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Source: *Current Science*, Vol. 87, No. 7 (10 October 2004), pp. 908-916
Published by: Current Science Association
Stable URL: https://www.jstor.org/stable/24109394
Accessed: 11-11-2022 11:40 UTC

Biomass gasification technology – a route to meet energy needs

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The paper addresses a distributed power generation system that has evolved at the Indian Institute of Science, Bangalore. The technological and field-related experience pertaining to open top re-burn down draft biomass gasification system coupled with the internal combustion engine or thermal device are brought out. The gasifier reactor design uses dual air entry – air nozzles and open top to help in establishing a thick high temperature zone to remove the contaminants in the product gas; a gas clean-up system to further refine the gas to ultra-pure quality. These elements are integrated with other sub-systems, namely feedstock preparation, ash handling, water treatment, process automation and other accessories to form an Independent Power Producer. Based on this technology there are over 30 units operating in India and abroad, with an accumulated capacity of over 20 MW. Over 80,000 h of operation of these systems have resulted in a saving of about 350 tons of fossil fuel, implying a saving of about 1120 tons of CO_2 – a promising candidate for Clean Development Mechanisms (CDMs), other than reduction in toxic gases like NO_x and SO_x.

A large population in the world are still not being serviced with energy needs at the minimum level even in the 21st century. This is true with the developing nations like India, Bangladesh, Sri Lanka, Pakistan, Latin American countries like Chile, Costa Rica, Brazil, etc., African countries like Zambia, Uganda, Zimbabwe, etc. and many others. Most of these countries are characterized by a large part of the population in scattered locales – in villages and hamlets. These remote locations make it uneconomical to extend the centralized grid. In addition, their economic structure is not strong towards importing oil for power generation applications. Further, the environmental considerations to reduce GHG have forced conservation of the use of fossil fuel. This has become one of the factors for the nations to reduce the use of fossil fuel and adopt suitable renewable energy device.

In the renewable energy scenario dominated by solar, wind and micro/mini hydel, biomass is beginning to look promising in the view of new emerging technologies. Even though each of the above energy sources has a niche market, biomass has been playing a key role in the renewable energy sector. The modern bio-energy has received comparatively little fiscal and financial incentive unlike its counterpart, namely the solar photovoltaics. However, for reasons like the cost effectiveness and availability factor, biomass-based technologies are becoming popular as they have edge over other renewables[1].

India an oil-importing country, with nearly 70% of its population living in half million villages and hamlets across the country and rich in bio-resources is ideally suited for biomass-based technologies. The Ministry of Non-conventional Energy Sources (MNES) has taken the initiative to develop research groups within India for technology and manpower development. As a consequence, one of the premier institutions namely, the Indian Institute of Science (IISc) has been involved in the field of biomass combustion and gasification over twenty years by conducting innovative research, technology development, dissemination, training, technology demonstration and testing of system in accordance to the international protocols. It is also involved in areas of consultancy, technology transfers and imparting training to the international participants.

It is important to begin this article by enunciating the motivation behind the development of gasifiers at IISc. Early in 1979, the attention of Shrinivasa and Mukunda[2] was brought to a singularly valuable document, the translation of Swedish experience on gasifiers by the Solar Energy Research Institute, USA[3]. A study of this document showed that the development of low power wood gasifiers posed problems of gas quality, in particular the problem of tar at part loads. At that point it was inferred that if any gasifier design had any chance of success, 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 reactor (however well designed) would be unfavourable for small power level systems. In order to ensure reliable operation with a good gas quality it is imperative that energy conservation is ensured by providing an environment close to adiabatic condition. A large number of tests on the classical closed top design gasifier revealed that while at one flow rate, close to the rated value, one would get nearly tar-free gas, but at reduced flow rates the performance would deteriorate.

The technology to harness energy by this route has taken place in spurts; the most intensive of these was dur-

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*For correspondence. (e-mail: dasappa@cgpl.iisc.ernet.in) ing 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 gasifiers – basic as well as developmental – of this period have been well documented in the English translation of the Swedish work[3]. Additional details and some classical description of the early work are also available in a review by Kaupp and Goss[4]. 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[5] who conducted systematic studies on what appeared to be simpler geometry of the reactor with an open top design. This design was being used in rice husk gasifiers earlier particularly in China[6]. However, this concept did not evolve into an acceptable technology for gasifying wood until recently when we examined and modified it to produce a workable technology for a range of power level from 1 to 1100 kg/h capacity[7].

In the light of the above background, this article attempts to critically review the current work and present various aspects related to design of gasifiers and highlight the state-of-the-art technology package for distributed power generation comprising biomass gasifier coupled with a diesel or gas engine.

Open top re-burn down draft gasifier – a state-of-the-art technology

The biomass gasification technology package consists of a fuel and ash handling system, gasification system –reactor, gas cooling and cleaning system. There are also auxiliary systems namely, the water-treatment plant to meet the requirements of industry and pollution control board. The prime mover for power generation consists of either a diesel engine or a spark-ignited engine coupled to an alternator. In the case of thermal system, the end use device is a standard industrial burner. The aspects of system design have been addressed in detail elsewhere[7].

Typical gasifier system configuration is shown in Figure 1. The novel open top down draft reactor design is a ceramic-lined cylindrical vessel with a bottom screw for ash extraction. The dual air entry – from top and the nozzles – permits establishing front moving propagation towards the top of the reactor. This favours a high residence time for the gases at elevated temperatures, eliminating the higher molecular weight compounds. Detailed measurements[8–10] have shown that the fraction of higher molecular weight compounds in the hot gas from an open top design is lower than in a closed top design. The cracking of the tars improves the overall gasification efficiency. These have been further strengthened by the measurements made jointly with collaborators from Switzerland on the gasification system in India and Switzerland; collaborators have further compared the performance with other gasifiers in Europe. Hasler[11] shows that of the nine gasifiers tested, the gasifier developed at the IISc has both tar and particulate at the lower end in the raw gas compared with the other gasifiers. The results for the IISc design presented are from elaborate tests conducted in India and Switzerland. The results from Switzerland also include results from fuel with 37% moisture. Figure 2 shows the variation of tar and particulate in the raw gas with varying moisture content in the fuel for different gasifiers including that of IISc design[11]. While both tar and particulate are undesirable components in the gas for end-use application, the level of tar in the gas is related to the thermochemical aspects of reactor design. This is related to air flow distribution, temperature profile in the reactor, heat loss from the reactor and related aspects. It is clear from about 35 test results[7,8,11] using different biomass, gasifier ratings and load conditions, the tar content in the IISc design is lower than that of many other designs, implying superiority in the reactor design. This has been possible partly due the high quality insulating material used for reactor construction and also air distribution between the nozzle and the reactor top. It is evident from these plots that with increase in moisture content, the tar level in the gas would increase.

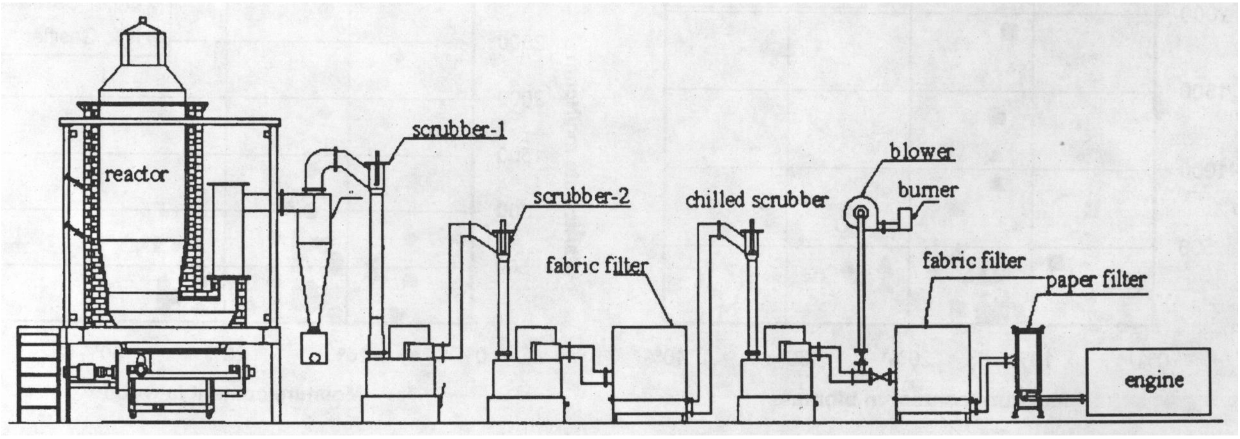

Figure 1. Typical configuration of the gasifier.

This is due to the reduction in peak temperature in the bed for thermodynamic reasons, which in turn reduces the effectiveness of cracking of the higher molecular weight compounds, namely tar. The tar content in the raw gas is in the range of 50–250 mg/Nm^3 for fuel moisture content less than 15%, beyond which it increases to about 700 mg/Nm^3. Figure 3 shows the variation of dust concentration in the raw gas with moisture content in the fuel. The particulate levels in the raw gas are found generally in the same range over the large number of tests. At higher moisture content level, the particulate is lower due to the gasifier operating at low power level, thus lower velocities in the reactor exit region. Particulate in the gas depends upon the design of the reactor exit, grate design and related geometry that would maintain low velocities to eliminate the carry over of particles from the reactor.

The other benefit in the case of superior reactor design is related to the energy available in the gas. Even at capacities in the range of 75 kg/h the cold gas efficiencies has been around[8,9] 75%. These results are among the best of conversion efficiencies presented by Hasler[11] of all the gasifiers. Measurements on the large capacity gasifier system at 650 kg/h, have resulted in cold conversion efficiencies in the range of 85%.

The recent development in the gas cooling and cleaning system provides dry producer gas with the tar and particulate level in the range of ppb levels. This has been possible by using C^n patented technology. In this process, hot high efficiency cyclones are used to remove dry particulates from the gas and ejector scrubbers to cool and clean the gas. The gas is de-humidified or dried using the principle of condensate nucleation, to reduce moisture and fine contaminants. Measurements for the gas quality by established procedure[7,12] have resulted in tar and particulate level less than 5 mg/Nm^3. Measurements on the particle size in the gas at the cyclone exit on the IISc design in Switzerland indicate that a majority of the particles (> 95%) are well below 0.5 μm. These measurements substantiate the results from the field installations discussed later in this article.

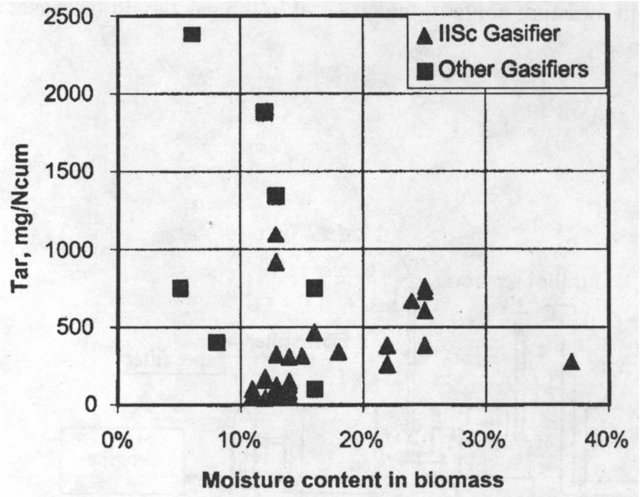

Figure 2. Variation of hot tar in the raw gas for different gasifiers with moisture content in the biomass[11].

The gasification technology package that was discussed earlier is based on some of the basic studies conducted in the areas of gasifier and producer gas engine. These studies are dealt in some detail in the following sections.

Gasifier studies

The essence of gasification is the conversion of the solid fuel to gaseous fuel by thermochemical 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 generation of gas occurs in two significant steps. The first step involves exothermic reactions of oxygen in air with the pyrolysis gas under fuel-rich conditions. The second step involves the endothermic reaction of these gases largely CO_2 and H_2O with hot char leading to product gases namely, CO, H_2 and CH_4. In the early part of the development, basic research towards the understanding of the processes occurring was carried out through single particle studies along with packed bed.

Several works[13–17] focused on both experimental and modelling studies of the reactions of wood-char spheres with oxygen, steam and mixtures of CO_2, O_2 and H_2O as functions of particle diameter, ambient temperature, composition and flow velocity. Char-based reactors are modelled 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. Modelling 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 cases of $C - O_2$, CO_2 and H_2O reactions, the conversion time dependence

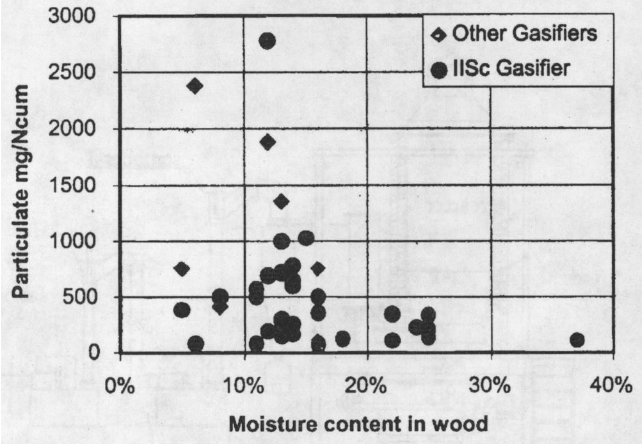

Figure 3. Variation of hot end particulate in the raw gas for different gasifiers with moisture content in the biomass[11].

for the char is shown to be $t_c \sim d_o^n$, where $n = 1.9$, 1 and 1.2 respectively. Figure 4 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 indicated in the figure have been evaluated for various ambient conditions and the model predictions are in reasonable agreement with the experimental results.

The experimental and the model results indicate the air mass flux with propagation rate as shown in Figure 5. The propagation rate is the rate at which the reaction front moves into the fuel bed. From the results it is clear that with increase in the mass flux the propagation rate initially increases, and decreases. The increase and decrease of the propagation rate have an optimum. This is due to heat release and heat loss rates at the reaction front. These are addressed in ref. 17. Results from the gasification process modelling are compared with the 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/m^2 s, propagation ceases and reaches extinction. This feature has been examined using the analysis proposed in the literature[18]. 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.

These 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, has led to the understanding of the performance of the open top reactor designs. They have provided ways to structure the design of the gasifier as well.

Producer gas engines

Producer gas to substitute the fossil fuels in internal combustion engines has been in practice since the World War II. Literature survey in the field of producer gas-based engines reveals modest research work. This could be attributed to two reasons, namely non-availability of standard gasification system that could generate consistent quality producer gas and the other relating to misconceptions about producer gas fuel. These misconceptions are (i) auto-ignition tendency at higher CR and (ii) large de-rating in power due to energy density being low. However, these perceptions need re-examination and clarification. The arguments against the classical view in favour of better knock resistivity are as follows. First, with the laminar burning velocity being high due to the presence of hydrogen (more so, with the IISc gasifier system) might reduce the tendency for the knock. Second, the presence of inert in the raw gas (CO_2 and N_2) might suppress the pre-flame reactions that are responsible for knocking on account of increased dilution. Also the maximum flame temperature attainable with the producer gas being lower compared to conventional fuels like methane, one could expect better knock resistivity. A survey of the literature shows that producer gas has not been subjected to study on knock behaviour.

Further, there is a general perception that producer gas being a low-density energy fuel, the extent of de-rating in power would be large when compared to high-energy density fuels like natural gas and liquefied petroleum gas. This could be misleading because what need to be accounted for comparison are the mixture energy density and not the fuel energy density per se. On comparison with CH_4, the mixture energy density for producer gas is lower by 20–25%. In addition, the product to reactant mole ratio for producer gas is less than one. These two parameters could contribute to de-rating of engine output. However, it might be possible to reduce de-rating by working with engines of higher compression ratio (CR).

Earlier work

Producer gas is being used in diesel engines in duel fuel mode for power generation application, i.e. producer gas

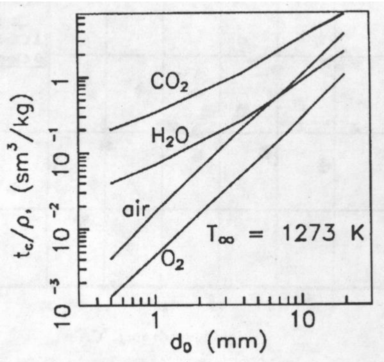

Figure 4. Normalized conversion time versus diameter for different reactants (of CO_2, O_2, H_2O and air) at T_{amb} = 1273 k, from the model.

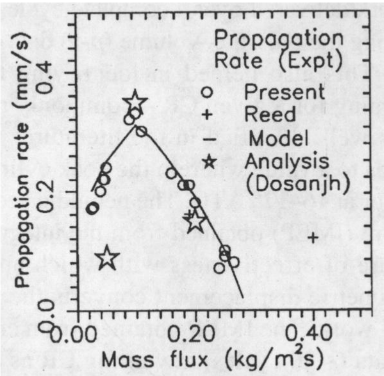

Figure 5. Propagation rate with mass flux in a packed char bed from experiments, model and analysis.

and diesel as fuel in proportion varying in the range of 20–30% of diesel has been achieved over many systems deployed in the field[19,20]. It is in the area of gas only operation that certain fundamental issues namely, the effect on compression ratio, spark timing, air-to-fuel ratio and gas carburetion were addressed. Producer gas as a fuel in a spark ignited engine has been addressed by a few researchers[21–27]. Most of the work is concentrated on modifying a diesel engine to operate on producer gas, with CR in the range of 7–11. The choice of limiting engine CR for producer gas operation is a result of experiences from other gaseous fuels like natural gas, liquefied petroleum gas, compressed natural gas and biogas, presuming that knock would occur when operated at higher CR.

Investigations at IISc

Research at IISc was taken up to address issues related to producer gas operation, and optimization of the power output from the given engine cylinder volume[28–30]. The primary factors that influence the performance of the engine are the gas calorific value, CR and molar changes due to combustion, leading to changes in peak pressures, peak temperature, turbo charger pressure and finally the quality of combustion for a given cylinder geometry[31].

Experimental investigation to establish the performance of the engines was set out on a three-cylinder engine. Pressure vs crank angle data was acquired in order to essentially establish if knock[32] occurs with producer gas operation at varying CRs. Apart from this, it was also used for identifying the optimum ignition timing, which is commonly referred to as minimum advance for brake torque (MBT). The outcome of these tests was that the engine worked smoothly without any sign of knock at the CR of 17. There was no sign of audible knock during the entire load range. Moreover, the absence of knock is clear from the pressure–crank angle (p–θ) data, which does not show any pressure oscillations, either at part load or at full load (wide open throttle) conditions. The p–θ diagram for engine at various CRs around optimum ignition timing is shown in Figure 6.

The other important issue is related to the spark timing. The net work delivered over a complete cycle can be found by integrating the pressure–volume (p-v) data over the four processes. This also helped in identifying the optimum ignition timing for a given CR – commonly referred to as MBT. It is well identified in the literature[32,33] that MBT corresponds to a value wherein the peak cylinder pressure should occur at 16–17° ATC. The net indicated mean effective pressure (IMEP) obtained from the integrated p-v data is a measure of effectiveness with which an engine of a given volumetric displacement converts the input energy into useful work. The IMEP obtained from ensemble average p-v data (~ 30 cycles) at varying CR as a function of ignition timing is shown in Figure 7. At CR = 17, the maximum IMEP recorded is 5.98 bar corresponding to a ignition timing of 6° CA and this declined to 4.85 bar with ignition timing being at 15° CA for CR = 11.5. These values are obtained at fuel-air equivalence ratio, $\phi = 1.08 + 0.2$ and fall within the anticipated value of $\phi = 1.0$ to 1.1 ref[32]. It is also evident from the plot that variations in the IMEP values are modest between ignition timings of 6 and 12° CA corresponding to CR = 17. The coefficient of variation of the IMEP at all CRs and ignition settings occurred well within 3–3.5%, implying low cycle-to-cycle variation. The reason for low cyclic variation is the faster rate of combustion occurring inside the engine cylinder. The faster rate of combustion is attributed to higher flame speeds due to the presence of hydrogen in the gas and to the combustion chamber design; the bowl-in-piston combustion chamber design generates higher turbulence levels[30], resulting in faster burn rate.

Emissions

It is interesting to bring another important result pertaining to the gaseous emission from the producer gas engine.

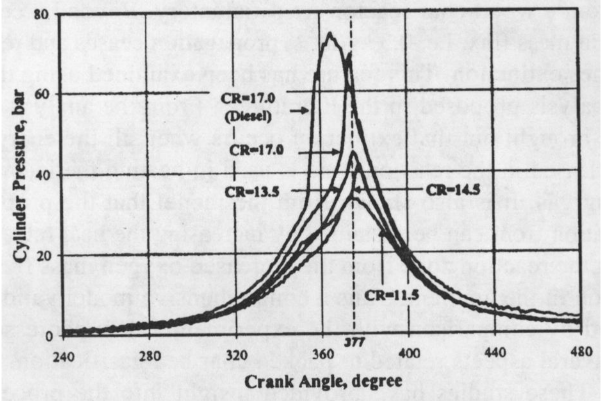

Figure 6. Comparison of p–θ curves at different CRs; Ignition timing is at MBT or close to MBT (within MBT + 2° CA). The p—θ curves correspond to ignition setting of 10°, 10°, 14° and 15° BTC for CR of 17, 14.5, 13.5 and 11.5 respectively. Operation in diesel mode at 90% of rated load (at optimum injection timing – 34° BTC). All are ensemble-averaged data over 30 consecutive cycles.

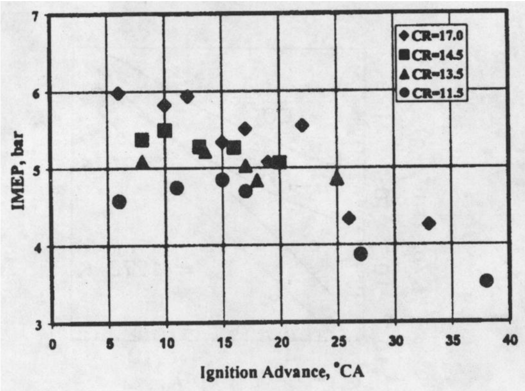

Figure 7. Variation of IMEP (net) for engine with ignition advance at various compression ratios.

The variation of nitric oxide (NO) at varying CR with ignition advance is shown in Figure 8. These results have been compared with the existing Central Pollution Control Board (CPCB) norms for diesel vehicles and Swiss norms. The NO level reduced with the retardation of ignition timing and this feature was observed for all CRs. The NO level was maximum at the highest compression ratio with advanced ignition timings, whereas for the MBT range of 6 to 20 degrees BTC the NO was roughly about the same in almost all the cases. However, there was one exception of NO being higher at MBT for CR of 13.5 due to leaner operation. It is known that NO generation is strongly dependent on the temperature and also residence time in the combustion chamber. With the flame speed of the gas mixture being high and the ignition setting retarded, the residence time in the high temperature combustion chamber is automatically reduced thereby helping in reduced NO generation. The above results match well with those reported in the literature[32], which shows small to modest variation of NO with CR.

Field experience of different power level gasifiers

Over the last two decades, field experience has been challenging but has led to considerable learning. Significant efforts were made during this period to meet the end use requirements both in terms heat and electricity using a variety of agro residues as the fuel. In the use of gasifier for electricity generation, three sectors are addressed, viz. village electrification, captive power generation and grid application – independent power producers. An overview of the field experience would be presented in this section, highlighting the technology reliability and the performance. Based on field data, cost related to operation and maintenance is highlighted.

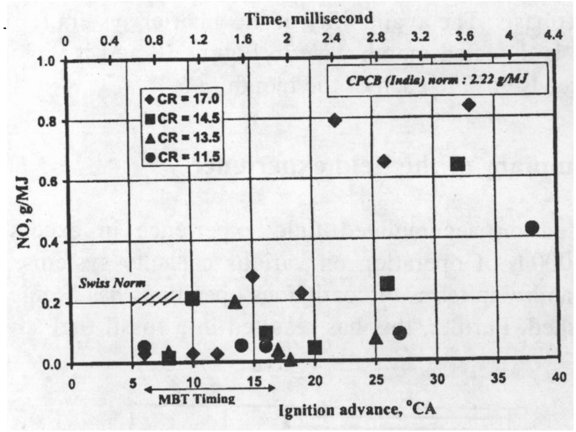

Figure 8. Variation of NO with ignition advance at various compression ratios.

Village electrification

In the case of village electrification, two major installations at Hosahalli and Hanumanthanagara in Tumkur district provide an insight into the social and technical issues[34]. Details of the experience in the electrification project at Hosahalli are provided by Ravindranath *et al.*[35]. The Hosahalli system is in operation for over sixteen years providing electricity for domestic and agricultural services. There has also been another experiment related to the use of gasifier for irrigation application[36]. These have resulted in establishing benchmarks for the new paradigm 'distributed power generation' systems as identified by the Ministry of Power in their document for Rural Electrification Strategy in India.

Captive power generation

Gasification systems have been used for captive power generation in industries to meet the energy demand. About six systems in the range of 100 kWe capacity are in the field to meet the electrical demand in a two/three shift mode of operation per day. Except for one unit, all the system packaging is for dual fuel operation. Figure 9 shows the details of operation of a system in Orchaa, in MP, to feed electricity to the hand-made paper unit. The system has been in operation since 1996 on an 8-hour basis, amounting to about 2000–2500 h of operation per year. The gasifier system uses a low density weed, Ipomea, as the fuel. The gasifier system has so far operated for over 17,000 h and has generated electricity of about half a million kWh. It

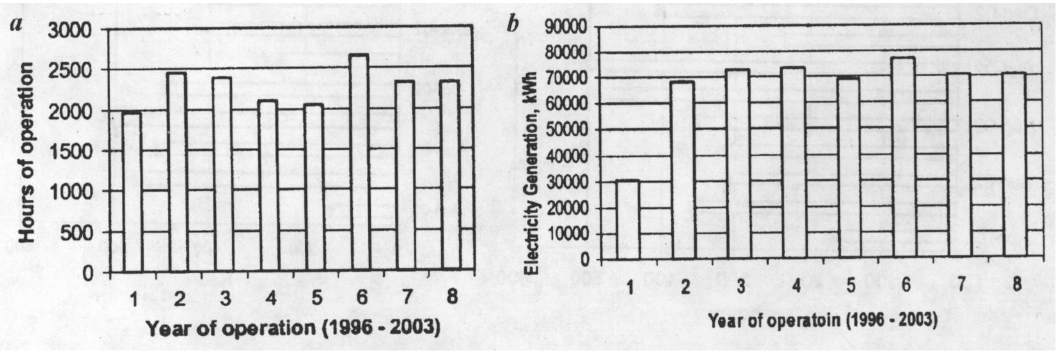

Figure 9. Hours of operation and electricity generation of a plant in Orccha for captive power generation.

has been possible to generate electricity with a specific fuel consumption of 0.1 kg of diesel and 1 kg of biomass per kWh. This amounts to a diesel savings of about 70% and an overall efficiency from fuel to electricity, of about 20%. The high fossil fuel consumption is related to the startup and shut-down operation using diesel in engine, as this location has no grid supply.

Experience with using gas engines for power generation has been at two locations – a 16 kWe capacity for farm application being used occasionally and a 120 kWe at industrial location for 3 shift operation for 5000 hours. Limited experience on system operating on a 3 shift has indicated a specific biomass consumption of about 1.2 kg/kWh. This amounts to an overall conversion efficiency of about 20%.

Grid linked generation

The experience in this sector is related to one major installation at a MW level. The system packaging was conceived as an Independent Power Producer (IPP), with all the fuel handling, ash handling, water treatment, grid paralleling, etc. A dual fuel engine is used as a prime mover. The system is designed to handle coconut shells as the fuel, with activated carbon as a by-product. The system has operated over 4800 h at an average load of 650 kWe and has generated about 2.9 million units of electricity, consuming about 2 million tons of biomass and 0.27 million litres of fossil fuel. The ash extraction is tuned to extract about 5% of the feed as char, which has an iodine number of about 600 which is extensively used in water-treatment plants. The overall wood to electricity conversion efficiency is about 25%.

Comparing the performance of dual fuel and producer gas only mode of power generation, the overall efficiency of dual fuel engine is nearly same or lower to that of a producer gas operation. This is due to combustion processes occurring in the dual mode, where diesel and gaseous fuel combustion occur simultaneously. This condition leads to incomplete combustion, resulting in high CO in the exhaust and also higher exhaust temperature[28] leading to higher losses. The producer gas alone mode of operation is a combustion of homogenous mixture of gaseous species resulting in better combustion. Thus the overall losses are reduced amounting to better efficiencies.

Thermal systems

About eight gasifier systems have been used in the field for various high quality heat applications in the capacity range of 0.2–5 MW. All the systems replace fossil fuel used to meet the energy application[37,38]. In the high temperature range, one gasifier has been connected to eight heat treatment furnaces to replace about 2200 litres of fossil fuel daily. This system has operated for over 14,000 h; every litre of fossil fuel is replaced by about 3.6 kg of biomass. Another system of about 5 MW thermal has been recently installed for a chemical industry to have kiln temperature in the range of 550–600°C, to replace about 280 litres of fossil fuel per hour. At low temperature application six systems in the range of 0.2–2 MW capacities are used in drying of marigold flowers and also in crumb rubber drying. All the systems generally operate on a 3-shift basis. The availability of the gasifier system for end use is depicted month-wise in Figure 10 and it typically exceeds 95% in each of the month.

Summary of the field experience

Based on accumulated field experience in excess of 80,000 h of operation on various capacity systems, the reliability in terms of continuous operations has been established. Further, this has resulted in a fossil fuel saving

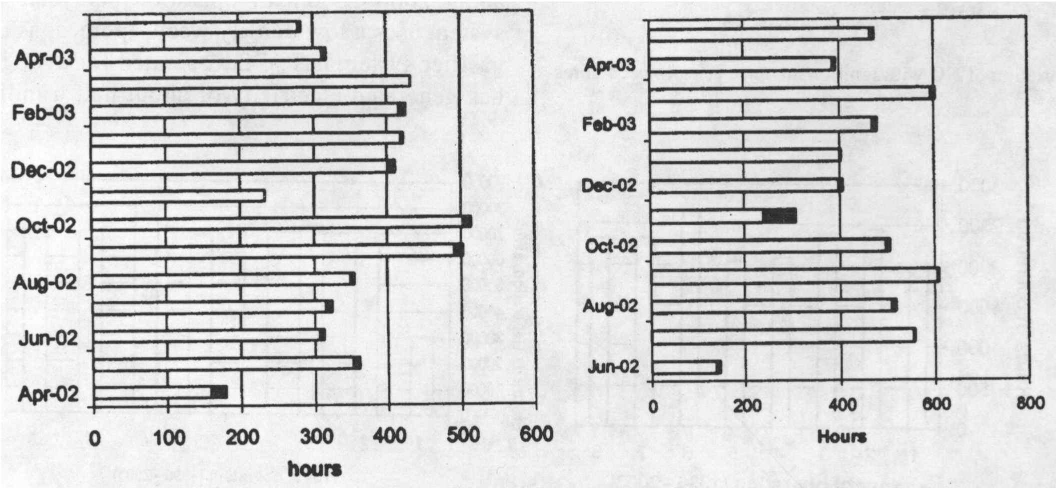

Figure 10. Monthly operating hours on a 0.2 MWth gasifier plant for crumb rubber drying at two different locations. Dark patches indicate the non-availability of the gasifier system due to maintenance.

Table 1. Operating cost distribution for thermal systems of different capacities

System location	Application	Hours of operation	Gasifier rating (kg/h)	O&M (Rs/kg/h)	Manpower (Rs/kg/h)	Total (Rs/kg/h)
Ideal Crumb	Thermal	5500	60	0.1	0.15	0.25
Tahafet	Thermal	10500	300	0.14	0.16	0.3
Arasi	Electrical	3000	500	0.08	0.16	0.24

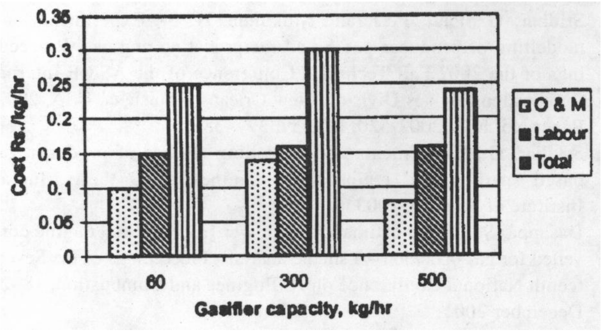

Figure 11. Distribution of cost towards O&M and labour for operating a gasifier system.

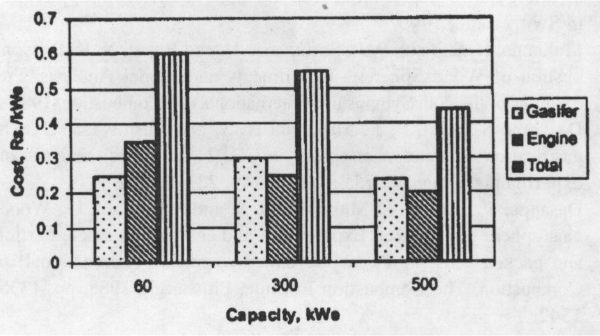

Figure 12. Distribution of cost towards O&M and labour for a gasifier and engine system.

of 350 tons; typical daily saving being about 18,000 litres of fossil fuel. This replacement of fossil fuel has resulted in a net saving of about 1120 tons of CO_2. The required system performance has been achieved in most of the cases. Another important aspect related to the reliability of the technology package is the supplementary investment required to maintain the system. Some of these issues are highlighted in the next few paragraphs for three field systems.

Based on cumulative 18,000 h of operation on the three systems indicated in Table 1, operating costs are estimated. The actual manpower cost has been accounted. The cost towards operation and maintenance are from the investment made by the user and the manufacturer over the period of run. This is shown in Figure 11.

Typical commercial rates for operation and maintenance (with manpower) of diesel engine are about Rs 0.2–0.35 per kWh. This excludes the fuel oil and lubricating oil costs. Using the O&M costs shown in Table 1, the overall cost for power generation is indicated in the Figure 12.

To service the requirements of distributed power generation and to meet the energy needs of various sectors, bioenergy has been found to be a successful resource. The global requirement of CO_2 neutral technologies and the clean development mechanism to address climate change should further motivate spread of gasifiers. At the Institute the technology has been licensed to three industries in India and two overseas.

Conclusions

The last two decades of R&D efforts at the Indian Institute of Science, in the area of biomass gasification have resulted in a technology package to meet the energy needs in various sectors. The gasification system has proved a reliable alternative for village electrification and industrial operations meeting thermal and electrical needs. The development relating to dual fuelling and gas alone operation of standard engines has resulted in field applications producing several million kilowatt-hours daily substituting fossil fuel. All the field performance has been documented, analysed and appropriate inputs taken to standardize the technology. These efforts have culminated into a patented biomass gasification technology that can use a variety of fuels and meet various energy needs.

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ACKNOWLEDGEMENTS. The work reported here has received technical, financial and moral support of many organizations and individuals. The Karnataka State Council for Science and Technology initiated the work; it was taken up in very significant measure by the Ministry of Non-Conventional Energy Sources whose subsequent financial support is responsible for what has been achieved.