TECHNICAL PAPER

Title: **Advances in Biomass Gasification Power Plants**

Authors: Harvey Wen, Connie Lausten, and Jon Pietruszkiewicz
Bechtel Corporation, Frederick, MD

Dr. Pat Delaquil, BG Technologies, Washington, D.C.

Dr. B. C. Jain, Ankur Scientific Energy Technologies, Vadodara, India

Date: April 6-8, 1999

Publication/Venue: American Power Conference, Chicago, IL

ADVANCES IN BIOMASS GASIFICATION POWER PLANTS

HARVEY WEN, CONNIE LAUSTEN, and JON PIETRUSZKIEWICZ
Bechtel Corporation, Frederick, Maryland

DR. PAT DELAQUIL
BG Technologies, Washington D.C.
DR. B.C. JAIN,
Ankur Scientific Energy Technologies
Vadodara, India

Abstract

This paper describes a new commercial application of the “down draft” type biomass gasifier for power generation with internal combustion (IC) engine generators. The advantages of the “Ankur” down draft gasifier, designed by Ankur Scientific Energy Technologies (ASCENT) over earlier down draft, updraft and fluidized bed gasifiers are discussed. A major achievement of the Ankur gasifier is the very low level of tars and oils in the product gas, an important feature if the gas is to be used for power generation via an internal combustion engine. The new gasifier has higher conversion efficiency, larger throughput, and better economics compared to earlier gasifier designs. A comparison of technology risks, fuel flexibility and costs is also made between the Ankur downdraft gasifier and other biomass gasification technologies.

Bechtel conducted gas quality tests, under contract to EnergyWorks, LLC, to confirm that the product gas from the gasifier is largely free of tars and other impurities, and the test results are presented in this paper. The ASCENT biomass gasification system is commercially proven in India for both thermal applications and electric power generating plants up to the 500 kW size.

Introduction

The use of biomass fuel, especially biomass wastes, for distributed power production can be economically viable in many parts of the world. Biomass is a clean and renewable fuel. The potential applications for biomass gasification include the following:

- Replace current natural gas or diesel fuel use in industrial boilers or furnaces
- Provide distributed power generation where power demands are in less than a few megawatts
- Displace gasoline or diesel fuel in an internal combustion engine generator

A review of these applications reveals that the biomass power plants are viable for small size plants ranging from a few hundred kilowatts to no more than a few megawatts. A larger biomass fired power plant may not be feasible because of fuel supply problems and its economic competitiveness. For a plant with only a few megawatts output, the use of a conventional boiler/steam turbine cycle is usually not economically feasible. The use of biomass integrated gasification combined cycle (IGCC) for power generation is under development, but it is not currently commercially proven and available. This paper is therefore focused on internal combustion engine based systems.

One major problem with the use of biogas in an internal combustion engine is the potential fouling of the engine by particulates, oils and tars. The review of various gasification technologies and the verification of tar content in a downdraft gasifier are described below.

Gasification

Biomass gasifiers may be categorized as moving bed updraft, moving bed downdraft, and fluidized bed gasifiers based on their configurations. The selection of the most suitable gasifier must consider the intent of its application. The characteristics of these gasifiers are briefly described below.

Moving Bed Updraft Gasifiers

This configuration is the same as that used in most “producer gas” coal gasifiers. The biomass material enters from the top of the gasifier through a lock hopper. The moving bed is divided into drying, gasification and combustion zones. The bed moves downward as fuel is consumed and the biogas exits from the top. The ash is discharged from the bottom of the gasifier. The updraft gasifier has the advantage of a simple, reliable design, but this configuration produces a biogas laden with wood oils, tars and particulates. The gas is suitable as a boiler fuel, but unsuitable for use in gas turbine or internal combustion applications unless these heavy hydrocarbon materials are removed. There are several 5 MW_{th} updraft Bioneer® gasifiers in operation in Sweden and Finland, serving small district heating plants.

Moving Bed Downdraft Gasifiers

In a downdraft gasifier, both the biomass bed material and gas produced move downward in a co-current manner. The biomass is partially combusted, and the product of this partial combustion then passes through a hot charcoal bed where the gas cools somewhat by the endothermic gasification reaction. While the temperature at the combustion zone is generally about 900^o to 1200 ^{o}C, the biogas temperature exiting the gasifier is maintained at about 300-450 ^{o}C.

The biogas from the downdraft gasifier generally has significantly lower levels of oils and tars compared to the other types of gasifiers, but it still requires gas clean up for particulates as well as for oils and tars. The efficiency of the gas clean-up system in providing biogas with very low levels of tars and particulates is critical. The low level of oil and tars in the biogas is an important feature in power generation applications since neither reciprocating internal combustion engines nor gas turbines can accept the fuel gas with oily tars.

Downdraft gasifiers were used extensively during WWII in cargo carrying trucks. It was estimated that hundreds of thousands of small vehicle mounted biomass gasifiers powering internal combustion engines were deployed during that period of time. However, many of these units were based on wood charcoal. Recent developments have shown that the downdraft gasifier can use biomass directly and can be scaled-up to sizes suitable for industrial applications. The largest industrial size downdraft gasifier that has been demonstrated is the Ankur 1500 kW_{th} gasifier.

Fluidized Bed Gasifiers

Most new developments in biomass gasification are focused on the utilization of fluidized bed gasifiers. In the past twenty years, fluidized bed combustion has been successfully developed for burning low-grade coals, and the technology developers are extending their applications to biomass gasification. A significant advantage of fluidized bed gasification is that the gasifier can be designed for high-pressure operation, thus increasing the biomass capacity throughput. They can also use air blown, oxygen blown, or a transport media for indirect heating.

The largest fluidized bed biomass gasifier today is a Lurgi designed circulating fluidized bed (CFB) unit rated at about 100 MW_{th} (Ref. 1). It is designed for air-blown, atmospheric pressure operation and is used to produce a low calorific fuel gas from wood, biomass and biomass residues. A 12 MWe biomass gasifier/gas turbine system is being planned in Italy using the Lurgi process.

The Battelle/FERCO gasification process employs circulating sand to indirectly heat and gasify the biomass (Ref. 2). The remaining char is burned to heat the circulating sand. It produces a medium calorific value gas without the need for an oxygen plant. A 40 MW_{th} demonstration gasifier is in operation in Vermont and creates a medium Btu gas that is injected to a boiler. The next phase of the installation will incorporate a gas clean up system and combustion turbine generator.

A number of pressurized fluidized bed gasifiers are in various stages of commercial development (Ref. 3). These pressurized gasifiers are being designed for 10-20 bar pressure depending on the gas turbine system fuel gas pressure requirement. A pressurized design is necessary to increase capacity throughput, and to eliminate the need for a gas compressor, but it also creates challenges in the biomass feeding system. The biomass preparation and feeding systems are more complicated and can be sources of outages.

Biogas Treating Systems

Biogas from most gasifiers contains impurities including oils, tars, flyash, and vaporized alkali compounds. The amounts of these impurities vary depending the type of gasifier. In general, the level of these impurities is the highest for the updraft gasifier, and the lowest in the downdraft gasifier. The sulfur content in all gasifiers is typically very low and its removal is not required.

The biogas from an updraft gasifier contains about 15% condensables, and the raw biogas is usually used in a furnace without cooling or treating. The particulates in the flue gas are removed in a baghouse downstream of the boiler. This biogas contains high amounts of oil and tar that preclude it from being used directly in an IC or a gas turbine engine.

The tar content in biogas from a fluidized bed gasifier has been reported to be in the range of about 100 mg/Nm^3 (90 ppmw) for heavy tar, and 4-12 g/Nm^3 (3,500 – 11,000 ppmw) for light tar. The tar condensation temperature is about 150 ^{o}C (Ref. 4). The use of this type of biogas in a gas turbine is possible if the tars are maintained in a gaseous phase, or a tar cracker or scrubbing system may be incorporated to the system.

Without a means of eliminating the tars before the gas turbine, the tars may condense out in the compressor before entering the combustion turbine. The particulates in the raw gas can be removed in a hot gas cleanup (HGCU) system. In several pressurized fluidized bed demonstration plants, HGCU systems operating at temperatures between 300–550 °C are being tested. The pressurized fluidized bed gasifiers and their HGCU systems are not yet commercialized.

The use of atmospheric CFB with an IC engine was tested in an Italian facility. It includes a CFB, a HGCU and a catalytic tar cracker to produce a clean gas for a 500 kW IC engine. The tar content was reported to be about 1000 mg/Nm^3 in the product gas at 820 °C (Ref. 5).

The tar content measured in the Ankur downdraft gasifier exit line was less than 5 mg/Nm^3. At this extremely low level, tar removal equipment is not required. The biogas treating system included in the Ankur system is comprised of a water scrubber and a final fine filter. The resulting gas contains no more than 10 mg/Nm^3 of particulates, which is below the IC fuel specification limits.

Tar and Particulate Test Results

Bechtel Technology and Consulting, under contract with EnergyWorks LLC, conducted tar and particulate testing on a BG-400 in Baroda India. The testing took place from January 19 to 23, 1998. The particulate test was designed to assess the particulate concentration in the producer gas according to EPA Method 5, modified for the equipment used and testing conditions. Standard procedures for gaseous fuel tar sampling do not exist. Therefore, procedures were developed based on EPA Method 5 sampling techniques, the American Society of Mechanical Engineers testing methods, and methods adapted from biomass experts Dr. Parikh, A. Das, and the National Renewable Energy Laboratory.

The BG-400 was tested for tar and particulate concentrations at operating levels of 100%, 75% and 50% load. Particulate samples and condensate samples were taken directly after the scrubber (before the fine filter) and after the fine filter. The samples were transported back to the United States where analyses were conducted by Clean Air Engineering and Philip Services.

Particulate concentration results may be found in Table 1 for concentrations at system loads of 50%, 75% and 100% both before and after the fine filtration system.

Table 1 Average Particulate Concentration Levels in mg/Nm^3

System Load	50%	75%	100%
After Filter	0.00	0.01	0.30
Before Filter	96.6	116.9	101.3

Methods used to conduct the gravimetric analysis were also in conformance with EPA Method 5 procedures. Laboratory results indicate that the particulate concentration results after the filter at all load levels were well within the 5 mg/Nm^3 performance standard set by Ankur Scientific Energy Technologies.

Tar concentration results may be found in Table 2. Similar to the particulate analysis, concentrations were determined at system loads of 50%, 75% and 100% both before and after the fine filtration system. Tars are defined as the organic substances washed out of the condensate from the producer gas.

Table 2 Average Tar Concentration Levels in mg/Nm^3

Load	50%	75%	100%
After Filter	1.131	2.786	1.338
Before Filter	0.795	4.186	4.970

The tar concentration results indicate that the gasifier performed within 5mg/Nm^3 performance standards set by ASCENT. The results do not show significant concentration trends that increase or decrease with load.

Scrubber Water and Biogas Condensate Compound Analysis

Philip Services Laboratory conducted a semi-volatile laboratory analysis by conducting a full scan gas chromatograph mass spectrometry (GCMS) analysis on a sample of water from the scrubber and on a tar sample. The tar sample corresponded to a 45 minute 100% load test taken after the fine filter. The sample consisted of the condensate collected in an ice bath after the sample stream of producer gas passed through the nozzle and test filter. The results for the condensate analysis did not detect any tars. The compounds detected consisted of natural fatty acids and phenols, a natural compound used in plastics.

The scrubber water analysis did detect some polyaromatic hydrocarbons some of which may be classified as light tars, including naphthalene, phenanthrene, anthracene, fluoranthene, pyrene, and chryrene. The scrubber outlet water also contained some octadecenanide (fatty acids found in bioata) and steric acid which is used in skin cream and soap. Steric acid is normally associated with ash. The test analysis does not conclusively indicate that no tars were in the condensate from the biogas. Some tars may have been lost in transport or due to handling for the gravimetric analysis. It should be noted that the procedures used by the laboratory and quality control standards for this test were high, indicating that losses were minimal.

Comparison of Gasification Technologies

A review of more than a dozen of biomass gasifiers and their treating systems was performed by Bechtel, with the following observations:

1. An updraft biomass gasifier system is not usually economically competitive for power generation via IC engines or gas turbines because it requires a complicated tar removal system to cleanup the oils and tars in the raw biogas.
2. Pressurized fluidized bed biomass gasifiers are under development, but they are not commercially proven and therefore are not offered with commercial guarantees.
3. The biogas produced from the Ankur downdraft gasifier is essentially free of oils and tars, and is suitable for use in an IC engine. The use of a downdraft gasifier with a gas turbine may not be a good match because it will require gas compression and the thermal efficiency gain may not justify the additional costs and complexity.

Downdraft Biomass Gasifier/IC Power Plant System Design

Figure 1 is a simplified process flow diagram showing the configuration of a downdraft biomass gasifier/IC engine power plant. This is one of the plant configurations offered by BG Technologies. It is comprised of an Ankur downdraft gasifier, a venturi scrubber, a fine filter, a diesel engine and control system.

The biomass feedstock suitable for the Ankur gasifier includes wood chips, biomass wastes such as rice husks and coconut shells and other fuel sources. The biomass resource should have a 20% moisture content or less. The raw biogas generated in the gasifier is water washed in a venturi scrubber and then polished in a final filter. The biogas is a low calorific gas and may be used in compression ignition engines if there is a 20 to 30% diesel fuel supplement. The biogas is connected to the air intake manifold of the diesel engine. During operation, it is necessary to use some diesel fuel for engine operation.

The performance of a typical 250 kW plant is shown below:

Biomass input	250 kg/hr
Gross power output	250 kWe
Thermal output	625,000 kcal/hr
Gasification eff.	>70%
Aux. load	12 kWe
Net power output	238 kWe
Biogas flow rate	625 Nm^3/h
Biogas heating value	>1000 kcal/m^3

Cost Comparison

It is difficult to compare costs for systems that are not identical in size or performance. However, based on available literature, indicative costs for fluidized bed gasifier based power plant were identified. The cost of updraft gasifier power plants is not readily available as it is not a viable technology for direct firing in an IC or gas turbine.

The cost of a CFB gasification combined cycle plant was estimated to be about $2,700 per kW for a 30 MWe demonstration plant and $1,400 for a future commercial plant (Ref. 5). The cost of a future commercial pressurized fluidized bed gasification combined cycle plant was estimated to be $1,245 per kW (Ref. 6).

The installed cost for BG-Systems will vary with the size and complexity of the installation. Systems in the 250 kWe to 1 MWe range will cost approximately $1200 per kWe, larger systems will generally be $1000 per kWe. Based on economic calculations for existing customers, the systems produce significant savings in fuel costs and can pay back their initial investment in less than three years.

Conclusion

After reviewing various biomass gasification technologies, it is our conclusion that the downdraft type gasifier is most suited for small, 250 kWe to 1 MWe, power generation units at the present time. The downdraft gasifiers have been proven in WWII for use in trucks. Its recent scale-up to an industrial size of 500-700 kW_e with direct use of biomass (instead of wood charcoal) has created a low cost option to utilize agriculture and forest product wood wastes for distributed power generation.

References

(1) Hirschfelder, H. and Vierrath. H., "CFB Biomass Gasification for Energy & Industry – Operational Results", EPRI/GTC Gasification Technology Conference, 1998.

(2) Farris, L., Paisley, M.A., Irving, J., Overend, R.P., "The Biomass Gasification Process by Battelle/FERCO: Design, Engineering, Construction, and Startup". EPRI/GTC Gasification Technology Conference, 1998

(3) Overend, R.P. and Bain, R, "The DOE/NREL National Biomass Power Program Gasification Project Updates".

(4) Liinanke, L., Horvath, A., Lehtovaara, A., and Lindgren, G., "The development of a Biomass Based Simplified IGCC Process", EPRI Gasification Technology Conference, 1994.

(5) Rensfelt, E.K.W., "Atmospheric CFB gasification – The Greve Plant and Beyond", International Conference on Gasification and Pyrolysis of Biomass, Stuttgart, Germany, 1997.

(6) Paisley, M. and Overend, R., "Biomass Gasification for Power Generation", 1994.

Figure 1 - Process Flow Diagram