Technology of Biomass Gasification

Biomass has been a major energy source, prior to the discovery of fossil fuels like coal and petroleum. Even though its role is presently diminished in developed countries, it is still widely used in rural communities of the developing countries for their energy needs in terms of cooking and limited industrial use. Biomass, besides using in solid form, can be converted into gaseous form through gasification route.

1. Concept and Principle

Biomass is a natural substance available, which stores solar energy by the process of photosynthesis in the presence of sunlight. It chiefly contains cellulose, hemicellulose and lignin, with an average composition of $C_6H_{10}O_5$, with slight variations depending on the nature of the biomass. Theoretically, the ratio of air-to-fuel required for the complete combustion of the biomass, defined as stoichiometric combustion is 6:1 to 6.5:1, with the end products being CO_2 and H_2O. In gasification the combustion is carried at sub-stoichiometric conditions with air-to-fuel ratio being 1.5:1 to 1.8:1. The gas so obtained is called producer gas, which is combustible. This process is made possible in a device called gasifier, in a limited supply of air.

Gasification is a two-stage reaction consisting of oxidation and reduction processes. These processes occur under sub-stoichiometric conditions of air with biomass. The first part of sub-stoichiometric oxidation leads to the loss of volatiles from biomass and is exothermic; it results in peak temperatures of 1400 to 1500 K and generation of gaseous products like carbon monoxide, hydrogen in some proportions and carbon dioxide and water vapor which in turn are reduced in part to carbon monoxide and hydrogen by the hot bed of charcoal generated during the process of gasification. Reduction reaction is an endothermic reaction to generate combustible products like CO, H_2 and CH_4 as indicated below.

$$C + CO_2 \longrightarrow 2CO$$
$$C + H_2O \longrightarrow CO + H_2$$
$$C + 2H_2 \longrightarrow CH_4$$

Since char is generated during the gasification process the entire operation is self-sustaining.

2. Open top re-burn down draft gasifier ~ a state-of-the-art technology

Among the biomass gasification technologies in the world, the open top, twin air entry, re-burn gasifier developed at Combustion, Gasification and Propulsion Laboratory (CGPL) of Indian Institute of Science (IISc) is unique in terms of generating superior quality producer gas. There are more than 40 plants that are successfully operating in India and overseas for heat and power applications. The biomass gasification technology package consists of a fuel and ash handling system, gasification system - reactor, gas cooling and cleaning system. There are also auxiliary systems namely, the water treatment plant to meet the requirements of industry and pollution control board. The prime mover for power generation consists of either a diesel engine or a spark ignited engine coupled to an alternator. In the case of thermal system, the end use device is a standard industrial burner.

The open top re-burn design (shown in Fig. 1) pursued at IISc has concepts that can be argued to be helpful in reducing the tar levels 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 re-burnt before passing though 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 in a closed top design. The cracking of the tars improves the overall gasification efficiency. The other benefit in the case of superior reactor design is related to the energy available in the gas. Even at capacities in the range of 75 kg/hr the cold gas efficiencies has been in the range of 75 %. These results are among the best of conversion efficiencies presented in the literature for other gasifiers. Measurements on the large capacity gasifier system at 650 kg/hr, has resulted in cold conversion efficiencies in the range of 85 %. The temperature of gas exiting the reactor is about 600 – 900 K, and is laden with contaminants in form of particulate matter (1000 mg/Nm^3) and tar (150 mg/Nm^3). 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. Typical composition of the gas after cooling to ambient temperature is about 18-20% H_2, 18-20% CO, 2-3% CH_4, 12% CO_2, 2.5% H_2O and rest, N_2. The lower calorific value of the gas ranges is about 4.7 – 5.0 MJ/Nm^3, with a stoichiometry requirement of 1.2 to 1.4 kg of air for every kg of producer gas.

The recent development in the gas cooling and cleaning system provides dry producer gas with the tar and particulate level in the range of ppb levels. This has been possible by using C^n patented technology. In this process, hot high efficiencies cyclones are used to remove dry particulates from the gas and ejector scrubbers to cool and clean the gas. The gas is de-humidified or dried using the principle of condensate nucleation, to reduce moisture and fine contaminants. Measurements for the gas quality by established procedure have resulted in tar and particulate level less than 5 mg/Nm^3. Measurements on the particle size in the gas at the cyclone exit on the IISc design in Switzerland indicates that majority of the particles (> 95 %) are well below 0.5 µm.

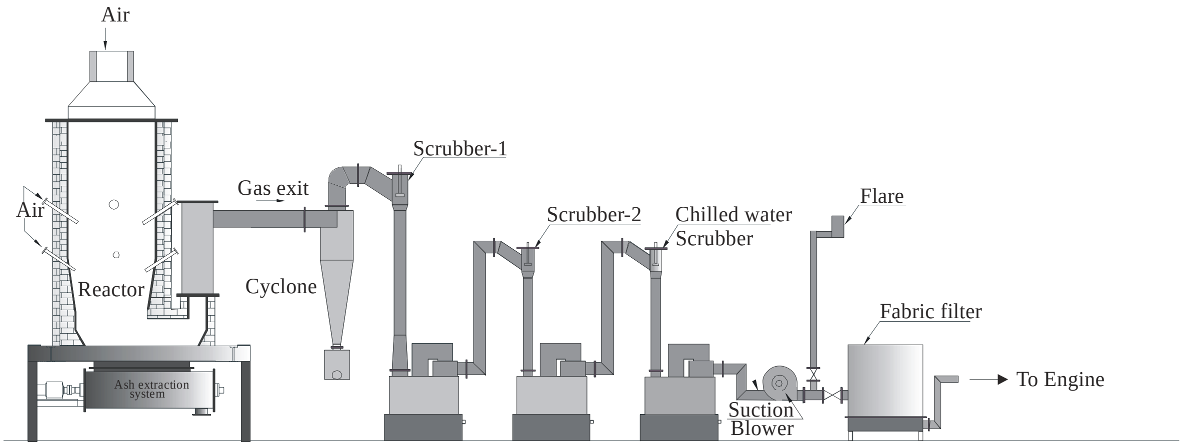

Fig 1: Typical configuration of the gasifier

3. Uses of Producer Gas

The producer gas obtained by the process of gasification can have end use for thermal application or for mechanical/electrical power generation. Like any other gaseous fuel, producer gas has the control for power when compared to that of solid fuel, in this solid biomass. This also paves way for more efficient and cleaner operation. The producer gas can be conveniently used in number of applications as mentioned below.

3.1 Thermal

Thermal energy of the order of 5 MJ is released, by flaring 1 m3 of producer gas in the burner. Flame temperatures as high as 1550 K can be obtained by optimal pre-mixing of air with gas. For applications which require thermal energy, gasifiers can be a good option as a gas generator, and retrofitted with existing devices. Few of the devices to which gasifier could be retrofitted are

a) Dryers: Drying is the most essential process in beverage and spices industry like tea and cardamom. This calls for hot gases in the temperature range of 120 130°C, in the existing designs. Typically the heat energy required is equivalent to 1 kg of biomass for 1 kg made tea. Gasifier is an ideal solution for the above situation, where hot gas after combustion can be mixed with the right quantity of secondary air, so as to lower its temperature to the desired level for use in the existing dryers.

b) Kilns: Baking of tiles, potteries require hot environment in the temperature range of 800-950°C. This is presently being done by combusting large quantities of biomass in an inefficient manner. Gasifiers could be suitable for such applications, which provides a better option of regulating the thermal environment. There will also be an added advantage of smokeless and sootless operation, whereby enhancing the product value.

c) Furnaces: In non-ferrous metallurgical and foundry industries high temperatures (~650-1000°C) are required for melting metals and alloys. This is commonly done by using expensive fuel oils or electrical heaters. Gasifiers are well suited for such applications.

d) Boilers: Process industries which require steam or hot water, use either biomass or coal as fuel in the boilers. Biomass is used inefficiently with higher pollutants like NO_x and with little control with respect to power regulation. Therefore these devices are appropriate to be retrofitted with gasifiers for efficient energy usage.

Apart from these, energy requirements in poultry farms, cold storage devices (vapour compression refrigerator), rubber industry and so on could be met using biomass gasifiers.

3.2 Power Generation

Producer gas can either be used in mono or dual-fuel mode in reciprocating engines. In case of mono-fuel mode of operation, the gas is fuelled to a SI engine, whereas in the dual-fuel mode it is operated along with small quantity of liquid fuel (high-speed diesel, furnace oil or bio-diesel) in a compression ignition (CI) engine. The choice of mode of operation is entirely dictated by the economics of operation.

Special features of IISc Technology

- ✓ Open top, twin entry system ensures a better thermal environment compared to the conventional closed top model- relatively higher through put for the same reactor size and also better gas quality
- ✓ Available in modules upwards of 5 kg/hr to 1100 kg/hr (5 kWe to 1.2 MWe)
- ✓ Multi-fuel capability – forest & plantation residue, agro residue, RDF in briquetted form with a maximum moisture content of 15%
- ✓ High gasification efficiency > 80%
- ✓ Superior gas quality, suitable for turbocharged R/C engines
- ✓ Low cost of electricity generation and competitive with the grid tariff
- ✓ Environmentally sound – low NOx in the engine exhaust
- ✓ Value addition products ~ activated carbon, along with energy





Multi -fuel option

The Current Status

In this era of the new millennium, gasification has evolved as a start-of-the-art technology at IISc and it can compete with some of the best technologies in the world. A wide range of technological packages have been offered to industries and institutions by it and its eight licensed technology holders both in India and overseas. The technology is being continuously upgraded based on technological advances and feed back received from the field installations. Also, IISc is working is close cooperation with Cummins India, who are offering their gas engine-generator sets for producer gas operation backed with warranties. Currently there are over 40 gasifier installations with a cumulative installed capacity of 15 Tons/hour.

3 x 213 kWe plant for industrial captive use

2 x 10 kWe plant for village electrification

Some of these systems are meant for thermal applications, where in the gas is combusted to meet the process requirement of industry. The remaining installations are meant for power generation application and includes both dual-fuel and gas engine mode of operation. The current installed capacity of gas engine-generator sets is over 3.0 MWe (March 2006) serving diverse requirements such as captive power in industry, grid linked independent power producer, energy service companies and village electrification. With the IISc's gasification technology offering multi-fuel option, there is flexibility for the end user/client to source biomass based on availability thereby keeping the cost of power generation at a minimal. The diverse range of biomass that is being used includes weeds such as ipomea, prosopis julifora, forest residue to industrial wastes such as sawdust and bamboo dust in briquetted/compacted form. Many of these plants are operated round the clock and the availability of the plant has been as high as 85 -90%. The plant with such high plant load factor is able to provide accelerated return to the investor apart from additional revenue in the form of by-product such as activated carbon. Cost of power generation as low as Rs 2.50/unit electricity generated has been achieved. To sum up the performance, currently the technology is making a modest saving to a tune of 20- 25 kilo Litres of fossil fuel per day and saving valuable foreign exchange to the country.