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A Preliminary Investigation of Compressed Producer Gas from Downdraft Biomass Gasifier

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Abstract: The developmental work on compressing of producer gas from downdraft gasifier using a single stage normal air compressor has been studied and evaluated. Producer gas, which generated from the downdraft gasification process is basically a combustible gas which can be used for heating purposes and as an alternative fuel to generate power in an Internal Combustion (IC) engine. In the current practice, the producer is used directly from downdraft gasifier mixed with air through a carburetor, mixer or simple T-joint before entering the cylinder of an IC engine. The producer gas has to be consistently generated and supplied to the engine and any shortcomings or unstable gas from the gasifier will affect the quantity and quality of the gas required. In this study, air compressor was used to induce the producer gas from the gasifier at 670 L min^{-1}, compressed it to 7.6 bar gauge pressure and discharged it to a specified flow rate. The discharged flow rate of the producer gas was regulated at 130, 150 and 170 L min^{-1} consistently at an output pressure of 2.0, 2.5 and 3.0 bar, respectively. It was found that the blue flame producer gas was able to flare continuously through two outlets of producer gas ports after the gasifier and one outlet of producer gas port after the air compressor. The discharged flow rate of producer gas was constant over the entire range set of pressures. Since, the output pressure was regulated higher than the atmospheric, the density of the producer gas proportionally increased with the increase in pressure and the gas flow rate supplied can be controlled to the desired consumption particularly in the IC engines.

Key words: Compressor, biomass, gasifier, gasification, producer gas

INTRODUCTION

Global concern on environmental issues and the fast depletion of fossil fuels have imposed a great strain on developed countries to find an alternative source of fuel which is environmental friendly as well as non-depleting. Biomass is one of the renewable energy resources which is capable of displacing large amounts of solid, liquid and gaseous fossil fuels. The solid biomass materials can be conveniently used as an alternative fuel through a process known as gasification. Gasification is the process of converting solid fuel into a gaseous fuel through a thermo-chemical conversion process. The process involves the utilization and conversion of biomass in an atmosphere by using air or steam as a gasifying agent to produce a low or medium heating value gas. The generated gas, known as producer gas is a mixture of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2) and water vapor (H_2O). However, the gasification process also produces fine dust, ash and condensable compounds of tar (Sridhar *et al*., 2001) which must be cleaned and removed to a permitted value if the producer gas is intended to be used as fuel in an IC engines. The typical composition of producer gas obtained from the downdraft gasification process on percentage volume basis over the last three decades is shown in Table 1.

Table 1: Composition of producer gas

	Percentage (%)		
Type of gas	Wood Gas as Engine Fuel (1986)	Shashikantha and Parikh (1994)	Zainal *et al.* (2002)
CO	15-30	15-25	24.04
H_2	10-20	15-20	14.05
CH_4	2-4	1-3	2.02
CO_2	5-15	10-15	14.66
N_2	45-60	40-50	43.62
H_2O	6-8	1-2	1.61

Today, due to the increase of fuel prices and environmental concern, there is renewed interest on the gasification technology. Biomass gasification is one of the biomass conversion technologies that can be

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effectively used and utilized for decentralized power generation plants and thermal applications. The technology can be realized in two ways: directly used in the boiler for steam production followed by running a turbine and treated the producer gas to run a gas turbine and IC engines.

Typically, the temperature of gasification is in the range of 800-900°C and the producer gas has a heating value of 4-12 MJ Nm^{-3} (McKendry, 2002). The main reason of low heating value is due to the dilution of the product gases with nitrogen from air during the gasification process. Therefore, the producer gas is difficult to liquefy or compress particularly in small-scale gasifiers (Russel, 2008). In the current practice the producer gas is used immediately once it is produced and quantity and the flow rates of the producer gas are slightly above ambient condition.

Compressing and storage of producer gas are viewed as attempts to store the gas and to be used at the later stage. Generally, the only equipment required to compress and store any type of gas are a compressor and a pressure vessel. However, the main problem with compressed gas storage is the low storage density, which depends on the storage pressure. Higher storage pressures will increase capital and operating costs (Wade, 1998). The producer gas can be compressed to a higher pressure than atmospheric, due to the fact that the producer gas has poor ignition or a delay in ignition characteristics (Singh *et al*., 2007). Therefore, the producer gas cannot be self-ignited unless there is a source of ignition such as spark plugs in Spark Ignition (SI) engine or diesel fuel in Compression Ignition (CI) engine (Sridhar *et al*., 2005).

Based on earlier research, compressing of producer gas has been tried by using switchgrass as a biomass fuel in gasification process (Asthma *et al*., 2006). The producer gas obtained was compressed using an air compressor and stored at 869 kPa of gauge pressure. The compressed producer gas was then converted into ethanol using microbial catalysts. The composition of producer gas recorded was 16.5% of CO, 15.5% of CO_2, 5% of H_2, 4.5% of CH_4 and 56% of N_2.

A feasibility study conducted by the US Department of Energy's National Technology Laboratory (2008), has revealed that the Integrated Gasifier Combined Cycle (IGCC) which operates the gasifier continuously can produce and stores the syngas instead of using it immediately. The compressed and stored syngas from gasification process may be used to produce electricity in gas turbines during periods of peak demand or when the tariff of electricity is at the highest price.

It has been seen so far that not many literatures have been done on the compressing and storing of producer gas from biomass gasification. Therefore, there is still room for researchers to study the concept and develop compressed producer gas for future use, particularly in the small scale power generation. Hence, the present study is aimed to develop and evaluate the feasibility of compressing the producer gas from biomass downdraft gasification process.

THEORETICAL ANALYSIS

Compressing producer gas in a cylinder by using air compressor: An air compressor can generally be defined as a device that is used to increase the pressure of gas or vapor, typically air or a mixture of gaseous and vapors. The basic principle of the device is taking a volume of gas or vapor and increasing it to a pressure higher than atmospheric pressure in a closed tank by reducing its volume. The gas in the pressured condition is stored in the tank at a specified pressure depending on its type and specifications. The gas can be stored in high pressure cylinders ranging up to 6000 psi (410 bar), normal pressure cylinders ranging between 2000 and 2500 psi (140 and 175 bar) and low pressure cylinders ranging up to 480 psi (34 bar). The common type of air compressor is the reciprocating air compressor which usually uses a piston within a cylinder as the compressing and displacement element. Single stage air compressors are generally used for pressures in the range of 70 to 120 psi while two stage air compressors are for pressures between 125 to 250 psi (Frankel, 2004).

Figure 1 shows a gas being compressed inside a cylinder by the movement of a piston. The gas is compressed from volume V_1 to volume V_2 and as the piston moves, the pressure is raised from pressure P_1 to pressure P_2 and the temperature also rises from temperature T_1 to temperature T_2. The final pressure depends on the final temperature, which depends on the degree of cooling that takes place during the process (Iynkaran and David, 2004).

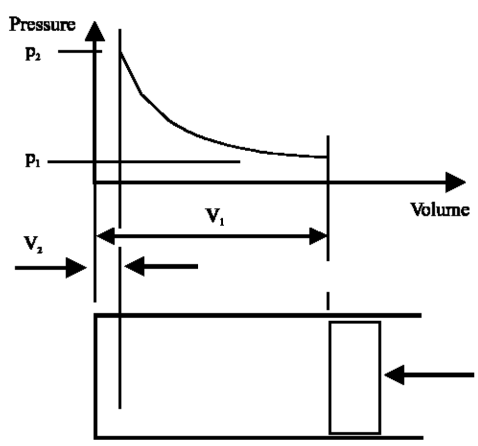

Fig. 1: Compression of gas in the cylinder

When air flows into the pipe, its mass depends on the pressure, temperature and composition prevailing at the compressor inlet. When pressure and temperature are considered, the actual volume of air flow is usually stated as Free Air Delivery (FAD). In an air compressor, the FAD is basically a volume of air drawn into a compressor from the atmosphere. After compressing and the cooling process, the air is returned to its original temperature but at a higher pressure. However, the term FAD does not mean that air is at standard conditions due to altitude, barometer and temperature that may vary at different locations and at different times.

By considering the initial air conditions P_1, V_1 and T_1 and the final compressed air conditions P_2, V_2 and T_2, using the ideal gas law:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad (1)$$

Usually it is assumed that the compression is perfectly cooled, the temperature remains constant and the final pressure is the lowest possible. Hence, the process is called isothermal and obeys Boyle's Law, PV = constant. Therefore, the temperatures are cancelled and the volume of FAD (V_1) from Eq. 1 becomes:

$$V_1 = \frac{P_2V_2}{P_1} = \text{FAD} \quad (2)$$

The actual rate of FAD is determined by taking into account the atmospheric pressure (P_0) and the time (t) taken for building up pressure in the compressor tank from atmospheric pressure to a specified gauge pressure. Therefore, Eq. 2 can be substituted as:

$$\frac{V_1}{t} = \frac{(P_2\text{-}P_1)\times V_2}{t \times P_0} = \text{FAD} \quad (3)$$

As mentioned earlier, Eq. 3 is relevant where the compressed air temperature is the same as the ambient air temperature by assuming perfect isothermal compression. In the event the actual compressed air temperature at a discharge pressure of T_2 is higher than the initial air temperature of T_1, the FAD has to be corrected by a factor as in the following equation:

$$\frac{(273 + T_1)}{(273 + T_2)} \quad (4)$$

Gasifier-air compressor flow diagram: The selection of a suitable air compressor to be coupled with a downdraft gasifier is the most important criteria in this research project as illustrated in Fig. 2. The amount of biomass and producer gas flow rate has to be properly calculated and balanced in order to avoid too much waste or an excess of producer gas generated from the gasification process. At any condition, the amount of producer gas supplied to the air compressor should be higher than the amount of gas delivered by air compressor. Otherwise, air will be entering the system and mixed with the producer gas in the compressor tank. For theoretical calculations, the efficiencies of the downdraft gasifier and the cooling system were taken as 70 and 95%, respectively (Sivakumar *et al*., 2008; Bhave *et al*., 2008).

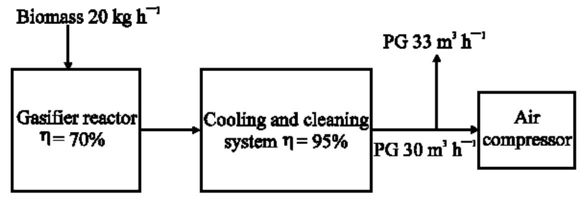

Fig. 2: Gasifier-air compressor systems

Other parameters involved in the calculations are including biomass specific fuel consumption, low heating value of producer gas and the biomass fuel feeding rate.

EXPERIMENTAL METHODS AND PROCEDURES

Experiments have been conducted on a single stage reciprocating air compressor in which the output flow rate of the compressed producer gas was regulated at 130, 150 and 170 L min^{-1} constantly, using a calibrated flow meter as the specifications is shown in the Table 2. The discharged output pressure was set at 2.0, 2.5 and 3.0 bar pressures, respectively.

Experimental setup: The experimental setups consisted of a downdraft gasifier, a producer gas cooling and cleaning system and air compressor. The downdraft gasifier was specifically designed and developed by Universiti Sains Malaysia (USM) to generate an acceptable quality of producer gas, consistently. The specifications of the gasifier and the air compressor used in the experiment are given in Table 3.

The 50 kg biomass fuel is fed into the gasifier through the top opening at a feeding rate of 20 kg h^{-1} as shown in Fig. 3. Air was supplied to the gasifier using a rotary blower, in which the capacity was higher than the required airflow rate. To prevent pressure build-up and the overloading of the motor of the blower, a by-pass valve was used to discharge some air to the atmosphere. Airflow to the gasifer was measured by using a calibrated rotameter in the range of 6-120 m^3 h^{-1} and controlled by

Table 2: Specifications of air flow meter

Items	Descriptions
Make and model	KI-Key Instruments FR 2000
Meter body	Clear acrylic with stainless steel float
Accuracy	±5%
Max pressure	65°C (150°F)
Flow rate	0-300 L min^{-1}

Table 3: Specifications of the gasifier

Items	Description
Type of gasifier	Downdraft, batch feeding
Fuel consumption	20 kg h^{-1}
Hopper capacity	100 kg
Type of biomass fuel	Off cut furniture wood
Biomass size	50-100 mm (cubic)
Conversion efficiency	70-75%

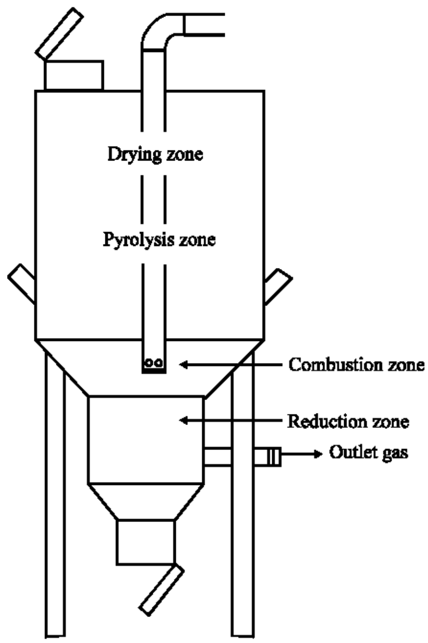

Fig. 3: Reactor of downdraft gasifier

using a ball valve. Air entered the combustion zone and the producer gas generated went out near the bottom of the gasifier at a temperature of about 550°C.

When the steady operation of the gasifier was achieved, the hot producer gas was allowed to pass through the attached cyclone to remove all particles and dust. The producer gas was then passed through a heat exchanger for the condensation of water as well as for the cooling process. The cooled producer gas then passed through a holding tank, followed by a filtering system to remove tars and other fine particles for cleaning process. The final temperature of the producer gas measured was around 35°C before entering the air compressor as shown in Fig. 4.

In this study, the gasifier was started for about 30 min earlier to stabilize the gas and at the same time the

Table 4: Specifications of air compressor

Items	Description
Type of air compressor	Ingersoll rand single stage
Horse power	5 HP
Rated capacity	670 L min^{-1}
Tank capacity	250 L
Working pressure	7.6 bar (110 psi)
Max working pressure	8.6 bar (125 psi)

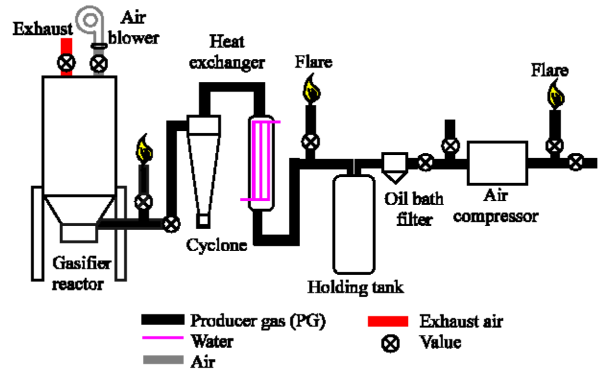

Fig. 4: Downdraft gasifier-air compressor systems

air compressor was also started to compress the normal air from surrounding. After checking the final gas outlet temperature of gasifier, the ball valve was fully opened to allow the producer gas to be compressed by air compressor. A single stage reciprocating air compressor was used to compress the producer gas as the specification is given in Table 4. Standard engine air filter and a pressure reducing valve were installed at the intake manifold and the discharged pipe of the air compressor respectively. The intake FAD of producer gas from gasifier was fixed at 670 L min^{-1} as per air compressor's specification. The producer gas was compressed from an initial pressure of 0 psi gauge pressure and temperature of 30°C, to an operating pressure of 7.6 bar gauge pressure. The compressor motor will re-start when the pressure in the tank drops to a set pressure of 4 bar.

Air inside the air compressor was first purged out to discharge any remaining air inside the compressor tank to the surrounding. The process was then repeated until the compressor tank was fully displaced by producer gas. The producer gas was then flared continuously at the producer gas ports throughout the experiment as an indicator for the presence of gas from the gasifier.

Hawlett Packard Module 4890 gas chromatography was used to measure the volume percentage of CO, H_2, CH_4, CO_2 and N_2 to determine the heating value of producer gas. To measure the composition with the gas chromatography, producer gas samples were taken from the sampling unit with gas sample containers through a sampling point in the gasifier.

RESULTS

Flare of producer gas: The capability of the producer gas to fuel engine or process heat application can be determined by the flaring of gas through a provided port in the biomass gasification process. As shown in Fig. 4, the gas was able to be flared just after the gasifier reactor; the other port of gas flare was located after the air compressor. It was found that the gas which flared had a blue flame without any smoke as compared orange/yellow flame in the gasifier. This phenomenon implies that the compressed producer having a good quality, almost free tars and particles which is needed for engine applications. However, it is still containing water vapor which is not desirable and should be removes before gas enters the engine.

Producer gas flow rate: Figure 5-7 show the performance of the air compressor in terms of producer gas output flow rate and pressure within a specific time period. An analysis of the composition of the producer gas showed that it consisted of approximately 17.5% CO, 2.3% CH_4, 10.25% H_2, 16.2% CO_2 and 54% N_2. It was observed that the producer gas flow rate was fairly constant over the entire range set of pressures. The gas flow rate slightly fluctuated at the beginning due to the rapid rising of the pressure in the tank and the time taken for setting-up the required flow rate. After 5 min, the flow rates were seen to be almost stable towards the end of the experiment. The percentage of the flow rate drops was in the range of ±5.2% in 130 L min^{-1}, ±4.7% in 150 L min^{-1} and ±4.5% in 170 L min^{-1}.

Discharge pressure: The discharge pressures were difficult to maintain as the air compressor motor ran on and off between the operating pressure to the minimum set pressure throughout the experiment. Therefore, it can be seen that the pressure fluctuated greatly at a higher discharge pressure as compared to a lower set pressure. The pressure drops calculated were ±6.5%, ±8% and ±10% for pressure of 2.0, 2.5 and 3.0 bar, respectively. The higher pressure drops implies that the higher capacity of air compressor should be used when higher producer gas flow rate is required.

DISCUSSION

As mentioned, there are not many literatures been done on the compressing and storing of producer gas from biomass gasification. Based on earlier study, the common flame color obtained from normal operating temperature of biomass gasification is an orange/yellow flame as discussed by Wander *et al.* (2004). However, a research conducted by Energy Research Centre of Netherlands (2008) has revealed that the clear blue flame producer gas flare was an indication of cleaned and free of tars of producer gas generated. For compressed producer gas, Roy *et al.* (2009) has been successfully carried out an experimental on simulated producer gas in which the air and producer gas were mixed and kept constant at two bar gauge pressure to fuel the IC engine. The study has also recovered the supercharged producer gas from updraft gasifier in determining the effect on engine performance and emission in the dual fuel IC engine. Therefore, this was a preliminary study to see

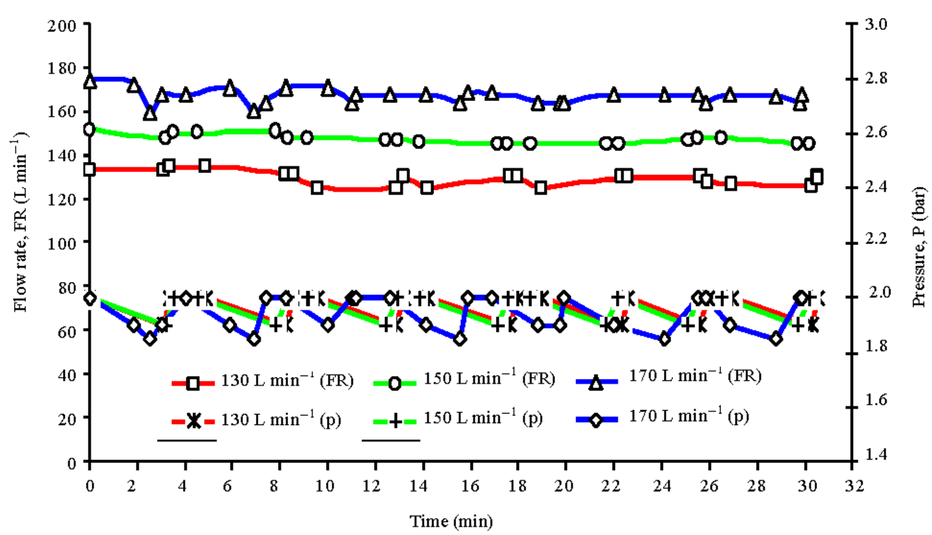

Fig. 5: Discharged flow rate and pressure at 2.0 bar

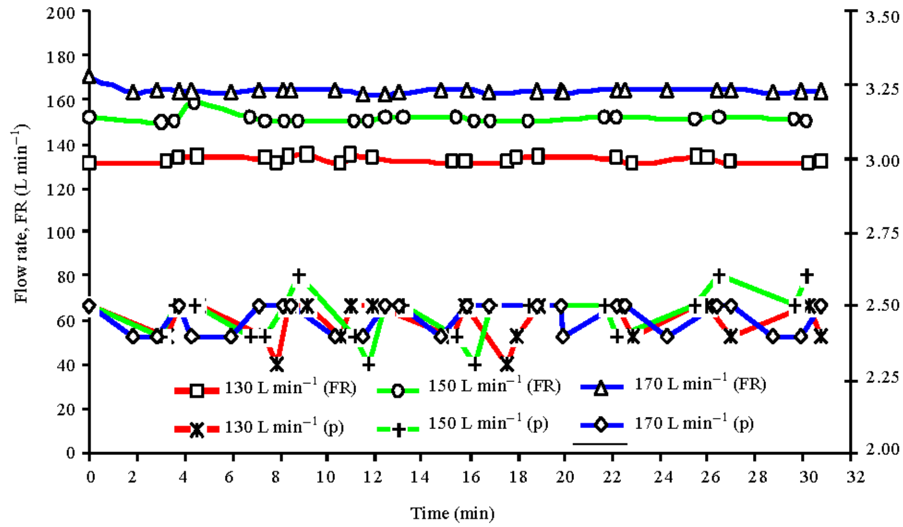

Fig. 6: Discharged flow rate and pressure at 2.5 bar

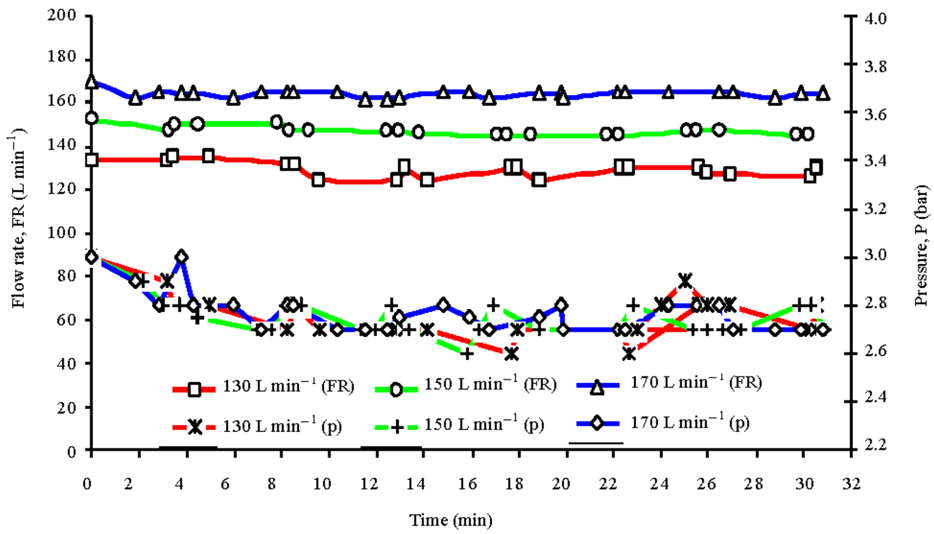

Fig. 7: Discharged flow rate and pressure at 3.0 bar

whether the compressed producer gas from downdraft gasifier could maintain its flow rate at pressure higher than atmospheric and the quality of the gas generated.

CONCLUSIONS

Compressing and storage of producer gas from downdraft gasification process has a number of advantages. This study has proved that the producer gas from the downdraft biomass gasification process can be compressed and stored for future use, particularly in a small-scale stationary power plant. However, the higher capacity of air compressor must be selected if the producer gas needs to be compressed and stored at higher pressure. The following conclusions were drawn from the present investigation undertaken. The important findings can be listed below:

- Good quality producer gas with a blue flare was obtained when the producer gas was compressed to a pressure higher than atmospheric
- The flow rate and the pressure of the producer gas were almost constant throughout the experiment; therefore, they could be varied to suit the required applications
- High pressure output will result in a higher mass flow rate of the producer gas

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