

## PRODUCER GAS ENGINES– PROPONENT OF CLEAN ENERGY TECHNOLOGY

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**ABSTRACT:** Biomass gasification is environmentally benign and holds large promise for the future. The research on producer gas engines commenced about a decade ago at Indian Institute of Science, Bangalore and today IISc and Cummins India Limited are partnering in developing and deploying producer gas engines. There are nearly 5 MWe power plants installed in the country and gained a cumulative experience of over 60,000 hours. Cummins India Limited is now offering producer gas engines in India backed with all commercial warranties coupled with the gasification technologies developed at the Indian Institute of Science. A range of gas engines up to 250 kWe capacity has undergone rigorous testing. The trials include tests for gas quality on engine performance, power output, emission and engine's response to load changes. The gas engines currently adapted for power generation application are fitted with a patented producer gas carburetion system which ensures nearly constant air-to-fuel ratio at various load factors. The producer gas engine power plants are serving applications like captive power, grid linked independent power and for distributed power generation. Some of these plants have been closely monitored and reliability studies conducted by the engine manufacturer. The studies indicate the wear of the engine's components assessed at the end of 5000 hours of operation are well within limits when compared to natural gas engine. **Keywords:** open top gasifier, producer gas engine, CDM technology, distributed power generation

### 1 INTRODUCTION

Biomass based power generation is gaining popularity in view of the high energy costs and also the environmental considerations. Various thermo-chemical conversion technologies are being practiced to meet the demand. Direct combustion technologies using steam route for both heat and power is in existence for industrial as well as space heating application. An extension of this technology to improve the efficiency has been the co-generation, which has gained importance in the industrial sector like, sugar, cement, paper, etc. These power generation routes have been found ideal for captive requirements, where the biomass availability is assured, to meet the heat and power demand. At large power levels, it has been found that biomass sourcing would play a critical role in the plant economics.

One important part of the thermo-chemical conversion which was addressed during the Second World War is the gasification technology. Even though there were limitations, the technology package was used in crisis. Over the last two and half decades, several groups in the world have been revisiting this technology. The advantage of this technology is in using reciprocating engines as prime-movers along with the gasification system to generate electricity at high efficiencies compared to the other technologies at power levels lower than 2 MW.

Indian Institute of Science has been working in this area over last 25 years and has developed state of the art gasification technology, generating engine quality gas. Initial development was focused on small capacity systems [1], and recently in the range up to 1 MW. Power levels from 5 kWe to 1 MWe are field tested and standardized. The paper addresses the requirements of producer gas quality for gas engine application, adaptation of natural gas engines and results from the field along with M/s Cummins India Limited on the performance of the gas engine operating on producer gas

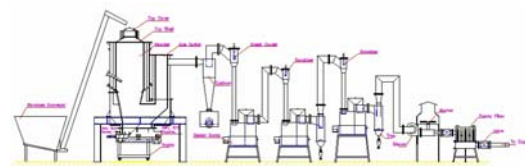
as a fuel.

### 2 THE GASIFICATION SYSTEM

#### 2.1 The system

The overall schematic of the gasifier system is depicted in Figure 1. The reactor is basically a downdraft system, where both gas and feedstock (Biomass) move downward as the reaction proceeds. The air required for gasification is partly drawn from the top, and the remaining from the air nozzles surrounding the combustion zone. The required suction for this process is obtained by using either a blower or an engine. Biomass after drying and pyrolysing in the upper zone of the reactor undergoes volatile combustion leaving fixed carbon or char by the time it reaches the oxidation zone. In the oxidation zone the volatiles undergo oxidation with the release of CO<sub>2</sub> and H<sub>2</sub>O. The product gas undergoes reduction in the presence of hot bed of charcoal and yields a combustible gas mixture.

The hot dust laden gas exiting from the reactor is led through a cooling and cleaning train, where the raw gas is cooled to ambient temperature in the cooling section and cleaned in the fabric filters and scrubbers. The gas then flows either to gas engine or to the flare.



**Figure 1:** Schematic a typical gasification system

## 2.2 Thermo-chemical Reactions

The thermo-chemical reactions converting solid bio-residues to producer gas occur in the reactor. The IISc Bio-residue gasifier (IBG) is novel as compared to World War II design. This is an open top down draft re-burn system with air for gasification being shared from open top and side nozzles. The reactor has a removable top cover kept open during operation and screw conveyor system for ash removal. The walls are lined with ceramic and insulation bricks.

The open top operations lead to bed stratification. Stratification is the formation of stable layers of pre-heating, volatile matter combustion and reduction zones with little opportunity for any gas to leak past any of the zones i.e. pass through without active participation. There will be an upward movement of the flame front into the moving bed of char with air flowing in the opposite direction. The flame front moves upwards into the un-burnt fuel. This is similar to the flame front moving in a premixed flame.

This movement of the front helps in establishing a larger hot zone leading to better preparation of the fuel as it moves downwards towards the second air supply zone or the nozzle zone. Studies to determine flow distribution under cold conditions indicate that the velocity distribution in a packed bed is homogeneous after a few particle diameters. This homogeneous velocity distribution results in temperature profiles which are nearly uniform across the cross section of the reactor. Thus, in the case of an open-top gasifier, the air/gas flow is homogeneous across the bed and the air/gas also passes through a long porous bed of fuel in the vertical direction. In the open top gasifier, the regenerative heating due to the transfer of heat from the hot gases (through the wall) to the biomass moving down increases the residence time in the high-temperature zone and thus leads to better tar cracking. 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 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 air flow from the top in the case of the open top system. The tar thus is eliminated in the best possible way by the high temperature oxidative atmosphere in the reactor itself. In the present design of the gasifier, the heat transfer from the hot gases flowing in the annular space, makes it possible to gasify wood chips that have moisture contents 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*.

In steady operation, the heat from the combustion zone near the air nozzles is transferred by radiation, conduction and convection upwards causing wood chips to pyrolyse and loses 70-80% of their weight. These pyrolysed gases burn with air to form CO, CO<sub>2</sub>, H<sub>2</sub>, and H<sub>2</sub>O, thereby raises the temperature to 1300-1500 K. The product gases from the combustion zone further undergo reduction reactions with char.

The product gas exits from the reactor at around 750-850 K, below the reduction zone. Typical gas composition (dry basis) at the reactor is as follows, 20 % CO, 20 % H<sub>2</sub>, 1 % CH<sub>4</sub>, 11 % CO<sub>2</sub> and the rest N<sub>2</sub>.

## 2.3 Cooling and Cleaning the gas

The first stage of cleaning the gas is by passing through cyclone where major amount of particulates are collected in dry form. The gas is cooled with water spray and scrubbed subsequently. The gas is also sub-cooled to condense the saturated moisture. In the process of moisture precipitation, fine particulate matter is also trapped. The clean dry gas is inducted to a blower and discharged to fabric filter before it can enter in to the engine.

## 3 POWER GENERATION FROM PRODUCER GAS

### 3.1 Properties of producer gas as a fuel

The producer gas has an air to fuel ratio of 1.2- 1.3 which calls for a different carburetor for use in a spark ignited engines.

The laminar flame speed at stoichiometry for producer gas is 30% higher as compared to natural gas. This calls for change in ignition timing for producer gas operations on these engines to achieve peak power.

The energy density and the peak flame temperatures of natural gas is higher than producer gas and also the product to reactant mole ratio subsequent to combustion is lower in producer gas. These factors contribute to the de-rating of a natural gas engine when operated with producer gas [2]. Table 1 compares the properties of Natural Gas (NG) and Producer Gas (PG).

**Table1:** Comparison of properties of producer gas with other fuels

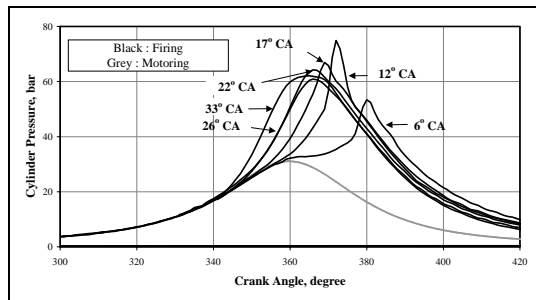
Properties	PG	NG
Chemical composition	CO, CO <sub>2</sub> , CH <sub>4</sub> , H <sub>2</sub> , N <sub>2</sub>	CH <sub>4</sub>
Fuel, LCV, MJ/kg	5.0	50.2
Fuel, LCV, MJ/Nm <sup>3</sup>	5.6	35.8
Air-fuel ratio at $\phi = 1$ (mass)	1.35	17.2
Energy density of A + F mixture, MJ/kg	2.12	2.76
Laminar flame speed at stoichiometry (cm/s)	50	35
Peak flame temperature (K)	1800	2210
Product-reactant mole ratio	0.87	1.0

### 3.2 Gas Engine operation with producer gas

Natural Gas engines are available as a product from engine manufacturers. This can be used for producer gas operations by using a different carburetor.

In establishing the use of producer gas a fuel, basic research has been carried out at IISc on converting a diesel engine to operate on producer gas [3]. Use of producer as a fuel at varying compression ratio has shown smooth operation at compression ratio of 17:1. The optimum ignition timing for producer gas operation at varying compression ratio was established during this study. Figure 2 shows the pressure-crank angle curves for varying ignition timing at 17:1 CR. It is evident that

pressure curve is smooth and there is no knock inside the cylinder.



**Figure 2:** Peak power output at different compression ratio

An important aspect in fueling natural gas engines with producer gas is to handle the A/F for producer gas at varying load conditions. The carburetion system for handling producer gas was successfully developed and tested to operate on various engine capacities.

### 3.3 Laboratory scale testing of the engines

After the initial development of the package for producer gas operation, IISc and Cummins India Limited (CIL) interacted closely for testing their naturally aspirated natural gas engine leading to a collaborative mode of operation. During the testing period, IISc and CIL worked closely to ensure that the gasification developed at IISc has a gas quality that does not foul the engine. These tests were carried out systematically and the engine conditions were jointly evaluated. After successfully testing a naturally aspirated engine, a turbocharged engine was also tested under lab conditions, to establish the gas quality for turbo charged after cooled engine. These engines were deployed for field operations. Performance of the system in the field was closely monitored jointly by IISc and the CIL to evaluate the technology package [4]. The findings from the field evaluation indicated that

- The gasification system was capable of generating engine quality gas. Gas quality for turbo charger with after cooler is critical, < 5 ppm is found to be acceptable.
- Peak power derating was about 30 % of natural gas output, related to fuel properties
- Turbo charger application is possible
- Only very fine dust found in the engine components at ppb levels.
- Carburetion system established for handling varying load.
- Specific fuel consumption of biomass  $1.1 \pm 0.1$  kg/kWh.
- Lubricating oil replacement at 500 hours instead of 700 hours

## 4 COMPREHENSIVE STUDY ON A GRID CONNECTED POWER PACKAGE

### 4.1 The field installation plant

The plant referred here is a grid linked IPP, Arashi

Hi-Tech Bio-power Pvt. Ltd located at Sultanpet in South India, near Coimbatore. The plant is located in a region where coconut shells are available in abundance and also proximate to an electrical sub-station (within few meters) for power evacuation. 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 due to non-availability of gas engines to operate on producer gas. The industrial class power plant is 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 bark that contribute 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. 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 filters (e) Flare (f) waste heat recovery (g) semi-automation using PLC (h) 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.

### 5 ENGINE AUDIT AT THE END OF 5000 HOURS OF OPERATION AT ARASHI HI-TECH BIOPOWER PVT LTD.

It has been an interesting experiencing in jointly evaluating the performance of producer gas as a fuel in an internal combustion engine designed for natural gas. Systematic monitoring of the system was carried out on all the engines at the end of 1000 hours of operations. Lubricating oil samples were drawn at regular intervals to assess the replacement schedule. At the end of 5000 hours of operations, two engines were dismantled to evaluate the performance at component level. The following sections will describe the finding during the evaluation.

#### 5.1 Engine Inspection

The components from the carburetor till the valve and cylinder were dismantled by CIL and were studied. Figures 3 to 6 shows engine components that were dis-assembled for inspection, the following being the major observations

- Extremely fine dry dust in the gas path; can be blown using a blower
- Extremely fine ash deposition on the turbine
- No wear on the turbine or compressor blade and the shaft assembly

- Turbocharger internal components like bearing housing, bush bearings, thrust washer, seal rings etc. are in good condition
- Dry dust deposition on the intake valves. However the seating area does not show any abnormal wear. Exhaust valves shows hard layer of ash. Exhaust valve seat area shows slight wear marks. Both the valves can be reused.
- Piston ring grooves show no abnormal wear or deposits. Piston rings show normal contact pattern & normal wear.
- Spark plugs tips showed normal wear and was clean.



**Figure 3:** The compressor and turbine after 5000 hours of operation



**Figure 4:** Intake and exhaust valves after 5000 hours



**Figure 5:** Piston and Piston rings after 5000 hours of operation



**Figure 6:** Spark plugs after 5000 hours of operation

The inspection was found encouraging and also qualified the gasifier for its clean fuel generation. Table 2 indicates the piston ring gap measurements on two sets of producer gas engines. The contact pattern and wear is found uniform and within the allowable limits.

**Table 2:** Piston rings measurement on 2 cylinders

Piston ring gap measurement	GG#1			
	Cylinder # LB5		Cylinder # RB2	
	With New liner	With Old liner	With New liner	With Old liner
	Inch	Inch	Inch	Inch
Compression ring	0.027	0.031	0.024	0.026
2nd ring	0.03	0.031	0.029	0.031
3rd ring	0.031	0.033	0.029	0.03
Oil ring	0.026	0.027	0.023	0.025
Piston ring gap measurement	GG#2			
	Cylinder # LB5		Cylinder # RB2	
	With New liner	With Old liner	With New liner	With Old liner
	Inch	Inch	Inch	Inch
Compression ring	0.026	0.027	0.024	0.027
2nd ring	0.032	0.033	0.032	0.033
3rd ring	0.035	0.037	0.032	0.035
Oil ring	0.029	0.03	0.033	0.034

## 6 SUMMARY

Close monitoring and reliability studies conducted by the engine manufacturer on producer gas engines; indicate the wear of the engine's components assessed at the end of 5000 hours of operation to be well within limits. Also, the engine lube oil quality has been periodically assessed and found to be satisfactory. This has helped in establishing

producer gas as an acceptable fuel in engines to generate green electricity.

## 7 ACKNOWLEDGEMENTS

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