GREEN ELECTRICITY ~ A CASE STUDY OF A GRID LINKED INDEPENDENT POWER PRODUCER

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

V.S.Prakasam Kummar and V.Chandra Mohan
Arashi Hi-Tech Biopower Pvt. Ltd.
Sulthanpet, Coimbatore, Tamilnadu, India.

ABSTRACT: Biomass gasification technology offers a cost effective option of power generation at power levels up to 3 MWe, for a wide variety of applications such as captive power in industry, grid linked independent power producer and distributed power generation. Today this technology is being utilized for power generation applications at a number of industrial sites in India and abroad. In India there are nearly 6 MWe equivalent power plants which are based on the state-of-the-art IISc's (Indian Institute of Science) open top re-burn down draft biomass gasification technology. One among this is installed as an Independent Power Producer (IPP), which is the largest fixed bed gasification system in the country. The The grid linked power plant operates on a range of feed stocks such as coconut shell, Julifora Prosopis and converts into electricity. Apart from electricity the plant also generates value added product namely partially activated carbon. The specific biomass consumption is measured to be within 1.0 ± 0.1 kg/kWh with an overall efficiency of 24-26%. 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.

Keywords: open top gasifier, producer gas engine, CDM technology, distributed power generation.

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 non-lignaceous 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, staged air entry, re-burn gasifier developed at Combustion, Gasification and Propulsion Laboratory (CGPL) of Indian Institute of Science (IISc), which is unique amongst all the gasification systems developed across the world in terms of generating superior quality producer gas [2, 3, 4]. There are more than 40 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 an integral 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 Independent Power Producer (IPP) is reported as a case study in this paper.

2 CASE STUDY

2.1 Plant Description

The plant referred here is a grid linked IPP named Arashi Hi-Tech Bio-power Pvt. Ltd located at Sulthanpet in South India, near to the city of Coimbatore. The plant is located in a region where coconut shells are available in abundance and also proximate to an electrical sub-station for power evacuation. The plant has been supplied and installed by one of the licensee of IISc technology. The power plant was installed in two phases. In the initial phase, one gasification system of 850 kg/hr was coupled to 1.0 MWe diesel engine, dual – fuelling was attempted using diesel, light diesel oil and furnace oil. Since the operations were financially unviable the diesel engine was replaced with gas engines. Also, another gasifier system of 850 kg/hr was installed. The industrial class power plant is now configured as 2 x 850 kg/hr gasifier coupled to producer gas engine of 5 x 240 kWe nominal capacity.

The plant originally conceived to use coconut shells as the feedstock is now able to successfully operate on weeds such as Julifora Prosopis containing thick bark that contributes to about 4% ash in the fuel. The integrated 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 two gasification units each of 850 kg/hr placed next to each other supplies gas to a common manifold which is in turn supplies gas to five gas engines.

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 (f) waste heat recovery (h) semi-automation using PLC (i) effluent treatment plant. The power package comprises of turbo-charged after-cooled Cummins producer gas engines of 240 kWe nominal capacity (GTA 1710G). The engine is coupled to 380 kVA alternator to generate electricity at 415 V. The electrical output from the individual gas engine-generator sets are synchronized with a common electrical bus which is in turn paralleled with the 11 kV State grid for power evacuation. The industry has a wheeling and banking arrangement with the State grid for power export to their sister concern that is involved in manufacturing. The State grid deducts 12% of the electrical units exported as wheeling and interfacing charges. The net revenue the power plant earns is about 6.7 US Cents/unit. This power plant is operational on 24 hours x 7 days mode.

An interesting feature of this plant is the ***Tri-generation***. Other than electricity generation, the thermal energy in the form of the waste heat is utilized for operation of a drier and chiller. The waste heat from the gas engine/s exhaust is utilized for energizing a 55 Ton of Refrigeration vapor absorption chiller unit (consumes only 12% electricity of the alternate vapor compression system). The cold water generated is the chiller is used for producer gas conditioning. Similarly the surplus heat available downstream of the vapor absorption chiller is used along with waste recovered from the gasifier (cyclone) for operation of biomass drier, meant for conditioning the raw biomass to about less than 15% moisture.

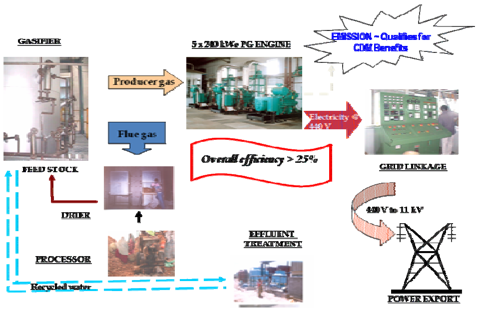

Figure 1: Power Plant configuration

2.2 Process Description

Each of the gasification unit comprises of 850 kg/hr capacity open top down draft re-burn gasifier reactor with gas cleaning and cooling system [6, 7, 8, 12] 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 hot 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 efficiency cyclone which separates the dry particulate matter from the raw gas (~ 80%). A jacket provided on the outer surface of the cyclone facilitates recovery of waste heat is used in part to meet the thermal requirement for biomass drying. The next intermediate process of gas cooling and scrubbing is carried in ejector design based scrubbers. The wash water for gas scrubbing is used in recycling mode after necessary treatment in the 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, 12] 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 the operation of vapor absorption chiller and drying of the biomass in a tray type biomass drier.

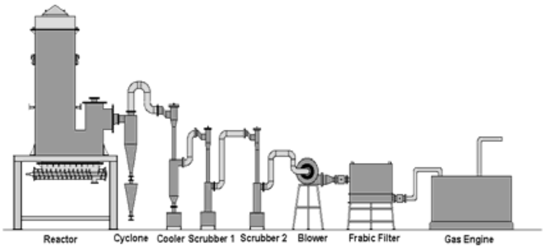

Figure 2: The Gasifier System

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 and a weed named julifora prosopis. The biomass is initially sized to about 50 – 75 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 was monitored over 30 hour time interval. The variation of gas composition and calorific value over 24 hour cycle is shown in Fig. 3, the gas contained 19 ± 1% - H_2; 20 ±1% - CO; 1.5 % -CH_4; 10±1% CO_2; 2 ± 0.5 % H_20 and rest, N_2. The mean calorific value of gas varied around 4.85 + 0.25 MJ/ kg, which corresponds to a cold gas efficiency of about 83 + 2%. Also, *the gas quality in terms of particulate and tar matter is found to be less than 1 mg/Nm^3 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 that involves the collecting the sample from the turbocharger inlet till the inlet valve. There has been consistency in collected sample weights in these approaches.

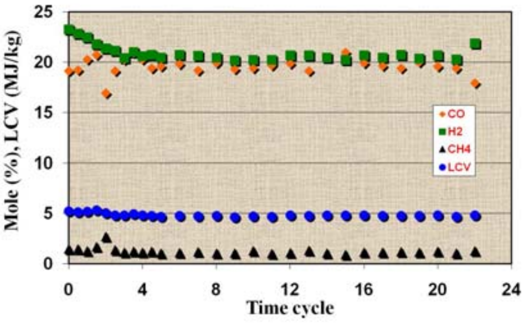

Figure 3: Producer Gas Composition with Time

2.3.2 Gas Engine

The plant was commissioned in two phases between August and December 2004. The plant became completely operational in January 2005, it has so far successfully completed over 12000 hours (until January 2007) of operation. It took about 4 months to stabilize the plant operations; subsequently the plant has been operating 24 hours x 7 days a week at an average load of 750 – 1000 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, 12]. The maximum power delivered by each of the engine is restricted to 240 kWe even though the peak output achieved was about 290 kWe; this was done because Cummins India Ltd wanted to gain operational experience over long duration until a point they were satisfied with performance.

Fig. 4 shows the cumulative number of units generated by the plant. During the stabilization of the plant took about 4 months, the issues were mostly related grid instability and associated safety measures. The grid instability rose out of the erratic behavior of the large number of wind mills that are in operation in the neighborhood; these wind mills use the same 11 kV line for power evacuation. After stabilization the average monthly electrical units generated was about 700 kWe for nearly a year. Biomass used during this period was a combination of coconut shell and Julifora Prosopis. In the subsequent time period when they switched over to Julifora Prosopis there was an issue of reactor ash accumulation in the reactor leading to frequent interruption in the operation. This was essentially caused due to higher ash content in the feedstock (4%) as compared to coconut shell. The issue was successfully resolved by making suitable modifications in the ash extraction region of the reactor. The main reason for the plant load being low during the major part of the year 2006 is largely related to non availability of right quality biomass and inadequate utilization of the biomass dryer particularly during the monsoon. The plant has completed about 12000 hours of operation as on January 2007.

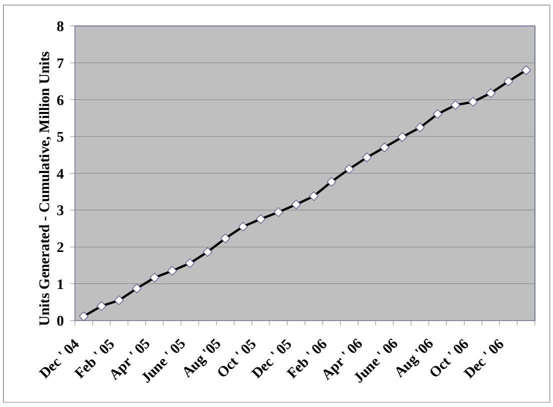

Figure 4: Units generated – Cumulative, Million Units

Fig. 5 shows the month wise specific biomass consumption (sfc) variation with time. As indicated earlier during plant stabilization period the sfc varied between 1.0 to 1.7 kg/kWh (operation largely at part load). Later the sfc recorded is about 1.0 to 1.2 kg/kWh, which corresponds to an overall efficiency (biomass – to – electricity) of 24 - 26%.

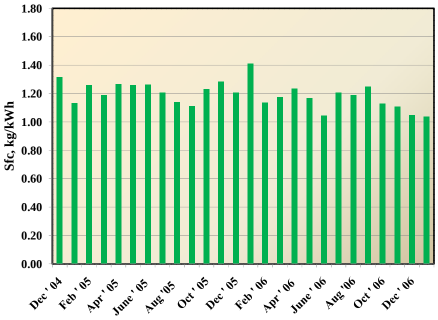

Figure 5: Month-wise specific biomass consumption

The gas engine has been jointly monitored by IISc and Cummins India Limited (CIL) and periodically inspected at the end of 3000 hours of operation. The inspection revealed that 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. Some of the relevant lube oil properties are shown in Table 1, based on these observations, CIL have recommended lube oil change once in 500 hour of operation. The next major inspection was conducted by stripping down two engines at the completion of about 5000 hours of operation. The engine was dismantled, components such as valves, piston assembly and cylinder liner were thoroughly inspected for wear and tear. The inspection revealed the components to have undergone wear and tear similar to that in a natural gas engine. Similar observations have been made on the cylinder head and valve components.

Table 1: Engine Lube Oil Properties

Parameter	**Fresh Oil**	**Used Oil (500 – 700 hrs)**	**Limit***
Kinematic viscosity @ 40 C, cSt	114	95 - 97	Low – 85 High - 155
TBN, mg/KOH/g	5.7	2.2 – 2.0	2.0

* CILs recommendation

Table 2: Gas Engine Emission (g/MJ)

Parameter	**Europe Stage II [13]***	**PG engine**
CO	0.97	0.5 – 0.7
NOx	1.67	0.15 – 0.2
PM	0.083	below detection limit

* Applicable for off-road diesel engines

Another important outcome of this monitoring was that there was no major difference was found in the maintenance time interval compared to natural gas or diesel engine. Similarly the cost incurred towards the engine maintenance was roughly the same as that of a natural gas engine. The major maintenance on the gasification part involved reconditioning of the fabric filter cloth. The rest of the elements called for servicing only \at the completion of about 2000 hours of operation.

Table 2 shows the summary of exhaust emissions in terms of CO, NO and particulate matter (PM) monitored over a large number of hours and close to rated power output. 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 and therefore clearly eligible for carbon credits.

The current operating cost (fuel + manpower + maintenance) per unit electricity generated is about 5 - 5.5 US Cents. The maintenance cost for the gas engine has been found to be comparable to that of a diesel engine.

2.3.3 By-product

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 550 – 700 (this implies a surface area of 500 to 550 m^2/g). Laboratory trails have shown that Iodine number could be enhanced to 900 – 1000 by heating in an atmosphere of water vapor. The promoter is able to sell partly activated char at 0.3 to 0.4 US$/kg after sizing it to meet the industrial requirement for water purification application. This additional revenue results in reduction in the electricity generation cost by about 2.0 US cents.

3 CONCLUSIONS

The case study brought out in this paper clearly shows that IISc’s biomass gasification is commercially tested at a reasonable power scale. Apart from this, several other plants are also 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 January 2007, there is cumulative experience of over 50,000 hours available from ten installations, serving in various modes of operation. This list includes the largest plant of 1.5 MWe just installed on commercial basis in southern India for captive consumption.

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