GREEN ELECTRICITY FROM BIOMASS FUELLED PRODUCER GAS ENGINE

G Sridhar, H V Sridhar, S Dasappa, P J Paul, D N Subbukrishna and N K S Rajan
Combustion Gasification and Propulsion Laboratory
Centre for Sustainable Technologies
Department of Aerospace Engineering, Indian Institute of Science Bangalore, India.
email: abets@cgpl.iisc.ernet.in

ABSTRACT: In the recent times issues like the Green House Gas (GHG) emission reduction and carbon-trading through Clean Development Mechanism (CDM) have gained large prominence as a part of climate change. Biomass gasification is one such technology which is environmentally benign and holds large promise for the future. These technologies are currently being utilized for power generation applications at a number of industrial sites in India and abroad. In India there are nearly 4 MWe equivalent power plants which are based on IISc's open top reburn down draft biomass gasification technology. In the field of power generation, there has been substantial effort in the development of producer gas engine; systematic experimental and modeling studies followed by long duration field monitoring. As a part of this effort, a gas carburetor has been designed for producer gas fuel and forms a part of the power package. The essential requirements of gas conditioning equipment are packaged to meet the engine quality gas as a power plant. Currently there are more than 3.0 MWe equivalent gas engines operating in the field; of this one is deployed in an Energy Service Company (ESCO), which sells green electricity to a textile industry. The company is located at Metupalyam in South India, near the city of Coimbatore. The power plant is configured with a 150 kg/hr gasifier coupled with a turbo charged after cooled Cummins make (GTA855G) gas engine. The plant is also provided with an effluent treatment plant and an engine-waste-heat based biomass drier. The plant commissioned in September 2003 has successfully completed over 7500 hours of operation, generating about 0.7 million units, thus saving a net CO2 of about 0.7 million Tons against a fossil fuel technology. The plant operates on a continuously to meet the end use requirement over 275 hours non stop operations hours of operation. The power plant utilizes a weed namely Julifora Prosopis which is abundantly available in the southern part of India and converts into green energy; additionally generates value added product namely partially activated carbon – Iodine no. of 400 - 450. The paper reports specific biomass consumption and engine emission monitored over long duration. The specific biomass consumption is measured to be within 1.1 ± 0.1 kg/kWh with an overall efficiency of 22-24%. It is also found to be environmentally benign in terms of emissions; NOx and CO levels are found to be much lower than most of the existing emissions norms of various countries including the United States and European Union. The paper also highlights results from other installations using this technology. Keywords: open top gasifier, producer gas engine, CDM technology

1 INTRODUCTION

In the recent times, gaseous fuels are gaining prominence as cleaner fuels for power generation via internal combustion engine route; the power generation package including both reciprocating engines and gas turbine machinery. Among the clean sources of fuel for power generation, natural gas has been exploited largely due to significant availability in specific locations. Similarly, there is also an impetus on using gas generated from industrial and municipal wastes, namely diluted natural gas - biogas and land-fill gas. As distinct from gas generation from biological/organic wastes by biological conversion process, which is limited to nonlignaceous matter, the gasification route can process any solid organic matter. The resultant gas known as 'Producer gas' can be used for fuelling a compression ignition (CI) engine in dual-fuel mode or a spark-ignition (SI) engine in gas alone mode. Harnessing of energy from biomass via gasification route is not only proving to be economical but also environmentally benign [1]. One such technology is the open top, twin air entry, re-burn gasifier developed at Combustion, Gasification and Propulsion Laboratory (CGPL) of Indian Institute of Science (IISc), which is unique in terms of generating superior quality producer gas [2, 3, 4]. There are more than 35 plants that are successfully operating in India for heat and power applications. In the field of power generation, there has been substantial effort in the development of producer gas engine; systematic experimental and modeling studies [5, 10] followed by long duration field monitoring. As a part of this effort, a gas carburetor has been designed for producer gas fuel and forms a part of the power package. Currently there are more than twelve gas engines powered installations in the country, of which a few are commerical. Among these installations one that is deployed as an Energy Service Company (ESCO) is reported as a case study in this paper. Also, performances of other gas engine based plants are highlighted.

2 CASE STUDY

2.1 Plant Description

The plant referred here is deployed in an Energy Service Company (ESCO) named Bagavathi Biopower Private Limited which sells green electricity to a textile industry. Bagavathi Biopower Private Limited is located at Metupalyam in South India, near to the city of Coimbatore. The plant has been supplied and installed by Energreen Power Limited, Chennai (a licensee of IISc). The industrial class power plant is configured as a 150 kg/hr gasifier coupled to a producer gas engine of 120 kWe nominal capacity. The entire power plant can be categorized into three sub units namely feed stock preparation unit, gasification Island and power package as depicted in Fig. 1. The gasification island comprises of (a) Reactor with ash extraction system (b) Cyclones (c) Gas cooling and cleaning system (d) Fabric filter\s (e) Flare (h) Instrumentation (i) effluent treatment plant. The power package comprises of a turbo-charged Cummins gas engine with natural gas output of 180 kW (GTA 855G, rated at 120 kWe with producer gas) with a producer gas carburetor. The engine is coupled to 180 kVA alternator to generate electricity at 415 V. The electrical output at terminal of the control panel is connected to a textile industry with electrical loads comprising of heaters, induction motors and textile machinery. The gas engine meant for natural gas has been adopted with a specially designed carburetor [5] to operate on biomass derived producer gas. The engine delivered a peak power output of 134 kWe during the load trials. This power plant established in an ESCO mode operates 24 hours x 6 days in a week.

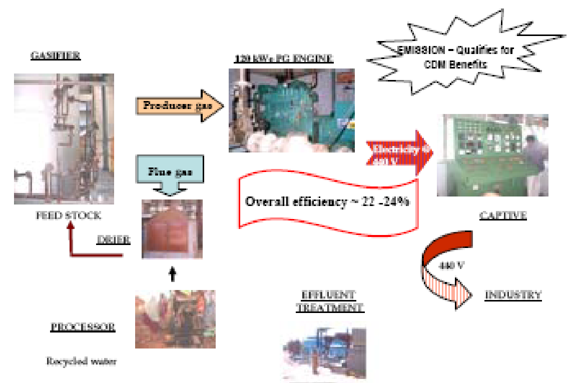

Figure 1 Power Plant configuration

2.2 Process Description

The gasification system comprises of 150 kg/hr capacity open top down draft re-burn gasifier reactor with gas cleaning and cooling system [6, 7, 8] as shown in Fig. 2. The reactor is a cylindrical shell with ceramic lining and an ash extraction system at the bottom. The open top re-burn design pursued at Indian Institute of Science (IISc) has concepts that can be argued to be helpful in reducing the tar levels to minimal in the resultant gas. This design has a long cylindrical reactor with air entry both from the top and the oxidation zone. The principal feature of the design is related to residence time of the reacting mixture in the reactor so as to generate a combustible gas with low tar content at different throughputs. This is achieved by the combustible gases generated in the combustion zone located around the side air nozzles to be reburnt before passing through a bottom section of hot char. Also, the reacting mixture is allowed to stay in the high temperature environment along with reactive char for such duration that ensures cracking of higher molecular weight molecules. Detailed measurements have shown that the fraction of higher molecular weight compounds in the hot gas from an open top design is lower than a closed top design [2, 6, 9]. The raw producer gas exits the reactor at about 800 to 900 K, and is laden with contaminants in form of particulate matter (1000 mg/Nm^3) and tar (150 mg/Nm^3) [2, 6, 9]. The hot dust laden gas is further processed in the gas cooling and cleaning system in order to condition the gas to a level that is acceptable for engine operations. The gas cooling and cleaning system processes the hot raw gas to a clean and dry gas with particulate and tar content less than a few ppb. This is possible using C^n patented technology [6, 7]. Firstly, the hot gas passes through a high

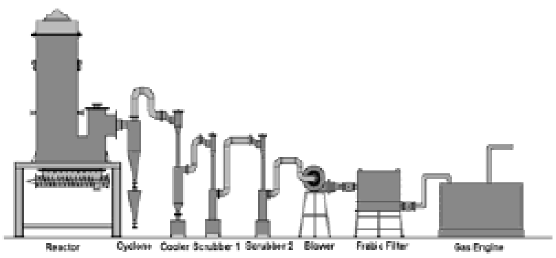

Figure 2 The Gasifier System

efficiency cyclone which separates the dry particulate matter from the raw gas (~ 80%). The next intermediate process of gas cooling and scrubbing is carried in ejector design scrubbers. The wash water for gas scrubbing is used in recycling mode after necessary treatment in the integral effluent treatment plant. The cooled and cleaned gas is further processed in another scrubber such that the resultant gas contains particulate and tar (P & T) matter less than 1 mg/Nm^3 [6, 7]. In this particular scrubber the gas is dehumidified using the principle of condensate nucleation wherein extremely fine particulate matter (~ 5 – 10 microns) is separated from the gas stream. The gas finally passes through a security fabric filter prior to flowing to the gas engine. The gas engine is provided with a producer gas carburetor system [5, 10, 11] such that the required air-to-fuel ratio of 1.3 ± 0.1 is maintained over the entire range of flow rates, thus permitting variable load operation. The waste heat from the engine exhaust is utilized for drying of the biomass in a tray type biomass drier.

2.3 Plant Performance

2.3.1 Gasifier

The gasifier reactor designed for multi-fuel option has been tested with a variety of feedstock namely coconut shell, casuarina and a weed named julifora prosopis. The biomass is initially sized to about 50 – 60 mm size in processing machine and partly dried by sun drying followed in a biomass drier such that the moisture content is within 15% on dry basis. Depending upon the ash content in the biomass the char/ash is extracted accordingly. The extraction would typically be about 5 - 6% (dry) for a biomass with an ash content of 2 -3%.

The performance of the gasifier in terms of gas composition has been monitored at random time intervals, usually when the system is operating close to rated condition. The producer gas was found to contain 19 ± 1% - H2; 19 ±1% - CO; 1.5 % -CH_4; 12±1% CO_2; 2 ± 0.5 % H_20 and rest, N_2. The mean calorific value of gas varied around 4..6 + 0.2 MJ/ kg, which corresponds to a cold gas efficiency of about 80 ± 2%. Also, *the gas quality in terms of particulate and tar matter is found to be less than 1 mg/Nm3 and has been found to be as low as 50 – 60 microgram/Nm^3 on a few instances*. The measurement of the contaminants have been carried out by using two different approaches, a standard wet method of P & T sampling and the second, which involves the collecting the sample from the turbocharger inlet till the inlet valve. There has been consistency in collected sample weights in these approaches.

2.3.2 Gas Engine

The plant commissioned in July 2003 has successfully completed over 7500 hours (until May 2005) of operation. It took about 3 – 4 months to stabilize the plant operations; subsequently the plant has been operating 24 hours x 6 days a week at an average load of 110 – 120 kWe. The maximum power delivered by the engine is recorded at 134 kWe. The ignition timing has been set at 22° CA (BTDC) based on optimization studies conducted on similar engine at the laboratory [5, 10, 11]. The end utility being a textile industry, there is susceptibility for large load variation. *The gas engine has been found to respond reasonably well to load changes as high as 35- 40% of the nominal output of the engine.*

Fig. 3 shows month-wise operation of the system during Aug '03 to Feb '05. During the plant stabilization, the duration of operation was lower. The stabilization period was slightly longer because of issues related to load management. The captive load had variations in excess of 60 % of the rated capacity. Even though under no-load condition this variation was acceptable, at the rated condition the engine frequency used to drop. With proper load management this issue was resolved. Subsequent to that the no. of hours of operation was around 400 hours except for few months during the onset of monsoon, wherein procuring dry biomass became a major bottleneck. At this juncture the flue gas based biomass dryer was installed. Once the dryer was installed, dry biomass was available on a continuous basis. The subsequent rise and fall in the no. of hours were more related to non-availability of plant load and has little to do with the availability of the plant for operations. The plant has completed over 7500 hours of operation as on May 2005.

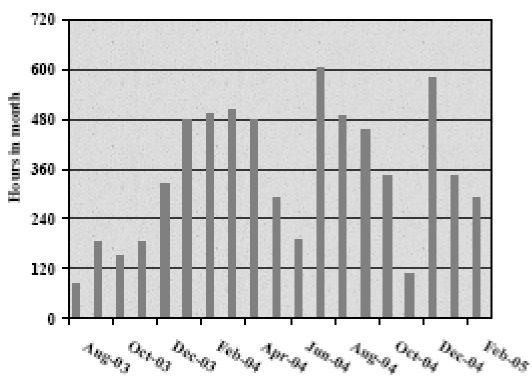

Figure 3 Month-wise no. of hours of operation

Fig. 4 shows the specific biomass consumption (sfc) variation with time. As indicated earlier during plant stabilization period the sfc varied between 1.2 to 1.7 kg/kWh. During this period the gas engine operated between 60-70% of the rated load and therefore the cause for sfc to be higher. Subsequently the plant operated at an average load between 100 and 120 kWe and sfc varied between 1.05 to 1.15 kg/kWhr. This corresponds to an overall efficiency (biomass – to – electricity) of 22 - 24%. There has been occasions when sfc has been in the range of 0.95 kg/kWh (on a daily basis).

The gas engine has been jointly monitored by IISc and Cummins India Limited and periodically inspected once every 1000 hours of operation. These inspections have shown the engine components (throttle valve, compressor of turbo-charger, after-cooler, intake manifold, intake valves and spark plug) to be clean and intact. Similarly the Total Base Number of lube oil quality has been found to satisfactory as per reports of the engine manufacturer. Currently lube oil change is being done once in 500hour of operation. The current operating cost (fuel + manpower + maintenance) per unit electricity generated is about 5 US Cents and moreover the maintenance cost for the gas engine has been found to be comparable to that of a diesel engine.

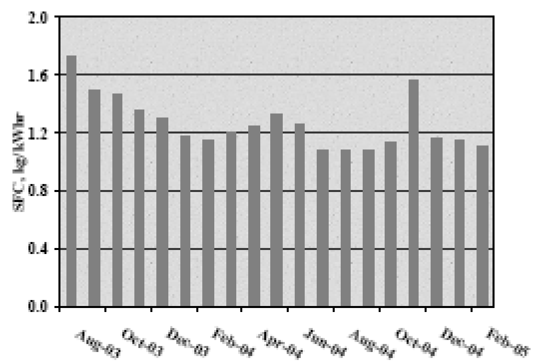

Figure 4 Month-wise specific biomass consumption

Table 1 shows the exhaust emissions of the producer gas engine power plant in terms of CO and NO at rated condition. The engine has no emission regulating device. As evident from the Table, the achieved emission levels are much lower than the existing Europe Stage II (valid up to 2004/5) emission norms for off-road diesel engines. All this has been achieved without any after-treatment for the engine exhaust emissions. These below mentioned figures reemphasize that biomass derived producer gas is an environmental benign fuel.

Table 1 Gas Engine Emission (g/MJ)

Parameter	Europe Stage II [12]*	PG Engine
CO	0.97	0.4-0.5
NO_X	1.67	0.2-0.3
PM	0.083	<< 0.0005

* Applicable for off-road diesel engines

2.3.3 By Products

In addition to electricity, value addition product namely partly activated carbon is also generated to an extent of 5- 6% of the gasifier throughput. One classical approach for activating the charcoal is to react it with water vapor at high temperature (800 – 1000° C). Whereas, in the gasifier reactor, the generated char moves through the system with non-isothermal distribution of temperature in a gaseous atmosphere where both water vapor and carbon dioxide are present and the residence time is controlled by the throughput at which the gasifier reactor is operating. Even though the conditions under which the char undergoes reaction with water vapor and carbon dioxide are not the best conditions for activation of a predetermined quality, nevertheless the conditions are favorable for activation. Thus char extracted from the reactor gets partly activated in situ of the reactor. Analysis has shown the adsorptivity of extracted char in terms of Iodine number to be in the range of 400 – 450. Laboratory trails have shown that Iodine number could be enhanced to 800 – 850 by heating in an atmosphere of water vapor. The promoter is able to sell partly activated char at a small price. However, they are yet to implement the above said process plant for higher returns.

3 OTHER PLANTS

Other than the above mentioned plant there are nearly ten other power plants that have been installed in the country. Today the total installed capacity of producer gas engine power plants in India is abut 3.6 MWe (IISc technology). One plant that needs special mention is the Arashi Hi-tech Bio-power plant at Coimbatore (southern part of India), which is the first and the largest Independent Power Producer (IPP) based on fixed bed indigenous biomass gasification technology in the country. The electricity generated from the plant is consumed at their sister concern using the State electricity grid. The power plant is configured of 2 x 860 kg/hr gasifier to supply producer gas to 5 x 250 kWe rating gas engines. This power plant is more sophisticated compared to earlier one and has provision for complete automation using PLC. The plant also has better waste heat utilization, where in the waste heat both from the gasifiers and the gas engines are used for operation of biomass dryers and a vapor adsorption type water chilling system. The plant operating in a semi - continuous mode has clocked over 18,000 hours (cumulative all five engines) since January 2005. There are two reasons for the plant load factor to be lower, one is related to gas engine stabilization, which has been successfully addressed the other is related to consistent availability of biomass. The biomass issue is being addressed by a novel approach wherein the waste land would be adapted for energy crop cultivation. This power plant performance was closed monitored for about 30 hour duration, wherein a number of parameters related to gasifier and gas engine was continuously monitored. The producer gas contained 20-22% of CO and H_2, 1.5 % CH_4. The sfc at 1.0 MWe capacity was recorded to be between 1.0 and 1.2 kg/kWhr.

One other plant that needs a special mention is Hindustan Pencils Ltd, Jammu (Northern part of India), where there are the four gas engine installed which operate on a gasifier fuelled with sawdust briquette. This is system is also unique in the sense that it is the first gasifier plant in the country working on briquette fuel and generating electricity. The electricity generated meets the captive requirement and is operated in a continuous mode.

4 CONCLUSIONS

The case studies brought out in this paper clearly establishes that IISc's biomass gasification is well established technology and a few plants to be successfully operating in commercial mode. Issues related to gas quality has been successfully addressed and to eliminate issue related to moisture content in biomass (seasonal) an engine/gasifier waste heat drier has been integrated with the package. As of July 2005, there is cumulative experience of over 25,000 hours available from eight plants, serving in various modes of operation.

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