MISSOURI WOOD GASIFIER

By

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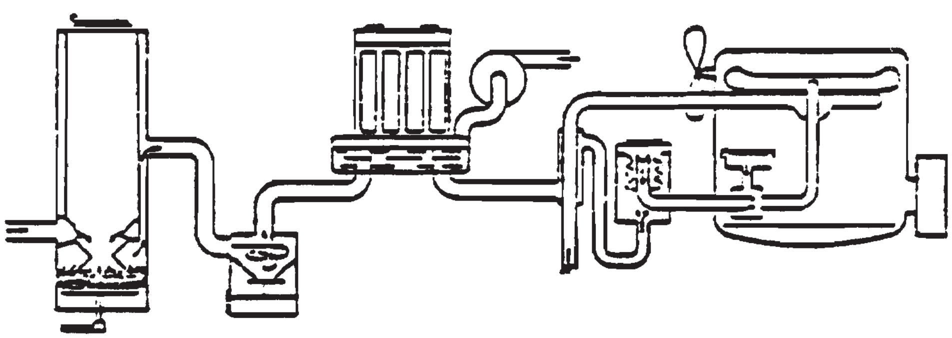

Sawmills - Farms - Industry

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Systems Design & Construction

Patent Pending by R & R Wood Products, California, Missouri

This sawmill gasifier was designed and constructed by Raymond Rissler of California, Missouri. He has graciously agreed to share his knowledge and design with us for public distribution.

Cover photo from "Gen Gas the Swedish Experiment from 1939 to 1945". To obtain the English translation of this book, you will need to order from U.S. Department of Commerce National Technical Information Service; 5285 Port Royal Road; Springfield, VA 22161. Price was $24.00 as of April, 1981.

WOOD GASIFICATION WORKSHOP

We have held several all day workshops in Jefferson City explaining the finer details, problems and suggested solutions about this type of wood gasifier.

We hope to be able to hold a few of these sessions at other locations around the state. Because of budget restrictions, this will only be possible if some sponsoring group will generate the audience and provide a meeting room.

Our past workshop registration fee has been $20.00 per person to cover the meeting room, mailing expense and the demonstration unit and technicians speaking fees.

If you would be interested in attending one of these workshops, please write to us, and we will notify you of the place and date of our next workshop.

If you would be interested in sponsoring one of these meetings, please let us know the location and the date; hopefully we can avoid conflicts in scheduling.

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Increase Woodland Products Through Timber Stand Improvement

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What Is Timber Stand Improvement?

Timber Stand Improvement (TSI) denotes management practices that improve the vigor, productivity, and quality of stands of trees.

In Missouri, young tree stands have become established readily following cutting or fire. But, tree quality, species composition, and individual tree form are often undesirable. Further reduction in quality comes when the better trees are harvested leaving the bad ones, and when fire scarred trees remain. The average Missouri woodland contains about 20 percent cull trees and produces at less than one-third its potential.

Using Timber Stand Improvement

Many options are open to a woodland owner. He may use a TSI program to increase the woodland's value for timber products, water, recreation, forage, wildlife, natural beauty, or for special products. Fortunately, work done to improve one use also benefits others in most cases.

Various practices used and tree species selected should fit the chosen emphasis for the woodland. The number of trees to keep depends on species, type of site, management goals, and size of the trees. Professional foresters are available to help determine a woodland's potentials and limitations and to help develop and carry out a suitable management plan.

Types of trees usually removed are:

1. Cull trees and wide spreading "wolf" trees.
2. Trees inferior because of their species.
3. Trees interfering with the growth and development of selected desirable trees.
4. Damaged trees (broken off, bent over, fire scarred, seriously barked, etc., but expected to live at least one cutting cycle).
5. Seriously diseased trees or trees serving as a breeding ground for undesirable insects.

It is important to remove or kill these types of trees as soon as possible after an area has been logged to properly release younger trees. Variety is important in a woodland environment so those trees necessary for den trees, aesthetics, or special foods should be selected and retained in the stand when beginning a program of TSI.

The following practices are among those used in Timber Stand Improvement:

Site Preparation for Natural Reproduction in Understocked Stands--preparing the site to allow natural seeding or resprouting of desirable species, or underplanting seedling stock to fully use the available growing space. This practice is used in poorly stocked stands to fill large openings and increase stand density, or to improve the species composition.

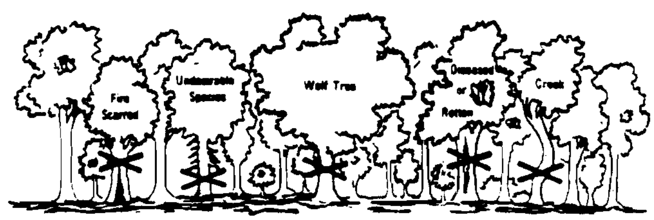

Figure 1. Eliminate your (X) trees. They steal plant food, moisture and space from your desirable trees.

Thinning--cutting trees from an immature stand to increase rate of growth and improve form of the remaining trees. Proper space varies depending on species, purpose of management, and site quality. Table 1 gives a range of spacing for trees of various diameters:

Release--removing or killing undesirable older overtopping trees to encourage fast growth and better quality of vigorous young desirable trees.

Pruning--removing lower limbs, to produce the maximum clear lumber or veneer in the butt log. Prune only selected hardwood trees where high-value species are grown on good sites. This is recommended primarily in managing black walnut.

In pruning lower limbs of young trees, don't remove too much of the food producing leaf surface of the tree. At least one half of the living crown of the tree should be left intact. Generally trees should be pruned before they reach 8 inches in diameter. Limbs to be removed should be pruned before they reach 2 inches in diameter to reduce the wound size, insuring proper healing, and to lessen the danger of entry by insects or disease organisms.

Table 1

Tree Diameter (in.)	Spacing Range (ft.)	Tree Diameter (in.)	Spacing Range (ft.)
2	4.6- 6.5	9	14.3-18.7
3	6.1- 8.2	10	15.6-20.4
4	7.6- 9.9	11	17.0-22.1
5	9.0-11.6	12	18.1-23.8
6	10.3-13.4	13	19.4-25.6
7	11.6-15.0	14	20.8-27.2
8	13.0-17.0	15	21.9-29.0

Certain species or management purposes may require other spacings. In any thinning the tallest desirable trees are usually favored.

Source: Even-Aged Silviculture for Upland Central Hardwoods -- USDA Agriculture Handbook 355.

Vine Removal--On some areas vines do considerable damage to trees. Vines not retained because of wildlife food value, fall color, etc., should be killed at the same time other stand improvement work is done. Remove them by cutting them as low to the ground as possible and immediately treating the stump with an herbicide.

Special Problem of Sprout Selection in TSI

Many Missouri hardwood species sprout heavily after fire or cutting. Sprouts grow rapidly and often form multiple-stemmed clumps. Use these guidelines for deciding how to handle sprout clumps.

1. Seedling sprouts, originating from severed seedlings, are as good as seedlings if the clumps are thinned to reduce crown competition and to avoid bad stump conditions from developing at the base when the trees become older.

2. Tree-stump sprouts are less desirable than seedling sprouts but may develop into good quality stems, depending on the size of the stump and the origin point of the sprout. Many hardwood sprouts decay through the large wound left at the base of a sprout when the parent stump rots away.

Sprout stands are best managed before they reach 20 years of age. Early treatment permits better selection of trees from the standpoint of attachment to and size of the parent stump, and greatly lessens the danger of decay from wounds left in cutting companion sprouts.

The best trees to leave come from seedlings, seedling sprouts, or sprout clumps arising from stumps 4 inches or less in diameter. Sprouts from larger stumps may be selected if they arise very low on the stump and if the parent stump wound is small.

If early treatment is made in a young stand it will enter maturity with the crop trees primarily single stemmed. Where there has been no early treatment, pole stands of sprout origin are likely to consist of sprout groups. After companion sprouts, joined at the base with a V-shaped crotch, have grown several inches in diameter, it is usually difficult to remove one without leaving a large wound at the base of the other, through which decay will develop. Twins of this type should be let alone. Where the sprouts have a low U-shaped crotch between them, however, or are entirely separated from each other above ground, one or more can be removed (See Fig. 2).

TSI Cost Sharing & Technical Assistance

Cost sharing practices are available for TSI. For further information contact your Extension Center, Missouri Department of Conservation District Forester, or County Agricultural Stabilization Conservation Service Office.

Free technical assistance on all timber management practices is available through local District Foresters of the Missouri Department of Conservation.

Methods of Removing Trees from Competition

The landowner should keep in mind that in many cases a properly conducted timber sale (improvement harvest) can accomplish a great amount of TSI. Undesirable trees not

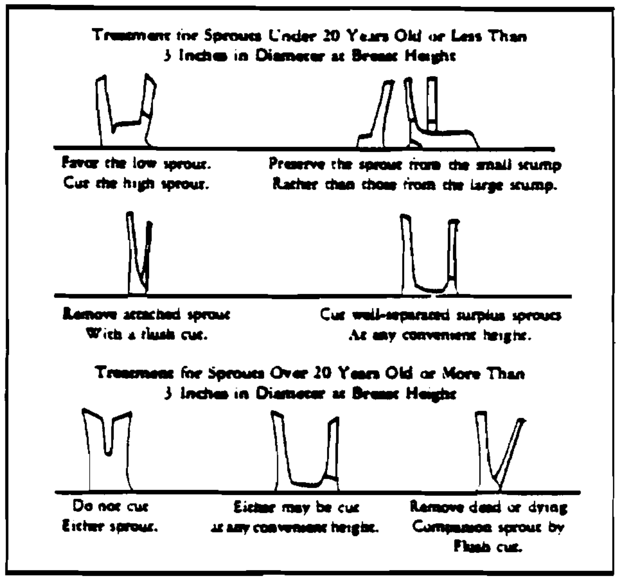

Figure 2. From USDA, "Timber Stand Improvement in the Southern Appalachian Region," No. 893.

merchantable may be removed by cutting, dozing, brush-hogging, girdling, or by chemical control. Chemically treating large trees is more economical than felling and is more certain to kill them than is girdling. Where control of re-sprouting is desired, chemicals are most effective.

Silvicides and herbicides are chemicals which act in several ways: As translocation poisons, plant hormones or growth regulators, contact poisons, or soil sterilants. Some of the more common herbicides used in TSI operations are 2,4-D, Amitrole and Ammate.

All these chemicals can injure sensitive trees, crops or ornamental plants if not used according to label instructions.

Many are volatile and their vapors and spray drift will damage desirable plants, especially on windy days.

Silvicides and herbicides can be applied as follows:

1. ***Frilling or Mechanical injection***--cuts are made through the bark and into the growing tissue of the tree completely around the tree. Undiluted 2,4-D amine is then applied to the fresh cuts until the chemical starts to flow from the cut. Mechanical injectors can be purchased or rented which apply the chemical at the time they make the cut.

2. ***Stump treatment***--of trees that have been cut. The stump should be thoroughly wet with chemical-carrier mixture immediately following cutting.

3. ***Basal spraying***--may be used effectively on trees less than 4 inches in diameter. Spray chemical-oil mixture on lower 12 inches of the trunk wetting the bark thoroughly.

For details about chemical mixtures, regulations, and precautions on these methods see UMC Guide 4865, *Woody Plant Control*.

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MISSOURI GEN GAS

The design and construction of this sawmill wood gasifier was made possible by a grant from the Missouri Department of Natural Resources, Division of Energy to the Reorganized School District #1 of Moniteau County (California, MO).

The Department of Natural Resources - Energy Division issued this grant because of the energy, the money and the jobs that can be utilized by the future uses of wood gasification.

According to figures from page 34 of a 1978 publication by the Missouri Department of Conservation, Forestry Section, entitled Wood Residues in Missouri; there are 847.22 million (mm) pounds of unused equivalent oven dry pounds of sawdust and shavings produced annually in Missouri. This converts to 1,236,286 barrels of No. 2 fuel oil or about 1% of Missouri's average annual oil and gasoline consumption. This also converts to $37,088,580 at $30 per barrel.

Over 90% of the money that Missourians spend on oil permanently leaves the state. For each $30,000 of energy dollars exported we lose one job to an oil producing state or country. This is 1,236 jobs lost because we are not utilizing these two waste products. This is a serious drain on Missouri's economy.

The technician that construced the gen gas unit had worked with a number of smaller size units since 1974. After a great deal of research and experimentation, two successful small units were finally operational. The knowledge and experienc gained from these small units was the basis for a larger unit now successfully operating at a local sawmill. A system design patent has been initiated for this unit.

The actual documented expense for the materials and parts on this gen gas unit is approximately $1,900 not including labor and administrative cost. Some additional parts on hand were not included in the cost. It is estimated these additional parts and supplies would add approximately $300 to the cost for a total of $2,200 for materials. Labor hours include 72 hours to convert and adapt the engine to gen gas. Construction of the gasifier, coolers, filters, and dryer took 116.5 hours, travel to locate materials required 41.5 hours. The total hours came to 230 hours.

Many recycled items were used in this gasifier. We have not tried to figure a cost based on new materials. These vary widely from place to place because of availability and the ingenuity of the people involved. Depending on materials on hand, your cost may be more or less for the same size unit.

COMPONENT PARTS EXPLANATION

This is an explanation of the working parts involved in the construction of a down draft gasifier. This particular unit runs with sawdust as a fuel that is converted to a low BTU gas, approximately 150 to 200 BTU/standard cubic foot (SCF), compared to natural gas which contains 1,000 BTU's per SCF.

Engine Power Loss

Because of the lower BTU content, the normal internal combustion engine will be derated (horsepower reduced) by about 50%. The heat content of gas from this sawdust burning unit does not greatly differ from the BTU value of any other wood fuel converted to gas in any similar air induced wood gasifier.

The Hearth & Air Intake

The core of the unit or the area where fuel is converted to gas is called the hearth area. This is the area where burning takes place with the correct amount of oxygen admitted to maintain enough fire to generate enough heat to gasify that part of the fuel which is not required to sustain the fire. If too much oxygen is allowed to enter the hearth, all of the fuel will be converted to carbon dioxide (CO_2) and water vapor. The CO_2 and water vapor will not produce power in the engine.

When oxygen in the air mixture intake is limited in the hearth area, most of the wood is converted to carbon monoxide (CO), some hydrogen and a few other combustible gases and water vapor. Carbon monoxide plus oxygen will burn to produce heat and pressure which is converted to power inside an internal combustion engine. (Hydrogen and the other gen gases will also burn, but the water vapor will not burn; therefore most water should be removed by cooling the gen gas.) A good filter is absolutely essential for an internal combustion engine

One reason for the low heat value of the produce of this type gasifier is that air contains about 80% nitrogen. Nitrogen is not combustible.

Hearth Component Design Explanation

The hearth is where the required burning and gasification takes place. (See drawing 1, 1A & 1B)

The hearth area is composed of a grate at the bottom, a restricter ring, a combustion zone and the air intake nozzles, referred to in the literature as "toures".

The hearth is a cylindrical shape, essentially one cylinder inside another with a space between the cylinders for passage of incoming air.

The grate supports the fuel. In this unit the grate is a discarded hammermill screen located a few inches below the restricter ring, and is the same diameter as the smallest cylinder.

A heat sensing device (pyrometer) is installed immediately below the restricter, but above the grate and extending into the hottest area of the grate. The pyrometer measures the effect of any changes or adjustments made in air flow that changes operating temperature. The operating temperature of most gen gas units is 2,372°F to 2,642°F at the hottest part of the hearth. (See gen gas book, pg. 116&119. In this unit the pyrometer reading ranges between 1,100 to 1,200°F because it is not in the hottest hearth zone.

The restricter ring outside diameter is the same size as the inside diameter of the smaller cylinder. There is a small hole in the center of the ring. This hole controls the volume of the combustion area and also controls the velocity of the gen gas that flows through to the engine. This flow rate does influence the heat gained by the gas passing through. If the gas dwells too long in the combustion area, a higher portion of the gas becomes non-combustible CO_2. Likewise, if the gas flows too slow the fire runs too cool and more of the gas passes through as tar, in vapor form, instead of converting to CO and hydrogen. Additionally, if the gas flows too slow the ash will build up on the grate and ultimately will choke off the flow of incoming air. A manually controlled shaker system will help eliminate ash build up.

The next vertical step up the hearth chamber is the air nozzle ring. These nozzles pass through the first (inside) cylinder wall and into but not through the hollow chamber between the two cylinders. Air nozzles should be made of materials that are highly resistant to high temperature. The number of air nozzles, their diameter and the height above the restricter ring is predetermined by a mathematical relationship to the size of the engine. Size or engine volume is determined by the bore, stroke and revolutions per minute of the engine you are operating. See Table 25&27 and Figure #77, pg. 123, 125, and 126 for the mathematical formulas in the Swedish Gen Gas Book (Sw. GB) section.

All materials in this hearth area are mild steel except for the nozzles, which are stainless steel and the grate which is high carbon steel.

Gen Gas Housing Component

The next component (see drawing 2A & 2B) is the gen gas housing and combination fuel storage container. The housing in this unit is a cylinder. The hearth unit (grate, restricter ring and air nozzle) is placed inside the housing with a space between the two cylinders. The space allows the down tube air intake pipes to extend from the top of the fuel bin down to near the bottom of the restricter ring. This down tube allows the air to be preheated as it travels down the tubes and through the outside hearth cylinder and up the hollow chamber to the nozzles. This also helps to cool the exit gas.

The above mentioned air preheating is important, especially for engines that operate intermittently as in sawmilling operations.

As the engine idles, the air moves more slowly through the gen gas combustion area resulting in a smaller fire. When the engine throttle calls for more fuel the vacuum inside the engine is increased calling for a sudden change in air flow. This demand for increased fuel results in a quick surge of outside air into the hearth and occurs more rapidly than the fire's ability to respond. This rapid air change results in further, but temporary cooling. Cooling results in less complete conversion to gas, which in turn means an increase in tar production. This combination of reactions means that a greater amount of both water vapor and tar may reach the engine resulting in sticking piston rings, valves and push rods. This results in contaminating the engine oil with the associated problems of increased wearing of all moving surfaces and harder starting.

The combination of water vapor and tar tend to carry a higher percentage of very fine particles of ash. The water has a tendency to carry ash through the filters. Air preheat is important and everything practical should be done to retain uniform temperature in the hearth area, especially with intermittent engine operation.

A surge tank or some supplemental fuel will help overcome the rapid change of the flow of cold air through the hearth area (see drawing #10).

Ash Pit

The gen gas housing ash pit also allows passage of the gas between the housing and the hearth and also functions as a preheater for the incoming air tubes.

When installing the grate, allow some space below the grate for ash accumulation. This space should be large enough for a minimum of one day operations. Consideration should be given to shape in the ash chamber. The slower the air moves in this space the more ash is retained close to the point of burning. This reduces the amount of ash that moves with the gas and reduces the load on the filters and coolers. (See Page C Appendix)

Rapid cooling of hot gases in the lower part of the housing prevents CO from reforming into CO_2. On this unit the gas leaves the gas exit port at approximately 300° F, indicating a rapid gas temperature drop below the 1400° F level, below which CO_2 forms very slowly.

The shapes discussed above have all mentioned cylinders. Other shapes can be used but a circle is the most efficient design from the stand point of enclosed volume versus square feet of material used. Air flows are more uniform in circular containers than in other shapes but other shapes have been used successfully, especially for the housing. It would be best to use a circle for the inside diameter of the restricter ring. Nozzle extension into combustion area can be shortened or lengthened to circular shape to control the cone shape and volume of hot coals.

Welding rods should conform to heat requirements of the component members. (Use high temperature resistant material on the nozzles and hearth area, unless their shape allows them to be insulated by the fuel or the ash.)

The gen-gas housing may contain a lid in addition to the hearth, air tubes, ash pit and the gas exit port. A lid does not seem to improve the operation with sawdust fuel but may protect the unit from wind or rain.

If small pieces of wood are used as fuel, or in mobile vehicles an air tight lid is required. This prevents bypassing the air tubes, thus avoids changing of design criteria. Any lid should have a spring tension or weight tension factor in the event of flash back. Flash back is an explosion resulting from accumulated gases in a cold generator or could result from rapid shut down on the suction side of the generator. Flash back has not been a big problem, but like all safety devices it's better to be safe than sorry.

The fuel reserve needs to be designed for several hours of use. Too little sawdust and the hopper must be filled more often in a batch feed, too much causes excess compaction resulting in reduced air flow. This is not a serious problem with chunk fuel but compaction can be a problem, especially with wet sawdust or sawdust that contains a lot of fines from a sanding operation.

Cyclone Ash Remover

Located immediately after the housing is either a baffle type ash remover or a cyclone type ash separator (or both) (see drawing #3A and #3B). The ash remover should be as close to the housing as possible. Ash is removed most effectively before the gen-gas cools down to the dew point. The ash remover does act as a cooler, but this is a secondary function.

The unit discussed here does not have a water spray bath for ash and tar removal, but a well designed and maintained spray or counter flow water bath is the most effective way to remove foreign materials. The bath should be installed prior to the condensors and coolers that reduce the gas to final design temperatures (104°F). If the water bath is too close to the engine in the flow circuit, it will be impossible to cool the gas sufficiently below the dew point to remove excess water vapor. A small amount of water entering the engine as vapor does not interfere with engine operation. Too much water vapor will condense out on cold engine surfaces. This condensing out can be a problem both when starting up the engine and also while the engine is running. The problem is greater in periods of high humidity or very cold temperatures.

The major problems are that incoming air may be cooler than your gen-gas. The incoming air may also be high in relative humidity. When the cool air mixes, the gen-gas temperature may be reduced below the dew point. Any cold engine surfaces further reduce the temperature and water vapor becomes liquid with all of its associated problems.

The need to remove water vapor from the gen-gas cannot be over emphasized. Regardless of the operating temperature, gen-gas is always at 100% relative humidity, further cooling produces liquid water.

Another reason for cooling below 104^{o}F is that gas becomes denser on cooling, which has the beneficial effect of containing more energy per cubic foot. This gives greater power per revolution of the engine. With the engine possibly derated about 50% for gen-gas operation, additional loss of power is very detrimental.

Heating the gas mixture by 10^{o}C (18^{o}F) causes a power loss of 3%. Avoid severe flow resistance; a pressure drop of 100 mm (3.93 inches) of water or .148 pounds of pressure would cause a power loss of 1%. Small diameter pipes increase flow resistance.

<u>Cooler Condensor</u>

In the unit we are discussing, the next fixture is a square tube (see drawing #4 & #5) cooler condensor. Square tubes are not necessary but are convenient to work with. This cooler has 12 tubes, baffled to form an "S" shaped flow pattern of 4 tubes flowing on each level of the "S". Since the gas is cooling it is also condensing water, the water flows with the gas and drops out into the condensate tank. The condensate is drained periodically.
It would be beneficial to add at least four more horizontal tubes to the cooler condensor.

After the condensate tank we have a split flow pattern. One line to the starter fan, one line to the oil bath filter and then to the engine. These two lines can be closed off from each other by a set of manually operated valves.

Starting Fan

The starting fan (drawing #6) is an old upright type vacuum sweeper motor, connected to 110-120 volt electricity. Automobile heater fans have been used in other units, and operated from the storage battery. Suction fans perform better than pressurized systems. Leaks in a suction system may reduce combustion efficiency but a pressure system leak may force gas such as oxygen depleting CO_2, poisonous CO, or explosive hydrogen into the building.

Be certain to vent your starting fan high enough and in the right wind direction to prevent gen-gas from accumulating in buildings. The gen-gas building itself should be well ventilated, both top and bottom. Avoid wind drift to other buildings where gen gas may accumulate.

A small air cock just after the fan will allow testing the flame of the gas before attempting to start the engine. After the gas supports a good flame the engine will usually start on the gen gas. You probably should consider assistance using gasoline or propane for easier starting.

Oil Bath Filter

After the gas burns readily at the starting fan test cock, the gas is diverted to the oil bath filter (drawing #7). This is a standard truck filter. Any good oil bath filter of sufficient capacity should work. A horsepower match should be a convenient method of sizing. If the horsepower information is not available, air flow would need to be calculated.

Engine Condensate Drain

After the oil bath filter, the gas flows toward the engine. Just before or at the bottom of the final filter is a drain cock for condensate. This removes accumulated water at the final filter, reducing the amount of water vapor at the engine.

Surge Tank - Reserve Fuel

The surge tank (see drawing #8). is a tank large enough to hold enough gen gas to allow a fast engine speed recovery. Because of the distance between the gas generator and carburetor in this specific setup there will be a delay in gen gas reaching the engine. The surge tank on this system (approximately 3 gallons) has proven to be too small for this engine; correct sizing of the surge tank has not been determined.

From the surge tank the gen gas passes through a four inch diameter plastic pipe. This pipe is filled with removable and washable plastic dishwashing kitchen sponges. These sponges can be washed in diesel fuel and reused. There is also a valve on the bottom of the filter for condensate drainage. (see drawing #9). This is minimum filtering and needs to be improved.

Carburetor Manifold

The final fixture of the gen gas system is the carburetor manifold with two accessory carburetors, one propane and one gasoline (for air mixing only). The manifold also allows for a fresh air intake for blending with the gen gas. The carburetor gen gas manifold sets on top of the original truck motor carburetor. The truck motor is a 1954 international 450 cubic inch "R" series. The motor was chosen because of familiarity along with capability and durability. European experience indicates that slow speed long stroke engines perform better with gen gas than high RPM engines.

This engine has the capability of running on gen gas, gasoline and/or propane independently. The engine could operate on any combination of three fuels by proper manual mixing of fuels. There is no cross linkage of fuel systems, but there are manual controls convenient to the saw carriage for operator adjustment if additional power is needed.

This unit will not run at idle with only the small petrol (gasoline) carburetor (approximately 8 HP) on the square tube manifold. This small gasoline carburetor is designed only for starting. The propane carburetor serves the same starting function, but can keep the engine running at idle speed and is capable of running the engine at full power but in practice is used primarily as a power boost for peak loading of the saw.

Alcohol fuels could also be used through a small carburetor, or a super charger to gain additional horsepower. A super charger without supplemental fuel assistance would require a 70% increase in gen-gas consumption (Sw. GB).

One other way to overcome horsepower deficiency is to start with a larger engine that could supply the power needed, after the necessary derating with gen-gas. A tandem engine could also be used with belt drive pulleys.

Most U.S. equipment is greatly oversized, derating is therefore not as detrimental as most people would imagine.

Total avoidance of the use of gasoline would enable the engine to run on cleaner burning gen-gas thus avoiding spark plug deposits and oil contamination from the by-products of burning gasoline.

Propane does not have these oil polluting contaminants of gasoline but is more costly than gen-gas.

Engine Adjustments

The engine has not been altered except to advance the timing approximately four to five degrees before normal firing to compensate for the slower burn of the gen-gas.

Engine power could be improved by increasing the compression ratios in the cylinder. Compression ratios of 10 or 11:1 have been suggested. It would be advisable to contact the manufacturer before deciding on a final ratio.

In gen-gas operation a standard gasoline engine is derated to about 70% of its rated power. This reduction is probably due to different burning characteristics of gen-gas compared to gasoline. However, the engine will run on rather wide air/fuel mixture limits. Excess or deficit air mixtures will cause a further loss of power. Improperly cooled gas (above 104^{o}F) or an excessively high intake manifold temperature or a loss of suction pressure caused by restrictive pipes and elbows may cause further power losses, all of which could total up to as much as 50% power loss. With reasonable gasifier design and reasonable air/fuel ratios it seems logical that 60-65% of normal power can very likely be achieved without changing the compression ratio. In general, cooling the gas another 10^{o}F will improve the power because cooler gas gives an increased fuel charge in the cylinder and also helps to reduce condensate that occurs when cooler air enters the warm gen-gas stream. If the air stream is at the same temperature as the gen gas, liquid dropout (as condensate) should not be a problem.

The International Harvester Distributor recommends a low ash oil for gen gas use. Because of the potential for water contamination the emulsifying qualities of the crankcase oil should also be known. Some oils coagulate and form jelly when contaminated with fairly small amounts of water. If the crankcase oil turns to jelly the engine locks up in a very short time.

Motor oil impurities are of two main categories.

1. Mechanical - abrasion and/or chemical.
    a. Iron particles (burs, shavings, grindings, slivers).
    b. Rust (from chemical action).

2. Oil Thickening Agents

   a. Dust from air intake (silica, etc.).

   b. Dust originating in the fuel - such as silica, quartz, potash, phosphate, copper, zinc, carbon, mangaenze, etc.

Table 28 from the Swedish Gen-Gas Book points out the extent of the problem with dust and oil crankcase contamination.

Table 28. DUST CONTENT OF AIR

Air Contamination 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 gravel pits farm work with tractors, etc.	over 200

In the case of 200 mg dust per m^3 air, a car with a 2 liter (310 cu. in.) engine would, when driving 100 km (62 mi.) without an air cleaner, sucks in 26 gm of dust. Some of this contamination can find its way into the crankcase oil, causing oil thickening and subsequent wear. (Note, 26 gm = .9 oz. of dust)

Be alert that your oil problems when using gen-gas fuel may in reality be caused by poorly maintained air intake filters. A sawmill is a very dusty place, and qualifies as about equal to highways and gravel pits.

Saw Dust Drying

This particular unit uses predried sawdust (see drawing #11), which is dried by use of a pull type four inch auger. The auger pulls fresh green sawdust through a six inch tube mounted inside of an eight inch tube. The eight inch tube is divided into two sections by the use of metal spacer. Hot exhaust gas from the engine enters the bottom level - flows horizontally some 14 to 16 feet, rises into the upper chamber, reverses direction for 14 to 16 feet until it passes outside through a four inch truck exhaust tail pipe. The auger is set at 10 to 15 RPM. This speed is for continuous sawing. The auger speed was set by trial and error and should be easily adjustable. The drying tube induces fresh air (see drawing #11 and #12) through an attachment on top of the eight inch pipe. The air flows through and around the sawdust and is exhausted from the opposite end of the drying tube by an exit port through the fan. This fan removes moisture vapor as it accumulates, greatly improving the drying efficiency. A small fan is adequate else too much sawdust is blown out of the tube. Caution should be exercised to clear the sawdust in the tube else it will burn from the latent heat in the tube. Drying does improve combustion efficiency. The gasifier runs best with 19 to 20% moisture in the fuel.

Older smaller gen-gas models (prior to this unit) were run successfully on fresh green oak and other hardwood sawdust. Because of improper filtering, several valve push rod changes were necessary. Toward the latter stages of operation, engines were successfully run on fresh green sawdust without valve problems. This was after several redesigns of the condensor and filter system. Filtering is the most critical part of gen-gas operations.

Energy Balance of Wet Sawdust

Air dry, or drier sawdust will improve the gen-gas combustion efficiency. Every pound of water converted to vapor (assume 70^0 outside air temperature and 70^0 sawdust temperature) requires 1,112 BTU's of energy. To drive all the moisture out of six pounds of fresh green wood (use above temperature) that contained 50% of moisture, would require 3,336 BTU's. One horsepower for one hour requires 2,545 BTU's with no loss for efficiency. Another way to state this is that it requires 1.3 horsepower to completely dry six pounds of 50% moisture wood. The energy required to dry the wood in the gasifier is lost. However, waste heat from the engine exhaust can be recovered to partially dry the wood fuel as previously discussed.

In the future we anticipate that all fuels will be sold on a BTU basis, perhaps including wood residue. To show the effect of drying the sawdust prior to gasification, consider that green oak has a moisture content of 50% and a BTU value of 4,300 BTU/lb. If the wood is dried to 25% moisture at no cost using exhaust gas waste heat recovery, the heat value is now 6450 BTU/lb., a 150% increase. If sawdust is priced at $10/ton, then:

$$\frac{\$10/T \times 1{,}000{,}000}{2000\#/T \times 4300\ BTU/\#} = \$1.16/mmBTU \quad (mm = \text{one million})$$

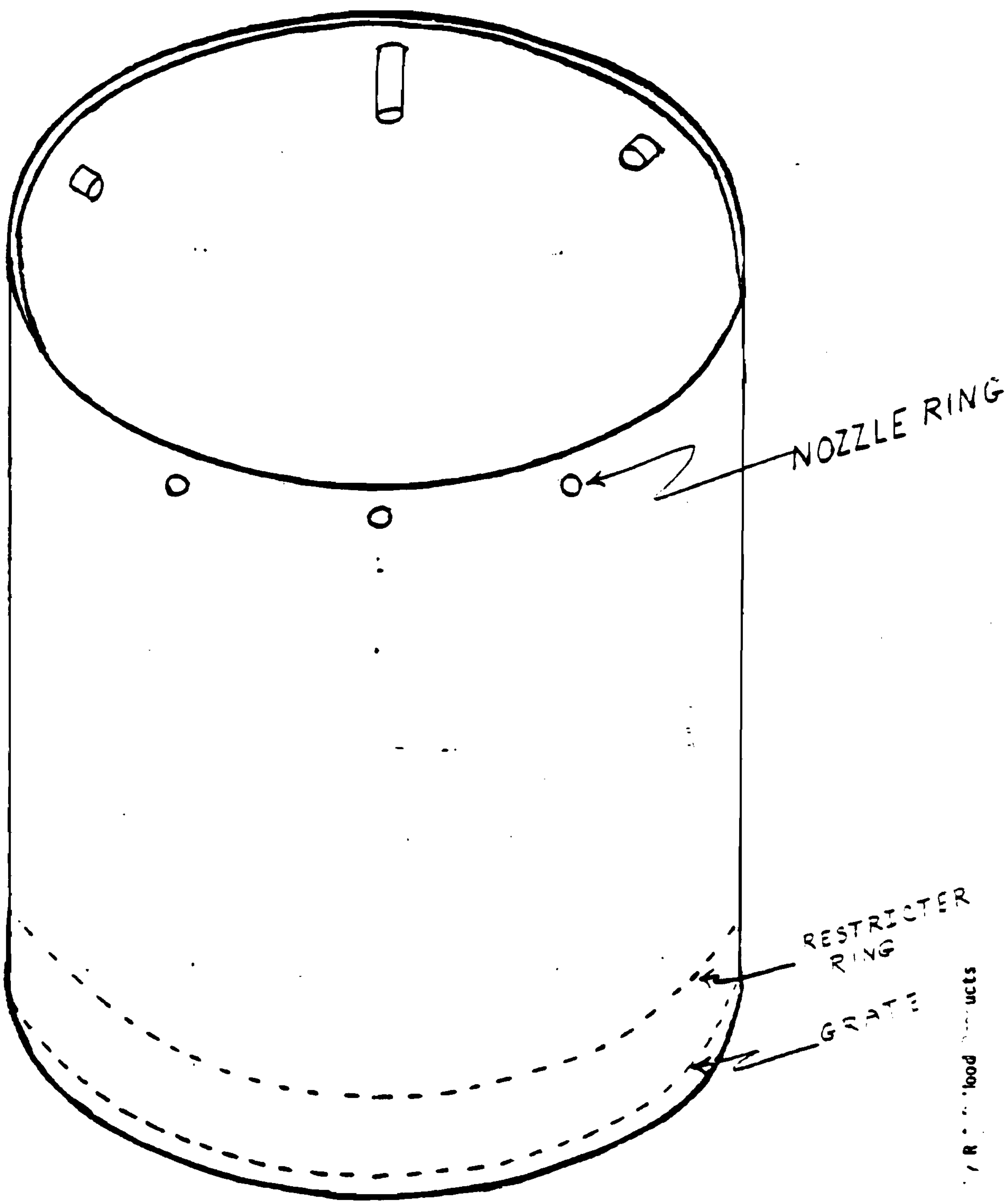
If the sawdust is dried to 25% moisture at no cost:

$$\frac{\$10/T \times 1{,}000{,}000}{2000\#/T \times 6450\ BTU/\#} = \$0.775/mmBTU$$

As you can see, the cost of energy has been reduced by 1/3 by using heat that usually is wasted. Also note that these prices compare with $5.00/mmBTU for natural gas (at 50¢/therm). Further, if your cost is other than $10/ton, simply put that value in the preceeding equasions to calculate your saving.

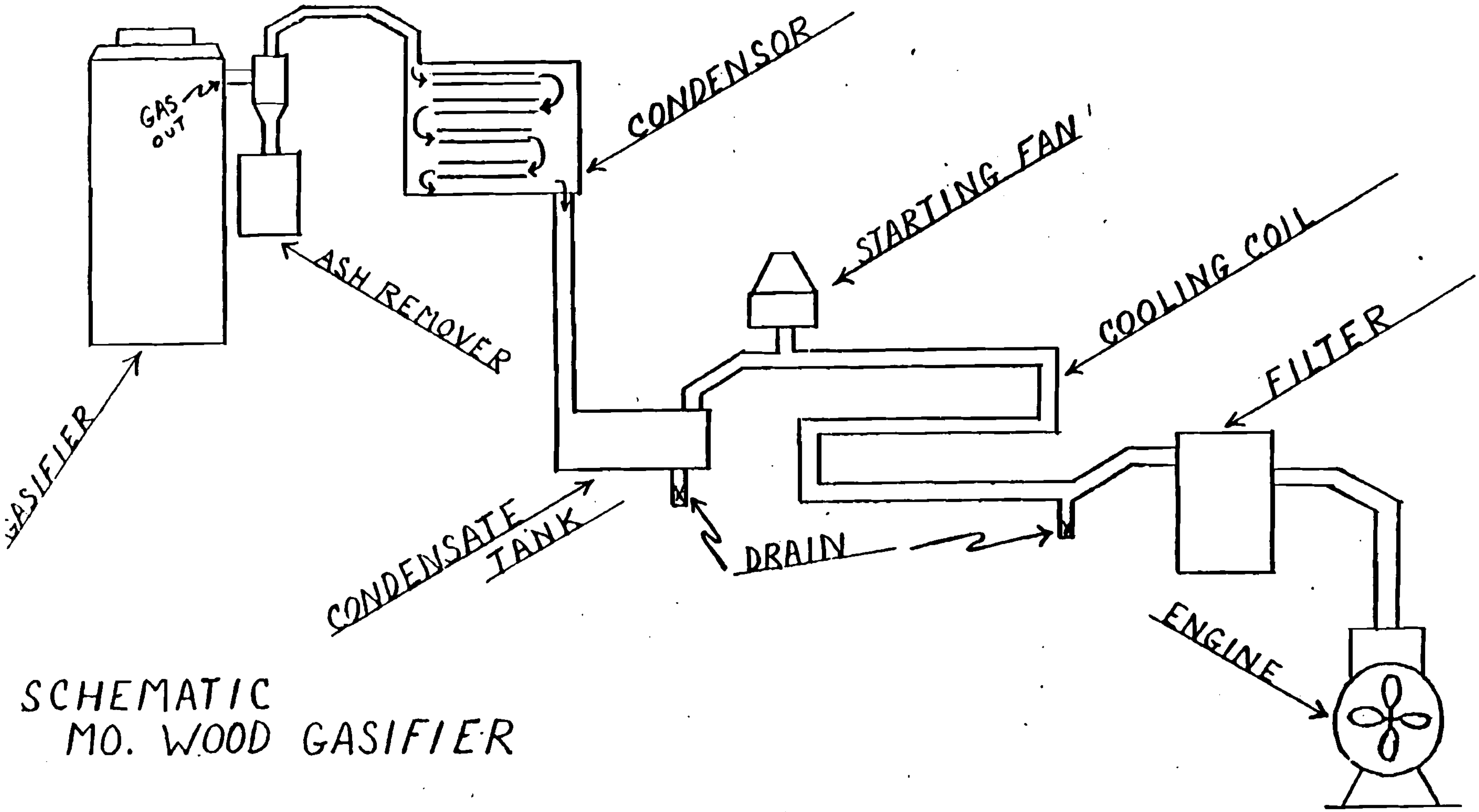
Stand-By Electricity

Plans have been made by the operator for a stand-by electric generator that can be operated from the gen-gas unit. This is intended to produce electricity for storage when the engine is idling between saw cuts. Details on hook up have not been completed at this date.



HEARTH: 18" HIGH, 16" DIA., MADE OF $\frac{3}{16}$" STOCK

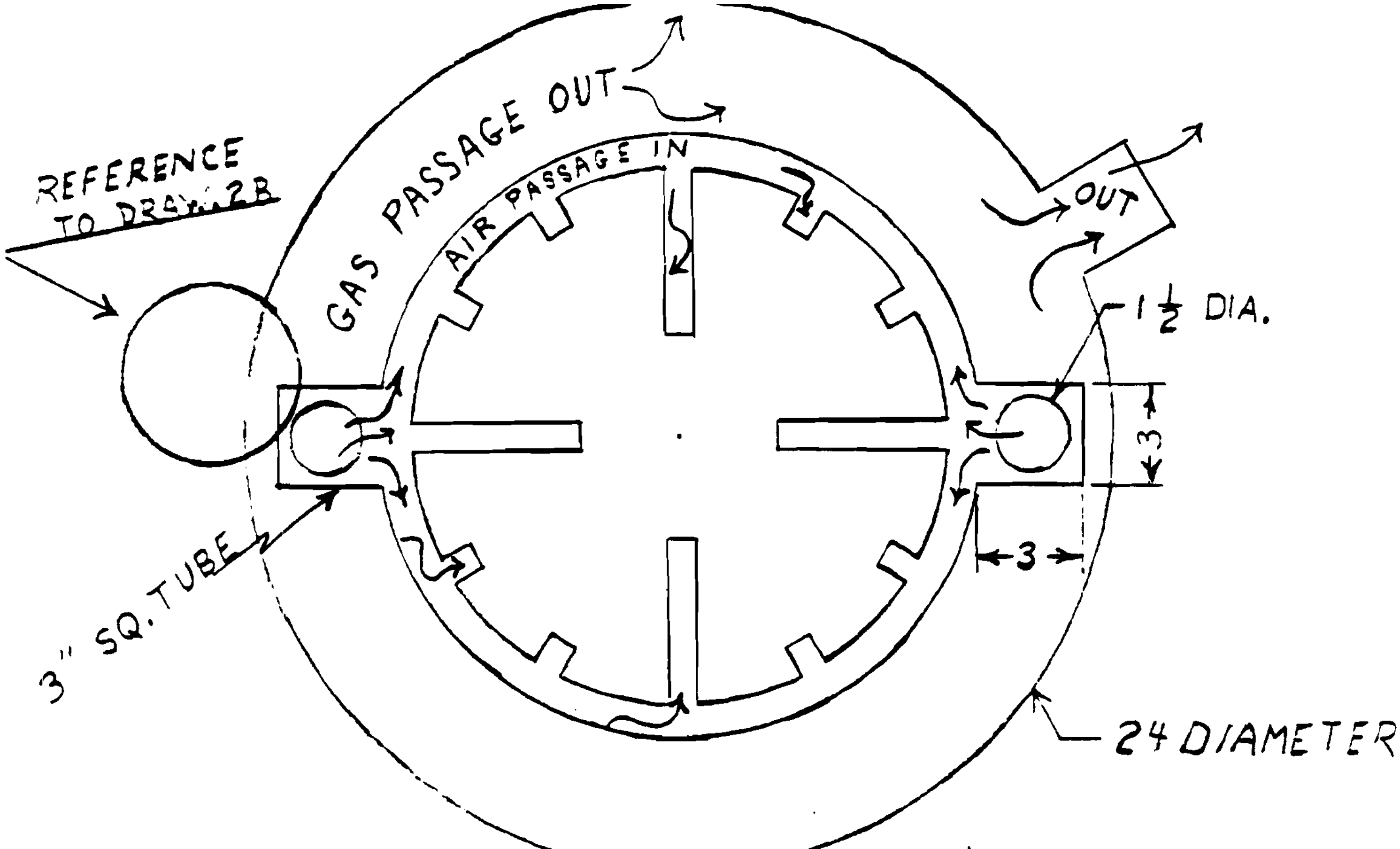
#1



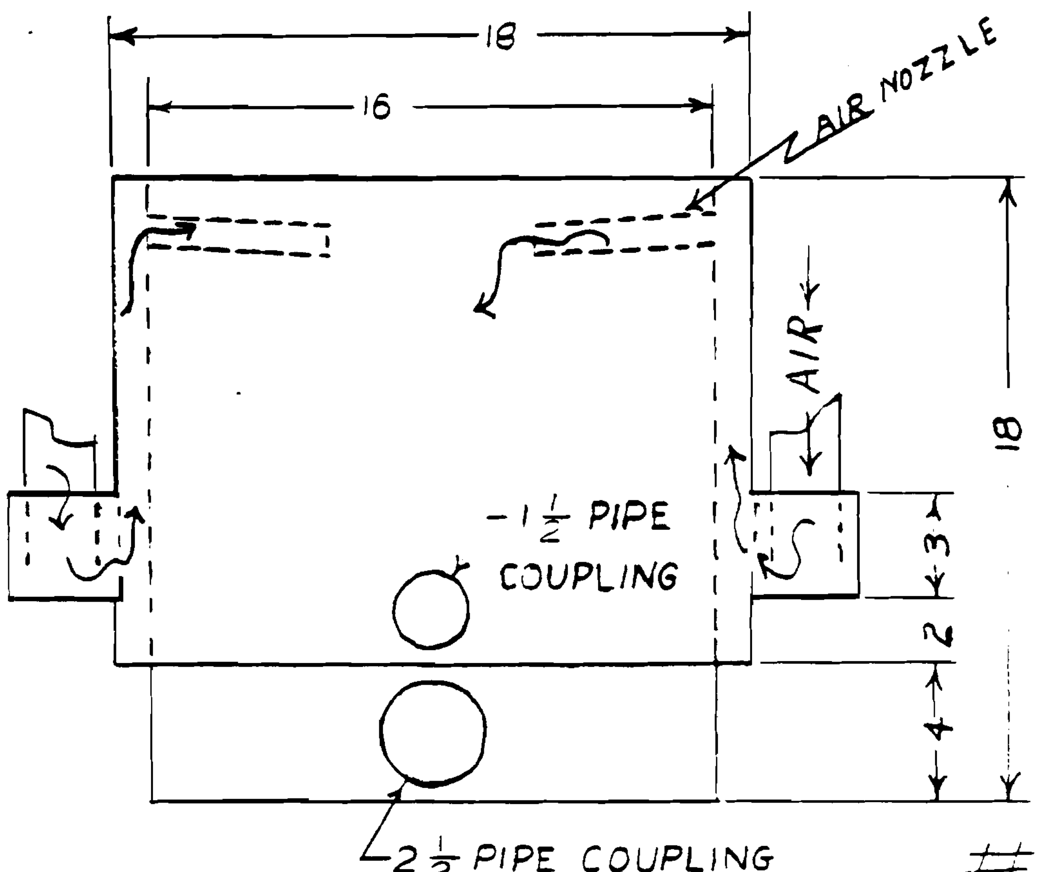
SCHEMATIC
MO. WOOD GASIFIER

Patent Pending by R & R Wood Products

California, Missouri

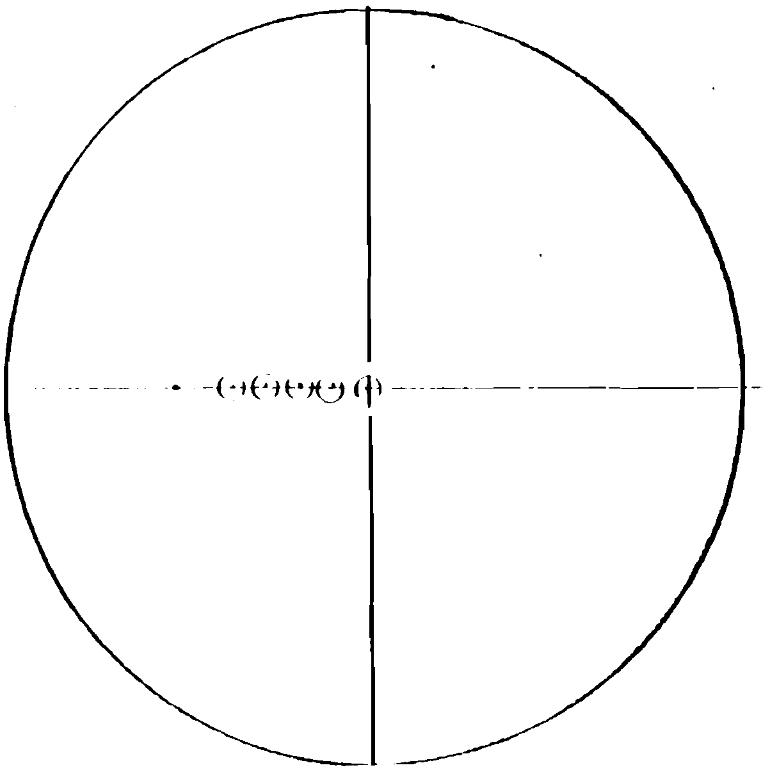


NOTE: AIR NOZZLES 1/2 I.D. STAINLESS PIPE
4 EA. 5 IN. LONG, 8 EA. 1 IN. LONG

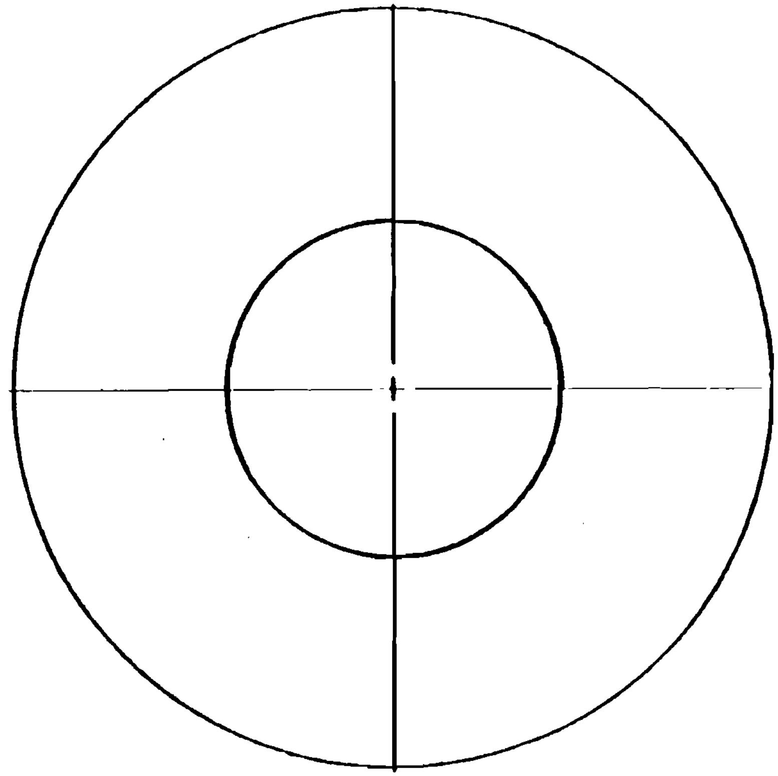


Patent Pending by R & R Wood Products
California, Missouri

#1B



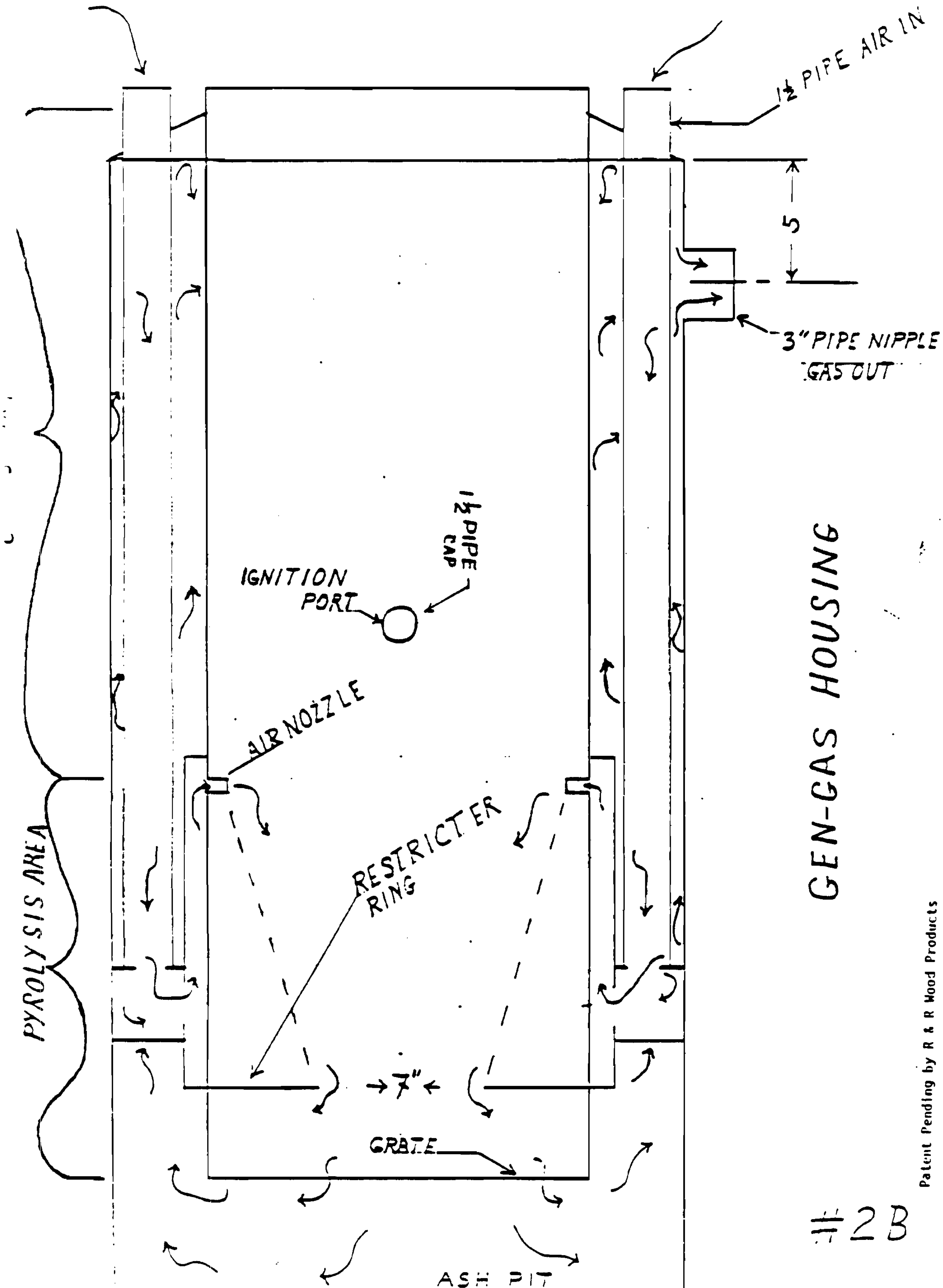
GRATE: 16" DIA. $\frac{3}{16}$" THICK, $\frac{1}{2}$" DIA. HOLES
3/4" ON CENTER



RESTRICTER: 16" DIA., 7" DIA. HOLE

Patent Pending by R & R Wood Products
California, Missouri

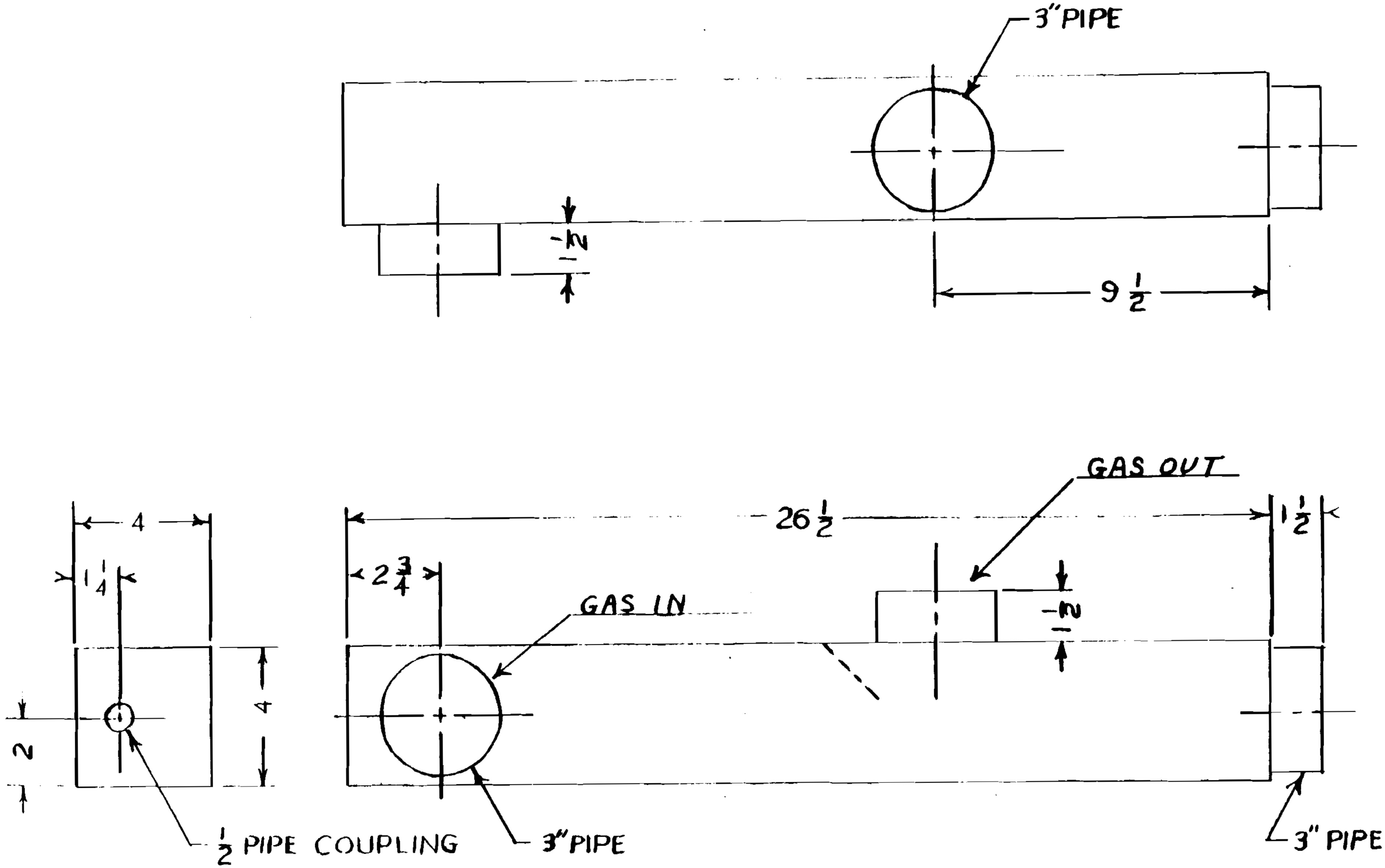
#1A



GEN-GAS HOUSING

Patent Pending by R & R Wood Products
California, Missouri

#2B

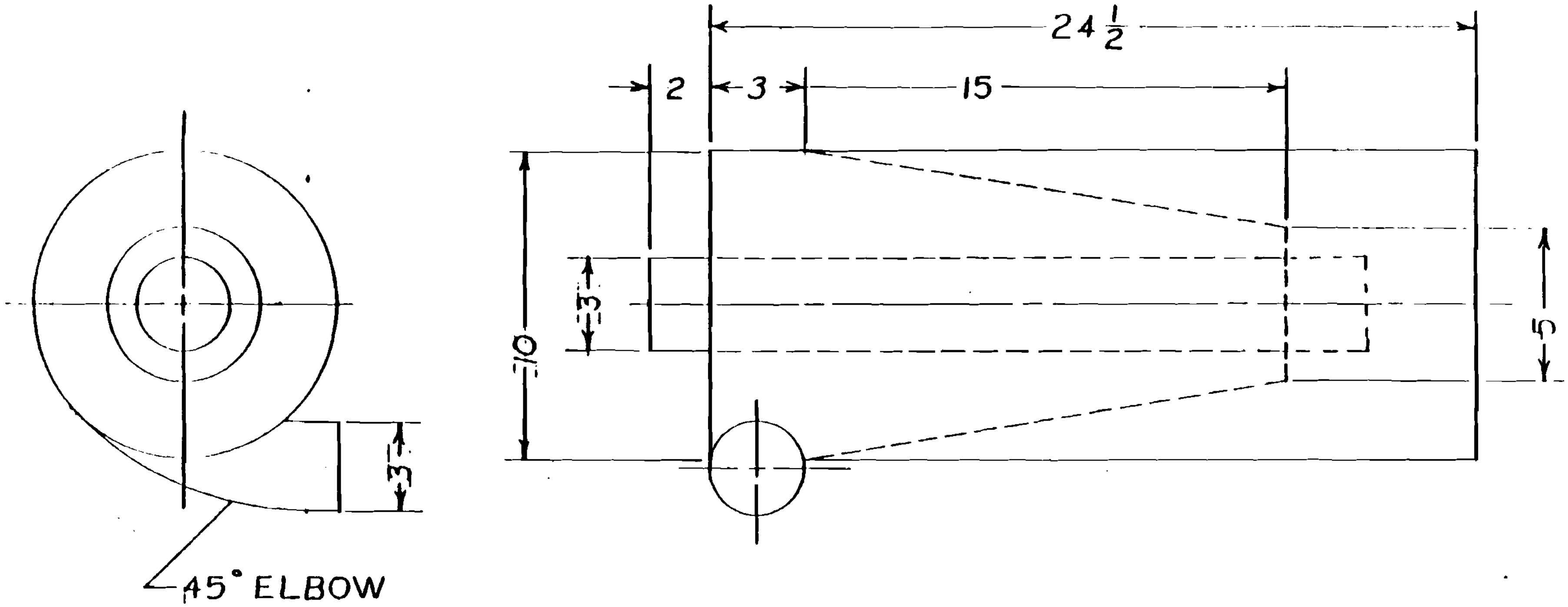


DRY ASH REMOVER

#3A

Patent Pending by R & R Wood Products

California, Missouri

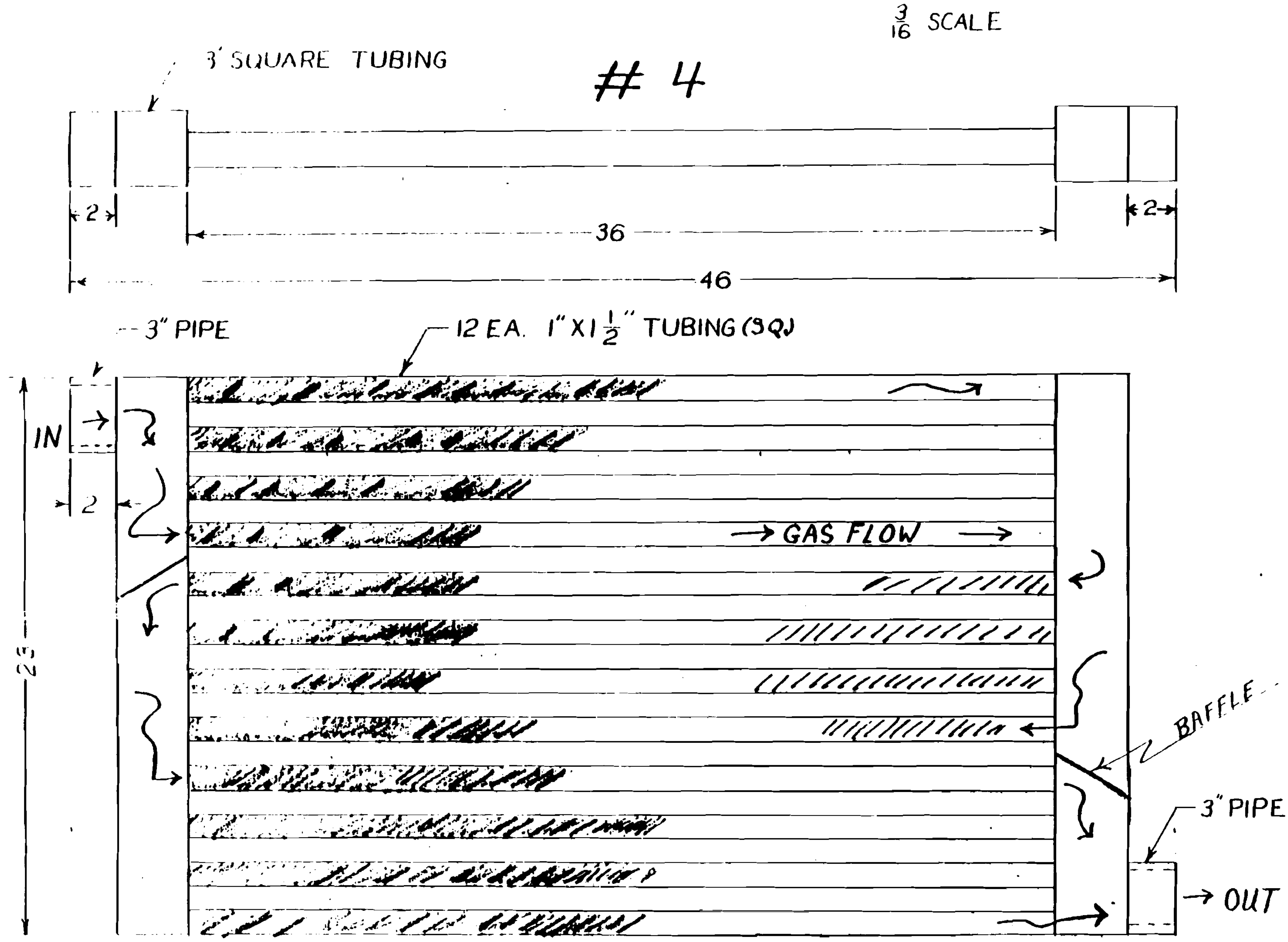


#3B

CYCLONE FILTER

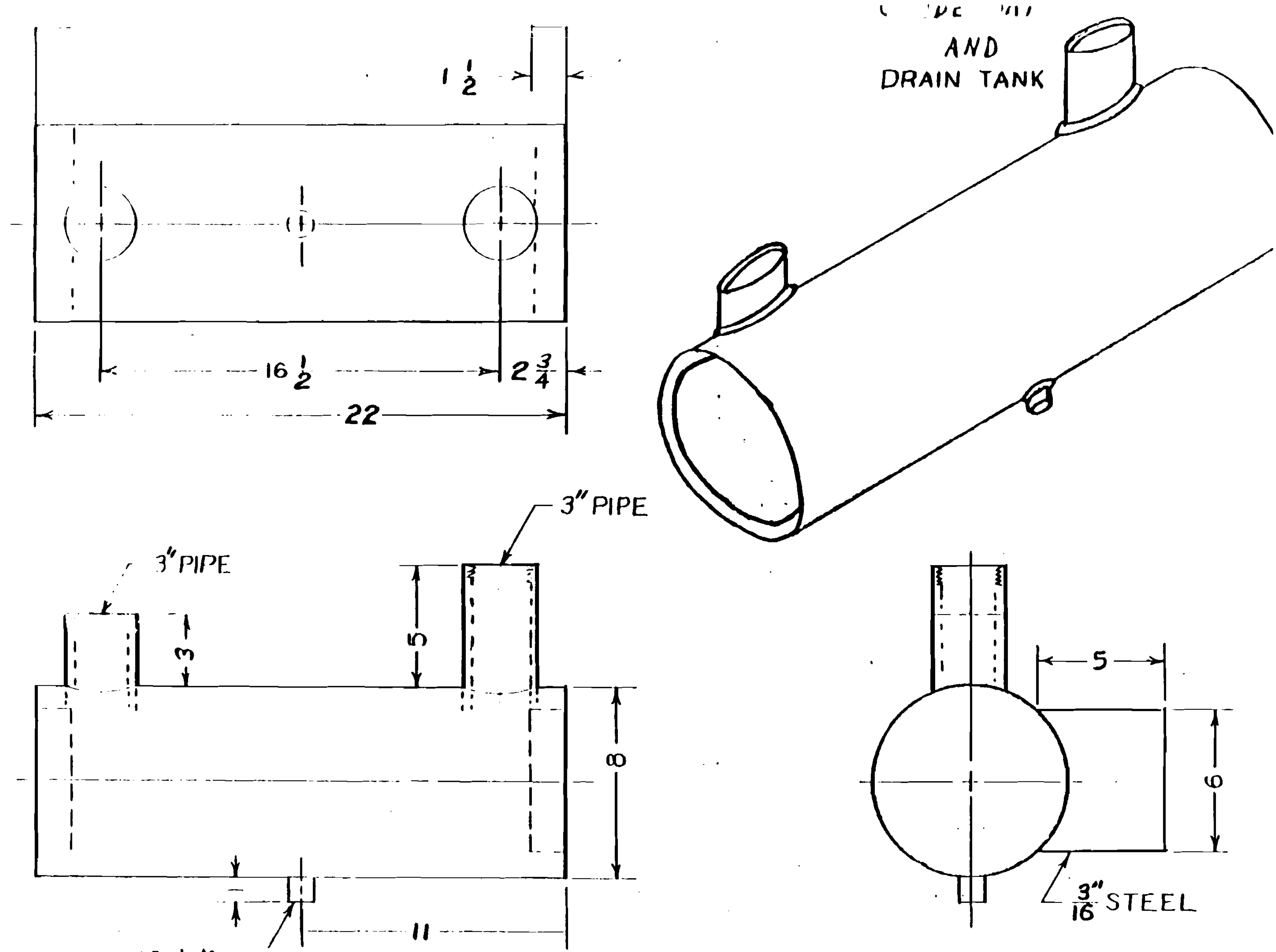
3/16 SCALE

Patent Pending by R & R Wood Products
California, Missouri



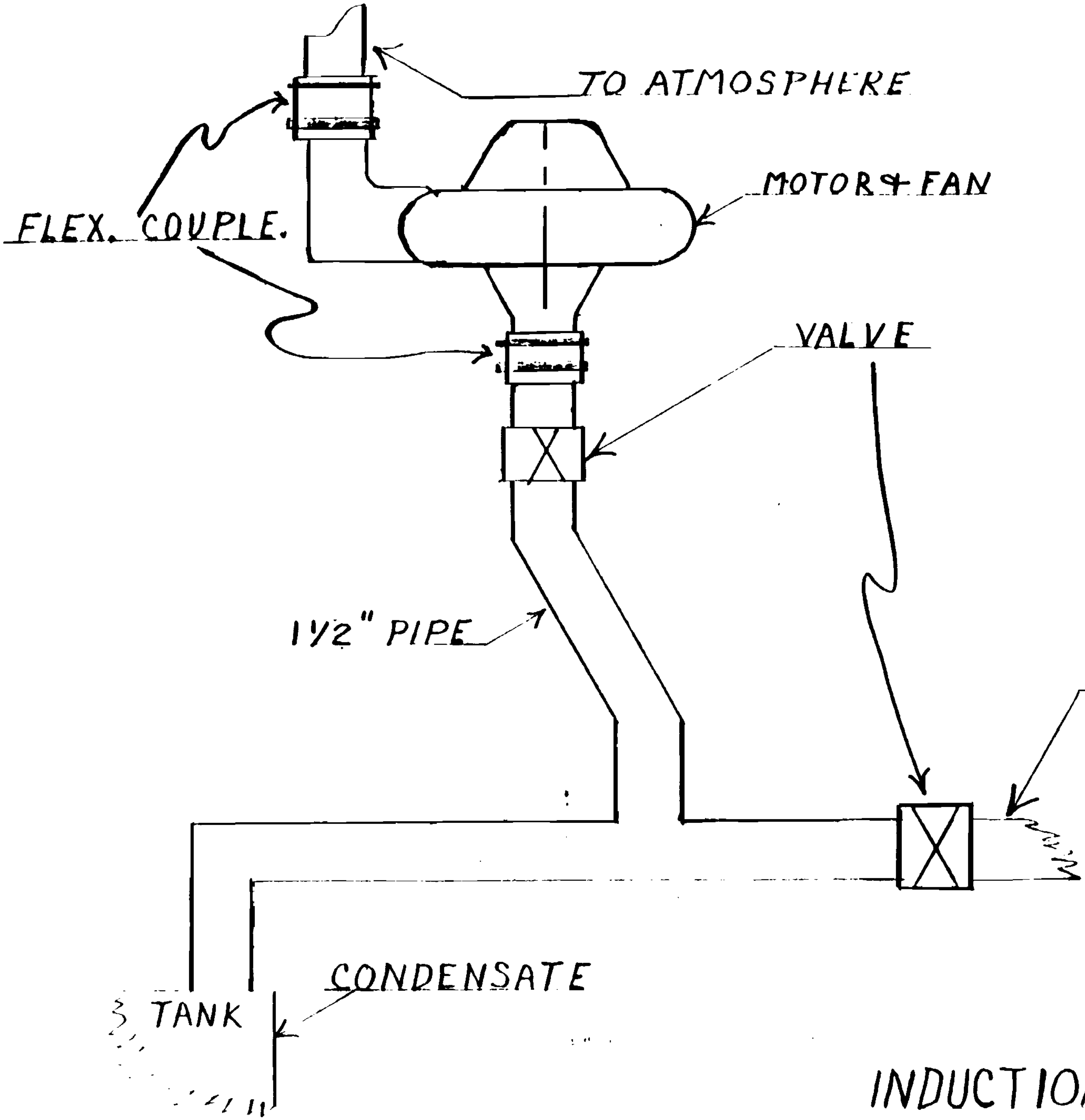
Patent Pending by R & R Wood Products

California, Missouri



#5

Patent Pending by K & R Wood Products
California, Missouri

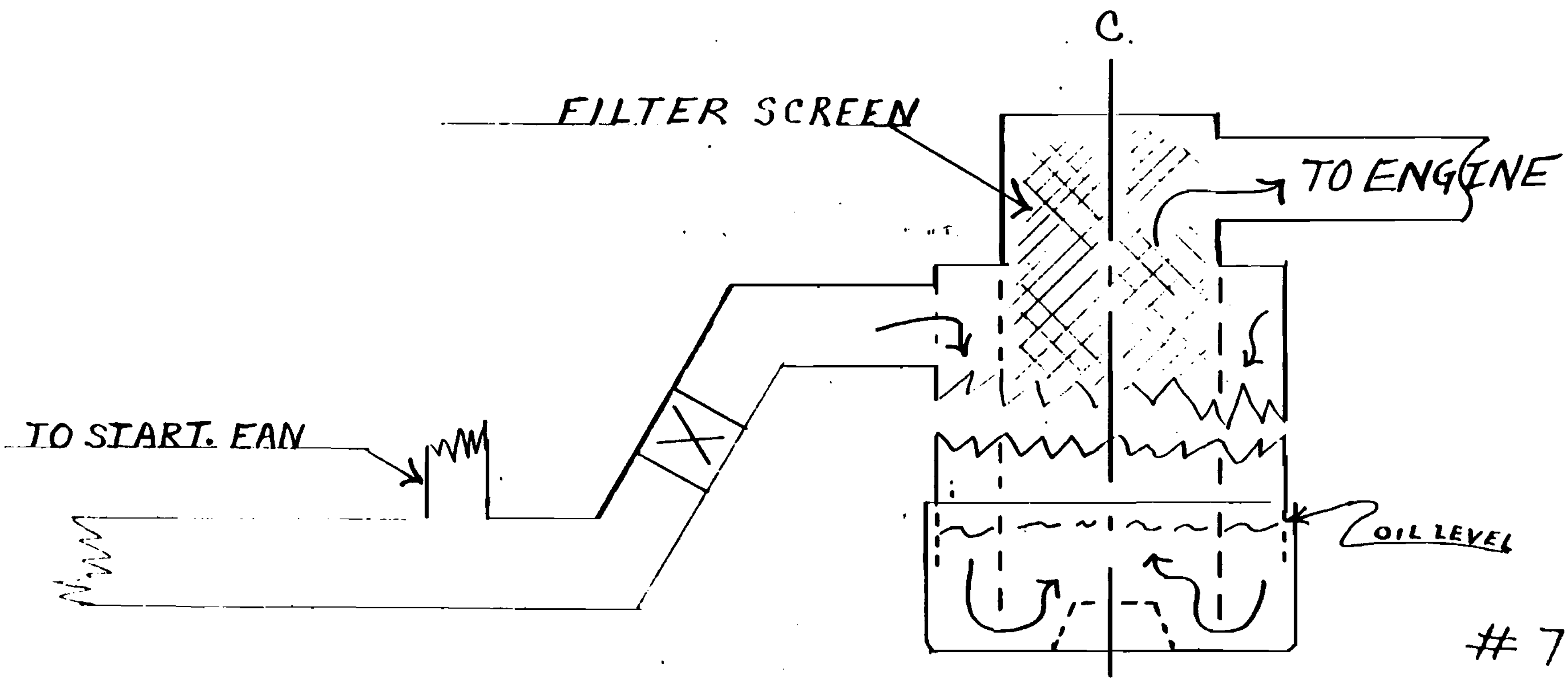


#6

INDUCTION STARTING FAN
NOT TO SCALE

Patent Pending by R & R Wood Products

California, Missouri

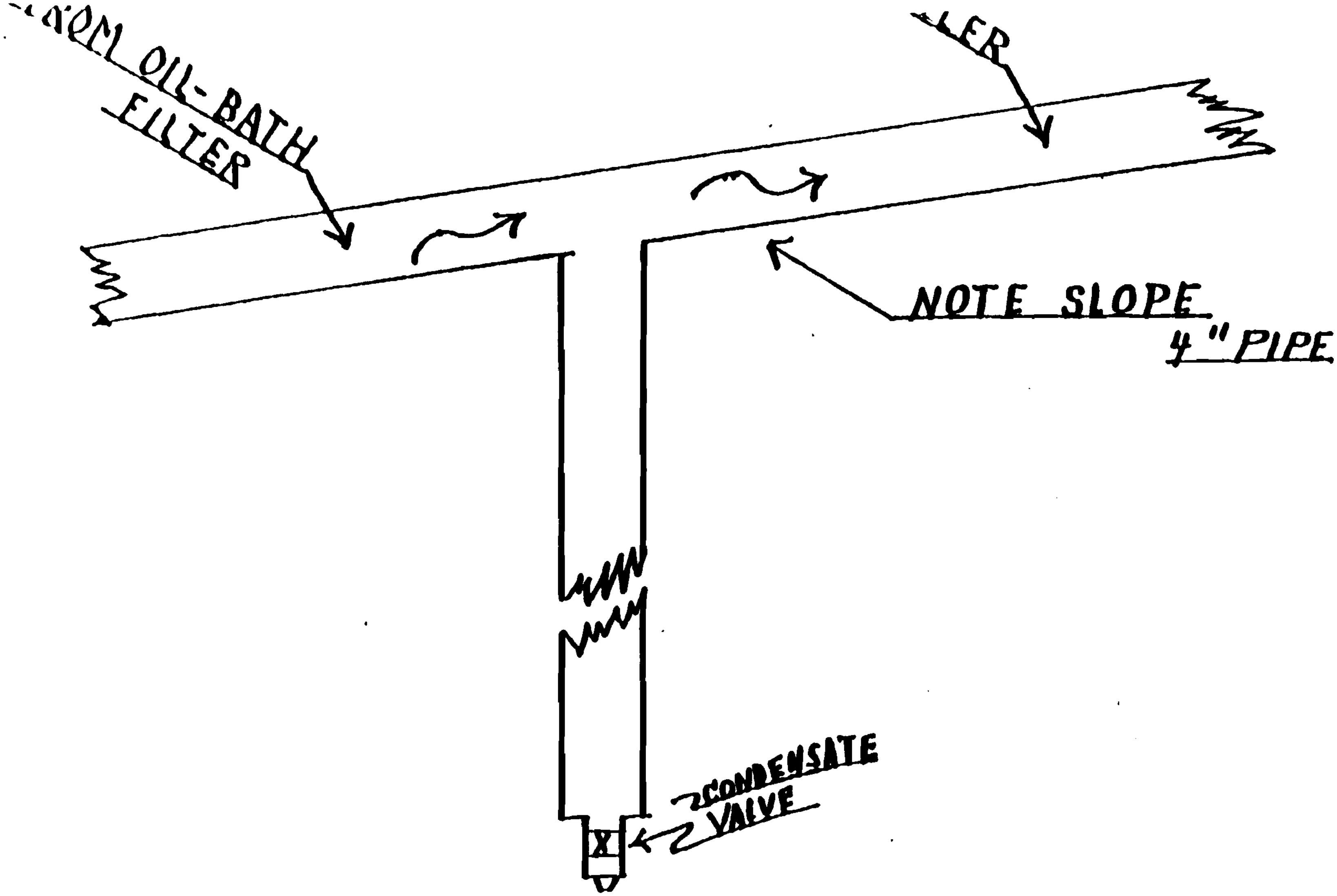


7

OIL-BATH AIR FILTER

Patent Pending by R & R Wood Products

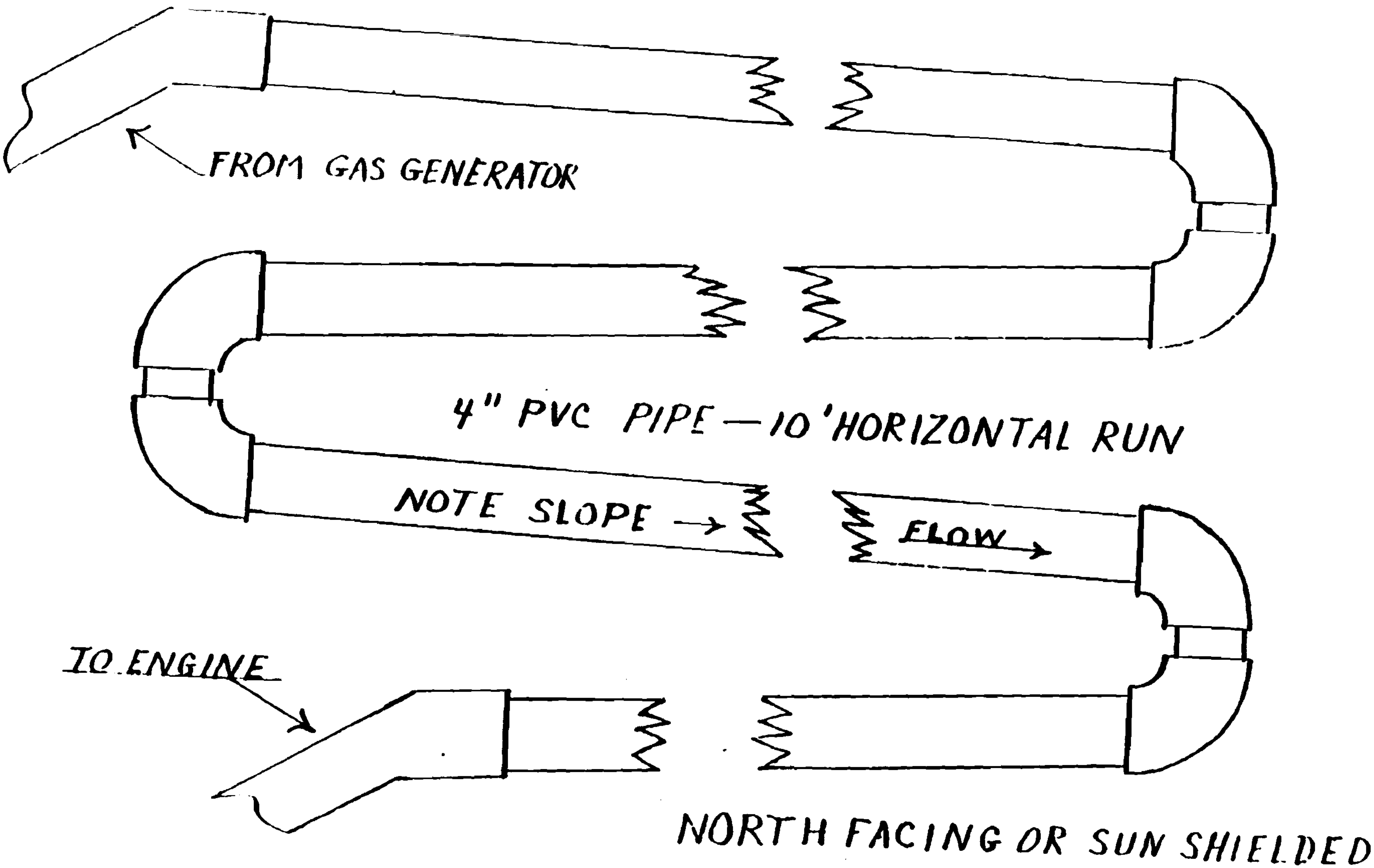
California, Missouri



#8

OUTSIDE COOLER
CONDENSATE DRAIN

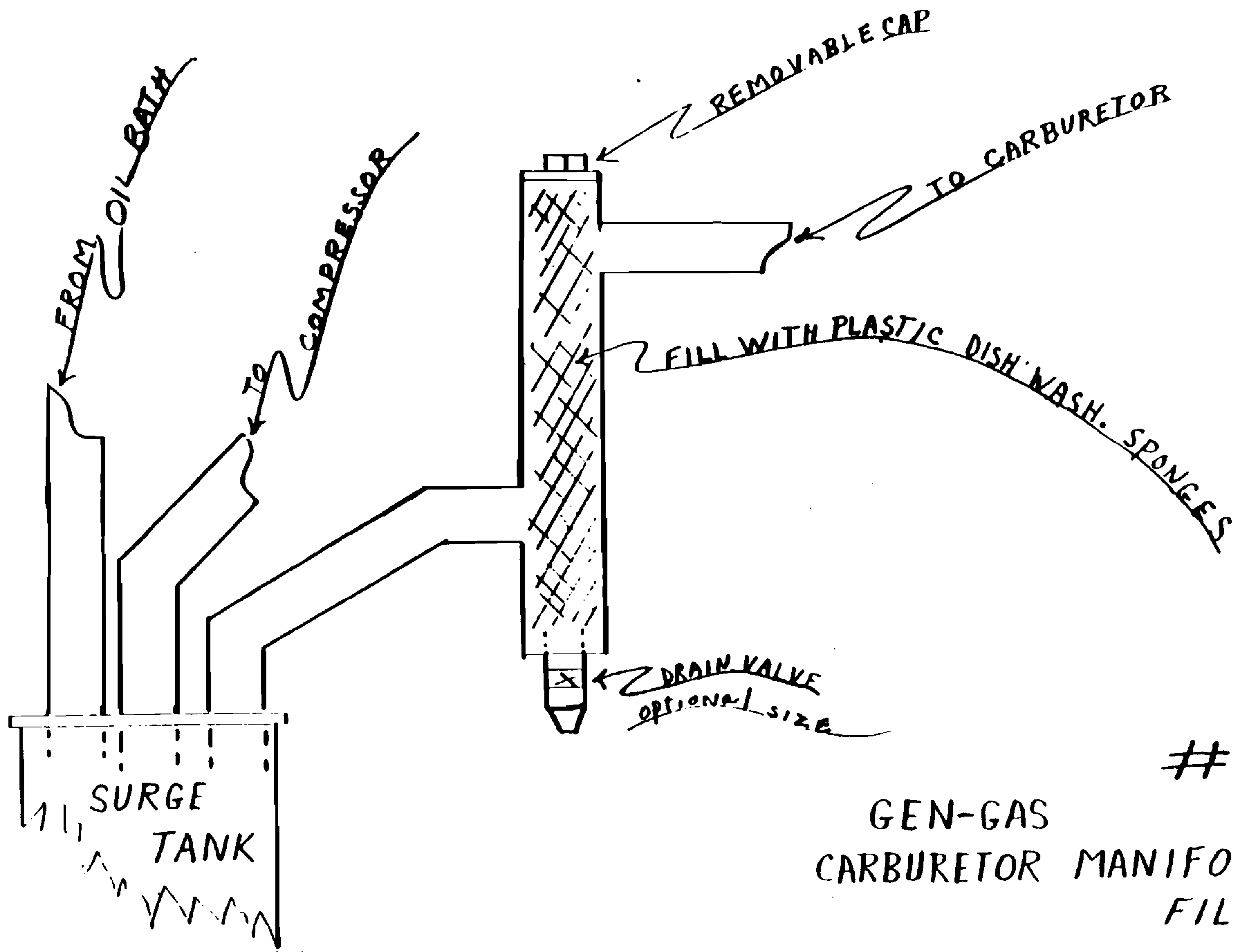
Patent Pending by R & R Wood Products
California, Missouri



9
OUTSIDE COOLER
1/8 = 1"

Patent Pending by R & R Wood Products
California, Missouri

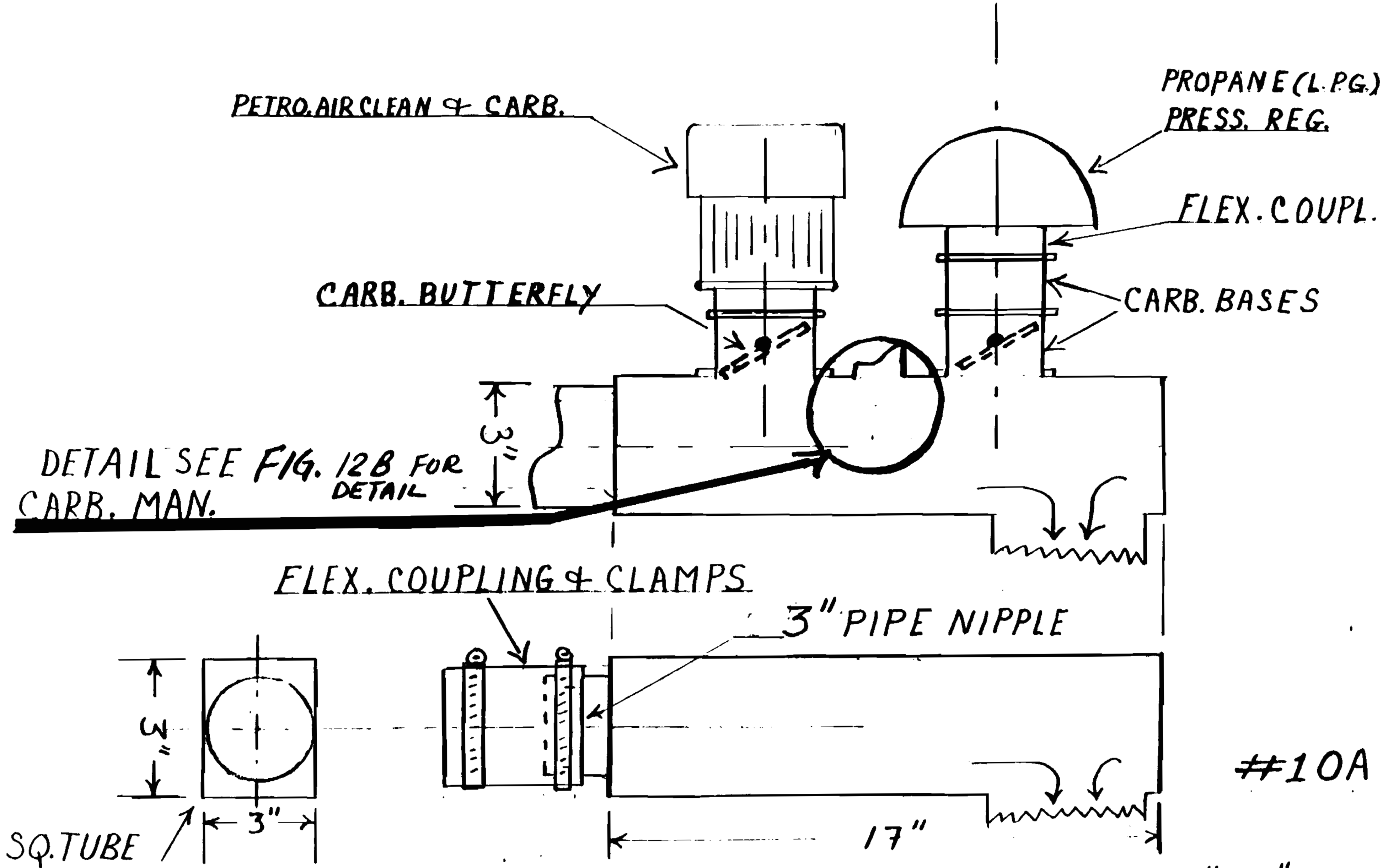
ALL PIPE 4" DIA



9

GEN-GAS
CARBURETOR MANIFOLD
FILTER

Patent Pending by R & R Wood Products

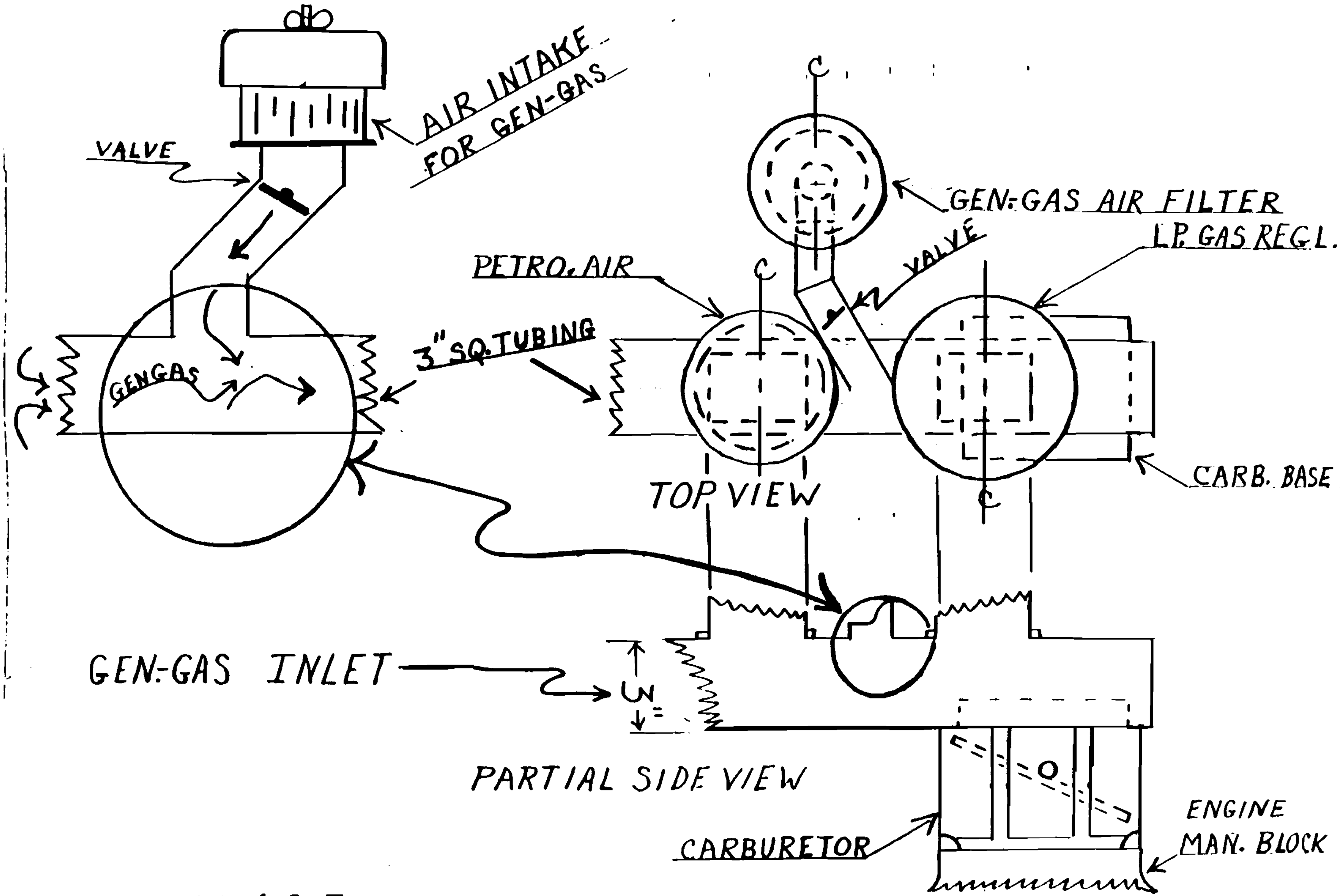


#10A

1/4" = 1" ≈

CARBURETOR MANIFOLD #1

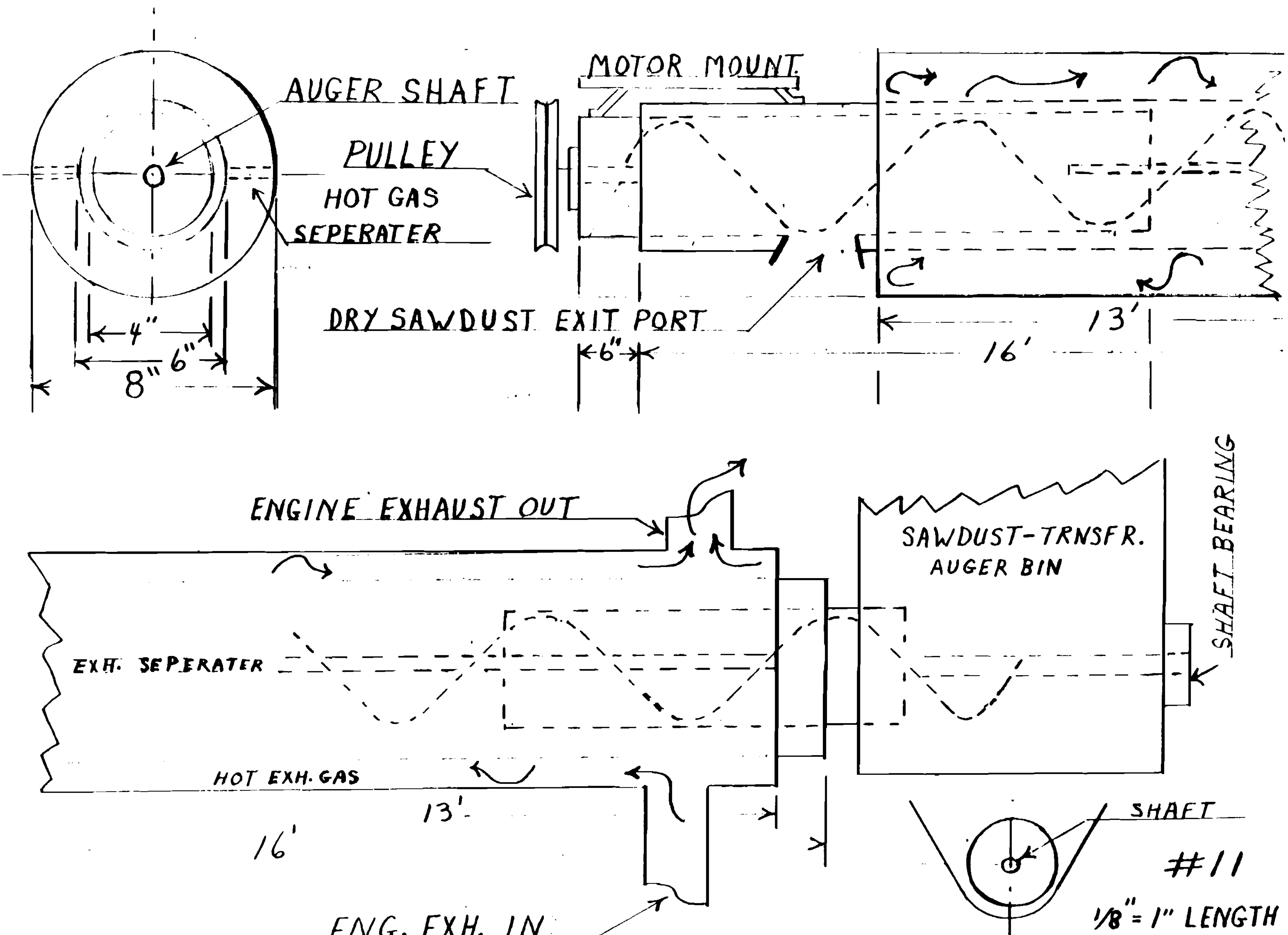
Patent Pending by R & R Wood Products



#10 B

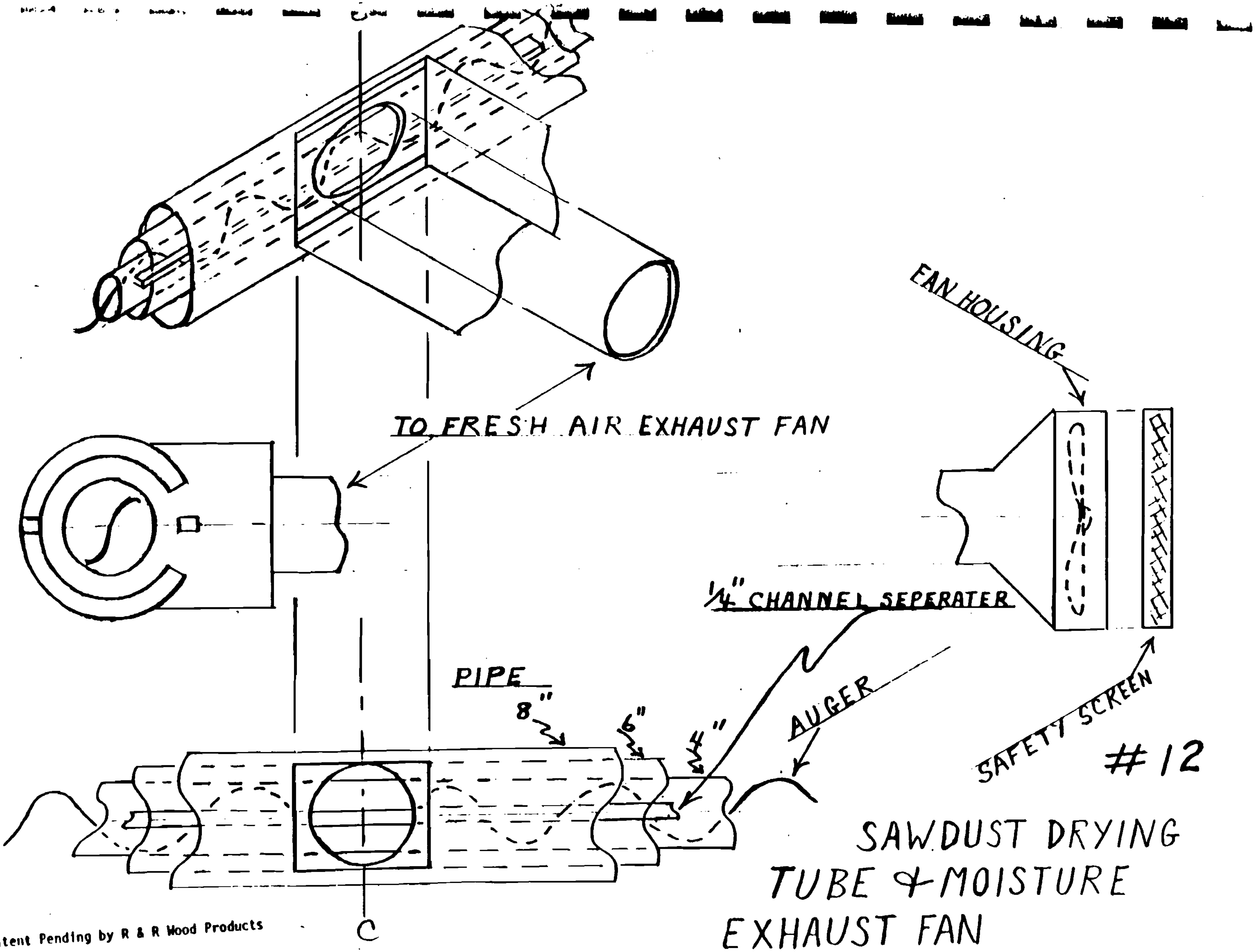
Patent Pending by R & R Wood Products

#2 VIEW CARBURETOR MANIFOLD



HEAT EXCHANGER-DRYING TUBE 1/4" = 1" DIA.

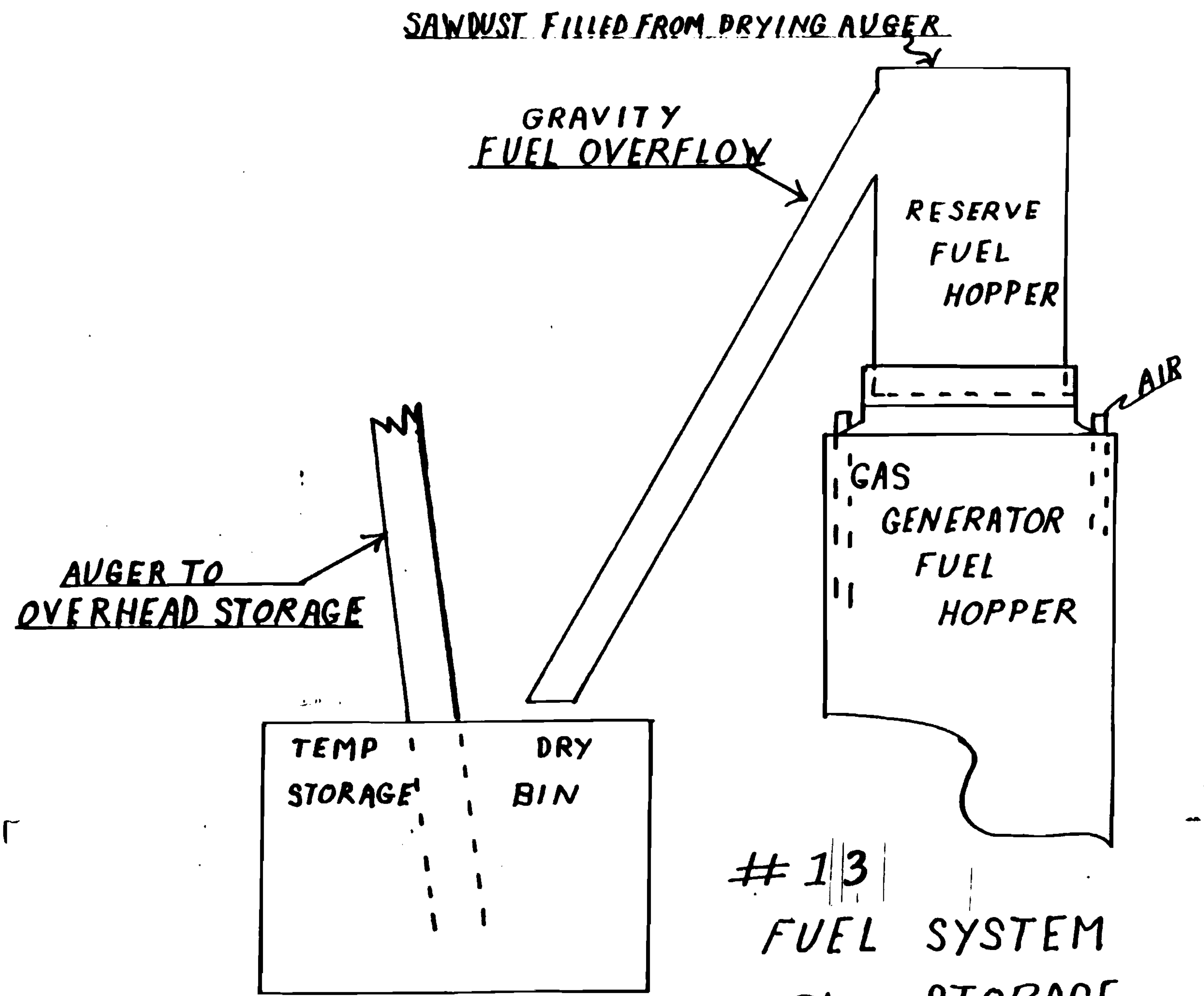
Patent Pending by R & R Wood Products



#12

SAWDUST DRYING TUBE & MOISTURE EXHAUST FAN

Patent Pending by R & R Wood Products



#13 FUEL SYSTEM + STORAGE OVERFLOW

Patent Pending by R & R Wood Products

DEPARTMENT OF NATURAL RESOURCES

ENERGY NOTE

The following printed material, pp. 116 thru 129 and noted as Chapter 5; "Cooling and Cleaning of Generator Gas" is reprinted from a book entitled "Generator Gas - The Swedish Experience from 1939 to 1945." (See also pp. 165 thru 170)

This publication was translated by Solar Energy Research Institute, 1536 Cole Boulevard, Golden, Colorado 80401. Copies can be obtained from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

In this section, the mathematics are based on metric units. The following conversion factors can be used to convert to conventional units.

CONVERSIONS FOR READING THE SWEDISH GEN-GAS BOOK

(We suggest you buy a metric conversion table for reference)

1 BTU = amount of heat necessary to raise temperature of one lb. of water $1^{o}F$

1 KW = 3,413 BTU

1 HP = 2,545 BTU

$1^{o}C = 1.8^{o}F + 32$

Example $(60^{o}C \times 1.8) + 32 = 140^{o}F$

1 cubic ft. water = 7.481 gallons = 62.47 lbs.

1 cubic ft. = 1,728 cubic in.

= .0283 cubic meters (m^3)

1 M^3 = 35.31467 cu. ft. = 61,023.75 cu. in.

1 L (liter) = 1,000 ml (milliliters) = 1.0567 qt.

1 qt. = .94635 L = 946.35 ml = 32 fl. oz.

1 cu. in. = 16.387 cc

1 cc = .06102 cu. in.

1 mile = 5,280 ft. = 1.6093 Km (kilometer)

1 Km = 3,280.9 ft. = .62 miles = 1,000 M (meters)

1 M = 100 cm (centimeter) = 3.28 feet = 39.37 in. = 1.0936 yards

1 ft. = 30.48 cm = 304.8 mm (millimeter)

1 inch = 25.4 mm = 2.54 cm

1 mph = 5,280 feet per hr. = 88 ft. per min. = 1.4666 ft. per second = .447 meters per second

1 Kmph = 3,280 ft. per hour = 54.666 ft. per min. = .911 ft. per second

1 meter per second = 196.8 ft. per min. = 11,808 ft. per hour. = 2.236 mph

1 lb. = 16 oz. = 453.592 g (gram)

1 kg (kilogram) = 2.2046 lbs. = 1,000 g = 35.27396 oz.

1 g = .035274 ounces

1 oz. = 28.349 g

Note: Unit cc is being discouraged as a liquid measure, ml (milliliter) is preferred under rules of the new S.I. (Systems International). Liter (L) is to used only for liquid measurement since one liter of water weighs one kg at norm conditions.

THE HAZARDS OF GENERATOR GAS OPERATION - GAS POISONING

These are essentially three hazards connected with gen-gas: 1) fire 2) traffic and (3) toxic hazards.

The fire hazard arises by discarding hot ashes or locating hot pipes too close to combustible materials. In vehicle gas generators involved in collisions that cause overturns, the gen-gas unit frequently dumps open flame onto the accident scene. Rear end collisions often pop the safety lid and hot ashes are forced out of the fuel hopper. This is especially bad if one of the autos spill gasoline from the force of the accident.

The toxic hazard is primarily carbon monoxide poisoning. Carbon monoxide is odorless and colorless and cannot easily be detected. Acute poisoning symptoms of CO are reasonably easy to diagnose. Chronic toxicity on the other hand can occur over long periods of exposure at low concentrations thus masking the symptoms and therefore can be overlooked or improperly diagnosed. Only a short exposure in an environment containing a few hundredths of a percent by volume is enough to cause acute poisoning. Acute carbon monoxide poisoning can occur at concentrations above 0.05% (500 parts per million). At this level and above, unconciousness results, death may be immediate and the poisoning effect is comparable to an acute brain hemorage or an acute heart attack. Statistics indicate that auto mechanics and chauffers were frequently victims of carbon monoxide poisoning. This also leads to greater incidence of traffic accidents because of reduced reaction time and drowsiness.

Because of reduced engine power there is also a greater tendency to keep the vehicle rolling when approaching a stop sign. Reduced power also increases the time it takes to pass other vehicles.

Exhaust gases from a gasoline engine may contain 6% to 7% carbon monoxide and it is well known that these fumes can cause sickness and death. Generator gas (gen-gas) contains over 20% carbon monoxide. It should be obvious that gen-gas is a greater hazard than gasoline engine exhaust. Only a small gen-gas leak in an unventilated space can cause a severe problem.

People having respiratory problems or heart conditions are more susceptible to carbon monoxide poisoning, however no one is immune. The greater the physical activity and the faster the breathing, the greater the problem with absorption of carbon monoxide into the blood stream, which then blocks the ability of the blood to transport oxygen. This is shown in figure 264 from the Swedish Gen-Gas Book Section.

Pages 305 through 314 are taken from "Generator Gas The Swedish Experience from 1939-1945". These pages give greater detail of carbon monoxide poisoning problems associated with generator gas operations. (See Swedish Gen-Gas Book Section)

Anyone involved with gen-gas would be well advised to READ THESE PAGES (305 thru 314) and become familiar with problems and the attempted solutions.

SWEDISH GEN-GAS BOOK SECTION

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.

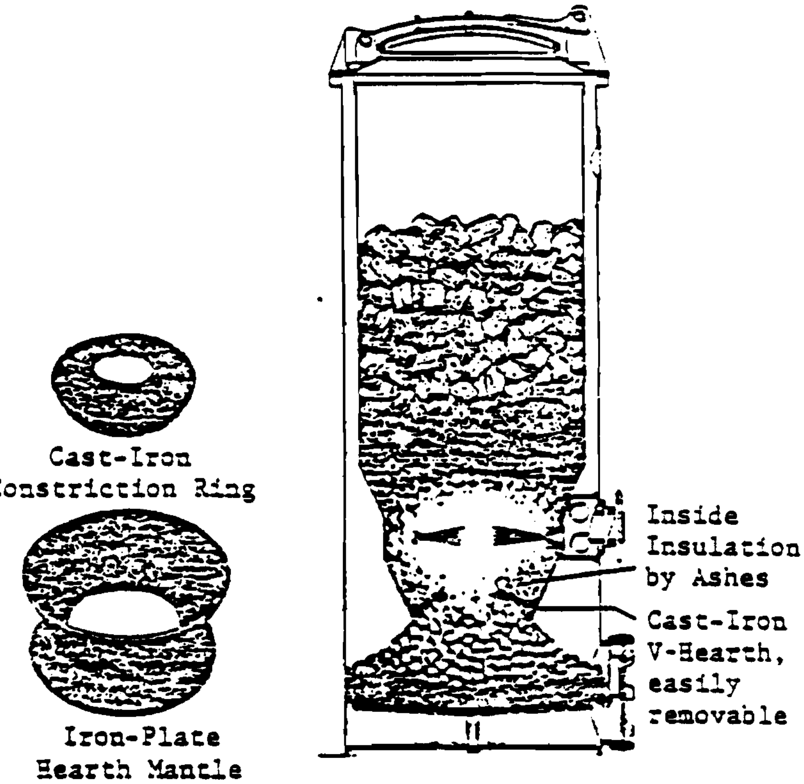


Figure 74. V-Hearth of Sheet Metal with a Cast Hearth Ring of Nonalloyed Iron for Installation in Generators of Various Makes.

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.

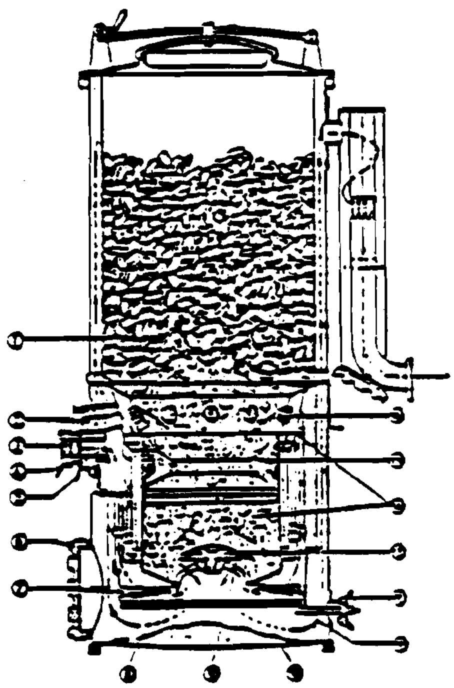


Figure 73. Imbert Generator for Wood, Brown Coal, and Peat, without Outer Charcoal Bed.

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

Figure 73 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.

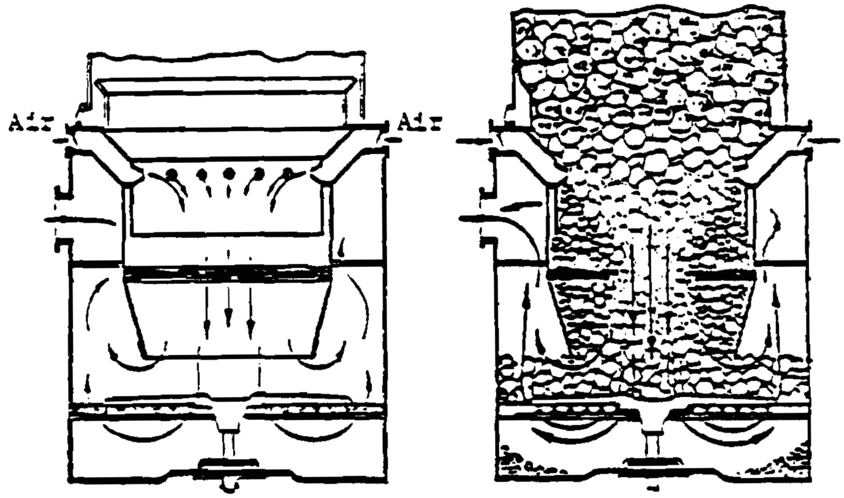


Figure 76. Zeuch Wood Gas Generator with a Removable Cast-Iron Hearth Ring.

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.

$$B_h = 0.36\ v_h Nm^3/cm^2hr \quad (53)$$

$$v_h = 2.78\ B_h\ m/s \quad (54)$$

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

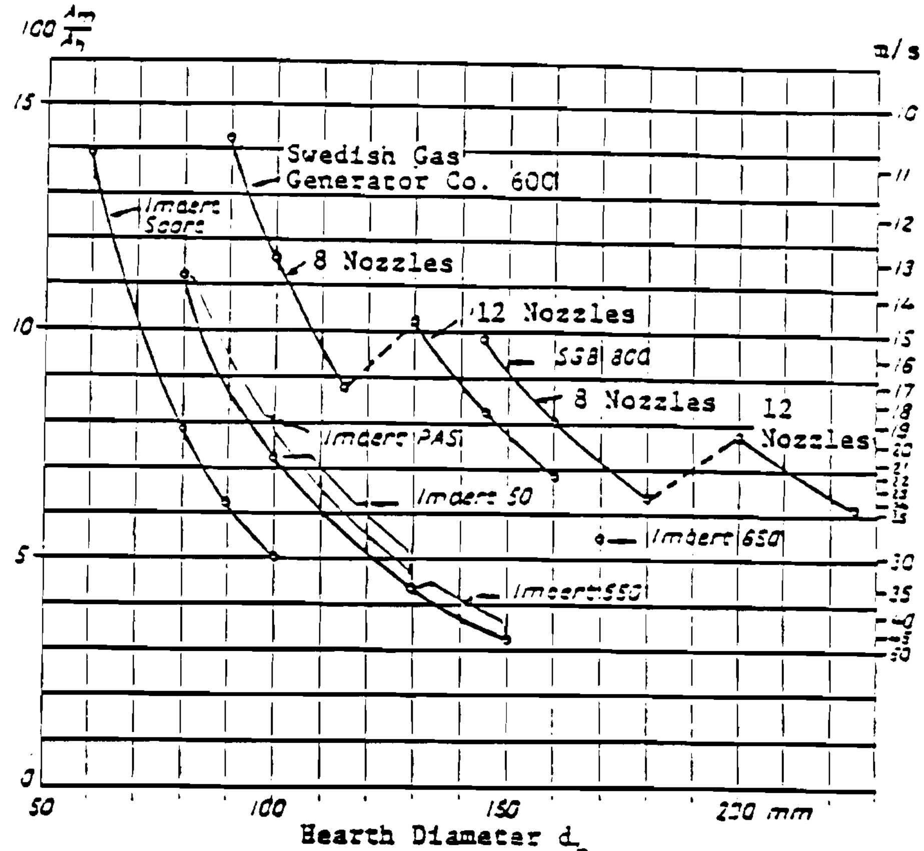


Figure 77. Graph Showing the Relation between the Total Nozzle Area and the Smallest Hearth Section, Air Velocity, etc., as a Function of Hearth Diameter at a Hearth Load of 0.9 Nm^3/cm^2hr.

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.

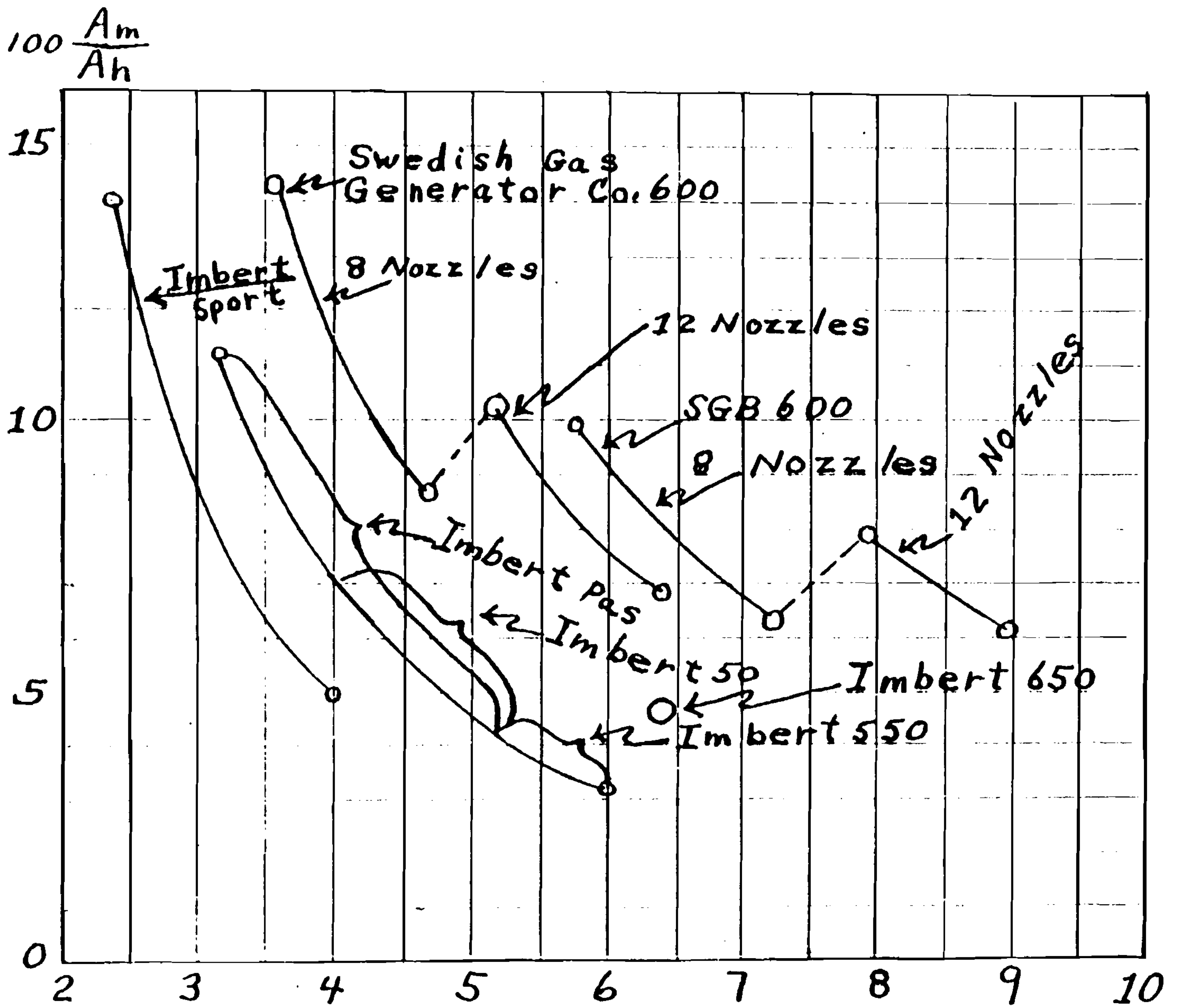


Figure 77. Graph showing the relation between the Total Nozzle Area and the Smallest Hearth Section. Converted to English units, adapted from the Swedish Gen-Gas Book, Figure 77, page 125.

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

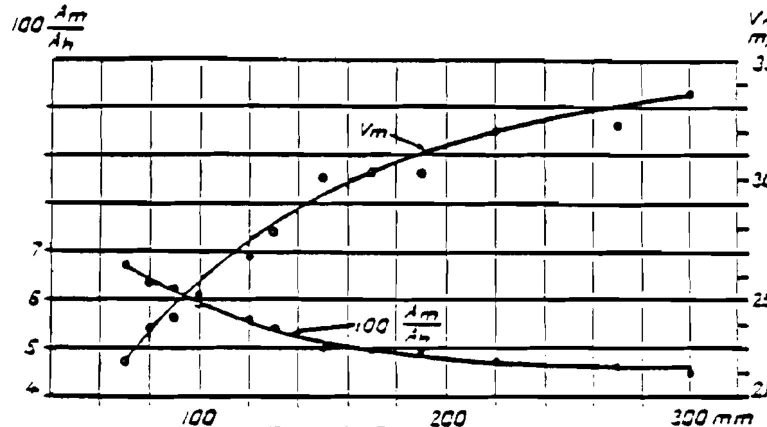
d_m = Nozzle diameter

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)



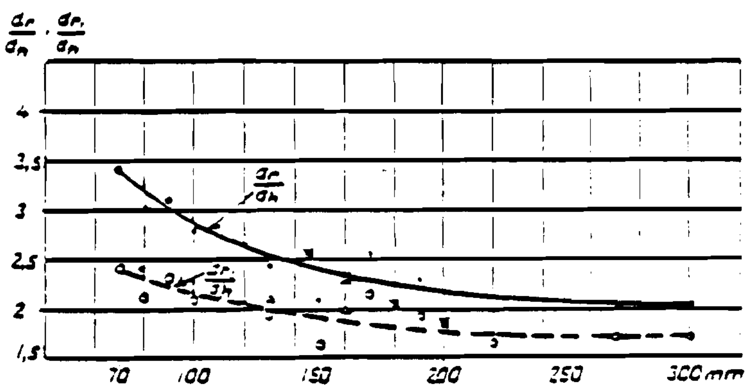
Hearth Diameter d_h

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.

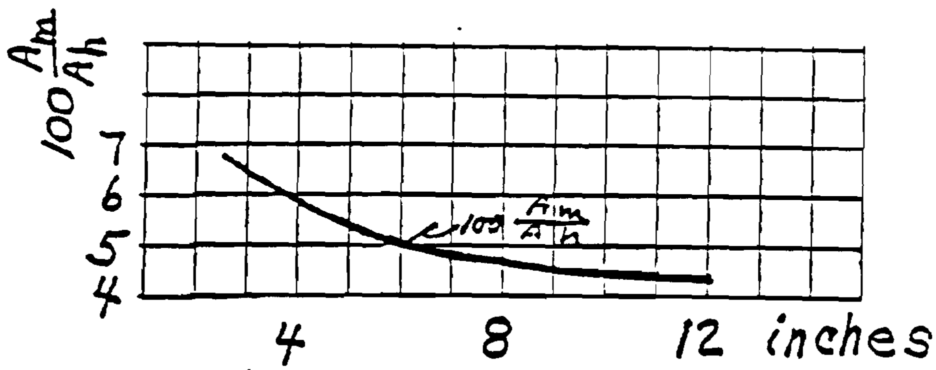
As for the diameter of the nozzle ring (d_r) in relation to the diameter of the hearth construction (d_h), a series of values from good generators are dotted into the graph of Figure 79; on the basis of this dotted scale, a continuous mean curve is drawn. In a similar way, the diagram demonstrates the 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.



Hearth Diameter d_h

• = $d_r : d_h$ } Hesselman Motor ▪ = $\frac{d_r}{d_h}$ SGB 800
o = $d_{r_1} : d_h$ }
▵ = $\frac{d_r}{d_h}$ SGB 600

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



Hearth Diameter d_h

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

(Extracted from Figure 78, pg. 127, Swedish Gen-Gas Book) mm converted to inches on the horizontal scale

The ratio. 100 $\frac{AM}{Ah}$ corresponds to column four, Table 27, page 126.

English units conversion from Figure 79 of the Swedish "Gen-Gas" literature

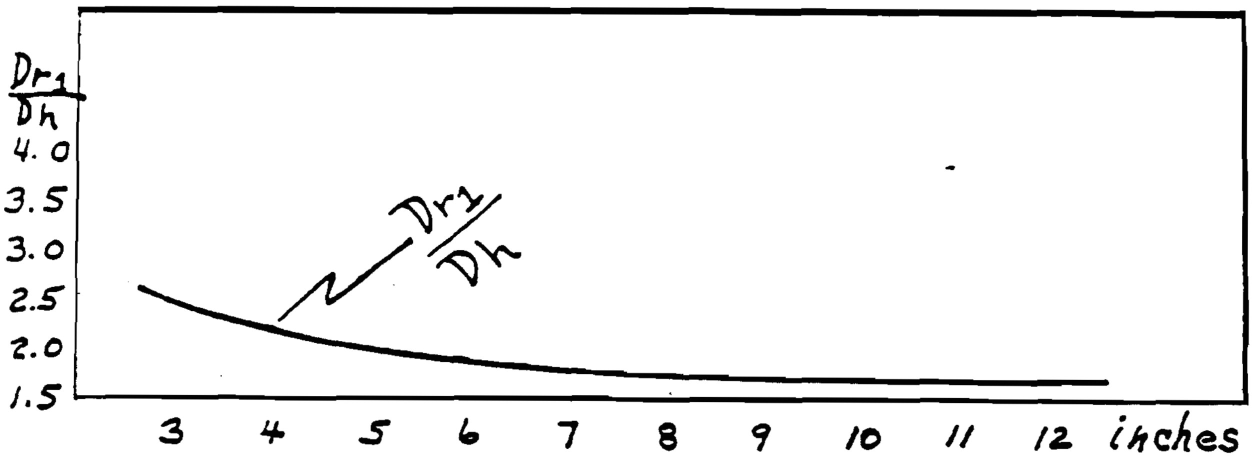


Figure 79 Diameter of nozzle ring opening (see appendix "C") diameter in relation to hearth constrictor ring diameter.

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.

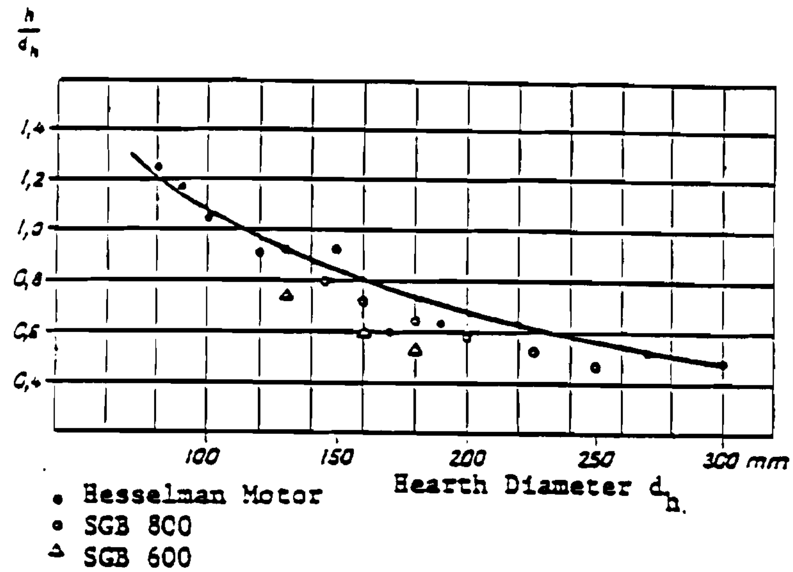


Figure 80. Height of the Nozzle Plane above the Hearth Constriction for Various Generator Sizes.

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 $\pi d^2_{r1}:4$ 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.

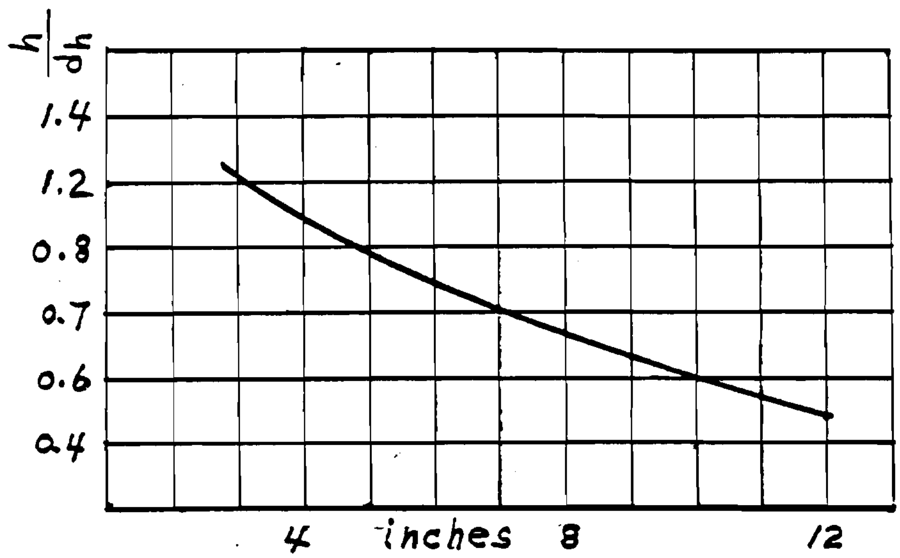


Fig. 80 - pg. 128 from the Swedish Gen-Gas Book conversion from metric units to english units.

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.

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.

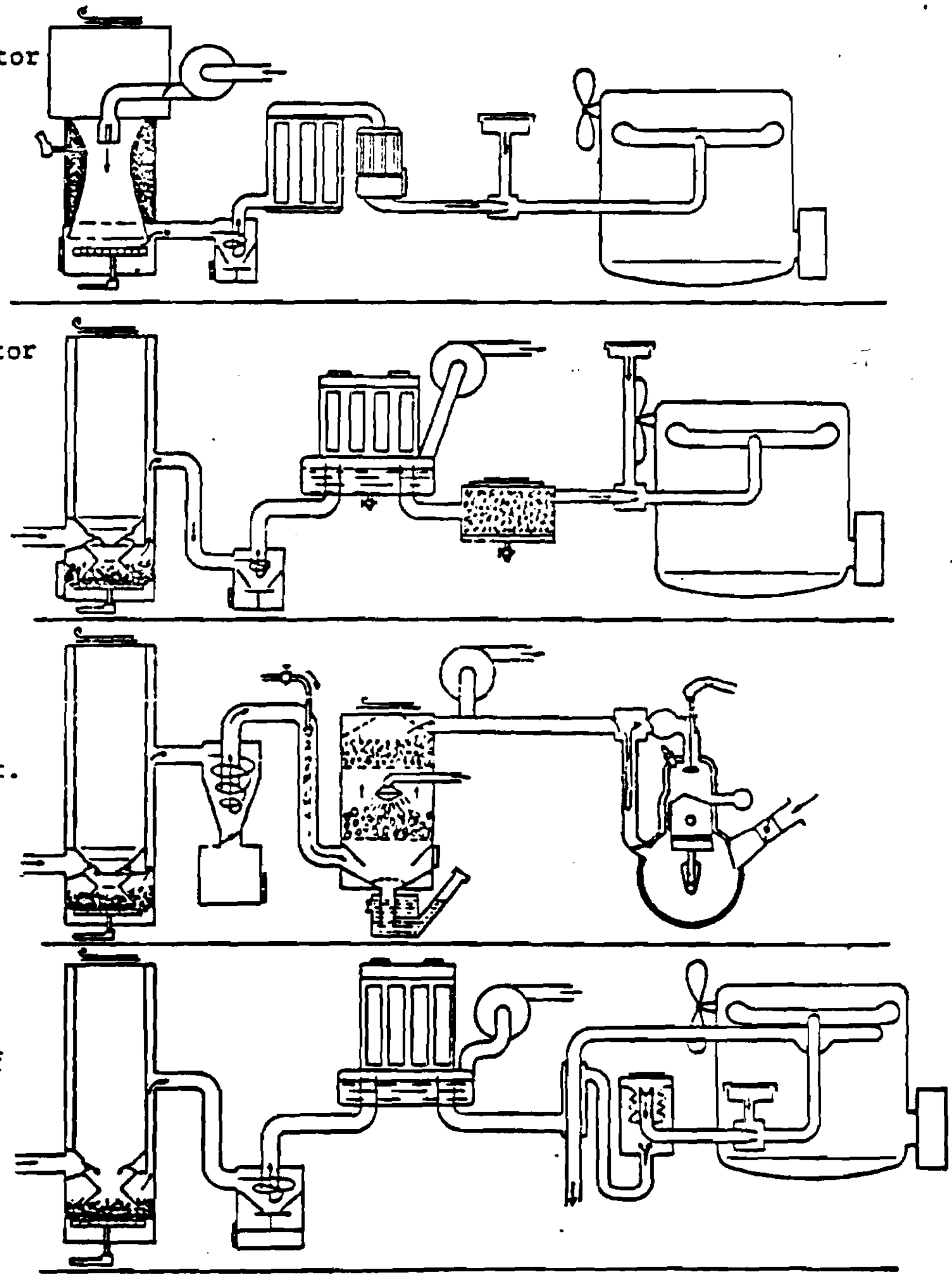


Figure 89. Schematics of Generator Gas Devices.

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.

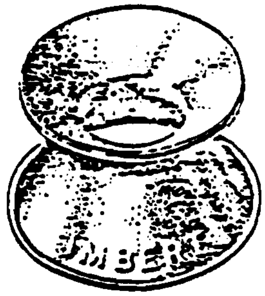
The design of ordinary wood gas generators makes it very important to carefully adapt the minimum hearth area to the operating conditions of the engine. In the beginning the generators were designed in a few sizes, with the size almost always given by the outer diameter of the generator level with the 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.

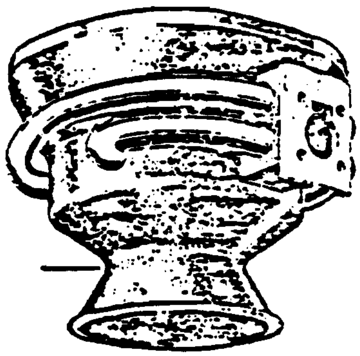
Table 31. DIMENSIONS OF GAS GENERATORS

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:						
Wolf & 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	3.6	" "
"	170/650/210	2100	650[b]	170	3.6	" "

[a]Square
[b]Cross section



A.



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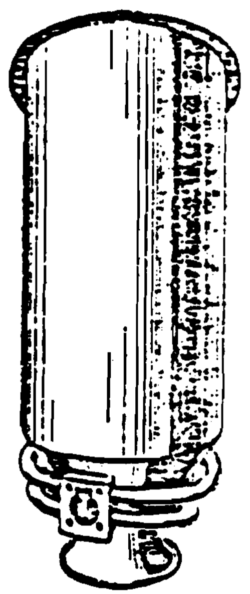


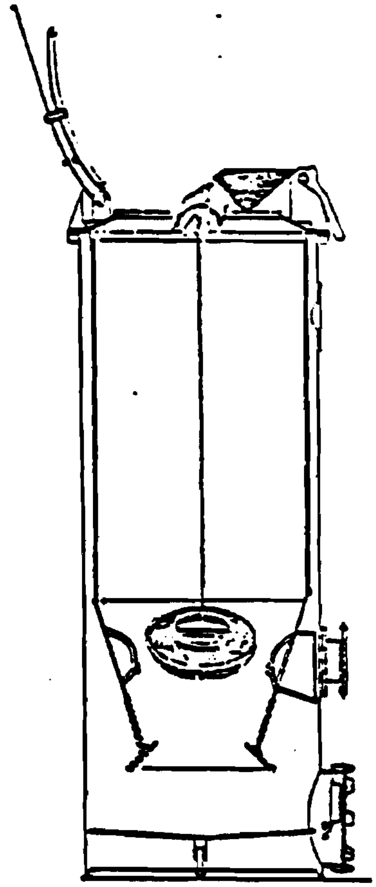
C.

Figure 117. Spare Parts for for an Imbert-Type Wood Gas Generator.

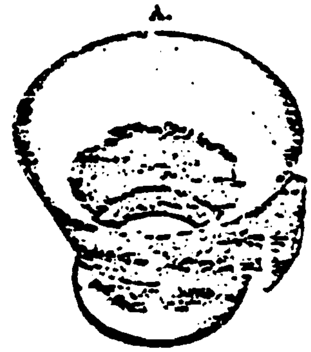
A. Hearth cone of alloyed cast steel.

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.



A.



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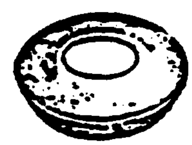


C.

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				Maximum Generator Gas Needed at 2300 rpm, L/sec	Power with Gasoline Operation, Hp	Generator Model Designation				
						Charcoal Gas		Wood Gas		
Type No.	Number of Cylinders	Cylinder Dimensions mm	Cylinder Volume, Litre			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.

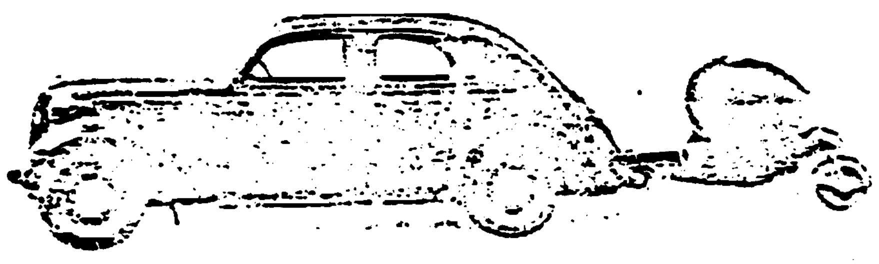


Figure 120. Gas Generator Installed on a Trailer, Volvo Type.

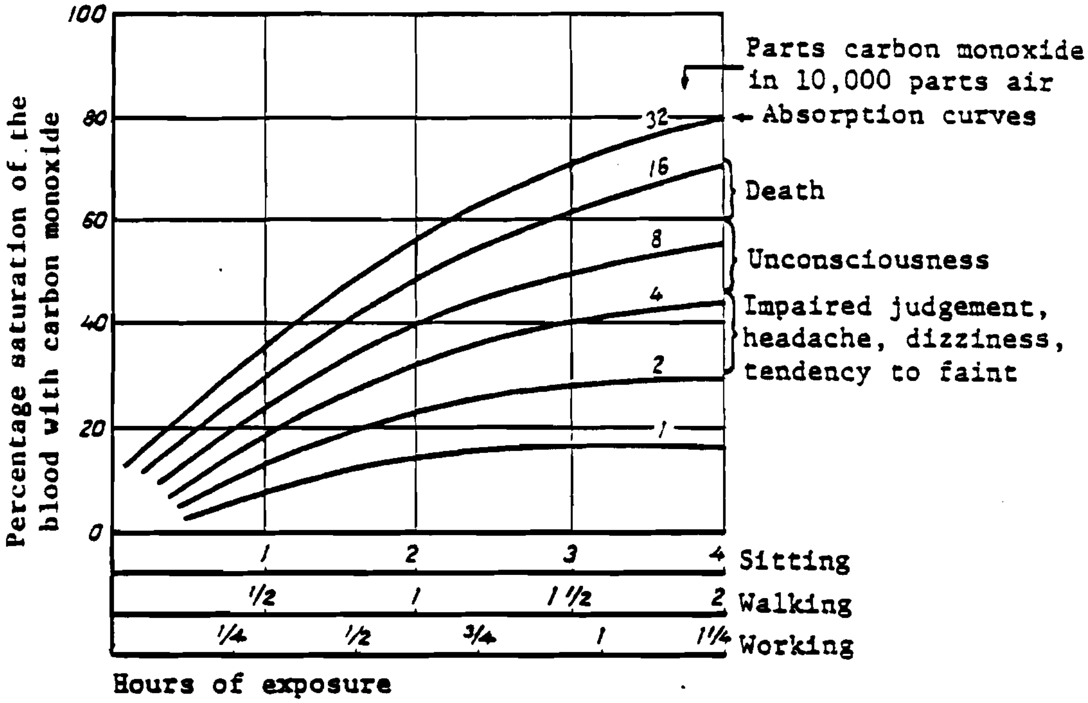


Figure 264. Absorption and Occurrence of Carbon Monoxide in the Blood.

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 Karbogen (a

Table 51. SYMPTOMS OF CARBON MONOXIDE POISONING

% Saturation of the Blood with Carbon Monoxide	Symptoms At Rest	Symptoms 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.

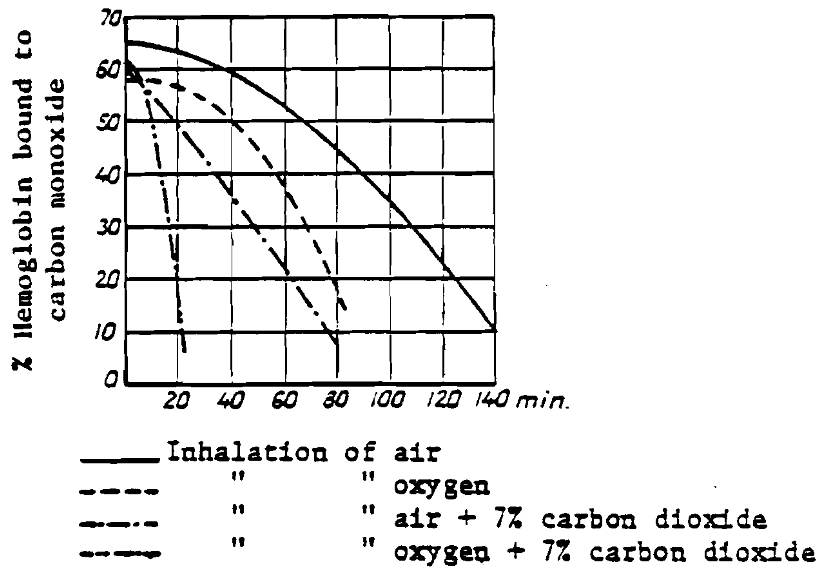


Figure 265. Treatment of Carbon Monoxide Poisoning.

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.

*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 . . . . 0.30% 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.

APPENDIX A

When designing a wood gas generator, the hearth diameter (d_h) is the critical value to estimate gas production rate. Many of the other dimensions such as grate height, nozzle areas, etc. are ratios of d_h.

This section will develop an estimated value of d_h for a given load of a hypothetical internal combustion, spark ignition, four cycle engine. To check our calculation the engine will be selected from the Swedish Gen-Gas for which the design work has been accepted. From this exercise you will be able to use the same equations and procedures to size a gas generation for your particular engine.

Two design parameters were developed in the Swedish Gen-Gas Book by experimental methods that will be used here. These are:

1. Maximum Hearth Load (B_h) = $1.2 \frac{m^3/h}{cm^2}$ $\left(\frac{4.55 \text{ ft.}^3/\text{min.}}{\text{inch}^2}\right)$

   This is actually an expression of the velocity of the gen-gas through the hearth restrictor ring area (page 166).

2. Air/fuel ratio is 1:1, or 50% of the fuel charge is gen-gas, 50% is intake air (page 165).

The selected exemplary engine is:

Bore 110 mm = 11 cm (4.33 in)

Stroke 136 mm = 13.6 cm (5.35 in)

Displacement Volume (V) $= \frac{\pi d^2}{4}$ x stroke x number of cylinder (Eq. 1.)

$$V(\text{metric}) = \frac{\pi \times 11^2}{4} \times 13.6 = 1{,}292 \text{ cm}^3 \times 4 \text{ cylinder} = 5{,}168 \text{ cm}^3$$

$$V(\text{English}) = \frac{\pi \times 4.33^2}{4} \times 5.35 = 78.8 \text{ in}^3 \times 4 \text{ cylinder} = 315.2 \text{ in}^3$$

4 cylinders, four-stroke cycle

RPM = 2,300

This engine is described as the first entry, table 32, page 169.

The engine requires fuel flow as estimated from the following equation.

$$V(\text{displacement volume}) \times \text{RPM} \times \frac{\text{charge}}{\text{rev.}} \times \frac{\text{0.5 gen-gas}}{\text{charge}} \times \frac{\text{60 min.}}{\text{hr.}} = \text{fuel flow (Eq. 2)}$$

The factor $\frac{\text{"charge"}}{\text{2 rev.}}$ is necessary for a four stroke-cycle engine. For a two stroke-cycle this factor would be 1.

Putting actual values in Eq. 2 gives the following values.

$$(\text{Metric})\ 5{,}168 \text{ cm}^3 \times 2{,}300 \frac{\text{rev.}}{\text{min.}} \times \frac{\text{charge}}{\text{2 rev.}} \times \frac{\text{0.5 gen-gas}}{\text{charge}} \times \frac{\text{60 min.}}{\text{hr.}} = 178 \times 10^6 \frac{c}{r}$$

$$(\text{English})\ 315.2 \text{ in}^3 \times 2{,}300 \frac{\text{rev.}}{\text{min.}} \times \frac{\text{charge}}{\text{2 rev.}} \times \frac{\text{0.5 gen-gas}}{\text{charge}} \times \frac{\text{60 min.}}{\text{hr.}} = 10.87 \times 10^6 \frac{\text{in.}}{\text{hr.}}$$

$$\text{Reducing - } 10.87 \times 10^6 \frac{\text{in}^3}{\text{hr.}} \times \frac{\text{hr.}}{\text{60 min.}} \times \frac{\text{ft.}^3}{1{,}728 \text{ in}^3} = 104.9 \frac{\text{ft.}^3}{\text{min.}}$$

Previously we identified B_h as a ratio of fuel flow to hearth restrictor area (in.^{2}), i.e., cubic feet per minute/square inches that was experimentally determined to be 4.55. Using conventional (English) units, the values now at hand can be calculated:

$$B_h = \frac{ft^3/min\ (fuel\ flow)}{in^2\ (hearth\ area)} = 4.55$$

$$\text{or Hearth area} = \frac{104.9}{4.55} = 23\ in^2$$

$$\text{Area} = \frac{\pi d_h^2}{4} = 23.$$

Solving for d_h = 5.4 in. diameter

This compares favorably with the value given in table 32, page 169 for this engine of 130 mm (5.12 inches) for the Imbert model gas generator. Therefore, the preceeding method can be used to calculate as a first estimate the diameter of the hearth restrictor ring. The gas generation should be fabricated so restrictor rings can easily be exchanged. If the size first used is not satisfactory, a slightly larger or smaller ring diameter can be tried.

APPENDIX B

The second critical dimension is the total area of the air intake nozzles. On page 127, Figure 78, we find the values of A_m (total nozzle area) for various sizes of A_h (hearth area).

In our example, $A_h = 23$ From the graph, Figure 78, we read:

$$100 \frac{A_m}{A_h} = 5.2$$

$$A_m = \frac{5.2 \times 23}{100} = 1.20 \text{ in}^2$$

If we design for 6 nozzles, then $\frac{1.20}{6} = 0.20 \text{ in}^2$ should be the area for each nozzle. Referring to a standard pipe size table we find 3/8 inch pipe has an area of 0.19 in^2, which is a good selection. It probably would be advisable to vary number of nozzles and pipe sizes to come as close to the required area for other values of A_m. (Refer to Table 3 on page B-1)

Table 3. Physical Properties of Pipe*
(Grinnell Co., Inc.)

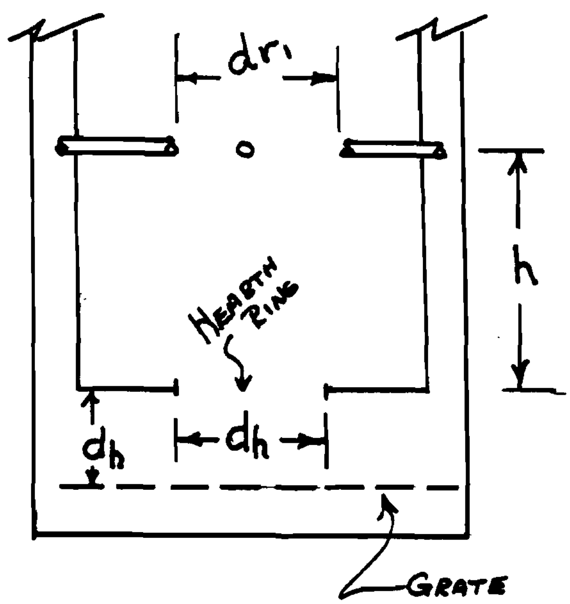
Nominal pipe size, O.D., in.	Schedule number†			Wall thickness, in.	I.D., in.	Inside area, sq in.	Metal area, sq in.	Sq ft outside surface, per ft	Sq ft inside surface, per ft	Weight per ft, lb	Weight of water per ft, lb	Moment of inertia, $in.^4$	Section modulus, $in.^3$	Radius gyration, in.
	a	b	c											
1/8 0.405	...	.....	10S	0.049	0.307	0.0740	0.0548	0.106	0.0804	0.186	0.0321	0.00088	0.00437	0.1271
	40	Std	40S	0.068	0.269	0.0568	0.0720	0.106	0.0705	0.245	0.0246	0.00106	0.00525	0.1215
	80	XS	80S	0.095	0.215	0.0364	0.0925	0.106	0.0563	0.315	0.0157	0.00122	0.00600	0.1146
1/4 0.540	...	.....	10S	0.065	0.410	0.1320	0.0970	0.141	0.1073	0.330	0.0572	0.00279	0.01032	0.1694
	40	Std	40S	0.088	0.364	0.1041	0.1250	0.141	0.0955	0.425	0.0451	0.00331	0.01230	0.1628
	80	XS	80S	0.119	0.302	0.0716	0.1574	0.141	0.0794	0.535	0.0310	0.00378	0.01395	0.1547
3/8 0.675	...	.....	10S	0.065	0.545	0.2333	0.1246	0.177	0.1427	0.423	0.1011	0.00586	0.01737	0.2169
	40	Std	40S	0.091	0.493	0.1910	0.1670	0.177	0.1295	0.568	0.0827	0.00730	0.02160	0.2090
	80	XS	80S	0.126	0.423	0.1405	0.2173	0.177	0.1106	0.739	0.0609	0.00862	0.02554	0.1991
1/2 0.840	...	.....	10S	0.083	0.674	0.357	0.1974	0.220	0.1765	0.671	0.1547	0.01431	0.0341	0.2692
	40	Std	40S	0.109	0.622	0.304	0.2503	0.220	0.1628	0.851	0.1316	0.01710	0.0407	0.2613
	80	XS	80S	0.147	0.546	0.2340	0.320	0.220	0.1433	1.088	0.1013	0.02010	0.0478	0.2505
	160	.....	...	0.187	0.466	0.1706	0.383	0.220	0.1220	1.304	0.0740	0.02213	0.0527	0.2402
	...	XXS	...	0.294	0.252	0.0499	0.504	0.220	0.0660	1.714	0.0216	0.02425	0.0577	0.2192
3/4 1.050	...	.....	5S	0.065	0.920	0.665	0.2011	0.275	0.2409	0.684	0.2582	0.02451	0.0467	0.349
	...	.....	10S	0.083	0.884	0.614	0.2521	0.275	0.2314	0.857	0.2661	0.02970	0.0566	0.343
	40	Std	40S	0.113	0.824	0.533	0.333	0.275	0.2157	1.131	0.2301	0.0370	0.0706	0.334
	80	XS	80S	0.154	0.742	0.432	0.435	0.275	0.1943	1.474	0.1875	0.0448	0.0853	0.321
	160	.....	...	0.218	0.614	0.2961	0.570	0.275	0.1607	1.937	0.1284	0.0527	0.1004	0.304
	...	XXS	...	0.308	0.434	0.1479	0.718	0.275	0.1137	2.441	0.0641	0.0579	0.1104	0.284
1 1.315	...	.....	5S	0.065	1.185	1.103	0.2553	0.344	0.310	0.868	0.478	0.0500	0.0760	0.443
	...	.....	10S	0.109	1.097	0.945	0.413	0.344	0.2872	1.404	0.409	0.0757	0.1151	0.425
	40	Std	40S	0.133	1.049	0.864	0.494	0.344	0.2746	1.679	0.374	0.0874	0.1329	0.421
	80	XS	80S	0.179	0.957	0.719	0.639	0.344	0.2520	2.172	0.311	0.1056	0.1606	0.407
	160	.....	...	0.250	0.815	0.522	0.836	0.344	0.2134	2.844	0.2261	0.1252	0.1903	0.387
	...	XXS	...	0.358	0.599	0.2818	1.076	0.344	0.1570	3.659	0.1221	0.1405	0.2137	0.361
1¼ 1.660	...	.....	5S	0.065	1.530	1.839	0.326	0.434	0.401	1.107	0.797	0.1038	0.1250	0.564
	...	.....	10S	0.109	1.442	1.633	0.531	0.434	0.378	1.805	0.707	0.1605	0.1934	0.550
	40	Std	40S	0.140	1.380	1.496	0.669	0.434	0.361	2.273	0.648	0.1948	0.2346	0.540
	80	XS	80S	0.191	1.278	1.283	0.881	0.434	0.335	2.997	0.555	0.2418	0.2913	0.524

APPENDIX C

Two other dimensions are important. The spacing of the grate below the restrictor ring is about one ring diameter, or 5.4 inches in our example. This dimension is not too critical.

The height of the nozzle location above the hearth restrictor ring is obtained from Figure 80, page 128. With a d_h of 5.4, the factor is about 0.9. Therefore:

$$0.9 = \frac{h}{d_h} \text{ or } h = 0.9 \times 5.4 = 4.8''$$



The nozzle opening circle diameter (d_{r1}) is obtained from Figure 79. For this example, for a hearth diameter (d_h) of 5.4, we pick off $\frac{d_{r1}}{d_h} = \underline{1.85}$ or $d_{r1} = 5.4 \times 1.85 = 10$ in.

APPENDIX D

An estimate of the probable horsepower developed by our engine can be calculated within reasonable accuracy.

From Appendix A - fuel rate was 104.9 ft^3/min. The heat value is estimated at 150 BTU/ft^3, but this value should be confirmed if possible by testing a sample.

By definition, 2,545 BTU's equals one horsepower at total conversion.

This engine probably is 20%-25% thermal efficient, say 22.5% as an approximatior

Then:

$$\frac{104.4 \text{ ft}^3}{\text{min.}} \times \frac{150 \text{ BTU's}}{\text{ft}^3} \times \frac{60 \text{ min.}}{\text{hr.}} \times .225 \text{ eff.} \times \frac{\text{HP hr.}}{2{,}545 \text{ BTU's}} = 83 \text{ HP}$$

The manual rates this engine at 80 HP, so our calculation accuracy is reasonabl

Addendum

Although the Swedish Manual refers to a 50% reduction in power output using gen-gas compared to gasoline, theoretically the value should be higher. This is dependent upon the heat value (BTU) of the gas, timing adjustments, engine conditions, etc. Theoretically, the air/fuel ratio should be closer to 1.5:1 than the 1:1 suggested in the manual. This should be confirmed by experience.