Thermo-Chemical Conversion of Biomass – a Retrospective and a Prospective

H. S. Mukunda, S. Dasappa, P J Paul, N K S Rajan, G Sridhar,
H V Sridhar and U Shrinivasa
Indian Institute of Science, Bangalore

Abstract

The work on thermo-chemical conversion of biomass was initiated at the Institute with the financial support from the Karnataka State Council for Science and Technology in 1981. During the first five years, one of the key question addressed was: Can a 3.7 kWe gasifier be built to produce engine consistent quality gas from woody biomass – even though small systems are prone to unfavorable thermal conditions? Studies showed that this question could be answered in the positive. The period 1985-90 was characterized by the demonstration of the possibility of new technologies that emerged from innovations in the laboratory. Soon there was a need to address requests for medium capacity systems. An automated 100-kWe gasifier with data acquisition system was set up at Port Blair. This system operated from 1990 led to several modifications and improved versions. The period 1990 – 1995, was studded with 'crossing several milestones' related to 'technology improvement' and device longevity. The problems addressed during this period related to enhancing reactor life using ceramics. These efforts led to emergence of landmark reactor technology – rammed mass technology and hard high allumina tile face.

The period of 1995 to 2000 was characterized by great interest from the Ministry of Non-conventional Energy Sources (MNES) and some interest from international groups, broadening the biomass feedstock types, adaptation to various type of engines, etc. The principal questions addressed were: Can feed stock range be enhanced to include other agro residues and urban solid waste. Can turbo-charged engines be run on producer gas without any technical problems? Can the issues related to gas engines be understood and technology elements built here. These led improving the scientific base. In doing so, many scientific questions were tackled. This period was also characterized by scientific developments involving, (a) modeling of combustion of individual biomass in specific geometric like sphere, (b) reactor as thermo-chemical device, (c) reactor design, (d) producer gas as a combustible medium, (e) physics of flame propagation vis-à-vis smooth burning in a high compression engines, heat balance and combustion in CI and SI engines has led to better science and engineering.

This vast experience has enabled evolving, designing; field-testing and installing a large number of open top reburn gasification systems from 3 kW – 1 MWe.

Technological improvements on the reactor were accompanied by improvements in the gasifier subsystems also. Manufacturing process also has been examined to ensure good quality assurance. These studies have led to,

a. interpreting gasification process as a two staged combustion process
b. using a staged conversion process to achieve clean combustion-(high efficiency and low pollutant emission)
c. adapting technology to low grade fuels like, agro wastes (sugar cane trash, agro residues), weeds (ipomea with high alkaline ash) and poorly segregated urban solid wastes.

Introduction

Gasification of biomass for use in internal combustion engines for power generation provides an important alternate renewable energy resource. The solar energy captured by photosynthesis and stored in the biomass makes it a high energy density system (9600 MJ/m^3). Gasification of this fuel in the present context is taken to mean partial combustion of biomass to produce gas and char at the first stage and subsequent reduction of the product gases, chiefly CO_2 and H_2O, by the charcoal into CO and H_2. The process also generates some methane and other higher hydrocarbons depending on the design and operating conditions of the reactor.

It is important to begin this discussion by enunciating the motivation towards the development of gasifiers at the Indian Institute of Science. Early in 1979, the attention of some of the authors of this report (Shrinivasa and Mukunda (1984)) was brought to a singularly valuable document, the translation of Swedish experience on gasifiers by the Solar Energy Research Institute, USA (SERI, 1979). A study of this document showed that the development of low power wood gasifiers posed problems of gas quality, in particular to the limitation of tar, more specifically at part loads. It was first inferred that if any design had any chance of success at all, it had to be of downdraft variety. Analysis indicated that the problems at low power level were related to heat generation vs heat loss rate. The heat loss through the hardware (however well designed) will be unfavorable for small systems. In order to ensure reliable operation with good gas quality it is imperative that energy conservation through providing adiabatic thermal environment is ensured. A large number of tests on the classical closed top design revealed that while at one flow rate, close to the rated value one would get nearly tar-free gas, at reduced flow rates the performance would be poor.

The development of the technology to harness this route has taken place in spurts. The most intensive of these was during the Second World War to meet the scarcity of petroleum sources for transportation both in civilian and military sectors. Some of the most insightful studies on wood gasifier - basic as well as developmental - of this period have been well documented in the English translation of the Swedish work (SERI, 1979). Additional details and some classical description of the early work are also available in a review by Kaupp and Goss (1984). Most of the subsequent work has been devoted to the replication of the systems already existing elsewhere. The next major input is from the laboratory studies of Reed and Markson (1983) who conducted systematic studies on what appears a simpler geometry of the reactor with an open top design, which was being used in rice husk gasifiers earlier particularly in China (Coovaththanachai, 1986). The concept however did not evolve into an acceptable technology for gasifying wood until recently when the present authors examined and modified it to produce a workable technology for a range of powers (5-500 kg/hr capacity).

With the above background, the present article attempts to critically review the available work and present various aspects related to design of gasifiers and highlights the state of the art technology package for biomass gasification coupled to diesel and gas engines.

Some basic studies on gasification

The essence of gasification is the conversion of the solid fuels to gaseous fuel by thermo chemical reactions of a fuel with oxidizer under sub-stoichiometric conditions the energy in biomass being realized in the form of combustible gases (CO, CH_4 and H_2).

The mechanistic behavior of a reactor

The generation of gas occurs in two significant steps. The first step involves exothermic reactions of oxygen in air with the pyrolysis gas under rich conditions. The second step involves the endothermic reaction of these gases largely CO2 and H2O with hot char leading to product gases. In the early part of the development, basic research towards the understanding of the processes occurring was carried out by carrying single particle studies along with packed bed.

Several studies (Mukunda et al (1984), Dasappa et al (1994, 1996, 1998, 1999, 2000) focused on both experimental and modeling studies of the reactions of wood-char spheres with oxygen, steam and mixtures of CO2, O2 and H2O as functions of particle diameter, ambient temperature, composition and flow velocity. Char-based reactors are modeled based on these studies to predict exit gas composition and propagation velocity. Model predictions are compared with results from experiments in the laboratory and also with those from the literature. Modeling was done in two parts: first on a single particle and then on a packed bed of particles. The model for the single particle consists of a mathematical model for a porous char sphere with conservation equations of mass and energy.

Based on the above studies, for the C-O_2 system, the conversion time dependence for the char oxidation is shown to be tc ~ d_0^n, where n = 1.9 and 2.0 for combustion at T ~300K and 1000 K respectively for particle diameters above 1 mm. The extinction of the char particle and the incomplete combustion are shown to be due to the heat loss rate becoming more important. A comparative study of the conversion process for different gaseous components indicates d_0^2 dependence in an air/oxygen environment as noted above and d_0^2 & $d_0^{1.2-1.3}$ dependence in the CO_2 and H_2O environments respectively.

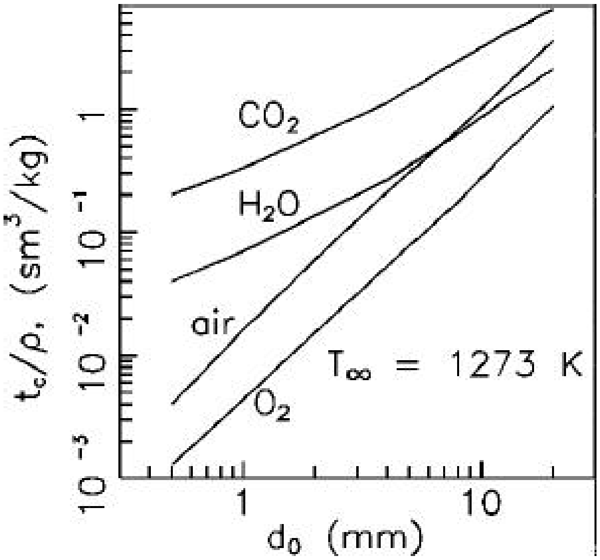

Fig 1. Normalised conversion time versus diameter for different reactants (of CO_2, O_2 H_2O and air) at Tamb = 1273 K, from the model

Figure 1 shows the results from the model with normalized conversion time and initial char particle diameter at 1273 K for different reactants. The rate of conversion with air and that with H_2O is comparable beyond a 7 mm diameter particle. The individual reactions as indicated in the figure have been evaluated for various ambient conditions and the model predictions are in reasonably good agreement with the experimental results.

Figure 2 shows the reactor setup for the experiments on packed bed reactor the results from experiments and analysis for a char reactor system. The experimental set up is a one-hundredth scale of a field -tested model. The model reactor consists of a quartz tube of 40 mm diameter, insulated on the outside. Thermocouples are located along the length of the reactor for measuring the temperature profile and the gas is taken to a quenching column before connecting to the burner. The experimental and the model results indicate the air mass flux with propagation rate is shown in figure 3. Propagation rate is the rateat which the reaction from moves into the fuel bed. From the results it is clear that with increase in the mass flux the propagation rate initially increase, and decreases. The increase and decrease of the propagation rate are related to the heat release and heat loss rates at the reaction front. These are addressed in Dasappa (1999). Results from the gasification process modeling are compared with experimental results for the char reactor system. The predicted propagation rates for varying mass flux match well with the experimental data. The model predictions for the exit gas composition from a wood char reactor are satisfactory. Beyond a certain mass flux, i.e., 0.3 kg/m2 s, propagation ceases and reaches extinction. This feature has been examined using the analysis proposed in the literature (Dosanjh (1987)). From the analysis it is brought out that extinction occurs when all the energy released in the reaction zone is used in heating the incoming gas. It is also shown from the model that the propagation front can be sustained by increasing the heat release in the reaction zone from the increased oxygen mass fraction in the ambient. Thus a comprehensive model validated by comparison with the experimental data addresses several aspects related to packed char bed gasification.

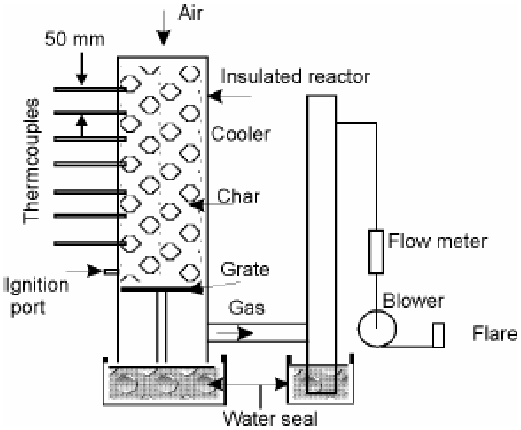

Figure 2. Experimental set-up for the packed bed reactor

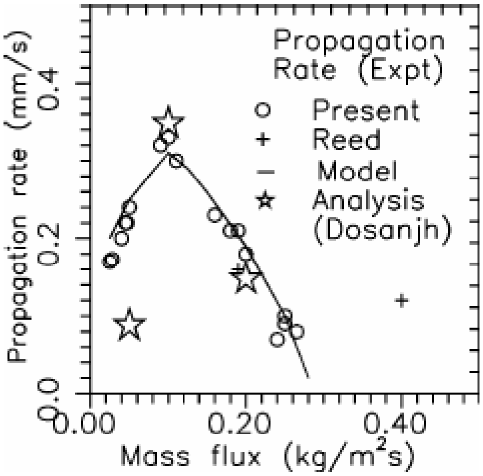

Figure 3. Propagation rate with mass flux in a packed char bed from experiments, model and analysis.

The above basic studies have provided insight into the process occurring in a typical gasifier. The influence of particle size for gasification, the relative importance of optimum mass flux as a part of the design, etc., have led to the understanding of the performance of the open top reactor designs.

Basic studies on gas engine

Systematic studies essential to establish the Highest Useful Compression Ratio (HUCR) for producer gas fuel, also indirectly establishing the octane rating for the fuel were conducted. The work on a producer gas fuelled spark ignition engine converted from a standard diesel engine with a compression ratio of 17:1 was done to establish knock free performance by capturing the pressure-crank angle trace. Subsequently the engine has been tested at varying CRs to arrive at an optimum CR for maximum brake power and efficiency.

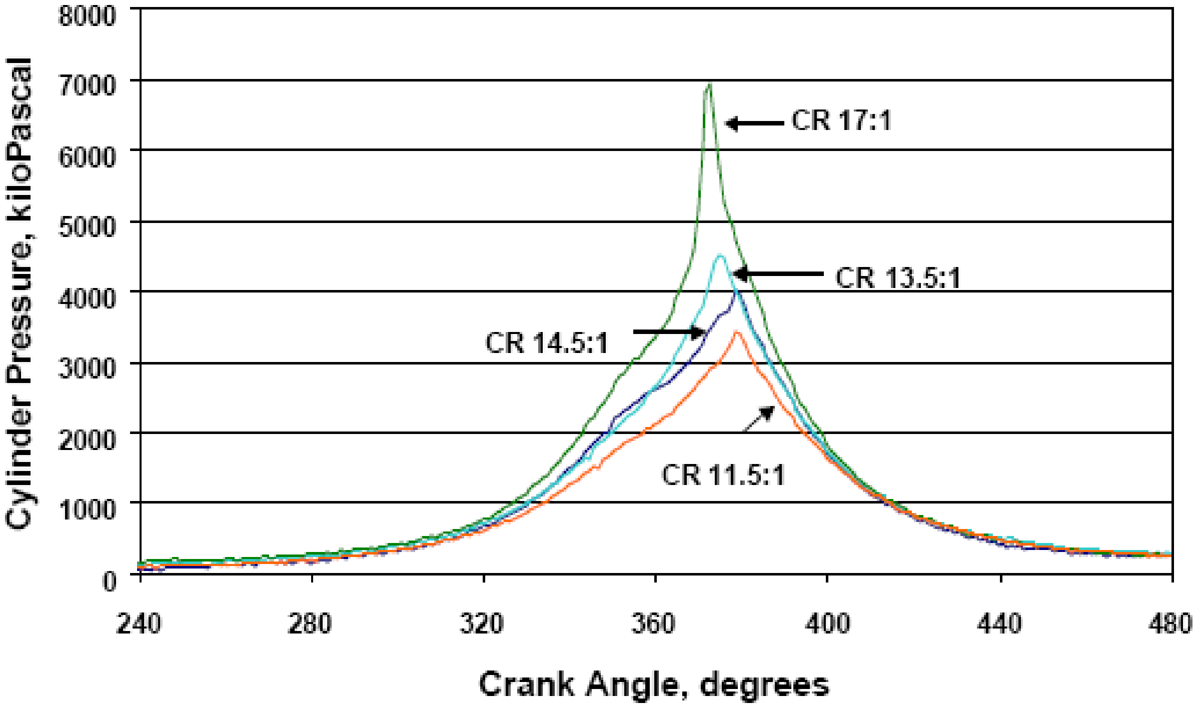

Fig. 4 Pressure-Crank angle diagram at varying compression ratio; CR 13.5:1 is at MBT and CR 17:1, 14.5:1 & 11.5 the ignition advance is suboptimum

Figure 4 shows the pressure trace for various compression ratios. From thefigure, it is evident that the peak pressure in the case of compression ration of 17 : 1, is nearly double compared with the case with compression ratio of 11.5 : 1. From the experiments, the maximum power out put of 17.5 kWe obtained was in the case of with a compression ratio17:1 compared with 15.3 kWe for 11.5:1. The overall energy balance has been analyzed, which indicates to a large fraction of heat (compared to diesel engine) with the cooling water.

Thus two issues regarding producer gas fuel namely, knocking at high CR's and large derating due to the use of low calorific value gas in the engine have been resolved favorably.

Design of gasifiers

The only reactor design available till recently was the closed top, where the upper portion of the reactor acted as a storage bin for the fuel, and air was allowed to enter at the lower part which consisted of charcoal. Developmental work at the Indian Institute of Science on wood gasifier, resulted in a design (Dasappa, 1989) with an open top, air entering both from the top and through the side air nozzles. This feature has resulted in a design which can handle wood chips of higher moisture content, up to 25 %, and with low tar levels (< 30 ppm) in the generated gas). This low tar level is due to the stratification of the fuel bed, which helps in maintaining a large bed volume at high average temperatures.

In the closed-top gasifier, the hopper region into which the biomass is loaded is relatively large, its size being generally dependent on the time to run a single uninterrupted cycle before reloading. The throat is the smallest cross section in the flow path for both fuel and gas. Throat diameter has an influence on the tar content in the gas and is determined by the need to balance two factors: large throat diameter leading to higher amounts of tar in the gas and small diameter leading to larger carryover of fine dust and ash. Higher is the value of the diameter, greater is the risk that tar-laden gases will escape the combustion zone, smaller the throat diameter, greater is the velocity of the gases that sweep through the throat and the reduction zones, collecting fine dust and ash. Another feature of the closed-top gasifiers that the diameter of the hopper is so large that heat transfer from the high-temperature zone generally affects wood chips near the hopper's wall rather than its center. Another drawback of the closed-top gasifier is that generating combustible gas of reasonable quality is more difficult when the moisture content of wood is high (15-30 %).

Generally, open top gasifiers have air being drawn only from the top (Reed and Markson, 1983). IISc gasifiers draw air from the top as well as through the side air nozzles (see the Figure 5). Combining the open-top with an air nozzle towards the bottom of the reactor helps in stabilizing the combustion zone by consuming the unconverted char left and also by preventing movement the of the flame front to the top. As a consequence, the high-temperature zone spreads above the air nozzle by radiation and conduction, aided by airflow from the top in the case of the open top system. The tar is thus eliminated in the best possible way by the high temperature oxidative atmosphere in the reactor itself. In the present design of the gasifier, heat transfer from the hot gases flowing in the annular space, makes it possible to gasify wood chips that have moisture content as high as 25%, with consistent gas quality from a range of biomass fuels. A further feature of the introduction of the air nozzle into the open top design is that *char conversion can be made near-complete*. Open top gasifiers without nozzles cannot have complete char conversion.

In a steady operation, the heats from the combustion zone near the air nozzles is transferred by radiation, conduction and convection upwards causing wood chips to pyrolyse and lose 70-80% of their weight. These pyrolysed gases burn with air to form CO, CO_2, H_2, and H_2O, there by raising the temperature to 1300-1500 K. The actual mean temperature is dependent on the superficial mass flux. The product gases from the combustion zone further undergo reduction reactions with char, to generate combustible products namely, CO, H_2 and CH_4. The product gas exits from the reactor at around 800-1000 K, below the reduction zone. Typical gas composition (dry basis) at the reactor is as follows, 19% CO, 18 % H_2, 1 % CH_4, 11 % CO_2, 10 % H_2O and the rest N_2.

Figure 5 shows the temperature variation from the air nozzle region in the classical closed top and the present open top design. It is clear that the width of the high temperature region, 600 K and above is about 1 m for the open top design whereas it is constant at about 0.4 m for the earlier design. What is more it can be controlled by decreasing the air flow through the air nozzle in the current design.

The size of the biomass chips is important for the successful operation of the reactor. The time for conversion is split into two parts, namely the flaming and char conversion time. These have been reasonably well understood through the basic studies carried out on the single particle. For any assumed reactor diameter the required heights for flaming pyrolysis and char conversion are then obtained from the given properties of the biomass, namely, density, specific heat and heats of phase change with a simple model for heat balance. The height of the reactor is then determined by requiring that the downward distance traveled by the woody biomass must allow for the residence time equal at least to the sum of the flaming (pyrolysis) and char conversion times. Because of the assumption of one-dimensionality the L/D of the reactor should be large, typically 6-8. Once the height is determined, the diameter can be obtained from the choice of a value for L/D. Qualitatively, smaller diameters are preferred in order to make the reactor compact and to permit the wall heat transfer to affect the entire cross section. Too small a diameter would necessitate the use of smaller wood chip size and higher-pressure drops at the nominal flow rates.

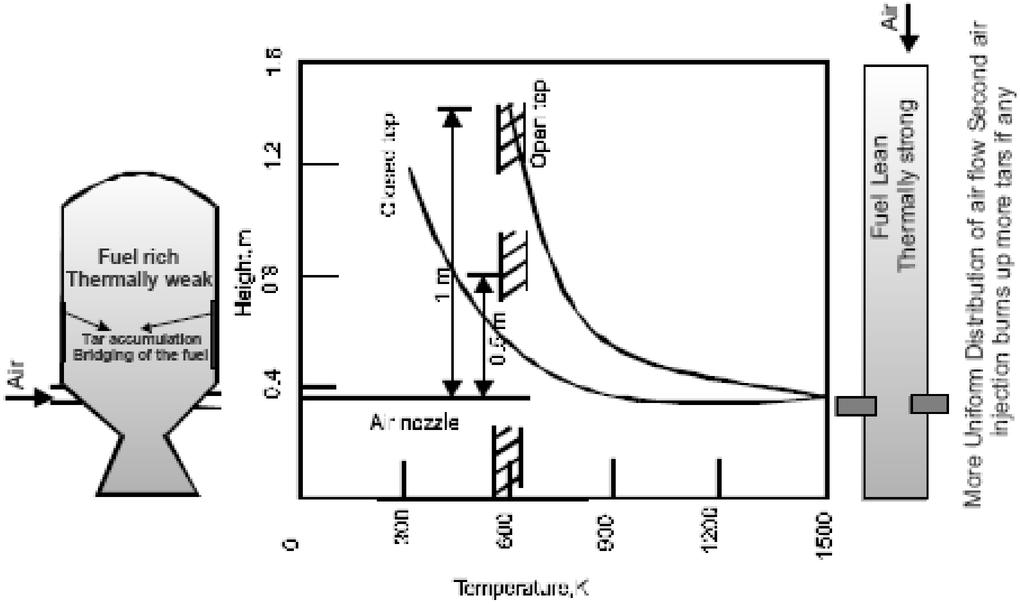

Figure 5: Temperature profile inside the reactor for closed and open top gasifier

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Technology package development

In the early stages of the developmental effort a closed top design was contemplated and several variations of this were tested in the laboratory. This has been documented in Shrinivasa and Mukunda (1984) and Dasappa et al (1985). The features that are evident from these prototypes with throat are that the L/D ratio has been modified compared with that of the standard closed top designs and the emphasis to improve the thermodynamics of the system. During this phase of the developmental effort where about 4 prototypes were tested, it was concluded that the final prototype, was claimed to meet most of the requirements, with features like a top water seal with a cap to help in remove condensates and high gas off-take point which helps to obtain good reactor performance.

This reactor design with throat was replaced with a throat less design which had several advantages indicated in the section above. This design was subjected to the field evaluation at 5 hp level initially, which led to development of other power levels.

The modern open top gasification system

Based on the field experience at 3.7 and 100 kW level, the need to redesign the geometry to protect against the high temperature oxidation and reducing environment was addressed. The current design of the reactor consists of a vertical tubular reactor with an open top and a water seal at the bottom as shown in figure 6.

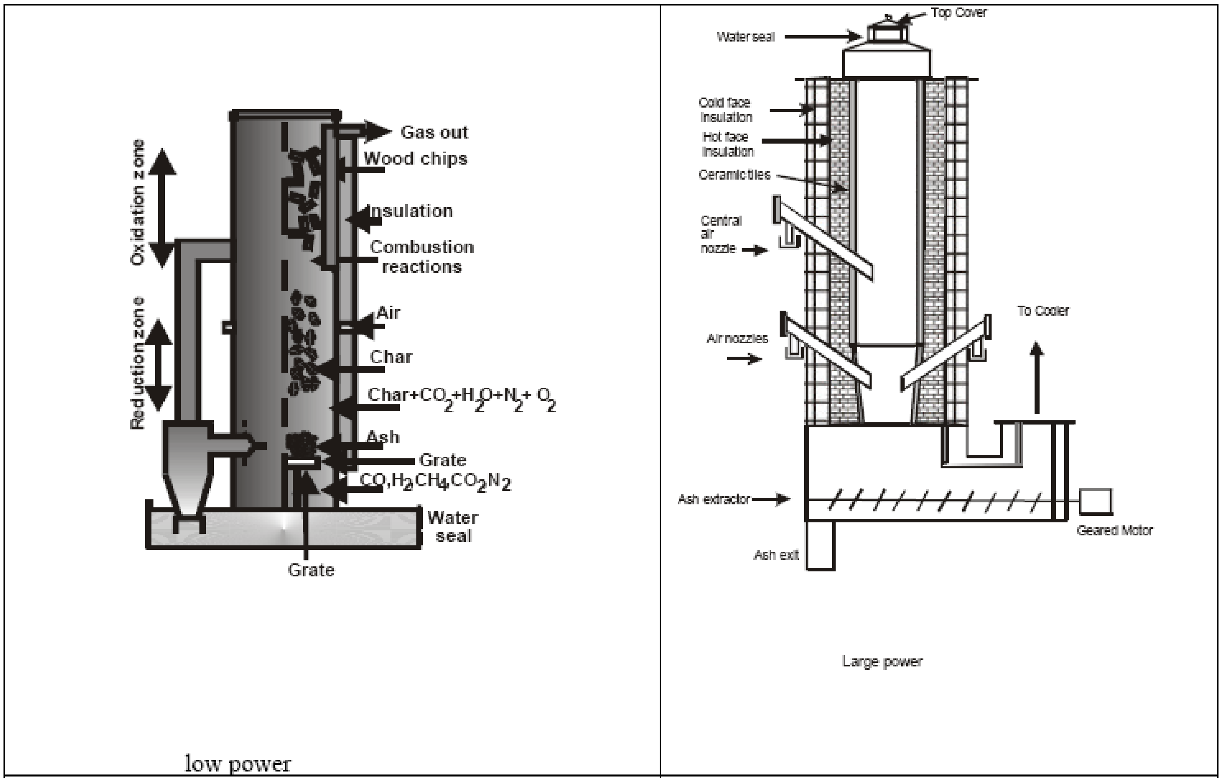

Fig. 6 Reactor geometry for the open top modern high and lower power levels

The low power level capacity systems, the lower two-thirds portion of the reactor, where the reactor bed temperature exceeds 600 C, is lined with a ceramic material of low thermal conductivity. This is to prevent high temperature corrosion in the presence of CO_2, O_2, CO, and carbon in the reactor. The upper part of the reactor is made of stainless steel with an annular jacket around it. The hot combustible gases generated are drawn below the grate and taken through an insulated pipe and through the upper annulus of the reactor, where part of the sensible heat if the gas is transferred to the cold wood chips inside the reactor. The entire reactor surface along with the recirculating duct which connects the bottom of the reactor to the annular region at the top is insulated with alumino silicate blankets. The hot gas which enters the annulus around 500 C, transfers some heat to the wood chips inside, improving the thermal efficiency of the system, in addition to drying the wood chips in this zone. The inner wall temperature reaches more than 350 C after a few hours of operation at full power and this condition is favorable for the preparation of wood chips before their entry into the combustion zone. At large power levels with the benefit of scaling up, the heat loss from the system walls being lower, the annular chamber is eliminated and the entire reactor is lined with bricks and tiles.

System configuration for Engine Applications

For engine application, gas must be cooled to room temperature and must be much cleaner compared to that for thermal applications. The requirements on the cleanliness are in terms of particulate and tar content. The acceptable upper limit of particulate content has been debated in the literature. Typical values of 50 mg/m3 (Kaupp, 1984) have been mentioned. However, if the particle size is smaller than a few microns, this limit is unimportant as the particulate matter flows along with the gas without deposition during its way to the engine at bends, corners and passages. As regards tar, there has been no clear statement of what the limit is. Understandably, no deposition of tarry material should occur in the passages. Such an occurrence is possible if tar has components with condensation temperature somewhat above the ambient.

In order to increase the density of the gas, the gas is cooled to ambient temperature by indirect and/or direct means and is filtered adequately to reduce the particulate content. Cooling in high power systems is best handled by direct injection of cooling water unless there is specific plan of utilization of the low grade heat. A sand bed filter is deployed to remove the particulates collected by the cooling water in the spray tower. Sand bed filtering technique was finally accepted for many applications as it is convenient, provides good filtration, inexpensive and is reusable since simple washing with detergent solution is adequate to refurbish the filter. The filter is separated into coarse and fine sections. The coarse filter is filled with sand of 0.5 to 2 mm size particles and the fine sand bed filled with 0.2 to 0.6 mm size sand. The size of the filter area is so chosen that the gas velocities through the filter bed do not exceed 0.1~m/s. This low velocity coupled with the tortuous path causes the removal a large part of the dust from the gas. Experiments have shown that some part of the tar also gets deposited in the filter circuit, particularly when the moisture carries over from the cooler causes slight wetting of the sand bed.

The particulate and tar (P&T) data are determined from a major test done for DASAG (Switzerland) in this laboratory along with some Swiss scientists. The Swiss team evolved the sampling and analysis procedure for P&T. The experiment included P &T data analysis for both hot and cold ends (Mukunda et al 1994). The reason for this is as follows. The amount of P &T generated at the hot end has to be brought down to acceptable levels by the cleaning system. Should the amount at the hot end be very large, then the load on the cleaning system also will be significant. This implies the need for a more elaborate cleanup system and/or more frequent maintenance. Very little data on the hot end P & T is reported in the literature. The current measurements indicate that the hot end tar is about 100 mg/m^3 and comes down to about 20 mg/m^3 at the end of the fine filter (cold end). The cooling water washes part of this tar; part is deposited in the sand bed filter. The particulate level also comes down from about 700 to 50 mg/m^3 at the cold end.

Another interesting accomplishment is in the area of power generation using producer gas in turbo-charged engines. The degree of cleanliness required is much higher than the naturally aspirated engines. The additional elements like high contact liquid scrubber and fabric filter have been specially designed to bring down the contaminants, i.e., tar and particulate to about 10 ppm each. These elements have now been used in the industrial captive power generation systems.

For operation in the dual-fuel mode, the arrangements are similar to the one shown in Figure 7 with addition of an engine in the circuit. The air intake is fitted with a manifold into which the air and gas lines are connected. The engine draws in both air and gas simultaneously and the gas air ratio can be controlled by operating the air control valve. The mixture also passes through the final filter so that any possible residual particulate matter is held back preventing possible deposition on the valve seat. The dual-fuel operation is aimed at reducing the diesel consumption at any fixed load.

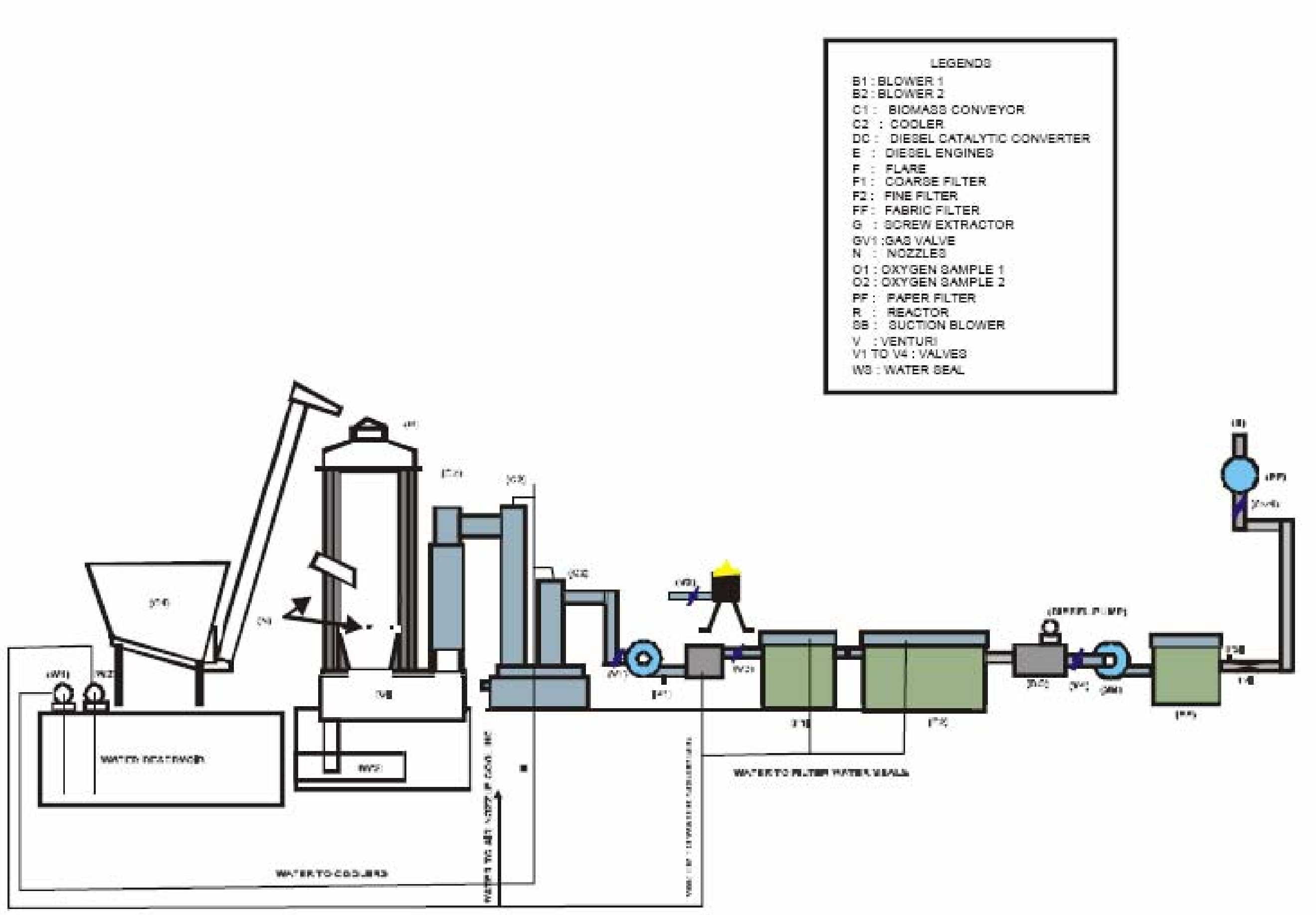

Figure 7: Schematic of a 500 kg/hr gasifier system

In an actual dual-fuel operation, the desired diesel replacement is achieved by reducing the air flow into the engine slowly by operating the air control valve. The engine draws in a specific flow rate through the air manifold. As the sum of air and gas flow rate is constant and when air flow is decreased, the gas flow through the system increases. This increases the contribution of the energy from the gas. Hence, the engine governor comes into operation and cuts down the diesel to maintain the speed. Reducing the airflow rate will reduce the diesel flow only as long as the gas-air mixture remains lean. The diesel replacement under conditions close to stall can be between 90 to 93 Allowing a safety margin of about 5 to 6 % for fluctuating loads to keep the operation away from stall, diesel replacement of 85-87 % can be obtained. This can be done either manually or through automation. In the case of manual operation, air valve is manually adjusted to obtain the desired diesel replacement after manually measuring diesel flow rate and load. The limitation of this system is that the response is slow in the case of varying loads; optimization of diesel replacement becomes difficult. In the control system which was specially designed for use with biomass gasifiers, the diesel flow rate, load and frequency measurements are also handled electronically and these are either processed in a PLC control system or passed on to a computer for acquisition and control.

Continuing on the performance in dual-fuel mode, the diesel replacement is around 85 % or above over most of the load range. The wood consumption is 0.95 to1.4 kg/kWhr. The biomass consumption depends on the size of the system and the moisture content of wood chips. A 3.7 kWe engine consumes

1.2--1.4 kg/kWhr and 100 kW engine consumes 0.9--1.0 kg/kWhr of biomass. The overall efficiency of operation, measured as the ratio of the final electrical energy output to the total input energy of diesel and wood, is another performance parameter. Diesel engines show full load overall efficiency of 24 % in 3.7 kWe engines and 35 % in 100 kWe engines. In dual-fuel mode, overall efficiency is 21 % in 3.7kWe engines and 27 % in 100 kWe engines at 85 % diesel replacement (Mukunda et al 1995). The reduction in overall efficiency is traced to poor flame speeds of producer gas mixtures and hence poorer combustion efficiency.

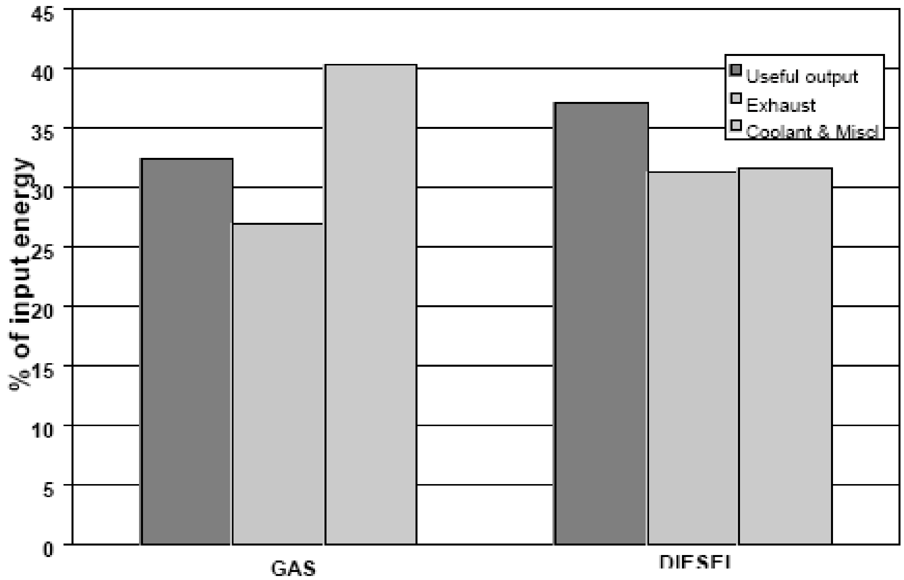

Fig 8. Overall energy balance in gas and diesel at 17:1 CR at peak output

Figure 8 compares the energy balance in gas and diesel mode (at rated output of 21 kWe) at CR of 17:1. The energy loss to the coolant was found to be about 40% as against 33% in diesel at the maximum power. Thus the heat loss from the cylinder walls in the case of gas engine was high compared with the diesel engine. The energy loss through exhaust in gas mode reduced by 5% compared with that of a diesel engine. The useful energy was about 32.5% at CR of 17:1 and declined to about 25.7% at CR of 11.5:1. The useful energy at CR of 13.5:1 stood about the same as that at 14.5:1 due to relatively leaner operation.

The increased amount of heat loss to the cooling water on a whole in gas operation could be attributed to engine combustion chamber design. It has been quoted in the literature that with engine geometries such as bowl-in-piston there shall be 10% higher heat transfer. The heat transfer to the coolant in the current case falls well within this range. With the increase in compression ratio the overall conversion efficiencies must improve thermodynamically, similarly the heat loss to the coolant and exhaust should have been reduced. However, there was increased energy loss to the coolant at higher compression ratio probably due to increase in heat transfer coefficient.

Field experience

Over the last two decades, the field experience has been both of learning and challenging nature. Significant efforts were made during this period to meet the end user requirements both in terms heat and electricity using of various agro residues as the fuel. The following list of table gives the some of the systems installed in the field.

Year	Location / plant owners	Gasifier rating and application	No. of Units	Operating Hours
1986 to 1990	Location: all over India. (Ministry of Non Conventional Energy Sources of Energy, MNES, Govt. Of India)	3.7 kWe (for running of water Pumps) Fuel : wood	250	40000 (Demonstration phases)
1988 & 1995	Hanumanth Nagar & Hosahalli, Tumkur, Karnataka, India. ASTRA, Bangalore.	Initially for 3.7 kWe and later to 20 kWe for drinking and irrigation water pumping and illumination Fuel : wood and mulberry sticks	3	8000
1990	Port Blair. Andaman & Nicobar Islands, India. Dept. of Electricity, (MNES, Govt. of India).	80 kWe – to meet the workshop load of Chattam saw mill Fuel : Saw mill waste	1	4000
1995	Chatel St Denis, Switzerland. Centre De Competence, C.C.C. (Test plant).	60 kWe connected to a gas engine to run on Single Fuel mode Fuel : Pine chips	1	About 1600
1996	Orchha, Tikamgarh, M.P., India	80 kWe – to meet the energy demand of a hand made paper industry Fuel : Ipomea weed	1	About 12000
1998	Roorkee, U.P., India. Central Building Research Institute.	800 kWth – a project to evaluate the feasibility of using in brick kilns Fuel : Wood chips and cotton stalks	1	About 500
1998	Ramnagaram, Dist. Bangalore, Karnataka, India. Senapathi Whitely Ltd.	500 kWe – to meet the captive power of an industry ; connecting to 2 X 275 kVA engine Fuel : Coconut shells	1	1500
1998	Gollahalli, Tumkur, Karnataka, India. Jawahar Navodaya Vidyalaya	100 kWe Fuel : Wood chips	1	800+
1998	Butachaques Island, 1200 kms south of Santiago, Chile	50 kg/hr gasifier coupled to 2 nos of dual fuel engine of 25 kVA capacity – island electrification Fuel : Wood chips	1	1900 as of June 2000

Year	**Location / plant owners**	**Gasifier rating and application**	**No. of Units**	**Operating Hours**
1999	Badadhara, Orissa, India. A DESI Power IRPP	100 kWe – to meet the energy demand of a village Fuel : Wood chips	1	Commissioned
2000	Father Jovita/ Kolar	50 kg/hr gasifier coupled to a gas engine of 20 kVA and dual fuel engine of 25 kVA capacity *Fuel : Wood chips*	1	500
2000	Synthite chemicals – Karai Madai, Chennai	2000 kWth – to meet the energy requirement for drying marigold *Fuel : Marigold waste and coconut shells*	1	500
1998	Agro Bio-chem - Davanagere	800 kWth to meet the energy requirement for drying marigold *Fuel : Wood chips*	1	3600
2000	Agro Bio-chem - Davanagere	2000 kWth to meet the energy requirement for drying marigold *Fuel : Wood chips and marigold waste*	1	Commissioned

The above list gives the various applications addressed in the implementation phase. During this period several technological improvements have been addressed and the concept of total package including the subsystems has been examined. At the time of this writing a total of 1.4 MWe and 3 MWth systems have been established using IISc technology. This has saved about (1.6 million units) 0.35 million litres of diesel in power generation and about 0.25 million litres of diesel in the thermal application. This is just the beginning of a new era for bio-energy systems.

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