle coefficient, and A the surface. The emissivity ε, being 1 for a "black body," is dependent on the surface properties of the two bodies, their shapes, and positions in relation to each other. For a polished iron surface ε is approximately 0.3, but for a surface covered by mill scale ε is approximately 0.65. These values are valid at 20°C. At 130°C, an ε value of 0.8 has been obtained for iron with an oxidized surface. The angle coefficient ϕ expresses how the surface is geometrically utilized from the viewpoint of radiation. If the entire surface of the radiating body can radiate in all directions, $\phi = 1$, but if part of the surface is obscured in one way or another ϕ will be less than 1. For instance, in a radiator constructed of a number of pipes placed beside each other, the pipes will obscure each other to some extent, so that ϕ will be less than 1. In many cases ϕ may be calculated approximately as the relation between the size of the surface that surrounds the device in question, and the heating surface A exposed to convection.

As shown in Equation (64) the temperature T_1 greatly affects the radiation; above all, this radiation manifests itself at higher temperatures. This is also indicated by the curves in Figure 95, which shows the amount of heat transmitted by radiation and convection at various wall temperatures. The curves are calculated for $\phi = 0.65$. It may also be of interest to see what proportion of the total stated heat quantity is to be classified as radiation. In Figure 95 this is stated for a few different values of the heat transfer coefficient during convection. The diagram is calculated with $\varepsilon = 0.65$ and $\phi = 1$; this means that the heating surface is unobstructed in relation to the surroundings. For a pipe cooler, for instance, the values would be lower than those shown in the graph.

The air usually used as a cooling medium is supplied by the vehicle motion or a fan. In generator gas operation of stationary engines and boat engines, water is sometimes used as a cooling agent, and the much higher heat transfer coefficients of water must be taken into account in sizing the cooling surfaces.

When there is an unlimited supply of cooling air, which is most often the case, it is of minor importance whether the radiator is arranged parallel or perpendicular to the flow. Only when the air supply is limited may something be gained in arranging the cooler perpendicular to the flow.

The size of the cooling surface is dependent on the gas flow, gas temperature before the cooler, water vapor content of the gas, desired final temperature, and heat transfer coefficient.

In order to cool G Nm^3/hr of generator gas from the temperature t_{g1} to the temperature t_{g2}, the following amount of heat must be removed:

$$\Phi_1 = G \cdot c_p \cdot (t_{g_1} - t_{g_2}) \text{ kcal/hr} \tag{65}$$

where c_p is the specific heat of the generator gas.

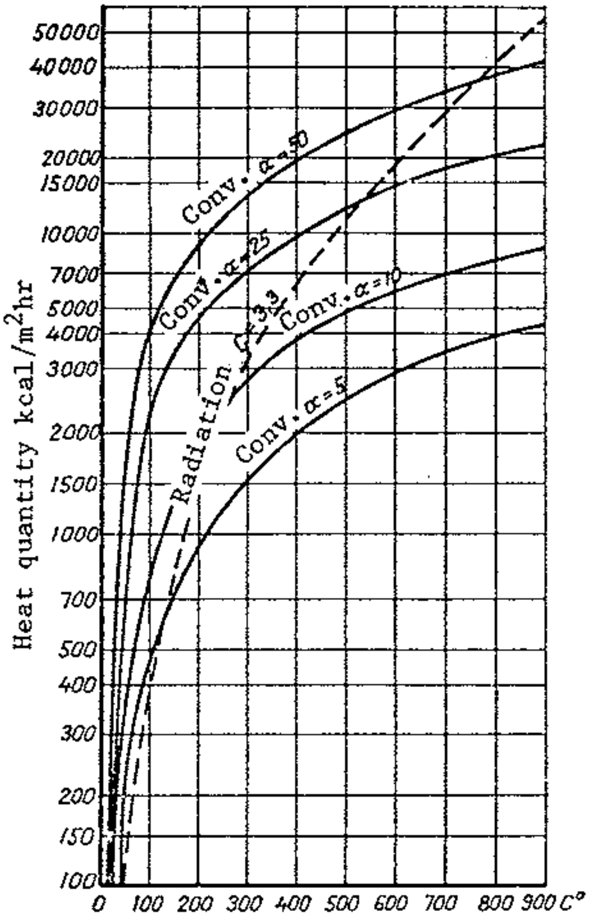


Figure 95. Heat Transfer by Radiation and Convection. Outer Temperature $20^{\circ}C$, $\varepsilon\phi=0.65$ (according to Tobler)

In estimates the gas quantity is usually assumed to be 2 Nm^3 per hp-hr. In sizing the cooling surface, the operating conditions must also be taken into account. For mobile engines using vehicle motion for cooling, large heat quantities must be removed during slow driving in low gear with a heavy load where the cooling effect of the air is relatively poor.

Instead of using the specific heat of the generator gas we may calculate cooling requirements from the enthalphy i, which is frequently more convenient. Equation (65) may then be written:

$$\phi_1 = G \cdot (i_1 - i_2) \text{ kcal/hr} \tag{66}$$

In Table 30 the enthalpy is given for various temperatures of air, for dry wood gas of average analysis, and for water vapor. The differences between the values for air and dry wood gas are not great, and for dry charcoal gas a value in between may be assumed. For water vapor, however, the enthalpy is considerably higher than for the other gases; therefore the calculations for water vapor must be separate, especially in more accurate estimates. The specific heat for the same gases is given in Figure 97.

Table 30. ENTHALPY OF GASES IN kcal/Nm^3

Temperature C°	Air	Wood Gas, Dry	Water Vapor
25	7.8	8.0	8.9
100	31.1	32.3	35.8
200	62.5	65.3	72.5
300	94.4	99.2	110.3
400	127.1	133.7	148.8
500	160.3	169.2	188.9

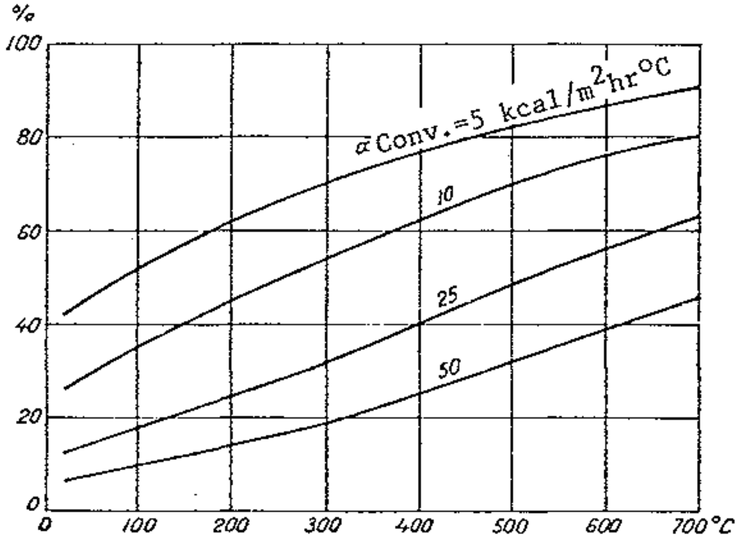


Figure 96. Radiation Heat Transfer in Relation to Total Heat Transfer at Various Convective Heat Transfer Coefficients $\varepsilon \cdot \phi = 0.65$

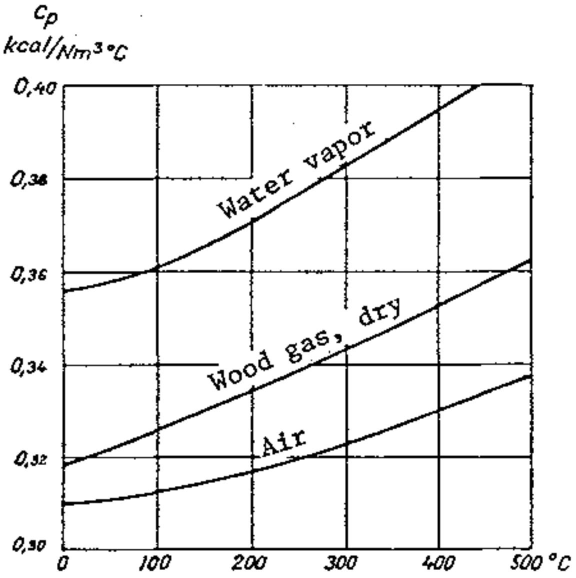


Figure 97. Specific Heat of Gases

When the gas has been cooled to the dewpoint, water starts to condense, and the heat of evaporation emitted in this way must also be removed. If the condensed water quantity is ΔG_v kg/hr, and the heat of evaporation of the water at the temperature of interest is r kcal/kg, the equivalent heat quantity will be

$$\Phi_2 = \Delta G_v \cdot r \text{ kcal/hr} \tag{67}$$

The total heat quantity will then be the total of Φ_1 and Φ_2 according to Equations (66) and (67), which constitutes a rather complicated function. Figure 81 shows the total heat quantity that must be removed when cooling generator gas with various dewpoints.

The temperature difference between the gas and the air will be changing during the entire cooling process; therefore, the heating surface area must be calculated step by step, especially since the specific heat and the heat transfer coefficients also change with the temperature. When the dewpoint for the gas is reached, an especially radical change of the specific heat takes place, which then will include the heat of evaporation; the heat transfer coefficient at the gas side also changes considerably.

If we assume a constant specific heat and a constant heat transfer coefficient, which we may do for short intervals, we can mathematically calculate the relation between the cooling of the gas and the size of the heating surface; thus arriving at

$$\frac{t_{g_1} - t_{g_2}}{t_{g_1} - t} = 1 - e^{-\frac{kA}{Gc_p}} \tag{68}$$

In this formula the air temperature t_l is assumed to be constant.

The graph in Figure 98 shows the gas temperature calculated according to Equation (68), as a function of the cooling surface at various constant heat transfer coefficients. The gas flow is assumed to be 100 Nm^3/hr, and the specific heat is calculated assuming 0.3 kcal/Nm^3°C. Condensation is assumed not to have taken place. The air temperature is assumed to be a constant 20°C, corresponding to an infinitely great air quantity.

When water vapor is condensed, the process will be that shown in Figure 99, which has been calculated using the heat transfer coefficient 14 kcal/m^2hr, and the dewpoint of the gas assumed to be 40°C. For estimates we may assume that the total heat quantity that must be transported away during condensation in relation to the heat quantity without condensation is 15:1 at a dewpoint 50°C, 9:1 at 40°C, and 5:1 at 30°C.

Charcoal Gas Coolers

When it leaves the charcoal gas generator the gas has been cooled from approximately 800°C to 400-500°C mainly by radiation from the generator walls. Heat losses in the gas pipe leading from the generator are considerable, due to the high temperature near the generator (see Figure 96). Heat losses are increased by air convection, especially that due to vehicle motion which occurs in most mobile installations. Depending on the location of the generator and the length of the gas pipe leading to the engine, the amount of

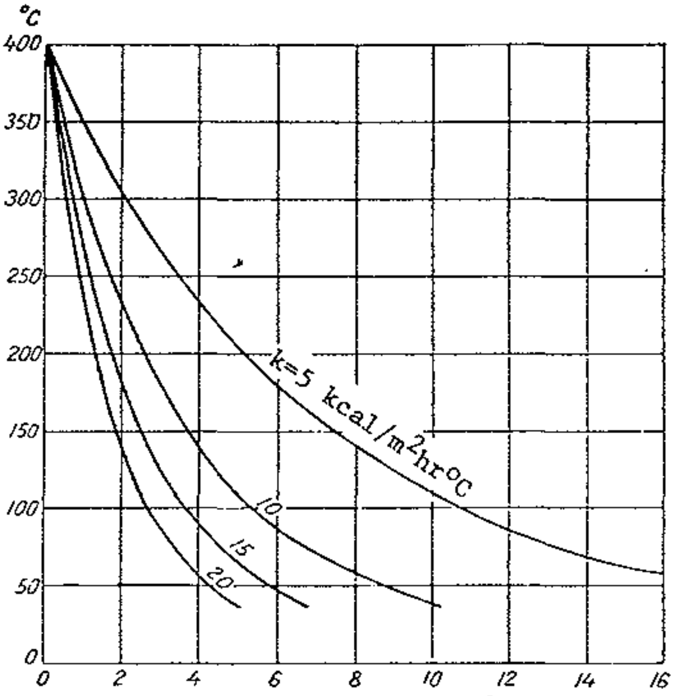


Figure 98. Cooling of 100 Nm^3/hr Generator Gas without Condensation at Various Heat Transfer Coefficients, Air Temperature 20°C (infinite air quantity)

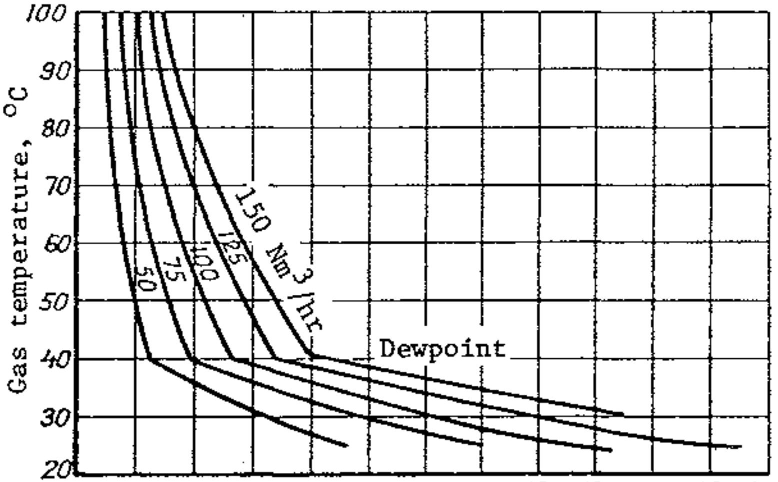


Figure 99. Generator Gas Cooling as a Function of the Cooling Surface at Various Generator Loads, Including Condensation of Water Vapor Below 40°C

cooling in the pipe may be sufficient, at least for small charcoal gas generators, so that a special cooler will not be necessary, particularly if the gas pipe is equipped with a suitable number of fins to increase the cooling surface.

For generators installed in the front of charcoal gas driven motor vehicles and for charcoal gas generators installed in special trailers, the cooling device will be rather simple, generally consisting of a suitable number of coiled pipes running horizontally over each other. The charcoal gas should not be cooled below 80°C to 90°C before entering a cloth cleaner, in order to safely prevent condensation of water vapor present in the gas. (When 10% moisture-content charcoal is used, the dewpoint is approximately 25°C-30°C, and for very wet charcoals 50°C-60°C.) Since the mechanical strength of most organic filter-cloth materials deteriorates (turns brittle) during periods of operation at temperatures above 120°C and are heat-damaged at temperatures exceeding 200°C, the cooling should be adapted to keep the temperature of the gas within an acceptable temperature range of 80°C to 120°C during a continuous load. This is made easier if the cooling surface can be regulated, for instance by shunts which are manually closed or opened for connecting or disconnecting appropriate parts of the cooling-pipe system. It can also be done automatically by a thermostat control (see Figure 169).

The cooling coils for cars are generally made of polished metal, which, apart from appearance, improves the heat transmission. Insulating dust formation on the pipes is prevented or more easily removed when the pipes are smooth and corrosion-free than when they are made of ordinary iron. (See Figure 94, which shows the considerable insulating effect of dust.) The nature of the pipe material in itself is, as mentioned earlier, of no practical importance for the heat transmission.

In the case of charcoal gas generators of relatively great capacity such as those for large trucks, buses, stationary engines, etc., a rather large cooling surface is generally required; this implies special cooling devices for speeding up the cooling process. For motor vehicles this is particularly true if the generator must be insulated (for instance, between wood walls behind the driving compartment) and the cooling by radiation is considerably decreased. Such coolers are generally of a flange, plate, or pipe type and their placement depends upon considerations of space, availability of wind, etc. (see more details in Chapter 6). Earlier, so-called baffle-plate coolers were used for charcoal gas driven car generators, at the same time serving as dust separators (i.e., gas cleaners). They consisted of sheet iron pipes with a diameter of approximately 200 mm, with perforated transverse walls fixed inside some distance from each other (Figure 100). When these devices were used for wood gas operation, where considerable quantities of condensation water are formed, they were designed for condensation cleaning with a container and water draincock, etc. In charcoal gas generators, their cleaning function was gradually replaced by cyclone and cloth filters, and the cooling function by the less bulky pipe cooler. Also, in wood gas generators this type of cooling cleaner has largely been replaced by more efficient devices.

For both wood and charcoal stationary gas generators a finned cooler was sometimes used, where the effect of the air convection could be magnified by spraying water from the outside, when running water or a water pump was available (Figure 101). However, cooling fins for gas coolers in stationary operation are not always favorable. When there is no wind they obstruct the rising air flow created by the heat if they are horizontal, and insulating dust layers are frequently collected between the fins.

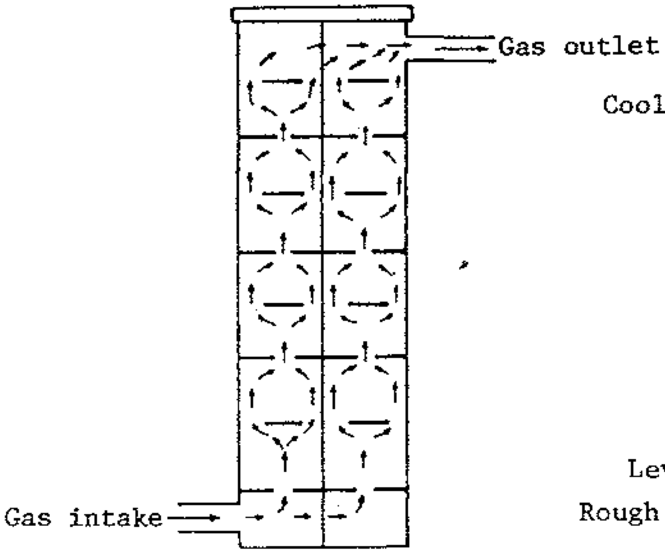


Figure 100. Schematic of a Baffle-Plate Cleaner and Cooler.

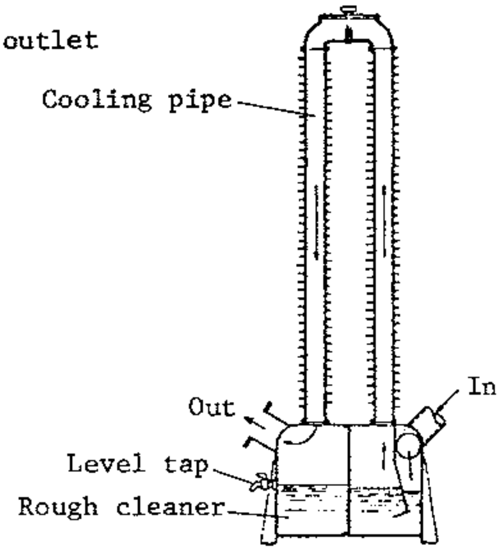


Figure 101. Fin Cooler. (May also be arranged with water being sprayed from the outside)

Wood Gas Coolers

The gas leaving a wood gas generator has been cooled to 300°C to 400°C by radiation from the generator and, in some designs also by utilization of the surplus heat of the wood gas for preheating the wood supply or the primary air. Moreover, in this case the strong radiation in the first part of the gas pipe is magnified by air convection. As opposed to charcoal gas, wood gas contains a significantly greater quantity of water vapor with a correspondingly higher dewpoint. When the gas temperature has dropped to the dewpoint, a significantly greater cooling effect is required for the same temperature decrease as shown earlier (compare Figures 81 and 99); therefore, the cooling surface of a wood gas generator will be correspondingly larger than that of a charcoal gas generator for the same gas flow.

For wood gas, cooling in most cases is combined with cleaning the gas including dust separation and water evaporation. These cooling-cleaners in wood gas generators will be discussed in connection with gas cleaning, since this function is included in the various designs.

Design and Shape of Generator Gas Cleaners

General Discussion

Gas that has been cleaned is, on the whole, free from tar when it leaves the gas generator. It is also free from substances that are harmful to motor operation and that can be separated or neutralized only chemically. The function of the gas cleaning is then to mechanically separate solid dust particles in the gas. Additionally, in the case of wood gas, as large a quantity of water as possible must be condensed by cooling. The cooling must be more extensive than with charcoal gas because the secondary air otherwise may cause condensation, when the wood gas is cooled to approximately 40°C before the mixer. As pointed out in the preceding section, deposition of solid dust particles takes place with condensation of the water vapor. If such a dust deposit is formed past the ordinary cleaners, the sludge will have a smell similar to tar from harmless phenols occurring with the gas, but tar deposits will not occur in the conduits to the engine. Possible tar mists, rarely exceeding 0.5 g/m^3 at the gas outlet, are practically always rendered harmless in the system's cleaner.

Separation of solid dust from the generator gas is principally accomplished in the ways described below; it should be noted that, in practice, the dust separation is accomplished by using several cleaning mechanisms at the same time. The cleaner frequently receives its designation from the intended main mechanism for each design.

a. By Weight of the Dust Itself

At a low gas velocity large and heavy dust particles are not readily carried along by the gas flow, but sink to the bottom due to their weight.

b. By Inertial Effects of the Dust Particles

In the case of rotation or change in direction of the gas flow, some dust particles may be thrown out of reach of the captivating force of the gas flow due to the effect of inertial forces. Cyclone cleaners work according to this principle.

c. By Absorbtion and Adhesion

Adhesion of dust particles to immobile surfaces (e.g., the walls of the cleaner, filter material, etc.), as well as to each other, so that bigger and heavier particles are formed, is important in all cleaning devices. The larger the total friction or contact surface for the gas during its flow, the larger quantity of dust is separated. Dry ashes in themselves have little adhesion, which is the reason that moistening them with water or oil greatly improves the cleaning effect. A delayed flow is also thought to provide time for finer dust particles to lose their electric charge, thus making possible their combining to form bigger dust grains that are more easily precipitated mechanically.

d. Washing

Ordinary air cleaners for automobiles use oil, which is considerably more efficient than water in separating and retaining the dust. However, oil cleaning is not commonly used for generator gas cleaning, although FM charcoal gas generators and "Olso" wood gas generators (Figure 102) use this method. When generator gas bubbles through a water layer, a rather small cleaning effect is obtained. Moderately moistened dust easily sticks together and does not whirl up so easily with the gas flow; therefore, a small water supply in the bottom of the coarse cleaner is frequently used to retain the dust. One advantage of water-washed walls in the gas stream is that heat transfer is frequently increased in this way. Also, water, since it splashes back and forth, seem to separate some dust in the gas through a direct impact effect. This has been proven empirically. In scrub cleaners both gas and filter materials (coke, etc.), are showered with water (see Figure 108).

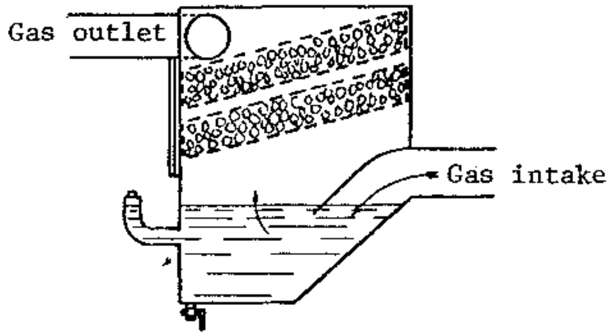


Figure 102. Oil Filter for Generator Gas Cleaning ("Olso" wood gas generator)

e. Condensation

The water vapor of the gas is, to a large extent, condensed with the dust particles as condensation nuclei. The dust is then precipitated together with the water and forms sludge. In order to achieve a good cleaning effect, intense cooling and relatively high gas temperature are required before the gas enters the cooler.

f. Filtering Through Cloths of Organic Material

Here a direct separation takes place through the fine mesh of the filter, which only lets through dust particles below a certain size (1-0.5 μ). As a rule, fabric of cotton, linen, etc., is used, but also cellulose fabric has proved to be useful. Recently, some products from the wallboard industry have exhibited good filtering properties. For cloth cleaning the temperatures must be above the dewpoint, and rather frequent manual cleaning of the filter is required, generally by compressed air.

g. Separation in a High-Voltage Electric Field

This procedure (the Cottrell method) is based upon the fact that dust particles (also tar) in a rectified high-voltage electric field migrate from the negative electrode to the grounded positive electrode and are deposited there. The original Cottrell method requires very high voltages (approximately 40,000-60,000 V). In more recent devices for lower voltages (approximately 15,000 V) the dust goes from the positive to the negative electrode. This device involves some consumption of electricity.

Cleaner Designs

Gas Supplies. The lower part of the gas generator has a large flow area, which gives the gas a low velocity. In this way most of the big dust particles are separated and fall down into the ash bin because of their weight. (In wood gas generators the charcoal or porous concrete beds also have the effect of filters.) In some cases there are cleaners specifically designed according to this principle; in these, the gas velocity is alternately decreased and increased (for instance, using baffle-plate cleaners). Such gas stores are, however, not always to the advantage of motor operation, since they may cause deviations from the proper mixing proportion of gas/air in case of changes in load. The cleaning effect of such a device hardly compensates for this disadvantage. However, the principle is applied intentionally to most cleaners with a relatively large volume.

Centrifugal or Cyclone Cleaners. In cyclone cleaners the gas is supplied tangentially in the cylindrical upper part of the cleaner. In the center of the cleaner is a "driving pipe"; the gas is first forced down into the cleaner, then sucked upward by this pipe. Three forces in the cyclone affect the dust particles in the gas: the frictional force of the gas in its flow direction; the centrifugal force when the gas being taken in tangentially is forced to spiral down into the cleaner; and finally the force of gravity. The frictional force of the gas and the centrifugal force increase when the gas flow approaches the center of the cleaner where the outlet is located, but the centrifugal force increases faster. Since these forces counterbalance each other, dust no longer flows in spirals but in concentric circles (Figure 103); the force of gravity makes the dust particles fall down to the ashbin in the bottom of the cleaner, out of reach of the gas flow. In fact the process is even more complicated because, among other things, double whirls are formed which to a large extent interfere with the dust separation. The degree of separation depends up the size of the dust particles, or really upon their rate of fall. Coarse particles are more easily separated than fine ones.

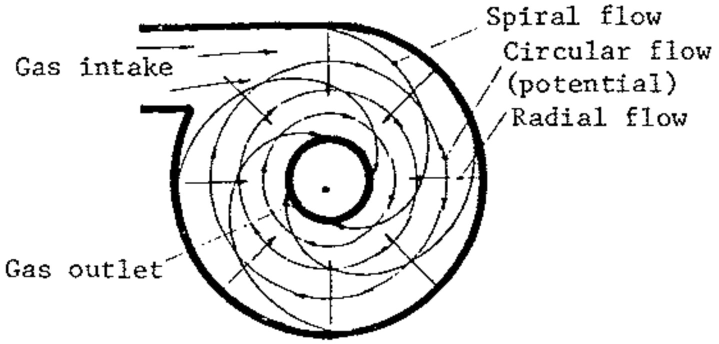
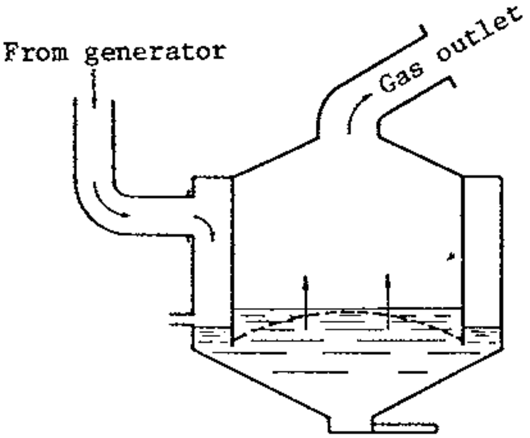


Figure. 103 Flow in a Cyclone Cleaner for Generator Gas.

The gas velocity has the following effect: at first the degree of separation increases with increasing velocity until a maximum value is reached, after which the degree of separation decreases again with further increase of the gas velocity. The dust content of the gas has a minor effect on the degree of separation. In addition, changes in load temporarily affect the dust quantity and dust size, which makes the cleaning function somewhat unpredictable. However, well-designed cyclone cleaners have demonstrated extraordinarily good dust-separating properties; according to practical experiences approximately 80% separation ability may be expected, in which, as mentioned above, the particularly large and heavy dust particles are separated.

Cyclone cleaners are generally of a dry type. Some moisture may be of advantage, however, in preventing precipitated ashes from whirling up. There are also wet cyclone cleaners (working with water), for instance in the wood gas generators produced by the Swedish Fan Factory, Inc. (Figure 104). A couple of common dry cyclones are shown in Figures 105 and 106. Some cyclones are also equipped with control valves used to keep the gas velocity at the inlet as constant as possible. In order to obtain a high gas velocity, the cyclone should be placed fairly close to the generator, so that the temperature of the gas will be high and its volume relatively great. In order to obtain as great cleaning effect as possible, the cleaner and its ashbin must be absolutely tight, which is the reason that the ash-emptying ports must be carefully sealed.



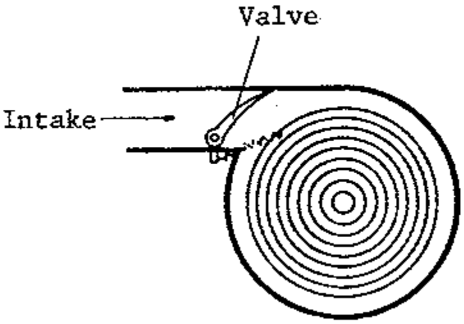


Figure 104. Wet Cyclone for a Wood Gas Generator. (The Swedish Fan Factory, Inc.).

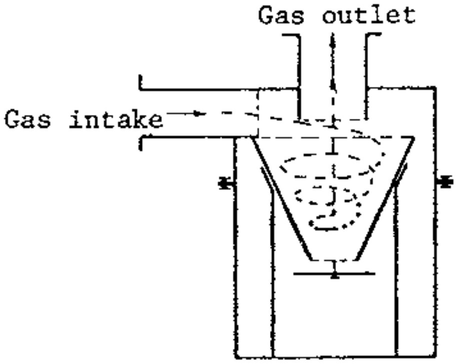


Figure 105. Cyclone Cleaner for a Gas Generator.

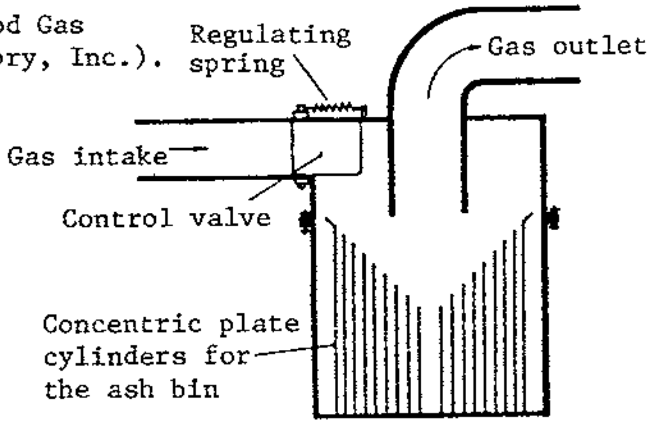


Figure 106. Cyclone Cleaner for a Gas Generator. (Note the control valve)(Enkiping's Works, Inc.)

Volume Filters (Adsorption or "Fine Cleaners"). In these gas cleaners, the weight of dust particles and their inertial forces (determined by velocity, weight, and direction of movement) act together with outer resistance forces; the resulting bumps or friction against surfaces, corners, and edges separate the particles from the gas flow. To store the separated particles away from the flow, dust containers are provided with a filtering layer made of suitably sized pieces and bits (preferably of reasonably homogeneous size and shape) of "raschig-rings"*, coke, pebbles, porous concrete, cork, glass, steel, or wood wool, etc., through which the gas must pass. Zigzagging through the filter mass, the gas is subject to bumps, friction, change of direction, change of velocity, etc. In this case too, some moisture content of the mass helps to retain the dust.

In a wood gas generator sufficient moisture is obtained through water condensation of the gas, since the voluminous cleaners bring about considerable cooling. In such cases a container with a drain cock for the condensed water is needed. The most common cleaner of this type for motor vehicles is the cork cleaner, filled with bits of cork. Wood

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*Rings made of ceramic pipes.

wool is also used; this material, however, lumps together during heavy condensation, and is hardly suitable. These types of cleaners require periodic cleaning, which should be done by flushing with water. A few common designs are shown schematically in Figure 107. The cleaners must, of course, be arranged so that the gas cannot take a short cut past the filter mass.

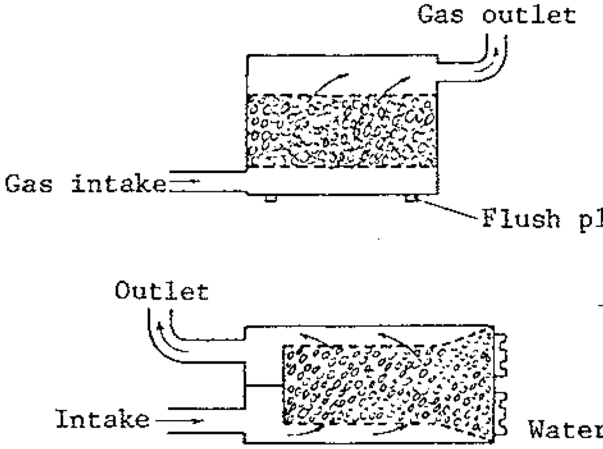


Figure 107. Schematic of Cork Cleaner for Wood Gas Operation.

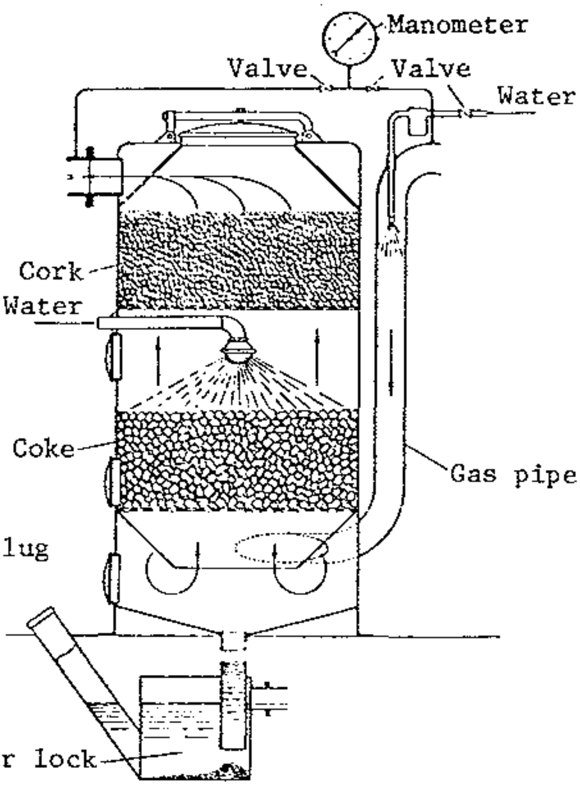


Figure 108. Scrubber Cleaner (Swedish Generator Gas Co.)

Scrubber Cleaners. Cleaners for generator-driven boats and stationary engines frequently use water supplied by gravity or by a water pump. A scrubber, often used in such cases, is at the same time a cooler and coarse and fine cleaner. Figure 108 shows a design used to a fairly large extent in Sweden for pulsator-driven motorboats and ships. It consists of a tall cylindrical container, horizontally divided by two perforated wall partitions into three chambers. The lower chamber is a wet cyclone, equipped with a gas inlet and a bottom drain with a water lock for the cooling and cleaning water. From here gas is sucked up into the middle chamber which is partially filled with coke, raschig-rings (rings made of ceramic pipes), etc. The filter layer is flushed from above, with water from a pipe entering through the chamber wall. In this way, not only effective cooling is achieved but also direct washing of the gas as well as cleaning of the filter pieces. From here the gas is sucked further up through a layer of cork in the top chamber, and from there to the gas outlet to the engine. In the feed line for the gas to the scrubber is another water inlet whereby the gas and the pipe walls are sprayed. This enhances both cooling and cleaning, since heat transmission is improved by wet walls and since, in addition, the water washes out some dust. Scrubber type cleaners are mainly used in cases where water is available and when weight and size are of little importance.

Condensation Cleaners (Wet Cleaners). As mentioned in connection with wood gas coolers, in some cases baffle-plate coolers are also used for cleaning. (Figure 109 shows such a device for a truck. Compare with Figure 100.) For this purpose, the cooler is equipped at the bottom with a sufficiently large condensation-water container with a drain cock.

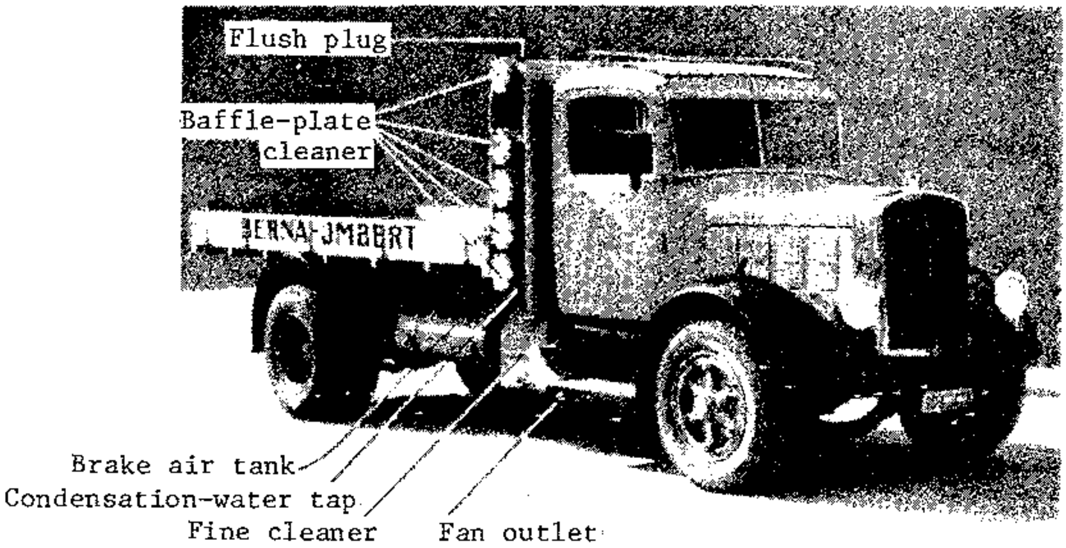


Figure 109. Baffle-Plate Cleaner, Placed Behind the Driver's Cab of a Truck.

For motor vehicles, however, condensation coolers and cleaners of a different type are generally used, and are preferably placed in front of the ordinary motor radiator of the vehicle (Figures 110 and 111). The water necessary for cleaning is obtained through condensation of the water vapor in the wood gas. After draining and cleaning, some water should be added, as a rule, so that the cleaner can function properly from the start. This device consists of an ordinary pipe cooler, connected with and placed above a relatively spacious condensation-water container, which is divided in two chambers by a partition wall. One chamber is connected with the gas inlet and the other with the gas outlet.

Thus, the gas passes from the inlet up into the cooler and from there down into the outlet. Since the gas, when entering, is relatively warm and is intensely cooled, a significant amount of water is condensed. This water runs down along the inside of the cooler pipes to the container. During operation, the water splashes, thereby effecting a significant cleaning. The condensation water carries the precipitated dust down to the container. This type of cleaner requires a subsequent dry fine-cleaner, usually consisting of the cork cleaner previously described. Sometimes the cork cleaner is built together with the water container of the condensation cleaner (Figure 110). During the later generator gas epoch cloth cleaners were used instead of cork cleaners--in some cases even placed

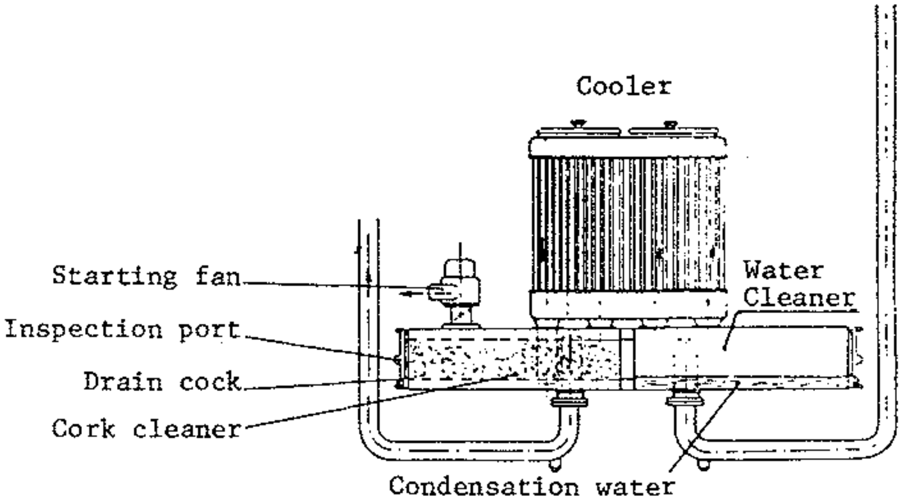


Figure 110. Condensation Cleaner and Cooler (Hesselman Motor Corporation)

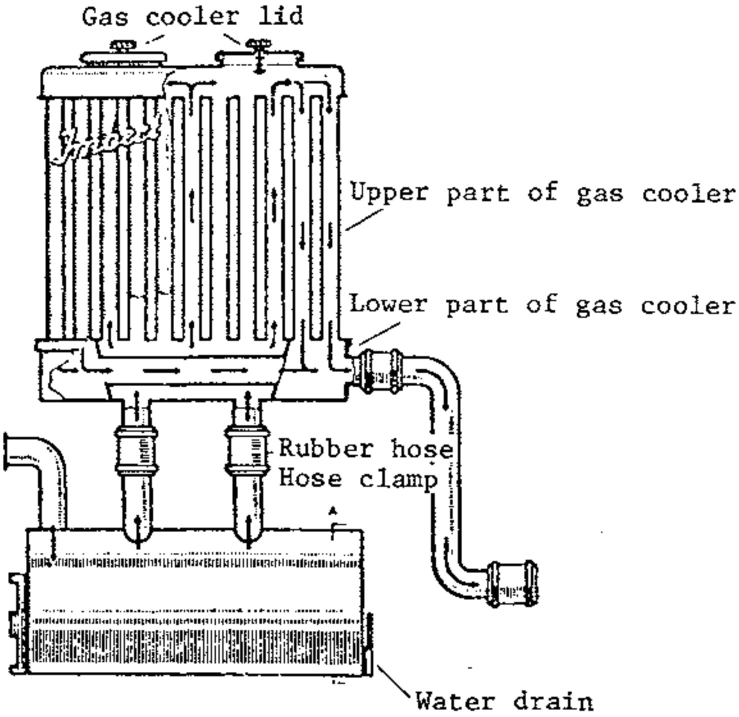


Figure 111. Imbert Condensation Cleaner and Cooler

before the condensation cooler—with, however, varying results. The cloth cleaner is no doubt the most efficient device for fine cleaning; but for wood gas, extensive safety precautions against condensation-water precipitation are necessary. The wet cleaners have proven very efficient for motor vehicles with wood gas operation and they are nearly indispensable. Even better results could be attained if the dimensions and temperatures were properly adapted—which frequently was not the case during the generator gas epoch.

Cloth Filters. Filters in which the gas must pass through fine-meshed "nets" of organic materials, for instance fabric cloths (cotton, linen, rayon, etc.), have proven to be extraordinarily effective for the relatively water-free charcoal gas. In practice, however, they should be preceded by rough cleaners, such as cyclones, to separate the large particles which may mechanically harm the cloth filters, before they enter the cleaner (in particular, glowing particles must be prevented from coming into contact with the cloths). Rough cleaners also reduce the total soot quantity, which at the gas outlet in the generator is approximately 5 g/m^3. The cyclone cleaner removes approximately 80% of the soot so the cloth cleaner has to separate most of the remaining approximately 1000 mg/m^3. A cyclone cleaner before the cloth cleaner, of course, makes it easier to clean the cloth cleaner, but the resulting gas cleaning will be somewhat worse than if only a cloth cleaner is used; as a matter of fact, motor wear has been less with the use of only a cloth cleaner than in combination with a cyclone. This seems to be due to the fact that the fine dust is more efficiently separated when it is mixed with coarser dust. In spite of this disadvantage it has, for the reasons mentioned, been proven advisable to connect a cyclone cleaner before the cloth cleaner.

The cloth cleaner used in connection with such rough cleaners must be manually cleaned fairly frequently to remove the collected ashes. This work, which can only be done manually, in addition to the sensitivity of the cloth cleaner to moisture and temperatures above 120°C, constitutes the greatest disadvantage of this otherwise extraordinarily effective cleaner. Due to the great risks of damaged cleaner cloths, cloth cleaners must always be combined with safety filters. To reduce the drop in pressure with cleaners of this kinds, their volume is made fairly large. With various designs, however, it has been possible to get a large filter surface although the outer dimensions are comparatively small. The filter cloths are then arranged in a great number of discs, sacks, concentric cylinders, pleated cylinders with a star-shaped cross section and even in accordion shape, etc. (see Figure 112). In the design, the effect of pressure variations upon the cloths must be carefully taken into account so that they do not press against each other or against the cleaner walls, when pressure changes take place in the cleaner. Other considerations such as accessibility and exchangeability of the cloths, protection against mechanical damage, sealing outward, the simplest possible cleaning of the cloths, employment of ashbins, etc., are also important. The dust separated by the cloths should automatically fall down into the ashbin through the "breathing" of the filter during operation. The filter cloths are frequently placed on a common framework so that they may be removed for cleaning all at one time. A supply of compressed air is, as a rule, necessary for the manual cleaning which must be done periodically.

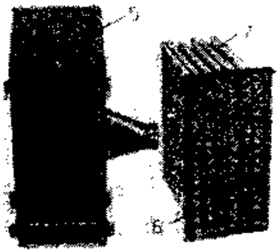


Figure 112. Cloth cleaner

When cloth cleaners are used it is advisable, especially during intermittent operation, to employ an adjustable cooling of the gas before it is sucked into the cleaner. This may be done by an arrangement of shunts, which, when necessary disconnect or connect certain radiators. The adjustment may be done manually—possibly with the aid of a remote reading thermometer—or automatically with a thermostat. (See Figure 169, Chapter 6.)

In order to make the cloth cleaner safer in operation, many special designs have been developed especially to make their use possible for the moisture-saturated wood gas. In order to use cloth cleaners in this case, the wood gas should have its dewpoint reduced by cooling and water condensation followed by subsequent heating, so that there is no risk of having the cloths get wet. Placing the cloth cleaners near the wood gas generator in order to obtain a high temperature, thus preventing water condensation on the cloths, does not eliminate the risk of their getting wet when cooling takes place during a short interruption of operation or during intermittent operation. The acceptable temperature range for cloth filters, when charcoal gas is used, is 80°C to 120°C, as mentioned earlier. These limits, which are already narrow, will be considerably narrower in the case of wood gas operation, since the dewpoint is considerably higher than for charcoal gas operation; this fact makes satisfactory operation impossible without the special measures mentioned above. When calculating the temperature conditions for the cloth filter for a wood gas generator, we must allow not only for continuous operation but also for stopping or idling. Great post-condensation of the wood gas is common. In this case, it may be advisable to place a precondensor in the generator, as has been tested by the Army. The device shown in Figure 89D would seem to be correct in principle. It shows a wood gas generator with, in consecutive order; a cyclone cleaner, a condensation or wet cleaner, heating of the cooled gas by exhaust heat of the engine, and a cloth filter. After the cloth cleaner, a simple cooler may be added, to obtain a more suitable gas temperature. The latter cooler would not seem to be necessary, however, during most of the year, since the secondary air, which constitutes about half of the gas mixture, has a low temperature due to Sweden's latitude, so that the temperature of the gas leaving the cloth cleaner is reduced.

In tests undertaken by Statens Vattenfallsverk in 1944 on a wood gas driven car with cloth cleaning (Figures 113 and 114), the results were good from the viewpoint of cleaning, which was to be expected, but poorer in maximum power and maintenance requirements, in comparison with ordinary devices (cork cleaners) for wood gas generators. As for Figure 114, where the cleaner, which in the other case was built onto a cyclone cleaner, was placed near the generator, the heat conditions will probably not be good for the durability of the cloths. The use of cloth cleaners in wood gas operation has not reached its final development—as well as gas cleaning on the whole—but it seems to have good prospects. (The experiences from these tests are discussed in more detail in Chapter 10.)

Electrofilters. Figures 115 and 116 show a schematic for Lurgi electrofilters. The necessary direct current high voltage is obtained in three stages. First, an alternating-current generator is operated with the help of direct current obtained from the car battery, after which the eight volt alternating current obtained in this way is stepped up to 15,000 volts, and finally is transformed again into direct current by a mechanical rectifier placed on the common shaft. The cleaner itself (Figure 116) consists of three main parts: a dry filter in the lower part; above that, in the center part, an electrofilter composed of

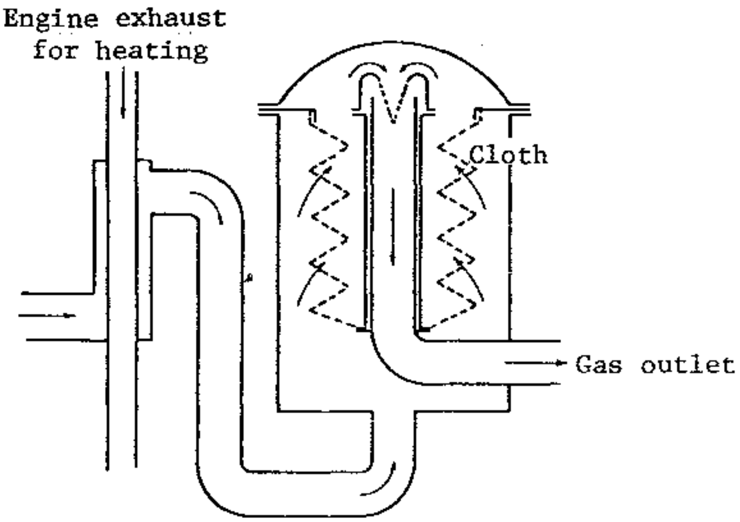


Figure 113. Cloth Cleaner Proceeded by an Engine Exhaust Gas Heater. (The cloth cleaner is placed after the wet cleaner)

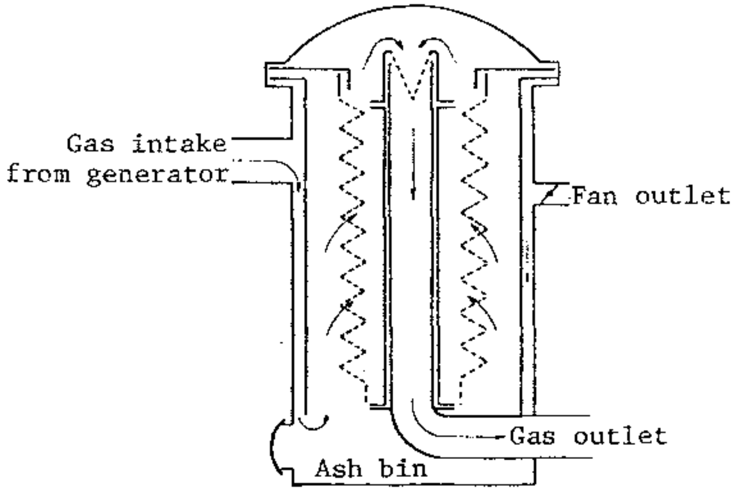


Figure 114. Cloth Cleaner Combined with a Cyclone Cleaner and Placed Immediately After the Generator.

concentric plate cylinders; and in the upper part a heating device to which heat is supplied from the exhaust gases of the engine. The electrofilter consists of two vertical electrode cylinders and three insulated hanging electrode cylinders, the latter positive and the former negative and grounded. As with cloth filters, this filter must be combined with a safety filter because of interruptions of service, in this case by flash-overs etc. The dry filter in the lower part may consist of raschig-rings and in the bottom there is a certain quantity of water to moisten the ashes and prevent them from whirling. The filter must be taken apart and cleaned after 8 to 50 hours of operation, depending upon the fuel. The filter involves a rather small pressure drop. It even separates drops of tar and is, under normal circumstances, more efficient in dust separation (below 0.5μ) than cloth filters. The current consumption is, according to reports, approximately 140 W.

However, the filter is expensive to procure and to use and it would seem to be subject to interruptions of service.

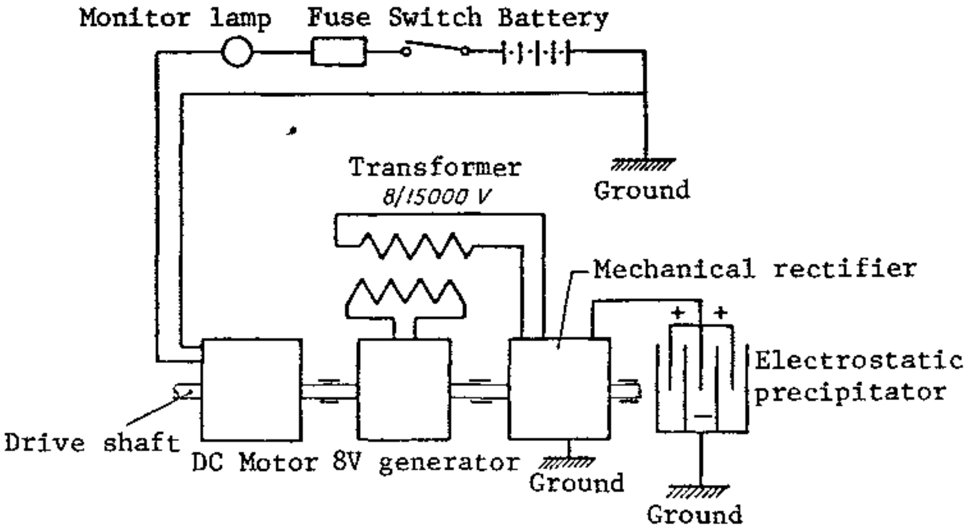


Figure 115. Schematic of an Electrofilter for Generator Gas Operation (Lurgi System)

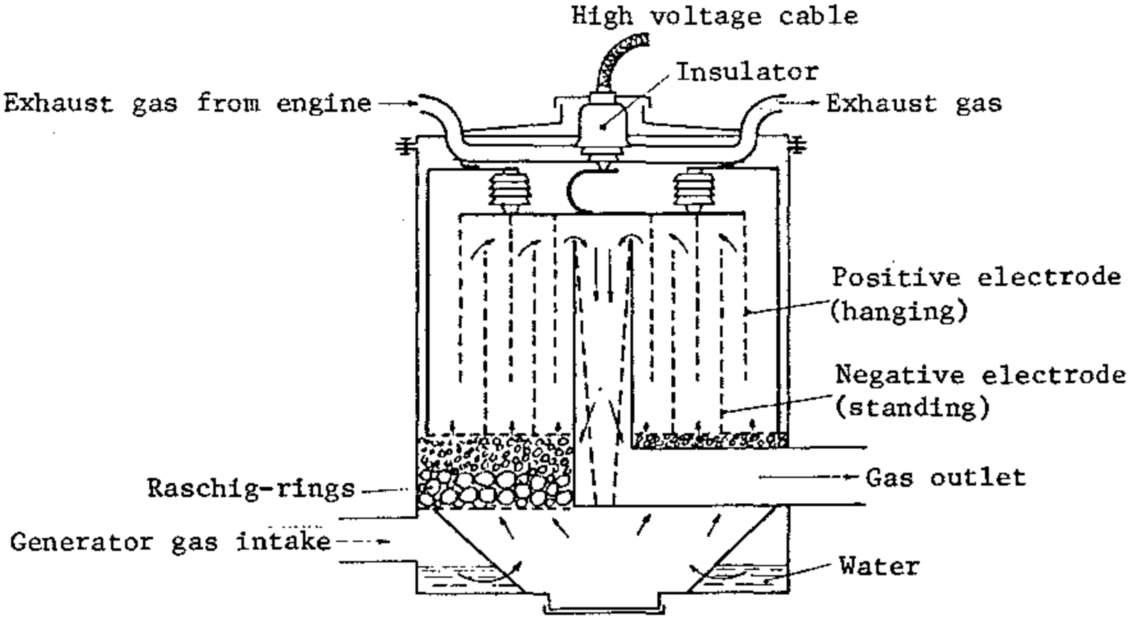


Figure 116. Schematic of the Electrostatic Precipitator Shown in Figure 115.

Chapter 6

ADAPTATION OF GAS GENERATOR FOR MOTOR OPERATION

When generator gas is to be used for the operation of combustion engines it must be thoroughly cleaned, and cooled to a temperature appropriate for filling the engine cylinder. The engines suitable for generator gas operation, with power output usually less than 200 hp, are extraordinarily heterogeneous not only in design, operating conditions, and size, but also in application and how they are installed. Mobile engines especially have been built to fit into vehicle chassis, boats, etc., in the most practical way, carefully utilizing the space and giving the best weight distribution; therefore, a relatively heavy and bulky gas generator installed with cleaner, cooler, piping, etc., must create various difficulties. The gas generator must be adapted to minimize such difficulties, while at the same time supplying the greatest possible power with high reliability. In addition, the installation must provide easy accessibility for service and repair.

This adaptation may be done according to the following guidelines.

1. Adaptation to the maximum size and variation of the gas need.
2. Adaptation to the way in which the engines are installed and used.
3. Adaptation for starting, increased reliability, control of operation, service, etc.
4. Adaptation to minimize fire hazard and carbon monoxide hazard.

The last point is discussed further in Chapter 8, "Installation of Gas Generator" in connection with relevant regulations.

The varying nature of motor operation has been a great obstacle to standardization efforts in the production of gas generators. A more extensive standardization of the generator gas field would have involved considerable front-end costs, which were not incurred due to the more or less temporary nature of the generator gas operation. To the extent that large and well-equipped business firms, including several large car and engine manufacturers, produced gas generators, the conditions of standardization were improved; the technical control exercised by the authorities contributed to this.

Adaptation of Gas Generators to the Engine's Gas Requirement

The maximum gas requirement of the engine is determined by its cylinder volume and its maximum rpm. About half of the sucked-in gas/air mixture may be considered, on an average, to be generator gas. Due to the relatively low heat value of generator gas, it is of the utmost importance that the capacity of the gas generator be adapted to the gas requirements of the engine, so that as great a volumetric efficiency as possible is obtained with a satisfactory gas quality. The need for great maximum power is especially pronounced in trucks, tractors, power tools, etc. These two factors are to some extent independent. An oversized gas generator (that is, the flow areas of the generator) causes little drop in pressure and consequently good cylinder filling for the engine, but the gas quality may be poorer because the reaction temperature in the generator hearth will be insufficient at the low gas velocities caused by the large flow areas. On the other hand, an undersized gas generator, which is chiefly characterized by too small a hearth area, results in good gas quality as a rule, but frequently also in constriction of the gas flow and consequently a drop in pressure and reduced maximum power of the engine. The gas temperature in the generator may, in such cases, sometimes become so high that vital parts of the generator are burned; also, the increased gas velocity may increase the ash content of the gas produced to such an extent that the cleaning system is not able to fulfill its function.

As shown in Chapter 4, "Shape and Design of the Gas Generator," the suitability of the generator depends to a considerable degree upon its adaptability to variations in the gas requirements during operation. This elasticity of the generator should be automatic, although a manual adjustment of the gas generator could be conceivable if operation is characterized by only two pronounced engine load conditions (full load and no-load), which is the case for some working machines such as fishing boats.

The automatic adaptability of the generator for varying loads is of the utmost importance for most mobile engines, which run under constant conditions only for short periods of time. This elasticity of the generator is usually expressed as the relation between the largest and the smallest hearth load of the generator (Nm^3/hr per cm^2 of the smallest hearth area) at which the gas velocity, according to experience, provides a satisfactory gas quality and pressure for the engine, and at loads which the generator can maintain continuously. This is of particularly great importance for wood gas generators, where a low specific hearth load may cause tar formation problems. Frequently, the rather great moisture content causes a temperature reduction in the hearth, so that the gas quality is lowered and the risk of tar formation is increased if the temperature is not kept high by a relatively high gas velocity. For wood gas generators of an ordinary design (Imbert types), the values 1.2 and 0.3 for maximum and minimum hearth load have been found to be suitable. These values give a ratio of 4 as an expression of the elasticity of the generator. We may assume that the hearth load, which really is an expression for the gas velocity, corresponds approximately to the number of revolutions of the engine. Thus, the ratio of 4 denotes the approximate relation between the greatest and the smallest number of revolutions of the engine during operation. It appears that this figure, especially for car engines, should be at least twice as large in order to attain fully satisfactory intermittent operation. As shown in Chapter 4, with a special hearth design equipped with a V-hearth, about 0.9 maximum and 0.05 Nm^3/cm^2hr minimum hearth load was obtained during 8-hour tests, corresponding to a value of approximately 18 for the elasticity of the generator. This would seem to indictate that adequately designed wood gas generators may attain a fully satisfactory automatic adaptability for variable operating conditions. Continuous evaporation of wood moisture in the generator's fuel storage (e.g., by a monorator or other similar design) would further improve the idling ability of the wood generator. The idea that, due to the type of fuel, charcoal gas generators are in principle more suitable for intermittent operation than adequately designed wood gas generators cannot be considered founded on fact. On the other hand, gas generators operated with small charcoal lumps or charcoal dust have great advantages due to their lesser weight and dimensions, when built into small cars and motorcycles; also, the small grain size of the fuel gives a large reaction surface and, consequently, greater reaction ability than is the case for wood gas generators and charcoal gas generators for large size charcoal.

The design of ordinary wood gas generators makes it very important to carefully adapt the minimum hearth area to the operating conditions of the engine. In the beginning the generators were designed in a few sizes, with the size almost always given by the outer diameter of the generator level with the air intake. A single minimum hearth area corresponded to each size. Practical experience, however, soon forced the manufacturers to produce a whole series of hearth sizes for each generator size. Since the hearths were worn out much faster during operation than other parts of the generator, the designers tried to facilitate hearth exchange by special devices (Figure 117). In this way, several small industries came into existence for production of replacement hearths with or without an air intake, intended for exchange. These did not always contribute to the quality of the spare parts. In the exchange, however, an improved adaptation to the operating conditions of the engine could frequently be obtained. The exchange, however, required welding and other kinds of garage work, frequently causing inconveniently long interruptions for operating the vehicle. The V-hearth, mentioned earlier, was in this respect a significant improvement, since the adaptation could be done in a few minutes by exchanging a cast-iron ring in the hearth (Figure 118).

Table 31 lists the most common sizes of generators. Some standardization is also indicated.

Table 31. DIMENSIONS OF GAS GENERATORS

Make	Model Designation	Height mm	Outside Dimension mm	Inner Diameter of Hearth mm	Fuel Volume hL	Comments
Charcoal gas						
Swedlund system:						
Hagglund & Sons	K-5-L	1800	550^a	275	3.0	
"	(K-6-L)	1855	550^a	290	3.0	
"	K-7-L	1905	590^a	310	3.5	
"	K-8-L	1960	660^a	320	4.3	
Generator Gas Co.	S-5	1588	460^a	275	2.00	
"	S-6	1642	525^a	275	2.75	
"	S-7	1677	570^a	275	3.25	
"	S-8	1950	655^a	385	4.30	
Wood gas						
Hesselman:.	50/13	1850	500^b	130	2.0	charcoal bed excluded
"	55/15	1850	550^b	150	2.7	" "
Bolinder/Trim:.	13/50	1850	500^b	130	2.0	" "
"	15/55	1850	550^b	150	2.7	" "
"	17/55	1850	550^b	170	2.7	" " (at a heavy load)
"	17/75	2330	750^b	170	6.0	charcoal bed excluded (bus motors)
"	17/75	1600	750^b	170	3.2	
Imbert:						
Wulf & Co..	130/550/170	1700	550^b	130	2.4	charcoal bed excluded
"	150/550/170	1700	550^b	150	2.4	" "
"	150/650/210	2100	650^b	150	3.4	" "
"	170/650/210	2100	650^b	170	3.4	" "

^{a}Square
^{b}Cross section

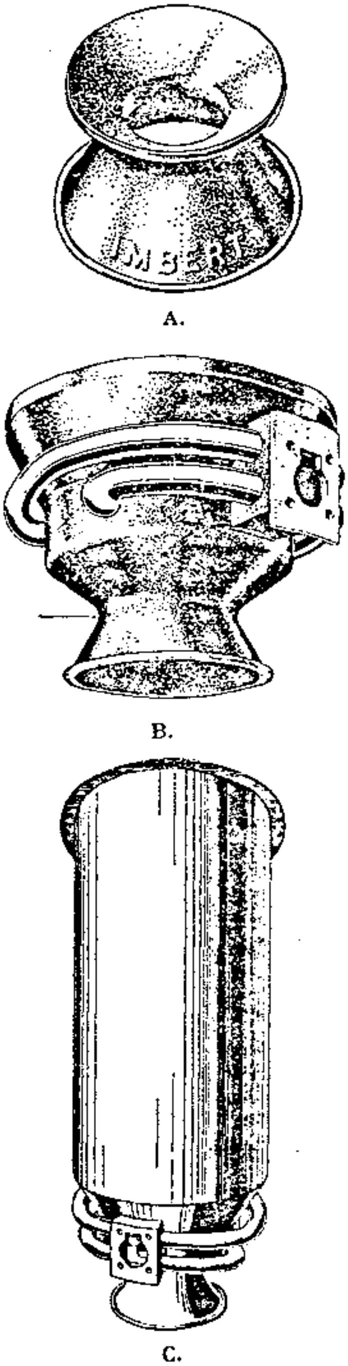


Figure 117. Spare Parts for for an Imbert-Type Wood Gas Generator.
A. Hearth cone of alloyed cast steel.
B. Hearth cone with air intake and charring cone to be connected to the inner mantle.
C. Complete inner mantle with hearth and air intake.

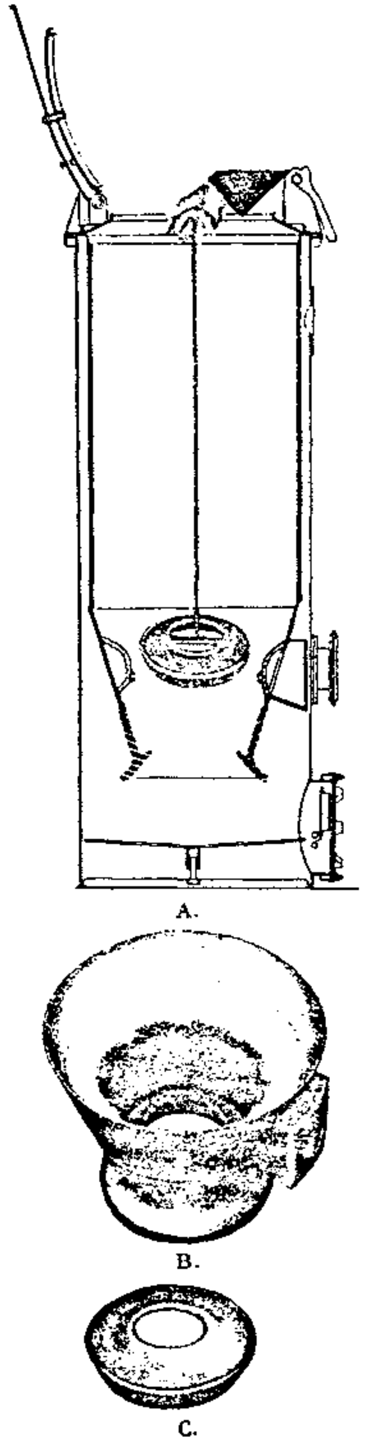


Figure 118. Wood Gas Hearth with Replaceable Hearth Ring and Automatic Ash Insulation (V-Hearth).
A. Changing the hearth ring.
B. Complete hearth with primary air intake and a hearth ring placed inside.
C. Hearth ring (cast iron).

Table 32, taken from a gas generator catalogue for Scania-Vabis, 1942, shows the sizes of gas generators on the market for the various engine types of the car manufacturers.

Table 32. THE SIZE OF GAS GENERATORS FOR VARIOUS TYPES OF ENGINES

Engine						Generator Model Designation				
						Charcoal Gas		Wood Gas		
Type No.	Number of Cylinders	Cylinder Dimensions mm	Cylinder Volume, Litre	Maximum Generator Gas Needed at 2300 rpm, L/sec	Power with Gasoline Operation, Hp	Gas Generator Co.	Hagglund & Sons, Inc.	Bolinder	Hesselman	Imbert
401	4	110 X 136	5.17	50	80	S-5	K-5	13/50	50/13	130/500/170
1664	6	110 X 136	7.75	75	130	S-7	K-7	15/55	55/15	150/550/170
16641	6	110 X 136	7.75	75	130	S-7	K-7	15/55	55/15	150/550/170
601	6	110 X 136	7.75	75	130	S-7	K-7	15/55	55/15	150/550/170
801	8	110 X 136	10.34	100	180	S-8	K-8	--	--	170/650/210

Note: At a heavy load, 170 mm cross section should be used instead of 150 mm cross section.

Table 33 lists smaller types of wood gas generators for passenger cars, etc.

Table 33. WOOD GAS GENERATORS AND HEARTH SIZES FOR PASSENGER CARS

Generator Size Outer Diameter at Air Intake	Bore Diameter of the Hearth
400 mm	60 mm
400 mm	70 mm
450 mm	70 mm
450 mm	80 mm

As indicated by the type designations in Tables 31 to 33, the outer diameter of the generator at the air intake, the diameter of the hearth for the gas flow through, and sometimes the total height of the generator were usually listed. The fuel storage areas of the generators varied considerably in shape and size, depending upon how they were built and what the operational needs were.

It is interesting that the number of hearth sizes listed in the tables increased more and more with experience, so that in the end there was a choice of a series from 55 mm up to 210 mm, with a 5- to 10-mm increment for the various diameters for the common sizes (400, 450, 500, 550, 650 and 750 mm) of wood gas generators intended for engines from 20 to 200 hp. In many cases there was some overlapping of hearth sizes for two close generator sizes. A 500-mm generator, for instance, could have hearths up to 140 and 150-mm bore diameter; a 550-mm generator, hearths down to 130 and 140 mm diameter. These adaptations were attained empirically and they were never tested theoretically. The nature of the fuel with regard to charcoal formation and very intermittent operating conditions could be of importance here.

When the gas generator is adapted to the engine's gas requirement, it should be noted that the gas requirement increases up to 70% if a supercharger is installed on the engine.

Adaptation of the Gas Generator to Various Engine Installations and Uses

How the gas generator is built in is frequently determined from case to case. In this chapter, the installation itself is not discussed (see Chapter 8); it should be done competently and in accordance with safety regulations. In this section, adaptation of the gas generator refers to its design, with regard to the ways in which a certain engine or whole series of similar engines are used and installed. For instance, weight, space, air resistance, and aesthetic considerations are of importance in designing the gas generator for automobiles; for tractors, boats and stationary engines, etc., certain technical requirements must be met.

Automobiles and Rail Vehicles

The adaptation of the gas generator to automotive operation is a complicated and difficult matter. No matter how competently a gas generator is installed in a car, it involves considerable interference with the initial overall design. Therefore in the beginning of the generator gas epoch, to simplify installation the complete gas generator was usually installed on trailers; in this way, only minimal changes had to be made to the car. Figures 119 to 125 show various designs of such trailers. Some trailers were made self-supporting, but others were designed as semitrailers with some of the weight resting on the rear frame structure of the car. In the latter case some reinforcements were required, but on the other hand, driving and backing, etc., were made easier.

Figure 119. Gas Generator Installed on a Trailer (Pivot Unit) of Lion Type.

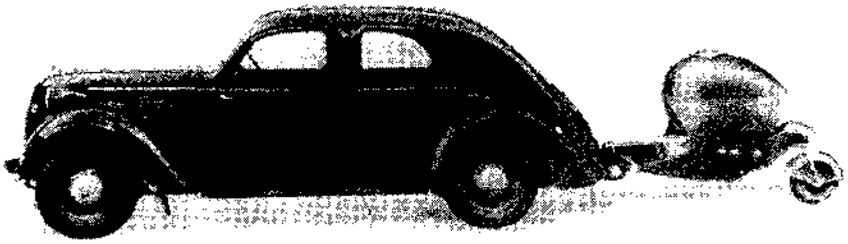


Figure 120. Gas Generator Installed on a Trailer, Volvo Type.

Trailers for gas generators have both advantages and disadvantages; namely,

Advantages

- Do not take up space in the car.
- Do not change the weight distribution or increase the load of the car.
- The car can easily be reconverted to liquid fuel.
- Reduced fire and carbon monoxide hazards. (The trailer can be stored outside the garage.)
- Standardized gas generators may be used for various car types.
- Service of the gas generator is easier.

Disadvantages

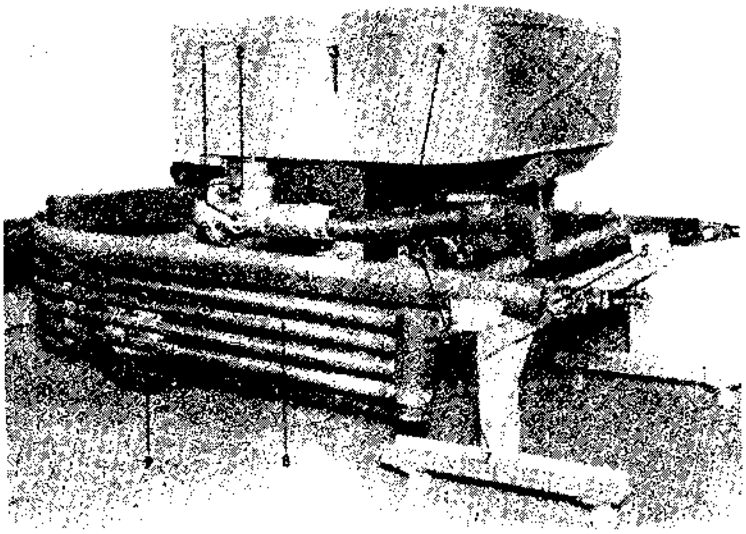
- Greater length of the vehicle (parking and garage space).
- In many cases reduced car speed.
- Increased fuel consumption (increased moving resistance).

It has not yet been determined whether the tire wear is greater when a gas generator trailer is used. One or two small wheels have to be added, but on the other hand, the strain on the tires of the car itself is less than if the gas generator were installed in the car.

For reasons that are difficult to explain, generator gas trailers for passenger cars were not as widely used as the advantages would seem to indicate. Perhaps one contributing factor was that modifications in the design of the car and body, caused by installing a gas generator, were considered of no importance since the car would be scrapped anyhow when new cars using gasoline appeared on the market again. However, for big bus enterprises the trailer system was retained because it was considered highly advantageous for servicing the generator and for the continuous use of the buses. This made it simpler to go back to liquid fuel, than if the buses had been converted to gas generators (Figures 123-125).

During times of unreliable and uneven oil supply, a wood gas generator installed in a trailer would seem to be a great help to car owners dependent upon the operation of their vehicles. This would make it possible to alternate driving on liquid fuel and generator gas according to the fuel supply situation.

When gas generators were first built into automobiles, the space and weight problems came to the fore. For passenger cars and buses the matter of appearance was also important. The smaller the cars or the engines, the more important the matter of weight and space; therefore, small cars ran on charcoal gas, since charcoal gas generators were lighter and of less volume than a wood gas generator. The weight of the fuel itself was less important since the fuel storage area of the generators rarely could hold more than



1. Fan switch.
2. Grease cup for reversing valve.
3. Charcoal container.
4. Gas pipe to engine.
5. Grease cup for hitch.
6. Hitch for fitting to the car.
7. Expansion pipe.
8. Gas cooler.
9. Pivot wheel.

Figure 121. GMC Pivot Unit.

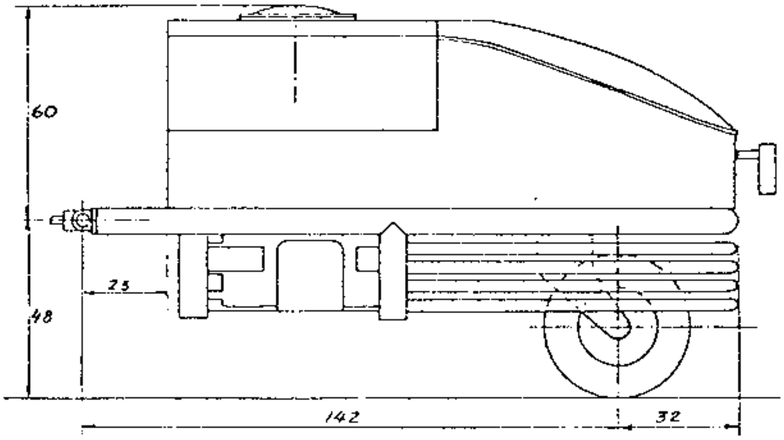


Figure 122. GMC Pivot Unit (dimensions in cm).

1.5-2 hL, which involved no more than 15-20 kg weight difference between charcoal and wood. As for ordinary charcoal gas generators (Swedlund, Gragas, etc.) the advantages in space and weight were not decisive. Not until the introduction of small charcoal and charcoal-dust generators (above all, the Kalle generator) did the advantages of low weight and small dimensions become decisive. An average sized Kalle unit weighs only about 50 kg and can be entirely installed in the front of the car without impairing weight distribution, center of gravity, visibility, air resistance, etc. (Figure 126). The only real disadvantage is the fuel problem, which is not to be disregarded. The production of suitable small charcoal depends upon the demand for retort furnaces where fine charcoal is a byproduct, thus making the supply fairly limited. As shown in the design description (Chapter 4), the Kalle generator is characterized by very fast reaction ability at various loads and short startup time. The fuel costs, however, are considerable and the sensitivity to the quality of the fuel fairly great.

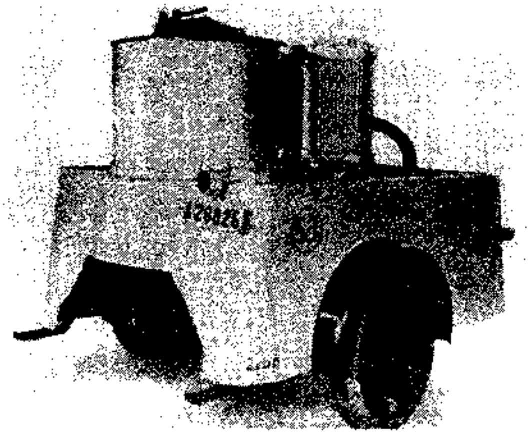


Figure 123. Trailer with a Self-contained Gas Generator for a Bus (Hesselman).

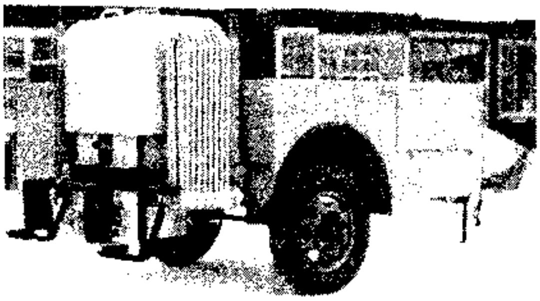


Figure 124. Trailer with a Gas Generator and Cargo Space (Hesselman).

Figure 125. Wood Gas Trailers for the Swedish State Railways.

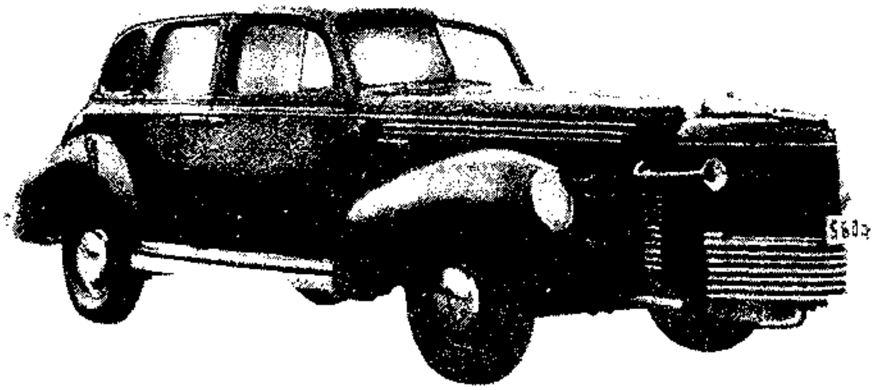


Figure 126. Kalle Gas Generator for Fine Charcoal, Installed in Front.

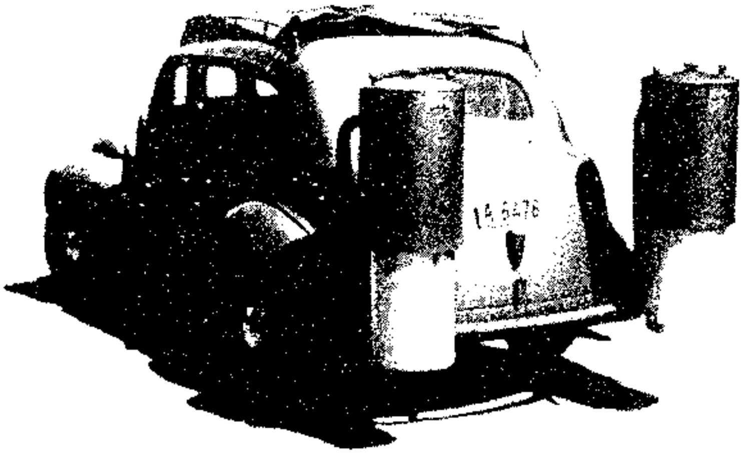


Figure 127. Charcoal Gas Generator for a Passenger Car, with the Trunk Space Retained.

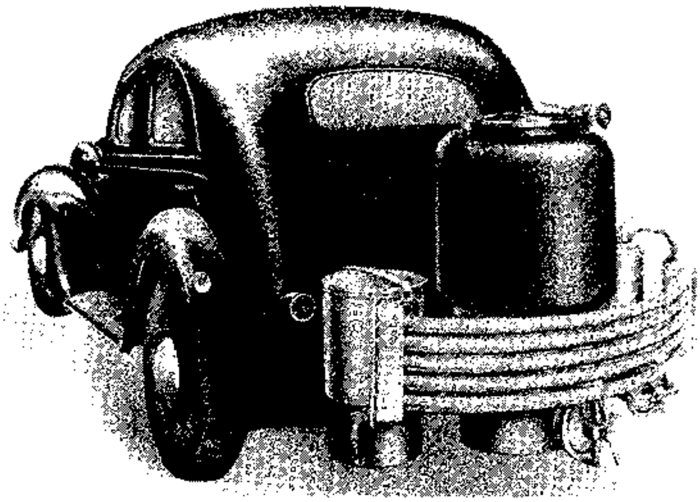


Figure 128. Charcoal Gas Generator for a Passenger Car, Installed without Interfering with the Car Body.

A useful improvement was carried through in this field, when several car manufacturers started to produce gas generators for their large models of passenger cars. As a rule the gas generator was then installed at the rear of the cars, in a way so that the trunk space of the car would not be limited. The fuel store was shaped to decrease the air resistance and to harmonize with the shape of the car itself as far as possible (Figures 127 and 128). Sometimes the gas generator could swing backward to make it possible to keep the trunk space (Figure 129). As for servicing the gas generator, the components were arranged so that the wood gas generator could easily be cleaned by water spraying and the cloth cleaner of the charcoal gas generator by compressed air. The spare tire and the fuel store were often placed on the roof of the car.

Figure 129. Folding (i.e., Back-swinging) Charcoal Gas Generator for a Passenger Car.

It has already been mentioned that, when equipping buses for generator gas operation, trailers were used to a large extent by big transportation enterprises. In other respects there were great differences in how the gas generators were built into various buses (Figures 130 and 131). To the extent that buses were equipped with large storage spaces for luggage (e.g., mail buses), the gas generator had to be placed so as not to limit this space; for this, the methods used were similar to those for passenger cars. Gas generators for buses were characterized by very large fuel stores in the engines, holding 3-6 hL of wood or charcoal. What has been said here about highway and city omnibuses was also true for rail buses. However, generator gas trailers were seldom used for rail buses (see Figure 132).

For equipping trucks with gas generators, aesthetic considerations were generally of minor importance; therefore, existing gas generators could be installed in most cases without extensive changes and adaptations to the exterior. Here, the weight of the gas generator itself was also of minor importance. It varied between 250-300 kg, most often distributed so that the front axle carried about 2/3 of the additional weight. The generator was then placed immediately behind the cab. Since the front tires of trucks are

Figure 130. Trunk Unit for Buses.

Figure 131. Mail Bus (Switzerland) with the Wood Gas Generator Entirely Enclosed.

generally of the same dimension as the doubly mounted rear tires and and their weight capacity is not normally exceeded, the weight of the gas generator is of minor importance in tire wear (Figure 133). A greater disadvantage was the fact that the truck bed was reduced, which displaced the center of gravity of the cargo toward the rear, thereby increasing the load on the rear axle.

Thus it was an emergency measure to install so-called "bogie axles" (the arrangement of a third, nondriving axle behind the rear axle); this frequently increased the legal cargo capacity of the truck. When semitrailers were used, the space and gross weight distribution of the gas generator was made much easier (Figure 134). Detailed provisions were

Figure 132. Charcoal Gas-Driven Railbus (Ostergotland's Narrow-Gage Railroads).

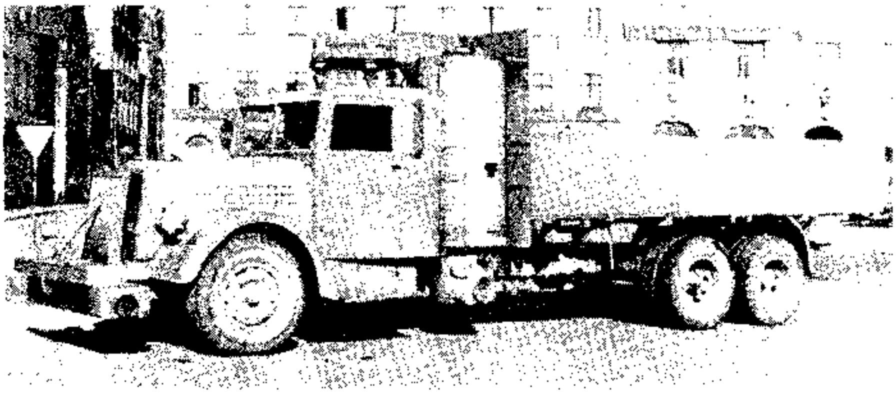


Figure 133. Wood Gas Generator on an 8-Ton Truck (Vabis) with an 8-Cylinder Engine (Gasoline power approx. 160 hp, generator gas power approx. 110 hp.)

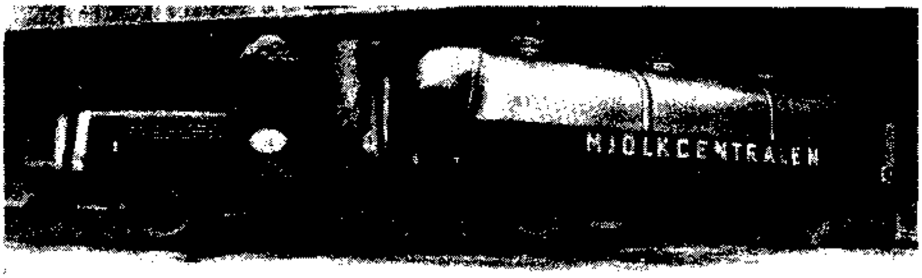


Figure 134. Milk Truck, 8-Ton, Shows How Conveniently a Gas Generator May Be Installed and Adapted to Save Space in Semitrailer Operation.

issued by the authorities concerning the installation of gas generators on trucks. (See Chapter 8). In charcoal gas generators the gas cleaner and cooler were installed in appropriate places underneath the truck bed, keeping the weight distribution as good as possible; easy accessibility and sufficient ground clearance were also taken into account. For wood gas generators with their relatively large condensation coolers and cleaners, it was natural to place the cooler at the front of the truck, in order to utilize the wind and the radiator fan.

Tractors, Mobile Equipment, Shunting Locomotives, Etc.

When gas generators are adapted to tractors, road graders, rollers and other special mobile equipment (Figures 135-139) the biggest problem to solve is the space problem. For tractors, as a rule it is advisable to place the generator between the front and rear wheels. For caterpillars, road graders, etc., the gas generator placement depends on the special circumstances of each case. The problem of cleaning generator gas and secondary air becomes more pronounced for all mobile equipment. It must be remembered that the primary air to the engine must also be cleaned.

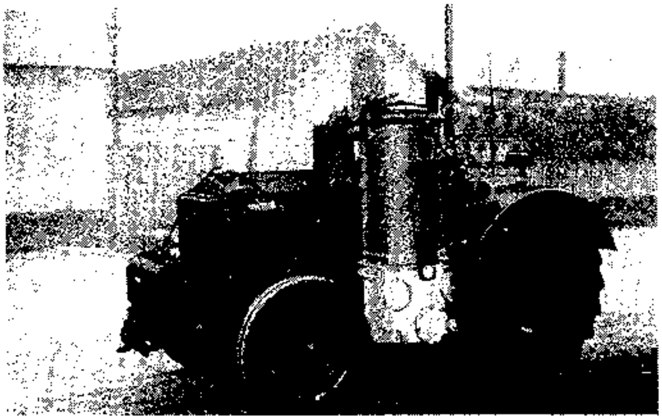


Figure 135. Wood Gas-Driven Tractor.

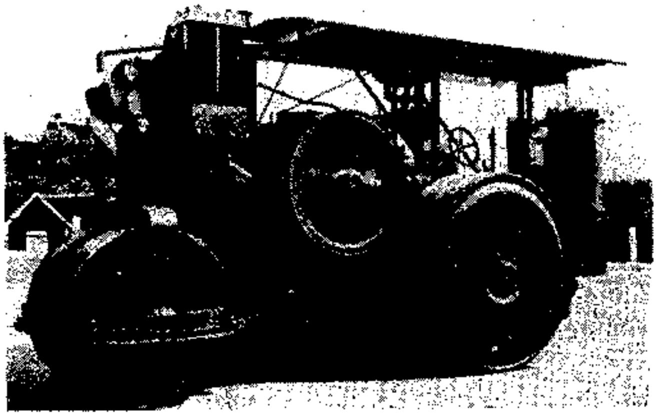


Figure 136. Wood Gas-Driven (Pulsator) Road Roller for the City of Stockholm.

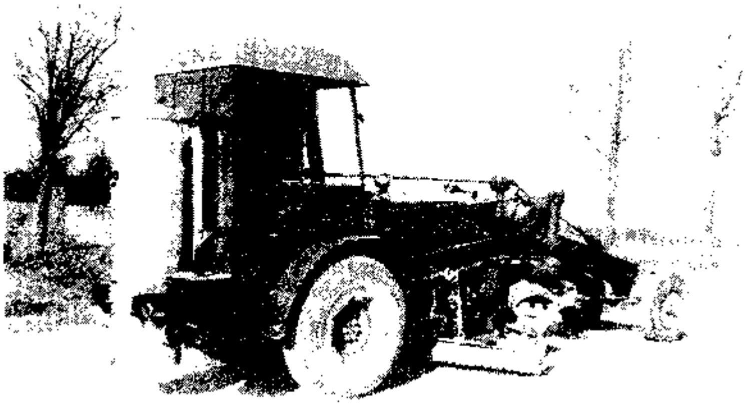


Figure 137. Wood Gas-Driven Road Grader.

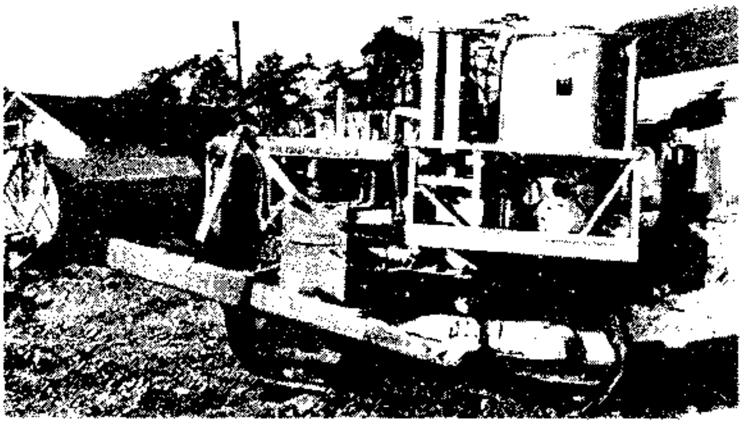


Figure 138. Wood Gas-Driven Caterpiller Tractor.

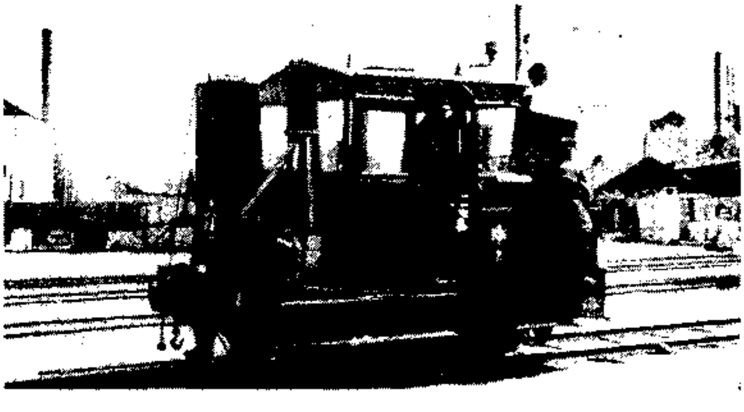


Figure 139. Charcoal Gas-Driven Shunting Locomotive For Ostergotland's Narrow-Gage Railroads.

It is quite natural, of course, that tractors should be operated with wood gas, due to the availability of wood for household use on the farms. Since tractors to a large extent run at full load, the operating temperature is relatively high, which contributes to good results with wood gas. Their relatively low speed, however, makes it necessary to pay close attention to the problem of cooling. A large cooler installed in the front should normally be arranged.

For road rollers, graders and other, mobile equipment with drivers' cabs, there are requirements of safety precautions against the carbon monoxide hazard as well as against fire; otherwise the gas generator conditions are similar to those of tractors.

Ships and Boats

Gas generators were fairly common on ferries, small cargo ships, lumber boats, small marine boats, and fishing boats. Also, some recreational boats, especially the larger ones, were equipped with gas generators with good results. Within the scope of boat engines are almost all kinds of combustion motors; two-cycle ignition bulb motors; four-cycle; carburetor and diesel motors, etc. The two-cycle motors, due to their relatively small suction for gas and air intake, were less suitable for generator gas operation than four-cycle motors. It was not until a supercharger system was used for conveying the generator gas to the motor cylinder (see Chapter 7) that two-cycle motors became useful for generator gas operation and even better than four-cycle motors. Such devices, however, made the gas generator as well as the installation more expensive. For adaptation of boat motors the following considerations were of importance.

- A risk of splashing water and, in general, abundant moisture.
- For saltwater boats, a risk of corrosion through the salt content of the air and the water.
- A need for a protected place for the relatively large fuel store.
- Special regulations by the National Swedish Ships' Inspectorate with reference to the operational safety of the ship, fire hazard, and carbon monoxide hazard (labor welfare).
- Relatively constant operational conditions with a maximum load and in many cases also long periods of idling (fishing, canal boats, etc.)

Since wood is considerably less hygroscopic than charcoal, it can be more easily protected from moisture; also, since the cloth filters used in charcoal gas generators are very sensitive to moisture, wood gas generators are, as a rule, preferred for boat operation. It is also much easier to procure wood than charcoal during voyages. Since ships, as a rule, have to go considerable distances without being able to renew the fuel supply, adequate space must be made for fuel on board, which limits the cargo space. In addition, the fuel must be protected from moisture and from being splashed. However, the wood must be expected, as a rule, to contain a larger moisture quantity than on land; therefore, the generators should be equipped with devices for continuous evaporation of water by condensation in the fuel store of the generator. For this purpose, the generator

Figure 140. Charcoal Gas-Operated Motor Boat.

may be built according to the monorator principle (see Chapter 4), equipped with a special precondensor or possibly with an inside, ring-shaped pocket in the fuel store made of perforated stainless plate, welded to the inner side of the generator plate and with an outlet to a special condensation-water container with a drain cock on the outside of the generator.

The need for a high temperature in the reduction zone of the generator is perhaps even greater for boats than in other cases, due both to the greater moisture content and to the extended periods of idling involved in certain kinds of fishing. For this, good insulation is required as well as the best possible adjustment of the hearth size to the gas requirements of the engine, etc.

For oceangoing boats, the saltwater corrosion must be taken into account. It was necessary to use more stainless metals in the generator and cleaning devices. Aluminum and aluminum alloys gave satisfactory results, which was important since the raw material could be obtained domestically. Also aluminum coating of steel plate by various methods was used in some cases.

The ample water supply made it possible to use very efficient cleaning and cooling devices for the gas generators including scrubbers (Figure 108) and wet cyclones. In such cases, special devices for draining the shower water, a water lock, etc., must be arranged.

A distinction may be made between vessels with and without decks with regard to gas generator installations. According to the directions issued by the Swedish Board of Commerce, gas generators intended for ships are always to be placed in the open air, thus on deck in the case of those with decks. It is then of the utmost importance that the heavily used deck space be utilized in the best way. The various parts of the gas generator must be placed so that they do not interfere with derricks, capstans, fishing tools, sheets, halyards, etc., and the steersman must have a clear view. There are detailed regulations regarding fire and carbon monoxide hazards as well as seaworthiness and maneuverability; each gas generator installation in a ship employing a crew was to be inspected by the National Swedish Ships' Inspectorate. This also applied to the installation of various components such as water locks, pipe joints, lids, etc.

Figure 141. Wood Gas Powered Fishing Boat, Swedish East Coast Type.

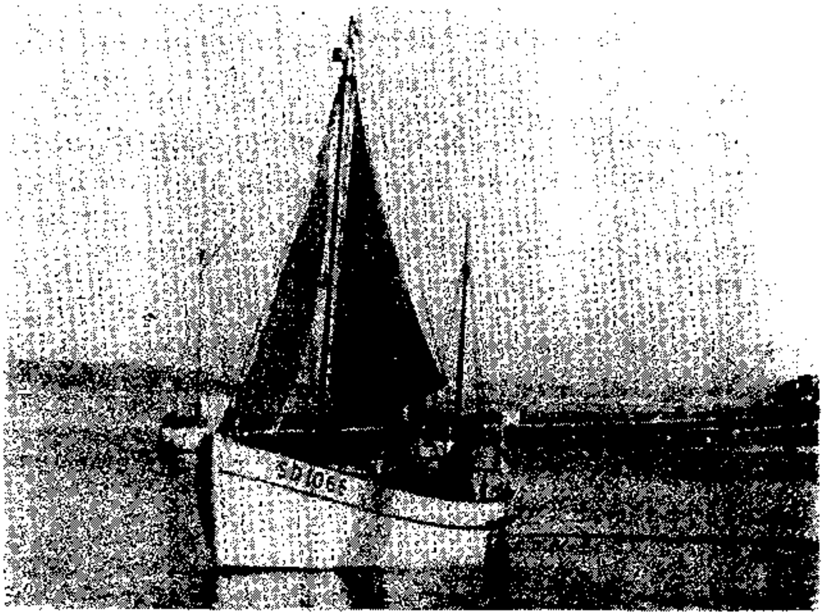


Figure 142. Wood Gas Powered Fishing Boat, Swedish West Coast Type.

The wartime experiences seem to indicate that generator gas operation of certain ships and boats, for instance, motor sailing vessels, timber boats, smaller fishing boats, marine small boats, etc., was satisfactory when suitable gas generators were used and the engines were changed for this purpose. On the other hand, generator gas operation was not suitable for large fishing vessels which frequently have to stay at sea for long periods of time. In this case a combination with diesel operation would be conceivable, in which the diesel would be used during the fishing itself and as a reserve, while the wood would be used for sailing to and from the fishing place. (Various installations for ships and boats are shown in Figures 140-143.)

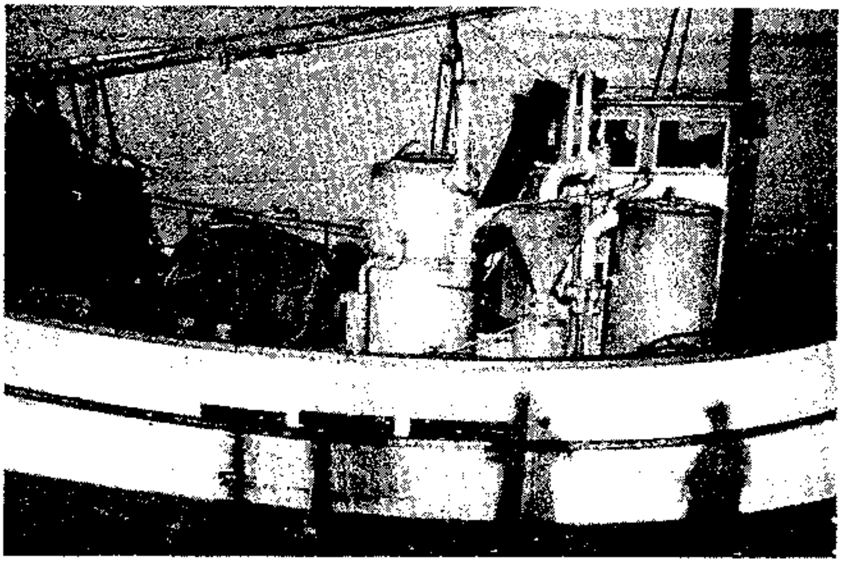


Figure 143. Wood Gas Generator Installation on the Deck of a Swedish West Coast Fishing Boat.

In the case of generator gas operation for boats, certain difficulties were added which were not as common on land; namely, the unfamiliarity of the boat owners with generator gas operation, the shortage of skilled mechanics and repair shops along the coasts, etc. Therefore, gas generators had to be installed with particular care. Moreover, the need became apparent for spare parts that could easily be replaced at sea. Generators were therefore designed so that a great many parts (fuel store, hearth, etc.), could easily be replaced without any real mechanical work; i.e., without welding. (For products of the Swedish Generator Gas Co., see Figure 69.)

Stationary Engines

For stationary operation the gas generator does not need to be adapted as much to the weight and space limitations as in other cases. On the other hand, the fuel cost is usually of particularly great importance. Therefore wood gas generators are the best for stationary engines. The operating conditions make it necessary to pay special attention to cooling since there is no wind related to vehicle motion. When gas generators are used in gravel crushers, etc., the demands on the gas and air cleaning systems are also increased.

Since the small power requirement in this case makes it desirable that the engine unit be portable, at least locally, "semi-mobile" installations of complete gas generators came into use for direct connection to the air intakes of stationary engines.

The gas generator, consisting of a cooler, cleaner, and sometimes also a starting battery, starting fan, illumination lamp, etc., was installed in a chassis on wheels or runners (Figures 144-146). The stationary engines operated by gas generators were usually two-cycle ignition-bulb motors, converted according to the pulsator system, in which full diesel power was obtained. Their operating conditions were relatively constant, consisting of long periods of maximum load, sometimes separated by rather long periods of idling. Seldom were there the partial load conditions found in car operation. These engines were mainly used for stone crushers, small saw mills, central power stations, threshers, pumping plants, etc.

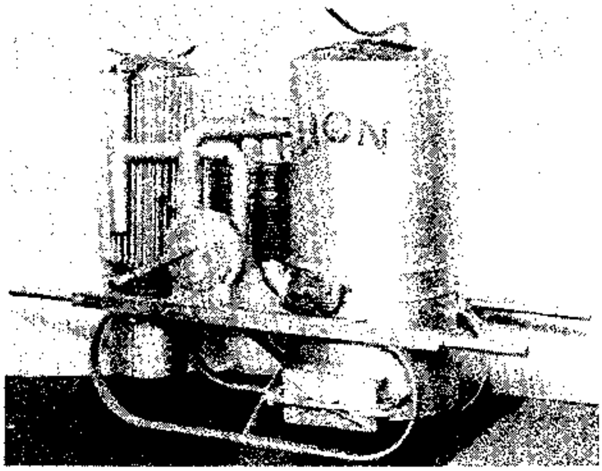


Figure 144. Semimobile Charcoal Gas Generator on Runners, Lion.

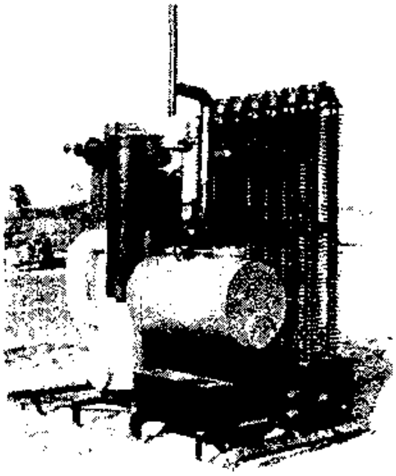


Figure 145. Semimobile Wood Gas Generator on Runners. Swedish Generator Co. (Such gas generators were used for forest lumber mills, highway gravel machines, etc).

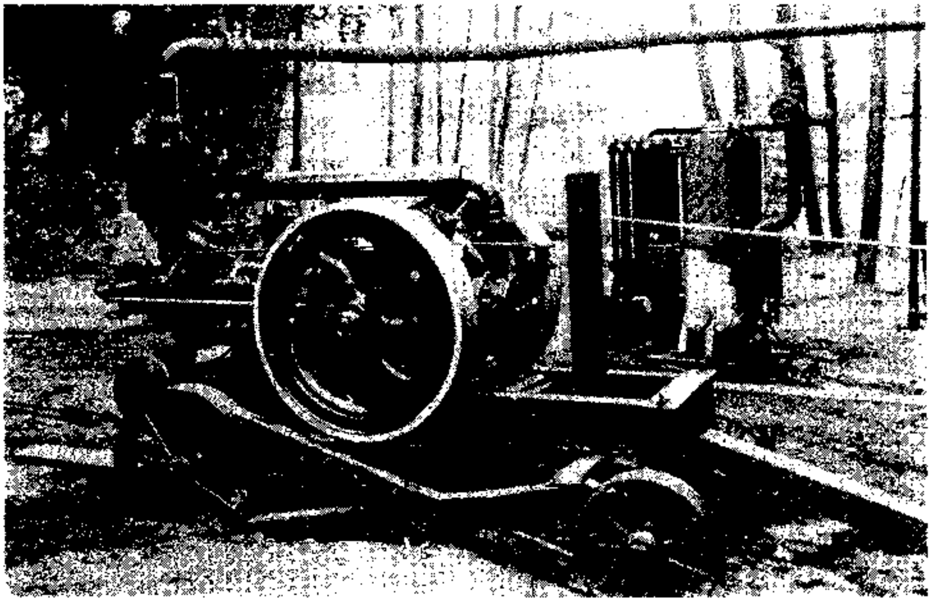


Figure 146. Semimobile Gas Generator on Runners, Pulsator Engine with a Wood Gas Generator. Swedish Generator Gas Co.

Special Equipment for Gas Generator Adaptation

For starting, operational control, improved power, maintenance and supervision, etc., the gas generator had to be equipped with various devices, instruments, and tools, which were manufactured by special industries and only rarely by the generator manufacturers.

Starting Devices

Special gas generator matches were used which burn with a hot flame for a relatively long time to ignite the fuel in the generator. They are usually inserted into the ignition pipe incorporated in the generator wall. These matches consist of a rather loosely compressed material, mainly aluminum with nitrates as oxidation agents. In one end is a more sensitive "scratch substance," which can be ignited against the friction surface of an ordinary match box. [4]

A generator may be fired or started with the help of the engine, which is started up with liquid fuel, after which the engine compression is partially utilized for sucking gas from the generator. This is, however, a fairly slow process requiring expert knowledge and experience. A fan is more commonly used to start the generator. This fan is sometimes hand-operated in the case of tractors, but, as a rule, is electrically operated from a battery (Figure 147). If there is a battery for igniting or starting the engine, it is of course used, but as a rule it should be reinforced or exchanged for a larger battery, since in addition to the fan operation (150-200 W for 1.5-1.75 m^3/min), there is increased work for the starter in the case of generator gas operation.

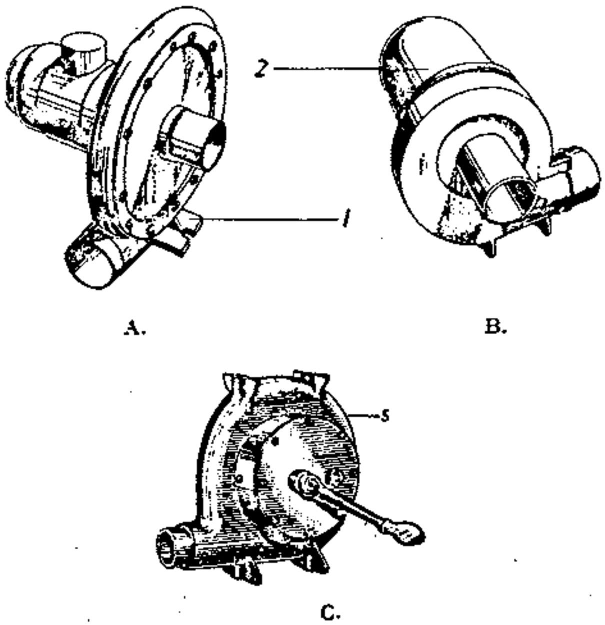


Figure 147. Various Gas Generator Fans. A and B: Operated by an electric motor C: Hand operated.

The fan is either used to create negative pressure (a suction fan) or to blow in air (a pressure fan). The pressure fan makes it possible to evaporate water vapor and tar mists from the fuel store when the filling cover is open during the beginning of the starting period, but it also involves a greater carbon monoxide hazard due to the positive pressure in the gas generator. Suction fans are usually used for wood gas generators and pressure fans for charcoal gas generators. In order to maintain the suction in the generator during idling conditions and a decreased load on the engine, a combination of a suction and blowing fan and a branch pipe with a check valve (in Sweden called "Automix" and in Denmark "SIMO-lefstart") may be used. The branch pipe is attached between the fan and the engine in the gas/air pipe. The fan, which may also be used as a starting fan, sucks gas and air (only gas in starting the generator), mixes them, and blows the mixture to the engine. If the suction power of the engine is small, the excess gas/air mixture, forced forward by the fan, goes out into the atmosphere, thereby maintaining combustion in the gas generator. The fan may be switched on or off by hand or automatically by centrifugal weights. The rotation speed of the fan may be regulated by a rheostat. The same electrical energy is consumed for the fan operation as for two headlights of a car. This device is shown in Figures 148 to 150.

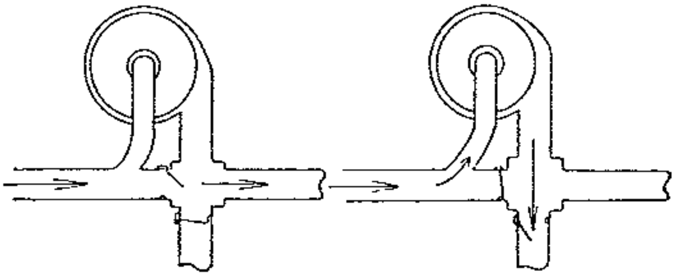


Figure 148. Suction and Pressure Fans for Starting (SIMO).

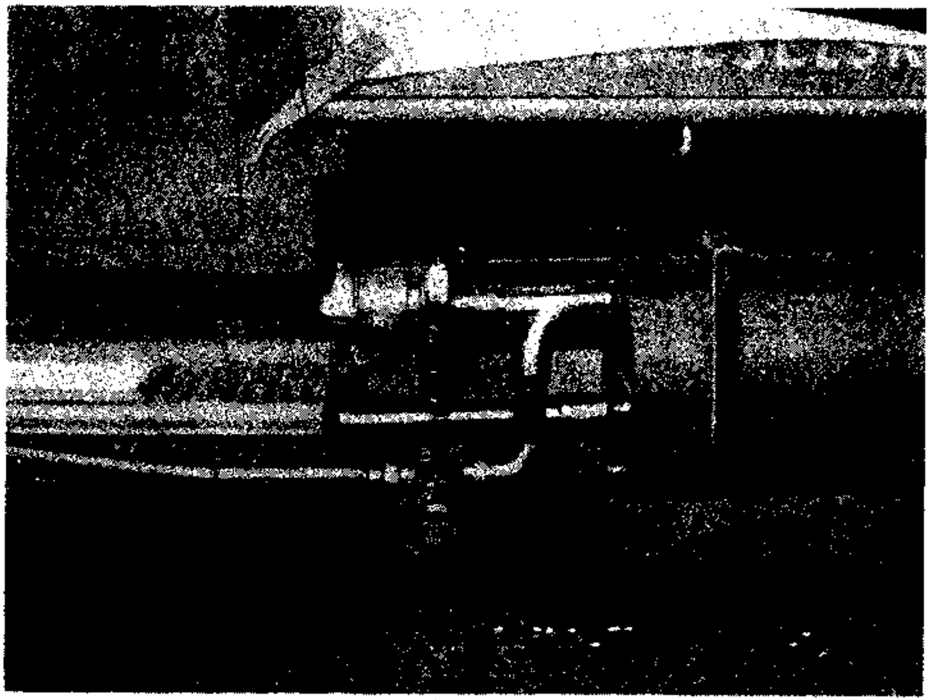


Figure 149. Installation of a Suction and Pressure Fan for Starting (SIMO).

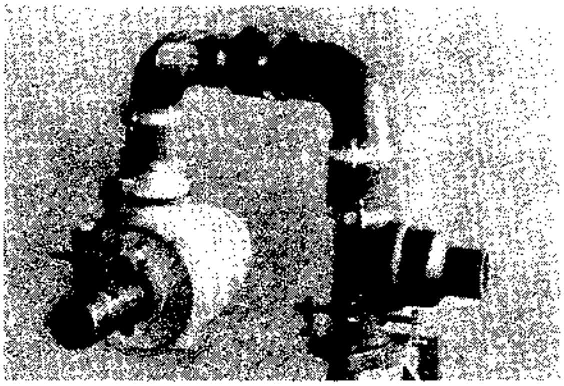


Figure 150. Auto-Mix Starter with a Combined Suction and Pressure Fan.

Kroll-Solex Starter. Figure 151 demonstrates the principle of a starter, which uses an ejector placed in the exhaust pipe of the engine (or in a pipe connected in parallel with it) to start the generator. By using a suitable jet nozzle, the suction may be considerably increased during idling, so that startup time will be shortened. This device has many advantages in addition to the lessened drain on the battery, but the availability of some liquid fuel is required.

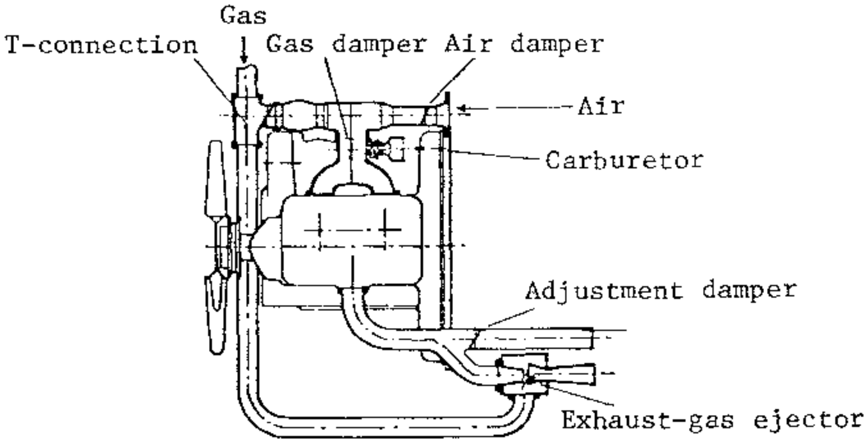


Figure 151. Kroll-Solex Starter Using Suction Effect of Exhaust Gases from the Engine.

Engine Heaters. To facilitate starting the engine during cold weather, thus saving the battery, various makes of engine heaters are used, which may be fueled by charcoal or alcohol or in some cases electrically (electric heaters in the cooling water). The engine heaters are hooked up to the cooling water system of the engine and circulate the water. For charcoal firing the device is similar to a double-jacketed cylindric iron stove. The pipe for the cooling liquid runs between the jackets. Firing can be accelerated through a blasting effect with the help of the generator fan (Figure 152). Figure 153 shows an engine heater that works according to the same principle but which is fired by alcohol; in this case the alcohol container is fitted into a cylindrical protective cover of sheetmetal outside the container jacket. Inside this there is an alcohol burner and a brass spiral for the cooling liquid.

Figure 152. Engine Heater Fired by Charcoal.

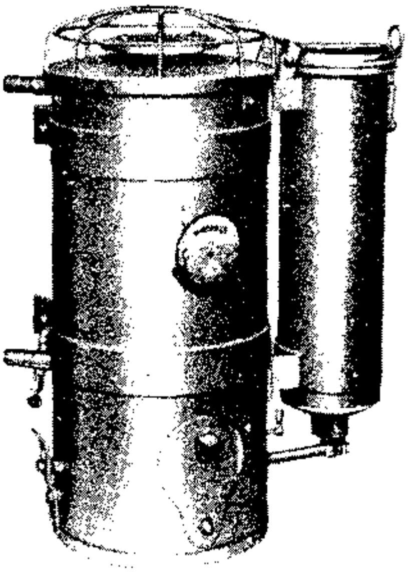


Figure 153. Engine Heater Fired by Alcohol.

Before the engine is started, the generator gas conveyed by the fan should be tested for its suitability for engine operation. This is usually determined by the color and purity of the flame after ignition.

One interesting device is a combination engine heater, air preheater, and mixture indicator called Sermi (Figure 154). The fan gas is conducted to a burner and is there burned with air added. This air comes from the air jacket of the heater that surrounds the water container; thus, the air is quickly preheated and the heat of the flame is increased. The preheater has a window through which first gas, then a mixture of gas and preheated air, flows and is ignited. As the mixture, through careful adjustment by the secondary-air control, becomes more correct, the flame is shortened like that of a Bunsen burner, and finally vanishes with a puffing sound down into the combustion space in the preheater. This means that the engine is ready to start. Initially the gas is thrown from the preheater to the cylinders because the suction of the engine affects a check valve. (Compare the device used for SIMO and Automix, Figures 148-150.)

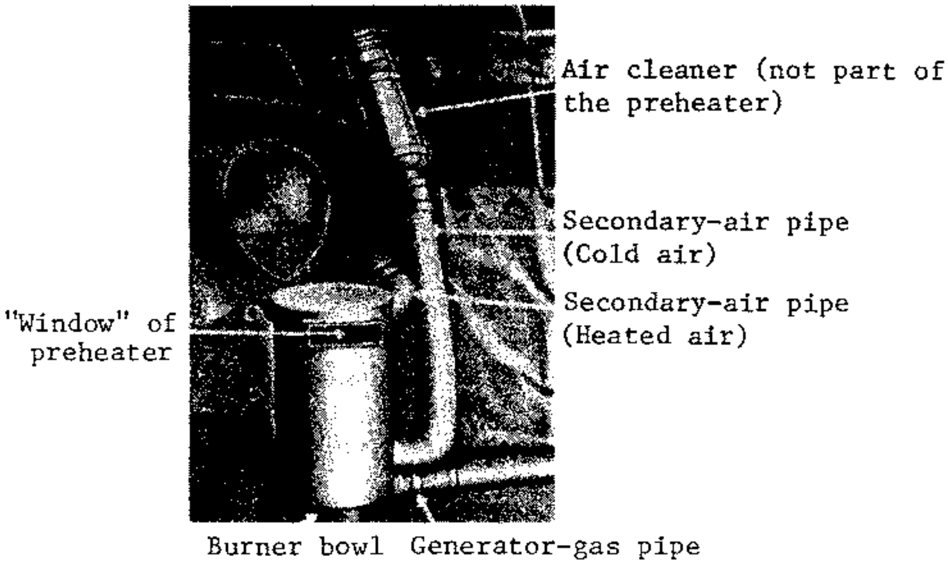


Figure 154. SERMI Engine Heater and Mixture Indicator.

Precondensors

To evaporate the excess moisture in the wood of a wood gas generator, a condensation pocket may be incorporated in the fuel container. In a generator that lacks such a device a precondensor may be installed between the fuel store of the generator and its lid frame (see Figure 155). The precondensor consists of a sheet metal jacket with an inside collecting channel for condensation water and a drain valve through which the water is carried to an outside container with a drain cock. This device is, as a rule, made of stainless steel because of the acid content of the gases. The utility of such precondensors is especially great after driving is finished, when much condensation usually takes place in the generator, and the fuel above, in,and below the hearth usually becomes quite wet. This is prevented to a large extent and makes subsequent starting easier. This device is particularly useful if cloth filters are used in generator gas operation.

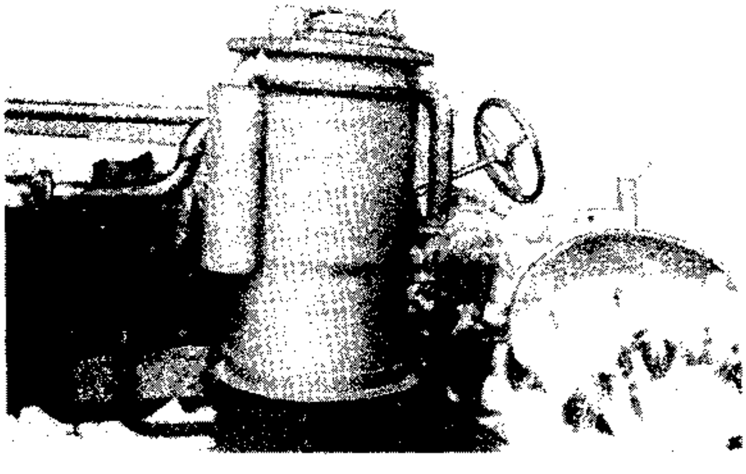


Figure 155. Precondensor for a Wood Gas Generator.

Preheater Heat Exchanger

In connection with the descriptions of the generator design and the cleaning and cooling apparatus for wood gas, it was mentioned that part of the heat of the wood gas produced in the generator is used to preheat the primary air. Also, the engine exhaust gases can be used for heating purposes; for instance, to heat the secondary air in order to avoid condensation of wood gas water in and after the mixer (Figure 85), or to heat the gas before the cloth filter (especially important for cloth filters in wood gas generators), so that the cloths will not be wet by condensation water (Figure 113). Since cooling of the gas between the cloth cleaner and the mixer is usually significant and the dewpoint of the gas would seem to stay around 40°C at the mixer, some condensation may be caused by the relatively cold secondary air. In this case, it is better to incorporate a condensation water pocket with a drain cock than to preheat the air, thereby decreasing the degree of wetting.

Gas Mixer

Special gas mixers are used to mix generator gas with the required quantity of secondary air for combustion. Such a gas mixer controls the air flow in relation to the generator gas flow at the same time that it effects an intimate mixture of generator gas and air. The latter is particularly important in the case of engines with several cylinders, since there will be an uneven distribution of combustible gas to the various cylinders in case of poor mixing. In order to effect a satisfactory mixture, some drop in gas pressure in the mixer must be accepted, which, as mentioned earlier, involves a decrease of the maximum engine power. On the other hand, a mixer with a small pressure drop and poor mixing may affect the engine power even more unfavorably, which is why an optimum should be sought. It may frequently be advisable to design the mixer for a relatively high drop in pressure, up to 500-600 mm of water.

Regulation of air quantity may be done either manually or automatically . An automatic device is very helpful, especially for car operation, since the driver then does not have to be concerned with this detail. Automatic mixers give a constant mixing ratio of gas and air, but the types used so far do not automatically regulate the ratio according to the thermal value of the gas. The latter seems to be of minor importance, however, since this adjustment can be done by hand.

Figure 156 shows a simple device (the Italian Imber Company) and Figure 157 a Swedish mixer. One of the best known automatic mixers was the Platen mixer, Figures 158 and 159. The membrane at the bottom (Figure 158) regulates the damper according to the pressure in the gas inflow, which depends upon the gas flow. To be fully satisfactory this automatic generator gas mixer regulating the air quantity should be combined with an additional device for mixing generator gas and air. In Figure 160 a mixer is shown with a venturi-pipe nozzle shaped to recover the pressure.

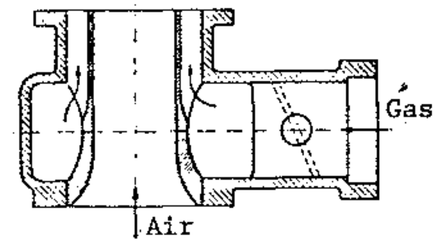


Figure 156. Ordinary Generator-Gas/Secondary-Air Mixer

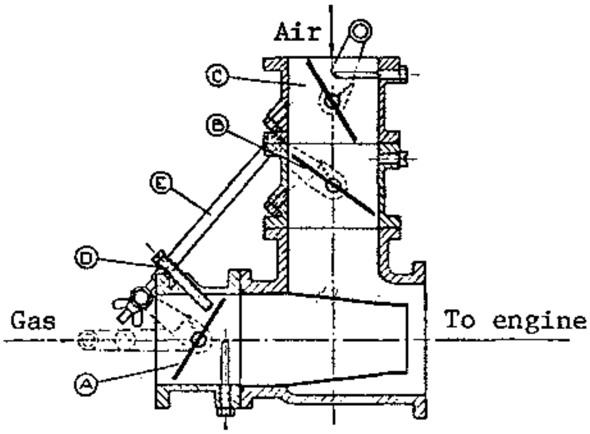
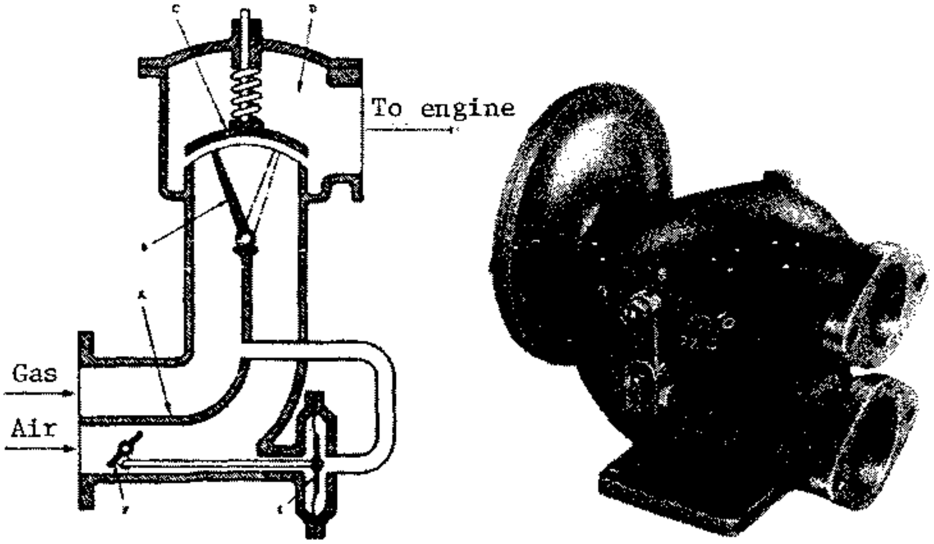


Figure 157. Hesselman Gas Generator Mixer.



Figures 158 and 159. Automatic Generator-Gas Mixer (Platen).

Controls

Control devices for cars having highly variable operating conditions are fairly complicated. The following devices are required:

1. A control for the damper for engine speed regulation.
2. A control for the secondary-air damper for variation of the mixing proportions.
3. A control for the fan damper.
4. A control for the ignition.
5. A control for the changeover switch to the garage carburetor.
6. A switch for the fan damper.

Existing devices are used as far as possible.

The secondary-air control should be designed for precision adjustments; i.e., it should have a high gear ratio. For control devices on the dashboard there are a great many different standard parts on the market; a few common types are shown in Figure 161. Bowden flexible cable is generally used for the control.

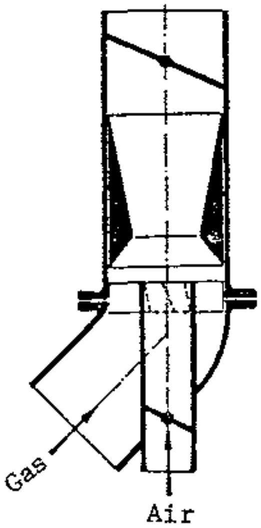


Figure 160. Finkbeiner's Principle for a Gas Generator Mixer.

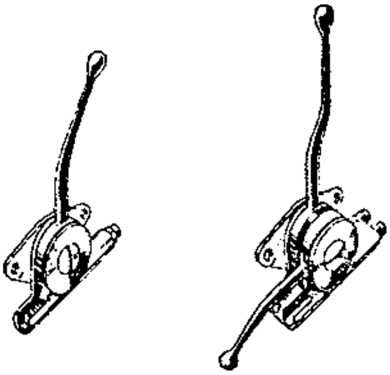


Figure 161. Single and Double Controls for Gas Generator Operation.

As mentioned in a different context, the possibility of increasing the gas generator power by simultaneously adding liquid fuel such as gasoline, is limited since the liquid fuel uses available air, thus significantly decreasing the generator draft. Some power increase may be obtained, however, if the quantity of liquid fuel added is well balanced. An example of this is to be found in the device used by the National Swedish Road Administration for snowplowing trucks (Figure 162). In addition to normal devices for switching the auxiliary carburetor and the generator gas pipe on and off for alternating driving on gasoline and generator gas, there is a device for the addition of gasoline when the gas throttle (C) is fully open. At this point, by further pressing the gas pedal (D) against a spring in the pedal stop (d_1) via the lever (c_4), the carburetor supplies an additional small quantity of a liquid fuel/air mixture, whereby a much-needed power addition is obtained for snowplowing trucks during frequently heavy loads.

When driving under constant operating conditions (e.g., boat operation, stationary engines for operating certain work machines, compressors, etc.), centrifugal governors should be used to keep the rotation speed constant and independent of changes in load. Such an automatic rotation-speed governor (see Figures 163-164) of the type used for ships, etc., which are rebuilt with pulsators, has an axle mounted in a case and operated from the engine shaft; centrifugal weights rotate with this axle and, by means of levers, move a sleeve placed on the regulator axle against a pull-off spring when the rotation speed increases. The sleeve is connected with the regulatory damper of the engine by levers and drag links. If there is a tendency for the rotation speed to decrease for some reason, the sleeve affects the damper so that it increases the opening of the valve, and vice versa. The pressure of the spring against the sleeve may be changed through a screw device. In this way it is possible to make adjustments for continuous operation with

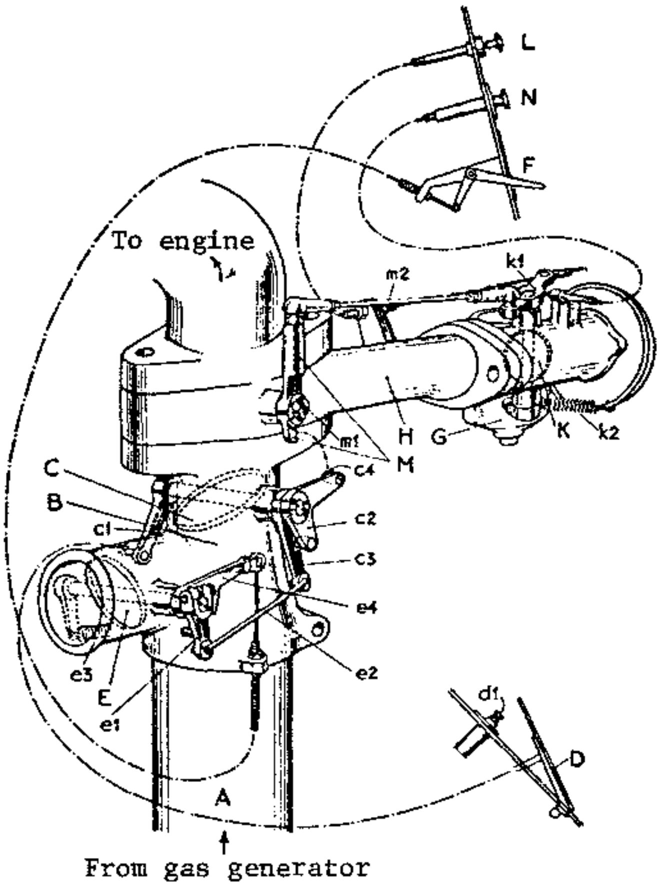
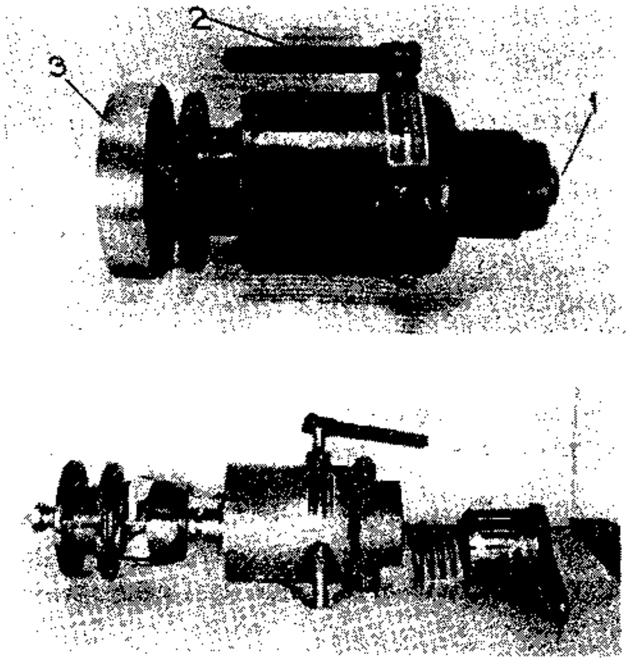


Figure 162. Device for Use on Snow-Plowing Trucks, to Increase Power by Adding Alcohol Fuel.



Figures 163-164. Centrifugal Regulator, Swedish Generator Gas Co. (Lower view: taken apart)

various, practically constant, rotation speeds. This device not only makes adjustment easier for generator gas operation but it also increases the reliability of operation. Such regulators may be used for both quantitative and qualitative regulation of engine speed.

Air Cleaners

The need for air cleaners for automobiles and tractors in order to reduce crankcase oil fouling and cylinder wear, etc., had been realized for a long time and air cleaners were a part of the standard equipment in most cases. In general, these air cleaners were badly maintained by car owners, who frequently forgot to clean them before clogging caused extensive air constriction. During the gas generator epoch, the importance of these air cleaners for reducing engine wear became obvious. The design of common air cleaners is shown in Figure 165. As a rule, they are of the oil-bath type. The air enters through a ring-shaped opening between the outer wall and the lid at the upper edge of the cleaner. At the bottom, the heavier dust particles strike a shelf and are caught and retained by an oil bath. After that, the air is sucked up through the filter insert, bringing some oil from the oil store, whereby the filter is kept moist so that finer dust particles are retained there. Air filters for cars, which are also suitable for secondary air in generator gas operation, are usually cleaned after approximately 3000 km of driving and hold about 1/2 L oil (motor oil SAE 30).

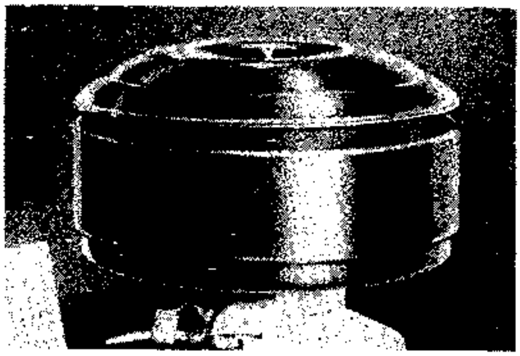


Figure 165. Oil Bath Air Cleaner

A simple and efficient air cleaner has been manufactured from filter material obtained during wood defibration. This porous material lets the air through without significant loss in pressure, but retains the dust. Air cleaners with inserts of such cellulose material (dry filters) are very simple; they consist of a sheetmetal cylinder that has, inside, a concentrically arranged filter cylinder made of cellulose plate and held by a steel nut or the like; it is designed so that the air entering axially between the filter and the plate cylinders must pass the filter, after which it leaves in the opposite direction closer to the cylinder axis leading to the carburetor.

Where the air intake is placed is also important. In the case of rail buses it proved to be best to place the air intake and the cleaner on the roof. To place it, as was done earlier, underneath the engine hood was not advisable, since dust would whirl up from the ground when the engine was at the rear.

Safety Filters

When cloth filters are used (mainly in charcoal gas generators), frequently those made of organic material—and thus sensitive to mechanical injury—tear, especially if the gas temperature is kept high to avoid water condensation. The material becomes fragile above approximately 120°C and is easily damaged. Should this happen, considerable quantities of dust and everything not retained in the cyclone cleaner would be taken into the engine if there were no trap or safety filter. Such filters are clogged fairly quickly if the function of the main cleaner is impaired. The drop in pressure then warns the driver. The filter usually consists of a net of 500 mesh/cm^2 bronze or brass wire (Figure 166) or of dense metal wool moistened by oil. The trap filters must be designed to cause a minimal fall in pressure in the gas conduit and they must be placed so that they are easily accessible.

Control Devices

For continuous control of the gas generator during operation, remote manometers and remote thermometers are sometimes advantages. The manometers can measure negative pressure at various points of the gas generator or pressure differences before or after a cleaner. As a rule, it would seem to be most useful to know the pressure immediately after the generator and immediately before the mixer. Figure 167 shows schematically a device for measuring pressure for wood gas generators.

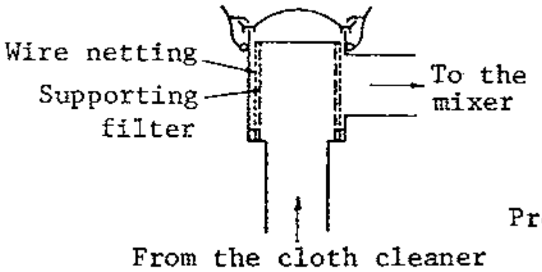


Figure 166. Safety Filter with a Wire Netting.

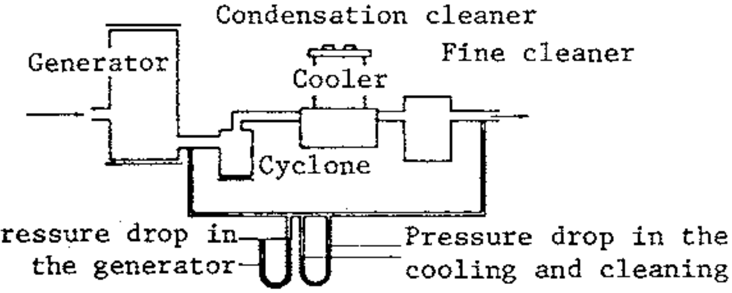


Figure 167. Device for Measuring Pressure in a Gas Generator.

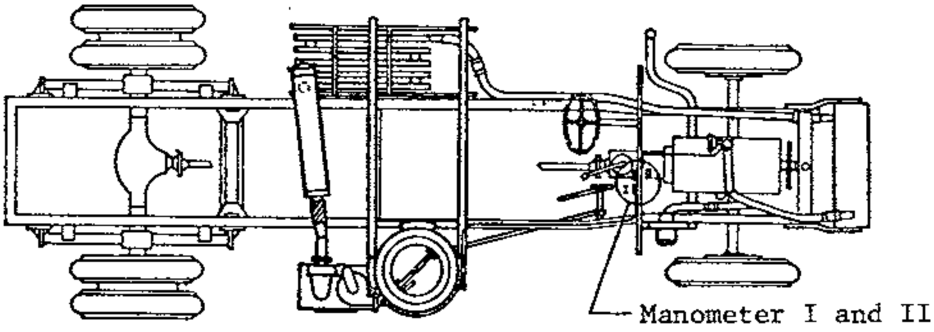


Figure 168. In certain German generators manometers are supplied as standard equipment. (I. For the negative pressure after the generator) (II. For the negative pressure immediately before the mixer)

Figure 168 shows how manometers are placed on a truck. Thermometers (bi-metal type) placed after a cooler or before a cloth cleaner can be very useful if they can be read from the driver's seat. If the cooler can be manually adjusted through shunts for varying the cooling effect, the driver's thermometer control is often suitable. In this respect a thermostat-controlled regulation of the damper device of the shunt is also conceivable (Figure 169).

There are some devices to control the level of the fuel store in the generator which, however, have not been used extensively in practice. A bi-metal thermometer, for instance, placed in the upper part of the generator and readable from the driver's seat, is useful in that it can prevent the fuel store from sinking too far down and causing damage through the temperature increase. This condition can be noticed through a sudden increase of power of the engine, but usually the damage is already done by then. The temperature in the generator is, however, highly dependant upon various conditions (loads, wind speed, moisture, etc.), so the device cannot be particularly accurate. Figure 170 shows schematically another device for controlling the fuel level.

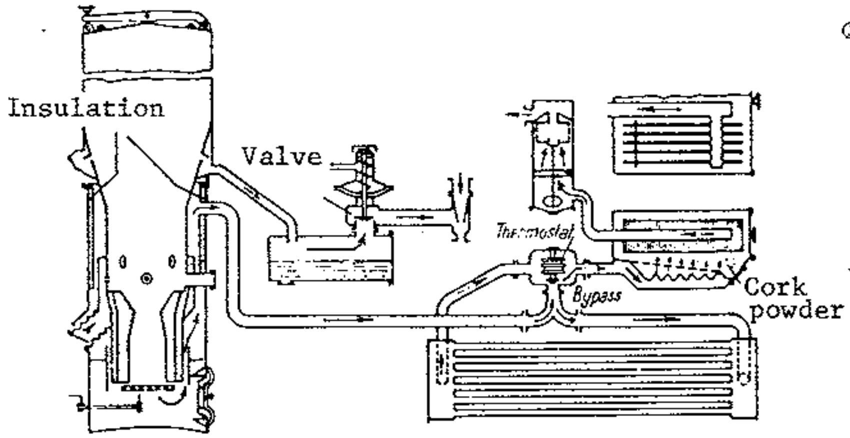


Figure 169. Thermostat Control of a Cooler

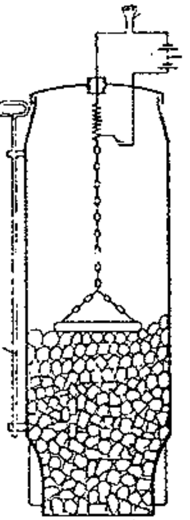


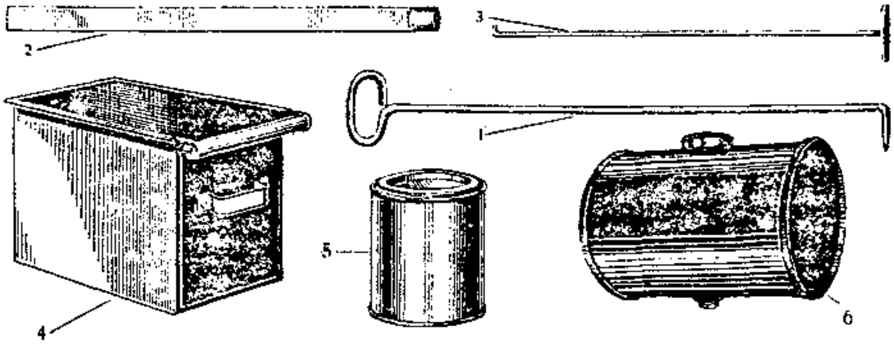
Figure 170. Device for Controlling the Fuel Level in Generators

Miscellaneous Equipment

In the equipment of the gas generator there are miscellaneous safety devices to prevent fire in the air intake of the generator, as well as fire extinguishers, water supplies, etc. (Figure 171). These are specified in more detail in ordinances issued by the authorities.

Standardized Gas Generators for Various Purposes

In Figure 89, Chapter 5, a few types of gas generators for various purposes are shown schematically. These can be considered to correspond to the standardized structures that gradually were developed during the generator gas epoch.



1. Loosening hook. 2. Lid iron. 3. Ash rake. 4. Ash bin.
5. Graphite can. 6. Tank for gasoline for starting.
Figure 171. Miscellaneous Tools for Gas Generator Operation

Charcoal Gas Generators for Motor Vehicles

The charcoal gas generator consists of the Swedlund type, as a rule, but Gragas' and Volvo's special charcoal gas generators were also used to some extent, especially for passenger cars. Kalle generators were used more and more for small cars during the last part of the generator gas epoch. After that followed, in sequence: cyclone cleaners, dry coolers, cloth cleaners, mixers, and inlet pipes. A pressure fan for starting was necessary at least for the Swedlund type. The cloth cleaner was sometimes placed next to the generator; this, however, involved the risk of damage to the cloths in the filter. Safety filters and flame guards were necessary. Deviations from the above composition of the various parts of the gas generator were more common for charcoal gas generators. As for wood gas generators a garage carburetor was necessary, at least for vehicles which could not easily be pushed by hand.

Wood Gas Generators for Motor Vehicles

The wood gas generator installation consists of a generator similar to the Imbert type, after which follows, in order: a dry cyclone cleaner; a condensation cleaner with a cooler, where the starting fan usually is placed; a fine cleaner, usually a volume filter with cork as filter material; a mixer; an air cleaner; and finally, often a specially designed inlet pipe, equipped with a separate so-called garage carburetor for driving indoors and for starting purposes. The cooler and the condensation cleaner are usually placed, as previously mentioned, before the radiator of the vehicle (also see Figure 133). Not until the last years of the generator gas epoch were cloth cleaners instead of cork cleaners brought into use to some extent, especially in the army when exhaust heat was used for heating in some cases. Wood gas cloth cleaners, however, are not completely satisfactory in practice.

Wood Gas Generators for Boats and Ships

For reasons already mentioned, boats generally used wood gas generators. After the generator a dry or wet cyclone followed—if the usual equipment for vehicles with condensation cleaners, cooler, and cork filter was not used—and, in addition, a scrubber with a water pump and a water lock as shown in Figure 89C.

Wood Gas Generators for Stationary, Pulsator-Operated Engines

For two-cycle ignition bulb type engines the wood gas generators on runners described above were used to a large extent (Figure 145). They consisted of the generator produced by the Swedish Generator Gas Co., having a V-hearth, cyclone condensation cleaner with a flange cooler, and a cork cleaner. Usually this generator was also equipped with a battery, starting fan, and in some cases an illumination lamp.

The rest of the various gas generators were equipped according to the choice of the customers and the manufacturers, with miscellaneous equipment parts such as heat exchangers, condensation pockets with drain cocks, manometers, thermometers, etc., for improved reliability and control. Standard generators were frequently modified with, for instance, special insulation of the hourglass-shaped hearths common in Imbert generators, by exchange of these for a V-hearth or other hearth type, and condensors placed in the upper part of the generators, etc. Also various kinds of automatic mixers, engine heaters, starting improvers (Auto-Mix, Simo, Sermi, etc.), were used.

The designs were developed and improved during most of the generator gas epoch, which is the reason that there was no complete standardization. The need for a technical authority to control and approve all the new designs in the generator gas field proved to be great. This control was exercised by the Generator Gas Bureau under the National Swedish Fuel Commission; it issued regulations concerning carbon monoxide hazards and fire safety (in cooperation with the National Swedish Ships' Inspectorate, fire insurance companies, etc.), and gave advice concerning increased reliability of service, etc. The Generator Gas Bureau issued, for all individual cases, approval certificates for the new designs, to the extent that they helped the adaptation of the gas generators to engine operation. Also, the Swedish Generator Gas Co. was founded with government funds; only one section of this company dealt with new designs in the field of wood gas generators, and suitable modifications of certain types of engines. The main task of this company was in the field of generator gas fuel, but the company also had a stabilizing effect on the prices of gas generators through a considerable production of wood gas generators, especially for tractors; it also rebuilt ignition bulb engines according to an improved system (the pulsator system), made improvements in the operation of wood gas generators during idling and low rotation speed, among other things through the V-hearth, and encouraged the use of domestic materials rather then imported alloyed metals, etc., which were difficult to obtain.

Chapter 7

ADAPTATION OF ENGINES TO GENERATOR GAS OPERATION

The power range for combustion engines suitable for wood or charcoal gas lies, with few exceptions, between approximately 10 and 200 hp. In practice, these are mainly mobile engines for transport service, farming, and fishing; and semimobile (i.e., easily movable) engines for stationary operation of stone crushers, compressors, etc. Basically, all combustion engines can be modified for operation with generator gas, but of course the costs of conversion vary, depending upon the original design and the engine's operating conditions. With the present gas generators, engine reliability is, on the whole, satisfactory. The operating conditions of some kinds of mobile engines are affected negatively by the shorter distances travelled in generator gas operation. The suitability for conversion to generator gas operation must be weighed in each individual case against the economic conditions at the time when conversion is being considered.

It is usually of little significance for the engine modification whether the gas generator is to be operated with wood, charcoal, or good peat. With regard to the technical properties of operation, charcoal gas generators (especially those using fine charcoal) seem to be more suited for small high-speed engines than wood gas generators of current designs, mainly due to lesser weight and dimensions. The fuel cost will be higher, however, with charcoal.

Engine Requirements for Generator Gas Operation

From a thermodynamic viewpoint, generator gas driven engines work with combustion at a constant volume with a special ignition device; therefore, diesel and antechamber engines must be rebuilt to fulfill these conditions. Generator gas engines are regulated simply by varying the volume of gas entering the chamber; i.e., a ready-mixed gas/air mixture, volume regulated by a damper, is sucked into the engine during the intake stroke of the engine to the combustion space. Injection engines, regulated by variation of the fuel quantity—for which the regulation is then qualitative—are also usually changed in this respect. Two-cycle engines that suck fuel and air into the crankcase are an exception, in that it has proved to be favorable for power and fuel economy to supply generator gas directly to their combustion spaces by positive pressure. This is done to avoid flushing losses and leaks and also because the suction of the crankcase is inadequate, especially during idling. Rotation speed regulation is then done qualitatively by means of a damper placed in the gas conduit.

The chemical composition and moisture content of gas produced in the generators depends upon the magnitude and variation of the hearth load. Thus, engines with more constant operating conditions and whose design is characterized by a relatively large cylinder volume, low rotation speed, large valve areas, etc. (greater volumetric efficiency), generally are better suited for generator gas operation than are small high-speed engines with widely varying operating conditions. For two-cycle engines with small negative pressure the modification will be more complicated, even though their rugged construction and, as a rule, constant operating conditions compensate for this to some extent.

Stationary engines and large truck engines for long distance driving are more suitable for generator gas operation than are the engines of passenger cars or trucks for city traffic. The conversion costs in each individual case are affected by these general conditions. All engines that are to be rebuilt for generator gas operation must be redesigned and modified, in order to increase the engine power and reliability that are decreased by the special properties of the generator gas.

Power Decrease During Generator Gas Operation and Preventive Measures

The decrease of power during generator gas operation relative to liquid fuel operation is, first of all, due to the relatively lower effective heating value of the generator gas and to other circumstances that are important for thermal efficiency during combustion in the engine. As shown earlier, the thermal value of the gas/air mixture during generator gas operation is only approximately 70% of that obtained during gasoline operation. This is valid for a stoichiometric mixture. However, the generator gas allows comparatively large deviations from the theoretical air requirement because the combustion limits are relatively wide. Excess or deficit of air, however, causes further decrease of the power; for instance, 20% excess air corresponds to a power decrease of approximately 10% (see Figure 26). A heat value of the gas/air mixture of approximately 70% corresponds to a power loss of approximately 30%. For diesel engines, on the other hand, which normally work with a much greater surplus of air than gasoline engines, the power loss is much smaller. The heat value of the diesel fuel mixture amounts in some cases to no greater a value than that of the generator gas mixture (Figure 172). A power decrease also occurs in this case although of a smaller magnitude and for other reasons. In order to increase the heat value of the generator gas mixture in the engine some have tried to add liquid fuel during those conditions when the power need is particularly great. The air sucked in by the engine is then first used for the combustion of the liquid fuel, which is the reason that suction in the generator decreases and sometimes even ceases, if the fuel quantity exceeds certain limits. This means of power increase is very limited and, in practice, also causes significant disadvantages with regard to the reliability of the generator gas operation of the engine.

A second cause of power decrease is that during combustion of the generator gas in the engine, a decrease of volume occurs (decrease of molecular number) as opposed to the increase of volume for liquid fuels. This decrease is about 10% in the case of a stoichiometric ratio, and is largely independent of the composition of the generator gas. Another cause for the decreased power is that the polytropical exponent (gas compressibility) during the compression strokes of the engine will be somewhat higher for generator gas than for liquid fuel operation, due to altered molecular weights and heat capacities; thus the working surface of the indicator diagram will be a few percent smaller (steeper compression curve). Timing advances may also decrease the power by a few percent through increased compression work of the engine. Advanced timing is needed for generator gas operation due to the relatively low combustion velocity of the gas.

In order to regain these thermal losses without changing the size of the engine, either the compression ratio of the engine can be increased or the volumetric efficiency can be increased by using a supercharger.

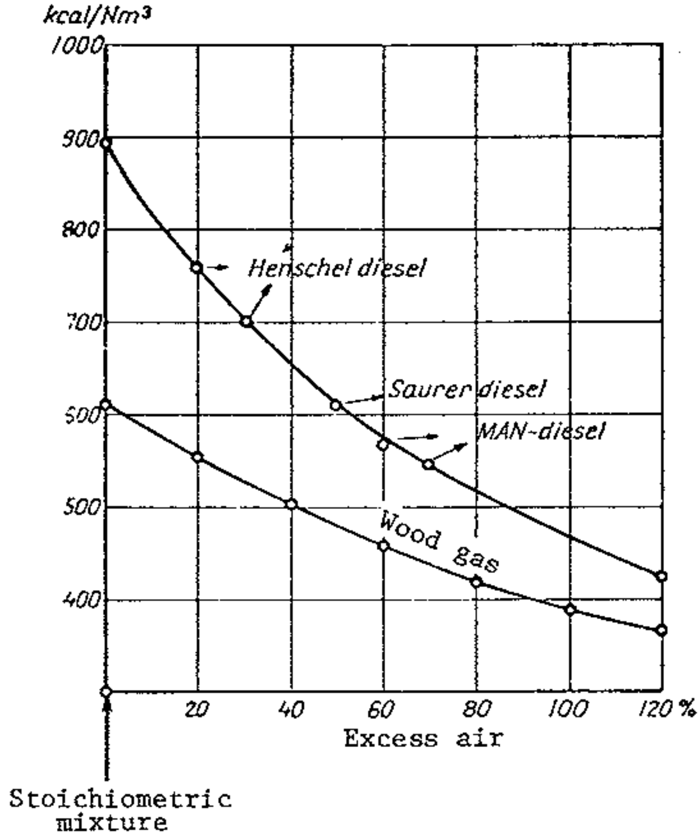


Figure 172. Heat Value of Fuel-Air Mixtures as a Function of Excess Air for Generator Gas and Diesel Operation.

As a rule, the compression, and thereby the thermal efficiency of the engine is increased, according to the relation term = 1 - $^{1-}$; here denotes the compression ratio, = C_p/C_v the exponent during adiabatic expansion, and C_p and C_v the specific heat during constant pressure and constant volume. As shown in Figure 173, the higher the compression ratio becomes and the greater the original compression ratio with liquid fuel, the smaller the increase. This fact, of course, is not valid for diesel engines, etc., where the compression ratio must instead be decreased for several reasons. The generator gas/air mixture has in itself a great nondetonating quality (octane value approximately 105); therefore, measures to increase the compression ratio of the engines for generator gas operation are limited only by considerations of the increased mechanical stress through increased combustion pressures. In Figure 174 theoretical combustion pressures are given for liquid fuels and generator gas as a function of various values of the compression ratio according to Hubendick, and corresponding values measured in experiments respectively by Richardo, Pye, and Finkbeiner (according to Tobler). Modern car engines work with compression ratios of up to seven and according to SAE information, we may within a decade expect further increases up to nine and ten, for which fuels with octane numbers of 95-100 already (1947) are being produced. Such engines are not designed to stand any further compression increase for possible changeover to generator gas operation, and for this reason it would probably not be necessary to make any engine modifications as are required in practice for the present car designs. It is a

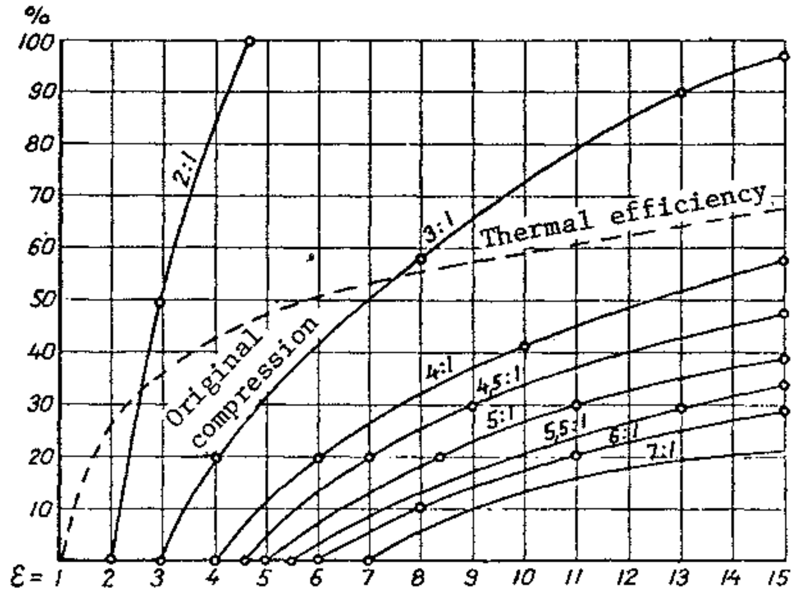


Figure 173. Percent Increase of Thermal Efficiency Due to Increased Compression Ratio, According to Expression $\eta_t = I - \varepsilon^{I-x}$

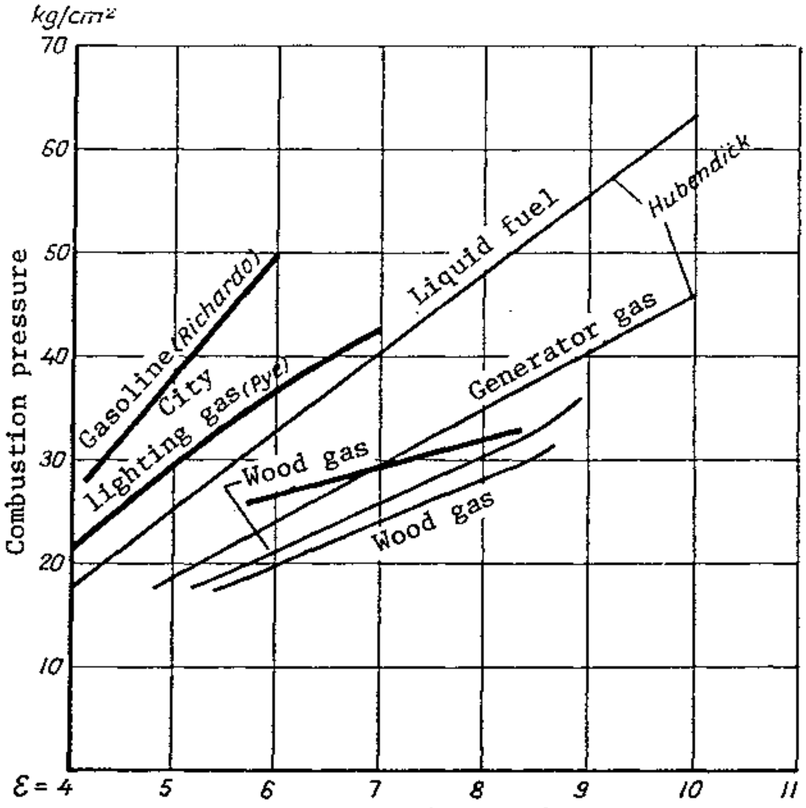


Figure 174. Combustion Pressures in Engines as a Function of Compression Ratio. (Thick lines are values determined experimentally, fine lines are calculated values.)

different matter in the case of engines which work with fairly low ε-values; for instance, tractors and certain other large two- or four-cycle engines. Design measures for various types of engines in these cases are described later under the respective engine headings.

The other measure for power increase during generator gas operation is supercharging. Theoretically, the following power may be obtained according to the gas laws.

$$\frac{N_k}{N_n} = \frac{T_n}{T_k} \cdot \frac{p + p_1}{p} \tag{69}$$

Here N_k is the power during compressor operation; N_n, the power without a compressor; T_n, absolute temperature without a compressor and T_k with a compressor; p, the total pressure of the gas without a compressor; and p_1, the pressure increase through it. Naturally, one must allow for a certain power loss through the operation of the compressor. In some designs the power loss through the compressor has been too significant to make the device worthwhile. On the other hand, exhaust-driven turbines, which will be discussed later on, have greater development possibilities. For a given mechanical stress increase on the engine, theoretically the supercharger operation seems to give a greater power increase than increased compression. If the combustion pressure in a compressor-driven generator gas engine is as great as during gasoline operation, approximately 90% of the gasoline power will be obtained.

The above-mentioned power losses during generator gas operation amount to about 45% to 50% in comparison with gasoline operation, and approximately 20% in comparison with operation with diesel or antechamber engines. They can, as a rule, be only partially regained through various measures for the engines and then at the expense of the original safety margin. The decreased power means, for cars, a decrease of the average speed and a rather significant decrease of the acceleration ability (Figure 175), which may be considered equivalent to the difference between the maximum power delivered at the rear wheels of the car and the driving resistance in the form of rolling and air resistance, which is denoted as the normal load curve in the graph.

For boats, where the propulsion force is about proportional to the third power of the velocity, the decrease of the peak output (top performance) for the engine during generator gas operation will not be as disadvantageous for the maximum speed as for cars. A decrease of the maximum power of the boat engine by 30% decreases the maximum speed only by approximately 10%. As will be shown later on, full engine power and even some power increase is obtained during pulsator operation of two-cycle engines.

However, it may be said that most engines of high-speed cars are oversized; therefore, the power decrease during generator gas operation actually involves only an insignificant decrease of the average speed and increased trouble with changing gears. The latter may be reduced, however, by choosing a lower final drive ratio which is often available from various spare-part warehouses. For heavy trucks and tractors, the decrease of the peak power output is more inconvenient, but on the other hand, the design possibilities for power improvements in these cases are usually good.

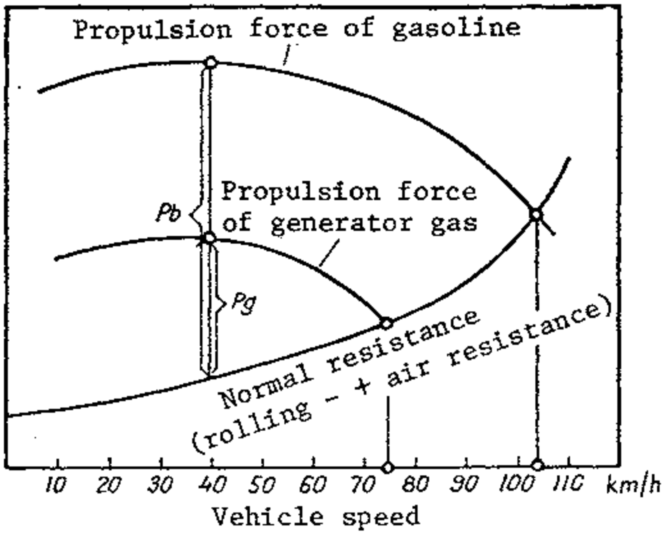


Figure 175. Comparison of the Power Characteristics of a Car during Gasoline and Generator Gas Operation. (P_b and P_g are excess power for climbing and acceleration during gasoline operation and generator gas operation, respectively, calculated at the rear wheels and for direct gear.) According to Gustafsson. [18]

Generator gas power may be lower than necessary due to pressure losses in the pipes, poor mixing proportions for gas and air, too high temperature and moisture content, etc. Improvements should be made in these respects for all types of engines.

In carburetor engines, the pressure loss in the intake manifold is significant, not only because of the construction of the carburetor but also because of the special shaping of the inlet pipe to obtain a good uniform mixture of the liquid fuel drops with the air and to prevent them from being deposited on the inside walls of the pipe. For this reason, the manifold has a rather rough inner surface and a great many sharp bends (for turbulence), a relatively small passage area to obtain high velocity (somewhat below the average velocity in the valve opening), and a so-called "hotspot" for heating the gas mixture. All these facts are unfavorable for generator gas, where the pipe should have a smooth inner surface, and bends of a large radius, and as large a passage area and short a length as possible. In order to avoid heating the gas-air mixture, especially in charcoal gas driven engines, the hotspot device should be disabled, since heating may affect the volumetric efficiency unfavorably. Figure 176 shows the heat value of the generator gas/air mixture before the engine (i.e., in the intake pipe), in percentage of the value at 0°C and 760 mm Hg, as a function of the gas and air temperature and the pressure. For instance, at an air temperature of 25°C, a gas temperature of 40°C and a pressure of 680 mm Hg (approximately 80 mm pressure drop in the intake pipe), a power loss of no less than about 23% occurs, which demonstrates how essential these facts are for generator gas operation. Figure 177 shows "normal" values of the pressure loss or the resistance in the generator gas piping and the intake pipe at velocities from 20 to 90 km/hr for an automobile. The resistance at the highest speed in the intake pipe itself is 40 mm Hg, or approximately 540 mm water. During operation, the resistance of the gas generator may increase, through fouling, to several meters of water. According to the general equation of state of the gases, a pressure decrease of 100 mm water or a heating of the fuel air by 10°C is equivalent to a power decrease of 1% and 3% respectively.

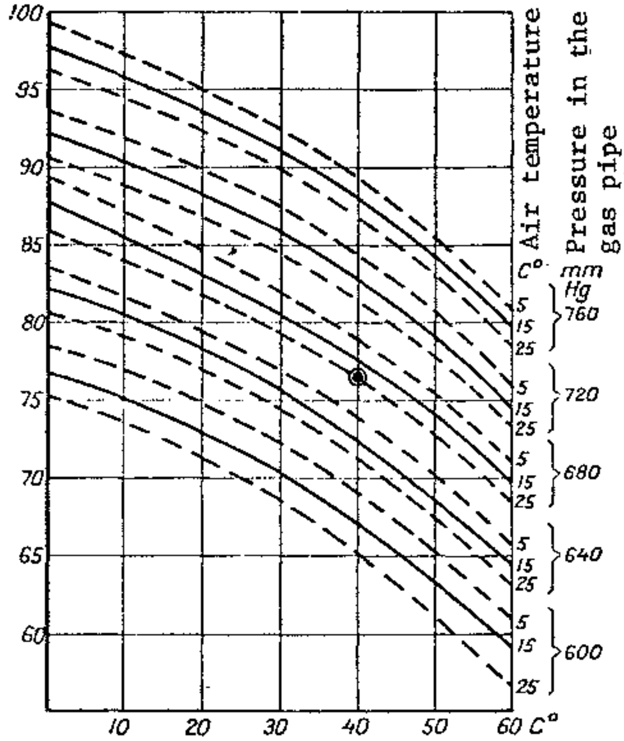


Figure 176. Heat Value of the Gas-Air Mixture in % of the Value at 0°C, 760 mm Hg.(Gas 100% and air 50% moisture saturated, mixing proportion 1:1) (Finkbeiner)

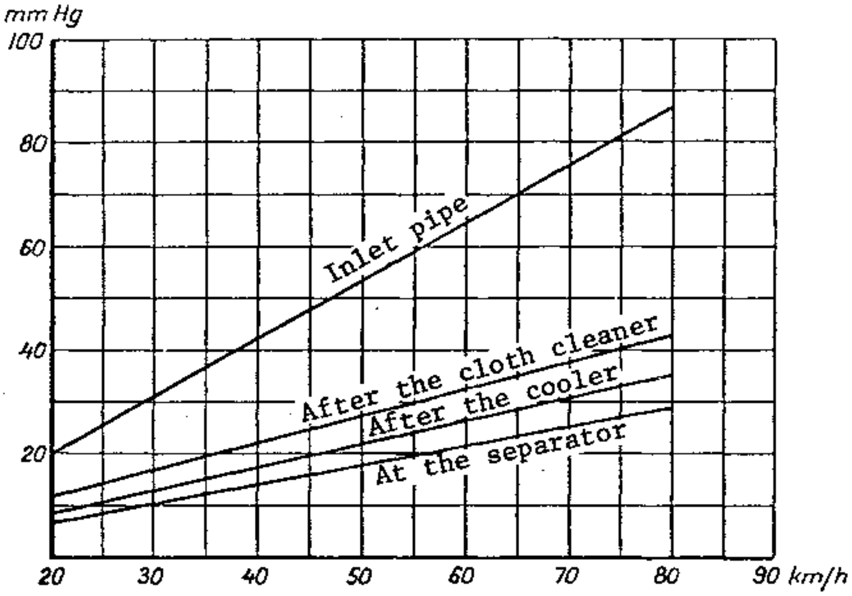


Figure 177. Pressure Losses in the Gas and Gas-Air Pipe to the Engine at Various Speeds for a Generator Gas-Driven Car, According to Gustafsson.[18]

The range between the lower combustion limit at maximum excess air to the upper combustion limit with a maximum fuel/air ratio is very great for the generator gas/air mixture; many times greater than for the gasoline/air mixture. This makes it possible to regulate mixing the generator gas with secondary air by hand with a simple damper. The function of automatic mixers is conditioned by the pressures in the gas and air manifold; they regulate the air quantity in relation to the gas quantity in a constant proportion independent of variations in pressure, for instance from soot formation, in the gas pipe from the generator. These regulators, however, as mentioned earlier, cannot change the air mixture according to the quality of the generator gas, which during intermittent conditions frequently may undergo rather great changes that also change the stoichiometric air requirement. For this reason there should first of all be a device for manual adjustment of the secondary air, perhaps in combination with an automatic mixer for more constant operating conditions.

Excessive moisture content in the generator gas also causes power decrease. If the wood in a wood gas generator contains 20% moisture, corresponding to ordinary air-dried car wood, approximately 0.3-0.4 kg water will form from 1 kg wood in the generator; this water will accompany the wood gas in the form of water vapor. During mixing with secondary air, which has a significantly lower temperature, there is a tendency for the water vapor to condense; this can cause the small soot particles always present in the generator gas to be deposited on the walls as dirt deposits that contain water and are similar to tar. By preheating the secondary air such condensation can be avoided, but the dust in the gas will then enter the engine. It is often best to locate the inevitable condensation caused by the secondary air at an accessible part of the pipe system with a condensation-water collector with a draincock. The effect of the moisture content of the wood on thermal value and power is shown in Figures 178 and 179 (also see Figure 30).

In general, good gas cleaners, mixers, and condensors cause pressure losses of up to a couple of hundred mm water column; this disadvantage is, however, outweighed by the advantages that have been proven in practice.

Engine Design Changes for Conversion to Generator Gas

Carburetor Engines

Most mobile engines suitable for generator gas operation are of the four-cycle carburetor type intended to be operated with gasoline or, in the case of tractors, with engine kerosene. They can be relatively easily converted to generator gas operation. The extent of engine modification will depend on whether or not the power requirement is of decisive significance for the operational purpose. On the whole, the engine changes will include the following measures.

I. ORDINARY MEASURES FOR CONVERSION TO GENERATOR GAS OPERATION

a. Change of the fuel system.
b. Change of the electric system.
c. Change of the controls.

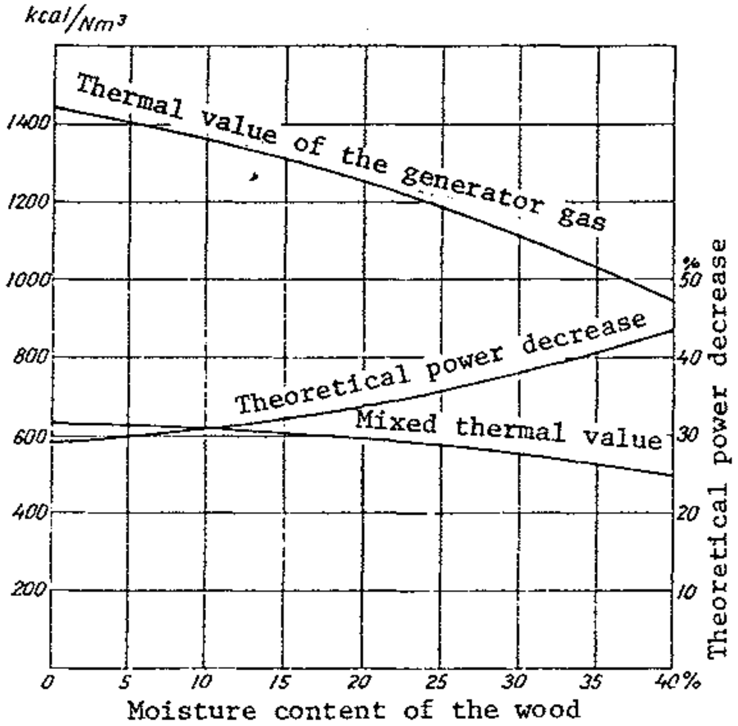


Figure 178. Effect of Moisture Content of the Wood on the Power of a Wood Gas-Driven Engine. (Schläpfer).

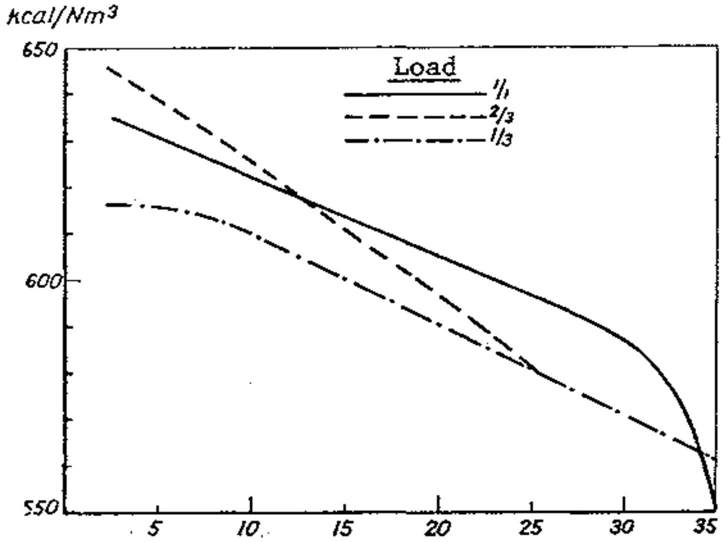


Figure 179. Theoretical Mixed Heat Value as a Function of the Moisture Content of the Wood at Various Loads, according to Gustafsson.[18]

II. SAFETY MEASURES

a. Installation of a garage carburetor with a tank.
b. Sealing of the engine and pipe system.
c. Control of the air and oil cleaner.

III. SPECIAL MEASURES FOR POWER INCREASE

a. Compression increase.
b. Supercharger construction and installation.
c. Replacement of the intake pipe.
d. Lower final drive/gear ratio.

Passenger cars and small trucks (delivery trucks) can usually be operated satisfactorily with the generator gas power obtained through the measures in items I and II in the list above. The existing carburetor and also, as a rule, the fuel tank are removed, after which the intake manifold is connected to the pipe for the generator gas/air mixture and parallel with the garage carburetor, which is to be used for starting and driving indoors. The throttle and ignition systems are changed for generator gas operation. The air cleaner and secondary-air piping details are discussed in Chapter 6. The relatively small high-speed engines are nowadays almost always overpowered for their operational requirements; the power decrease of 40% to 50% caused by the measures just described for the conversion to generator gas involves fewer disadvantages than might be expected. Cars of this kind are, as a rule, converted to generator gas operation only out of necessity and the decrease of average speed and the increased gearshifting requirement during generator gas operation must be accepted, since use of the car is made possible during times when liquid fuel cannot be obtained.

As these engines generally have compression ratios of about seven, the power increase through further increase of the compression is hardly justified from a technical or economical viewpoint. In Figure 173 it was shown that an increase of the compression ratio from seven to nine leads to an increase of the generator gas power by approximately 10%; Figure 174 shows that at the same time the combustion pressure is increased from approximately 30 to 40 kg/cm^3, which may have dangerous mechanical consequences for the engine. Also, problems may arise with ignition at a compression ratio as high as nine.

On the other hand, much may be gained by replacement of the intake manifold (Figure 180), in some cases up to a 10% to 15% power improvement. A 10% lower final drive ratio sometimes can also considerably improve the drivability and decrease the gearshifting requirements. In many cases there are final drives available with various gear ratios for standard cars.

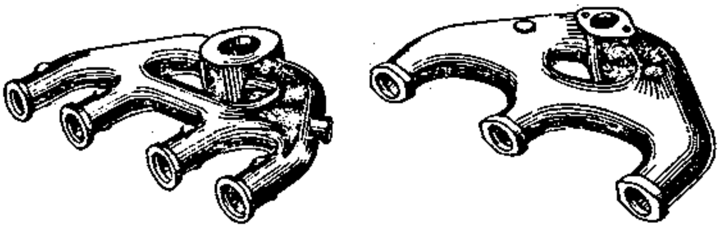


Figure 180. Specially Designed Intake Manifolds for Generator Gas Operation (Volvo, Chevrolet).

Large trucks, tractors, and power tools often need the greatest possible power; more extensive changes may be justified for this reason. Operating conditions and engine design are also usually favorable for generator gas operation, since these engines, as a rule, have rather constant operating conditions, low rotation speed, and low compression. The compression ratio for truck engines is rarely higher than 5.5-6 and for tractors running on engine kerosene, at the most 4.5. In this case good results may be achieved by increasing the compression ratio. This is done by decreasing the volume of the engine's combustion space—in the case of flathead engines, with a new cylinder head; in the case of overhead valve engines, with new higher pistons. When a new head is installed it should have a shape suitable for the combustion chamber so that the intended power gain through the compression increase is not eliminated by impaired combustion conditions or a decreased volumetric efficiency. It is not, as a rule, advisable to plane off the existing cylinder head since this almost always involves a constriction of the intake gas just above the inlet valve. This is clearly demonstrated in Figure 181 which shows the shape of a modern combustion chamber for flathead engines. Figures 182 and 183 show high compression pistons for overhead valve engines. If the engines are worn, the cylinders should usually be rebored when the pistons are exchanged. The piston head should be given a shape such that whirl formation will be facilitated. If the compression ratio has been increased for generator gas operation, then it must be restored to its normal value when going back to gasoline operation.

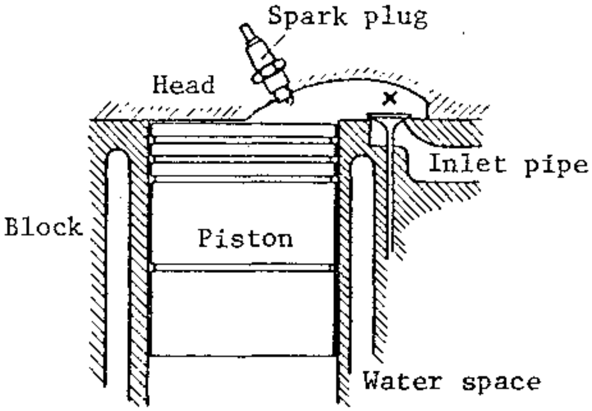
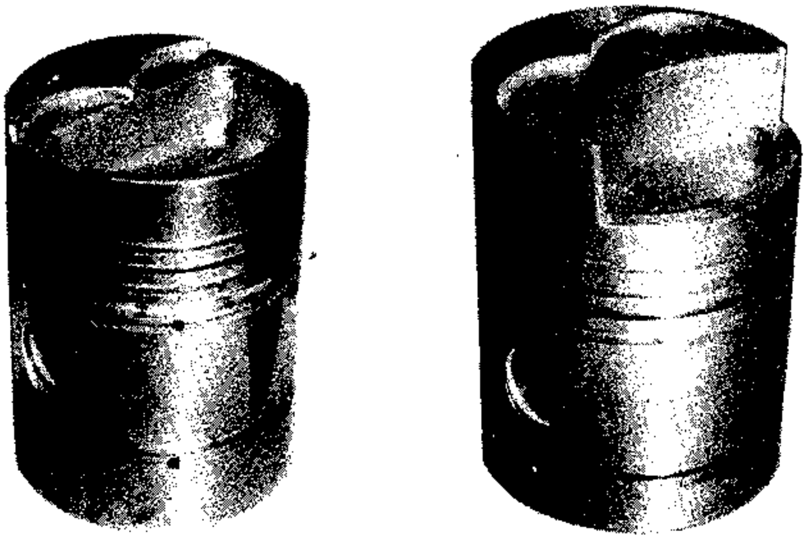


Figure 181. Combustion Space in a Slide-Valve Engine, According to Richardo's Principles. (If the cover is planed off there will be a constriction at x.)

Power increase through a supercharger will be described later on in this chapter. Since such a device is relatively expensive, it has not been common so far for cars. It is, however, not improbable that certain types of exhaust-gas-driven compressor devices will prove to be favorable for generator gas operation in that they increase the net power without significantly increasing the mechanical stresses on the engine.

Diesel and Antechamber Engines, Four-Cycle Type

Mobile genuine diesel engines of a four-cycle design and of a size that makes them suitable for operation with generator gas are rare. A preferred compromise is the antechamber engine, which works with a somewhat lower compression ratio and runs more



Figures 182-183. Special Pistons for Increased Compression for Generator Gas Operation (overhead valve engine). Volvo and Scania-Vabis

smoothly with a higher mechanical efficiency as compensation for somewhat increased thermal losses in compression as compared to the unadulterated diesel engine. The fuel economy is about the same for both kinds of engines.

The antechamber engines are, as a rule, designed so that the antechambers are replaceable; they also have an electric heater plug for starting a cold engine. By taking out the antechambers and inserting suitable plugs, the compression ratio can be adjusted. The resistance of the electric ignition devices to high pressure primarily determines how far the compression ratio is to be decreased. Frequently its maximum is fixed at approximately 9.5 to 10. In some engines the pistons also must be exchanged for shorter ones or, rather, pistons with concave heads, so that combustion takes place mainly inside the piston. Instead of the heater plugs just mentioned, ordinary spark plugs are put in with heat ranges that correspond to the high pressures and combustion temperatures. The existing intake manifold can often be used, since, even in oil operation, it is designed to give the smallest possible pressure loss as opposed to the case in carburetor engines. As has already been pointed out, diesel engines (excess air ratio approximately 1.7) and also the antechamber engines (excess air ratio approximately 1.4) work with relatively large amounts of excess air. This is the reason that the thermal value of the fuel mixture of an oil-fueled engine frequently is only insignificantly greater than that of a good generator gas mixture (excess air ratio approximately 1.1). The power decrease involved in the changeover to generator gas is therefore fairly trivial. Since the bearing pressures are decreased during generator gas operation, thinner oil may be used in the engine, whereby starting is facilitated and also some power increase obtained. Figure 184 shows an antechamber engine rebuilt for generator gas operation with a simple intake pipe and a starting carburetor. Since the compression ratio after the generator gas changeover still is relatively high, 9.5 to 10, gasoline cannot be used when driving with a garage carburetor without a high proportion of alcohol or tetraethyl lead to increase the octane number.

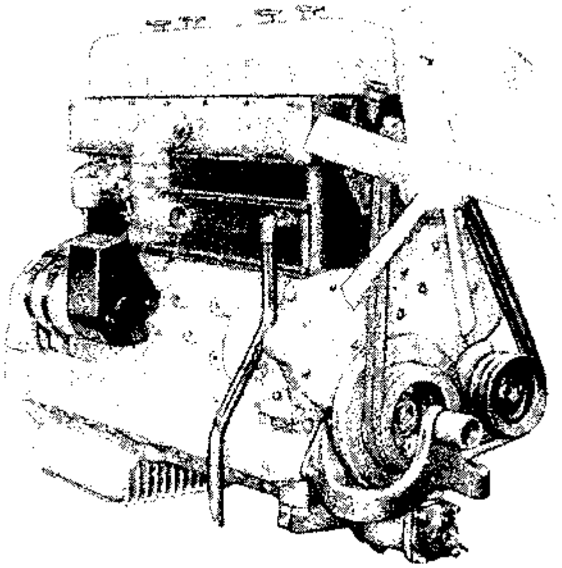


Figure 184. Antechamber Engine, Rebuilt for Generator Gas Operation (Scania-Vabis)

Hesselman Engines

The Hesselman engine is a low pressure injection engine with an electric ignition device. In order to obtain the necessary mixing of fuel and air, this engine has the pistons and combustion space specially shaped to obtain an intense whirling, which is also favorable for generator gas operation. The Hesselman engines can easily be converted to generator gas by removing the injector devices and connecting to the generator gas pipe, and installing a garage carburetor in the usual manner. A compression increase is not necessary as a rule, since these engines most often work with a somewhat higher compression ratio (ε = approximately 7) than the carburetor engines. Suitable threaded plugs are put into the threaded holes for the injector nozzles.

Two-Cycle Ignition-Bulb Engines

Due to their simplicity and reliability, and because they can be operated with inexpensive fuels, two-cycle ignition-bulb engines have come into widespread use in many areas of importance for the economy; for instance, ship engines, power equipment, stationary or semimobile-stationary operation of electric generators, lumber mills, farming, gravel crushers, etc. The possibility of also operating these engines with generator gas is therefore of great importance.

There are certain difficulties involved in generator gas operation of two-cycle engines. For instance, the gas-air mixture cannot be sucked immediately into the combustion space but must be added either through the crankcase or by a special pump. (The latter is more common.)

The gas-air mixture, in spite of all cleaning devices, always contains some solid particles and water vapor, which during condensation are immediately deposited as dirt. The tendency to deposit is much greater in two-cycle than in four-cycle engines, since condensation of moisture in the fuel mixture in the two-cycle engine is not prevented or counteracted by compression and combustion heat.

Ignition-bulb engines have a relatively weak and pulsating suction that puts high demands on the design of the gas generator, especially under idling conditions. Flushing the cylinders with an excess fuel-air mixture involves fuel losses that may affect generator gas operation very unfavorably with regard to distance travelled, as in the case of boats. Introducing the generator gas into the crankcase also involves some risk of leakage of toxic carbon monoxide. The ignition with glow plugs normally used for these engines cannot be used for generator gas operation. Ignition with the help of liquid fuel and a turbulence chamber for generator gas operation has also proved unreliable. Electric ignition with a spark plug—as a rule, two for each cylinder—is not only most reliable, but also provides the best power, since the ignition time can be set to fit the operating conditions.

Two systems for the conversion of ignition-bulb engines to generator gas operation are characterized by the way fuel is supplied to the engine cylinder. In the ordinary way, fuel is supplied by the crankcase (the crankcase system) or else directly to the cylinder through controlled or gravity-operated valves activated by overpressure. This pressure is obtained either through a separate gas pump operated from the engine, or by the pumping effect of the crankcase, although the generator gas is not allowed to enter the crankcase. About the same or even greater power is obtained for generator gas operation with the latter system. This is due less to increased filling than to an improved shape of the combustion chamber and the advantages of the electric ignition. [5,6]

<u>The Crankcase System (Jonkoping's Engine Factory, Inc.)</u>. In the crankcase system, the changes for generator gas operation are limited to the following:

a. Arrangement of an inlet valve for the gas/air mixture in the crankcase;

b. Introduction of an electric ignition device;

c. Safety valve in the crankcase to protect against crankcase ignitions;

d. Centrifugal regulator for the gas damper.

Starting usually is accomplished with liquid fuel, and for changeover to generator gas operation the gas generator must be fully ready for operation, rendering combustible gas. If the generator were to be fanned up by the engine, considerable fouling of the inlet valve and engine crankcase would take place.

The advantages of the simple changeover are counterbalanced, however, by considerable disadvantages, a few of which have already been mentioned: considerable fuel loss caused by the flushing with gas/air mixture; great risk of fouling the engine; poor idling; risk of gas leakage through the main bearings, etc.

This arrangement is shown schematically in Figure 185.

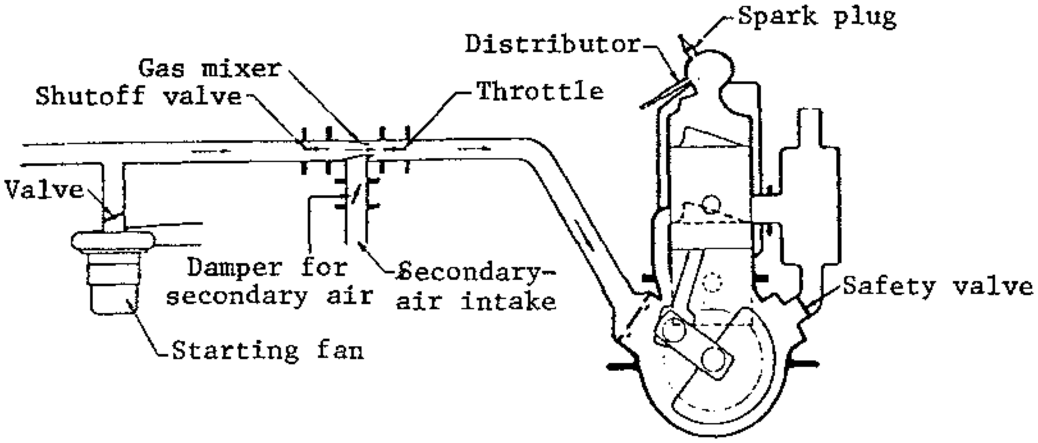


Figure 185. Two-cycle Ignition-bulb Engine, Converted to Generator Gas Operation According to the Crankcase System.

Gas Pump (Skandiaverken, Inc.). In the system with a separate gas pump, air is taken through the regular air intake of the engine into the crankcase, thence to the combustion space in the cylinder. Its head design with an ignition bulb is, however, exchanged for a cylinder cover with a valve, operated from the crankshaft and mechanically operated by means of an eccentric for taking in generator gas, and an electric ignition device with, as a rule, two spark plugs per cylinder. A reciprocating pump or compressor operated from the engine shaft pumps the generator gas from the gas generator to the cylinder through the mechanically operated valve. Regulation of engine speed is done by means of a butterfly valve (throttle) arranged in the gas pipe to the compressor; thus there is no qualitative filling regulation in this case. Through this device, schematically shown in Figure 186, good results are obtained for both power and fuel economy. This conversion is, however, relatively expensive, which is why it is more suitable for large single or multicylinder ignition-bulb engines, such as those for ships.

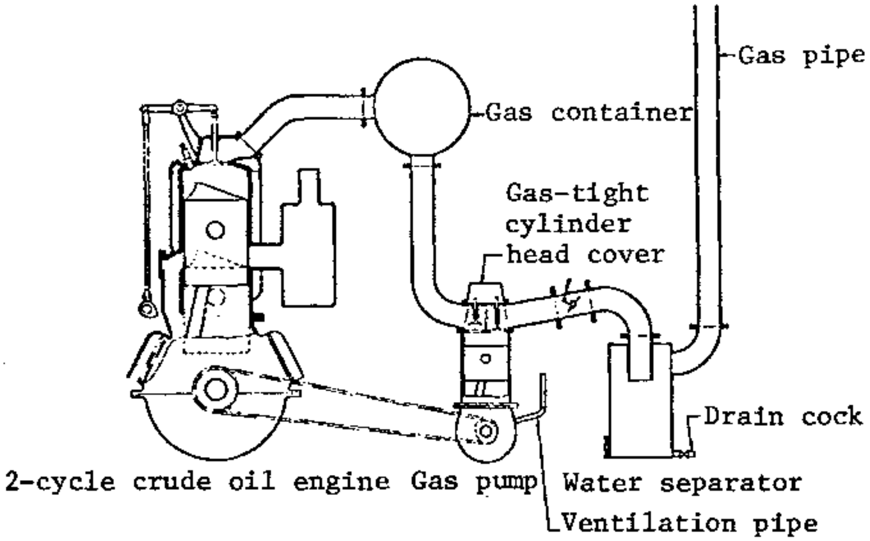


Figure 186. Two-cycle Ignition-bulb Engine, Converted to Generator Gas Operation with a Separate Gas Pump.

In order to make the conversion less expensive it would be conceivable to use gravity operated valves, which open automatically through the pressure changes. Due to the mode of operation of such valves, some power decrease due to pressure drop must be taken into account as well as risks of functional trouble through fouling.

The Pulsator System (Swedish Generator Gas Co., Blomquist). In the pulsator system, pressure variations in the crankcase are utilized to suck the gas from the gas generator and force it into the combustion space; thus a special gas pump is not needed. Flushing and combustion air is sucked into the crankcase in the usual way through a one-way valve (see Figure 187), but is fed into the valve through a short pipe equipped with a damper. During the induction strokes of the piston through an adjusted constriction of this damper an underpressure is obtained in the crankcase corresponding to the flow resistance in the gas generator. As in the gas pump system, the head of the engine cylinder is replaced by a cylinder head with a mechanically operated valve and electric ignition.

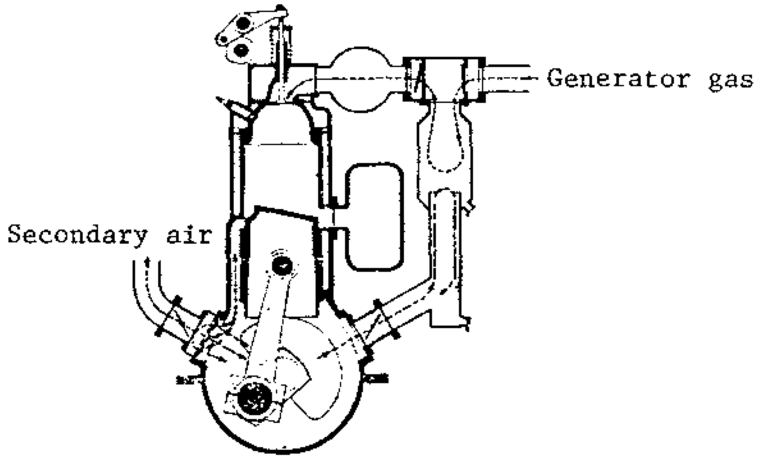


Figure 187. Two-cycle Ignition-bulb Engine, Converted to Generator Gas Operation with the Pulsator System (relatively low speed).

In the gas pipe from the gas generator to the combustion chamber, a valve chamber called the pulsator chamber is located close to the engine, and is connected with the crankcase by means of a pipe, the pulsator pipe. Through pressure variations in the crankcase, the generator gas is subjected to a pumping effect in the pulsator pipe and chamber, and is thereby sucked from the gas generator to the chamber, then forced out from it to the cylinder. Double one-way valves, opening toward the engine in the pulsator chamber, allow some quantity of gas to be sucked and forced to the engine with each pressure variation. In low-speed engines, there is a container between the pulsator chamber and the engine for equalization purposes. The pulsator chamber and the pipes are of such dimensions that the gas is not sucked into the crankcase before the pressure increase, which conveys gas to the engine, begins. The engine valve is kept open below approximately 90° for low-speed engines, so that the opening occurs about 25° before the bottom dead center, when flushing in the engine has gone so far that approximately atmospheric pressure prevails in the cylinder. The gas then enters the combustion space during some overpressure, is mixed with the air that has come in, and is compressed.

Power is regulated by means of a damper placed in the pulsator pipe; it increases or decreases the pumping power of the crankcase in relation to the gas generator. Here, as in the case of the gas-pump device, there is qualitative filling regulation. By combining the regulating damper with a centrifugal regulator it is possible to maintain constant engine speed independent of load changes for the engine (within limits governed by the engine design).

For high-speed ignition-bulb engines the pulsator principle, as described above, proved to be unsuitable. In such cases the pulsator pipe running from the crankcase is connected to the side of the cylinder opposite the pulsator valve (in this instance, a one-way valve), through which the gas sucked in from the gas generator immediately reaches the overhead valve of the cylinder. Gas resistance is thus reduced to a minimum, which makes a higher rpm possible. With this device, however, the specific fuel consumption is increased (Figure 188).

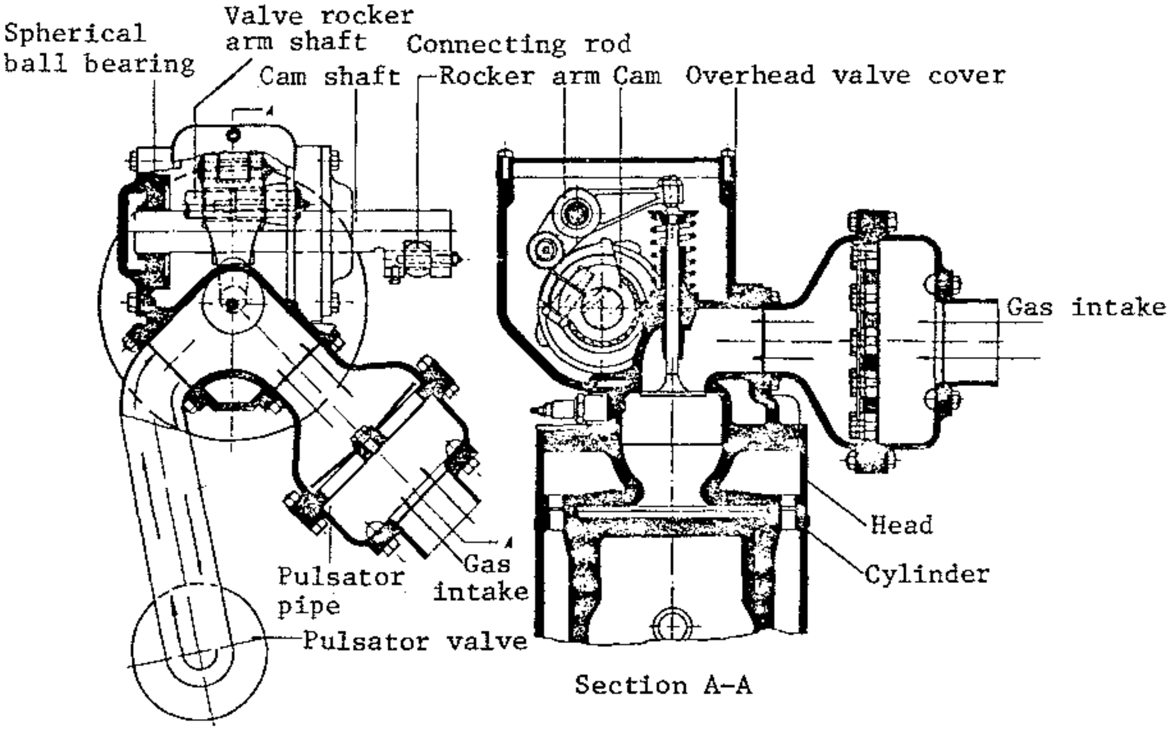


Figure 188. Pulsator System for High-speed Two-cycle Engines.

Through standardization of the cylinder cover and the valve device, in combination with a spacer (designed for various types of engines) between the cylinder block and the pulsator cover, it has been possible to adjust the pulsator system (Figures 189-190), with only a few variations, to a great number of two-cycle engines of extremely heterogenous types and dimensions.

Bolinder-Munktell (Wallgren-Evrell). An overpressure procedure was used in Bolinder-Munktell tractor engines. The conversion of the oil-driven tractor engine comprises, according to Figure 191, the following steps. (The conversion concerns Bolinder's tractor engine, a semidiesel type W-7.)

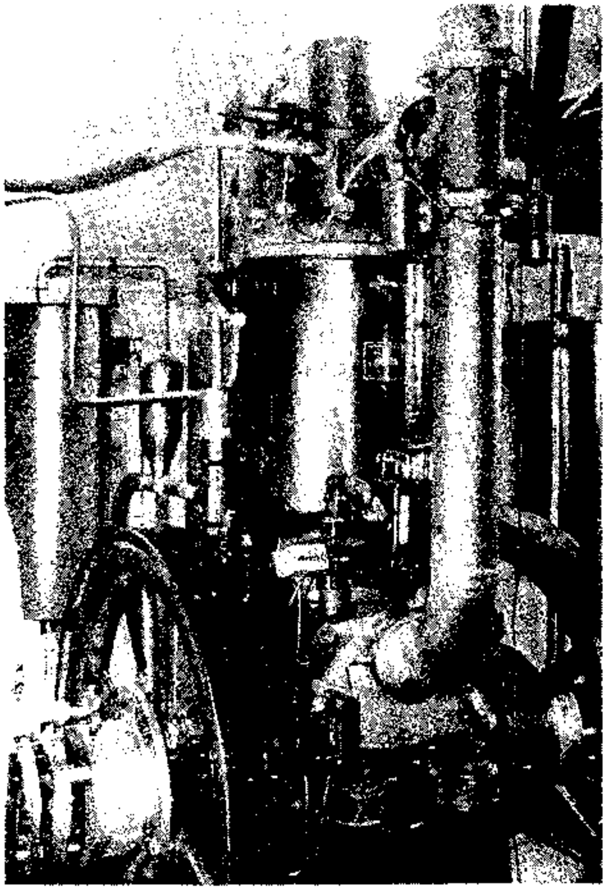


Figure 189. Pulsator Converted Low-speed One-cylinder Ignition-bulb Engine.

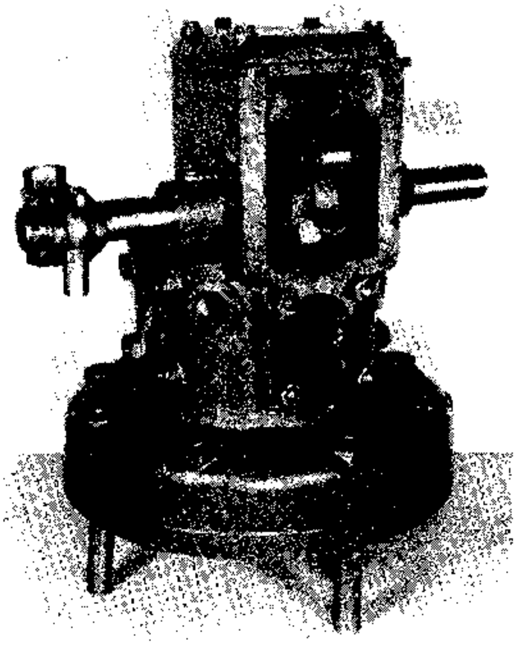


Figure 190. Standard Diesel Pulsator Conversion. (Cylinder head with a camshaft and spacer.)

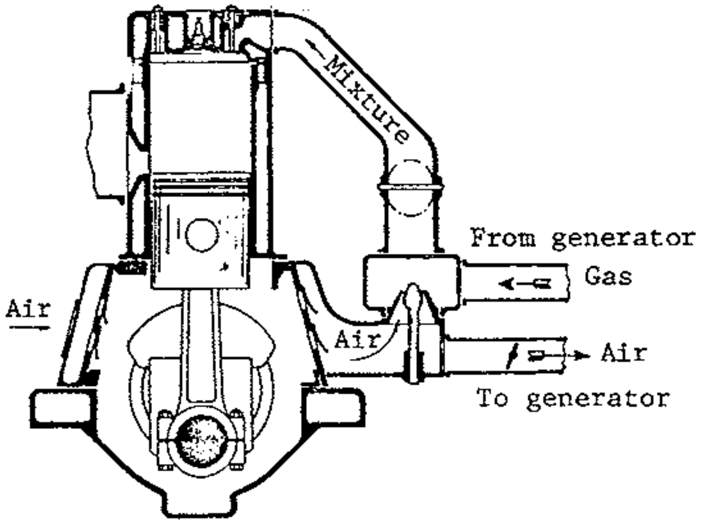


Figure 191. Bolinder-Munktell's Two-cycle Tractor Engine, Type W7, for Generator Gas Operation (Automatic valves in the engine, overpressure in the generator).

The air channel between the crankcase and the cylinder was shut off by a covering plate. The air valves on the regulator side were replaced by two flapper valves. To these were connected a distribution chamber for air and a mixing chamber for generator gas/air with a damper-regulated pipe to the cylinder cover. The cylinder cover was replaced by a special cover with automatic valves and spark plugs.

The engine was equipped with a magnet device and cam-controlled starting valves. The device works in the following way. The piston, during its upward movement, sucks in only air to the crankcase through the intake valves. During the downward stroke, the air in the crankcase is compressed and forced out through one-way valves to the distribution chamber, from which some goes to the gas generator primary air, and some to the mixing chamber secondary air, where it is mixed with generator gas from the generator, which during the air inflow from the crankcase is subjected to overpressure. The gas/air mixture passes from the mixing chamber through a regulating damper to the valves of the head. When the escape gate, during the downward stroke of the piston, has been uncovered, pressure in the combustion space is somewhat lower than atmospheric pressure, whereas the generator gas mixture outside the inlet valves has some overpressure. The gravity-operated valves are automatically opened and they let in the gas mixture which during the upward stroke of the piston is compressed and ignited by means of the spark plug. Here, there is quantitative filling regulation. In order to obtain low spring tension of the inlet valves, sometimes up to six are arranged in the cover. The entire conversion is costly but renders, as do the gas-pump and pulsator systems, full oil power. The gravity-operated valves invite functional trouble, however, especially because they are highly dependent upon the purity of the generator gas mixture to prevent clogging. Overpressure in the generator makes it impossible to refill fuel during operation, unless changeover to liquid fuel is possible in the meantime.

Two-Cycle Carburetor Engines

An increasing number of two-cycle carburetor engines for outboard motors, motorcycles, and small cars have come into use in recent years. Due to small dimensions and high rpm they are, in principle, not well suited for operation on generator gas, although the conversion would be rather simple because of their design, which theoretically is in accordance with the conditions for generator gas operation. As their lubrication under normal conditions is almost always done by mixing lubricating oil in the liquid fuel, a special injection device for lubricating oil must be arranged for generator gas operation, as a rule in the transfer pipe to the combustion pipe. There has not been any appreciable factory production of gas generators for these small engines, but handy engine owners have kept their machines running with homemade gas generators, which, however, require extremely careful and skilled maintenance.

It is conceivable that, if the number of small engines of this type increases considerably, a solution of the generator gas problem will be brought forth by necessity. Briquettes with a high heat value would seem to be a suitable fuel in that case.

Ignition System for Generator Gas-Driven Engines

Ignition Method

The ignition process in an engine cylinder may be divided into *the ignition time*, which is the time required to reach ignition temperature after local heating of the gas mixture, and *the combustion time*, which is the time required to achieve combustion. [10a,26a] It can be mathematically proven that the energy needed for ignition is decreased when the rate of the energy supply is increased. Experiments by the American, Morgan, showed that the greatest possible volume of gas has its temperature increased to ignition (corresponding to a minimum of ignition time) by a spherical heat source. An electric spark between the electrodes of the spark plug at the first moment appears as a bright glow during a very short time, about 1 μs (10^{-6}s), immediately followed by an electric arc of relatively long duration, about 500-1000 μs. The former part is called the capacitive component of the spark and it has, in spite of the high voltage and high current strength, relatively insignificant energy due to its short duration. The latter part of the spark is called the inductive component and carries most of the electric energy supplied to the spark plug. It has been experimentally established that the fuel mixture is ignited without the assistance of the high-energy electric-arc component of the spark. The electric energy excess from the ignition device, appearing in the shape of a more or less "thick" spark, is mainly used as a reserve. It is utilized when the flash-over resistance between the spark plug electrodes, for various reasons, has increased and the voltage requirement at the spark plug has increased accordingly. Too great energy in the spark is harmful to the life of the electrodes.

It will be seen from the foregoing that ignition by an electric spark should be more favorable than any other known ignition method for engines, owing to the fact that such a great energy quantity is supplied in such exceedingly short time by the capacitive component of the spark.

The combustion time itself is conditioned by the spreading velocity of the ignited "flame front" of the gas volume. From an engine design viewpoint this time, which is significantly longer than the ignition time, would seem to be of the greatest importance. The flame velocity is conditioned by the chemical properties of the gas mixture, pressure, temperature, moisture, etc., as well as by the turbulence and diffusion. The combustible components of generator gas are carbon monoxide and hydrogen, the former with a low flame velocity of approximately 0.5 m/s maximum, the latter with a high flame velocity of approximately 3 m/s maximum (see Chapter 2). For gasoline, the corresponding value is approximately 3 m/s. Wood gas, due to its higher content of hydrogen, is somewhat better off in these respects than charcoal gas. Thus, generator gas has, due to its chemical composition, poorer combustion characteristics than gasoline. Added to this is the fact that, during operation, generator gas as opposed to gasoline constantly undergoes considerable changes of chemical composition, pressure, moisture, etc., whereby the average combustion rate becomes lower than is indicated by the figures mentioned above. This is true even for constant operation, but to an even larger extent for varying operating conditions, as in the case of motor vehicles.

The time available for combustion of the gas mixture in the engine is, especially at higher rpm's, very limited. In order to obtain as complete combustion as possible, the ignition must take place before the piston reaches the top dead center of the compression stroke; the higher the rpm, the earlier. For engines with varying rpm, the ignition advance must therefore be constantly changed with the rpm, which frequently is done automatically with the help of a centrifugal regulator. But also in engines with more constant operating conditions (stationary engines, boat motors, etc.), it should be possible to change the ignition setting in the case of generator gas operation to meet various demands during starting as well as during operation. This can only be done manually. Electric spark ignition is the only ignition method where the time of ignition can be controlled in this way, automatically and manually, and, therefore, is the only possible alternative for generator gas operation. Engines that normally work with other ignition methods, such as compression ignition (diesel and antechamber engines) or ignition bulb, must be equipped with an electric apparatus for spark ignition when being converted to generator gas operation.

The demands on the electric equipment for ignition and starting in generator gas operation are greater than for gasoline engines. Therefore it is not always possible to use existing electric systems for engines with electric ignition, when changing over to gas operation. Some changes and parts replacement may be necessary.

Battery or Magneto Ignition

On the whole, the same views concerning the suitability of battery or magneto ignition are valid for the ignition system for generator gas operation as for gasoline operation. They are both equally reliable and have similar ignition properties if they are well designed. Since it is beyond the scope of this section to deal more closely with the functions of these different systems, only wiring diagrams are given for them here (Figures 192 and 193). Most motor vehicles have battery ignition, in spite of the higher initial costs (before mass production), which probably is due to the need for illumination and the possibility of using electric starting. Since the starting requirements are significantly

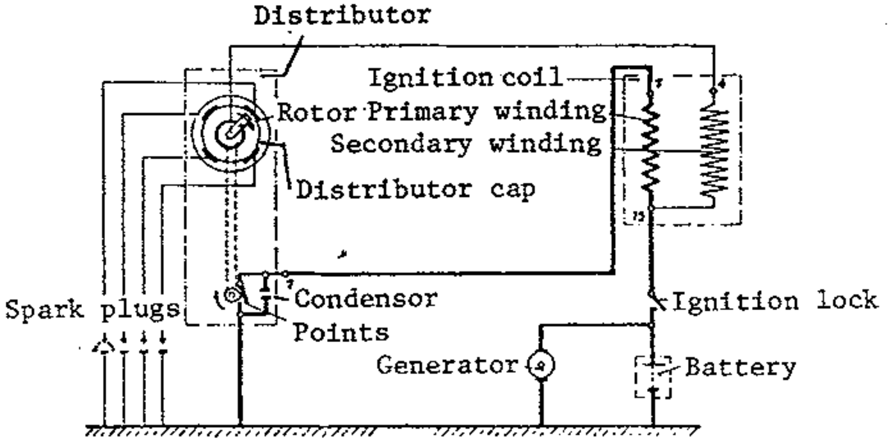


Figure 192. Schematic for Battery Ignition (Robo Co.)

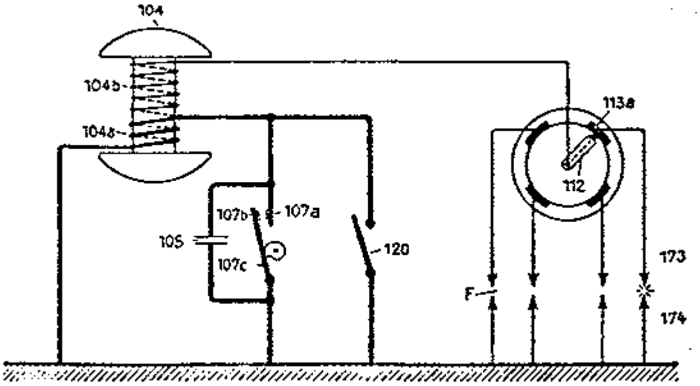


Figure 193. Schematic for Magneto Ignition

104 = Armature
104a= Primary winding
104b= Secondary winding
105 = Condensor
107a= Contact-breaker switches
107b= Contact-breaker points
107c= Contact-breaker arm
112 = Rotor
113a= Distributor segment
120 = Short-circuit switch
173 = Center electrode
174 = Side electrode
F = Spark gap

greater for generator gas operation than for gasoline operation, it is best to choose battery ignition, when an engine which lacks an electric system is to be converted to generator gas operation. The battery is used not only for operation of the starting engine but also for operation of the starting fan. In addition, when there is a battery, illumination can be arranged inexpensively, which very often is a great advantage. Generator gas operation is in itself so much more difficult than gasoline operation, that one should try to facilitate it as much as possible. When going back to liquid fuel operation, the battery, starting engine, and illumination can be retained in most cases, even though the electric ignition device is no longer required. When engines which are already equipped with electric ignition are converted to generator gas operation, the question concerning battery or magneto ignition may also become important.

As mentioned, most carburetor engines already have battery ignition, but in those cases where magneto ignition is to be found, a changeover to battery ignition should be considered, especially with regard to improved starting possibilities, electric operation of the starting fan, and better regulation of the ignition setting, but also with regard to electric illumination.

Sometimes it is necessary to keep the magneto ignition for economic reasons; for instance, in tractors, stationary engines, or boat motors. In such cases the magneto must give off a sufficiently powerful spark during starting. The magneto should be equipped with an impulse starter, since the directly connected magneto, as opposed to the battery ignition apparatus, gives low voltage at low rpm's. The impulse starter consists of an elastic coupling between the drive shaft and the magneto shaft and a cam device which periodically retains and releases the magneto shaft, at which time a spring twists the magneto axle a few degrees with great speed at the same moment that the contact breaker opens and the spark is produced. The increased speed gives the spark greater energy. When the engine has reached a few hundred revolutions per minute, the device is switched off automatically by centrifugal weights.

A higher voltage at the electrodes of the spark plugs is required if the compression ratio increases, if there are deviations from the stoichiometric mixing proportion, if the electrode distance increases and the electrode tips are deformed, if the moisture increases, if the turbulence increases, or if there is increased soot-fouling of the spark plug insulator where the current that has been lost must be compensated for through increased energy. As already mentioned, the later arc component of the ignition spark contains large energy reserves, 50 to 60 times more than are normally required, which are not used under ordinary circumstances. In case of impaired flashover conditions for the ignition spark, these reserves are used more or less for increasing the voltage of the spark plugs. During the past generator gas epoch, it was found that the above-mentioned factors affecting voltage were of greater importance for generator gas operation than for gasoline operation, which permitted an increase in maximum power output of the ignition device. In modern engines, where the maximum voltage of the ignition system is 10-20 kV, any further power increase would not seem to be necessary for the electric system, apart from the engine-starting circuit. For the engines of the 1940s and older engines with an ignition voltage of 7-10 kV, certain changes should, however, be carried out. (See Thanderz. [44a])

Diesel and Antechamber Engines

As emphasized earlier, it is mainly four-cycle diesel engines and antechamber engines for vehicles that are to be considered for generator gas operation. As a rule, these vehicles have a battery electric system for starting and illumination; in addition, they have glow plugs for starting, screwed into the cylinders. Instead of these glow plugs, spark plugs may be installed. Since there is a battery, it is, in most cases, advisable to install an ignition coil and current distributor for the ignition. A magneto device is also conceivable, especially one of vertical type, whose size, shape, and performance are practically equivalent to the current distributor used for battery ignition. It must, however, be equipped with both automatic and manual ignition advance.

Ignition-Bulb Engines

As mentioned, an electric ignition system must be used for generator gas driven ignition-bulb engines, whether they work with a pulsator, gas pump, or crankcase system. In cases where there is no space for a battery and where it is difficult to arrange operation of the current distributor and the generator, magneto ignition may be considered. This mainly applies to some tractors and, in a few cases, boat motors. As a rule, battery ignition should be used, whereby an electric starting engine and starting fan may be installed. This is especially important for tractors where there is no flywheel starter. Figure 194 demonstrates a mechanism for an oscillating contact breaker in a pulsator-converted ignition-bulb engine. Also an ordinary rotating contact-breaker mechanism may be considered in many cases.

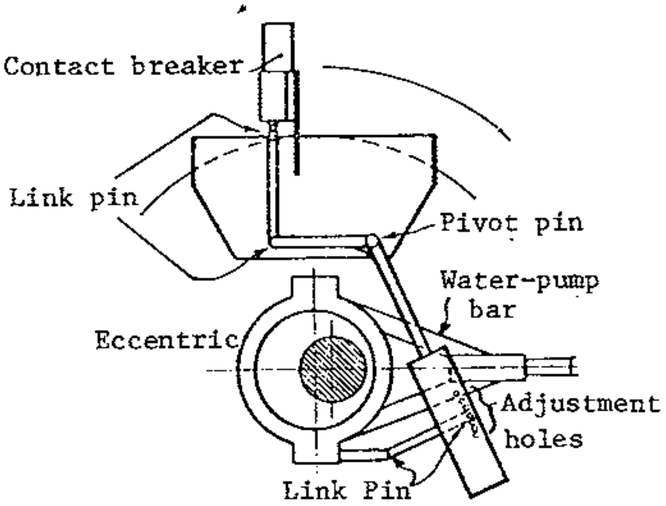


Figure 194. Driving Mechanism for a Reciprocating Contact Breaker for a Pulsator-Driven 2-Cycle Engine.

Figure 195 demonstrates a wiring diagram for the battery-ignition system suited for generator gas operation of a two-cylinder ignition-bulb engine with a special ignition coil for each spark plug. A control lamp indicating when the ignition is on is also a part of this device.

A great number of ignition-bulb engines are started by the flywheel's being pulled up in the wrong rotation direction against the compression. The ignition must then be set so that the ignition spark is timed correctly under such conditions. Figure 196 demonstrates an example of contact-breaker cams for this purpose. In order to facilitate the start, a buzzer device is sometimes used, whereby a flow of sparks may be fed to the cylinder during the start. The buzzer is disconnected by hand after the start. In the case of magneto ignition this method of starting the engine must also be taken into account.

Spark Plugs

The same rules for the choice of a spark plug with proper heat number apply to generator gas operation as to gasoline operation. The heat number depends upon the length of the spark plug insulator; the shorter it is, the faster the heat is removed and the "colder" the spark plug and vice versa. The numbering, usually in "heat numbers," originates in the Bosch-scale (see Figure 197), where the heat numbers correspond to the number of seconds during which the plug can run in a special testing engine without preignition. It is possible that a scale with a more practical basis for numbering will be used in the foreseeable future; namely, the IMEP scale. IMEP means the Indicated Mean Effective Pressure, where the heat number figure corresponds to the highest indicated engine power

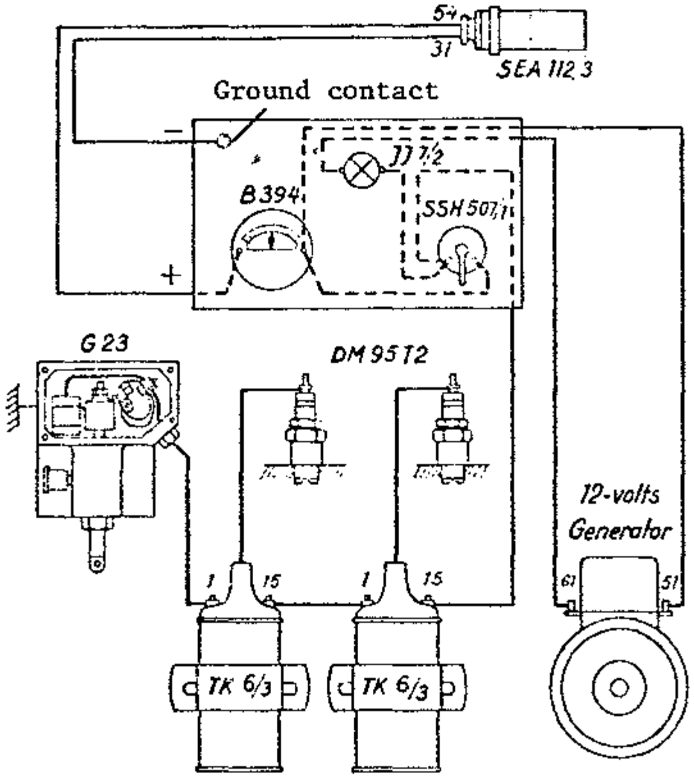
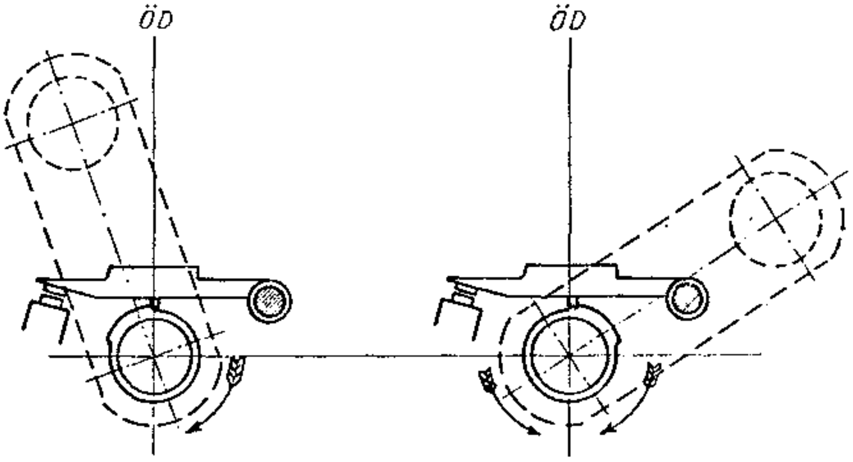


Figure 195. Wiring Diagram for a 2-Cylinder Generator Gas-Driven Ignition-bulb Engine (Battery Ignition). From the Robo Co. Catalogue.



Operation Start

Figure 196. Contact-Breaker Cams for the Backstroke Starting Spark for Starting Large Ignition-bulb Engines.

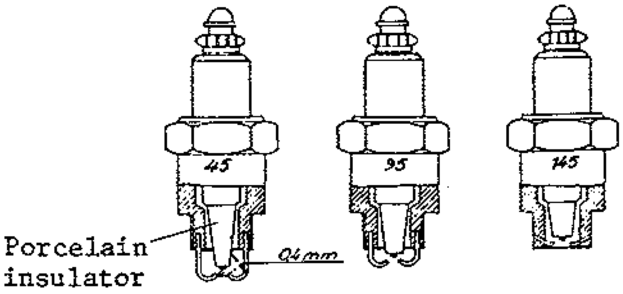


Figure 197. The Heat Numbers of the Spark Plugs Depend Mainly Upon the Length of the Porcelain Insulator. 45 Warm Plug and 145 Cold Plug

that the plug can stand without auto-ignition of the fuel/air mixture. A spark plug insulator should keep a normal working temperature of 400° to 500°C in order to be "self-cleaning," by which is meant an ability to burn away existing deposits of soot, etc. However, the temperature should not exceed 900°C, since such a high temperature would cause preignition in the engine. Nowadays, excellent insulation materials are available, such as andalusite and aluminum silicate. Such insulators should be glazed for generator gas operation by a base material of feldspar and quartz, so that deposits can more easily be removed. Modern spark plugs for gasoline engines are not glazed in this way, because tetraethyl lead forms an electrically conductive lead glass with the glaze. The new metallic-looking "sintox"-spark plugs may also be used (base material sintered aluminum). On the whole, in generator gas operation it is advisable to use spark plugs with somewhat higher heat numbers than in gasoline operation, especially to faciliate the start. The spark plug clearance (gap) varies with different engine types. In general it should be adjusted somewhat more frequently during generator gas operation than gasoline operation, or after approximately 5,000 km or 100 hr driving.

Ignition Cables

The ignition cables should be dimensioned for the increased voltage and current intensity. Modern plastic materials such as neoprene have started to replace the old enameled cables. The plastic material is better than materials used formerly for several reasons. It is more resistant to dielectric losses (in the high voltage wires), to heat,oil, gasoline, water, etc., and it has greater mechanical durability. Also, it more effectively shuts out the air, whereby electric radiation (the "corona effect") has no tendency to form ozone and nitric oxides, which have a drying effect on rubber and cable casings and which corrode the conducting metal.

The ignition cables should be installed well separated from each other (see Figure 248), in order to prevent induction phenonmena such as "glow ignitions".

Ignition Coil and Condensors

During the past generator gas epoch, specially-designed "high-power coils" were sold for increased ignition voltage. In this category were improved condensors, whose important function is to prevent spark formation in the contact breaker and to increase the induced voltage. The ignition device should not be oversized, however, so that too much electric energy is supplied to the spark plugs. The need for sparkover voltage between the spark plug electrodes varies considerably and may be several times greater under unfavorable circumstances than during normal operating conditions. Too great an excess of energy is, as mentioned, unfavorable for the life of the electrodes, even though a large amount of energy may be advantageous at a cold start. As a measure of suitability of the ignition device for generator gas operation, a spark length of approximately 7 mm (sparkover ability) was used in Sweden under atmospheric pressure in a testing device of 3-point type. This corresponds to an electrode voltage of approximately 14 kV in the combustion space of the engine.

Generator and Battery

Due to a more difficult start and the need of electric energy for the starting fan, the demands on the battery increase considerably in generator gas operation. Therefore, an additional battery is often connected parallel to the usual one; the latter must be in good condition, so that the newly connected battery is not drained of energy by the old one. The generator must be either replaced or rewound for the increased current requirement (from 20-30 A to 30-40 A). It should also be equipped with a voltage regulator if it is of the inexpensive 3-brush type, in order to obtain full current intensity. The air cooling of the generator should be supplemented in connection with the rebuilding. During generator gas operation, the battery requires more frequent inspections, increased protection from cold (which considerably decreases the capacity of the battery), and careful maintenance of all switches and cable connections. A spark shield is advisable for the commutator of the generator for fire protection. A competent car-electric garage should examine the electric device in its entirety at the time of conversion to generator gas operation and also regularly during operation. When starting, the driver must remember that the battery needs time to "recover" between each starting try. We usually recommend periods of 10 s of engine-starting operation, separated by approximately 30 s of battery recovery.

Ignition Advance and Voltage Requirement During Generator Gas Operation

Due to reasons already mentioned, ignition of the generator gas/air mixture must occur earlier than is the case for gasoline operation; i.e., the basic setting of the ignition advance device should be earlier. Especially in engines having varying rpm (vehicles) there should also be an automatic ignition advance centrifugally regulated according to the rpm. Vacuum regulation of the ignition advance according to the intake manifold pressure is used in many cars, but it is not necessary and can be dismantled during conversion to generator gas operation. Figure 198 shows ignition-advance curves for generator gas and gasoline operation. In practice it has been found favorable for generator gas operation to move the ignition advance forward 10-15 crankshaft degrees during slow rotation (the basic setting). However, the conditions of generator gas operation, as emphasized earlier, are so varied that manual ignition advance is necessary for both start and operation, whether under constant or varied conditions.

In ordinary car engines, the maximum voltage at the spark plugs was, immediately after the war, about 7 kV or somewhat more, while the need during generator gas operation was considered to be approximately 50% greater. In more modern engines, about 1950

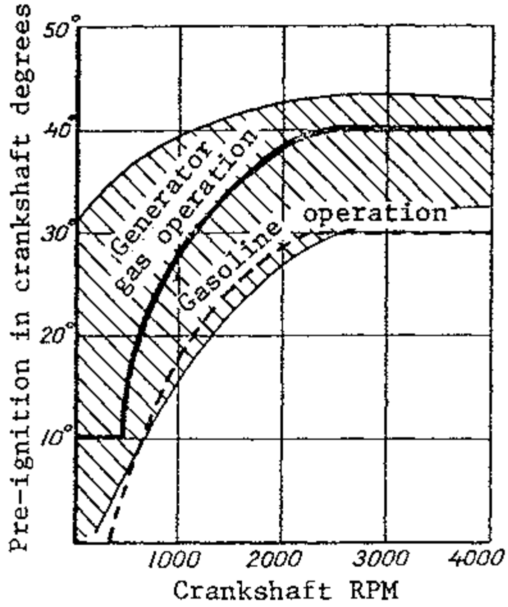


Figure 198. Ignition-Advance Field during Generator Gas Operation (Shaded). (Solid curve, advance suitable for generator gas operation; dashed curved, for gasoline operation) From the Robo Company Catalogue.

and later, the ignition voltage is, as a rule, over 10 kV and in some types up to 20 kV. When such engines are changed over to generator gas operation, the electric ignition equipment would not seem to need any improvement. In addition there was great improvement, after the war, of electric system design and material. In particular, the modern synthetic plastic materials have helped to protect cables and devices from chemical and mechanical attacks. The difficulties with the electric devices of the past generator gas epoch will therefore be reduced in the future.

Lubrication Problems Associated with Generator Gas Operation

The problem of lubrication during generator gas operation is concerned with the following facts typical for such operation.

1. Thinner oil than normal.
2. Increased fouling.
3. Higher mean rpm.

With the gas cleaning improvements of current gas generators, the risks of increased wear of the engine due to impaired lubrication are rather small, provided that adequate lubricating oil is used. One cause of impaired lubrication disappears in the case of generator gas operation; namely, dilution with noncombusted fuel, for instance from choking. The generator gas contains no substances which can be directly corrosive to the engine. However, conveyed dust particles (soot, ashes, etc.), may cause increased fouling of the engine (precipitated by water condensation), especially in the wintertime and during intermittent operation. In the case of wood gas operation, the moisture content of the gas may be inconveniently high.

Experience from the blockade period has proven that poorer lubricating oils and considerably prolonged driving periods between oil changes, as well as increased rpm due to the power decrease during generator gas operation, did not cause significant damage to the engines, as had been expected. This may be due to the fact that the car owners were aware of the risks and more careful than usual in keeping the cleaning devices in good condition. The relatively high operating temperatures during generator gas operation and a decreased number of cold starts (since the engine rarely is shut off in generator gas operation due to starting difficulties) probably also helped in decreasing the fouling of the engine. Modern research in the field has shown that "overcooling," rather than overheating, causes lubrication trouble due to increased fouling of the engine. Almost all dirt deposits take place in the presence of condensation water and as a consequence of mixed-in water. In the pipes from the gas generators, there are almost always a great many small whirling ash particles, etc., no matter how good the cleaning is; these particles are deposited as tar-like dirt as soon as condensaton water is formed. By keeping the engine running, the risks of condensation-water formation are decreased. Black fouled crankcase oil usually does not have an impaired lubricating ability, but in the presence of water the dirt is precipitated and deposited in the engine, thereby disturbing the circulation process. An increased number of oil changes, careful collecting of the oil for cleaning, and improved cleaning devices (cloth filters for wood gas operation, etc.) are all effective means of protecting the engine against rapid wear and of minimizing the oil consumption. Especially engines with intermittent operating conditions require careful supervision, in these respects, since the risk of condensation water formation is great in this case.

During generator gas operation, the crankcase oil often thickens considerably (alkali compounds); therefore, thinner oil than normal should be used.

Supercharger Operation

Due to lack of space and complications arising from the need for special cooling, great power losses for operation, etc., superchargers that are mechanically operated from the engine have not become popular for generator gas operation. Add to this, that in spite of an existing supercharger, the need for acceleration still may make rebuilding the engine necessary for increased compression. This considerably raises the price of conversion to generator gas operation.

According to tests carried out by the Generator Gas Committee of 1937, [56] considerably better results were obtained with a screw-type supercharger than with a centrifugal type. Figure 201 shows the results of tests with a Volvo truck equipped with a screw supercharger, manufactured by the Ljungstrom Steam Turbine Company.

In a mechanically driven supercharger, the outlet pipe is often equipped with an overpressure valve, through which a possible excess of the gas/air mixture (as in case of a decreased load of the engine) is brought back through a return pipe to the inlet pipe of the supercharger. The gas suction is decreased considerably in this way. In order to retain under such circumstances sufficient suction in the generator, the overflow gas mixture is, according to a Finnish design, emitted into the open air (Fabricius) instead of to the supercharger inlet. The fuel loss caused by this is said to be quite insignificant.

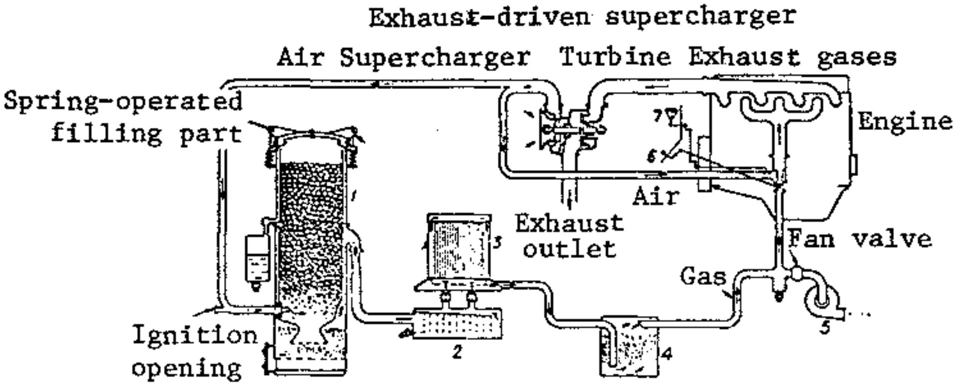


Figure 199. Schematic for an Exhaust-driven Supercharger for Generator Gas Operation, According to Gustafsson. [18]

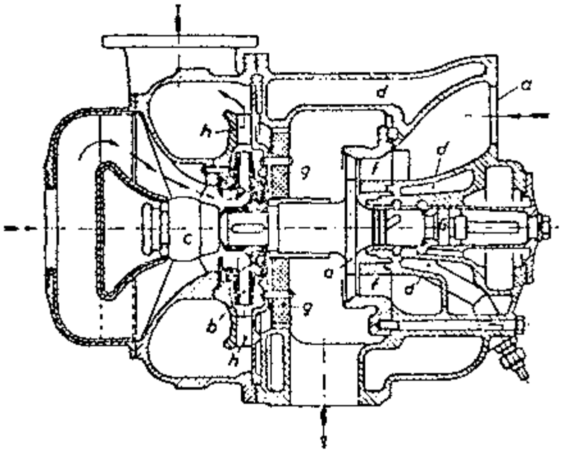


Figure 200. Cross Section of a Supercharger According to the Diagram in Figure 199.

When supercharger operation is planned for engines, it must be observed that larger gas generators than normal must be used to meet the increased gas consumption. Operation of the supercharger by means of an exhaust turbine is also of interest (Figures 199 and 200). The compressed air is divided so that one part goes to the gas generator, which then will be under overpressure, and one part to the mixer. A similar air distribution was mentioned earlier in connection with conversion of a two-cycle Bolinder Munktell system. A disadvantage of this overpressure procedure is the leakage risk in the generator and the pipes, and that the fuel cannot be refilled during generator gas operation. In supercharger operation, the specific fuel consumption is somewhat lower than in generator gas operation without a supercharger. In supercharger operation it is particularly the peak output (Figure 202) that increases, which is of great value for generator gas operation.

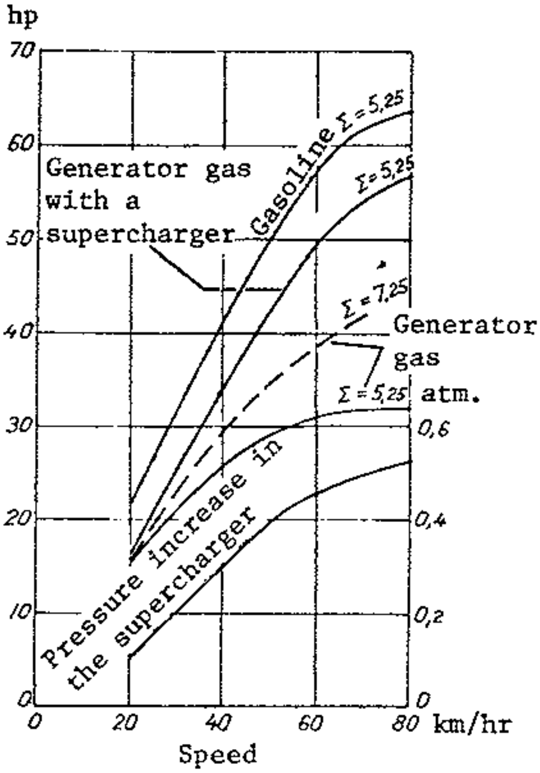


Figure 201. Rear-Wheel Power of a Volvo LV94D with and without a Supercharger, and Showing the Supercharger Pressure Increase.

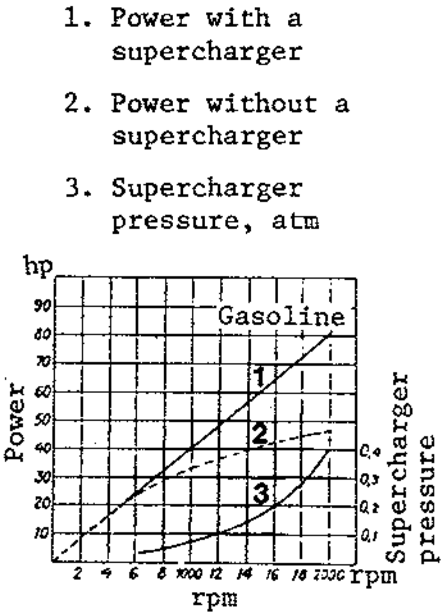


Figure 202. Diagram Showing the Power Increase during Supercharger Operation.

Chapter 8

GAS GENERATOR INSTALLATION

Standardized gas generators designed for motor vehicles and produced in large numbers are, as a rule, easy to install. In these cases, the manufacturers have already taken into account not only operational properties, appearance, etc., but also easy installation. This fact, which is favorable for the vehicle owners, applies first of all to passenger cars and also to some extent to tractors; i.e., generally so-called type-inspected motor vehicles (see below). Usually it is the car and engine manufacturers themselves who produce the complete gas generators to fit their own designs.

In addition to these devices produced in volume, there is an equally great number of motor vehicles, trucks, buses, power tools, ships, etc., which are suitable for generator gas conversion from a utilitarian viewpoint. In these, the operating conditions, space etc., are so varied that a standardized gas generator cannot be used, which is the reason that the installation work is correspondingly complicated and extensive. This work is preferrably done by garages, motor-car repair shops, shipyards, etc.; the various parts of the gas generator, various cleaners, cooler, etc., are shaped and placed in various ways from case to case. Thus the garage has a design function. The demands on its competence and resources must therefore be considerable. During the past generator gas epoch, a great number of generator gas courses, welding courses, etc., were successfully given all over the country (Sweden), on private and public initiatives, to increase the knowledge of gas generator mechanics. The function and reliability of the gas generator equipped engine is, after all, dependent on the correct completion of the installation work.

Although detailed control of each gas generator installation is inconceivable, certain minimum requirements must be fulfilled from the viewpoint of safety (carbon monoxide and fire hazard). Such requirements were issued by government authorities, and car and ship inspectors and fire inspectors enforced them. In addition, the gas generator manufacturers themselves developed special installation regulations for their products, whereby the greatest power, durability, and reliability are gained. In the following paragraphs a survey of these general safety instructions and installation principles will be given.

These instructions usually concern some examples for trucks and passenger cars; they may be used where applicable for other installations as well.

General Safety Regulations for Generator Gas Installation

Circulars issued by the National Swedish Fuel Commission and the Generator Gas Bureau give some regulations for generator gas installation, mainly for motor vehicles. These regulations were required and had to be followed, above all those pertaining to safety concerning carbon monoxide and fire hazard. The regulations also contained advice that "should be" followed; namely, advice for maximum power, reliability, etc. In order to receive a driving permit, it was necessary to fulfill at least the required regulations.

For so-called test types of gas generators for motor vehicles and power tools, it was required, among other things, that the manufacturer supply installation drawings with all dimensions given, material information, etc., accompanied by a guarantee of adequate material and work. The most important regulations included:

Inspection

Each vehicle that is subject to the regulations in the motor vehicle ordinance, is equipped with a gas generator, or has had a gas generator replaced, must be submitted for a first-time inspection or a repeat inspection by a motor vehicle inspector as soon as possible, or at the latest within 14 days from the date of purchase or replacement.

Ventilation

The gas generator must be installed so that the generator gas, as much as possible, is prevented from entering the driver's cab or any space intended for passengers.

The driver's cab or any other covered car body should not be heated by a device into which exhaust gases of the engine are conducted. Air from the air intake under the hood must not be used for heating or ventilation of the vehicle, nor should ventilation be done by fan extraction.

The ventilation and oil-filling openings in the crankcase of the engine must be equipped with a discharge pipe angled back and out to the right side of the vehicle (sloping downward in order to avoid a liquid lock). The orifice of the pipe must be pointing to the rear. The oil filler is to be equipped with a tight cover and the oil gage rod with a tight packing. The exhaust port to the fuel pump is to be closed.

The valve hood covering the valves is to be tight. If the valve hood is equipped with a ventilation pipe it is to have its outlet outside the engine hood at a distance of at least 0.25 m behind the radiator of the engine.

Vehicles or machines equipped with a gas generator with a pressure fan should not use a circulation fan or windscreen wiper operated by vacuum from the inlet manifold of the engine, due to risk of poisoning.

Driver's Cab

The driver's cab should, when possible, be equipped with an exit at both sides. When fully opened, the door must leave a free opening of at least 400 mm width. The gas generator must not be installed so that it infringes on the driver's space. The floor in a covered car body or driver's cab or a space intended for passengers must be well fitted and tight. The wall between the engine and the driver's cab or the space intended for passengers must be as tight as possible.

The Gas Generator

The gas generator must be designed and installed so that fire hazards, as far as possible, are prevented (Figures 203 and 204).

If the distance between the generator and a combustible part of the vehicle or its cargo is less than 30 cm, a safety wall must be built around the generator to the required extension and height; also, woodwork belonging to the vehicle and located closer to the generator than 30 cm must be plated (see Figures 203 and 204). If the cargo reaches a height greater than the generator within a distance of 1 m from it, the safety wall must extend to the full height of the cargo. The safety wall must be light and of sufficient strength (of sheetmetal or of wood, plated toward the side of the generator). A plated car body may be considered to be a safety wall. If the cargo consists of inflammable goods, special attention must be paid to protection from ignition.

The distance between the generator and the safety wall must not be less than 10 cm. If the distance is between 10 and 15 cm, an insulation wall must be placed in the space between the generator and the safety wall; the distance from the center of the insulation wall to the generator or the safety wall must not be less than 5 cm. The insulation wall is to be made of noncombustible material and strong enough not to warp.

The space between the generator and the safety wall is to be appropriately covered to prevent fuel from falling down during refilling. This cover, which may be made of netting, perforated sheet metal, etc., must not, however, interfere with the air circulation around the generator.

When the generator is installed in the trunk space, no matter what the distance to combustible material, a safety wall as well as an insulation wall must be arranged in the trunk space and in a way which provides sufficient ventilation around the generator. The trunk-space door must not be replaced by a cover of an inflammable material, such as pegamoid (fabrikoid), cloth, etc. (Figures 205-207).

Primary-Air Intake

The primary-air intake is to be equipped with a self-closing valve and a flame guard as well, both of types approved by the Generator Gas Bureau. The self-closing valve should be lockable from the outside, or else there should be another lockable shut-off device approved by the Generator Gas Bureau and easily accessible, in addition to the return valve.

The primary-air intake should be placed at least 0.7 m from the nearest opening or door.

Preferably, the primary-air intake of the gas generator should consist of a pipe extended to be level with the upper edge of the fuel container. The opening of the pipe should be designed to make a connection possible to the ventilation device in the garage. The device for ignition through the primary-air intake must also be of a type approved by the Generator Gas Bureau and so designed that it cannot be left open after ignition has occurred.

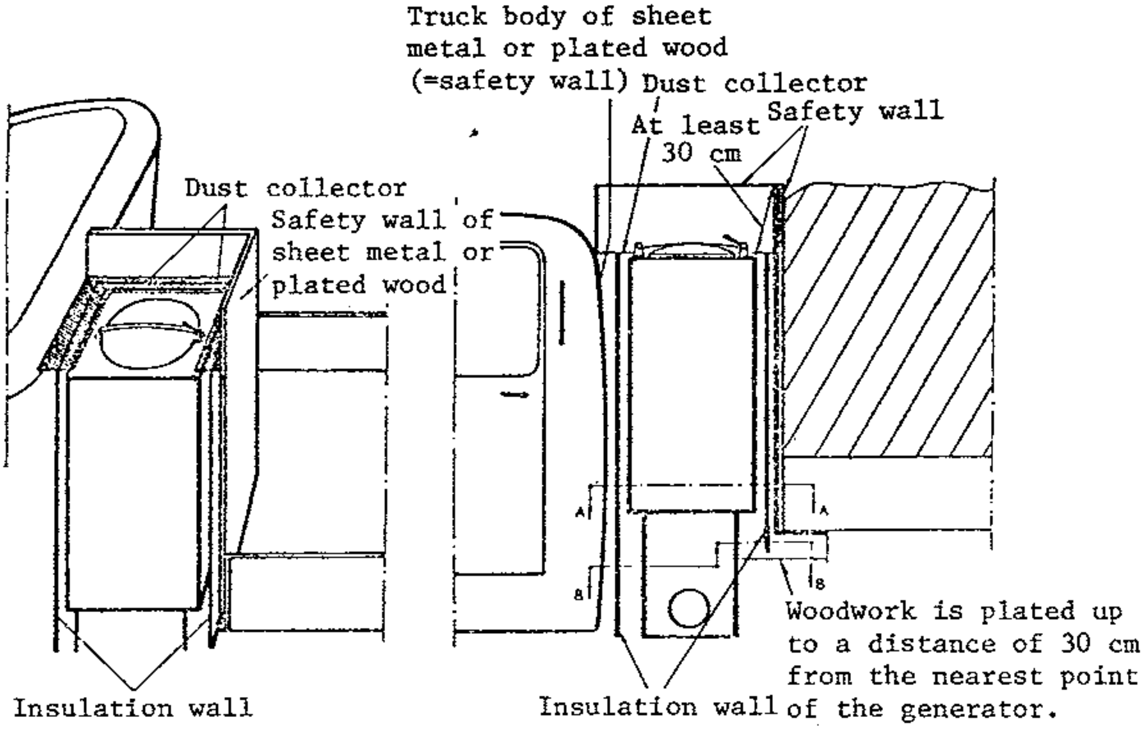


Figure 203. Assembly Schematic for a Truck Generator

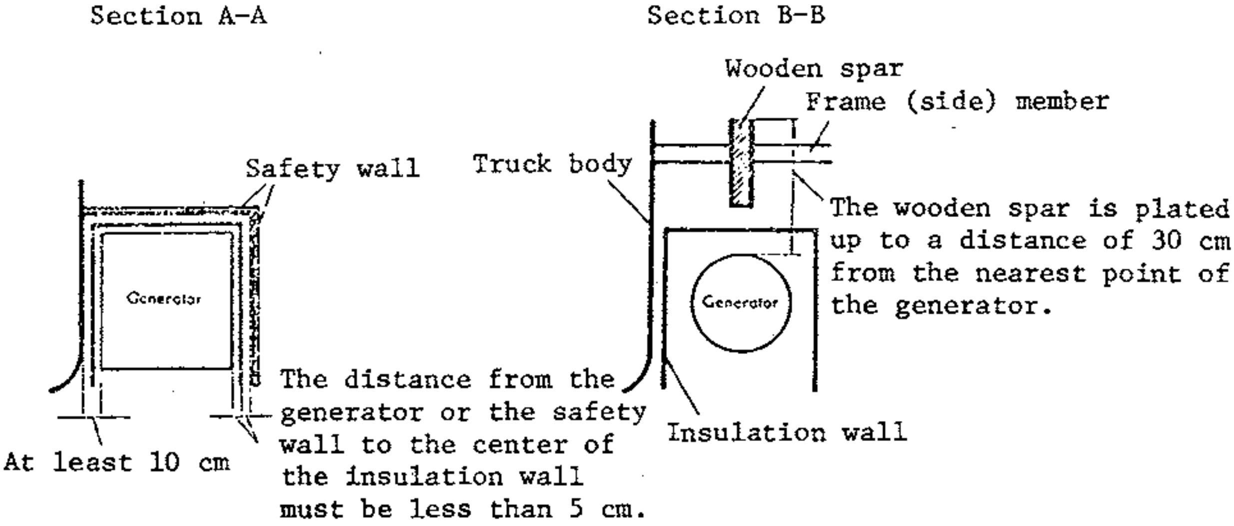


Figure 204. Section Views of Figure 203.

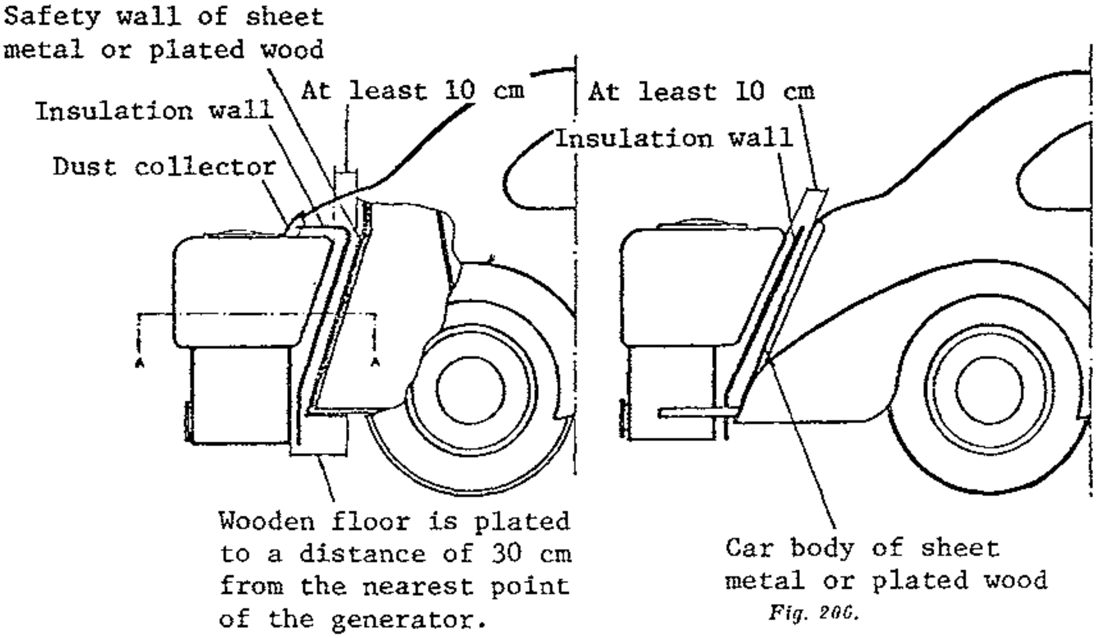


Fig. 206.

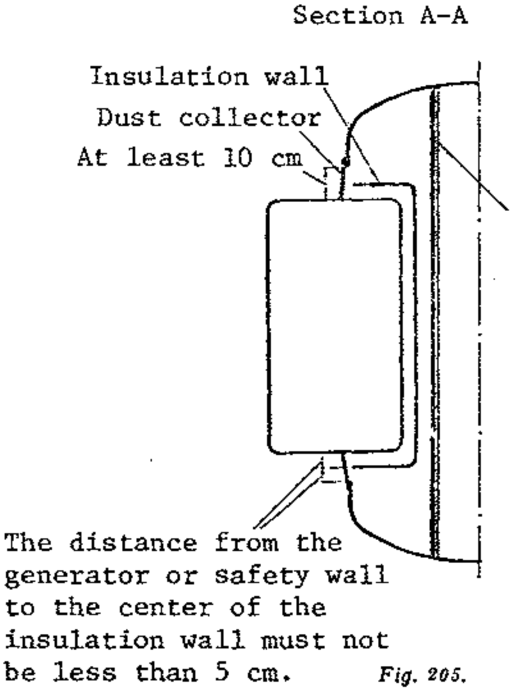


Fig. 205.

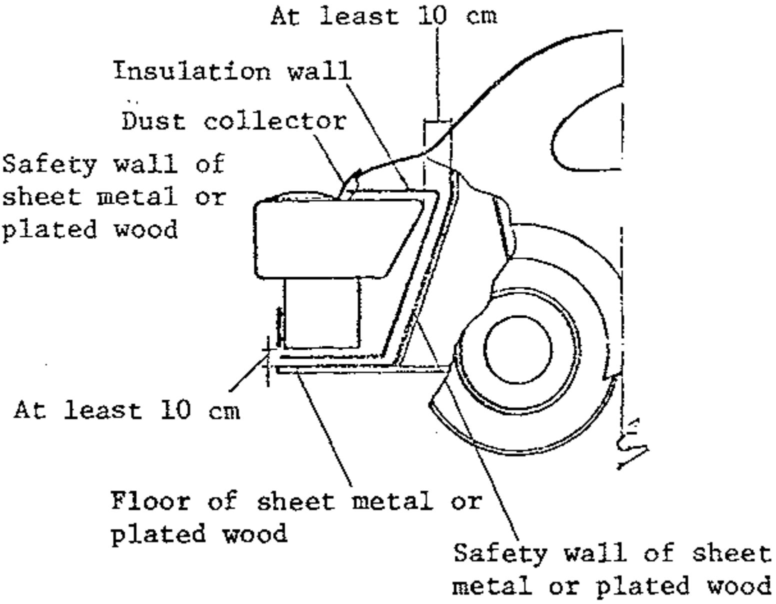


Fig. 207.

Figures 205-207. Rear Installation of a Passenger Car Generator.

Ground Clearance

The clearance between the lowest part of the gas generator and the ground should be adequate. When the generator is placed between the axles of the vehicle, an adequate clearance is approximately 20-25 cm; when installed at the front or at the rear, approximately 25-30 cm, all measured when the vehicle is loaded.

Gas Conduit, Gas Cleaner, and Gas Cooler

The gas pipe and the gas cleaner between the gas outlet from the generator and the gas cooler are also to be insulated from woodwork in the same way as the gas generator. In the case of a completely double jacketed wood gas generator, the gas pipe (including the cyclone cleaner and cloth cleaner) may, from the standpoint of insulation, be considered as a gas cooler up to a length of 2.5 m from the gas outlet of the generator. In the case of a wood gas generator with a cloth cleaner preheated by exhaust gases, it must be insulated as a gas cooler, no matter what the length of the gas conduit between the generator and the cloth cleaner. For other designs of gas generators, the Generator Gas Bureau gives directions on an individual basis.

Woodwork belonging to the vehicle, located closer than 15 cm to the gas cooler, must be plated. The distance between the gas cooler, complete with fittings, and combustible materials must not be less than 4 cm. If the distance is between 4 and 6 cm, an insulation wall of noncombustible material must be installed; the distance from the center of the insulation wall to the gas cooler or combustible material must be no less than 2 cm.

In the case of a charcoal gas generator, the gas cooler should preferably not be placed beneath the truck bed, especially if freight is carried which may be damaged by moderate heat.

The gas cooler must be free to expand in the direction of the gas conduit as well as in the longitudinal direction of the cooler itself. To neglect this would involve a risk of leaks due to thermal stress, a risk of fire in the system, and if cloth cleaners are used, ruined cloths. The installation should always be made so that the cooler can be effectively cleaned.

Fan, Fan Duct, Fan Outlet

If a fan is placed under the hood, special attention must be paid to the tightness of the fan and the fan duct.

If the damper in the fan outlet is combined with a switch for the fan, the spring of the damper must, in order to prevent the damper from possibly starting up the fan through the spring force, be mounted so that the greatest tension in the spring is obtained at a fully open damper position.

In an installation with a starting fan or compressor, the fan outlet must be mounted so that gas cannot enter the hood, or any space intended for the driver, passengers, or cargo. When the outlet is installed, it must be remembered that the gas is lighter than the surrounding air.

In a large bus with a permanently installed gas generator, the fan outlet must be extended so that the outlet opens out over the top of the chassis, at least 1.0 m from the nearest opening or door. In the case of a bus equipped with a gas generator installed in a special trailer, the fan outlet must be extended to the upper edge of the fuel container, no less than 1.5 m above the ground.

In motor vehicles other than buses, the fan outlet should preferably be directed upward and open out to the right of the centerline of the vehicle, at least 1.5 m above the ground and at least 0.5 m from the nearest opening or door, opening out over the roof. An alternative, which, however, may involve a certain risk, is to direct the outlet horizontally outward to the right, where it must open out at least 0.7 m from the nearest opening or door. If there is a device in the vehicle which can turn on the fan automatically, the fan outlet should then be extended so that it opens out over the roof of the vehicle. The device for automatic fanning must be equipped with a special switch, to deactivate it entirely.

There must be no cover over a fan outlet which is directed upward; it could give the fan gases an undesirable flow direction. The outlet should also be arranged so that the flame, during testing of the gas, cannot cause a fire in the vehicle, the cargo or the surroundings. It is advisable to place a special test-ignition pipe, equipped with a tap that opens when the gas is tested, in a fan outlet pipe which is directed upward.

In power machinery, the fan outlet must open out at a height over the ground or the driver's cab which insures that the fan gas is carried off well above the driver's head. The fan outlet should be equipped with a turning 90° pipe bend.

A fan outlet, which is to be connected to a mechanically operated exhaust device, must be dimensioned and designed (Figure 208) to fit a standardized connection of the device.

Secondary-Air Intake

The secondary-air intake must not be placed under the engine hood or in a space intended for the driver, passengers or cargo.

The secondary-air intake for a gas generator with a pressure fan must be arranged in accordance with the above regulations for a fan outlet.

The secondary-air intake in a gas generator with a suction fan must be placed at least 0.4 m from the nearest opening or door. In the case of a bus with a gas generator equipped with a suction fan, the above regulations which require the secondary-air intake to be equipped with a fan outlet would apply.

It must be ensured that the gas cannot escape from the gas mixer. A tight-fitting damper or shut-off device must always be placed before the automatic mixer, either in the gas pipe or in the secondary-air duct. Damper shafts, wires, and control devices must be in good condition.

All dampers must be working correctly and in a way so that gas or air cannot pass uncontrolled. When starting with liquid fuel, it is important that the changeover valve completely closes off the generator gas.

The air intake to the carburetor must be equipped with a tight-fitting lid which is kept closed when the engine is not run on liquid fuel; otherwise the air intake of the carburetor must be connected to the secondary-air intake.

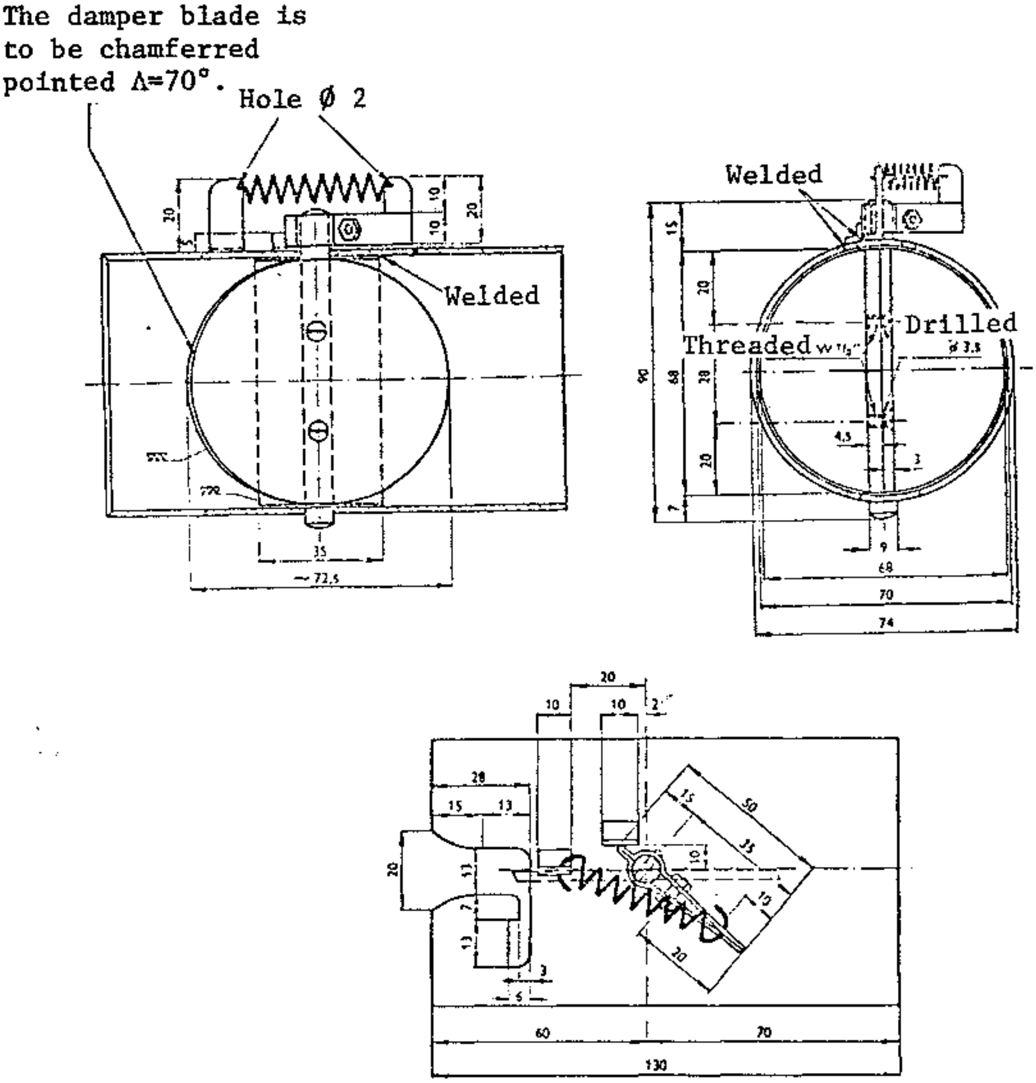


Figure 208. Standardized Fitting for Connecting a Generator Gas Fan Outlet to an Exhaust Device in a Garage, etc.

Fuel Tank

In vehicles which are converted to generator gas, the fuel tank must be placed sufficiently far from the generator, fan outlet, and engine heater for solid, liquid, or gaseous fuel. It is sufficiently far if the fuel tank is placed outside the chassis frame on the side of the vehicle opposite to the gas generator; or, when the gas generator is placed on a trailer or in the trunk, if the distance between the generator and the fuel tank is at least 1 m. However, a container with liquid fuel and holding at the most 5 L may be placed closer to the generator at a minimum distance of at least 0.5 m. It must be permanently mounted in a suitable, protected place outside the engine hood.

A fuel tank placed under the engine hood must not be connected to the engine and must not contain liquid fuel. A pipe to the fuel container must not be soldered.

Piping

Piping as well as joints and flange connections must be tight. A gas pipe must not be run through the driver's cab or any space intended for passengers, unless the pipe is seamless or has a pressure tested seam.

The gas pipe and the secondary-air duct should be sufficiently thick. Unnecessary pipe bends, pipe lengths and welding seams as well as wrinkled pipe bends should be avoided, since they cause power loss. A rubber hose may be used only for short joints (no more than 100 mm) in a straight pipe and not until after the gas cooler. The pipe ends must be equipped with a retention bead if the distance between the pipe ends exceeds 1/4 of the pipe diameter. A rubber hose joint must not be used under the car floor or the fender. A reinforced rubber hose may be used between the gas generator in a trailer and the motor vehicle as well as in hinged, swiveling, and folding gas generators. A metal hose may not be used for the gas pipe, fan outlet, or secondary-air duct.

In the case of gas generators on trailers, which usually are disconnected from the motor vehicle when put into the garage, there must be a special device (see Figure 209) on the trailer, which closes the outlet of the gas pipe mounted on the trailer when the generator is disconnected from the gas pipe of the vehicle.

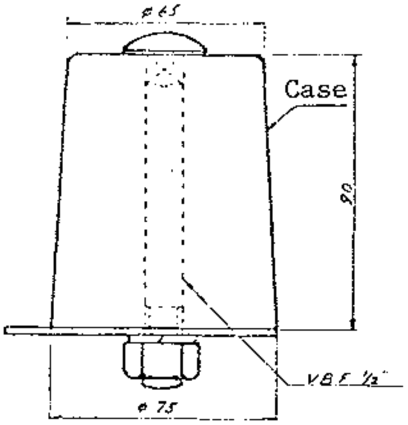


Figure 209. Shutoff Device for a Gas Pipe, Particularly for the Gas Pipe Leading to a Trailer.

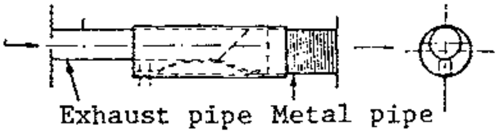


Figure 210. Connection for the Exhaust Pipe of the Engine to an Exhausting Device.

The gas pipe from wood gas generators must have an incline toward the condensation-water container. Where necessary, a screw plug must be attached for draining condensation water. Open drain holes are not permitted.

In power machinery the exhaust gases should preferably be drawn off upward, and the exhaust pipe must open out well above the operator's head, even when he must stand up to maneuver the equipment.

Great poisoning risks are involved if the exhaust pipe opens out over an opening or door in the vehicle. This should be taken into account particularly in vehicles with a specially-built car body; e.g., a delivery van or a car with a covered platform.

Device for Adding Liquid Fuel During Generator Gas Operation

Any device (not a carburetor) for adding liquid fuel during generator gas operation must be of a type tested and approved by the Generator Gas Bureau. For the use of such a device, the following directions are to be followed:

1. The fuel container must be placed lower than the device. If the device is equipped with a float the container may, however, be placed differently. The container, which must not be equipped with an automatic filling device, must be assembled in full accordance with the issued directions.
2. There must be an easily accessible shut-off device in the pipe from the fuel container.
3. The air intake of the device is equivalent to a secondary-air intake. It should be equipped with an air cleaner. It is advisable to connect the air intake of the device to the secondary-air duct.

Hydrostatic Test

After a sufficient number of test drives a hydraulic test must be conducted on the gas generator before delivery. There is a risk that thermal stress and settling after the assembly may have caused leaks in the gas generator. Hydrostatic testing should be done with air at a pressure of no less than 0.2 atmosphere. The tightness is tested by brushing on soapy water.

Other Directions

Devices for fastening the gas generator to the chassis of the car must be of adequate dimensions. Drilled holes for the supporting beams of the gas generator must not be so large or placed in such a way that the frame is weakened; drilling the beam flanges should be avoided.

When mounted in front of the radiator, the gas generator must not hide the headlights. An approaching driver, who is in front of the vehicle at an angle of 30° to the right or the left of the center line of the vehicle, must be able to see both headlights.

A simple test of this is made by standing in front of the vehicle on the center line of the vehicle and taking 10 steps ahead of the headlights and after that 6 steps to the side at a right angle. From this position, both headlights should be visible. Otherwise, the headlights must be moved or additional ones mounted.

Note: In the Welding Commission a proposal has been worked out for directions for assembly-welding of certain pipes or pipe systems (pipe-welding standards); these regulations will be issued by the National Swedish Insurance Office in its capacity of managing the Labor Inspectorate Head Agency. According to this proposal, among other things, welding jobs involved in the manufacturing and assembly of gas generators with pipes may be carried out only by enterprises which have been approved by the Labor Inspectorate for such jobs (pipe-welding licensees).

In addition to the directions in the circulars of the Fuel Commission, special regulations were approved by the National Swedish Inspectorate of Explosives and Flammable Liquids on trucks, which were to transport explosives of the "first class." For ships with employees, special regulations were issued by the Board of Commerce, the Ships' Inspectorate.

General Guidelines for Gas Generator Installation

Trucks

From the viewpoint of weight distribution and vision, it is advisable to place the gas generator on the right side of the vehicle if it is a left-hand-drive truck. In some cases, large containers or cylinders for the vehicle brakes may present an obstacle, in which case left-side installation would be preferable. Such a position may also be advantageous with regard to the nature of the gas generator and the tubing (especially in wood gas generators, where the cork cleaner is not built as a unit with the wet cleaner and the cooler).

If the truck is to carry long loads (beams, pipes, etc.) that are placed along the sides of the vehicle past the cab, the gas generator must be placed close to the longitudinal center of the vehicle either in front of the radiator, behind the cab, or in case of no trailer, possibly at the rear.

Usually, the generator is suspended on two channel irons (Figure 211) placed behind the cab gable across the frame members of the cab and is fastened to the fastening flange intended for this purpose. It is most important that the prescribed minimum distance to the ground, 250 mm, be maintained. The distance between the beams is adapted to the outer diameter of the generator. Sometimes, the cyclone cleaner is attached to the opposite side of the vehicle on the same beams, which must then be somewhat bent or supplemented with adequate braces since the cyclone cleaner frequently has a smaller diameter than that of the generator. If possible, the cyclone should be located on the same side as the generator in order to decrease the risk of condensation-water formation and also to avoid heating the truck bed too much. For the same reasons it is sometimes advisable not to place the cooler of a charcoal gas generator on top of the chassis frame underneath the truck bed (in case of cargo sensitive to heat; Figure 212). Frequently, the cooler for the charcoal gas generator may be fastened to the top of the cab, where a good wind-cooling effect may be expected.

When the generator and the cleaners are attached, the maximum width allowed for the vehicle must not be exceeded, particularly in the case of the generator mounts. If the distance between the generator and the wooden beam under the truck bed is sufficient, the only change is the mounting of the two channel irons. If the distance is too small, the wooden beam has to be cut and the truck bed must be supported in a different manner, with an iron plate, etc. If a separate fastening flange is supplied for the generator it should be carefully welded to the generator jacket after having been fitted to maintain the prescribed distance, so that the mantle is not damaged. A separate flange is usually supplied for the gas outlet in the generator. First a place for it should be marked out, not too close to the hood; a 75-100 mm hole is cut out with a welding torch, after which

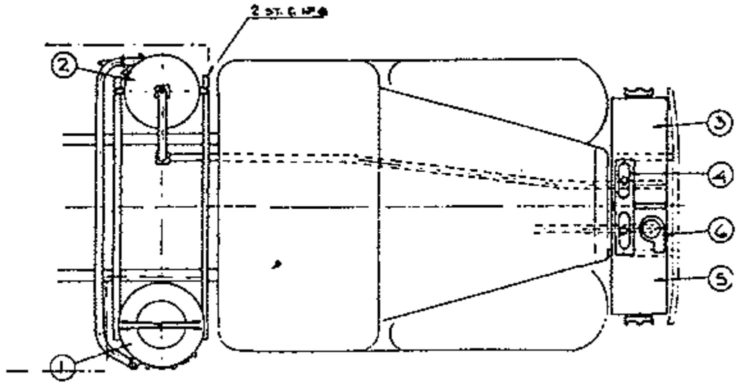


Figure 211. The Generator and Cleaner are Often Placed Between the Same Transverse Channel Irons.

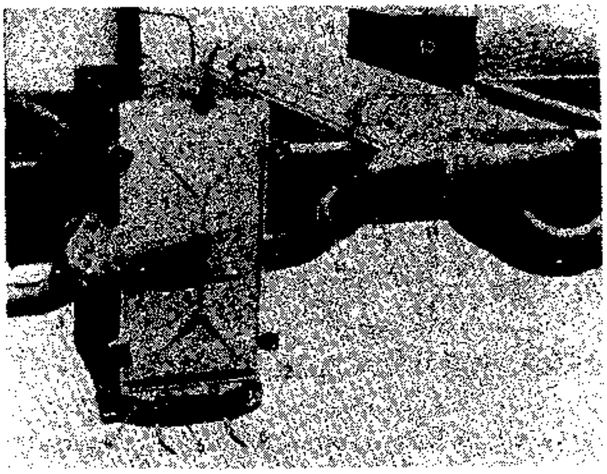


Figure 212. Charcoal Gas Generator with a Cooler Placed on the Frame Members of a Truck (not advisable for cargo sensitive to heat)

the flange is welded. The cutout must be done obliquely with the flame, so as not to damage the jacket, and the outer jacket must not be dented. The edges of the hole should be bent outward. If they point inward, they may cause soot to deposit in the generator.

The generator should be insulated from woodwork according to the regulations (Figures 213 and 214). The conduit between the generator and the cyclone cleaner may be insulated with asbestos in the wintertime in order to prevent significant condensation-water formation; this applies primarily to wood gas generators. Preferably the pipe should be an expanding type, due to thermal stress, and be equipped with adequate flush plugs, since considerable condensation-water formation is common.

In most wood gas generators, the wet cleaner, cooler, and fine cleaner (cork) are built together and intended to be placed in front of the car radiator. It is advisable to attach the unit with iron bands over the frame members or their extensions; the bumper is moved forward. The generator gas cooler must be placed as close to the radiator as possible, in order to utilize the fan effect to its fullest. When a cleaning device is mounted, the pipes must slope toward the cleaner, so that condensation water can be collected and the draining devices can be used. When running a pipe under the car, it is sometimes

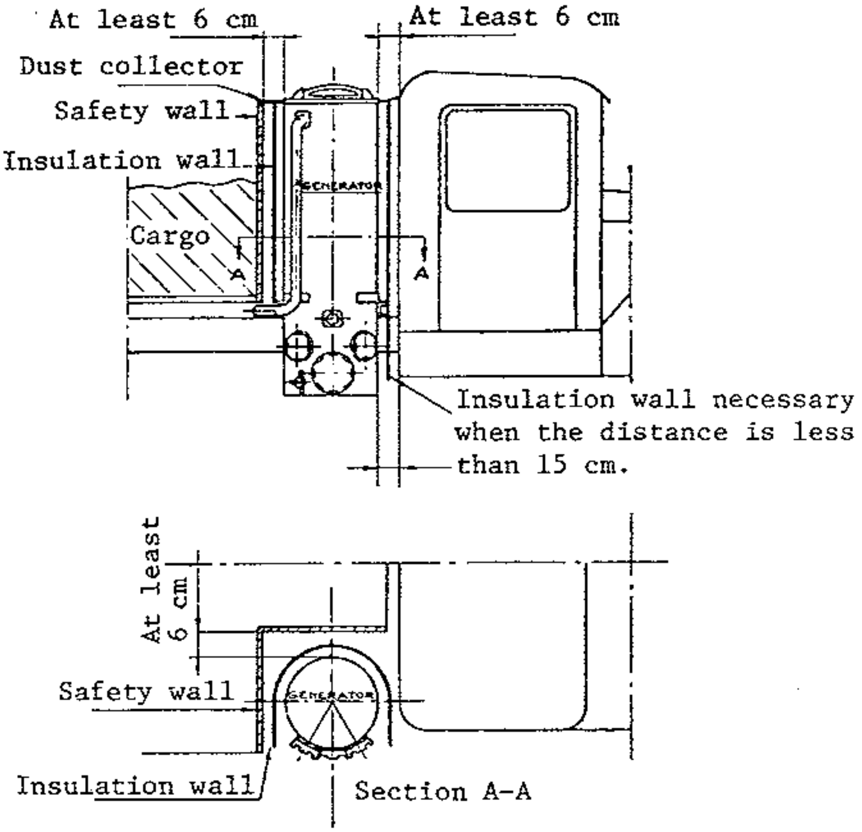


Figure 213. Assembly of a Wood Gas Generator, Normal Cargo Height.

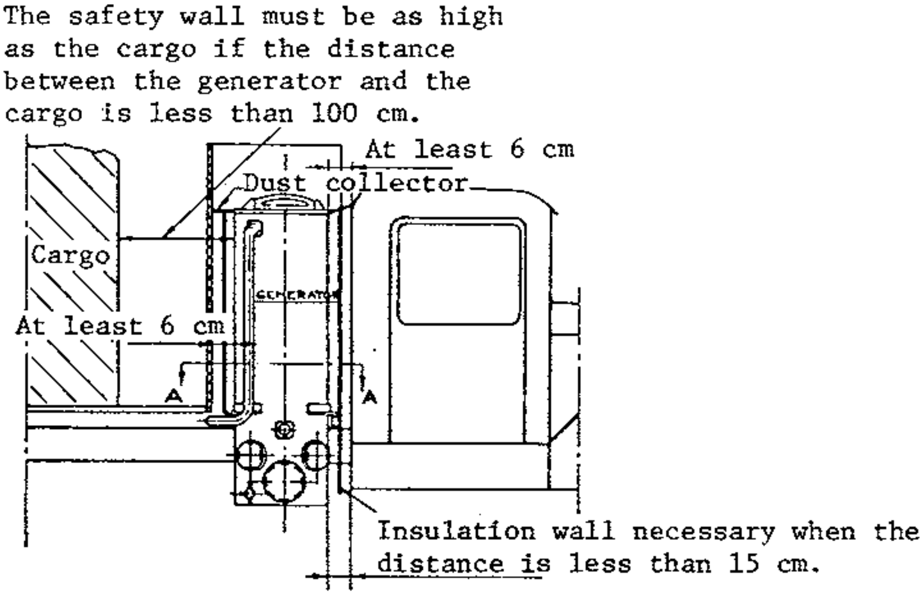


Figure 214. Assembly of a Wood Gas Generator for a High Cargo. (Hesselman Motor Corporation)

difficult to achieve much of an incline; this is the reason that special condensation-water collectors with draincocks must be placed at the lowest place (Figure 215). Of course, it is not at all advisable to try to arrange a continuous draining through small holes in the pipes. Dangerous gas leakage often results from such a procedure; also dust may enter, possibly causing damage to the engine.

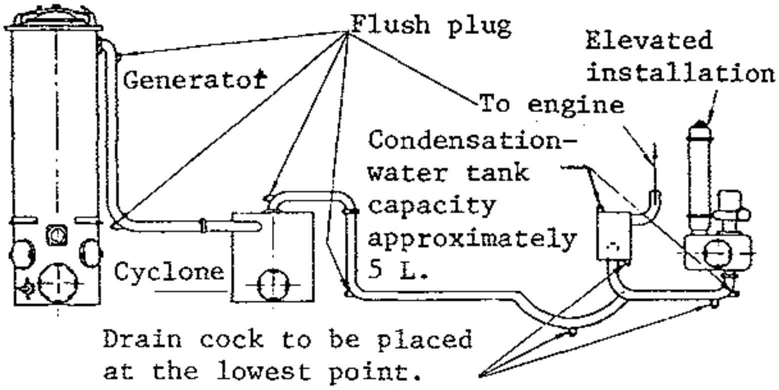


Figure 215. Piping and Flush Plug Arrengements in a Gas Generator.

Care should be taken that collected condensation water during pronounced accelerations or at various inclinations of the vehicle cannot run into the gas pipe, thus disturbing the operation. The gas pipe from the fine cleaner to the engine should rise upward so that condensation water cannot enter the engine.

It is important that the generator and cleaner, etc., are attached to the chassis with enough resilience to allow for adequate heat expansion in the pipes and the chassis itself. If the cleaners are light, they can be supported by the gas pipes, but usually not in the case of trucks; they must then be placed on the chassis frame with brackets. Holes should be made in the frame such that its strength is not significantly decreased.

Generator gas manufacturers have made available special printed directions for mounting the fan, generator gas control, garage carburetor, mixer, etc. These directions can be followed in detail if the mounting of such generator gas equipment is not prevented or made more difficult by special devices found on trucks. For this, flanges and other fastening devices are often supplied.

On trucks with power-operated dumpers (Figure 216) (usually hydraulic), the operation of the dumper frequently may be an obstacle to mounting the channel irons mentioned above. It is then necessary to block them up or else attach the generator and possibly the cyclone cleaner by means of brackets. The holes in the channel iron should be close to the rib in order not to weaken them too much. Sometimes it may be advisable to fasten them with angle irons to the chassis members.

In addition to safety regulations and the rules mentioned above, the following information concerning the slope of the piping is applicable.

1. The gas pipe should be run so that it will be as short as possible in order to lessen flow resistance. For the same reason, there should be as few bends as possible.

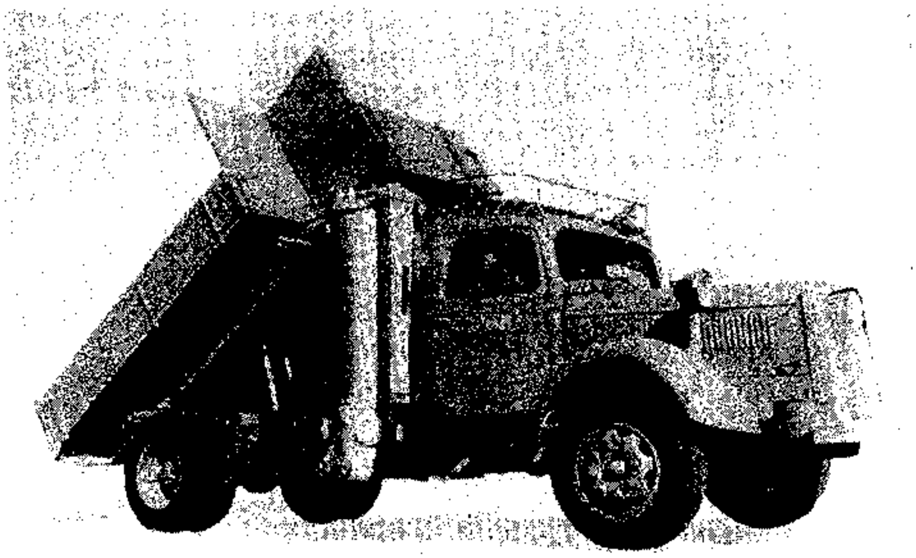


Figure 216. Dump Truck with a Wood Gas Generator.

2. Easily accessible drainplugs or draincocks should be placed where condensation water is collected (see Figure 217).

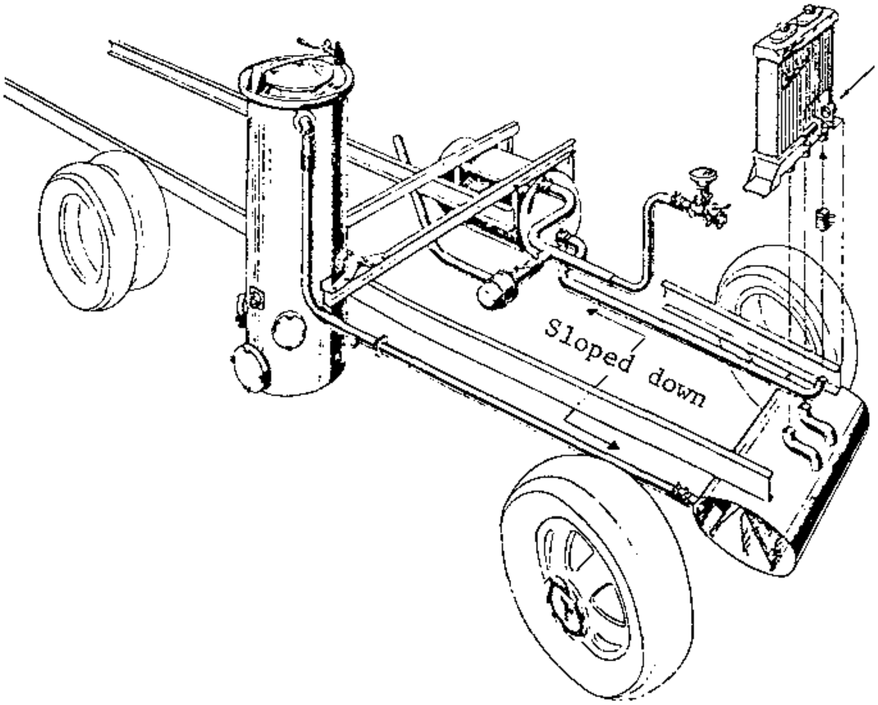


Figure 217. Installation of an Imbert Wood Gas Generator on a Truck.

3. The pipes should have a relatively great cross section for the smallest possible resistance. The gas velocity should, for this reason, not exceed 5 m/s.

4. Where the gas still has a high temperature, i.e., before the cooler, the pipe diameter should be greater than after the cooler. The conduit before the cooler should have approximately 1/4 greater diameter than after it.

5. Before the cooler, hose may not be used for pipe connections; instead pipes with flanges or, where possible, welding should be used. After the cooler, however, a rubber hose may be used and should be used whenever possible. This is also applicable for the connection between the vehicle and a gas generator trailer (reinforced hose). A metal hose must not be used for the gas pipe. Underneath the vehicle or the mudguard, rubber hose must not be used for pipe connections. The rubber joints must not be more than a distance of 1 cm between the pipes and they should be equipped with a clamp and preferably a retention bead as well, so that the hose cannot easily come loose. A bead can easily be made by welding a rather thick iron wire (2-3 mm) onto the pipe end. Rubber bands must not be used, since they can easily be slipped off by suction, thus causing interruption of service.

When the pipes are measured, cut, and welded, it is advisable to block them up in their places and spot weld them, after which they are removed and completed. Misalignment of the pipe ends should be carefully avoided, since it may increase pressure drops and cause soot to collect. For the same reason the welding joint should be as smooth as possible on the inside.

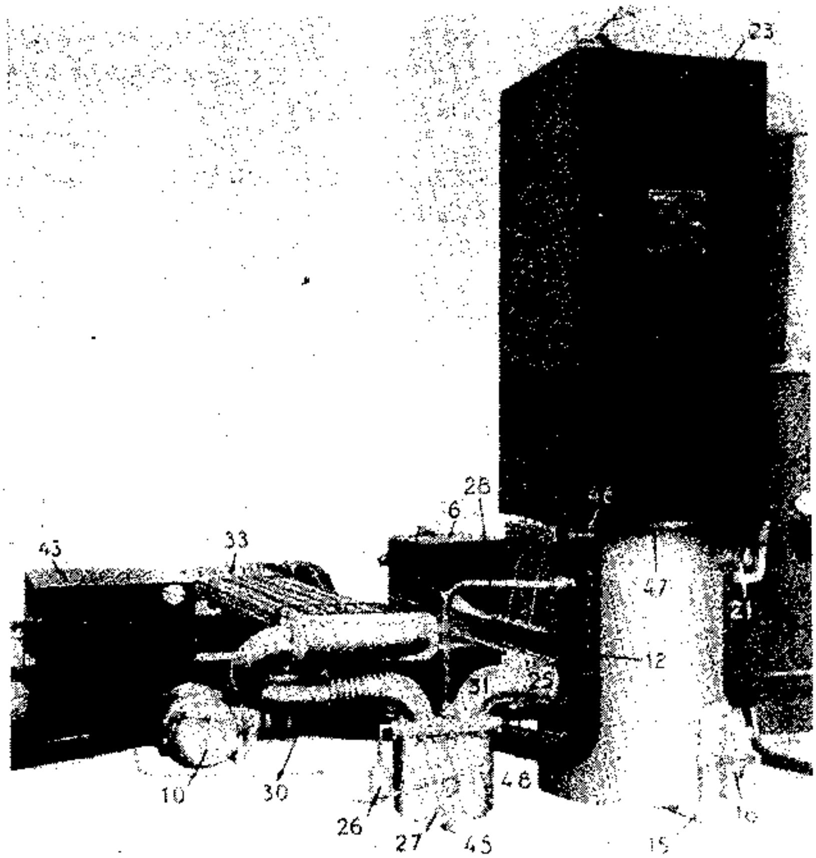
After the gas generator has been mounted on the chassis and the truck bed put on again, a careful check of all gas connections should be carried out with regard to the fire-protection regulations. As a rule, the gas generator should also be tested hydrostatically to see if there is any leakage. To place manometers for reading the pressure after the generator and immediately before the mixer would be useful, although it has not been done very often.

On trucks pulling semitrailers, there is often adequate space for placing a gas generator between the rear gable of the cab and the front gable of the truck bed or the superstructure. Adequate space for spare tires, wood store, etc., is also found in these places (see Figure 134).

The installation should be done so that all ports, flush plugs, and draincocks are easily accessible for service.

Passenger Cars, Rear Installation

For passenger cars, apart from special pivot trailers, either front or rear installation is used. On the whole, front installaton was used for small charcoal units (Kalle) generally for small cars. For large passenger cars and taxi cabs, rear installation was most common; the gas generator was then either built into the trunk or else placed so that the trunk space could be entirely or partially retained. Passenger cars with rear installation were, as a rule, type inspected by the car manufacturers and the installations were relatively simple. Such built-in gas generators were usually intended to be built into the trunk so that only the trunk lid itself would have to be removed.



6. Generator gas cleaner. 10. Starting fan. 12. Primary-air pipe. 15. Shaking arm for the grate. 16. Ash port. 21. Inspection port and handle. 23. Fuel container. 24. Fuel port. 25. Gas outlet. 26. Water float. 27. Steam boiler. 28. Steam pipe. 30. Gas pipe with an expansion section. 31. Gas pipe. 33. Gas cooler. 43. Water tank. 45. Drain plug for water. 46. Pipe sleeve. 47. Sealing flange. 48. Flange.

Figure 218. Installation of a Swedlund Charcoal Gas Generator on a Truck.

In all rear installations, the gasoline tank must be removed, the springs reinforced with a few blades, and the shock absorbers adjusted for the increased load. The gasoline line is plugged.

In addition to the removal of the trunk lid, the bottom of the trunk may also have to be cut out. In all installations, irrespective of the distance to combustible materials, both a safety wall and an insulation wall must be arranged in the trunk space and in a way so that there is adequate ventilation around the generator.

If the bottom of the trunk can be left intact, adequate ventilation is arranged by an ejector duct or ventilation openings. The openings are placed so that dust is prevented as much as possible from entering the trunk. This is quite difficult, since, during running of the car, a rather pronounced vacuum is usually created around the trunk lid.

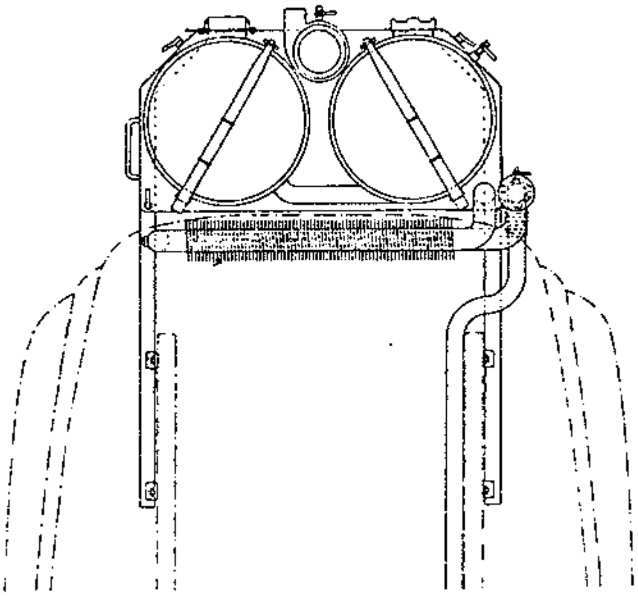


Figure 219. Rear-mounted Wood Gas Generator for a Passenger Car (top view).

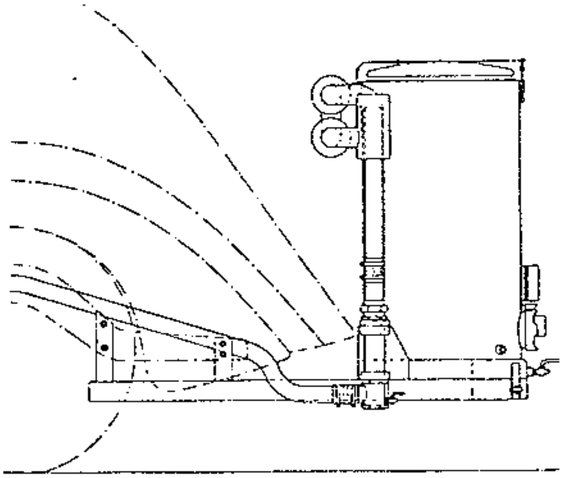


Figure 220. Wood Gas Generator for a Passenger Car (side view).

The gas generator is suspended on channel irons that are fastened to the crossmembers of the frame with bolts. The gas cooler of a charcoal gas generator may be placed underneath the rear bumper. The part of the trunk lid that surrounds the gas generator should be covered by dust collectors so that fuel cannot spill into the trunk during filling. The dust collectors may be of netting or perforated sheet-iron, so that the air circulation and cooling are not obstructed.

In order to leave the trunk space free for its original purpose, the gas generator may also be placed on a platform outside the chassis. This gradually became the most common method for rear installation. The gas generator could then be mounted either fixed or hinged. Figures 219 to 223 show examples of various installation methods. As a rule, the platform is supported by angle irons, which are fastened in the same bolt holes in the frame as the shock absorber mounts or possibly in the upper flange of the frame. The gas

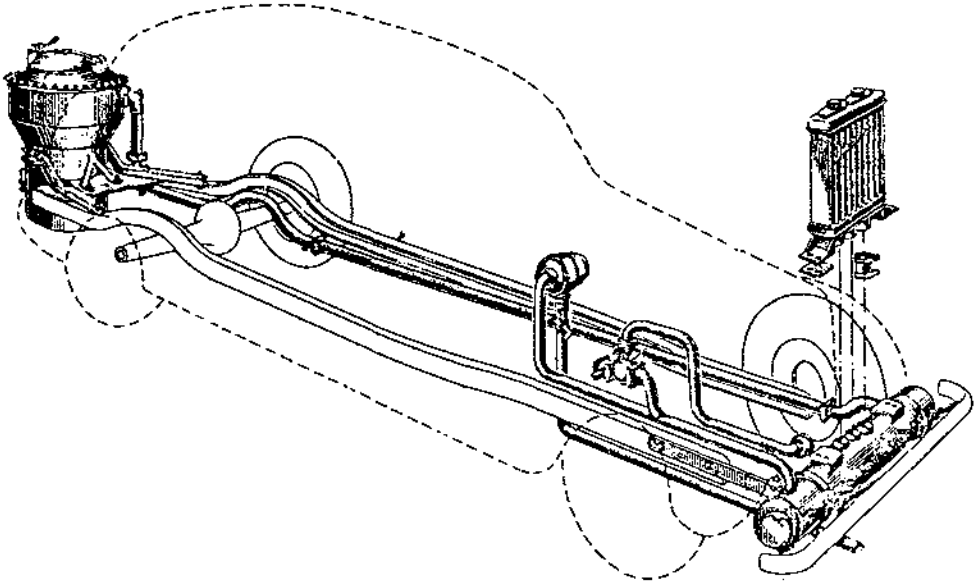


Figure 221. Wood Gas Generator for a Passenger Car.

generator is placed either directly onto these angle irons or on a platform built on the angle irons. For insulation with regard to fire hazard the same regulations are applicable as for truck installation. The distance to the ground must not be less than 250 mm.

When a rubber hose is used, as in the case of hinged gas generators, the gas must not have a higher temperature than 100°C.

In the case of charcoal gas generators, the generator was often mounted behind the car body to the right on a platform, fastened at the same spots in the frame as the shock absorber; the cyclone cleaner was placed on the opposite side, and the cloth cleaner was mounted at the front of the car. In such cases there was no need for a special cooler, since the gas piping supplied enough cooling. The generator should not be welded to the mantle plate, since it usually is not durable enough. Special suspension devices, flanges, etc., should be arranged for this purpose and the generator should be equipped with a support at the top, as a rule placed above the trunk lid. This support should be sufficiently resilient.

In the case of wood gas generators, the gas pipe from the rear-installed cyclone cleaner to the front-installed wet cleaner may run over the roof of the car; thus, a good slope may be obtained in the pipe, avoiding a water lock. A condensation-water collector should, in such cases, by placed immediately after the cylone cleaner.

Passenger Cars, Front Installation

Front installation is, as a rule, used for charcoal gas generators using fine charcoal or charcoal dust, due to their relatively low weight. Many advantages are gained with such installations; the car body is left free; the pipes are short, fire hazard is reduced, accessibility for service is good, installation work is simple and inexpensive, etc. The following installation directions are for Kalle units.

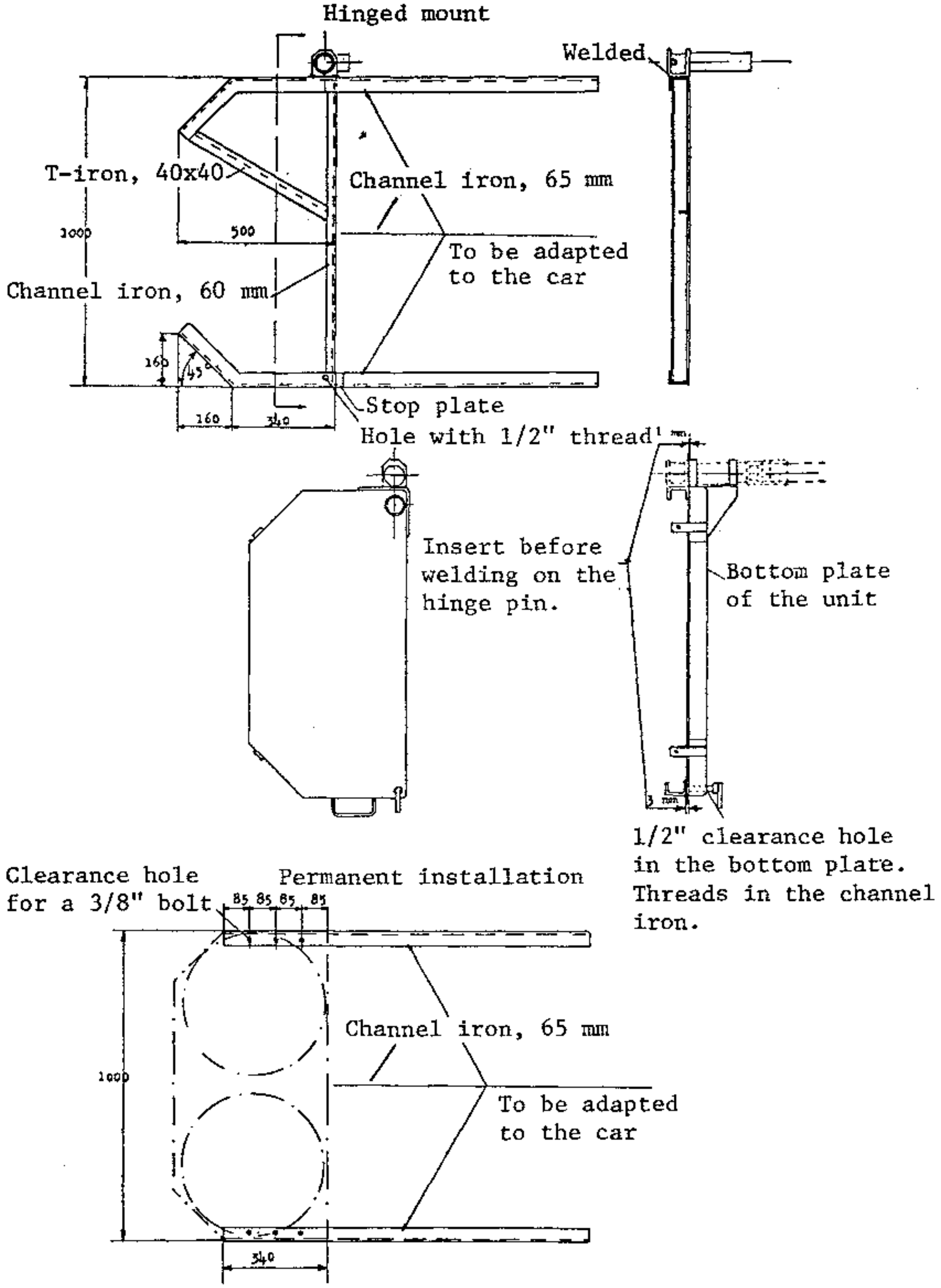


Figure 222. Platforms for Hinged and Fixed Installation, Respectively, of Gas Generators on a Passenger Car.

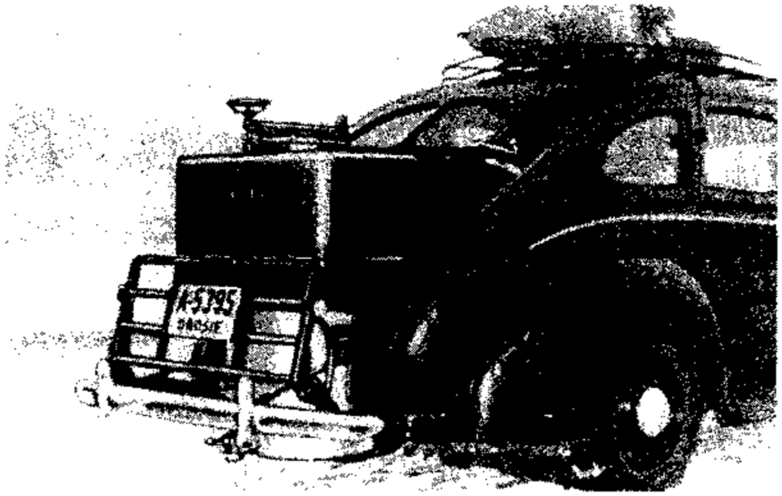


Figure 223. Charcoal Gas Generator Partially Built into the Trunk of the Car.

The gas generator is mounted on two iron supports, which are fastened to the frame. The unit is very light, the weight being only about 80 kg when the generator is full. Still, there will be strain on the frame of the car as well as the iron supports for the unit, and therefore the installation should be carried out with great care. This is particularly true for fastening the iron supports to the chassis frame, so that the unit does not shift or loosen. The installing garage or possibly the car manufacturer can supply information about the carrying ability of the car and whether additional spring leaves need to be inserted.

The Gas Generator. The mounting is shown in Figures 224 and 225. The front bumper is removed and the unit fastened by means of two angle iron supports that have been attached to the chassis frame in the same holes as used for the bumper. The dimensions of these support irons should be at least 62 X 10 mm or 75 X 8 mm. There must be no notches or similar defects to weaken the carrying ability. If possible, the holes should be drilled at the center of the iron.

In the mounting procedure the unit is placed in front of the car on some kind of support, and is then inclined backward to prevent it from tilting forward after the support has been removed and the load deflects the springs and support irons. It should be at a height of approximately 300 mm above the ground. After this, measurements are made and the shape of the support irons determined. The height from the ground to the lowest point of the unit must not be less than 250 mm, when the vehicle is fully loaded.

The upper bracket must also be done with great care. Two round irons (10 mm diameter) or possibly flat irons at least 21 X 4.5 mm, respectively, are placed crosswise as shown in the figure. The irons are pulled through the radiator grillwork and fastened to the bolts that hold the headlights or the radiator. Where the irons cross over each other they should be fastened together by welding or with a bolt. The irons may also be placed lengthwise, but then the generator must be satisfactorily propped up.

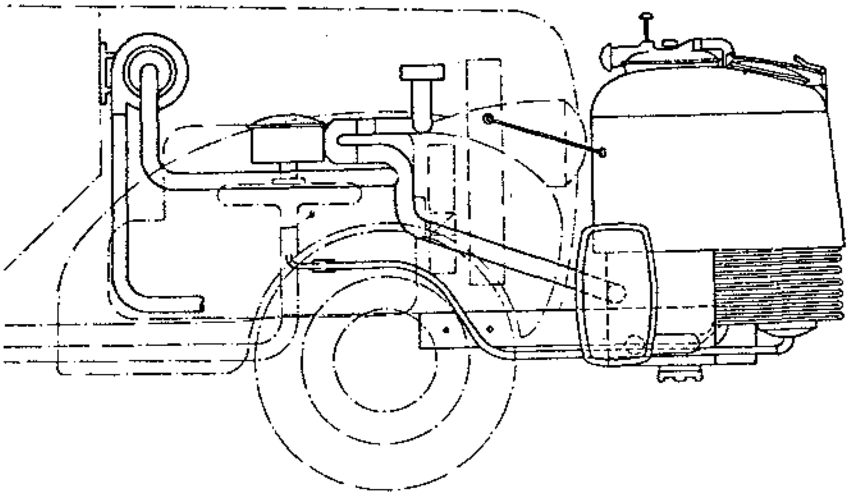


Figure 224. Front-installed Charcoal Gas Generator (Kalle)

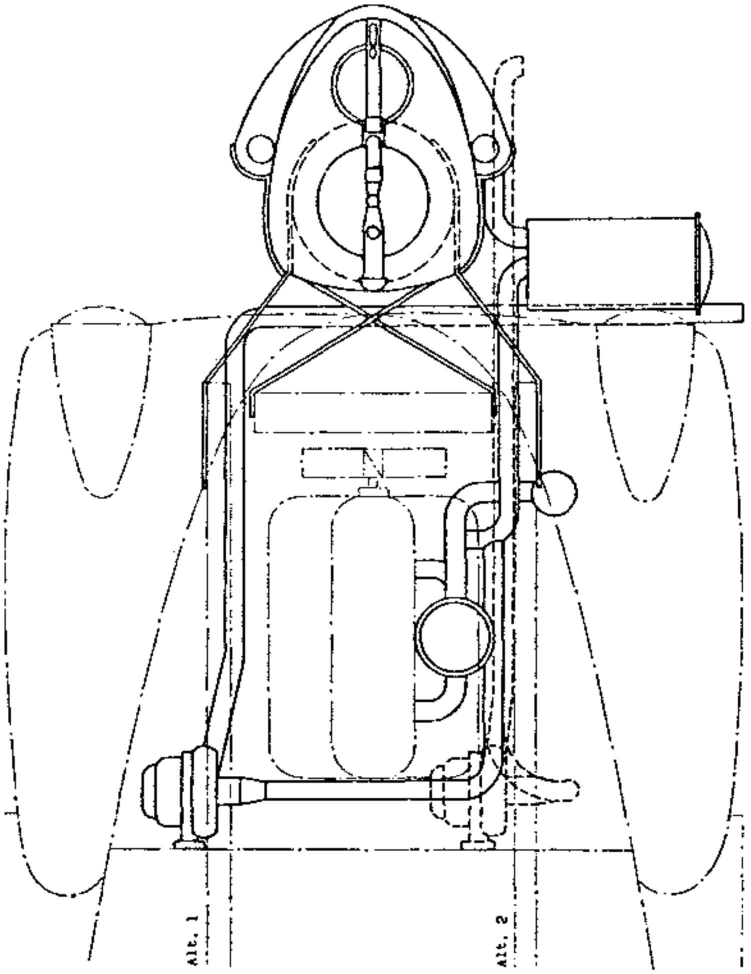


Figure 225. Plan view of Figure 224.

It is important that the edge of the filling port of the generator is level and even, and that it has not been damaged during transport. It is of the utmost importance that the fuel lid be tight. If any straightening is required, it should be done by striking from the inside.

The Gas Cleaner. The gas cleaner is placed on the right side of the unit. It should be fastened to the right support iron on a bracket of flat irons. Figure 226 shows an example of such an installation. The cleaner must be placed so that the port may easily be opened and the filter taken out for cleaning. On the inside of the lid the gas cleaner is marked "UP" to indicate that this side is mounted upward.

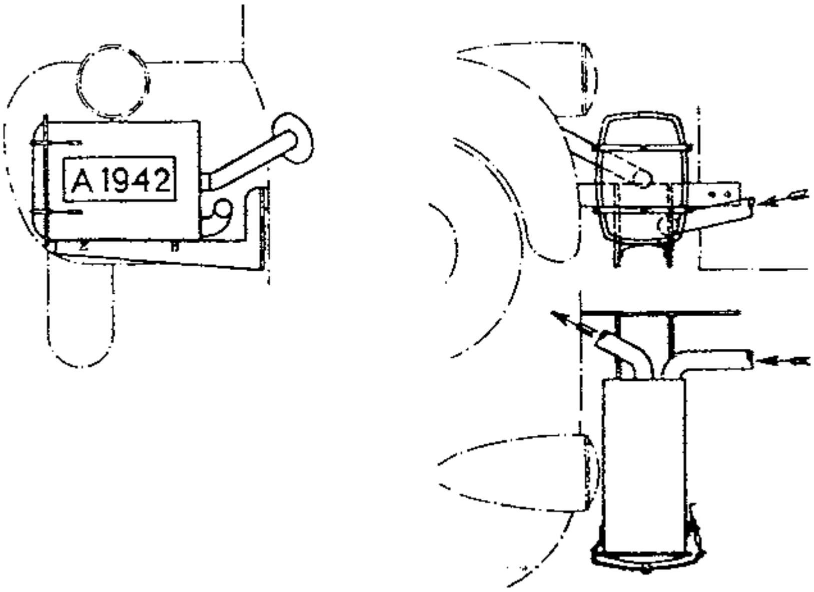
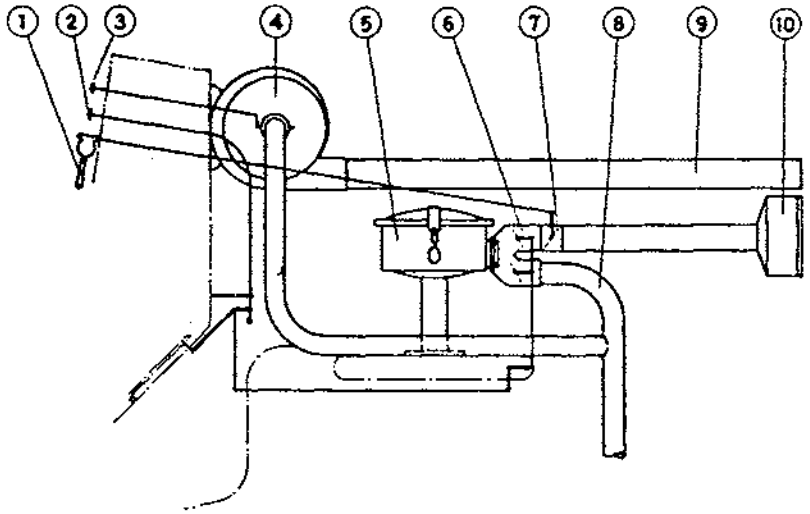


Figure 226. Installation of the Cleaner in a Kalle Charcoal Gas Generator.

Due to the fact that positioning of the gas cleaner must vary widely for different cars, it has not been possible to equip it with a bracket. For installation, holes should be made in the gable of the cleaner, as shown in Figure 226. Inside the gas intake is a distribution plate so that the gas does not hit the cleaner cloth directly. It should be fastened directly onto the casing, not onto the cassette.

The gas cleaner is connected to the cooler with a pipe, which is sloped down to the gas cleaner. A rubber section should be placed in the gas conduit between the cooler and the gas cleaner. The outlet from the cooler is at the bottom to the right. From the gas cleaner, a pipe is run to the engine. This pipe should be run with few bends, at a slope up to the mixer device. A fitting is made in the pipe for a duct to the fan, as shown in Figure 227.

The Starting Fan. The fan is placed horizontally underneath the engine hood. The installation is made considerably easier, because the fan shroud can be turned in relation to the base. Special attention must be given to the tightness of the fan or the fan duct. An electric cable to the fan must be equipped with a fuse or wired through some of the fuses already existing in the car.



1. Air control. 2. Hand accelerator. 3. Fan damper and switch. 4. Starting fan. 5. Mixer. 6. Damper case. 7. Secondary-air damper. 8. Gas pipe from the cleaner. 9. Gas pipe from the ignition fan. 10. Air filter.

Figure 227. Piping for a Front-Installed Charcoal Gas Generator.

In the case of front installation, the gas pipe should be run as straight as possible. Pipes should not be run underneath the engine but rather through mudguards or the cowl. When piping goes through car-body metal, rubber should be used to prevent rattle and to allow the pipe some free motion. The ordinary regulations for insulation are also applicable for front installation, and the fan outlet must open out at least 70 cm from the nearest opening in the car body; for instance, the grill openings of the engine hood. If the gas generator is equipped with a pressure fan, the secondary-air intake is to be considered a fan outlet.

Sometimes it may be advantageous to replace the ordinary radiator fan of the engine with a truck fan of greater capacity.

The installation of the mixer, starting carburetor, controls, etc., must be adapted to the type of engine or car in question. Frequently, detailed installation directions concerning these are supplied by the manufacturers.

Passenger Cars, General Safety Measures

Due to the risk of carbon monoxide leaks, extreme care must be taken to prevent gas from leaking into the driver's cab, passenger space or anywhere in the vehicle. Gases that come from the engine crankcase (oil-filling hole, crankcase vent, etc.) should be efficiently evacuated. The pipe of the crankcase vent must be extended to the right side of the vehicle underneath the footboard. It should be run so that water lock cannot occur. The pipe end must be shaped so that the suction created by vehicle motion is not impaired and the exhaust gases really are drawn out of the crankcase. There should be an approximate 30° angle between the direction of travel, obliquely backwards, and the end of the evacuation pipe. Any devices for the supply of fresh air to the crankcase (the oil-filling lid vent, air-intake in the case of overhead valve engines, etc.), should be equipped with an extension pipe, so that the air intake will be outside the engine hood. These air intakes must be located at least 25 cm behind the radiator grillwork. If there is an opening in the flywheel casing, it should be closed since gas may escape through the end-journal bearings of the crankshaft.

The crankcase evacuation vents should not be connected to the fan outlet, since the crankcase ventilation is impaired in this way. There is sometimes a risk that combustible gas could enter the crankcase if the fan outlet is connected with the secondary-air system, causing ignition in the engine crankcase when the gas is tried during fanning.

Packings of the exhaust pipe and muffler must be tight. Sometimes it may be advisable to lengthen the exhaust pipe, especially for trucks and buses.

Vacuum-operated windshield wipers and fans should be replaced by electrically-operated ones, since carbon monoxide also may enter the vehicle in this way.

Buses and Rail Buses

For buses and rail-buses the instructions given above are, on the whole, applicable. Due to the great number of passengers, there must be even more careful control of gas leaks and fire hazards. If a trailer for passengers or cargo is not being used, generator gas trailers are frequently excellent for bus operation. They are, as a rule, factory assembled. There are also trailers with both a gas generator and cargo space. The common rules for trailer operation are applicable for the gas connection. The gas hose may in this case be reinforced rubber.

Tractors and Power Tools

Gas generators for operation of tractors are usually manufactured for each specific type of tractor. For the installation of such gas generators on tractors already in use, the manufacturers supply detailed instructions for each tractor type and, as a rule, also necessary assembly materials, thus facilitating the gas generator assembly.

For gas generator installation on power machinery with a driver's cab, similar regulations as for trucks and passenger cars are applicable, with regard to fire and carbon monoxide hazards.

There are certain regulations related to fire protection concerning parking tractors in farmyards.

Ships and Motorboats

The conditions for installing gas generators on ships and motorboats are even more intricate and varied than for trucks. With possibly the exception of certain kinds of fishing vessels, hardly any boat is like another; and, in addition the engines are of many different types, makes, and sizes. At the beginning of the generator gas epoch, quite a few small recreational boats were already equipped with gas generators originally designed for motor vehicles, as well as, in some cases, with specially-designed generators. It was not until pulsator and gas-pump systems for the conversion of ignition-bulb engines were developed that utility boats and ships such as fishing boats, motor sailing vessels, lumber-floating boats, inspection boats, etc., were equipped with gas generators, usually more or less specially designed wood gas systems. As a result, the special installation regulations and inspection obligations by a government authority (the Ships' Inspectorate) were instituted. Like the ordinances mentioned earlier concerning motor vehicles and power machines, issued by the Generator Gas Bureau of the Fuel Commission and others, these safety regulations were concerned with carbon monoxide and fire hazards as well as with seaworthiness and maneuverability.

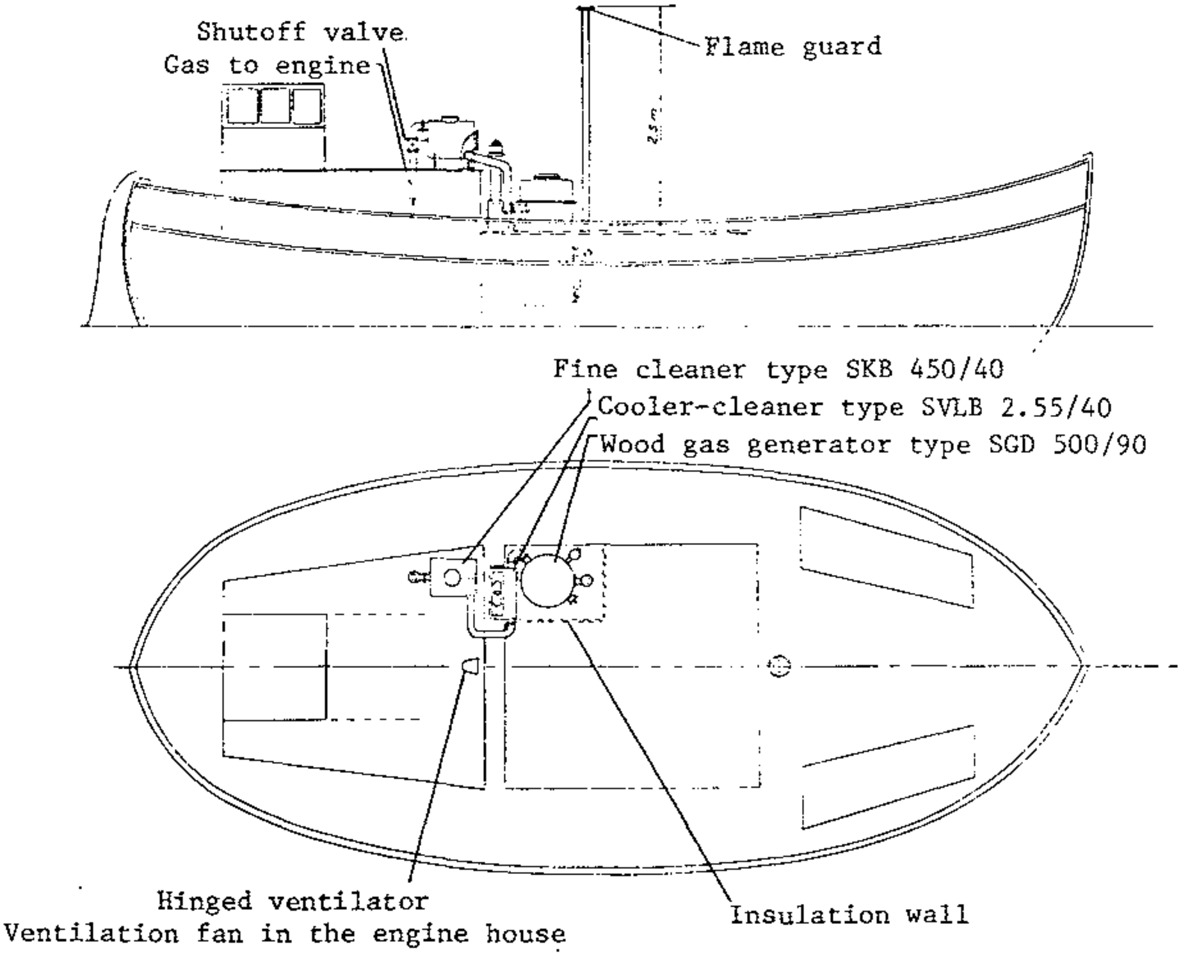


Figure 228. Installation Drawings for a Wood Gas Generator for a Boat.

Generators for Small Recreational Boats. These boats generally have four-cycle engines of the carburetor, Hesselman, or sometimes diesel type. Those boats with two-cycle outboard motors as a rule cannot use gas generators due to small dimensions, high rpm and, to some extent, the location of the motor.

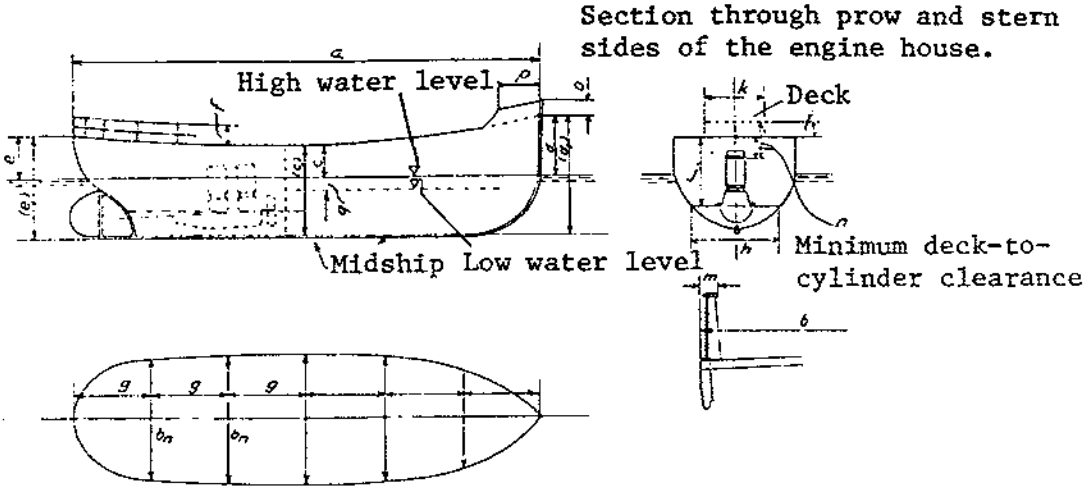


Figure 229. Installation Drawings for a Wood Gas Generator for a Boat.

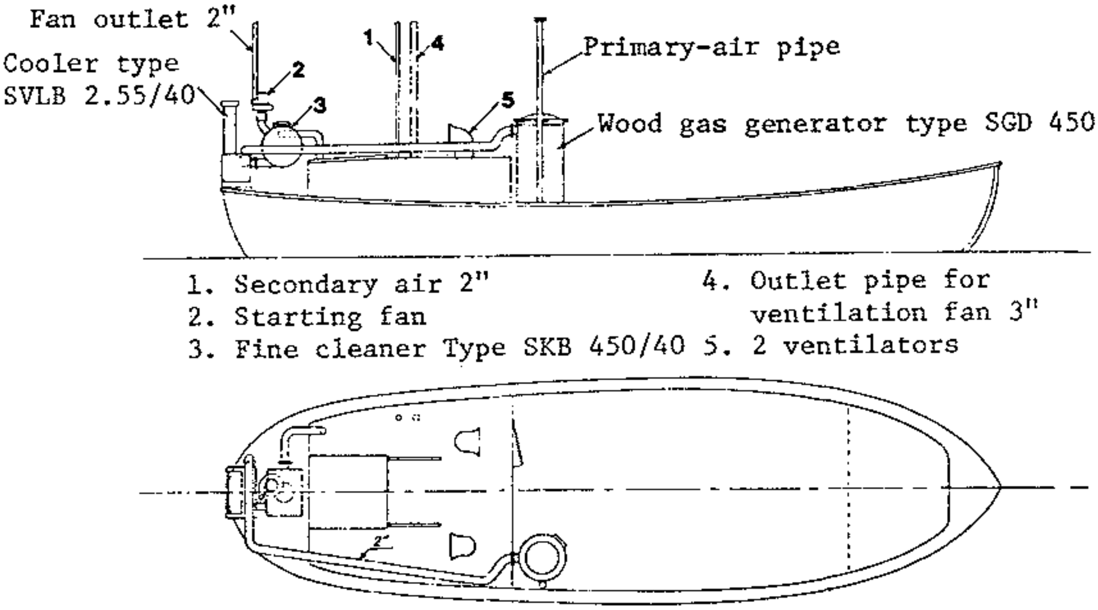


Figure 230. Installation Drawings for a Wood Gas Generator for a Boat.

Because of the space on board it is advisable to place the gas generator in the cockpit, which may necessitate replacing the existing tiller with a steering wheel. The deck space underneath the generator should then be covered with some material such as asbestos cement so that dirt can easily be swabbed away. The gas generator must be lightweight and the boat sturdy, so that the stern will not be weighted down, particularly since there will be no gasoline load forward. The wood store can be limited. For a 30-hp engine in approximately a 9-m boat, a wood store of 1-1.5 hL would seem to be sufficient. Filling should be possible with the engine running. The net weight of the generator may then be kept to approximately 100 kg. The cyclone and wet cleaner with its cooler are placed near the generator. Arrangements should be made so that flushing with water is possible. The cooling should be great enough that the gas pipe can be run, without fire hazard, all the way to the engine. It is advisable to use a scrubber-type cleaner (see Figure 108), since soot is automatically removed through this kind of device. The piping to the cleaner and from the engine must be sloped. If a scrubber is used, its bottom must be so far above the water surface that the pressure drop in the generator does not prevent water from running from the scrubber. If there is not sufficient space available, a condensation container may be placed at the lowest point of the gas pipe, similar to those underneath generator gas-operated trucks. The condensate in this container may be sluiced out by means of a "speed sucker."

The water pressure created by the speed of the boat may be used instead of a pump for water cooling; for instance, by forcing sea water up into a pipe.

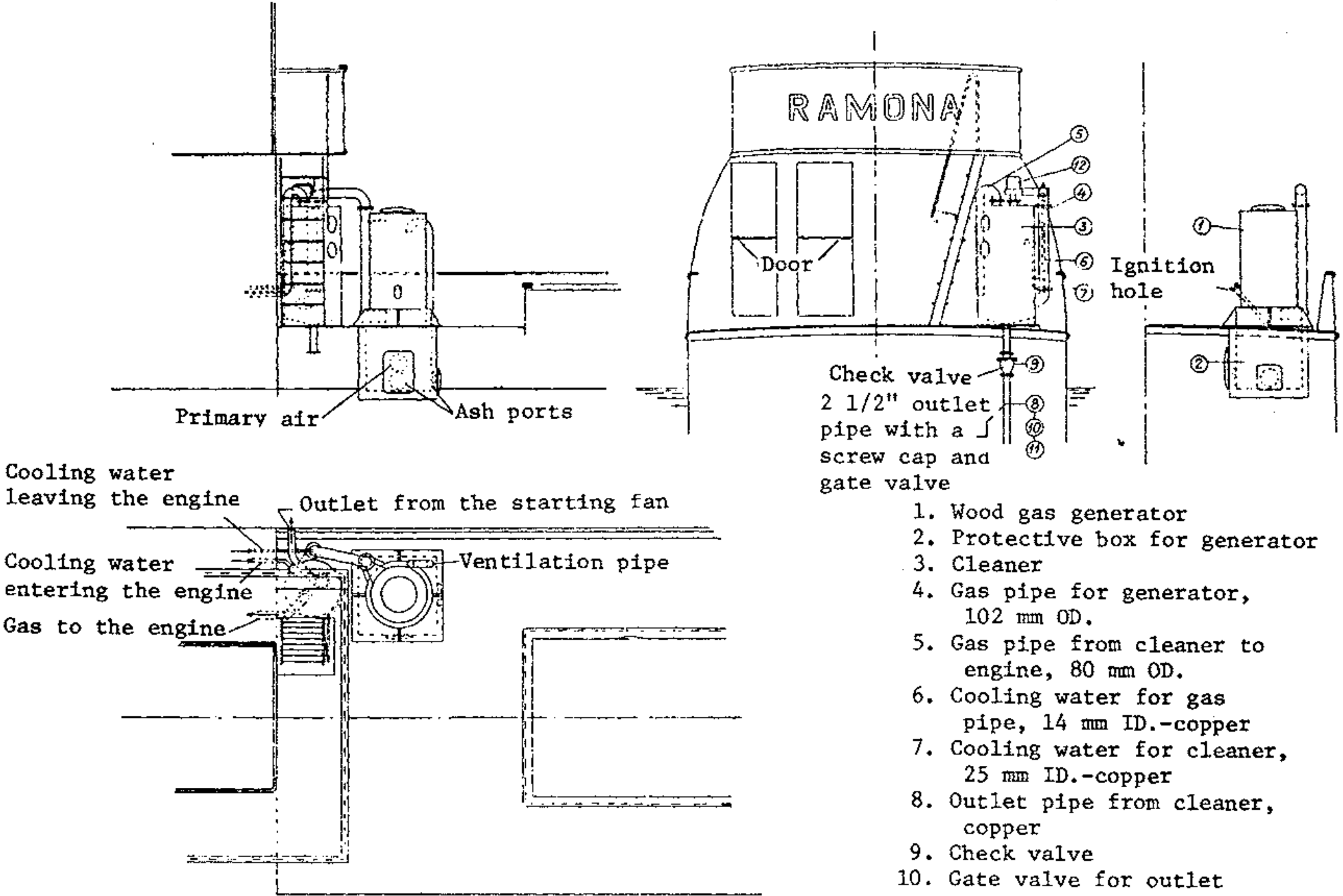
Charcoal gas generators are not very well suited for boat operation, since it is difficult to obtain charcoal along the coast and in addition, since charcoal is very hygroscopic; i.e., it readily absorbs moisture.

The piping should be run as straight as possible, just as in other kinds of generator gas units, and pipe bends should be avoided. Rubber joints may be used as soon as the gas has passed the cooler (below 100°C). The location in the body depends upon the space in each individual case.

Assembly of Large Gas Generators for Ignition-Bulb Engines. When installing the gas generator it is important that the view of the steersman is not obscured and that gas generator parts do not get in the way of hawsers, derricks, capstans, etc. Particularly in the case of fishing vessels, positioning of the various gas generator parts and pipes can frequently become a rather difficult problem, since there must be sufficient freedom of movement for the fishing equipment on deck, where, according to regulations, the gas generator must be placed. All wood that is within a distance of 300 mm from the generator must be insulated with asbestos or something similar, or be plated. This also applies to warm gas conduits, cyclone cleaners, etc. Use of a pressure fan for starting the generator is not permitted on ships. The fan must be placed above deck and the outlet pipe must be placed at least 2.5 m above the deck or floor and so arranged that the gas flows freely upward. The same provisions are applicable for the primary-air pipe to the generator and the intake for the secondary air. Evacuating pipes from safety valves, blowcocks, crankcase, etc., should be placed a satisfactory height above deck and must not be connected to the fan outlet. Damper shafts, as well as ports, flush plugs, cocks, etc., should be absolutely tight.

The ventilation of the engine room, if there is one, must be efficient. Two intake vents of at least 200 mm diameter are prescribed and the pipes from these should open out close to the floor. In addition, there should be two exhaust vents, both equipped with suction fans with a capacity of at least 175 m^3/h. One of these should be mechanically started at the same time as the starting fan for the generator, but it should also be possible to keep it running independently. The other fan must always be running during operation of the engine. The vent outlets should open out at least 2.5 m above the deck, or the floor.

There are also provisions concerning the ventilation of living quarter and cargo spaces in generator gas-operated ships. Open boats which do not have special engine houses should have their cabins and other closed rooms equipped with ventilation of a design determined by the Ships' Inspectorate.



1. Wood gas generator
2. Protective box for generator
3. Cleaner
4. Gas pipe for generator, 102 mm OD.
5. Gas pipe from cleaner to engine, 80 mm OD.
6. Cooling water for gas pipe, 14 mm ID.-copper
7. Cooling water for cleaner, 25 mm ID.-copper
8. Outlet pipe from cleaner, copper
9. Check valve
10. Gate valve for outlet pipe, copper
11. Screw cap for outlet pipe, copper
12. Starting fan

Figure 231. Installation Drawings for a Wood Gas Generator for a Boat.

As a rule, special assembly drawings are made during the gas generator installation and sent to the Ships' Inspectorate for approval (see Figures 228-231). During the subsequent inspection by the Ships' Inspector, quite a few changes may be required, especially if the shipyard that carries out the conversion is not fully familar with this kind of work.

The piping must be done with great care and judgment, not only with regard to carbon monoxide and fire hazards but also due to the fact that often the very long pipes required involve large pressure drops accompanied by power decrease. Frequently, room for the fuel store must be made in the cargo space; it should be protected from being splashed, if it is placed on deck or in an open boat. Figures 140 to 143 show further samples of gas generators for boats and ships, and in Figure 89C, a diagram is given for a wood gas generator connected to a large ignition-bulb engine with a pulsator.

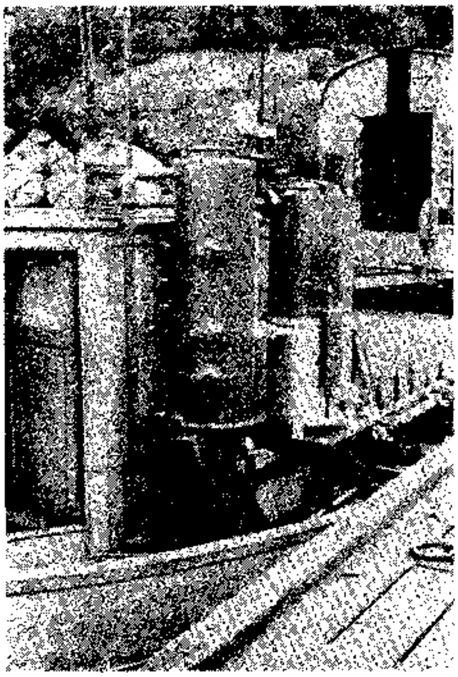


Figure 232. Deck Installation on a Boat.

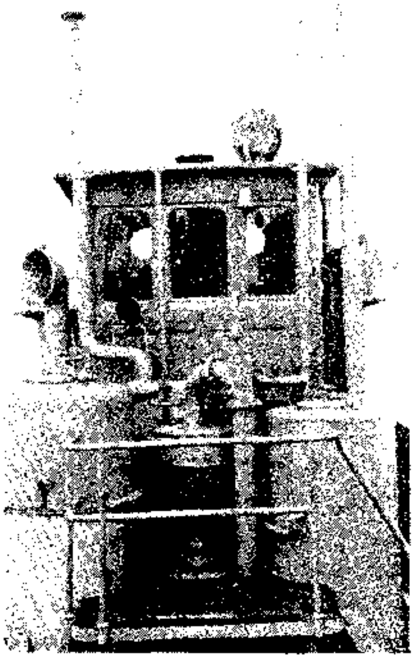


Figure 233. Installation of a Wood Gas Generator on a Pulsator-Operated Boat.

Chapter 9

GARAGE AND SERVICE*

There were many cases of carbon monoxide poisoning in Sweden during the generator gas epoch, mainly because safety regulations were not followed.

A garage used for generator gas operated vehicles should be easily accessible and preferably on the ground floor. It should have tight walls so as not to let gas into the rest of the building; also, the floor should slant outward, so that the vehicle can be easily rolled out through the exit, which should be that of the garage only. When the vehicle is to be started, the doors should be left open at least a half minute before anyone enters the garage. Then the vehicle may be rolled out; preferably it should be started about 10 m from the garage. For the ventilation of this type of garage, an air intake at a low spot far away from the gas generator and an air outlet near it are adequate.

Small garages are to be preferred. The greatest problem for large garages is satisfactory ventilation. In order to be able to start up the gas generators indoors, the following conditions are required:

1. Adequate general ventilation is essential; i.e., air circulation corresponding to a complete air exchange four times an hour.

2. When the gas generator is being fired up, the gas outlet of the fan must be tightly connected to a special power-operated, adequately sized, exhausting device vented into the open air. The fan of the gas generator must not be used in the garage; use only the suction of the ventilation system itself.

3. When the car engine is being started, the exhaust pipe must be directly connected to an exhausting device.

Service premises, such as car repair shops and garages, should be located away from densely built-up areas, on the outskirts of towns. Special equipment needed for servicing gas generator operated vehicles are additional welding equipment, pressure gages, control devices for electric systems, exhausting devices, an improved ventilation system, devices for cleaning charcoal gas filtering cloths, and charcoal trays for emptying out charcoal.

Devices recommended for industrial hygiene are as follows:

1. An oxygen inhalation system with karbogengas (oxygen with a 7% carbon dioxide content), to remove carbon monoxide from the blood but also to prevent mild poisoning in the first place.

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*Note: This chapter is a summary of the original material published in Swedish. Therefore the figures appearing in the original (Figures 234-236) have not been reproduced herein.

2. Combustion devices for burning carbon monoxide present in the fan gases.

3. Carbon monoxide indicators.

The latter two were not fully developed or commonly used during the generator gas epoch, one reason being cost.

There are few problems with carbon monoxide poisoning when dealing with gas generators in the open air. However, parking of generator gas operated vehicles very close to each other at parking lots should be avoided.

Chapter 10

PRACTICAL OPERATING EXPERIENCE*

Generator gas is a typical substitute fuel, used when there is limited or no supply of liquid fuel. It involves not only inconveniences but also hazards as serious as fire and poisoning. However, the difficulties may be less for generator gas used for heating purposes, such as in boilers and hot air engines.

Both wood and charcoal gas generators are useful. The charcoal gas generator may be better for small engines, but wood fuel is easier and cheaper to manufacture, store, and distribute. With the recent improvements of wood gas generators there should be no technical reason for preferring the charcoal type.

When an engine is converted to generator gas operation, one of the problems is a decrease in power. In the case of trucks, tractors, stationary engines, etc., it may be desirable to increase the power by installing a supercharger. In order to increase the reliability of the vehicle and its adaptability to varying loads, the best solution may be to convert to a system that makes alternate driving on generator gas and liquid fuel possible. In the Kroll system, the kinetic energy of the exhaust gases of the engine are used to start the generator, which simplifies generator gas operation but requires gasoline. In such cases, the generator gas is mainly used for continuous driving. The liquid fuel is used in the garage, for starting, loading and unloading, shunting, and when maximum power is needed. The switch to generator gas is made while the vehicle is moving; this minimizes the risk for interruption of service due to poor gas. However, the changeover cannot take place until the generator gas has reached a sufficient thermal value. This kind of system is a great help to the battery, since there is no need for electric fanning or other inconveniences connected with starting a gas generator. Also, the hazards of carbon monoxide poisoning and fire are reduced.

There are specially made gas generators for cars and tractors to choose from; in other cases there are standardized types available. Size, gas cleaning system, and therefore cost, are dependent upon the gas requirement of the engine and the operating conditions. For intermittent operation, hearth rings with easily replaceable choke rings are preferable. For charcoal gas operation, cloth cleaners are best; for wood gas operation, a combination of condensation cleaner and cork cleaner.

The quality of fuel used for gas generators is quite important; more so for charcoal gas generators than for wood gas generators. The wood fuel should have a moisture content of no more than 20% to 30%; also the individual piece size should be adequate, containing no splinters, rough bark, sawdust, etc. The moisture content of charcoal should be approximately 10% to 12%, the piece size must be adequate and there should be no ashes or impurities such as sand or soil.

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*This chapter is a summary of the original material published in Swedish. Therefore the figures and table appearing in the original (Figures 237-247, 249-257; Table 34) have not been reproduced herein.

In the case of wood gas generators, a charcoal bed must be built up in the combustion zone below the air nozzles. Also, in the reduction zone, below the combustion zone, there must be charcoal for reduction of carbon dioxide and water vapor. This lower part of the charcoal bed also has filtering (ash particles), supporting (the wood above) and insulating properties. The reduction takes place, as a rule, only inside the actual hearth; therefore, the charcoal below or outside the lower part of the hearth mainly serves as a filter and support and may be replaced by such material as porous concrete, which does not crumble so easily.

To build the charcoal bed, first charcoal is put in through the filling port of the generator to about 10-15 cm above the level of the air nozzles. Then, through the inspection openings at the bottom, strong charcoal, coke, or porous concrete is packed around the hearth until the level reaches approximately the middle of the openings or possibly the narrowest section of the hearth. After this, dry wood is put in up to about a third of the volume of the fuel store. Filling is not completed until the engine is running on generator gas. The charcoal in the oxidation zone is ignited by a generator gas match inserted through a special ignition hole, sometimes the primary-air intake. If there is a suction fan it should be working awhile before ignition; a pressure fan, however, should not be started until after the match has been inserted. In the latter case the lids may be open to let out useless smoke, gases, and water vapor. For initial startup using gasoline the ejector effect of the engine exhaust can be used for much stronger air suction in the producer.

The generator gas is ready to use for operation after 6 to 12 minutes. Before the engine is started, the quality of the gas is tested by ignition. The flame should be red-blue and burning steadily; if it has a white or gray core, the fuel is too moist; if the flame is too short, the pressure drop is too great or the hearth clogged, etc.

If the generator has been used and shut off, but still contains both charcoal and wood, the generator must be degassed before igniting for operation again, in order to avoid dangerous explosions. The filling port lid is then opened, but the gas must not be ignited. (If, however, there is still a glow, the gas should always be ignited.) The lid is left open for about a half minute, after which the fan is started up with the secondary-air damper and carburetor damper closed. While the fan is running, the wood is carefully stirred up. Also, the outer porous concrete or charcoal bed is loosened up, but not the charcoal in the oxidation or reduction zones. After the fan has been running for about one minute it is shut off, the grate is shaken, the ashes raked out, and the inspection-port cover lubricated with graphite oil and closed. After this, the fuel is ignited and the gas tested as described earlier.

There is no need for inserting a charcoal bed in the charcoal gas generator. A pressure fan is generally used for starting a charcoal gas generator. This helps to dry the charcoal without the water vapor going through the cloth cleaner; the lids should then be open during fanning. When a charcoal gas generator is to be filled with fuel, it is advisable to put used charcoal that has been saved from earlier driving and is particularly dry in the oxidation and reduction zones. The flame of the ignited gas is usually bluer than in the case of wood gas, and usually does not have the gray-white core caused by water vapor. It is best to have a third of the fuel container filled with fuel when driving is stopped for the day. That way, there will be dry fuel for the following day, which will greatly facilitate starting. After an interruption of 3 to 4 hours, the generator does not have to be reignited if the dampers were left open. After being stopped for only 5 to 10 minutes, fanning is usually not required before starting. It is, however, better for the battery to use fanning rather than the starting engine.

A gas generator must not be started indoors because of possible carbon monoxide poisoning. For driving in and out of a garage a so-called garage carburetor should be used. (Special devices for starting up a car engine were described previously.) For driving on generator gas it is important to keep the correct working temperature. The idling speed should be no less than 800-1,000 rpm. Also, it is better to have an air deficit than an air excess during periods of small load operation. During operation, no maintenance measures are needed for 150-200 km driving, after which the ashes must be raked out and the condensation water drained. On the whole, more maintenance is required in generator gas operation than in gasoline operation. The engine oil must be checked each day; this is also true for the air cleaner under dusty conditions. The gas pipe, cooler, and cleaner must be flushed clean each day with water (wood gas generator), and the cloth cleaner and safety filter blown out (charcoal gas generator). After 1,250-1,500 km, the generator must be carefully inspected for air leaks, etc. For this examination all fuel must be emptied out and the generator must be degassed. Defective parts such as the hearth ring may have to be replaced.

In the wintertime because of low temperatures, even more maintenance is required. One great problem then for generator gas operation is the increased water condensation and the risk that the water will freeze. Insulation of exposed parts, especially the cyclone cleaner and its pipe, is essential, as well as frequent draining through drain plugs, not only in the condensation-water container but in low pipes and all cleaners, etc.

As in operation on gasoline, a similar fouling of the engine takes place in generator gas operation. However, the fouling originates from ash and dust particles, mainly alkali and soot, that enter the engine with the gas mixture. Charcoal gas usually also contains a relatively great quantity of mechanically abrasive impurities such as iron and silicon compounds. During intermittent operation engine fouling is much greater than during continuous driving with a heavy load. The Generator Gas Bureau of the Fuel Commission inquired of several companies about the wear on the cylinders during generator gas operation. The answers were in many ways quite conflicting but, on an average, it appeared that cylinder wear is somewhat worse from generator gas operation than gasoline operation, and that charcoal gas is somewhat worse than wood gas operation.

The consumption of lubricating oil is somewhat greater for generator gas operation than operation on gasoline; in some cases, however, it has been reported to be less than for diesel operation.

During the generator gas epoch there was a general shortage of materials, which led to the development of improved designs using low alloy materials. In the charcoal gas generators kanthal (an iron-aluminum alloy) was used for the nozzles, which were exposed to high heat. Hearths made of sheet-metal were protected by charcoal and ash layers.

Mixtures of steel alloyed with nickel and chrome were used for the hearths of wood gas generators. Before rationing, the hearths contained about 20% chrome and 20% nickel; after rationing 18% to 25% chrome and 2% to 4% nickel. The combustion zone operates at 1200°C to 1300°C and the hearth material up to 1000°C. Therefore, the life of the hearth was usually only 5,000 to 20,000 km, depending on the driving conditions, even with first-rate material. The durability of the hearths became even less after regulated production, due to metal rationing. The alloy permitted under regulated production was:

Cr.	Approximately 6.00%
Si	Approximately 1.50%
C	Approximately 0.20%

However, the V-hearth design using a protective ash insulation during operation had about as long a durability with this material as earlier with high-alloyed materials.

For oceangoing ships corrosion-resistant materials such as aluminum had to be used.

One problem during wood gas operation is the adaptation of the charring to various loads. Charcoal surplus occurs, as a rule, during a heavy load in the generator especially if the hearth is undersized. Charcoal surplus may be counteracted by using harder wood. Charcoal deficit is caused by prolonged low load or too large a hearth diameter. It may be counteracted by using softer wood.

Briquettes may be manufactured by pressing charcoal dust, peat, or sawdust with or without use of a binding agent. Briquettes of charcoal dust may be used in charcoal gas generators; briquettes of peat, sawdust, or brown coal in wood gas generators. The advantages of using charcoal briquettes may be summarized as: better gas with higher engine power, longer driving distance per volume unit fuel, less work when filling fuel, and less work due to slagging of the generator. The main disadvantage is the somewhat longer ignition time required for briquettes as opposed to charcoal. Also, the generator units are primarily designed for charcoal operation, not for operation on briquettes.

With peat briquettes, there is a risk of their crumbling or sticking together, thus constricting the primary-air supply. This is related to the ash and tar content of the briquettes. If the ash content is low, good results may be obtained; the travel distance is then greater per hL than with wood. With peat coke, tests have shown that the driving distance per hL is greater than with charcoal. However, the slag formation is greater, as well; this is particularly true of a peat with high ash content.

For charcoal gas generators, a cloth cleaner in combination with a preceding cyclone cleaner is superior to other cleaning devices. However, the cloth cleaner is sensitive to both heat and moisture. At a temperature above approximately 120°C it becomes brittle, and at a temperature of over 150°C it will be heat damaged. The lower temperature limit is dependent on the dewpoint of the gas; i.e., its moisture content. Usually there is condensation at about 40°C; for wood gas, however, at about 80°C. For charcoal gas it is advisable to use a minimum temperature range of 70°C to 80°C and a maximum range of 130°C to 140°C. For wood gas the minimum temperature range could be raised to 90°C to 100°C by placing the cloth cleaner relatively close to the generator and the cyclone, or by heating the gas with the engine exhaust gases before the cloth cleaner; also, a precondensor may be used.

It would be advantageous to replace the heavy and bulky condensation cooler of the wood gas generator as well as the cork cleaner with a cloth cleaner in combination with the cyclone cleaner. In order to achieve this goal, considerable improvements would have to be made, however. Tests with cloth cleaners for wood gas operation were carried out on a Volvo passenger car in 1943 and 1944. The results indicate that cloth cleaners still do not give satisfactory reliability in wood gas operation. However, the prospects for further development are good. The following improvements must be made: decrease of the pressure drop during operation, longer intervals between cleaning of the cloths, and increased protection for the cloths against moisture as well as mechanical and thermal stress.

TROUBLESHOOTING CHART FOR A WOOD GAS GENERATOR (HESSELMAN)

The starting fan does not draw, or draws only slightly.

1. The fan damper is closed.
2. The flap for the primary-air intake is sticking.
3. The flame guard for the primary-air intake is clogged by impurities.
4. The water level in the cleaners is too high. Note: During winter driving the water must always be drained from the cleaners and pipes before long interruptions in driving.
5. The gas conduit is clogged due to failure to flush.
6. The cork in the cork cleaner is very dirty. Change the cork. Never fill the cork cleaner more than 3/4 full with dry cork.
7. The charcoal bed of the generator is clogged by charcoal dust; therefore cleaning and changing the charcoal is necessary.
8. The fan is defective. The blade wheel has come off the axle or is very dirty.

The starting fan draws properly, but the flap of the primary-air intake does not open.

1. The secondary-air damper or the gasoline carburetor damper is open.
2. The fuel-filling lid is not tight or not closed.
3. Some inspection port lid, draincock, or flush plug is open.
4. The gas conduit is broken.

No combustible gas is produced.

1. Extra air is entering through the secondary-air damper, carburetor damper, some inspection opening, draincock, or flush plug.
2. The wood is hanging in the generator. Open the fuel-filling lid and stir the wood down. Warning! Do not push the wood down through the combustion zone! If you do a gas with tar content will form.
3. The wood is too coarse.
4. The gas contains too much water vapor due to moist wood.
5. The charcoal bed has become moist because wood was filled in the day before, just before the vehicle was put away.
6. The charcoal bed does not reach an adequate height. Fill in charcoal to the middle of the upper inspection openings.
7. The generator is clogged. Change the charcoal bed.

Starting difficulties in spite of adequate gas.

1. The fan damper is open.
2. The damper of the gasoline carburetor is open.
3. The spark plugs have become wet due to too moist gas.
4. Too great spark gaps in the spark plugs. Adjust to 0.4 mm.
5. The battery is discharged.
6. The ignition is set too low.

The engine runs unevenly.

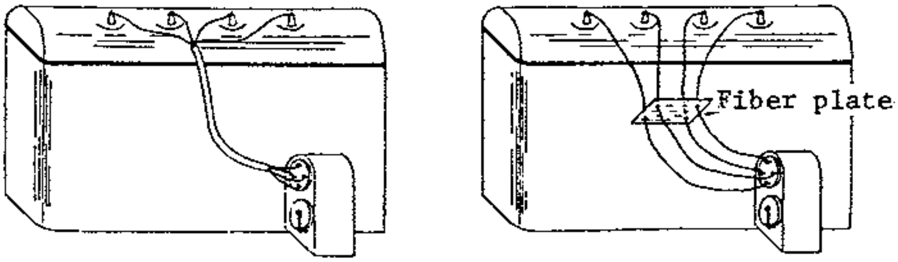
a. when pulling:
   1. The secondary-air control is adjusted incorrectly.
   2. The fuel container is empty.
   3. Faulty ignition. Sparkover is some spark plug.
b. during idling:
   1. Too much water in the cleaners.
   2. Waterlock in the gas conduit.

The engine is abnormally weak.

1. The secondary-air control is adjusted incorrectly.
2. The fire in the generator burnt down too far.
3. Too late ignition.
4. The flame guard on the primary-air intake of the generator is stuck.
5. Extra air is entering the generator through the inspection openings. The packing between the outer and inner mantles at the primary-air intake is broken.
6. The fuel-filling lid is not tight.
7. The cork in the cork cleaner is dirty.
8. Too much water in the cleaners.
9. The charcoal bed of the generator is clogged. If it does not help to loosen the charcoal and shake the grate the charcoal must be changed.
10. Unsuitable or too moist wood.
11. The fire hearth of the inner mantle is damaged by fuel having been added too late.

The engine knocks in the intake pipe.

1. Too rich mixture; i.e., the secondary-air damper is not open enough.
2. The ignition cables are damaged, so that there are sparkovers.
3. The ignition cables are poorly installed. In order to avoid induction sparks, the cables should be well separated from each other. Never put the cables in a common collecting pipe (see Figure 248).



Not this way

But this way

Figure 248. The ignition cables must be separated to avoid "scintillation ignitions".

4. Sparkover in the distributor lid.
5. Too great electrode distance in the spark plugs. Should be 0.4 mm.
6. The wrong type of spark plug. Carefully follow the manufacturer's directions when chosing spark plugs.
7. Faulty valves in the engine.

Sharp noises in the generator.

1. The generator was not ignited according to the directions given.
2. The fuel-filling lid is not tight.

The outer mantle of the generator becomes abnormally hot.

1. The inspection opening lids are not tight.
2. The screws that hold the primary-air intake have come loose.
3. The packing between the outer and inner mantles at the primary-air intake is damaged.
4. The wood has burnt down too far.

Abnormal fuel consumption.

1. Unsuitable or too moist wood is being used.
2. The fuel-filling lid is not tight.

Tar deposits in the engine.

(This trouble is manifested by the engine valves binding and the piston rings sticking. The pistons also may get stuck in the barrels.)

1. Second rate charcoal was used for the first filling of the generator.
2. Wood was pushed down through the combustion zone.
3. The wood used was too moist.
4. The wood was burnt down too far, after which wood was filled in without first filling in charcoal.
5. The engine has run idle too long. Always shut off the engine during long interruptions in the driving.
6. The nozzles or the fire hearth of the inner mantle are damaged.
7. Too great a hearth area in the generator.

TROUBLESHOOTING CHART FOR A SMALL CHARCOAL GENERATOR (KALLE)

	I. Problem	II. Cause	III. Action
1.	Hot fuel container.	Fuel shortage. If not, leak in the filling lid.	Fill in charcoal, tighten the lid.
2.	The vehicle runs in a jerky way.	The charcoal in the generator is running low.	Fill in fuel.
3.	The engine loses power. The membrane indicator is low.	Great resistance in the generator.	Remove slag from the generator, clean the generator and the flame guard.
4.	The engine loses power. The membrane indicator is high.	Great resistance after the generator.	Clean the cooler, filter, and safety filter.
5.	The membrane indicator shows tendencies to get stuck. The filter bin contains mainly large charcoal pieces.	Burnt grate. Slag in the generator.	Look over the generator and clean the wind sieve. Control the quantity of return gas.
6.	Tar deposits in the filter apparatus and the safety filter.	The fuel has too high a loss due to burning or too great a tar content.	Buy approved fuel.
7.	Moisture precipitation on the cloths. The dust is jet black (should be grey).	Moist fuel or gas too cold.	If the gas is too cold the cooler must be screened off or else the distributor, which is located on the opposite side against the filter outlet, must be removed.
8.	Difficult start.	Dusty filters, slag in the generator. Dampers are not tight or are adjusted incorrectly or are stuck. The filling lid is not tight. Too rough engine in case of cold weather and thick oil.	Remove slag from the generator, clean the filters.
9.	Puffs in the mixer.	The intake valves are not tight or the spark plugs are too soft and ignite by incandescence.	Call a service man.
10.	The engine starts but stops again.	The check valve is stuck.	Remove the flame guard and see that the flap is easily moveable.

TROUBLESHOOTING CHART FOR A SMALL CHARCOAL GENERATOR (KALLE) (continued)

I. Problem	II. Cause	III. Action
11. The nozzle quickly burnt off.	Lack of return gas.	Clean the wind sieve and control the return gas.
12. The nozzles are slowly burnt off.	Too little return gas.	Increase and control the return gas.
13. Nozzle burnt off and covered with slag.	Impure fuel.	Remove slag from the generator and buy better fuel.

Chapter II

THE ECONOMICS OF GENERATOR GAS OPERATION

Generator gas operation in its widest sense includes cars as well as machines, boats, stationary engines, heating furnaces, etc.

Four-Cycle Engines for Vehicular Operation

In car operation we have to allow for both fixed and variable costs. Interest, principal, car tax, car insurance and garage costs as well as driver's wages, accident insurance, office costs, etc., when applicable, are included in the fixed costs. Fuel, oil, tires, repairs, service, car wash, etc., are counted among the variable costs.

As for the fixed costs, it should be mentioned here that the capital invested in gas generators in Sweden during World War II, plants for producing generator gas charcoal and generator gas wood, fuel supplies, ventilation devices in garages and car repair shops, etc., may be estimated, in round figures, to be at least 400 million kr, perhaps close to a half billion kr.

As for the variable costs or the actual operational costs, the fuel cost dominates; this will be dealt with more in detail later.

A Comparison Between the Fuel Costs of Generator Gas Operation and Those of Liquid Fuel Operation

In a comparison between the consumption of gasoline and car charcoal, respectively, it may be found that, during favorable conditions, approximately 1.1 kg car charcoal is equivalent to 1 litre gasoline. Careful practical tests have shown, however, that when driving without stopping, one can estimate 1 litre gasoline to be equivalent to approximately 1.25 kg car charcoal and approximately 2.25 kg car wood, respectively. The latter figure is given somewhat on the high side in order to include the comparatively insignificant consumption of charcoal for the charcoal bed, estimated to be at the most 1.5 kg per 100 km, corresponding to approximately 6 kg wood or approximately 6% of the cost of the car wood.

The stated consumption figures do not include the fuel consumption during firing up, starting, interruption of service, idling, cooling off, etc. Because of this, it is necessary for long distance driving to increase the figures by at least 10% so that gasoline is equivalent to approximately 1.4 kg car charcoal and 2.5 kg car wood, respectively. These figures have also proved to be realistic when comparing the consumption of kerosene with car charcoal and car wood, respectively, for tractor operation.

For ordinary highway driving it is advisable to use somewhat higher figures so that 1 litre gasoline is equivalent to approximately 1.65 kg car charcoal and approximately 3.0 kg car wood, respectively. For delivery driving, especially city traffic, these figures must be futher increased according to the type of driving. For distribution driving in a city with constant interruptions with the engine still running, as well as for a passenger car in city traffic with frequent interruptions, it may then be necessary to use nearly double the figure; i.e., figures as high as approximately 2.75 kg car charcoal and approximately 5.0 kg car wood, respectively, as equivalent to 1 litre gasoline (where the gasoline engine is shut off at every stop, whereas the generator gas engine is kept running). These high figures are based on the experience that the consumption of generator gas fuel during idling of the engine amounts to approximately 75% of the consumption during normal driving. In fact, for a car with very discontinuous driving, the fuel consumption per hour is a more reliable basis for estimation than the fuel consumption per mile driven.

In addition to the idling time, the size of the load, among other things, affects fuel consumption. Thus, experience has shown that the fuel consumption of a truck during idling is approximately 75% of the consumption during full load. Other factors affecting fuel consumption include the type of car and gas generator, the nature of the fuel, and the road conditions.

A few of the best years' fuel consumption tests will be summarized here. However, it must be remembered that the most recent years saw improved economic results through research and experiments.

Under the Gas Generator Bureau's auspices, a series of tests were conducted during the summer and fall of 1940 on wood gas-operated trucks to ascertain the reliability and economy of operation with various kinds of wood fuel and fuel mixtures. For a four-cycle 50 hp 3-ton truck as well as for a six-cycle 95 hp 3 1/2-3 3/4-ton truck with normal load and in practical operation, a consumption of approximately 0.22-0.24 kg car wood per ton-km useful load was obtained. In case of overload the wood consumption went down all the way to 0.16 kg per ton-km useful load; however, at the cost of the life of the truck.

For a comparison, a few results will be reported from the economy contest of the Royal Swedish Automobile Club for generator gas operated trucks in September 1940. Careful statistics were kept of the charcoal and wood consumption of a great enough number of average size trucks to obtain a fairly reliable mean value. The charcoal was mixed birch and softwood charcoal in an approximate proportion of 20/80.

From the contest record for Class V with charcoal gas operation, all 13 average size trucks were taken out with a load from 2670 to 3790 kg (average 3180 kg) and a total weight from 5900 to 6950 kg (average 6470 kg). The charcoal consumption amounted, on the average, to approximately 0.13 kg per ton-km useful load and 0.065 kg per ton-km total weight, respectively.

For Class V with wood gas operation, in the same way eight average size trucks were taken out with a load from 2580 to 4710 kg (average 3700 kg) and a total weight from 5650 to 8700 kg (average 6900 kg). On an average, the wood consumption amounted to approximately 0.21 kg per ton-km useful load and approximately 0.11 kg per ton-km total weight, respectively. In accordance with what has been said above, the figure 0.21 (also with regard to the charcoal consumption for the charcoal bed) may in practice be increased to approximately 0.23 kg per ton-km useful load and approximately 0.12 kg per ton-km total weight, whereby the relative consumption of wood/charcoal will be approximately 1.75.

For futher comparison let us look at some of the results from the winter contest of the Royal Swedish Automobile Club in February 1941, where, on one hand, a mixed charcoal was use, birch and softwood in an approximate proportion of 75/25 and, on the other hand, car wood of birch.

In Class 5, smaller trucks, seven trucks with an average weight of 5380 kg and an average useful load of 2620 kg had an average wood consumption of approximately 0.22 kg per ton-km useful load and approximately 0.11 kg per ton-km total weight.

In Class 6, somewhat larger trucks, seven trucks with an average weight of 6510 kg and an average useful load of 3010 kg had an average charcoal consumption of approximately 0.14 kg per ton-km useful load and approximately 0.065 kg per ton-km total weight. In the same class, the two smaller wood gas driven trucks with an average weight of 6675 kg and a useful load of on an average 3070 kg had an average wood consumption of approximately 0.22 kg per ton-km useful load and approximately 0.10 kg per ton-km total weight.

The four largest wood gas driven trucks in Class 6, with an average weight of 7430 kg and an average useful load of 4260 kg had an average consumption of only approximately 0.18 kg per ton-km useful load and approximately 0.10 kg per ton-km total weight. The low figure 0.18 is explained by the very favorable relation for large trucks between the useful load and the total weight.

The consumption figures obtained during the contest and the test results of the Gas Generator Bureau are in good agreement with each other when compared, especially if the somewhat more realistic nature of the tests done by the Gas Generator Bureau in practical operation is taken into account. For trucks in very good condition and mainly driving without stopping with very few and comparatively short interruptions, we may estimate for average size trucks (3- to 4-ton useful load) and with full load, a charcoal consumption of approximately 0.14 kg per ton-km and a wood consumption of approximately 0.24 kg per ton-km (including the charcoal for the charcoal bed), respectively, in both cases figured on the useful load. Including the charcoal for the charcoal bed we may estimate the relative consumption of wood/charcoal of approximately 1.75.

If we use the wartime retail price of 5 kr per hL mixed charcoal (birch and softwood) and a hL weight of 17.5 kg, corresponding to 0.285 kr per kg, and if we also assume that car wood of birch with some alder and softwood mixed in and with a hL weight of 32.5 kg, costs 3 kr per hL, corresponding to 0.0925 kr per kg, we arrive at the following fuel costs. For a 3- to 4-ton truck with full load and a charcoal consumption of 0.14 kg per ton-km useful load, the charcoal cost will be approximately 0.04 kr per ton-km useful load. For a wood gas truck of the same kind with a consumption of 0.24 kg wood per ton-km useful load (including charcoal for the charcoal bed) the fuel cost will be approximately 0.022 kr per ton-km useful load. The fuel cost for operating a truck with wood gas would, consequently, amount to only 55% of the fuel cost for charcoal gas operation.

If the above-mentioned figures 0.14 kg and 0.24 kg, respectively, per ton-km useful load are converted to hL per 10 km for a 3-ton truck, we obtain a consumption of approximately 0.24 hL charcoal per 10 km and approximately 0.22 hL wood per 10 km, respectively. In practice, it is customary to assume that the consumption of charcoal and car wood, respectively, is equal. However, according to the tests the wood consumption (including the charcoal for the charcoal bed) actually is somewhat less than the charcoal consumption, measured in hL.

If these consumption figures, 0.24 hL charcoal and 0.22 hL wood, respectively, per 10 km are compared with figures given by the Road Haulage Association of Sweden, which are based on purely practical experiences from June 1, 1941, to May 31, 1942, there is a significant divergence. As an average for 82 charcoal gas trucks (2.2-3.8 ton) with a total driving distance of approximately 2,870,000 km, the charcoal consumption was stated as approximately 0.325 hL per 10 km. For 107 wood gas trucks in the same size categories and with a total driving distance of approximately 4,285,000 km, the wood consumption was on an average approximately 0.320 hL per 10 km.

From the Swedish Board of Telecommunications operation in 1943 of a fairly large number of trucks, the following fuel consumptions were averaged: for 1-2 ton trucks, 0.33 hL charcoal per 10 km and 0.27 hL wood per 10 km, respectively; and for 2-5 ton trucks, 0.39 hL charcoal per 10 km and 0.34 hL wood per 10 km, respectively. The consumption of charcoal was on an average 1.18 times the wood consumption. If the charcoal in the charcoal bed is included in the wood consumption, the charcoal consumption can be estimated to approximately 1.1 times the wood consumption (calculated in hL per 10 km).

The Stockholm Breweries Ltd., reported for the two-year period from October 1, 1942, to September 30, 1944, for 3-ton trucks, a consumption of 0.63 hL charcoal and 0.54 hL wood, respectively, per 10 km. The consumption of charcoal, as for the trucks of the Swedish Board of Telecommunications, was an average 1.18 times the wood consumption. The high fuel consumption figures for the brewery trucks are mainly explained by the type of traffic; i.e., city traffic with comparatively short driving distances with many interruptions. The average number of kilometers per hour for the charcoal gas trucks was only 7; for the wood gas trucks, 6.3 km/hr.

The following table of the fuel consumption on various transportation distances for a 3.5-ton truck in a large trucking enterprise would seem to agree well with practical experience.

1. Transportation distance in km	5	10	25	50	100	150
2. Gasoline L per 10 km	4.00	3.75	3.50	3.00	3.00	3.00
3. Wood hL per 10 km	0.50	0.40	0.35	0.30	0.30	0.30

The great difference between the test results and the figures based on purely practical experiences is mainly due to consumption during firing up and cooling off, more and longer interruptions for loading and unloading, waiting, breaks for meals, etc. This does not mean, however, that it would not be possible to achieve an improvement of the operating economy in practical operation through increased operating control and instruction of the drivers.

A further explanation of the divergence is also found in the already-mentioned fact that, in some cases, the calculation for fuel consumption per hour is more reliable than per driven 10 km. Thus, tests with a truck on roads of various quality (from road Class I to V) have shown that the engine load generally is practically constant, and thus also the fuel consumption per hour is rather constant. The following table shows the test results.

Road Class	Average Speed km per hour	Wood Consumption hL per 10 km	Wood Consumption hL per hour
I	40	0.25	1.00
II	30	0.33	0.99
III	24	0.42	1.01
IV	15	0.67	1.00
V	10	1.00	1.00

Information regarding the fuel consumption of buses was obtained from the Swedish Association of Bus Owners for a great many vehicles. This information, shown in the table below, is valid for the period from June 1, 1941, to May 31, 1942.

Number of Buses	Maximum Load, kg	Average Driving Distance, Units of 10 km per yr	Charcoal Consumption hL per 10 km	Wood Consumption hL per 10 km
14	2210	1190	0.51	--
29	3146	2337	0.37	--
23	3620	3380	0.35	--
30	3860	4676	0.29	--
21	3060	2312	--	0.37
31	3350	3378	--	0.35
55	3730	5000	--	0.30

The following table shows the costs for fuel of various kinds for large suburban buses carrying approximately 50 passengers. For liquid fuel, the 1939 price level is used; for generator gas fuel, the price level of 1944.

Fuel	Consumption per 10 km	Price, kr	Fuel Cost kr per km
Gasoline	5.00 L	0.27 per L	0.135
Diesel oil	3.25 L	0.20 per L	0.065
Car charcoal	0.50 hL	5.00 per hL	0.250
Car wood	0.45 hL	3.00 per hL	0.135

The February 1941 contest of the Royal Swedish Automobile Club also included economy tests for passenger cars, the results of which can only be stated in kg per ton-km as calculated on the contest weight of the car (weight of car plus crew). The fuels were birch and softwood charcoal in the proportion of 75/25 and hard birch wood. The figures in the table below constitute the average for several cars and state the fuel consumption in kg per ton-km contest weight.

Fuel	Small Passenger Cars, Contest Weight 1220 kg	Average Size Passenger Cars, Contest Weight 1675 kg	Large Passenger Cars, Contest Weight 2150 kg	Average
Car charcoal	0.127	0.130	0.131	0.13
Car wood	0.230	0.243	0.244	0.24

If the stated consumption figures are converted into units of km driven per hL car charcoal and car wood, respectively, the results are:

Fuel	Small Passenger Cars, Contest Weight 1220 kg	Average Size Passenger Cars, Contest Weight 1675 kg	Large Passenger Cars, Contest Weight 2150 kg
Car charcoal	114 km	80 km	63 km
Car wood	115 km	81 km	62 km

During normal highway driving we can, as a rule, estimate that a small passenger car may be driven 75-85 km per hL. With small charcoal units, we may get up to 100 km or even more. For an average size passenger car we may, in practice, estimate 55-60 km per hL charcoal or wood. For taxicabs in city traffic we must assume higher consumption figures due to long interruptions at the station, waiting, and comparatively short driving distances. In such cases we can estimate only approximately 40 km per hL charcoal or wood.

Fuel consumption of passenger cars was actually high in comparison with that of trucks. The fuel consumption figures of the somewhat larger trucks per ton-km total weight are approximately 0.065 kg charcoal and 0.11 kg wood, respectively, as opposed to the corresponding figures of the passenger cars which are approximately 0.13 kg charcoal and approximately 0.23–0.24 kg wood, respectively. The explanation of this fact is primarily that passenger car engines are mostly oversized in relation to the total weight.

With this information as a basis we can estimate how much the gasoline and diesel oil may cost per litre in order to give the same fuel cost as generator gas fuel as an average for the entire car fleet, and also for various categories of cars.

If we use the conditions as they were during the war, the total consumption of generator gas fuel was approximately 50 million hL per year, of which approximately 25 million hL were charcoal and approximately 25 million hL were wood. With a charcoal price of 5 kr per hL and a wood price of 3 kr per hL, the total fuel cost will be approximately 200 million kr per year. If we assume that an average of 1.65 kg charcoal and 3.0 kg wood, respectively, is equivalent to 1 L gasoline, the 50 million hL generator gas fuel will be equivalent to approximately 540 million L gasoline. The gasoline may then cost 200 million kr or 0.37 kr per L in order to have the fuel cost for gasoline operation the same as for generator gas operation (with an equal division between charcoal and wood consumption). The gasoline price before the war was approximately 0.27 kr per L including 0.12 kr tax per L.

If we compare the estimated entire fuel cost—200 million kr per year—of generator gas operation with the cost for diesel oil for the same car fleet, we find that in case of only diesel operation approximately 375,000 L diesel oil would be consumed, which then would be allowed to cost approximately 0.53 kr per L. The diesel oil price was before the war approximately 0.20 kr per L including 0.09 kr per L in tax.

In order to estimate the competitiveness of fuel costs after the war, we may then assume the following starting-point values.

Car Charcoal: mixed charcoal of 17.5 kg per hL - 2.50 kr per hL = 0.143 kr per kg

Car Wood: mixed wood of 32.5 kg per hL - 1.50 kr per hL = 0.046 kr per kg

For the entire car fleet with the same division of charcoal gas and wood gas operation, in order to have the same cost for the fuel only as for the generator gas fuel, gasoline would have to cost approximately 0.185 kr/L and diesel oil approximately 0.265 kr/L.

If we make the same kind of estimate for the vehicle type for which generator gas operation may most likely be considered after the war, namely, for large trucks in long distance traffic, information can be found in the records of the winter contest of the Royal Swedish Automobile Club. The average for three large wood gas driven trucks was: total weight 7650 kg, useful load 4450 kg, and wood consumption (including the charcoal in the charcoal bed) approximately 916 kg in a driving distance of 1213 km with some regulated interruptions. Using the assumptions above, the fuel cost for the transport would be on an average 42.30 kr. Since this contest was mainly a matter of driving without stopping, we may assume the gasoline equivalent to be 2.5 and the diesel oil equivalent 3.6. The gasoline consumption corresponding to the generator gas fuel would then be 365 L and the diesel oil consumption 255 L. In order to have the same fuel cost as for wood gas operation, the gasoline would have to cost approximately 0.116 kr per L and the diesel oil approximately 0.166 kr per L. The vehicles in this case were well maintained and in contest driving; therefore, we must assume that the result in practical operation with generator gas would have been somewhat worse, whereby the figures would have been roughly 0.13 and 0.185 kr per L, respectively.

If we make the same estimate for an average size passenger car with charcoal gas operation, we derive from the contest record that seven cars with an average total weight of approximately 1700 kg, had an average charcoal consumption of approximately 315 kg for a distance of 1427 km at an estimated postwar price of 45 kr. The corresponding postwar price of gasoline would be approximately 0.235 kr per L and that of diesel oil approximately 0.225 per L. Again in this case it was a matter of long distance driving with only a few interruptions.

Judging from the fuel cost figures only, the competitiveness of generator gas as opposed to gasoline would look quite promising, especially in the case of wood gas operated long distance vehicles.

From practical farming operation with two-cycle crude-oil tractors, less favorable figures were obtained. A tractor of this type consumed before the war approximately 50 L crude oil at 0.08 kr per day, corresponding to a fuel cost of approximately 4 kr per day. On the same farm a somewhat larger tractor of the same make consumed approximately 12 hL generator gas wood. If the price for this in home industry is assumed to be 2 kr per hL, the daily cost for just the fuel would be approximately 24 kr. The consumption of lubricating oil at the same time was also doubled.

A Comparison Between Other Elements of Costs

Many factors other than the fuel cost affect the profitability of generator gas operation in the direction of an increase of both fixed and variable expenses. Thus, we must allow for interest and principal of the gas generator including installation expenses, an increased expense for car insurance and vehicle tax due to the gas generator, increased lubrication expense, service and repairs of the generator gas equipment, increased garage expenses (fan devices, etc.), for the prevention of accidents due to generator gas poisoning, and an increased number of breakdowns.

Add to this that we must allow for somewhat decreased load capacity due to the weight of the gas generator, somewhat decreased cargo space due to the gas generator and a somewhat lower average velocity due to the decreased engine power and impaired output of the car. According to some information the traffic speed during bus operation with generator gas decreases by up to 12% to 15% in comparison with operation with liquid fuel. Thus, more buses are needed and more people must be paid.

As a matter of fact, the comparisons that are usually made between gasoline and generator gas operation of a truck are technically and economically rather misleading. The decrease of the engine power by 40% to 50% during generator gas operation means that one will have to put up with driving with a less powerful engine in the case of generator gas operation. Why then, could one not put up with driving a 40% to 50% smaller—and consequently cheaper—engine in the case of gasoline operation? The same reasoning could be used for the size of the car itself. The gas generator involves an additional load of approximately 200 kg on a truck (we assume the tank for the liquid fuel to be dismantled); this load infringes on the useful load of the truck within the permitted maximum total weight. A 3-ton truck with a 90-hp gasoline engine, for instance, will during generator gas operation become approximately a 2.8-ton truck with a 50-hp generator gas engine. In order to find a fair comparison between the expenses, both fixed and variable, the comparison should really be made between gasoline operation of a 2.8-ton truck with a 50-hp engine and a generator gas operated truck built for a 3-ton load and with a 90-hp engine (during gasoline operation). Taking this into account, the comparison between the operational results of gasoline and generator gas operation, respectively, become rather unfavorable for the generator gas truck. Also, the increased maintenance and repair work will necessarily infringe upon the effective working time of the truck, thus making the economic outcome even poorer.

Finally, it is important to take into account the considerably increased expenses for ventilation, etc., of garages and car-repair shops involved with generator gas operation, due to the poisoning hazards.

The costs of procuring and installing wood gas generators and charcoal gas generators for large trucks are practically the same, roughly 2400 kr. For average size trucks wood gas generators are up to 20% more expensive than charcoal gas generators, and for average size passenger cars the price difference is even greater. The purchase and installation for a tractor is approximately 2000 kr for a wood gas generator.

If we assume an interest rate of 4% and a write-off time of four years for the gas generator, the interest and principal for the wood gas installation in an average size or large truck may be estimated at approximately 700 kr per year; for a charcoal gas driven average size truck, somewhat less.

The total increase of the annual fixed expenses for the truck in comparison with gasoline operation may be assumed to be approximately 675-825 kr; the lower amount is for an average size charcoal gas truck and the higher amount for a large wood gas truck. If there is a choice between diesel operation and wood gas operation, the latter with a gasoline engine adapted for this purpose, the difference in cost will be less or none, due to the fact that the diesel engine is more expensive than the gasoline engine.

As for the variable expenses, apart from the matter of fuel which has already been discussed, somewhat greater lubricating-oil consumption is to be expected due to somewhat more frequent oil changes. This extra cost, which incidentally is somewhat disputed, is so relatively insignificant that it probably can be left out of the cost estimate.

As for the cost of increased service due to generator gas operation, the total time for firing up, slagging, fuel refilling and other maintenance of the gas generator including more frequent periodic overhauls could be fairly estimated to be, on an average, one hour per workday. If this cost is, for instance, 1.75 kr per day during 300 workdays or 525 kr per year, and the truck is driven 35,000 km per year, the service cost will be approximately 0.015 kr per km.

Add to this the maintenance and repair costs for the gas generator, which are very difficult to estimate beforehand. They are associated with the care that the gas generator receives, as well as with the preventive measures taken to avoid extensive repairs. At a guess, they may be estimated at, on an average, 525 kr per year. The total cost of service and repairs would then amount to 1050 kr per year, which would be equivalent to 0.03 kr per km for a driving distance of 35,000 km per year. Maintenance and repair costs are, of course, connected with the number of kilometers and hours of driving. In an inquiry arranged by the Swedish Royal Automobile Club, the mentioned costs were reported, in the case of an annual driving distance of at least 30,000 km for a truck and 1,000 hours for a tractor, to be 0.01-0.025 kr per km for an average size truck or bus and 0.10-0.25 kr per hour for a tractor. According to one specification the costs were 0.025 kr per km for a driving distance of 35,000 km per year, and 0.017 kr per km for a driving distance of 60,000 km per year.

In addition to the repair costs for the gas generator, certain increased expenses must be taken into account for the car itself due to increased stress resulting from generator gas operation. Also, even when the gas generator is taken care of in the best possible way, it is to be expected that engine repair will be necessary somewhat more frequently during generator gas operation than during gasoline or diesel operation. Another additional cost incurred by generator gas operation is the increased strain on the electric system, especially on the starting engine and the battery; the latter must be exchanged more frequently than during operation on liquid fuel. However, it is likely that the starting difficulties will be, to some extent, eliminated through technical progress. These increased repair costs can hardly be estimated with any degree of accuracy.

The decrease of carrying capacity of a generator gas truck due to the weight of the gas generator (as a rule 300 kg in a truck) can be compensated to some extent by removing the gasoline or diesel-oil tank. On the other hand, the fuel weight will be greater for the generator gas truck. The net increase of the load may be estimated at approximately 200 kg for an average size or large truck.

The reduction of the average velocity of the truck coupled with the time loss caused by the increased maintenance and repair work can be of great disadvantage and it may reduce the profitability of the truck. It is, however, difficult to make any general estimates with regard to this.

Finally, the increase of ventilation costs, etc., for garages and car-repair shops is considerable if generator gas operation is in general use. Especially for large-scale bus operation, the more general disadvantages of generator gas operation are noticeable: traffic is more difficult to handle, interruptions of service are more common, and reliability is less than in operation with liquid fuel; all this is difficult to state in figures. In some cases, however, driving conditions may be such that the weaknesses of generator gas operation are, on the whole, eliminated. This is true for long distance driving on a good smooth road, where the decrease of average speed will be insignificant; it is also true when there is a supply of fuel produced in domestic industry. Under such circumstances, the transportation capacity of the generator gas car is almost equal to that of the gasoline car. On the basis of the figures and statements given above, approximate estimates of the economic prospects of generator gas operation may be made with regard to its competitiveness after the war, as well as from the viewpoint of the time of crisis with the unit prices and conditions prevailing then.

Summary and Tables for Four-Cycle Engines

Six typical examples of operating-cost estimates for various types of generator gas cars are given below, where the chosen parameters have been simplified in some respects for:

- a small passenger car in private use,
- an average size passenger car in private use,
- an average size passenger car in commercial use (cab service in a large city),
- an average size truck in private use,
- an average size truck in commercial use, and
- an average size bus in commercial use.

The estimated costs relate only to the vehicles themselves. In the case of commercial use, the costs for driver, loading personnel, conductor, administration, office, tickets,

Table 35. COSTS FOR VARIOUS TYPES OF CARS

Costs	Small Passenger Car in Private Use	Average Size Passenger Car in Private Use	Average Size Passenger Car in Commercial Service	Average Size Truck in Private Use	Average Size Truck in Commer- cial Service	Average Size Bus in Commercial Service
Purchase price net, car incl. tires . . . . .kr	4,250	6,500	10,000	13,000	13,000	22,000
" " " " excl. " . . . . "	3,850	6,000	9,350	11,250	11,250	20,000
" " " tires, one set . . . . "	400	500	650	1,750	1,750	2,000
" " " gas generator, incl. mounting . . "	1,250	2,500	2,500	2,500	2,500	2,500
Interest rate . . . . %	4	4	4	4	4	4
Average interest per year, car, incl. tires . . . . .kr	96	146	240	297	312	514
" " " " gas generator. . . . . . . "	34	67	67	67	67	67
Write-off time, car . . . . years	8	8	5	7	5	6
" " " gas generator . . . . "	3	3	3	3	3	3
Depreciation per year, car excl. tires. . . . . .kr	482	750	1,870	1,608	2,250	3,334
" " " gas generator. . . . . "	417	834	834	834	834	834
Average insurance value incl. gas generator . . . . . "	4,000	6,000	9,000	11,000	11,000	19,000
" " " excl. " " . . . . . "	3,000	5,000	8,000	10,000	10,000	18,000
Average insurance premium incl. " " . . . . . "	400	450	650	575	775	925
" " " excl. " " . . . . . "	375	425	625	550	750	900
Service weight, car, incl. gas generator. . . . . . .kg	1,150	1,700	2,000	3,200	3,200	5,100
" " " excl. " " . . . . "	1,000	1,500	1,800	2,900	2,900	4,600
Car tax incl. gas generator . . . . .kr	92	162	204	464	464	722
" " excl. " " . . . . "	64	134	176	410	410	642
Garage rent per year. . . . . "	250	300	300	400	400	500
Driving distance per year . . . . 10 km	1,000	1,500	4,000	3,000	5,000	5,000
Fuel consumption per 10 km, gasoline. L	1.4	2.0	2.5	3.5	3.5	4.0
" " " " " charcoal. . . . . .kg	2.3	3.2	4.5	5.6	5.6	6.4
" " " " " " . . . .(hL)	(0.13)	(0.18)	(0.26)	(0.32)	(0.32)	(0.37)
" " " " " wood. . . . . .kg	4.2	5.9	8.4	10.4	10.4	12.0
" " " " " " . . . .(hL)	(0.13)	(0.18)	(0.26)	(0.32)	(0.32)	(0.37)
Fuel price, charcoal, per kg. . . . . .kr	0.30	0.30	0.30	0.30	0.30	0.30
" " " " (hL). . . . . "	(5.25)	(5.25)	(5.25)	(5.25)	(5.25)	(5.25)
" " wood " kg. . . . . "	0.10	0.10	0.10	0.10	0.10	0.10
" " " " (hL). . . . . "	(3.25)	(3.25)	(3.25)	(3.25)	(3.25)	(3.25)
Fuel cost per 10 km gasoline^b . . . . "	1.35	1.75	1.74	2.16	2.03	2.28
	1.08	1.38	1.23	1.52	1.39	1.56
" " " " " charcoal. . . . . "	0.69	0.96	1.35	1.68	1.68	1.92
" " " " " wood. . . . . "	0.42	0.59	0.84	1.04	1.04	1.20
" " " " " gasoline^b . . . . "	1,344	2,619	6,954	6,470	10,130	11,356
	1,074	2,064	4,914	4,550	6,930	7,756
" " " " " charcoal. . . . . "	690	1,440	5,400	5,040	8,400	9,600

Table 35. (continued)

Costs	Small Passenger Car in Private Use	Average Size Passenger Car in Private Use	Average Size Passenger Car in Commercial Service	Average Size Truck in Private Use	Average Size Truck in Commercial Service	Average Size Bus in Commercial Service
Fuel cost per 10 km wood. . . . . .kr	420	885	3,360	3,120	5,200	6,000
Oil, grease, etc., cost per year. . . . . "	75	100	275	200	350	350
Tires, one set, " " " . . . . 10 km	4,000	4,000	4,000	5,000	5,000	4,500
Tires cost incl. repairs per year . . . . .kr	125	225	700	1,100	1,800	2,250
Repair, lubrication,etc., car per 10 km . . . . . . ore[a]	20	25	25	30	30	40
Repair, service, gas generator per 10 km. . . . . . "	15	15	15	15	15	15
Repair, lubrication, etc., car per year . . . . . . .kr	200	375	1,000	900	1,500	2,000
Repair, service, gas generator per year . . . . "	150	225	600	450	750	750
Fixed costs per km, gasoline. . . . . ore[a]	12.7	11.7	8.1	10.9	8.3	11.8
" " " " charcoal. . . . . "	17.8	18.1	10.5	14.2	10.2	13.8
" " " " wood. . . . . "	17.8	18.1	10.5	14.2	10.2	13.8
" " " year, gasoline. . . . . .kr	1,267	1,755	3,211	3,265	4,122	5,890
" " " " charcoal. . . . . "	1,771	2,709	4,165	4,245	5,102	6,896
" " " " wood. . . . . "	1,771	2,709	4,165	4,245	5,102	6,896
Variable costs per km, gasoline[b]. . . . . ore[a]	17.5	22.2	22.4	28.9	27.6	32.0
	14.8	18.5	17.3	22.5	21.2	24.8
" " " " charcoal . . . . "	12.4	15.8	20.0	25.7	25.6	29.9
" " " " wood . . . . "	9.7	12.1	14.9	19.3	19.2	22.7
" " " year, gasoline[b]. . . . . .kr	1,744	3,319	8,929	8,670	13,780	15,956
	1,474	2,764	6,889	6,750	10,580	12,356
" " " " charcoal . . . . "	1,240	2,365	7,975	7,690	12,800	14,950
" " " " wood . . . . "	970	1,810	5,935	5,770	9,600	11,350
Total costs per km, gasoline[b] . . . . ore[a]	30.2	33.9	30.5	39.9	35.8	43.7
	22.7	30.2	25.4	33.5	29.4	36.5
" " " " charcoal. . . . . "	30.2	33.9	30.5	39.9	35.8	43.7
" " " " wood. . . . . "	27.5	30.2	25.4	33.5	29.4	36.5
" " " year, gasoline[b] . . . . .kr	3,011	5,074	12,140	11,935	17,962	21,846
	2,741	4,519	10,100	10,015	14,702	18,246
" " " " charcoal. . . . . "	3,011	5,074	12,140	11,935	17,902	21,846
" " " " wood. . . . . "	2,741	4,519	10,100	10,015	14,702	18,246
Costs of charcoal gas operation are equivalent to a gasoline price per litre of. . . . . ore[a]	96.0	87.3	69.6	61.7	58.0	56.8
Costs of wood gas operation are equivalent to a gasoline price per litre of . . . . "	77.2	68.8	49.2	43.4	39.6	38.8

[a] Ore = one hundreth of a kr.

[b] Where two figures are given for gasoline operation, the upper one is a comparison with charcoal gas operation and the lower one with wood gas operation. See the explanation above for how the costs for gasoline operation were calculated.

etc., have not been included; all these costs vary a great deal and are not really within the scope of this analysis.

In order to reach a comparison between the costs for a charcoal gas or wood gas car and a gasoline car, entries have also been made in the estimate for a car without a gas generator. Assuming that the total operating costs during gasoline operation are as great as during charcoal gas or wood gas operation, we may, by working backward, arrive at the gasoline price which in the various cases is equivalent to the costs during charcoal gas or wood gas operation.

Among the usual fixed costs were counted: interest, principal, car tax, insurance, and garage. Among variable costs were counted: fuel, oil, tires, repairs, and service. The fixed costs were assumed to be equal for both charcoal gas operation and wood gas operation; thus, the gas generators are assumed to cost and weigh the same in both cases.

The following basis was used for the estimates of the various expense entries. Interest was calculated at a rate of 4%. Write-off time was assumed to be 5 to 8 years for various types of vehicles; for the gas generator, however, write-off time was assumed to be 3 years in all cases. Insurance costs were estimated as a mean value for various parts of the country, based upon complete insurance without bonus. The cost is based upon an average during the write-off time.

The price of car charcoal (mixed birch and softwood charcoal) was assumed to be 5.25 kr per hL and the price of car wood (birch), 3.25 kr per hL. The hL weight being 17.5 kg for charcoal, the price of it will be 0.30 kr per kg, whereas the price of wood with a hL weight of 32.5 kg will be 0.10 kr per kg.

The relative charcoal/gasoline fuel consumption was assumed to be, for ordinary varied driving, 1.6, and for taxi driving in a city, 1.8 kg charcoal per L gasoline. For wood gas operation the same fuel consumption in hL as in charcoal was assumed, and the cost for charcoal for the charcoal bed was assumed to be included in the cost for the wood.

There are many opinions concerning the relation between the fuel costs and maintenance and repair costs. Many maintain that generator gas operation wears the engines more; others declare that there is no significant difference in this respect. In the following analysis, the repair costs are the same, for the sake of simplicity, for the various fuels.

Table 35 gives a list of the estimated operating costs under the given assumptions for the six car types previously mentioned.

The effect upon the operating costs caused by an increase of the annual driving distance is illustrated in Table 36. The figures are the total costs per km in ore. (100 ore = 1 kr)

An analogous estimate may be made when diesel oil is used for fuel. It is also possible to make corresponding approximate estimates of the economic prospects of generator gas operation using various assumed fuel prices. The estimation in Table 37 is made rather in favor of generator gas operation.

For an average size truck or bus in commercial use and with an annual driving distance of 50,000 km, a diesel oil price of approximately 0.30 kr per L is obtained, equivalent to an assumed postwar price of car wood of 1.50 kr per hL. For an average size truck in

Table 36. THE EFFECT OF DRIVING DISTANCE ON COSTS

Car Type	Driving Distance Per Year 10 km	Charcoal Gas Operation Ore/km	Wood Gas Operation Ore/km
Small passenger car in private use.	1,000	30.2	27.5
" " " " "	2,000	22.7	20.0
Average size passenger car in private use	1,500	33.9	30.2
" " " " " "	3,000	26.4	22.6
Average size passenger car in commercial service. . .	4,000	30.5	25.4
" " " " " " " . . .	8,000	26.8	21.7
Average size truck in private use	3,000	39.9	33.5
" " " " " "	6,000	34.8	28.4
Average size truck in commercial service.	5,000	35.8	29.4
" " " " " "	10,000	32.2	25.8
Average size bus in commercial service.	5,000	43.7	36.5
" " " " " "	10,000	38.5	31.3

Table 37. COSTS PER HOUR AND PER 10 km DURING WOOD GAS OPERATION

Transportation Distance	km	5	10	25	50	100	150
Cost per hour:							
Truck excl. tires.	kr/yr	1,089	1,336	1,633	1,960	2,178	2,450
Wood gas generator	"	773	773	932	940	1,215	1,230
Interest	"	548	558	569	581	605	516
Garage	"	240	240	240	240	240	240
Gasoline	"	96	96	96	96	96	96
Automobile tax	"	482	482	482	482	482	482
Automobile insurance	"	575	575	575	575	575	575
Office cost.	"	487	448	378	325	274	255
Tarpaulins, etc.	"	250	250	250	250	250	250
Care of the wood gas generator	"	394	394	394	394	394	394
Driver's wages	"	3,834	3,834	3,834	3,834	3,834	3,834
Accident compensation.	"	64	64	64	64	64	64
Heath insurance.	"	36	36	36	36	36	36
Total	kr/yr	8,868	9,086	9,483	9,777	10,243	10,522
Effective hours per year		2,009	2,035	2,081	2,117	2,151	2,163
Cost per hour	kr	4.41	4.46	4.56	4.62	4.76	4.86
Cost per 10 km:							
Fuel cost, average with or without load (car wood at 2.75 kr/hL). . .	kr per 10 km	1.15	0.91	0.80	0.69	0.69	0.69
Oil cost (oil at 2.40 kr/L).	" " " "	0.12	0.12	0.12	0.10	0.10	0.07
Tire cost (tires at 277.50 kr/each).	" " " "	0.49	0.49	0.43	0.43	0.39	0.39
Repair cost, etc..	" " " "	1.31	0.86	0.53	0.42	0.38	0.36
Total	kr per 10 km	3.07	2.38	1.88	1.64	1.56	1.51

private use of 30,000 km per year, a gasoline price of approximately 0.40 kr per L is obtained equivalent to the assumed post-war price of car charcoal of 2.50 kr per L. For an average size passenger car in private use of 15,000 km per year the gasoline price will be, in the same way, approximately 0.70 kr per L.

For a comparison and check, some information may be given from large scale users of generator operated trucks. The Road Haulage Association of Sweden has compiled the estimates given in Tables 37 to 40 of the expenses for operating a 3.5 ton truck with wood gas and gasoline, respectively.

Table 38. COST PER ASSIGNMENT DURING GENERATOR GAS OPERATION

Transportation Distance	km	5	10	25	50	100	150
Assumptions:							
Loading and unloading time . .	hr	1.25	1.25	1.25	1.25	1.25	1.25
Driving speed, average with or without load	km/hr	20	25	30	33	33	35
Driving time per assignment. .	hr	0.50	0.80	1.67	3.00	6.00	8.60
Hourly cost.	kr	4.41	4.46	4.56	4.62	4.76	4.86
Cost per 10 km average with or without load	"	3.07	2.38	1.88	1.64	1.56	1.51
Cost per assignment:							
Cost per 10 km	kr	3.07	4.76	9.40	16.40	31.20	45.30
Driving time costs	"	2.21	3.57	7.62	13.86	28.56	41.80
Loading and unloading costs. .	"	5.51	5.58	5.70	5.78	5.95	6.08
Cost per assignment.	kr	10.79	13.91	22.72	36.04	65.71	[a]93.18
Cost per 10 km total	"	10.79	6.95	4.52	3.60	3.29	3.10

[a] In case of charcoal gas operation and with a charcoal price of 4 kr/hL, this cost will be 95.13 kr for a 150 km transportation distance. With a charcoal price of 2.80 kr/hL, the cost will be 87.63 kr.

Table 39. COSTS PER HOUR AND PER 10 km DURING GASOLINE OPERATION

Transportation Distance	km	5	10	25	50	100	150
Cost per hour:							
Truck excl. tires.	kr/yr	1,089	1,336	1,633	1,960	2,178	2,450
Interest	"	452	461	471	483	491	501
Garage	"	200	200	200	200	200	200
Automobile tax	"	428	428	428	428	428	428
Automobile insurance	"	537	537	537	537	537	537
Office costs	"	512	473	400	340	285	264
Tarpaulins, etc.	"	250	250	250	250	250	250
Driver's wages	"	3,834	3,834	3,834	3,834	3,834	3,834
Accident compensation.	"	64	64	64	64	64	64
Heath insurance.	"	36	36	36	36	36	36
Total	kr/yr	7,402	7,619	7,853	8,132	8,303	8,564
Effective hours per year		2,063	2,089	2,140	2,180	2,217	2,232
Cost per hour	kr	3.58	3.64	3.67	3.73	3.75	3.83
Cost per 10 km:							
Fuel cost, average with or without load (gasoline at 0.30 kr/L) . . .	kr per 10 km	1.00	0.93	0.88	0.75	0.75	0.75
Oil cost (oil at 2.40 kr/L).	" " " "	0.10	0.10	0.10	0.07	0.07	0.05
Tire cost (tires at 277.50 kr/each).	" " " "	0.49	0.49	0.43	0.43	0.39	0.39
Repair cost, etc..	" " " "	0.72	0.47	0.28	0.22	0.20	0.19
Total	kr per 10 km	2.31	1.99	1.69	1.47	1.41	1.38

Table 40. COST PER ASSIGNMENT DURING GASOLINE OPERATION

Transportation Distance	km	5	10	25	50	100	150
Assumptions:							
Loading and unloading time . .	hr	1.25	1.25	1.25	1.25	1.25	1.25
Driving speed, average with and without load	km/hr	25	30	35	38	38	40
Driving time per assignment. .	hr	0.40	0.66	1.43	2.63	5.26	7.50
Hourly cost.	kr	3.58	3.64	3.67	3.73	3.75	3.83
Cost per 10 km	kr/10 km	2.31	1.99	1.69	1.47	1.41	1.38
Cost per assignment:							
Costs per 10 km.	kr	2.31	3.98	8.45	14.70	28.20	41.40
Driving time costs	"	1.43	2.40	5.25	9.81	19.72	28.72
Loading and unloading costs. .	"	4.48	4.55	4.59	4.66	4.69	4.79
Cost per assignment.	kr	8.22	10.93	18.29	29.17	52.61	74.91
Total Cost per 10 km total . .	"	8.22	5.46	3.66	2.92	2.63	2.50

Table 41. SUMMARY OF THE 1943 COSTS FOR GENERATOR GAS OPERATED TRUCKS OF THE SWEDISH BOARD OF TELECOMMUNICATIONS, DIVIDED INTO VARIOUS FUEL AND COST CATEGORIES

Vehicle	No.[a]		10 km Driven	Total Costs (in kr)									Gasoline Operation Total in 1939 kr	Charcoal or Wood hL 1943
				Ak	Dk	Sk	Rk	Gk	Fk	Ok	Kk	Total[b]		
Truck, 1-2 ton	29	Total	67,376	20,765	140,754	1,869	45,408	9,159	17,389	116	32,135	267,595		22,050
(charcoal gas driven)		Per truck	2,323	716	4,854	64	1,565	316	600	4	1,108	9,227	3,633	
Truck, 2-5 1/4 ton . . .	43	Total	86,463	40,525	209,898	5,194	82,277	17,795	29,190	2,129	33,750	420,758		33,541
(charcoal gas driven)		Per truck	2,011	942	4,881	120	1,913	414	679	49	785	9,783	4,033	
Truck, 1-2 ton	6	Total	12,541	1,667	16,309	824	9,487	1,045	3,495	--	8,440	41,267		3,340
(wood gas driven)		Per truck	2,090	278	2,178	137	1,581	174	582	--	1,406	6,876	3,386	
Truck, 2-5 1/4 ton . . .	81	Total	149,274	41,364	250,330	8,618	161,515	26,945	51,861	5,281	57,853	603,767		50,415
(wood gas driven)		Per truck	1,843	511	3,090	106	1,994	333	640	65	714	7,453	3,829	

[a] Number includes all vehicles in the statistics; i.e., including those driven only part of the year.

[b] Interest on capital not included.

Costs per 10 km (in ore)

Ak	Dk	Sk	Rk	Gk	Fk	Ok	Kk	Total	Total 1939	Charcoal or Wood L/10 km	Additional Cost in Comparison with 1939 %
31	209	3	67	14	27	--	48	399	150	33	166
47	242	6	95	21	34	2	39	486	184	39	164
13	131	7	76	8	28	--	67	330	150	27	120
28	168	6	108	18	35	4	39	406	184	34	120

Legend:

Ak = Amortization cost for the vehicle.
Dk = Operating cost (costs for fuel, maintenance, and repair of the gas generator, etc.
Sk = Maintenance costs for the vehicle (washing, lubrication, etc.).
Rk = Repair costs for the vehicle.
Gk = Tire costs.
Fk = Fixed costs (taxes, insurance, and garage).
Ok = Accident costs.
Kk = Crises costs (costs for materials and mounting of the gas generator; set of tires, body, and engine replacement from 60 hp to 85 hp on a Ford).

Table 42. COSTS FOR GENERATOR GAS POWERED TRUCKS, STOCKHOLM BREWERIES CO.

	Average Per Truck and Year	
	Wood Gas Trucks 3 Ton	Charcoal Gas Trucks 3 Ton
Number of 10 km driven	1,045	1,355
Number of driving hours	1,651	1,935
Fuel consumption in hL	560	845
Fixed costs, kr:		
Amortization	560.--	870.--
Tax	382.--	499.--
Traffic insurance	133.--	153.--
Garage rent	450.--	450.--
Garage labor	189.--	181.--
Truck inspection	9.--	9.--
Administration	210.--	258.--
Total fixed costs, kr	1,933.--	2,420.--
Operating costs, kr:		
Fuel	1,821.--	3,971.--
Oil	40.--	53.--
Tires	570.--	563.--
Repair and maintenance	2,028.--	1,655.--
Collision damages	21.--	7.--
Equipment	798.--	911.--
Miscellaneous common costs	643.--	897.--
Total operating costs, kr	5,921.--	8,057.--
Total cost, kr	7,854.--	10,477.--

Table 43. USE OF TRUCKS, STOCKHOLM BREWERIES CO.

	In % of the Usual Number of Work Days	
	Wood Gas Trucks	Charcoal Gas Trucks
Distribution driving	48.3	33.9
Driving at the plant	13.9	35.5
Leasing to other plants	2.1	4.1
Repair	17.2	12.5
Standstill	14.6	6.9
Leasing to military	3.9	7.1
Total	100.0	100.0

If we convert these figures of the Association to an assumed peacetime price for car wood of 1.50 kr per hL, we find that the cost per transportation assignment would be as high for wood gas as for gasoline operation, if the gasoline price were:

Transportation Distance, km	5	10	25	50	100	150
Gasoline Price, ore per L	91	65	48	45	44	42

Table 41 gives an account of operation of trucks under the auspices of the Swedish Board of Telecommunications. The following information compares the total operating costs during charcoal gas and wood gas operation with gasoline operation in 1939. For charcoal gas operation the total operating costs were approximately 2.5 times the costs for gasoline operation in 1939, and for wood gas operation approximately 2.2 times the cost of gasoline operation in 1939. The ratio between the operating costs with wood as compared to charcoal was approximately 0.8.

The Stockholm Breweries Ltd. gave the information shown in Tables 42 and 43 for the company's wood gas and charcoal gas operated with trucks for the two-year period October 1, 1942, to September 30, 1944. The specifications in Table 43 state the average per truck and year for the company's generator gas trucks during this period. The ratio between the operating costs with wood and charcoal in this case was approximately 0.75. The fixed costs ratio was approximately 0.80 and the variable costs ratio approximately 0.735.

Statistics covering the operating and maintenance costs of 126 generator gas trucks in the 3-ton category, belonging to the Stockholm Breweries Ltd., and the Apothecaries' Mineral Water Ltd., show a comparison between generator gas operation and gasoline operation (Table 44). The pre-war statistics are for the year 1937 and the generator gas statistics for the budget year 1942 to 1943. When studying this comparison it is necessary to remember that the great increase in repair costs for the generator gas trucks is due to the rise in price of spare parts and wages; also the conversion of a great many trucks to "bogies" is a part of the repair account. It must also be remembered that these statistics are for distribution driving in Stockholm, where generator gas operation is less favorable than in the case of driving without interruptions.

Table 44. COSTS OF OPERATING 3-TON TRUCKS

	Charcoal Gas Operation kr	Wood Gas Operation kr	Gasoline Operation kr
Fuel per 10 km	2.93	1.74	0.59
Repair costs per 10 km	2.55	3.33	0.37
Total per 10 km.	5.48	5.07	0.96
Hourly costs for fuel and repairs	3.84	3.21	0.38
Annual cost for fuel, repairs, and maintenance.	7,441	5,811	946

A comparison of bus operations is available from Gothenburg's and Malmo's Tramways as shown in Tables 45 and 46.

Table 45. GOTHENBURG'S TRAMWAYS, 1940. COSTS OF BUS OPERATION IN ORE PER VEHICLE-KILOMETER

	Real Costs 1939 (mainly diesel buses)	Generator Gas Buses (estimated in October 1940)	Trolley Buses (estimated in November 1940)
Administration	1.18	1.3	1.3
Traffic.	21.29	31.0	28.0
Fuel costs	6.75	40.0	10.0
Power lines.	--	--	1.2
Vehicles, garage, etc.	17.86	30.0	14.0
Sanding, devices at stops, etc.	1.00	1.5	1.5
Repair shops and storage . . .	1.53	1.7	1.7
General costs.	0.53	0.6	0.6
Total operating costs	50.14	106.1	58.3
Interest and write-off	13.22	19.0	11.0
Total cost	63.36	125.1	69.3

Additional data is available for the 1943 bus operations of Railroads, Inc., Stockholm-Saltsjon. According to this information, the operating cost including amortization, maintenance, and service of the gas generators for wood gas operation is approximately five times that of diesel operation before the war and the cost of charcoal gas operation is approximately seven times that of diesel.

If compared with gasoline the operating cost ratios would be approximately 2 and 3, respectively. Even if the gas generator and the fuel had been obtained with no cost, generator gas operation during the war would have proved to be more expensive than diesel operation before the war but somewhat less expensive than gasoline operation, disregarding the impaired efficiency of the vehicles during generator gas operation.

As for wood gas operation of farm tractors, one estimate shows that, in case of an assumed wood price of 1 kr per hL or approximately 0.30 kr per kg (in home industry), a fuel oil price of at least 0.60 kr per kg is equivalent to the costs of wood gas operation for an assumed operation of 600 hours per year. The fuel consumption was assumed to be 0.25 kg liquid fuel and 1.0 kg wood per hp-hr. The cost of the gas generator included repair cost as well.

The owner of a large car-fleet compiled the statistics in Table 47, showing the average costs for a great number of cars of various types.

From the information above we gather that generator gas operation, and in particular wood gas operation, is much more likely to be competitive for long distance vehicles such as trucks and highway buses with high annual mileage, rather than for small vehicles,

Table 46. OPERATION COSTS OF MALMO TRAMWAYS IN 1940

Operating weight of the buses, approximately 7600 kg. Calculated driving distance per year per bus, 60,000 km.	ore/km
1. Gasoline operation	
July 1, 1939 (gasoline price: 0.25 kr/litre)	10.8
1940 (" " : 0.72 kr/litre)	33.8
2. Diesel operation	
July 1, 1939 (fuel oil price: 0.166 kr/litre).	4.5
3. Charcoal operation	
(Charcoal price: 5.40 kr/hL. Incl. costs for refills and care of the gas generator but after a deduction of 0.008 kr/km due to reduced vehicle tax. Cost of buying and mounting of the charcoal gas generator, approx. 5,000 kr, not included.	26.5
4. Wood operation	
(Wood price 2.40 kr/hL. Incl. costs for refills and care of the gas generator but after deduction of 0.008 kr/km due to decreased vehicle tax. Cost of buying and mounting of the wood gas generator, approx. 5,000 kr per car, not included.	14.2

Fuel costs for the generator gas operation are the following:
charcoal gas buses with trunk unit and 6.5-litre engines
0.19 kr/km, equivalent to 7 kg charcoal per 10 km;
charcoal gas buses with trailer units and 7.8-litre engines
0.24 kr/km, equivalent to 9 kg charcoal per 10 km;
wood gas buses with trunk units and 7.8-litre engines
0.11 kr/km, equivalent to 15 kg wood per 10 km.

Table 47. STATISTICS COMPILED BY A LARGE VEHICLE-FLEET OWNER FOR THE AVERAGE COSTS OF 600 VEHICLES IN OPERATION (OF VARIOUS TYPES AND MAKES)

	Operating Cost,[a] Excl. Fuel Per 10 km (in Ore)		Fuel Cost Per 10 km (in Ore)		Total Cost Per 10 km (in Ore)		Total Additional Cost, 1943		Additional Cost of Fuel Only	
	1939	1943	1939	1943	1939	1943	Ore	%	Ore	%
Passenger car, charcoal gas operated	85	226	35	76	120	302	182	152	41	22.5
Delivery van, charcoal gas operated	72	221	40	100	112	321	209	186	60	29.0
Truck, 1-2 ton, charcoal gas operated	102	267	48	132	150	399	249	166	84	34.0
Truck, 2-5 1/2 ton, charcoal gas operated	117	330	67	156	184	486	302	164	89	29.5
Truck, 1-2 ton, wood gas operated. . .	102	249	48	81	150	330	180	120	33	18.0
Truck, 2-5 1/2 ton, wood gas operated. . .	117	304	67	102	184	406	222	120	35	16.0

[a] In "operating cost" are included: amortization cost for the vehicle; cost for vehicles and repair of the gas generator, etc.; upkeep costs for the vehicle (wash, lubrication, etc.); repair costs for the vehicle; tire costs; fixed costs (taxes, insurance, garage); accident costs; and crisis costs (meterials and mounting of the gas generator, set of tires, body, etc.).

passenger cars, and service vehicles with low annual mileage. Most of all, high mileage is needed to offset the increased fixed expenses. A rough minimum could be set at 30,000 km per year for a car and 1,000 hours per year for a tractor.

Estimates concerning the effect of driving distance upon the price of gasoline at which generator gas would become competitive, show that this price decreases rather considerably with the driving distance; in the case of distances over 70,000 km per year, however, it becomes an almost horizontal line. An estimate for a 3.5-ton truck with an assumed unit price of car wood of 1.50 kr/hL shows that the comparison price is lowered from 0.45 kr/L in the case of 35,000 km/yr to 0.37 kr/L in the case of 50,000 km/yr and to 0.33 kr/L in the case of 65,000 km/yr. In the case of a hL-price of 2 kr, the corresponding figures will be 0.50, 0.43, and 0.39 kr, respectively. These calculations attempt to estimate the loss due to the decreased effectiveness of the generator gas. If we do not take this into account the figures will be lower; in case of the car wood price of 1.50 kr/hL, 0.35, 0.31, and 0.29 kr/L, respectively; and in case of the car wood price of 2 kr/L, 0.40, 0.37, and 0.33 kr/L, respectively.

For a wood gas tractor the figures start becoming horizontal only at approximately 1500 hr/yr. In the case of a hL-price of 1.50 kr, the comparable price of liquid fuel will be 0.25 kr/L for a driving time of 750 hr/yr, 0.225 kr/L for 1,000 hr/yr, and 0.21 kr/L for 1250 hr/yr.

A survey by the Royal Swedish Automobile Club concerning a comparison between the price of liquid and solid fuel gave the following results. The question, "At what gasoline or crude oil price would it be profitable to go back to liquid fuel?" was answered by 165 truck owners. The average for the highest gasoline and crude oil price was 0.37 kr/L and 0.19 kr/L, respectively. The 165 truck owners also answered the question of the price of car charcoal and car wood that would justify continuing with generator gas if the gasoline price were 0.50 kr/L. The average for the highest car charcoal and car wood price was 3.23 kr/hL and 2.08 kr/hL, respectively.

Another estimate, concerning the fuel cost only, shows the following comparative costs for gasoline and charcoal.

<u>For Nonstop Driving on Highways:</u> 100 L gasoline = 140 kg car charcoal = 8 hL car charcoal at 5.25 kr/hL = 42 kr.

<u>For Varied Driving:</u> 100 L gasoline = 165 kg car charcoal = 9.5 hL car charcoal at 5.25 kr/hL = 50 kr.

<u>For Commercial Driving in a City:</u> 100 L gasoline = 210 kg car charcoal = 12 hL car charcoal at 5.25 kr/hL = 63 kr.

In these three different cases, a hL-price of 5.25 kr would then be equivalent to a gasoline price of 0.42 kr/L, 0.50 kr/L, and 0.63 kr/L, respectively.

In Table 48 approximate ratios between the consumption of liquid and solid fuels are given.

Table 48. APPROXIMATE RELATIVE RELATIONSHIP BETWEEN THE CONSUMPTION OF SOLID AND LIQUID FUELS

Four-cycle engines for motor vehicles, rail-buses, etc.

Gasoline engine

Gasoline	Car charcoal	Charcoal wood	Gasoline	Car wood	Firewood
100 L	0.95 m^3	2.1 m^3	100 L	0.9 m^3	0.8 m^3
100 L	165 kg	750 kg	100 L	300 kg	300 kg
105 L	1.0 m^3	2.2 m^3	110 L	1.0 m^3	0.9 m^3
60 L	100 kg	450 kg	33 L	100 kg	100 kg
48 L	0.45 m^3	1.0 m^3	120 L	1.1 m^3	1.0 m^3
13 L	22 kg	100 kg	33 L	100 kg	100 kg

Diesel engine

Fuel oil	Car charoal	Charcoal wood	Fuel oil	Car wood	Firewood
100 L	1.65 m^3	3.6 m^3	100 L	1.55 m^3	1.4 m^3
100 L	285 kg	1,300 kg	100 L	500 kg	500 kg
60 L	1.0 m^3	2.2 m^3	65 L	1.0 m^3	0.9 m^3
35 L	100 kg	450 kg	20 L	100 kg	100 kg
28 L	0.45 m^3	1.0 m^3	70 L	1.1 m^3	1.0 m^3
8 L	22 kg	100 kg	20 L	100 kg	100 kg

Hesselman engine

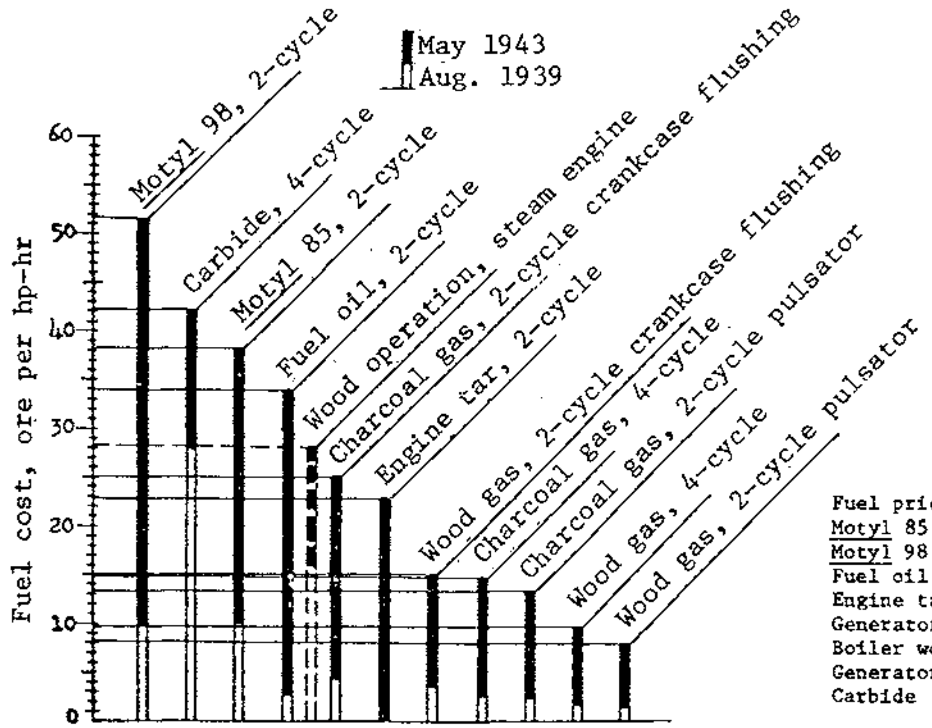
Fuel oil	Car charcoal	Charcoal wood	Fuel oil	Car wood	Firewood
100 L	1.3 m^3	2.9 m^3	100 L	1.25 m^3	1.1 m^3
100 L	230 kg	1,050 kg	100 L	400 kg	400 kg
75 L	1.0 m^3	2.2 m^3	80 L	1.0 m^3	0.9 m^3
43 L	100 kg	450 kg	25 L	100 kg	100 kg
35 L	0.45 m^3	1.0 m^3	90 L	1.1 m^3	1.0 m^3
9.5 L	22 kg	100 kg	25 L	100 kg	100 kg

Two-cycle engines for power tools, etc.

Kerosene	Car charcoal	Charcoal wood	Kerosene	Car wood	Firewood
100 L	1.0 m^3	2.2 m^3	100 L	0.95 m^3	0.85 m^3
100 L	175 kg	800 kg	100 L	310 kg	310 kg
100 L	1.0 m^3	2.2 m^3	105 L	1.0 m^3	0.9 m^3
55 L	100 kg	450 kg	32 L	100 kg	100 kg
45 L	0.45 m^3	1.0 m^3	115 L	1.1 m^3	1.0 m^3
13 L	22 kg	100 kg	32 L	100 kg	100 kg

Low-Speed Two-Cycle Engines

It is of course no surprise that generator gas operation is economically favorable when prices are high for all kinds of liquid fuels. This fact is illustrated by the bar graph in Figure 258, giving the approximate fuel cost per hp-hr for various fuels and operating systems. In the graph the height of the white part of the bars indicates conditions in August 1939, from which costs have been calculated using the raw material price of that time. For engine tar, no pre-war price could be ascertained. For comparison, the costs for a wood-fired steam engine were also marked on the graph.



Fuel price:	
Motyl 85	75 ore/L
Motyl 98	1.02 kr/L
Fuel oil	1.20 kr/L
Engine tar	65 ore/kg
Generator gas wood	3 kr/hL
Boiler wood	8 ore/kg
Generator gas charcoal	6 kr/hL
Carbide	48 ore/kg

Figure 258. Approximate Fuel Cost per hp-hr for Various Fuels and Operating Systems.

The graph in Figure 259 gives a current comparison between the fuel costs when operating with engine tar and generator gas with the crankcase and pulsator systems, respectively. The following consumption figures, common in usage, were chosen for a basis: engine tar 0.35 kg/hp-hr; wood in the crankcase system, 0.05 hL/hp-hr; and in case of pulsator system, 0.027 hL/hp-hr. The prevailing average price of wood was set at 2.50 kr per hL. The superiority of the pulsator system is striking.

This superiority also stands out if we enter in the graph the initial costs for the conversion to generator gas operation. For the 40 hp engine referred to in the graph, they were estimated at 8,500 kr for a pulsator system and 6,500 kr for a crankcase system. If from the respective ordinate values we draw lines parallel with the "cost rays" from the origin, or the points of intersection of the lines we obtain a picture of the operating time needed to make up for the initial costs. It appears, for example, that the higher initial cost for the pulsator in comparison with the crankcase system will be leveled out after 700 hours,

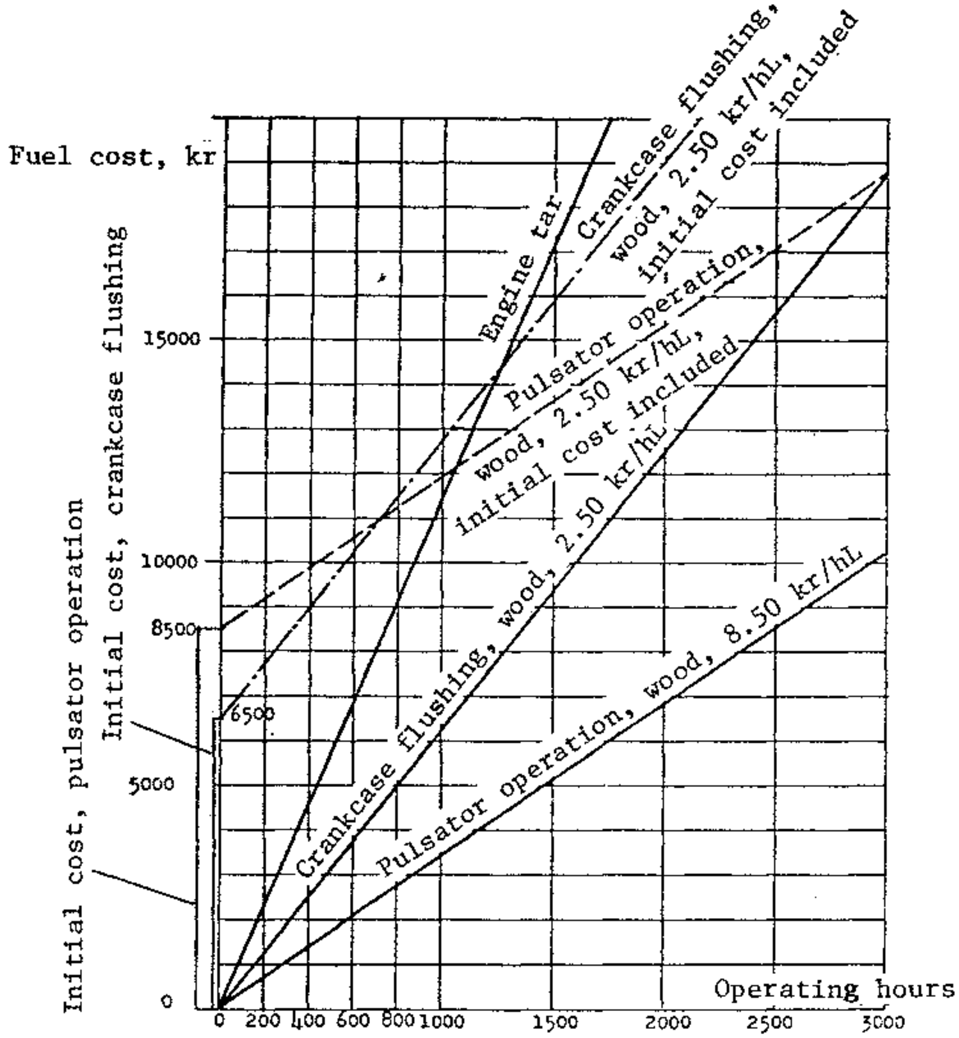


Figure 259. Fuel Costs for Various Fuels for a 50 hp Two-Cycle Engine.

and that pulsator operation after 2,000 hours has become approximately 3,700 kr less expensive than crankcase operation. If we compare tar operation with generator gas operation, we find that the crankcase sytem pays off after approximately 1,250 hours, whereas this occurs in the case of the pulsator after approximately 1,050 hours, so in this respect the pulsator is also superior.

In this context, one observation should be made about practical conditions. If we have procured a 50 hp engine for an industrial plant of some kind, its power would rarely be very much on the high side. If we convert to generator gas with crankcase flushing, we cannot get more than 35-40 hp from the engine, which is the reason that the old engine may not be sufficient for the purpose. In other words, it may be necessary to replace the engine with a larger one. To the initial cost should then be added the current difference in price between the old engine and the new one. This was not done in the graph; therefore, the crankcase system was somewhat favored under the circumstances. This reasoning does not apply to the pulsator, however, since it does not cause a power decrease but, on the contrary, a power increase in the case of engines with low rpm.

Economic considerations are of course essential when we have to decide whether generator gas operation of two-cycle engines should be principally considered to be an emergency measure or whether it may also last during peacetime with an opportunity of oil impact. Obviously, the operating economics, above all, would be the decisive factor in determining whether generator gas operation will last or not. Under such circumstances we may assume with good reason that only the best generator gas system can last in competition. At present, the pulsator system occupies first place on the ranking list; therefore, the basis for the following discussion will be the average consumption figure found for wood during pulsator operation; namely, 0.85 kg/hp-hr (0.027 hL/hp-hr).

In the graph of Figure 260, the parity prices of fuel oil and generator gas wood for pulsator operation are shown; for the latter the costs for amortization and maintenance of the generator gas device were included, varying between 0 and 5 ore/hp-hr. The ordinate and abscissa for a certain point at any of the oblique parallel lines also provide information about the oil and wood prices that give the same operating cost at the amortization provision in question. Figure 261 shows a similar statement for engine tar and pulsator operation.

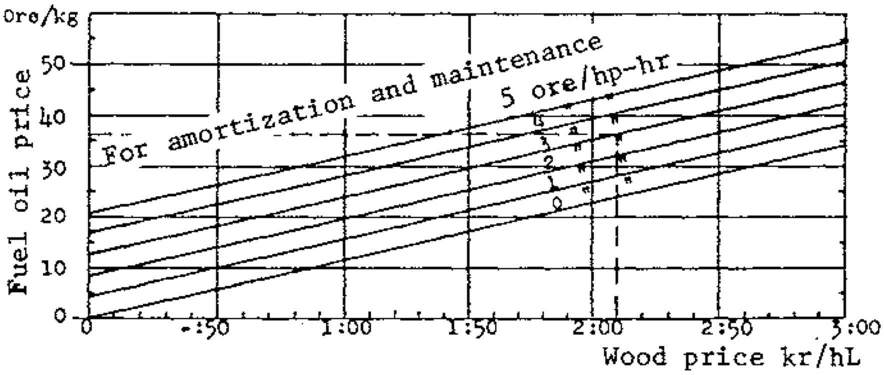


Figure 260. Parity Values for Fuel Oil Operation and Generator Gas Operation with a Pulsator.

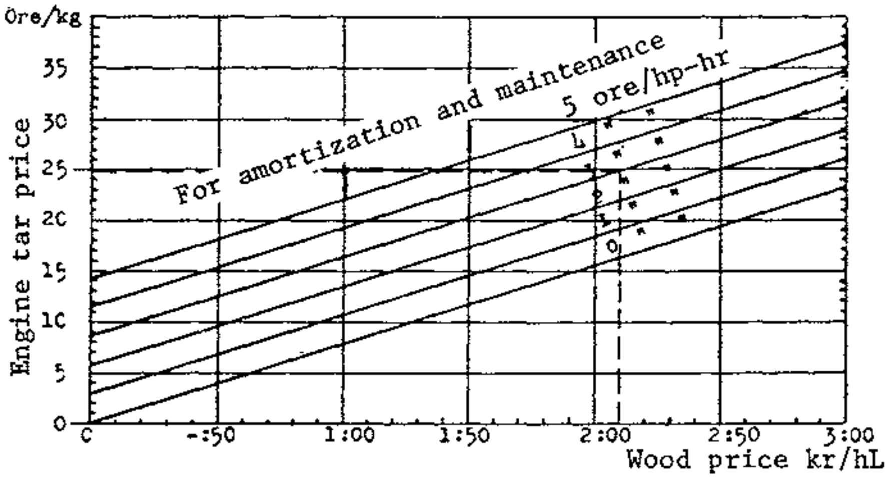


Figure 261. Parity Values for Operation on Engine Tar and Generator Gas Operation with a Pulsator.

In calculating the diagrams, the following parity equation was used.

$$y = \frac{a + wx}{z} \tag{70}$$

where y = the price of the liquid fuel in ore/kg

x = the price of the generator gas wood in ore/kg

w = the wood consumption in hL/hp-hr

z = the consumption of liquid fuel in kg/hp-hr

a = cost provision for amortization and maintenance of the generator gas device, in ore/hp-hr

For the diagrams, the following values were used:

w = 0.027 hL/hp-hr

z = 0.24 kg/hp-hr for fuel oil

z = 0.35 kg/hp-hr for engine tar

The great variation in the provision for amortization and maintenance may raise questions; this variation has its basis in pratical circumstances, however. One possibility concerns a device that by the end of the war was fully paid off by the already mentioned profit of operation; it may then be interesting for the owner to know under what circumstances he can profitably use the device as long as it can be used with minimum maintenance. The provision of amortization and maintenance in that case will be only a few tenths of an ore per hp-hr. On the other hand, we may want to study the case of a device, bought at a crisis-time price, which is not especially effectively used; in this case the amortization account should be burdened by a few years' interest on the fixed capital that has not been fully amortized. Under such circumstances, the provision for amortization and maintenance should be set at 0.05 kr/hp-hr. This value is approximately valid for a device of 50 hp, which cost 8,500 kr and should be amortized in four years with an operating time of 1,000 to 1,100 hours per year. In "normal" cases the value that is to be entered in the cost estimate will be somewhere between these two limits. For 1946 we can probably allow for 0.02-0.03 kr/hp-hr for amortization and maintenance, and it seems possible that, after the crisis prices of materials and labor have been liquidated, it will become as low as 0.01 kr/hp-hr in case of rationally used devices of high quality.

In the graphs a parity example was drawn with dashed lines for a wood price of 2.10 kr/hL in areas with good wood supplies, the amortization provision being 0.03 kr/hp-hr. As is evident, the pulsator operation will then be less expensive, as long as the oil price stays above 0.36 kr/kg. If it were a matter of generator gas equipment already paid off and with no plans for new acquisition, the oil price would have to go as low as 0.25 kr/kg in order to be economic at the wood price mentioned. (For engine tar, the corresponding figures would be approximately 0.25 and 0.16 kr/kg, respectively).

It may be interesting to study the oil price curve after World War I, as shown in Figure 262. At the time of the outbreak of WWI, the oil quotation was 0.12 kr/kg and at the turn of the year 1918-1919, 1.10 kr/kg. During 1919 the price rapidly declined to a temporary rock-bottom quotation of 0.18 kr after which it rose to 0.52 kr. In the middle of 1921, the price was once again 0.18 kr and later declined with minor fluctuations during the following ten years to 0.10 kr/kg. During four months in 1932, the bottom price of 0.09 kr was quoted. The basis for the price increase during World War I was then about the same as at the outbreak of World War II. The oil prices of the diagram are the quotations from the import ports and should consequently be considered as minimum prices for Sweden.

In the graph the wood price curve is also drawn with a thick solid line for the corresponding time. It is based on the average price for the 49 districts of the National Swedish Welfare Board and are valid for birch logs, f.o.b. the production place. It is then wholesale price for prime grade wood, which was converted to hL of generator gas wood according to the relation $1 m^3 = 12$ hL. The cost of cutting is not included in the price, not only because it is impossible to determine this cost afterward, but also because the wood price entered in the graph is considerably higher anyway than the price that has actually been paid for generator gas operation; generator gas wood was to a large extent manufactured from branches and waste wood.

The wood price curve is strikingly similar to the oil price curve, in spite of the fact that the two prices do not directly have anything to do with each other. The fields of application for the two fuels were so different that an economic balance due to competition hardly could have arisen.

In order to get a picture of how pulsator operation would have done in competition with oil during this period, three parity curves for wood were drawn with dashed lines in the graph, calculated from the oil price of that particular time. These three curves are valid for the included amortization costs of 0.001 and 0.002 kr/hp-hr, respectively. The graph should be interpreted to mean that for a certain point of time pulsator operation would have been more economical than oil operation, if the parity price curve for wood is above the curve for the real wood price and vice versa.

The graph now gives one piece of very interesting information; namely, it turns out that for the fuel cost only (i.e., without provisions for amortization and maintenance) pulsator operation was superior during the interwar years, whereas, on the other hand, with an amortization of 0.02 kr/hp-hr for the generator gas equipment, oil operation would have been more economical ever since the spring of 1921 as well as during the temporary oil slump for a few months in 1919. With an amortization of 0.01 kr/hp-hr, the pulsator would have been economic right up to 1930, when the oil price had declined to 0.13 kr/kg; after that, oil operation would have been leading for three years, followed by a four-year period of approximate balance, after which the pulsator by the middle of 1937 would have come back in the lead, and maintained the lead during the war.

The graph clearly shows that the quality of generator gas equipment is extremely important in competition with oil in case of low oil prices. The same thing, however not as obviously, is shown by the preceding parity graph. It is necessary to design the generator gas device so that its permanent parts are extremely durable; at the same time the parts that easily wear out should be inexpensive to replace. (Examples of such a design may be found in the last generator types of the Swedish Generator Gas Co. with replaceable

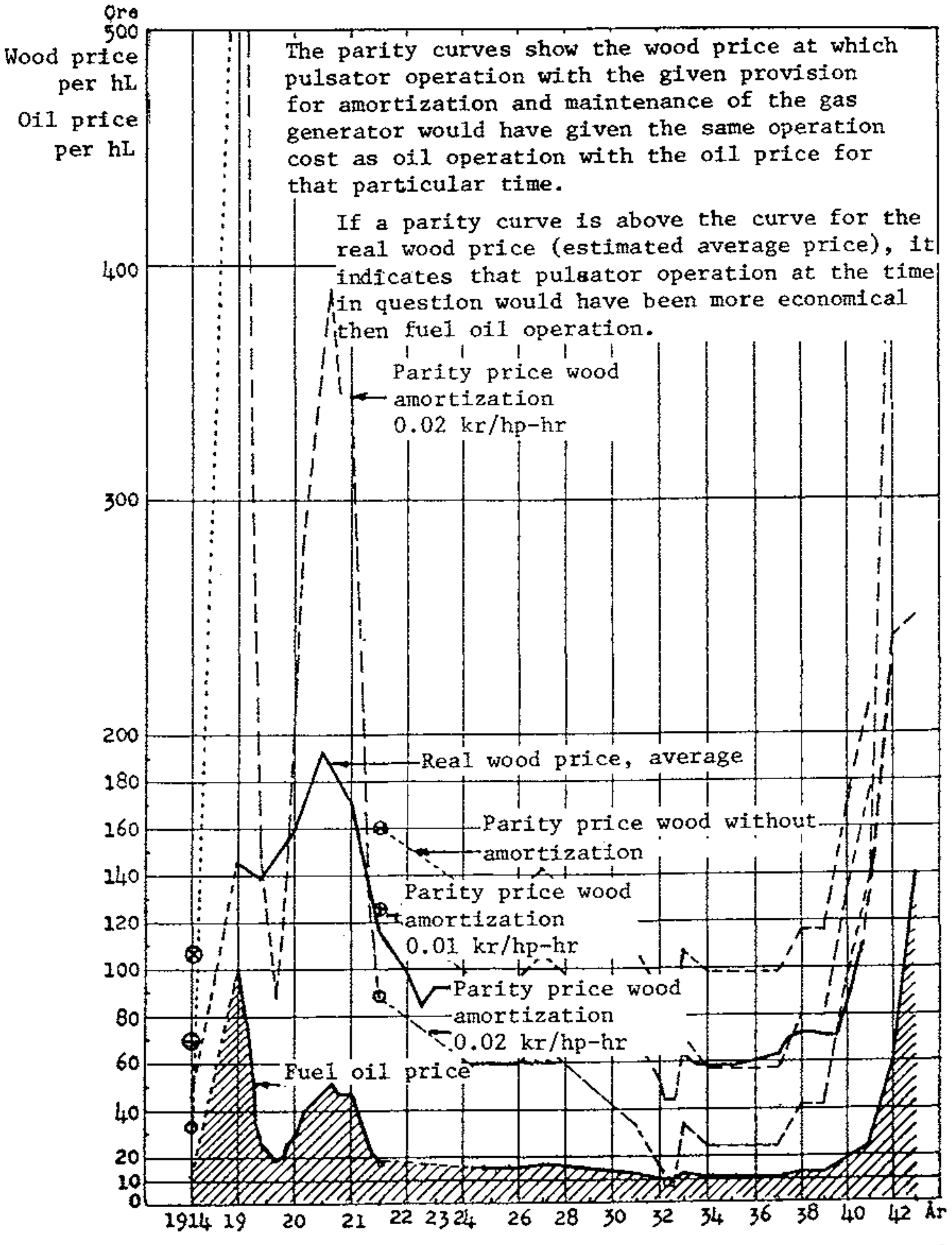


Figure 262. Comparison between Pulsator Operation and Fuel Oil Operation during the Years 1914-1943.

hearths of iron; the life of the hearth was 1,500-2,000 hours, after which it could be replaced for a new one for some 20 kr. If we get down to an amortization and maintenance cost of 0.01 kr/hp-hr—which is a realistic figure for peacetime—the parity price of wood is 1 kr/hL in the case of an oil price of 0.15 kr/kg. It was 10 years after World War I before the oil price declined below the just-mentioned figure, as opposed to 3 years for the wood. Thus, the prospects for generator gas operation with a pulsator or an equal system seem rather favorable, especially for enterprises with cheap wood available. Within the wood industry, for instance, where wood during peacetime can be obtained for practically the cutting price (0.15-0.20 kr/hL) from otherwise worthless waste, such generator gas operation would almost always pay.

It has always been difficult for generator gas operation to enter the marine field. This is true not only because seamen are somewhat conservative but also because earlier endeavors did not give satisfactory results. Even though the pulsator does constitute a technically satisfactory solution to the generator gas operating problem for boats, the need for a large bunker space remains in the case of long trips. For ships that frequent coast and canals this disadvantage is, however, of minor importance. Also, during peacetime it would be conceivable to use more qualified fuels than wood for generator gas production, for instance, coke, briquettes, or anthracite, thus obtaining longer distances per fuel load. Table 49 shows the work available per hL bunker space during pulsator operation on various fuels and during operation on liquid fuels.

Table 49. WORK PRODUCED PER hL OF FUEL TANK VOLUME DURING PULSATOR OPERATION AND OPERATION ON LIQUID FUELS. RELATIVE ACTION RADII.

Fuel	kg/hL	kcal/kg	kcal/hL	hp-hr/hL	Relative driving distance, calculated from hp-hr/hL				
Birch wood. . .	32.5	3,550	115,000	37.5	1.0	0.36	0.17	0.13	0.1
Coke 40/60. . .	46.0	7,000	320,000	104.0	2.8	1.00	0.48	0.37	0.3
Anthracite. . .	87.0	7,700	670,000	218.0	5.8	2.10	1.00	0.77	0.6
Engine tar. . .	100.0	7,500	750,000	285.0[a]	7.6	2.75	1.30	1.00	0.8
Fuel oil. . . .	85.0	10,000	850,000	355.0[b]	9.5	3.40	1.64	1.25	1.0

[a] Fuel consumption 0.35 kg/hp-hr.
[b] Fuel consumption 0.24 kg/hp-hr.

This table shows, for instance, that the travel distance per fuel load for birch wood and coke are in the ratio of 1:2.8; the corresponding figure for anthracite is 5.8; for engine tar, 7.6; and for fuel oil, 9.5. The oil appears, of course, much superior. The comparison figure between anthracite and fuel oil is, however, only 1.64. We should perhaps remember that the total efficiency of a generator gas device with a pulsator is about twice as high as for a steam engine fired with the same fuel. Since probably no one believes that the time of the steamship is definitely over, the 100% more efficient generator gas operation with a pulsator may likely have a use in this area also. For example, in 1943 the Danes had in operation a 3,000-ton ship specially built for generator gas operation on ordinary bunker coal.

The results obtained from a test run of the M/S Ramona are interesting; this ship was first rebuilt for generator gas operation using the crankcase system, and later was once again rebuilt for operation using the pulsator system with a mechanically operated top-valve device. Table 50 shows that the power during pulsator operation is considerably increased not only in comparison with the crankcase system but also in comparison with oil operation.

Table 50. COMPARISON OF OIL OPERATION WITH VARIOUS SYSTEMS OF GENERATOR GAS OPERATION FOR M/S "RAMONA"

Hull	Engine	
Length 21.71 m	Make	"Vanern"
Width 4.01 m	Power	40 hp
Tonnage net 40.38 t	Speed	400 rpm
Tonnage gross 67.32 t	Piston Stroke	300 mm
Draft Cargo 60 t: 1.8 m	Cylinder Diameter	260 mm
" " 80 t: 2.1 m	Number of cylinders	1

Operation	Fuel Oil		Wood Crankcase Flushing 100% Birch		Wood Pulsator 75% Birch, 25% Softwood	
Fuel Consumption	10 L Oil Per Hour		Two Sacks Per Hour		1 1/3 Sacks Per Hour	
Cargo	Speed, Knots	RPM	Speed, Knots	RPM	Speed, Knots	RPM
Completely Empty. . .	6.35	415	5.0	400	6.80	430
Normal Empty.	6.10	400	5.0	400	6.30	400
Cargo 60 ton.	5.90	400	4.7	400	6.15	400
" 80 "	5.60	400	4.4	400	5.80	400
Propeller blade pitch Oil = 100%	100%		95%		105%	

To summarize what has been said, it may be emphasized that the war years brought about improvements in and good experience with generator gas operation of two-cycle ignition-bulb engines. The development is far from complete, and new achievements for generator gas operation in this field can undoubtedly be expected. Generator gas operation under suitable conditions is not restricted to periods of crisis, but may also have a use during peacetime.

Chapter 12

THE HAZARDS OF GENERATOR GAS OPERATION

Chapter 1 included a summary of how generator gas operation served Sweden in a critical situation. Unfortunately, however, generator gas operation involves certain serious problems, such as:

Toxic hazards

Fire hazards

Traffic hazards

Of these the toxic hazards are indisputably the most serious, if effective countermeasures are not taken. It is necessary to take into account not only the danger of acute poisoning (which is easier to handle), but also the treacherous, insidious chronic poisoning, which in the case of large scale generator gas operation may become very dangerous for public health.

The fire hazard is also serious. It is true that these are mainly economic matters; but, during a blockade, the effect on military preparedness and economizing of resources can be very serious if the car fleet and supply of necessities are reduced by fire accidents.

The traffic hazard caused by generator gas operation is also dangerous, although it is given little attention. Forceful countermeasures against the traffic hazard are well justified.

Toxic Hazards

To poorly informed persons, the "generator gas illness" may appear to be a relative newcomer among our diseases, a new phenomenon caused by the generator gas epoch of the years 1939 to 1945. Thus it is important to emphasize from the start that generator gas poisoning is nothing but carbon monoxide poisoning, well known for a long time. A suspicion that some toxic substance other than carbon monoxide would play a part in the origin of the poisonings, especially cyanogen compounds, has not been verified with any degree of certainty. Acute generator gas poisoning is thus identical with the "smoking illness" well-known of old, that may develop if a tile-stove damper is closed too early, or if a city gas pipe is unlit or is inadvertantly left open, or if a gasoline truck is allowed to run idle in a poorly ventilated garage. Thus, also the so-called acute "garage death" is nothing new.

Why is it then that the "generator gas illness" has attracted so much attention and been discussed so much? The causes for this are not difficult to find. Earlier, acute carbon monoxide poisoning was relatively rare, as a rule an accident caused by negligence, carelessness, or oversight. As soon as generator gas started to come into more general use as a fuel, the frequency of the acute poisoning cases increased substantially. It is not surprising that this fact caused great alarm and resulted in demands for rigorous preventive countermeasures. A considerable number of deaths from acute generator gas poisoning further accentuated the seriousness of the situation.

Chronic generator gas poisoning was known previously and described in detail under the name of chronic carbon monoxide poisoning, although many researchers doubted that it existed. Chronic in this case does not mean that it would be a chronic incurable disease, but rather alludes to the fact that the symptoms are insidious (there need not have been any noticeable acute symptoms) and also to the fact that the effects may be of long duration; finally, this illness is caused by a long influence of carbon-monoxide concentrations which are not significant enought to produce acute poisoning symptoms. American and German monographs tell the exact same thing about this chronic form of poisoning as has been revealed by analysis of the chronic generator gas illness here in Sweden. There is, however, one important difference: earlier, relatively little was known about this disease compared to what has been learned during the generator gas epoch. This resulted in expansion of the diagnostic basis in many important respects, and, through accumulated additional experience, provided a more detailed and complete clinical picture of this disease. Finally, methods were developed from this information to give a more accurate diagnosis. Even before the generator gas epoch, chronic carbon monoxide poisoning was already recognized in civilized countries as an occupational disease, liable for damages; a diagnosis was based only on the existence of certain subjective symptoms in connection with a finding that there had indeed been exposure.

Many were puzzled by generator gas illness in a short time becoming our most common occupational disease. It was a well-known fact, however, that carbon monoxide for warmblooded animals and human beings constitutes one of our most potent poisons. Only a short stay in an environment containing a few hundredths percent by volume is enough to cause a malignant acute poisoning. Above 0.05% by volume, unconsciousness results. If higher concentrations are inhaled, death may ensue immediately. The poisoning effect is comparable in speed with an acute major cerebral hemorrhage or that of an acute serious coronary thrombosis.

Since the exhaust gases from gasoline-fueled cars may contain up to 6% to 7% carbon monoxide, the poisoning hazard and danger are obvious. Generator gas contains over 20% carbon monoxide. It is easy to understand then why the poisoning hazard increased substantially when generator gas units were used on an increasing scale around 1940; before long, over a hundred thousand people were more or less involved with generator gas operation. It was practically impossible to inform the general public in time of the types of hazards and how to avoid them, as well as to create, fast enough, protective countermeasures in the form of control, etc. A carbon monoxide content of 25% to 30% means that only one small indiscretion or one leak may in a few minutes release a lethal quantity of gas. If the dose is smaller, the condition for chronic poisoning arises. It may well be said that during the first years of the generator gas epoch, conditions of exposure sufficient to cause chronic generator gas poisoning existed everywhere that there were generator gas vehicles. Statistics show that garage and car repair workmen especially, as well as truck and bus drivers, were most frequently victims of this disease.

Surveying the development of the situation, we may point out that the concerned authorities stepped in relatively early and forcefully. Thus, it was possible to minimize the hazards and to keep the occurrence of really serious cases within reasonable limits. The work of the Fuel Commission and its Gas Generator Bureau as well as the medical-technical committee closely connected with the Commission, was of the utmost importance in this.

What is the Effect of Carbon Monoxide?

The poisoning effect of carbon monoxide is that it interrupts the vitally important oxygen supply. Oxygen, which is supplied through the inhaled air, and is necessary for the metabolic processes in the organism, is distributed to all cells and tissues of the body by attaching itself to the hemoglobin as a means of transport. Normally this means of transport is capable of adequately fulfilling the fundamental task of sustaining life. In case of certain diseased states, however, the transport ability is reduced or the distribution ability impaired. Thus, in case of a weak heart the transport ability suffers as a consequence of impaired circulation. In case of a serious attack of asthma, in spite of the retained transport ability, the distribution will still be inadequate because the oxygen of the inhaled air does not reach the hemoglobin in sufficient quantities. In both cases, the patient becomes cyanotic and there is a risk of "inner suffocation."

In the case of carbon monoxide poisoning, the case is somewhat different; namely, carbon monoxide has approximately a 250 times greater tendency to combine with hemoglobin than does oxygen. This means that carbon monoxide "suppresses" the oxygen even at a relatively low carbon monoxide content in the air; it also monopolizes the anchoring places of the hemoglobin, thus preventing it from filling its function as oxygen conveyor. Blocking of the ability of the hemoglobin to bind and transport oxygen becomes more and more complete in proportion to the magnitude of the carbon monoxide concentration. Figure 263 illustrates what has just been said. It also demonstrates how, at a carbon monoxide concentration of only 0.01% by volume, approximately 13% to 14% of the entire hemoglobin quantity is blocked for the oxygen after equilibrium is reached; at a concentration of 0.03% by volume more than one-third of the hemoglobin is prevented from working, and at a concentration of 0.07% to 0.08% by volume CO, more than 60% of the hemoglobin is not functioning. The carbon monoxide content of generator gas is over 20%. Figure 264 illustrates with a number of curves the absorption and occurrence of carbon monoxide in the blood when a person is exposed to air with various proportions of carbon monoxide, and also shows how the results are conditioned by whether the inhalation takes place while resting, while walking, or while working.

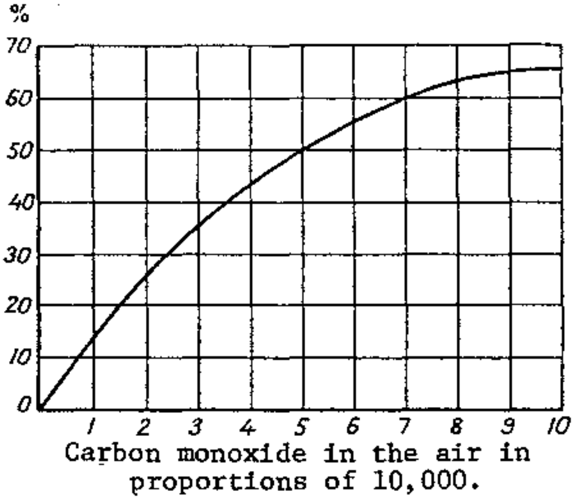


Figure 263. Percentage Saturation of Hemoglobin with Carbon Monoxide, at Equilibrium.

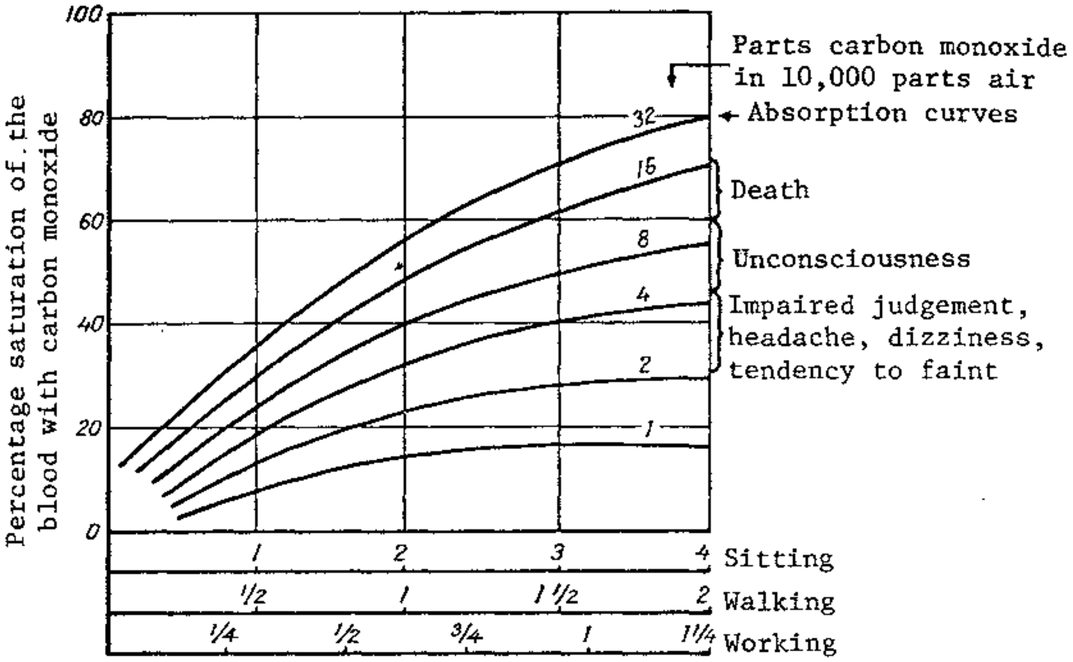


Figure 264. Absorption and Occurrence of Carbon Monoxide in the Blood.

A few examples may be stated. At 0.05% by volume CO in the air, provided the person in question is sitting and not working, unconsciousness will set in after approximately four hours in the environment mentioned. During ordinary walking (i.e., without heavy work) the same degree of poisoning will be reached after two hours, and during regular work after an even shorter time, 1 1/4 hours. Simple reflection indicates that such differences must exist. The exchange between the inhaled air and the blood must, of course, be faster during intensified breathing and faster circulation. This teaches one important thing for taking care of poisoning cases, either imminent or already poisoned: when taking the patient away from the poisoning influence, out into the open air, it should be done as fast as possible, but without his active cooperation. All exertion on his part must be avoided. Preferably, the patient should be carried out from the dangerous zone.

Table 51 shows how acute poisoning symptoms arise and develop according to the magnitude of the carbon monoxide content. Only after 30% to 40% of the hemoglobin is blocked by the carbon monoxide do more serious symptoms develop.

First aid in case of carbon monoxide poisoning consists of the following:

1. Move the poisoned person quickly out into the open air or to a room with fresh air and good ventilation.

2. If the poisoned person is unconscious, every second is valuable. Loosen tight clothes around the neck. Remove foreign objects from the mouth (false teeth, etc.) and immediately give him artificial respiration, if breathing has stopped or is weak. As soon as possible, give him inhalation of <u>Karbogen</u> (a

Table 51. SYMPTOMS OF CARBON MONOXIDE POISONING

% Saturation of the Blood with Carbon Monoxide	Symptoms	
	At Rest	During Physical Exertion
0-10	None	None
10-20	None	During exertion, dizziness, heart pounding, and difficulty in breathing may occur.
20-30	Headache may occur.	In case of exertion, pressure at the forehead. Mild headache.
30-40	Headache in the forehead or back of the head, pulse increase, heartbeat, nausea.	In case of exertion, dizziness, fainting, possibly unconsciousness are added.
40-50	All symptoms more pronounced, nausea, vomiting, dizziness, increased tendency for unconsciousness.	
50-60	Deep unconsciousness with increased breathing and pulse rate.	
60-70	Deep unconsciousness with slow pulse and low breathing rate, possibly death.	
70-80	Respiratory failure and death.	

mixture of oxygen and carbon dioxide). Detailed instructions come with each apparatus. Always see to it that the rubber bubble contains gas. If it becomes empty, the poisoned person may suffocate. If there is no Karbogen available, oxygen inhalation may be substituted as an emergency. Watch over the poisoned person for the next few hours!

3. Do not expose the poisoned person to cold.

4. Always call a physician. An injection, preferably directly into the blood vessels, of some stimulating substance (for instance, lobelin) may have a lifesaving effect.

5. In case of mild carbon monoxide poisonings without unconsciousness the poisoned person should, if possible, be treated with Karbogen or, if this is not available, with oxygen.

Even in quite severe cases of poisoning, the effect of these countermeasures can be outstanding. Figure 265 illustrates how the inhalation of Karbogen within approximately 25 minutes may lead to a "degassing" from 60% to 70% carbon monoxide content to as little as 5% to 10%. Inhalation of pure oxygen has the same effect within approximately 80 minutes* and is thus quite useful. Every nurse and health worker should learn to handle the Karbogen apparatus.

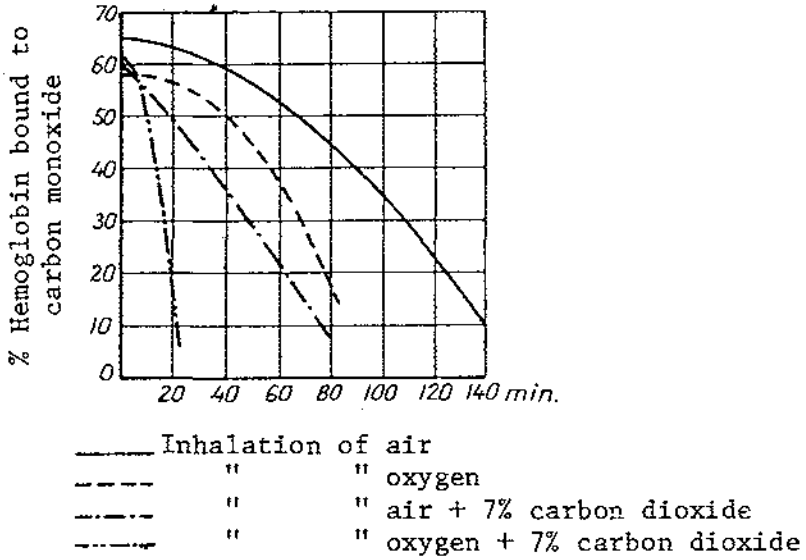


Figure 265. Treatment of Carbon Monoxide Poisoning.

The question of whether medication should be employed is not so easy to answer. Since, in every case, a physician should be called, he should judge the situation and take necessary measures in the particular case. Finally, an appeal!

The person acutely poisoned by carbon monoxide must be carefully looked after even after he seemingly has recovered. It has happened that after awhile victims once again have fallen ill with serious symptoms.

With chronic generator gas poisoning, we encounter an entirely different picture of symptom development and course. The symptoms, as it were, sneak up on the victim. He becomes tired and uncomfortable, frequently irritable and touchy, less perservering than before, has difficulty sleeping, and an annoying headache frequently sets in early. The desire for intimate family life virtually dies out in many cases, and troublesome frequent urination is not rare. Some eyesight disorders may arise, which, of course, are of the utmost importance from the viewpoint of road safety. In addition, there are frequently a number of rather characteristic, but not specific, mental symptoms or defects; for instance, a striking impairment of the memory or the ability to concentrate and learn. Also the temporal development of the symptom picture is to some extent characteristic for this illness.

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*Actually, the difference between the oxygen and Karbogen effect is likely to be even less.

Earlier, in the United States and Germany the diagnosis was mainly based on these symptoms; of course, it also had to be established that there had indeed been conditions of exposure and other causes of the symptoms had to be ruled out. A diagnosis based on this has been sufficient in the countries mentioned for compensation under the legislation on occupational diseases. Of course we were also obliged to resort to the same basis of diagnosis in Sweden during the generator gas epoch. This basis was, however, later expanded in an objective direction. The occurrence of dizziness, walking disorders, etc., was an impetus to carry out the so-called oto-neurological test for diagnosis and judgment. In a great number of generator gas cases this test was found positive, but it is not specific for carbon monoxide poisoning. The occurrence of eyesight disorders gave rise to special eye examinations of the cases; in some cases such deviations from the normal were proven, which most likely must be considered to indicate brain damage.

Hypersensitivity to carbon monoxide has also been established in many cases. Exposure tests frequently were useful in determining this.

The mental symptoms and impairment, mentioned above, resulted in the introducion of psychiatric evaluation and testing, especially of cases difficult to appraise, with a view to separate the real poisoning cases from primary or secondary common neurosis, etc. In different ways attempts have thus been made to expand the objective diagnosis of chronic carbon monoxide poisoning.

The treatment of the chronically generator gas poisoned must primarily be directed toward getting them away from the influence of poison. Change of environment has proved to be useful. It appears that cases discovered early, where there was no serious damage, are fully capable of working; not, however, in a generator gas environment. It is very important that an opportunity for change in work be created to a sufficient degree; this is an important task for social workers in the clinics. Among other means of therapy, vitamin and insulin treatments have been tried and were possibly of some use. On the whole there has been a good prognosis for generator gas poisoning if the victim has been removed from the influence of generator gas in time. Unfortunately, however, there is a small number of cases where serious mental disorders remained and for which the final prognosis cannot be determined. In addition, cases with continued heart trouble were found.

The generator gas era of the war is now over. The stationary generator gas operations still remain in industrial plants, etc. These conditions of chronic generator gas poisoning, which were in existence even before the generator gas epoch when there were a great many cases of the illness,remain. It is obvious that the experience with diagnosis, symptoms, and prognosis from the generator gas era is relevant and helpful in treating carbon monoxide poisoning, even during more normal conditions.

After liquid fuels became available the number of cases of generator gas poisoning decreased considerably. This fact must, however, not make us lose all interest in the poisoning question. Generator gas preparedness requires continued research in the field, keeping in mind a possible new wartime use. To a limited extent, generator gas operation is likely to continue also after the war, especially in stationary form; there is then a risk that such limited generator gas operation could cause proportionally more cases of poisoning than during the time when everyone—motorists and others—were alert to the risks. Finally, there are still chronic cases of poisoning that require continued observation and care.

The Gas Generator Research Council has emphasized that after the changeover to peacetime operation, to the extent that generator gas would still be used as fuel, an absolute requirement must be enforced that there be protection against health hazards for all who run the risk of inhaling gas. All units should be subjected to an effective, obligatory control, so that only types that are safe from poisoning are allowed to enter the market. The Research Council is of the opinion that the control employed so far for gas generators has not been able to completely exclude less suitable types from the market. During the first half of 1945, 230 vehicles were inspected because of police reports; 155 vehicles, i.e., 67%, were found to have faulty gas generators.

The Research Council recommends tightened regulations concerning both the inspection of the gas generators and the right to bring a generator gas operated vehicle into a repair shop. It is also the opinion of the Council that a central organization should be founded that would have the authority to issue technical instructions, carry out testing, and take care of technical safety-related activity based on the experience available.

Technical Aspects of Generator Gas Poisoning

Generator gas poisoning is often caused by technical defects of the gas generator. A few things related to the risk of poisoning should first be pointed out about the function of the gas generator. When the engine is running, independent of the location of the fan, the entire system is under negative pressure. If the gas generator is equipped with a suction fan, the entire system is kept under negative pressure even during fanning, which is why the poisoning risk through leakage is minimal. When using a pressure fan, the risk of poisoning is different; the pressure fan system creates pressure in the generator, cooler, cleaner, and piping. Consequently, if there is a leak at any point between the generator and the engine, gas escapes during fanning and may cause poisoning. If a pressure fan system is used, the leakage possibilities must be carefully checked with regard to the risk of poisoning.

When the engine is shut off, gas formation still goes on for a while in most types of generators and causes an increase of pressure in the generator. Evaporation of the water which may be in the fuel or on the generator wall contributes to this. Sometimes, after a wood gas fueled engine is shut off, a white or yellow gas can be seen escaping particularly from the primary-air intake; in the case of charcoal gas generators the escaping gas is not visible. The pressure increase after the engine is shut off lasts for approximately 20 minutes. Due to this it is not adviseable to stay in the car during this time. For the same reason, the gas generator should be allowed to cool for at least 20 minutes before the car is driven into the garage. This is true when either suction and pressure fans are used.

It should be emphasized that the gas formed during the "post-gassing time" has a carbon monoxide content of 23% to 27% and is thus very poisonous.

The pressure increase during the "post-gassing time" is so considerable that gas leaks out even from a tight gas generator (i.e., without real leakage points), for instance through the filling opening of the gas generator. If there is leakage, the poisoning risk increases because the gas leaks into the vehicle or underneath the engine hood and from there into the driver's cab. Hydrostatic tests or leakage tests of the entire generator gas device including its pipes should be conducted occasionally. During a hydrostatic test, the entire gas generator is pressurized. A simpler and more reliable method for detecting leaks is to use a smoke stick especially made for this purpose (see circular NR 355 of the National Swedish Fuel Commission). It is particularly important that all welding on the generator and its piping is adequate. One common and dangerous defect is that the filling lid is not tight due to a faulty packing. Because of this, after the generator has been left off a while, it may start burning like a stove. Air may also enter through the primary-air intake, if its flame guard and check valve are not tight, and the leak at the filling lid will then serve as a gas outlet. This is particularly risky with a car that is put into a garage, for instance under a living room. Some of the worst poisoning accidents in Sweden were caused by such circumstances.

A leaking pipe or hose, improper location of the secondary-air intake, the fan outlet, or the hot-air intake for heating the car body, as well as inadequate ventilation of the crankcase may also create a risk of poisoning.

Aspects of Industrial Hygiene During Generator Gas Operation

In addition to what has been said concerning the risk of generator gas poisoning, the differences between a gasoline and a generator gas engine during starting and idling should be recalled; these differences justify special garage regulations for generator gas cars.

The gas mixture that, during the starting of a gasoline engine but before ignition, flows through the engine and out through the exhaust pipe, contains practically no carbon monoxide. On the other hand, the engine of the generator gas car is, during the often prolonged starting attempts, fed a gas that contains 20% to 30% carbon monoxide. Thus it is obvious that starting attempts with generator gas inside a room must involve the most serious poisoning hazards. During generator gas operation the exhaust gases of the engine generally contain a greater proportion of carbon monoxide than during operation on gasoline and are thus more hazardous, especially during idling.

Since a carbon monoxide concentration in the air as low as 0.02% to 0.03% (equivalent to 1 m^3 generator gas in 1000 m^3 air, and 1 m^3 exhaust gases from a generator gas car during idling in 5000 m^3 air, respectively) involves a risk of poisoning, it is obvious that rather rigorous garage regulations are justified for generator gas operation. It is necessary to keep in mind that, in a garage, carbon monoxide is not evenly mixed with the air but occurs in layers or areas with considerably higher concentrations.

The requirements of the Labor Welfare Act for protection against unhealthy working conditions have given the Labor Inspectorate an opportunity to step in and bring about necessary ventilation in those garages that fall within the category to which this law applies. Other garages, however, have not been controlled in the same way up to now.

The regulations that were applied earlier to ventilation of garages for gasoline operated cars are now considerably more rigorous for premises which come under the Labor Welfare Act, where a generator gas operated vehicle in a warm state is admitted to be stored for a relatively short or longer time; i.e., garages, cargo spaces, and car repair shops. (Also see Chapter 8.)

It is very important to follow the regulations and directions for generator gas operation carefully—above all those that aim at preventing generator gas poisoning. Not only for one's own safety must the regulations and directions be followed; negligence in this respect can also affect other persons and harm their life and health. Anyone who through negligence or carelessness exposes another person to poisoning, be it of a mild or serious nature, may be held legally responsible.

It is most dangerous to break the regulation not to ignite, fan, start, or run idle indoors. Consider that the starting fan in one minute emits about 200 L carbon monoxide; i.e., enough to bring, in a 1000 m^3 garage, the carbon monoxide concentration up to a hazardous level. The same risk also occurs during idling indoors; for instance in a small garage of approximately 50 m^3 volume, in less than a minute.

Many believe themselves to be safe by fanning, starting, etc., with the doors and windows of the garage open or by first pushing the car halfway out of the garage. Experience has shown, however, that such measures are far from satisfactory. Also, it is not enough to lead away the fan and exhaust gases with a pipe or a hose that is put through the door or the window without real extraction being arranged. During severe cold it is, of course, most tempting to break the safety regulations; therefore, hazards are the greatest during the winter.

However, it is not enough to follow regulations and directions. One must also think carefully for oneself, because the directions cannot cover everything. One great risk is that anyone who works daily with generator gas is easily lulled into a sense of security, thus belittling the hazards and perhaps thinking himself to be "less sensitive."

One serious aspect of generator gas poisoning is that it shows itself in such a dramatic way. Not much is needed to cause dizziness and unconsciousness, which may be especially disastrous if one is alone in a garage or car when the poisoning occurs, and cannot get away from the dangerous environment without assistance. Therefore, do not work alone for an extended period of time with generator gas!

Even if reasonable safety measures are taken, carbon monoxide may enter the car body. Therefore, never sit in the car during fanning and air out the car body properly after fanning. If there are passengers in the car, it is the driver's duty to warn the passengers before starting the fan and to emphasize to them the risk they are running by remaining inside during the fanning. This is particularly important in the case of a bus with perhaps 20 to 30 passengers, many of whom very likely do not realize the risk and do not notice when the fan is started. Do not rely on the passengers reading the placard in the bus and realizing the seriousness of the fanning hazard.

One common mistake during the fanning is to stand or work close to the car, even quite close to the fan outlet or downwind from it. Due to the risk to other people, especially children, the driver must not go away from the car during fanning, but neither should he stand or allow another person to stand dangerously close to the car. Also, one should avoid standing or working close to the engine outlet while the engine is running. The exhaust gases from an idling generator gas engine contain 5% to 8% carbon monoxide and are considerably more dangerous than the exhaust gases from a gasoline operated engine. Loading and unloading of goods should never be done while the fan or the engine is running. Neither should anyone perform such jobs as changing tires, pumping tires, putting on chains, etc., at that time; these are all jobs which involve crouching quite close to the car.

One should also avoid fanning or starting several generator gas cars at the same time if they are parked close to each other. Excluding bus or truck garages, many cases of poisoning have occurred when several generator gas vehicles that were parked close to each other, were removed at the same time. Neither should one fan, start or idle generator gas cars in narrow passages, etc., where the air stands still without sufficient supply of fresh air. Fanning, idling, etc., underneath a protective roof or in sheds or barracks with more or less open walls should also be avoided. People used to trust that the air exchange in such "airy" premises would be sufficient to prevent poisoning. However, that is not the case, and the premises mentioned should be considered areas where fanning, etc., must not be done. On the whole, fanning and starting during calm and especially in case of hazy weather conditions is more hazardous than in clear weather with "clear" or "light" air and some wind.

Another common mistake is to fan or run idle for a long time immediately outside the open door to a garage or a workshop. The gases are then frequently forced directly into the room with a risk for the personnel working there. Similarly, passengers or personnel in a bus may be exposed to poisoning through fan or exhaust gases flowing from a generator gas vehicle parked beside the bus.

Carrying out repairs and adjustments on the car when getting ready to start may involve poisoning hazards, particularly during fanning. If a repair or adjustment has to be done while the gas generator is warm, the fan should be shut off and the air given an opportunity to flush around the vehicle before the job is started. If it is necessary to lift up the engine hood, one should not immediately lean in under it but first let the air flow in there. One should also avoid leaning down over the engine, especially if a spark plug has been removed; in general, one should avoid leaning down over any part of the generator gas device when it is hot or contains gas. Neither should one carry out any repairs lying on the ground beside or underneath the car while the gas generator is still hot; at any rate, neither fan nor engine should be running then. On the whole, jobs involving repair or adjustments on the car or gas generator should, as far as possible, be conducted when the gas generator is cold and, like the engine, properly aired out. With regard to "post-gasification" it is necessary to assume that any living quarters situated immediately against or above a garage or car repair shop have completely tight walls and roof as well as effective ventilation.

Special attention should be paid to the role played by physical exertion in generator gas poisoning. There are frequent reports of how cases of poisoning with mild symptoms have taken a serious turn with dizziness and unconsciousness because of considerable physical exertion, for instance running out of the garage, attempting to start the engine with the starting crank, etc. This fact should warn us, when noticing the first symptom of poisoning, to stay as calm as possible while evacuating the poisonous premises with slow careful movements.

Medical Apparatus, Carbon Monoxide Indicators, Alarm Devices

The treatment with Karbogen gas (oxygen with approximately 7% carbon dioxide added) is carried out with the use of an inhalor equipped with an inhalation mask; the inhalor is connected to a Karbogen gas cylinder.

Carbon monoxide examinations can be done using various methods and with the use of more or less sensitive indicators. The American indicators of the M.S.A. type used by the Gas Generator Bureau are available in two models, a portable one intended for measuring a possible quantity of carbon monoxide in the air, and a stationary model intended for use as an alarm device to warn against carbon monoxide hazards in car repair shops, warehouses, garages, etc. The measurement is based upon a catalytic combustion of carbon monoxide in the tested air to carbon dioxide, by which the temperature increase affects a thermocouple connected to a millivoltmeter graduated in percent by volume carbon monoxide. With this method it is possible to accurately read as low a carbon monoxide content in the air as 0.002% by volume.

Another type of carbon monoxide indicator, the Drager model, makes possible an accurate reading of carbon monoxide in the air as low as 0.003% by volume. This indicator is also based upon catalytic combustion, and the carbon monoxide content is read on the scale of a mercury thermometer. This device can also be used as an alarm device if platinum points are mounted into the thermometer in such a way that the mercury column will close the current between the platinum points at a certain content of carbon monoxide.

Still another indicator is based upon the iodine-spent oxide method according to the reaction: $5CO+I_2O_5 = 5CO_2+I_2$. If the air sample is sucked through the device with a velocity of approximately 200 cm^3/10 min, an estimate of the carbon monoxide content can be made with an accuracy of at least 0.003% by volume.

In order to detect carbon monoxide in a room, the palladium subchloride method may be used, in which a drop of water, preferably distilled, is placed on a sheet of paper impregnated with palladium subchloride. If the air contains carbon monoxide, a brown ring is formed around the water drops. The time it takes for the ring to become visible depends upon the carbon monoxide content of the air. The following contents can be determined reasonably accurately:

1. The ring visible after 5-10 sec	0.50% CO
2. The ring visible after 30 sec	0.20% CO
3. The ring visible after 3 min	0.03% CO

This method may also be used by placing a solution of palladium subchloride and salt in water in small porcelain bowls in the room whose air is to be examined. After 12 hours or 24 hours the bowls are inspected. In case of very small carbon monoxide content a dark brim is formed around the liquid surface. In case of higher contents of carbon monoxide, however, a glassy film of the metal palladium is formed on the surface of the contents of the bowl.

An estimate of the carbon monoxide present in the air may also be made by means of the absorption method. The gas-air mixture is passed through a solution of 1.7 g silver nitrate, 36 cm^3 of 10% ammonia water and 200 cm^3 8% sodium hydroxide in 760 cm^3 distilled water. The carbon monoxide content of the air may be determined by measuring the quantity of the gas-air mixture supplied and the time that is required for a certain deposit of silver nitrate. In this method a definite coloration of the analytic solution results and the time necessary for it is measured. If the apparatus is well designed, it is possible to estimate the carbon monoxide in the air with this method in the regions of about 0.01% by volume.

The Gas Generator Bureau has had the opportunity to examine some carbon-monoxide indicators manufactured in Sweden; however, none was considered adequate.

National and Local Government Measures

The National Gas Generator Committee appointed on November 10, 1939, shortly after the outbreak of war, had among its duties the following:

1. To undertake necessary examination and tests to improve the technical conditions for gas generator operation;
2. To supply advice and directions in order to have only technically adequate gas generator units manufactured and to have the installation of the units managed in a satisfactory way;
3. To arrange, within the limits of available funds, educational courses for assembly and maintenance of gas generator units as well as for operation of a vehicle equipped with such a unit.

In the instructions to the National Swedish Fuel Commission on June 14, 1940, there is only a general statement about gas generator matters that it is the duty of the commission "to handle questions concerning gas generators for motor operation." Among these matters should be mentioned: "combating the increase of poisoning accidents involved with gas generator operation." Since, at this point in time, no other authority was in charge of these urgent matters, which were beyond the Commission's main task, the Commission had to take care of this through the Gas Generator Bureau which started its work on July 1, 1940.

In the fall of 1940, the Commission initiated a permanent cooperation between the Gas Generator Bureau and various medical and social institutions and in December 1940 founded the "Medical-Technical Committee for Generator Gas Matters." This Committee was a part of the Fuel Commission and its members were the technical director of the Gas Generator Bureau, the director of the Swedish Institute of Public Health and one more representative of this Institute, two representatives from the National Swedish Board of Health, two from the National Swedish Social Welfare Board, one from the labor organization, as well as Associate Professor Ernst Salen as a representative for Sabbatsberg's Hospital and one expert in the field.

During the spring of 1941 a generator gas clinic was opened, by agreement between the City of Stockholm and the Fuel Commission, in Sabbatsberg's Hospital with room for 10 patients and in addition an out-patient department. Similar clinics were also opened later in other cities.

The Swedish Government dictated on December 12, 1941 that after January 1, 1942, research concerning poisoning hazards would be conducted under the supervision of the administration of the Swedish Institute of Public Health. The Medical-Technical Committee then changed its name to the Gas Generator Council. The Superintendent of the Institute of Public Health acted as chairman during the meetings, however without being a member of the council. The work during 1942 followed the same direction as during 1941. However, since the number of cases of generator gas poisoning increased at an alarming rate, especially the chronic poisonings, the Gas Generator Council in December 1942, moved that the administration of the Swedish Institute of Public Health ask the Government for an expansion of the work including, among other things, that examination stations similar to the generator gas clinic in Stockholm be established in about seven different places in Sweden and that physicians from these various places should gather in Stockholm for a week to get an idea of their tasks by sharing the observations and experiences of the generator gas clinic in Stockholm.

However, in a letter to the Government on December 30, 1942, the administration requested that the work be allowed to follow on the whole the same guidelines as during 1942 and thus that the proposal of the Gas Generator Bureau not be granted. The administration was, nevertheless, in favor of granting 5000 kr for the educational course. The Government asked the National Swedish Board of Health to give their opinion regarding the request of the administration. In their opinion, the Board of Health emphasized the necessity of stabilizing and expanding the work of the Gas Generator Council, especially since gas generator operation was becoming more common for stationary operation in foundries, workshops, steelworks, etc. The Board of Health proposed that the Government appoint a Gas Generator Research Council to handle the work in question and that the Government appoint the chairman and vice chairman of this council; that necessary funds be granted for 1943 so that the examination work concerning generator gas poisoning could be expanded as soon as possible to other parts of the country than Stockholm; that 10,000 kr be granted for completing hospital equipment for this purpose; and that 5000 kr be granted for supplementary education of physicians.

No changes were brought about during 1943, however, but in the 1944 Riksday (parliament) the Government presented a bill on this matter that complied with rather far-reaching demands, and according to which the Gas Generator Research Council would be a part of the Board of Health. The technical control was handled all along by the Gas Generator Committee and the Gas Generator Bureau of the National Swedish Fuel Commission, respectively.

When the Gas Generator Bureau of the Fuel Commission is discontinued in the spring of 1946, its tasks in the field of generator gas poisoning will have to be taken over by some other government agency—the Gas Generator Research Council, the National Swedish Board of Health, the Swedish Institute of Public Health, or the Labor Inspectorate.

The generator gas clinics located at Sabbatsberg's Hospital and Caroline Hospital as well as the examination stations in Uppsala and Orebro would seem to have a function at least for the time being.

After this was written, once liquid fuel was available again, gas generator operation of vehicles ceased to a large extent. In this connection, the stations in Uppsala and Orebro were considered superfluous and the work was discontinued. The clinic at the Caroline Hospital which is open to the entire country has been expanded also to include other occupational diseases. The same is true for the examination station of the City of Stockholm, which has been moved to the Southern Hospital.

Fire Hazards

The statistics covering fire accidents in connection with gas generator operation show that the risks of car fires are considerably greater during gas generator operation than during operation on liquid fuel. Actually, the risk during the first part of the gas generator era was several times greater. In particular, there was a very great number of garage fires. Steps taken in the form of directions and instructions from authorities in close cooperation with the insurance authorities, as well as publicity and increased understanding and attention on the part of motorists, have improved the situation considerably with regard to car fires.

During the first five gas generator years (October 1, 1939-September 30, 1944), 2,865 gas generator car fires were reported to the Gas Generator Bureau. The total amount for damages caused by these fires is not known but could roughly be estimated as: cars, 4.5 million kr; cargoes, 750,000 kr; garages and other property, 10 million kr; a total of roughly 15 million kr. The high average value for the fires, approximately 5250 kr, can be explained by the total number of fires and also by the many garage fires often at night and of no known cause.

In order to get a picture of the fire frequency, the period October 1, 1939, to September 30, 1944, was divided into half-year periods. Since the season affects fire frequency in some ways, the periods chosen were winter and summer half-years, thus October 1 to March 31 and April 1 to September 30, respectively.

Table 52 shows the number of cars damaged and destroyed by fire, for which the following designations are used:

K = Charcoal gas car
V = Wood gas car
P = Passenger car
L = Truck
O = Bus, all generator gas operated
D = Miscellaneous vehicles such as tractors, motorcycles and vehicles operated with liquid fuel.

Data is taken from the statistics kept by the Gas Generator Bureau of the National Swedish Fuel Commission. (The letter designations are also used in Tables 53 and 54.)

Table 52. NUMBER OF MOTOR VEHICLES DAMAGED OR DESTROYED BY FIRE

	Period	K	V	P	L	O	D	Total K+V+D
I.	1 Oct. 39-31 March 40 . . .	21	0	1	17	3	0	21
II.	1 April-30 Sept. 40	63	8	8	59	4	0	71
III.	1 Oct. 40-31 March 41 . . .	194	102	111	173	12	0	296
IV.	1 April-30 Sept. 41	230	145	182	183	10	4	379
V.	1 Oct. 41-31 March 42 . . .	290	230	246	260	14	2	522
VI.	1 April-30 Sept. 42	202	114	191	120	5	6	322
VII.	1 Oct. 42-31 March 43 . . .	210	111	185	122	14	19	340
VIII.	1 April-30 Sept. 43	201	112	167	140	6	49	362
IX.	1 Oct. 43-31 March 44 . . .	172	119	151	128	12	11	302
X.	1 April-30 Sept. 44	157	84	131	106	4	9	250
	Total	1,740	1,025	1,373	1,308	84	100	2,865

The remarkably great number of fires that occurred during period V, the winter half-year 1941/1942, were related to the severe winter.

In order to get a clearer picture of the development tendency, we should relate damage frequency to the average number of gas generator cars in traffic during each half-year. Table 53 gives the estimated average number of registered gas generator cars of various categories during each half-year.

Table 53. AVERAGE NUMBER OF REGISTERED GENERATOR GAS CARS

	Period	K	V	P	L	O	Total K+V
I.	1 Oct. 39-31 March 40 . .	--	--	--	--	--	1,200
II.	1 April-30 Sept. 40 . . .	--	--	--	--	--	3,500
III.	1 Oct. 40-31 March 41 . .	18,790	8,660	8,020	17,450	1,980	27,450
IV.	1 April-30 Sept. 41 . . .	34,050	23,170	20,810	33,130	3,280	57,220
V.	1 Oct. 41-31 March 42 . .	42,040	27,630	28,550	37,570	3,550	69,670
VI.	1 April-30 Sept. 42 . . .	41,400	28,220	30,830	35,360	3,430	69,620
VII.	1 Oct. 42-31 March 43 . .	44,980	27,630	33,980	35,200	3,430	72,610
VIII.	1 April-30 Sept. 43 . . .	46,310	27,550	35,000	35,310	3,550	73,860
IX.	1 Oct. 43-31 March 44 . .	46,145	25,705	33,660	34,660	3,530	71,850
X.	1 April-30 Sept. 44 . . .	46,520	25,275	33,850	34,410	3,535	71,795

The stagnation during period VI is rather noticeable and may be explained by the reorganization of the statistics from April 1, 1942; this should also be taken into account when evaluating the figures in Table 54.

The number of fires per half year and per thousand registered gas generator cars is obtained by dividing the values in Table 52 by the values in Table 53.

Table 54. NUMBER OF FIRES PER YEAR PER 1,000 REGISTERED GENERATOR GAS CARS

	Period	K	V	P	L	O	Total K+V
I.	1 Oct. 39-31 March 40 . . .	--	--	--	--	--	17.5
II.	1 April-30 Sept. 40	--	--	--	--	--	20.3
III.	1 Oct. 40-31 March 41 . . .	10.3	11.8	13.8	9.9	6.1	10.8
IV.	1 April-30 Sept. 41	6.8	6.3	8.7	5.5	3.0	6.6
V.	1 Oct. 41-31 March 42 . . .	6.9	8.3	8.6	6.9	3.9	7.5
VI.	1 April-30 Sept. 42	4.9	4.0	6.2	3.4	1.5	4.5
VII.	1 Oct. 42-31 March 43 . . .	4.7	4.0	5.4	3.5	4.1	4.4
VIII.	1 April-30 Sept. 43	4.3	4.1	4.8	4.0	1.7	4.2
IX.	1 Oct. 43-31 March 44 . . .	3.7	4.6	4.5	3.7	3.4	4.1
X.	1 April-30 Sept. 44	3.4	3.3	3.9	3.1	1.1	3.4

As shown in Table 54, the increase during period V mainly concerned trucks and wood gas operated cars. If we examine period V more closely, we find that its latter half, i.e., the first quarter of 1942, was characterized by a remarkably great number of fires, approximately 350, of which 120 were garage fires. This is equivalent to almost four fires a day, and would seem to be a result of the unusually severe winter. This observation provides a warning that special caution is needed during wintertime, especially in garages.

Passenger cars constantly show higher rates than trucks; the cars were more liable to have fires due to defects in the electric equipment. For both categories, the last periods show a happy improvement from the point of view of fire.

The relative change of the amounts of fire damage for the cars themselves is illustrated by Table 55, in which the relative figure for the amount of damage per registered car is set at 100 for period IV. Period V also stands out especially, and the increase during period IX is noteworthy.

Table 55. RELATIVE AMOUNTS OF DAMAGE PER REGISTERED CAR

	Period	Amount of Damage Per Registered Car
IV.	1 April-30 Sept. 41	100
V.	1 Oct. 41-31 March 42	116
VI.	1 April-30 Sept. 42	54
VII.	1 Oct. 42-31 March 43	57
VIII.	1 April-30 Sept. 43	59
IX.	1 Oct. 43-31 March 44	82
X.	1 April-30 Sept. 44	55

An investigation of the geographic distribution of the gas generator car fires shows that the statistics for the five northern provinces are poor in relation to the number of registered gas generator cars. If we set the average fire figure for the entire country at 100, the figure for the northern provinces is an average of 140 as compared to 93 for the central and southern provinces.

A study of the frequency and changes of the various fire causes can tell something both about the effect of regulations and directions already issued and about whether there is a need for further preventive measures. Table 56 conveys information in this respect.

In the table, the captions mean the following:

A. Sparks during fuel filling

B. Liquid fuel for starting

C. Defective insulation, overheating

D. Engine heater

E. Electric equipment

Table 56. FREQUENCY OF FIRE CAUSE

Period	Number of Cases Per 10,000 Registered Generator Gas Cars							Electric Fires As % of Generator Gas Fires
	A	B	C	D	E	Other Causes	Total	
III. 1 Oct. 40-31 March 41. .	9.1	13.8	16.0	0	24.2	44.9	108.0	22
IV. 1 April-30 Sept. 41. . .	4.2	0.9	7.3	0	24.1	29.5	66.0	36
V. 1 Oct. 41-31 March 42. .	1.0	1.9	4.7	5.7	33.2	28.5	75.0	44
VI. 1 April-30 Sept. 42. . .	1.3	0.9	2.7	0.1	20.2	19.8	45.0	45
VII. 1 Oct. 42-31 March 43. .	1.4	0.1	1.7	1.2	21.6	18.0	44.0	49
VIII. 1 April-30 Sept. 43. . .	1.5	0.5	2.2	0	15.3	22.5	42.0	36
IX. 1 Oct. 43-31 March 44. .	0.8	1.0	1.4	0.8	20.3	16.7	41.0	49
X. 1 April-30 Sept. 44. . .	0.6	0.0	2.1	0	17.4	13.9	34.0	51

The figures given under the captions A, B, C, and D, unambiguously show how favorably the frequency of the gas generator fires was affected by the regulations and directions issued by the authorities and the insurance companies in unified action.

Thus, fire due to sparks during fuel filling has decreased considerably through more rigorous directions concerning covering of the cargo with tarpaulins. Fire caused by liquid starting fuel hardly ever happens, thanks to a more rigorous regulation concerning the location of the starting tank. The regulations for insulation of the gas generator have been repeatedly supplemented and made more rigorous on the basis of experience gained. The result has been good, as shown in the table. As for the engine heaters, they did not come into existence until period V and during this period caused 40 fires. A quick intervention of authorities and insurance companies all but eliminated this fire hazard.

In the cases mentioned, as in other cases where carelessness or lack of forethought have caused gas generator fires, the increased experience and understanding of car owners and motorists have contributed to a better situation with regard to gas generator car fires.

By far the most gas generator fires were caused by faulty electric equipment (short-circuit) as shown in Table 56. This must, however, be accepted with some reservation; the explanation "short-circuit" was sometimes seized upon more or less correctly in uncertain or inexplicable cases. On the other hand, it is likely that some unexplainable fires, especially night fires in garages, actually could be classified as "electric fires."

In the short-circuit statistics, passenger cars are in a worse position than trucks, and commercial passenger cars worse than private passenger cars.

Among the short-circuit damages those caused by the battery or the battery cables predominate. Thus, during 1942 every third damage, a full half of the total amount of indemnity for short-circuit damages, was classified under this fire cause. The starting engine also has to a rather large extent contributed to the short-circuit damages, in that gas generator operation involves both mechanical and electrical overloading of the starting engine with destroyed insulation and short-circuit as a consequence.

Fire damage occurring in the garage and caused by short circuit is also rather frequent and represents, on an average, large amounts of damage, almost three times as great as the mean average value for all short-circuit damages. This is due to the fact that garage fires happen mostly during the night, causing total loss.

The fire-damage statistics for cars, compared with the pre-war period, show unfavorable figures in spite of a significant improvement during the latter part of the war; therefore, preventive measures should be concentrated primarily upon reducing the short-circuit hazards. Preferably, all the electric equipment should be checked during each comprehensive car repair. When meeting the usual requirements of the equipment, the special directions for gas generator cars given in circular nr180A of the Fuel Commission should be observed. The motor-vehicle examiners should also, when inspecting a gas generator vehicle, pay special attention to the electric equipment.

Traffic Hazards

The considerably decreased car traffic during the war did, of course, lead to a decrease in the number of accidents as well as the number of people injured or killed in such accidents. It would also have been reasonable to assume that the percentage decrease of the number of car accidents would be greater than the percentage decrease of traffic. At any rate, earlier experience has shown that to be the case; with less traffic on streets and roads, the risk for accidents should decrease quite significantly. However, the last years' statistics concerning the number of traffic accidents in relation to the number of cars in traffic unfortunately give quite a different picture of the actual situation.

The number of cars in use and insured by the insurance companies during the war years was less than 30% of the number of 1939. It is, of course, true that these vehicles during the war years consisted of proportionately more dangerous vehicles from the viewpoint of road safety; namely, trucks. Also, these vehicles were more intensely used than before the war. Still, one would have expected that the number of the car accidents and their consequences at least should not have exceeded the percentage mentioned.

The statistics of the insurance companies show, however, that during the five years from July 1, 1940, to June 30, 1945, the number of reported traffic-insurance damages amounted on an average to 32% of the 1939 figure. If we look at the statistics of the consequences of the accidents, the figures will be even more remarkable. Thus the number of people injured during the five years mentioned, on an average per year, was 37% of the 1939 figure; and the number of people killed per year no less than, on an average, 42% of the corresponding figure for 1939.

The enormously increased bicycle traffic during the war naturally increased the risk of collisions between cars and bicycles, thus contributing to the increase of serious personal injuries. This explanation would not seem to be sufficient, however, for the increased traffic hazards, which, to a certain extent, probably could be attributed to the altered manner of driving resulting from the gas generator operation. The decreased engine power causes increased shifting of gears, and the impaired acceleration gives lower average speed. In this way the driver is easily tempted to maintain a uniform speed that is too high in difficult situations, in curves, crossroads, etc.; in the same way the driver is more tempted than before to "take a run" before ascent. The impaired acceleration also makes it more difficult to pass another car; the passing distance, which always increases the chances of accident, becomes significantly longer. With an increased knowledge of gas generator operation, however, the risks mentioned have been noticeably decreased.

In addition, one serious traffic hazard that has hardly been noticed and investigated originates in poisoning by carbon monoxide that has entered the driver's cab and, in connection with this, inadequate ventilation of the driver's cab. In this, we have to take into account both acute and chronic poisoning, resulting in possible impairment of the driver's attentiveness and reaction rate, which is detrimental to the road safety. Some cases of driving into the ditch, collision, and other events that are otherwise difficult to explain may possibly be categorized as acute or chronic generator gas poisoning, in that even seemingly rather insignificant mistakes in the operation of a gas generator car could have caused consequences as serious as dizziness and unconsciousness. In some cases, the poisoning causes symptoms similar to intoxication; the driver crosses over to the wrong side of the roadway, does not know what he is doing, etc. The first part of this chapter also deals with this matter.

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GLOSSARY

Air filter—a device for separating solid and liquid impurities from air, especially secondary air in generator gas operation.

Ash box—a box for collecting ashes.

Ash port—opening for removing ashes, etc., from the lower part of a gas generator.

Ash space—a space situated beneath the grating of a gas generator, intended to collect ashes, etc.

Burning limit—the limiting proportions of the fuel/air mixture where the mixture changes from being combustible to being noncombustible.

Changeover switch—in a gas generator car, a valve or vent that makes driving possible with either liquid fuel or generator gas.

Charcoal gas--generator gas manufactured from coal, charcoal, or charcoal briquettes, sometimes with water vapor added or recycled flue gas.

Charcoal gas generator—a gas generator for charcoal or charcoal briquettes.

Charcoal layer or charcoal bed—in gas generator operation, a layer of granular charcoal placed beneath and around the lower part of the hearth in a wood gas generator to serve as heat insulation. This layer or bed lets the gas through by a filter effect, and serves as a foundation for the charcoal in the hearth. Also see "porous concrete layer."

Cloth filter—a gas purifier with a cloth filter, usually of textile fabric.

Cloth stand—a fitting in the cloth filter for holding filter cloths.

Coal briquette—a fuel of compressed coal powder and a fixing agent; in the case of charcoal as raw material, called charcoal briquettes.

Combustion zone—the part of the hearth in a gas generator where combustion takes place.

Condensation water collector—a device in a wood gas generator for collecting water originating from fuel moisture that has condensed on a relatively cold part of the wall of the fuel container.

Condensation water mantle—in a wood gas generator, the inside, usually perforated, wall that, together with the outer mantle of the generator, creates a closed space at the bottom against the fuel container and an open space at the top, equipped with an outlet for condensate.

Cork filter or cork cleaner—a gas purifier for the final cleaning of generator gas, consisting of a container with layers of small cork pieces through which the generator gas passes; used almost exclusively in wood gas generators.

Cross-burning—burning in a gas generator with the gas mainly directed horizontally or crosswise.

Cyclone purifier or cyclone cleaner—a gas purifier, where solid and liquid particles are separated with the help of centrifugal force.

Downward burning—burning in a gas generator with the gas mainly directed downward.

Expansion pipe—the part of a pipe that is able to absorb the change in the length of a pipeline during a temperature change.

Fan case—a nonmoving case in which the impeller rotates; equipped with inlet and outlet openings for gas or air.

Fan shaft—the shaft to which an impeller (fan) is attached.

Fan valve—the cutoff valve in the pipe of a starting fan.

Filter cloth—the cloth in a cloth filter that lets gas through (usually of textile fabric or paper pulp), or in a safety filter (of metal).

Fine purifier or fine cleaner—sometimes used as a collective (common) name for the final filter that purifies generator gas.

Flame arrestor or flameguard—a device preventing flames from extending out through the primary-air intake at positive pressures in the gas generator.

Fuel container—the part of a gas generator holding the fuel, corresponding to the fuel tank for liquid fuels.

Gas cooler—a device in a gas generator for the cooling of the hot generator gas.

Gas exhaust—the opening in a gas generator through which the gas leaves the generator.

Gas generator—a device in which generator gas is produced by burning a solid fuel followed by reduction of carbon dioxide and water vapor in a glowing charcoal layer to the combustible gases CO and H_2.

Gas generator car—a car whose engine is operated by generator gas.

Generator gas match—matches manufactured especially for igniting a gas generator, usually containing aluminum powder and nitrates.

Gas mixture—in wood gas operation, a mixture of generator gas and air (secondary air). Should not be used as a name for a mixture of air and atomized solid or liquid fuels, which should be called fuel/air mixture.

Gas purifier or gas cleaner—a device for separating solid and liquid particles from gas. In a gas generator the purification takes place in two steps: primary purification in the cyclone purifier, the wet cleaner, or the scrubber; and final purification in the cloth filter or the cork filter.

Gas ring—in a Swedlund generator, a ring supported against the hearth mantle. The casing of the gas generator rests on this ring.

Gas valve—a valve in the gas duct.

Generator gas--gas produced in a gas generator especially in large industrial establishments. For motor operation the recommended word is "gengas."

Generator gas engine—a combustion engine designed for, or adapted by a design change to, generator gas operation.

Grating—in a Kalle generator, a perforated pipe serving as a grate of variable size.

Grating--in a gas generator, a perforated plate or grill of a heat-proof material in the bottom of the gas generator above the ash space.

Hearth—in a gas generator, the construction element bordering to the lower opening of the fuel container, in which burning and reduction take place. The name "oven" is also used for the hearth in a charcoal gas generator.

Hearth cone—in a wood gas generator, the lower conical part of the hearth.

Hearth ring—in certain wood gas generators, a replaceable ring placed in the lower part of the hearth and determining the smallest bypass area of the hearth.

Ignition cartridge--a cartridge with a flammable substance for igniting a gas generator.

Ignition port--in a gas generator, an opening, which can be shut off, through which the gas generator is ignited.

Impeller—the part of the fan equipped with blades or flaps.

Inlet pipe—in a generator gas engine, a pipe through which the gas mixture, or generator gas in a pulsator and gas-pump system, is supplied to the motor.

Inside mantle—in a gas generator with a double jacketed fuel container, the inside wall to whose lower end the hearth is connected.

Inspection port—a port or opening through which the fire is inspected, frequently serving as ash port as well.

Lower burning limit—burning limit at fuel deficit.

Main valve—a valve for regulating the gas mixture to the engine.

Mixed heat value—effective heat value of the mixture of generator gas and air.

Mixer—in a gas generator, a device for mixing generator gas and secondary air; corresponding to the carburetor of a carburetor engine.

Mixing chamber--the space in a mixer where generator gas and air mix.

Mixing proportion—the proportion between the volume of air and the volume of the generator gas in the gas mixture.

Normal cubic meter—the unit of gas measurement used in this book; e.g., for a gas that is measured at a temperature of 0°C and at a pressure of 760 mm Hg; this term is abbreviated Nm^3.

Outer mantle—the outer wall of a gas generator with a double-jacketed fuel container.

Peat gas—gas manufactured from peat.

Peat gas generator—a gas generator for peat.

Pivot—a shaft for a turning motion.

Pivot car—a trailer with only one rear wheel, which pivots.

Porous concrete layer—in gas generator operation, a stratum of relatively fine porous concrete placed beneath and around the lower part of the wood gas generator to serve as heat insulation, letting the gas through with a filter effect and serving as a foundation for the charcoal in the hearth.

Preheater—a device for heating of fuel, air, or fuel/air mixture, usually with heat recovery.

Primary air—in a gas generator, air entering the generator for the production of generator gas.

Primary air intake—in gas generators, an opening through which primary air is supplied.

Primary air nozzle—in a gas generator, the nozzle through which primary air is blown into the combustion zone of the generator. Several primary-air nozzles are usually directed inward.

Primary air pipe—in a gas generator, a pipe connecting the primary-air intake with the primary-air nozzle or the primary-air ring.

Primary air ring—in a gas generator, a ring-shaped channel for primary air.

Primary air valve—in a gas generator, a valve for throttling or shutting off the primary air.

Pulsator—a device for operation of a two-stroke combustion engine, in which pressure changes in the crankcase air result in an oscillating gas column for pumping generator gas directly to the combustion space through a vent, usually operated mechanically, without having the gas pass through the crankcase.

Rear vent—in a wood gas generator, a suspended plate preventing the return flow of gas during air intake.

Reduction zone—the part of the hearth in a gas generator where carbon dioxide and water vapor are reduced in a glowing charcoal layer to combustible gases.

Refilling port—an opening for the fuel in a gas generator.

Refractory lining—a firebrick covering on the inside of the generator hearth.

Return ejector—a device in a Kalle generator for returning rough-grained charcoal particles from the wind screen.

Rinse plug—a threaded plug for the opening through which the gas generator is washed clean.

Rough purifier—sometimes used as a collective name for various mechanisms for purifying generator gas from all rough, solid impurities.

Safety filter—in generator gas operation, a layer of gauze or similar material placed in the gas duct after the cloth filter to prevent impurities from entering the engine in case of a faulty cloth purifier. If the safety filter gets clogged that means that the filtering (purifying) system does not work satisfactorily.

Scrubber—a primary gas purifier, usually consisting of a vessel with a thick layer of coke, which during operation is rinsed by water showers; it is used in marine and stationary gas generators.

Secondary air—in gas generator operation, combustion air added to the generator gas for burning in the engine.

Secondary air intake—an opening through which secondary air is supplied.

Secondary air pipe—in a gas generator, a pipe connecting the secondary air intake and the mixer.

Secondary air valve—a valve for throttling or shutting off the secondary air; it may be placed in the secondary-air intake or in the secondary-air pipe.

Shaking arm—a handle for shaking or turning the valve grating.

Shaking grating—a movable grating which may be shaken or turned with a shaking arm.

Smoke stick—a stick of a smoke-producing substance used to test pressures in a gas generator to discover possible gas leaks.

Soot—the term for solid impurities in generator gas.

Soot box—in a gas generator, a detachable box for collecting soot.

Soot port—an opening through which soot is removed.

Starting fan—in gas generator operation, a hand or electric motor-driven fan to achieve the draft through the generator needed for ignition, so that adequate generator gas may be obtained rapidly to start the engine.

Steam generator—a low-pressure boiler sometimes used in a charcoal gas generator for generating water vapor, which together with the primary air is forced to enter the generator; the steam generator is heated by the hot gas from the generator.

Stoichiometric mixture—a mixture of generator gas and the air quantity required for complete combustion without any air surplus.

Theoretical mixed heat value—the heat value of the stoichiometric mixture of generator gas and air.

Upper burning limit—burning limit at fuel surplus.

Upward burning—burning in a gas generator with the gas mainly directed upward.

Wet cleaner—a primary gas purifier for wood gas, where the gas is made to pass through water.

Wind screen—a special-design cyclone filter for a Kalle gas generator, from which coarse-grained charcoal particles separated with the help of exhaust fumes are brought back to the primary air pipe of the gas generator.

Wood gas—generator gas manufactured from wood.

Wood gas generator—a gas generator for wood.

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