

## ON THE OPERATION OF A HIGH PRESSURE BIOMASS GASIFIER WITH GAS TURBINE

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**ABSTRACT:** Gas turbine operations with liquid and gaseous fossil fuels are an established route for power generation. Use of low calorific value fuel like producer gas in gas turbine is not well established and currently there are no Gas turbines designed for this fuel. This paper focuses on the work done at the Combustion Gasification and Propulsion Laboratory of Indian Institute of Science to develop a high pressure gasifier to handle variety of biomass and fuel a gas turbine. The gas turbine explored in this work is Rover's gas turbine designed for Aviation Turbine Fuel (ATF) operation. The adaptation of combustion chamber to accept producer gas as fuel is also discussed.

The combustion chamber of the Rovers turbine was retained and the liquid fuel injector was replaced with gas distributor. Experiments on the combustor were conducted with producer gas at ambient pressure and elevated pressure to test the ease of ignition and stability. Several distributor designs were experimented to establish the right type for obtaining stoichiometric air and fuel mixing at the spark plug. The gas turbine was run with producer gas, the efficiency with aviation turbine fuel and with biomass was found to be roughly same.

**Keywords:** producer gas, gas turbine, high pressure gasifier

### 1 INTRODUCTION

Gas turbines have been widely used for large scale continuous power generation in addition to aerospace applications. In the lower power ranges the reciprocating engines have edge over the gas turbines due to their higher efficiencies. With respect to power generation, it is possible to increase the overall efficiency using gas turbine by a combined cycle operation. Usually steam cycle is coupled to exhaust of the gas turbine which have fair amount of heat and excess air to generate steam and use it in the steam turbine. The overall process will have better efficiencies if requirements of heat, power and process steam are met together.

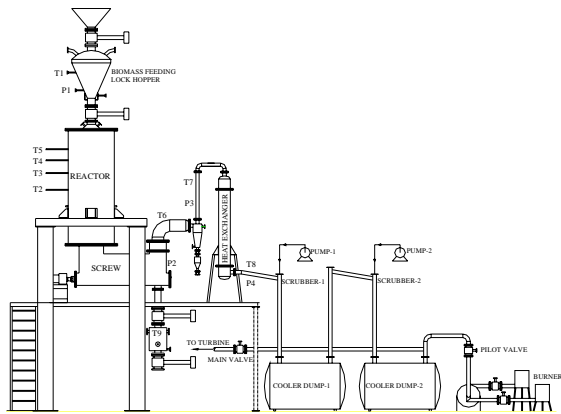
Gas turbine can operate with different liquid fuels and variety of gaseous fuels. It is also possible to use solid biomass to generate hot air for turbine by in-direct firing. A better option would be to gasify the solid biomass and burn the gas in the combustion chamber directly. This option has been tried by Biomass Engineering Ltd., U.K and Conversion and Resource Evaluation Ltd., Northern Ireland wherein an atmospheric pressure gasifier is used to produce clean producer gas which is compressed and subsequently combusted in gas turbine combustion chamber [1]. An approach similar but with a pressurized gasifier for generating gas under pressure to match the turbine inlet pressure has been successfully demonstrated. Several other designs of the gasifier like circulating fluidised bed gasifier and other fixed bed gasifiers have been tried with gas turbine [2]. Indian Institute of Science with its two decades of research work has successfully demonstrated open top down draft gasifier system (IBG) which has been used to fuel reciprocating engines at various power levels. The Ministry of New and Renewable Energy (earlier MNES) funded the research project at the Institute to develop a gasifier to fuel a gas turbine.

On the approach to be adopted like pressurising the air for gasification or gas subsequent to gasification, it was felt that pressurising the air would involve less work and this approach was chosen to be followed. The high pressure gasification also needed auxiliary systems like lock hoppers for fuel feeding and ash extraction. This was made possible by the collaborating partners in the research namely Bharat Heavy Electricals Ltd (BHEL), Trichy and Indian Institute of Chemical Technology (IICT), Hyderabad. This paper addresses the testing of high pressure gasifier and coupling this to a Rover's gas turbine.

### 2 HIGH PRESSURE GASIFIER

#### 2.1 The system

A design capacity of 75 kg/hr was chosen for the gasifier with an idea of operating a micro turbine of 50 kWe with an efficiency of 25–30 %, which could be easily demonstrated in a laboratory scale. The design and sizing was chosen based on the earlier experience in operating atmospheric pressure gasifier [3]. An air compressor which can deliver air at 5 bar (abs) was used to supply high pressure air to reactor at the top as well as at the nozzles. A screw extraction system is employed for char and ash extraction. The gas goes to cyclone, heat exchanger and scrubbers before it can go to either startup flare or gas turbine. At the startup, a choked nozzle for rated flow was used to hold the pressure in the upstream elements, while the gas is being flared. The gasifier schematic is shown in Figure 1.



**Figure 1:** Schematic of High Pressure Gasifier

The system was equipped with PLC controls and interlocks for operational safety. The system was instrumented with pressure and temperature sensors after each element for data acquisition. The gas composition measurements were done during each run.

## 2.2 Lock hopper systems

The biomass feeding to the reactor and ash/char extraction from reactor was through lock hoppers. The lock hoppers were designed and supplied by BHEL, Trichy and IICT, Hyderabad. The feed lock hopper system includes the top hopper, which is open to atmosphere and a feed hopper between the top hopper and the reactor with leak-proof knife-edge valves on both ends of the feed hopper. To load biomass into the reactor, the top hopper is filled with biomass while the knife-edge valves are closed. The feed chamber below is depressurized by opening a vent valve and the valve below the hopper is opened. The biomass from the hopper is transferred to the feed chamber after which the valve is closed. A pressurizing valve is opened to raise the pressure of the chamber to that inside the reactor. The valve below the feed chamber is opened to transfer the biomass in to the reactor. The same logic is used for removing ash/char in the system.

## 3 TESTING OF HIGH PRESSURE GASIFIER

### 3.1 Flare mode trials

The system was initially tested in flare mode for qualification of the system elements. To start the system is operated in the induced draft mode with a blower employed to create the necessary draft. The lock hopper feed valves were kept open to simulate conventional open top down draft gasifier. Torching at ignition nozzles were done to ignite the reactor. Upon obtaining continuous flammable gas, the ignition nozzles were closed, the blower was switched off and valve closed to isolate it from pressure line. The lock hopper was then closed and air supplied under pressure. A different flare with a choked nozzle was used to operate in the pressurized mode. Operational details like biomass consumption, pressures and temperatures across various elements, operating pressure, amount of ash/char extracted and gas composition were noted down periodically. The system was tested with wood chips and bagasse and coffee husk briquettes at 2.0, 3.5 and 4 bar

pressure (guage). The results of a few tests with wood chips have been presented in table 1.

**Table I:** Gas composition with wood chips at different pressures

Pr., Bar	Mean gas composition, %,			
	CH <sub>4</sub> ~ 1 – 1.5 % in all cases	CO	H <sub>2</sub>	CO <sub>2</sub>
2.0	20.0	21.0	10.0	
4.0	20.0	14.0	11.0	
4.0	11.6	14.5	16.0	
4.0	18.0	15.0	10.0	
4.0	11.0	20.0	19.0	
2.8	12.0	15.0	21.0	
2.5	15.0	15.0	20.0	
3.3	13.0	19.0	16.0	
3.5	15.0	19.0	17.0	

The system operations showed slight variations in gas composition mainly due to uncertainties in loading of biomass due to closed operations. However achieving continuous flammable gas encouraged to take the next step for power generation in Gas turbine.

## 4 TESTING OF GAS TURBINE

### 4.1 Rovers Gas Turbine

Efforts to find a right sized micro gas turbine for producer gas operation proved futile as the manufacturers of standard gas turbines backed out from providing their system for this fuel. Finally, a Rovers gas turbine which had served as an auxiliary power unit for air craft was sourced and tested. The specification of the turbine is provided in table 2. The system was designed for liquid fuel operation namely Aviation Turbine Fuel (ATF) or high grade Kerosene. The combustion system is a can type combustion chamber with liquid fuel injector and high energy spark ignition system. The fuel system has a twin fuel pump, containing separate metering and recirculating pumps, a temperature control and an over-speed governor. In addition the system has an air/fuel ratio control, a combined metering and pressurizing unit and a fuel pressure transmitter. The supply to the pump is taken from a low pressure filter mounted on the exterior of the front panel. The fuel tank outlet with a positive head was connected to this filter.

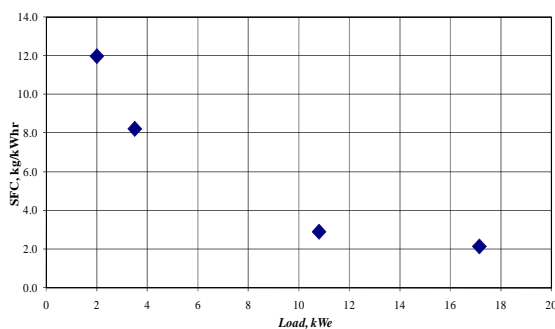
**Table 2:** Specifications of the gas turbine

Engine Rating	32 kWe at ambient air up to 45 °C. Air bleed at 45 g/s at sea level conditions
AC generator	40 kVA, 3 phase, 208 V, 400 HZ at 8000 rpm.
Compressor	Single stage Centrifugal
Air mass flow	657 g/s at sea level conditions
Pressure ratio	3.2 at sea level conditions
Combustion chamber	Single can, reverse flow spill type burner
Turbine	Single stage, axial flow
Fuel consumption (max)	11.8 g/s

4.2 Performance Tests with Liquid Fuel

A resistive load bank was arranged for loading the turbine and fuel consumption measured by level depletion in the tank. The readings displayed in the panel like pressure (P2), exhaust temperature, rpm were recorded.

The turbine could be loaded to about 18 kW. The specific fuel consumption was found to be about 2 kg/kWh, amounting to about 5 % efficiency. Figure 2, shows the plot of fuel consumed in the gas turbine with load. The low efficiency of gas turbine is due to the low pressure ratio and no recuperation.



**Figure 2:** Load vs SFC curve with ATF

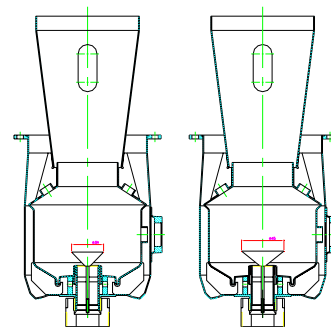
5 ADAPTATION ON GAS TURBINE FOR PRODUCER GAS OPERATION

The combustion chamber had a profile well set for matching the required A/F ratio for ignition and complete combustion with staged air addition for controlling the turbine inlet temperatures. To design a similar combustor and built one would require special facilities which will

not be available in general fabrication shops. Hence it was decided to use the existing combustion chamber and do necessary modification to accept the producer gas. The High pressure gasifier is rated for 75 kg/hr of biomass consumption and the maximum gas generation will be 52 g/s. The A/F ratios in the gas turbine will turn out to be around 10 – 12 (52 g/s of gas and 650 g/s of air). Hence, the combustor was to be qualified outside for such mixture ratios. The observations were to be made regarding:

1. The ignition of producer gas using the ignition system meant for liquid fuels – This is important as the gas turbine has a high energy ignition unit which is well integrated with the system and any further changes calls for modifications.
2. Flame stability at various mixture ratios – This is important to ensure that flame blow off does not take place.
3. Average exit gas temperature.
4. Maximum skin temperature of the combustor body – This ensures whether there is any local burning or hot spots.

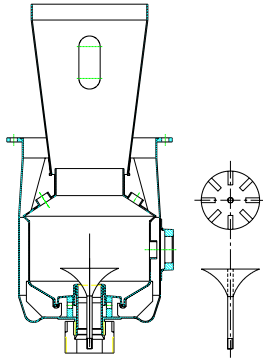
In order to utilize the existing combustor and sparking system, a gas injector in place of liquid fuel injection system was to be built. The injector should have a cone inside the combustion chamber to deflect the gas towards the wall in order to have ignitable mixture near the spark plug. To accommodate into the existing set up and maximize the gas flow path the injector was built as depicted in Figure 3. Two cones of designated as small and large based on geometry were built to evaluate the ignitable limits of the mixture.



**Figure 3:** Assembled view of both the cones

Both the cones were tested along with the combustion chamber and ignition system with the help of an atmospheric pressure gasifier. An air hood and a separate air blower were used to simulate the air flow from the compressor and A/F ratio at several stages. Ease of igniting the mixture and no local burning was the criteria set for acceptance. The larger cone showed stable operations and higher chance of ignition occurrence at high air to fuel ratios. The larger diffuser cone was integrated with the combustion chamber and similar test performed with the high pressure gasifier. Ignition did not pose problem but blow off occurred indicating that A/F for subsequent combustion was not proper. The mixture was fuel lean, hence the area for gas needs to be

increased. This was done by giving a contour to the side of the diffuser and also slots cut in the land. Figure 4 shows the diffuser geometry after incorporating these changes. This was assembled to the cone and again tested by operating the high pressure gasifier. The ignition as well as subsequent combustion was smooth. The combustor along with the gas diffuser was integrated to the turbine and operated.



**Figure 4:** Changed diffuser and combustor settings

## 6 OPERATING GAS TURBINE WITH PRODUCER GAS

### 6.1 Experiments

The gasifier was started in the same sequence as described in section 3.1. The gasifier was allowed to stabilize for an hour before starting of the gas turbine. The gas turbine was cranked to 20% rated speed, the ignition system energized and manual gas valve opened gradually. Upon the system acquiring 40% rated speed, the ignition was switched off and gas valve opened judiciously to allow the system to acquire 100% rated speed. The system showed no difficulty in start up or subsequent operations. During the trials, the parameters measured were pressure raise after compressor, turbine inlet and exit temperatures, producer gas composition and biomass consumption. The gas turbine was operated under different loads and the maximum load achieved was around 11 kWe. The results are shown in Table 3.

**Table 3:** Results of experiments

Load (kWe)	Absolute Pr, Bar	Gas Flow rate, g/s	Air flow Rate, g/s	A/F	Oil temp, °C	Exhaust gas temp, °C	% rpm	P2, Bar
7.89	4	109.9	650	5.91		451	96	1.7
10.10	4	94.1	650	6.90		477	98	1.7
7.89	4.3	115.4	650	5.63	120	464	97	1.7
11.43	4.3	116.1	650	5.60		470	96	1.7

### 6.2 Performance

Based on the gas flow rate, the efficiency in producer gas is around 1.6%, the efficiency with liquid fuel system on a similar load is around 2.7%. The best efficiency with liquid fuel mode at rated condition as per catalogue [4] would be around 6.4%. This low efficiency is due to low compressor pressure ratios and non-recuperative mode of operation.

## 7 SUMMARY

- High pressure gasifier based on concept of twin air entry fixed bed re-burn system has been built, operated and demonstrated with different bio-residues.
- A liquid fuel operated gas turbine is adapted for producer gas operation retaining the original combustion chamber and ignition system.
- Ease of operation and performance remained roughly same with both the fuels.
- The concept can be scaled up to few MWs with combined cycle operations for higher efficiencies.

## 8 ACKNOWLEDGEMENTS

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