
Biomass Gasification - A Review

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ABSTRACT

Biomass gasification process, biomass converts organic or fossil based carbonaceous materials into a gaseous mixture of CO, CO₂, CH₄, H₂ and H₂O. This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. In gasification the combustion is carried at sub-stoichiometric conditions with air-to-fuel ratio being 1.5:1 to 1.8:1. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas. It offers the most attractive alternative energy system for agricultural purposes. Most preferred fuels for gasification have been charcoal and wood. However biomass residues are the most appropriate fuels for on-farm systems and offer the greatest challenge to researchers and gasification system manufacturers. The power derived from gasification of biomass and combustion of the resultant gas is considered to be a source of renewable energy. Maximum usage of producer gas has been in driving internal combustion engine, both for agricultural as well as for automotive uses. However direct heat applications like grain drying etc. are very attractive for agricultural systems. A spark ignition engine running on producer gas on an average produces 0.55-0.75 kWh of energy from 1 kg of biomass. Biggest challenge in gasification systems lies in developing reliable and economically cheap systems. Future development should concentrate on reducing the cost of the gasification plant itself since it is the gasification plant the main cost factor. Also future applications like methanol production, using producer gas in fuel cell and small scale irrigation systems for developing countries offer the greatest potentialities.

Key-words: *Gasification, producer gas, energy conversion and syngas.*

INTRODUCTION

Gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas and is itself a fuel. The power derived from gasification of biomass and combustion of the resultant gas is considered to be a source of renewable energy; (NNFCC, 2011; www.biomass.uk.com; www.gastechnology.org; www.waste-management-world.com) the gasification of fossil fuel derived materials such as plastic is not considered to be renewable energy.

Gasification systems-instead of directly burning the fuel to generate heat-convert biomass into a low-Btu to medium-Btu content combustible gas, which is a mixture of carbon monoxide, hydrogen, water vapor, carbon dioxide, tar vapor, and ash particles. In a close-coupled gasification system, the combustible gas is burned directly for space heat or drying,

or burned in a boiler to produce steam. Alternatively, in a two-stage gasification system, tars and particulate matter are removed from the combustible gas, resulting in a cleaner gas suitable for use in a genset, gas turbine, or other application requiring a high-quality gas (Figure 1).

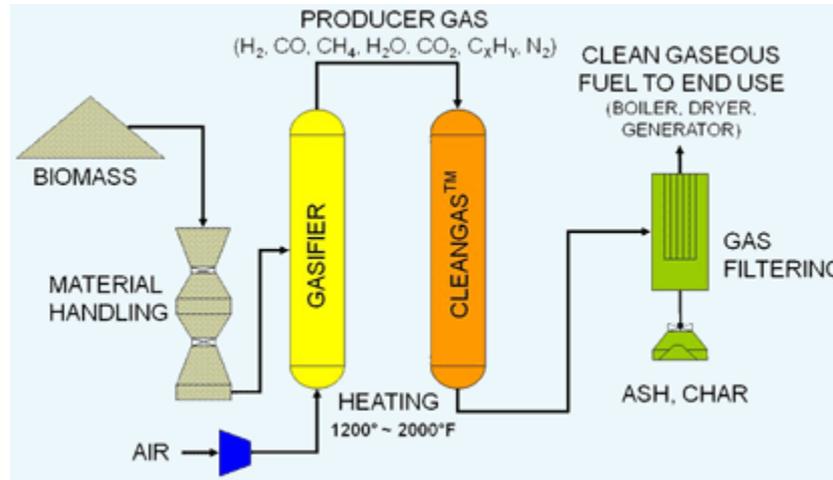


Figure 1: Example of two-stage gasification (Courtesy of Frontline Bioenergy)

Char gasification is the endothermic process where the char, solid residue from a pyrolysis process, is transformed into a gaseous mixture of CO, CO₂, CH₄, H₂ and H₂O in a reducing atmosphere usually composed of CO₂ and H₂O. Being char gasification an endothermic process, some source of heat is required. The common heat source is the combustion of the volatile matter released during pyrolysis. The addition of an oxidation agent is necessary for this combustion process. As already mentioned previously, the thermal degradation of biomass in the presence of an oxidation agent should rather be referred as devolatilization and not pyrolysis. Figure 2 (a) & (b) shows schematically the char gasification process.

It is however common to denote as “biomass gasification” the overall process where not only the char is transformed into gas but where all drying, devolatilization, volatile matter combustion and char gasification take place. The biomass gasification process is also referred as “pyrolysis by partial oxidation”.

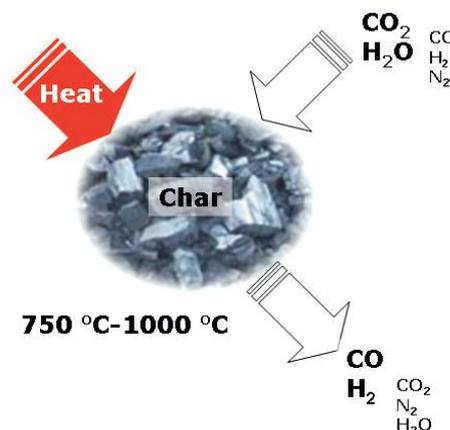


Figure 2 (a): Sketch of the char gasification process

It intends to maximize the gaseous product, and generally takes place between 800 and 1100 °C. The product gas contains CO, CO₂, H₂, H₂O, CH₄, N₂ (if air is used), apart from contaminants like small char particles, small amounts of ash and tar.

Gasification Reactions

As previously referred, biomass gasification can be considered as a three-step process: devolatilization -producing volatile matter and char-, secondary reactions of the volatile matter and char gasification.

The main chemical reactions involved in char gasification are:

Boudouard reaction: $C + CO_2 + \text{heat} \rightarrow 2 CO$

Water-gas reaction: $C + H_2O + \text{heat} \rightarrow CO + H_2$

These reactions are endothermic and very slow at temperatures below 800 °C.

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.

The essence of gasification process is the conversion of solid carbon fuels into carbon monoxide by thermo-chemical process. The gasification of solid fuel is accomplished in air sealed, closed chamber, under slight suction or pressure relative to ambient pressure. Gasification process occurring in general explained in this section.

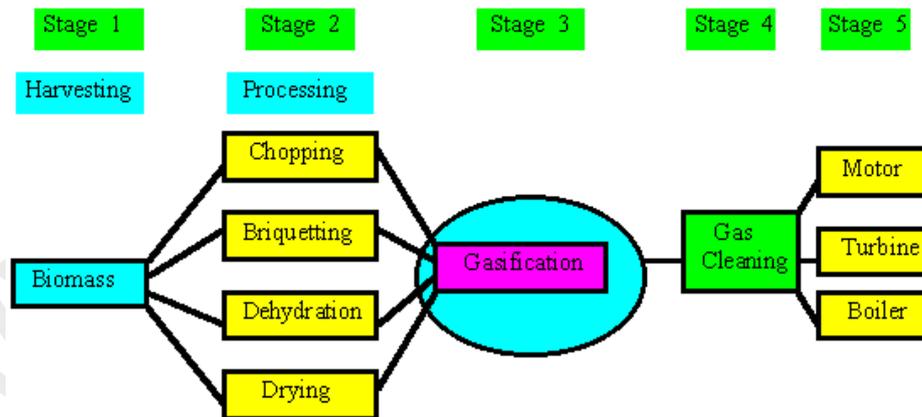


Figure 2 (b): Complete gasification process

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.

(a) 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 wood 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 wood 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 wood gasifiers..

(b) Power Generation

Using wood gas, it possible to operate a diesel engine on dual fuel mode. Diesel substitution of the order of 80 to 85% can be obtained at nominal loads. The mechanical energy thus derived can be used either for energising a water pump set for irrigational purpose or for coupling with an alternator for electrical power generation, either for local consumption or for grid synchronisation.

An appropriate site to realise the above application is an unelectrified village or hamlet. The benefits derived from this could be many, right from irrigation of fields to the supply of drinking water, and illuminating the village to supporting village industries. The other suitable sites could be saw mills and coffee plantations, where waste wood (of course of specified size) could be used as a feed stock in gasifiers.

(c) Wood Gasifier

This system is meant for biomass having density in excess of 250 kg/m³. Theoretically, the ratio of air-to-fuel required for the complete combustion of the wood, defined as stoichiometric combustion is 6:1 to 6.5:1, with the end products being CO₂ and H₂O. Whereas, in gasification the combustion is carried at sub-stoichiometric conditions with air-

to-fuel ratio being 1.5:1 to 1.8:1. The product gas thus generated during the gasification process is combustible. This process is made possible in a device called gasifier, in a limited supply of air. A gasifier system basically comprises of a reactor where the gas is generated, and is followed by a cooling and cleaning train which cools and cleans the gas. The clean combustible gas is available for power generation in diesel-gen-set. Whereas, for thermal use the gas from the reactor can be directly fed to the combustor using an ejector.

HISTORY AND DEVELOPMENT

The history of gasification dates back to seventeenth century. Since the conception of idea, gasification has passed through several phases of development. Year wise development of the technology is given below: -

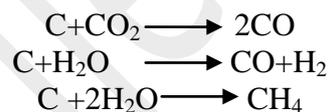
- 1969** Thomas Shirley conducted crude experiments with carbonated hydrogen.
- 1699** Dean Clayton obtained coal gas from pyrolytic experiment.
- 1788** Robert Gardner obtained the first patent with regard to gasification.
- 1792** First confirmed use of producer gas reported, Murdoch used the gas generated from coal to light a room in his house. Since then, for many years coal gas was used for cooking and heating.
- 1801** Lavoisier proved the possibility of using waste gases escaping from charring of wood.
- 1804** Fourcroy found the water gas by reaction of water with a hot carbon.
- 1812** developed first gas producer which uses oil as fuel.
- 1840** First commercially used gasifier was built in France.
- 1861** Real breakthrough in technology with introduction of Siemens gasifier. This gasifier is considered to be first successful unit.
- 1878** Gasifiers were successfully used with engines for power generation.
- 1900** First 600 hp gasifier was exhibited in Paris. Thereafter, larger engines upto 5400 hp were put into service.
- 1901** J.W. Parker run a passenger vehicle with producer gas.
In the period 1901-1920, many gasifier-engine systems were sold and used for power and electricity generation.
- 1930** Nazi Germany accelerated effort to convert existing vehicles to producer gas drive as part of plan for national security and independence from imported oil.
- 1930** Began development for small automotive and portable gas producer. British and French Government felt that automotive charcoal gas producer is more suitable for their colonies where supply of gasoline was scarce and wood that could be charred to charcoal was readily available.
- 1939** About 2,50,000 vehicles were registered in the Sweden. Out of them, 90 % were converted to producer gas drive. Almost all of the 20,000 tractors were operated on producer gas. 40 % of the fuel used was wood and remainder charcoal.
- 1945** After end of second world war, with plentiful gasoline and diesel available at cheap cost, gasification technology lost glory and importance.
- 1950- 1970**
During this decades, gasification was "Forgotten Technology". Many governments in Europe felt that consumption of wood at the prevailing rate will reduce the forest, creating several environmental problems.

1970 The year 1970's brought a renewed interest in the technology for power generation at small scale. Since then work is also concentrated to use fuels other than wood and charcoal.

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-



Biogas System

(a) Simple Biomass Gasification Systems

Simple gasification systems produce syngas with a low- heating content at atmospheric or low pressure. The fuel syngas can be used for operating gas engines for small-scale power production. In general, the syngas is not suitable for advanced turbines or chemical production.

(b) Advanced Biomass Gasification Systems

Advanced gasification systems generally involve integration with higher efficiencies and produce heat or combined heat/power generation. These systems are necessary for the Western countries for controlling of greenhouse gas emissions. Seven companies that have advanced gasification systems are reviewed.

(c) Foster Wheeler Gasification Technologies

Foster Wheeler owns several gasification patents and gasification technologies. Some of these were developed by Ahlstrom Pyropower (API). Foster Wheeler acquired API and has likewise acquired these gasification technologies. The different gasifiers are the atmospheric

updraft gasifiers (Bioneer), atmospheric circulating fluidized-bed gasifiers (Pyroflow), and the pressurized circulating fluidized-bed gasifiers (Bioflow).

(d) Bioneer Atmospheric Updraft Gasifiers

Foster Wheeler developed the atmospheric updraft gasification technology for converting biomass to heat for small districts. These are known as the BIONEER gasifiers. A total of ten BIONEER gasifiers have been installed. The maximum plant size is 10 MWth fuel input with most of the plants in the range of 3-8 MWth input. They can't be operated with sawdust or other smaller components because the feedstock is too fine to be effective in the process. These gasifiers are simple to operate, and the technology is well proven.

(e) Pyroflow Atmospheric Circulating Fluidized-Bed Gasifiers

The next generation of gasifiers from Foster Wheeler is known as the Pyroflow gasifiers. They are atmospheric circulating fluidized-bed gasifiers (ACFB) developed in the 1980s by API as shown in Figure 3.

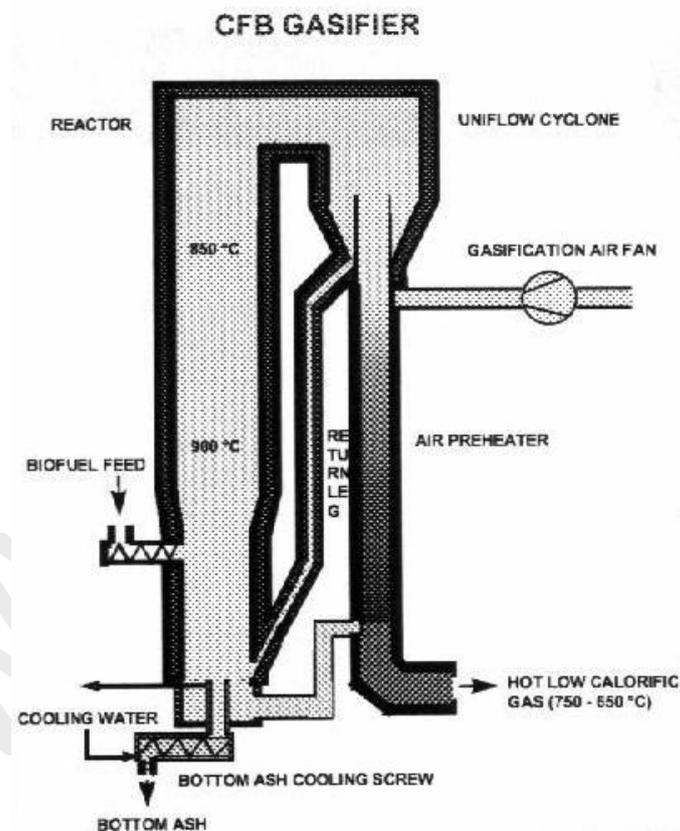


Figure 3: Foster Wheeler's Pyroflow ACFB Gasifier

The first commercial installation by Foster Wheeler Energia Oy in 1983 was to Wisaforest Oy pulp and paper plant in Pietarsaari, Finland, with a 35 MW capacity (Engström, 1999). Two more units were installed in two pulp mills in Sweden (Norrundet Bruk Ab, Norrsundet, Sweden and ASSI, Karlsborgs Burk, Sweden) in 1985 and 1986, both 27 MW. Another 17 MW unit was installed at Portucell pulp mill in Rodao Mill, Portugal, in 1986. A fifth installation in 1998 was at Kymijärvi Power Station in the city of Lahti in southern Finland.

This plant is operated by Lahden Lämpövoima Oy. A flow diagram of the gasification process for heat and power at Lahti is shown in Figure 4.

Kymijärvi Power Plant, Lahti, Finland

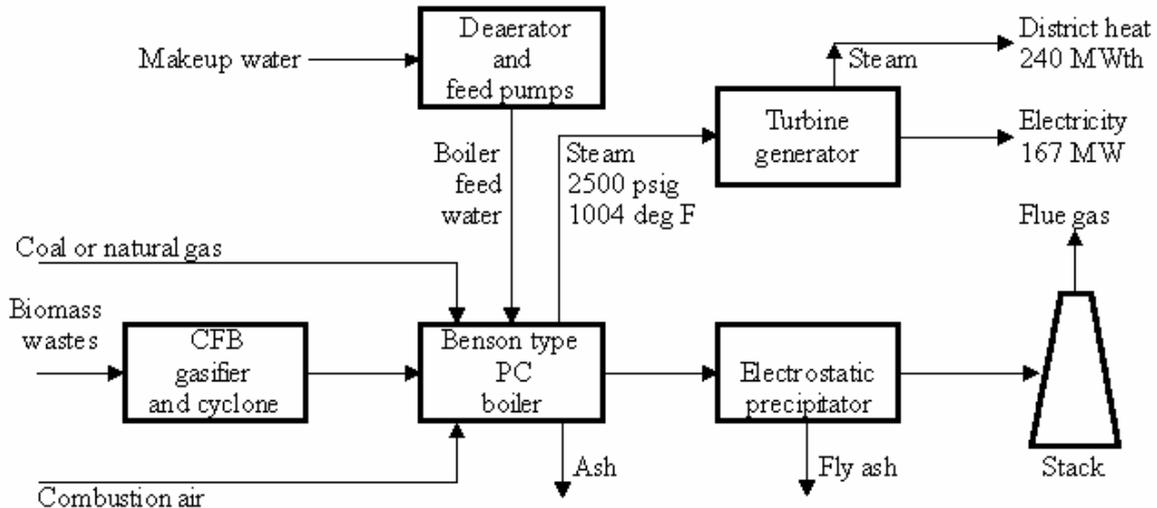


Figure 4: Flow Diagram for the CFB gasifier at Lahti, Finland

GASIFICATION PROCESSES

This section focuses on the gasification agent and on how to provide heat for the gasification process-

(a) Air gasification: Gasification takes place usually at 700-1000 °C. Fredriksson and Kjellström (1996) experimented in their cyclone gasifier with the gasification temperature and found that a minimum temperature of 800 °C was required for stable gasification (wall temperature above 600°C). The yield of products and operating temperature depends on the amount of oxidant added to the system. Values of the air excess ratio for gasification are usually between 0, 2 and 0, 4, being the optimum value about 0, 25. If the air excess ratio is lower, the char will not be gasified and some energy will be retain in the wood as charcoal; if the air excess ratio is higher, then some of the gas will be burned and temperature will rise rapidly. Reed and Das (1988) and other investigators have observed that in a fixed bed, the equivalence ratio is self-controlled by having a constant bed height.

The ratio CO/CO₂ (or H₂/H₂O) is a measure of the producer gas quality. About the 30% of the biomass is burned to provide energy for gasification of the rest. The amount of excess oxygen depends on the efficiency of the process that can be improved by insulation, drying of the biomass or air preheating (Reed and Das, 1988).

Wang and Kinoshita (1992) performed parametric tests for atmospheric nitrogen/oxygen gasification. They examined the effect of residence time, equivalence ratio, gasification temperature and steam injection on the gas yield, composition and heating value. Among their conclusions it is interesting to point that the concentrations of CO and H₂ were found smaller than theoretically predicted and still CO₂ and CH₄ yields were higher than predicted.

(b) Steam gasification: The gasification process referred as “steam gasification” can use as a gasifying agent either only steam, a mixture air/steam, a mixture oxygen/steam, or others. A

higher steam content of the gasifying agent results in an enhanced H₂ content of the product gas.

Pure steam gasification produces synthesis gas (syngas), that mainly contains hydrogen and carbon monoxide and that can be used for methanol production among other applications. However, the raw syngas also contains unwanted components like methane and tar that have to be removed in a conditioning process. For methanol production as well as for some fuel cell applications, the H₂/CO has to be adjusted to a certain value. These processes do always involve catalytic reactions and are slightly out of the scope of this work.

The steam atmosphere enhances the reforming reactions and the char gasification reactions producing then lighter gases such as H₂, CO and CO₂ (Rapagnà and Foscolo, 1996; Rapagnà and Latif, 1997). On the other hand, since the steam gasification reactions are very endothermic, the heating rate diminishes and consequently, the formation of methane also decreases (Fredriksson and Kjellström, 1996).

(c) Supercritical water gasification: This quite new process is somewhat similar to steam gasification but initially the water is in the liquid phase at 350-600 °C and at pressures about 17-35 MPa (Minowa *et al.*, 1997). A nickel catalyst promotes the reaction between the water and the biomass. The process gives large yields of hydrogen and carbon dioxide and a very low yield of methane.

(d) Oxygen gasification: The main consequence of having a nitrogen free gasification agent, and consequently also a nitrogen free product gas, is the considerable increase in the heating value (11,5 MJ/Nm³). However, oxygen gasification is economically unattractive in the opinion of many. A possible alternative could be to use oxygen-enriched air, what could be less expensive and improve considerably the syngas quality.

In some cases, oxygen is added in the steam gasification process to provide some energy for the endothermic reactions so the process is auto-thermal. However, in the opinion of Aznar *et al.* (1993), this procedure is not recommended because the heating value of the product gas will diminish with oxygen addition.

(e) Indirectly heated biomass gasification: As already mentioned, the most relevant reactions for biomass gasification are endothermic. So far, we have considered processes where part of the biomass (part of the volatiles) burn inside the gasification reactor, providing thus heat for the process. Alternatively, one can provide heat indirectly, i.e., by other means without making use of the produced fuel gas. This process can produce medium heating value gas without requiring oxygen.

(f) The allothermal gasification: The gasification agent itself, essentially steam, carbon dioxide or/and nitrogen, provides the heat required for the endothermic gasification reactions. The gasifying agent is heated (or generated, if steam) by combustion of part of the product gas (approx. 25%), after dust removal, with air or oxygen. The allothermal gasification process presented by Kubiak and Mühlen (1998) is shown in Figure 5.

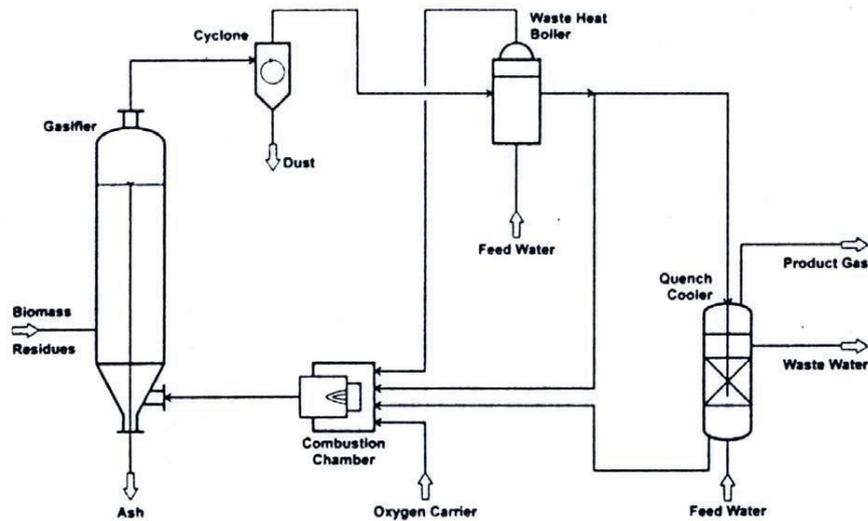


Figure 5: Allothermal gasification for waste and biomass (Chughtai and Kubiak, 1998)

(g) Char gasification: Some researchers have investigated the gasification of the char, what implies that a previous process (slow or fast pyrolysis or devolatilization) has taken place. The pyrolysis conditions influence greatly the reactivity characteristics of the char. However, the gases produced during devolatilization or pyrolysis will be still present in a real case, but might have been removed in experimental installations.

The presence of the product gases has to be taken into consideration. For peat and coal, the product gases significantly reduce the gasification rate. However, for biomass-derived fuels, the high yield of volatile substances and the different types of ash-forming materials can even catalyze the gasification reactions (Moilanen and Saviharju, 1997).

In Espenäs opinion (1993), the presence of freshly formed pyrolysis gases reduces the reactivity of highly reactive char. Furthermore, he shows in his experiments that the moisture content of the fuel in fast pyrolysis increases the reactivity.

TYPES OF REACTOR

(a) Fixed-bed gasifiers: These reactors are rather easy to construct and operate and are widely available, especially in developing countries. They are suitable for small scale applications but have in general limited scale-up properties. The size of fixed bed gasifiers is in most cases below 1 MW. The reason for its limited size is that a high temperature zone is required to reduce the tar content of the product gas; as the gasifier diameter increases, it is more difficult to create such a high temperature zone.

An advantage of fixed bed gasifiers is the low particle content of the product gas, since the bed of char itself acts as a filter. There are mainly two types of fixed bed gasifiers, depending on whether the gasification agent is feed from the top of the reactor, as the biomass, or from the bottom and therefore counter-current to the biomass flow. The latter design is called “updraft” gasifier and is not very much in use. It produces a lot of tars because the products from devolatilization do not cross the high temperature zone of the reactor. The updraft gasifier is only suitable for heat production applications, where the tar content of the product gas is irrelevant.

When both biomass and gasification agent flow downwards, the gasifier is called a “downdraft” gasifier. The most popular design is known as the Imbert gasifier and it is characterised by a reduction in diameter just below the air supply. The reduction, or throat, helps creating a high temperature zone for tar cracking. An alternative design is the Stratified downdraft gasifier, or open core. This design has no throat and both biomass and gasification agent are fed from the top of the reactor. The stratified downdraft gasifier is easier to construct but presents other disadvantages like operation instability. Figure 6 shows the three fixed bed designs mentioned.

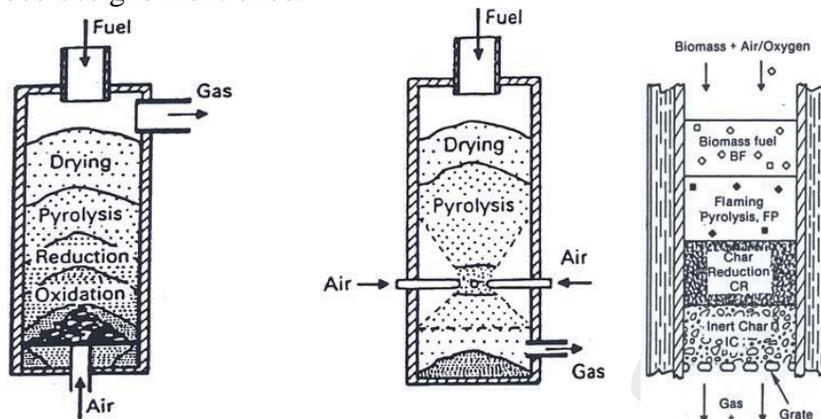


Figure 6: Fixed-bed reactors. a) Updraft, b) Imbert downdraft, c) Stratified downdraft (Reed and Das, 1988)

(b) Fluidized-bed gasifiers: In the opinion of Consonni and Larson (1994), the fluidized bed reactors represent the most promising gasifier design for directly heated biomass gasification. They present higher throughput capabilities and greater fuel flexibility than fixed beds and can accept low-density feedstock. They required minimal pre-processing of feedstock. However, as referred by Williams and Larson (1996), they present more problems regarding gas quality control because of the higher temperature outlet (800-1000 °C) at which alkali metals will not condense and because much more particulate is carried over. Ceramic or sintered-metal filters are required.

Still, circulating fluidized beds (CFB) allow for more complete fuel conversion and higher specific throughputs than bubbling beds. Figure 7 shows both gasifier designs. Examples of commercial biomass-fired atmospheric CFB’s are: Ahlstrom (Finland), Lurgi (Germany) and TPS/Studsvik (Sweden) (Williams and Larson, 1996).

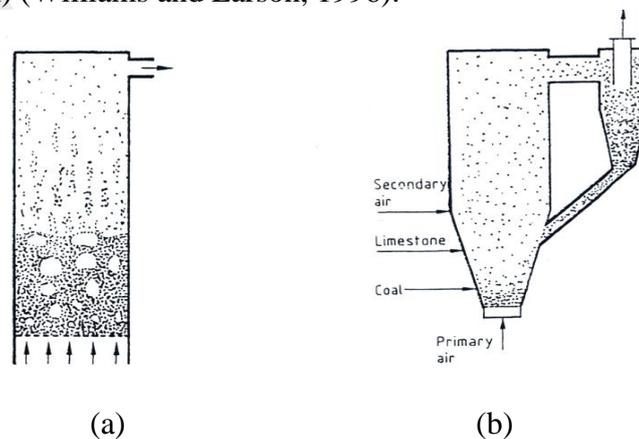


Figure 7: Fluidized bed reactors: a) Bubbling bed, b) Circulating bed

(c) **Pressurized gasification:** With pressurized gasification, the fluidizing agent is pressurized before entering the gasifier. In case of gas turbines, it is necessary to compress the fuel gas previous to combustion if gasification takes place at atmospheric pressure. This second process has more thermodynamic losses associated and also, compressing the product gas can be problematic due to the tar content. Tar would not be a problem in a pressurized system because it will burn in the combustor (as long as the temperature in the cleaning system does not go below 400 °C and if the residence time inside the combustor is long enough for complete tar burning) (Bridgwater, 1995).

However, the biomass feeding system becomes more complex in a pressurized reactor and inert gas leakage could also take place. Furthermore, a pressurized installation requires successful large-scale demonstration although this does not seem to pose big difficulties (Consonni and Larson, 1994).

The commercial-scale pressurized systems under development in 1994 operated within a pressure range of 20-35 bar. These systems will therefore be able to directly fuel existing small-to-medium power output aeroengines (pressure ratio between 18 and 22), but not the new large engines with pressure ratios around 30 (intercooling included). Preparing the gasifiers for such pressures will involve further development of biomass feeding systems, fluidization characteristics and chemical kinetics. Barbucci and Trebbi (1994) recommend pressurized gasification at high temperatures so the product gas can be directly fed in the combustion chamber and maintain most of the sensible heat. They ensure that the efficiency can increase by 3 points if the design avoids gas cooling.

However, the equipment for hot gas cleaning (ceramic filters) still shows poor mechanical resistance and low efficiency in alkali vapors removal at high temperatures. As already mentioned in Section 1.5.4.3, the capital costs of a pressurized system are much higher than the atmospheric one, mainly due to higher equipment and construction costs. On the other side, pressurized systems have a lower volume and allow higher processing rates (Larson *et al.*, 1989). Finally, given the high reactivity of biomass, a pressurized system does not offer great advantages from the chemical kinetics-point of view. Gas compositions and heating values are nearly the same in both systems (Bridgwater, 1995).

Espenäs (1993) conducted several experiments for steam gasification at different pressures. The reaction rate increases for higher pressures (and higher steam partial pressures) for char formed during pyrolysis at the same pressures. However, his results also show that peat char formed at high pressure is less reactive than char formed at low pressure, both with slow heating. Finally, he concludes that the pressure influence in the char gasification process can't be generalized and that depend on the type of fuel and the reactor scheme.

According to Wang and Kinoshita (1993), the advantages of high-pressure gasification are the higher reaction rate due to increased partial pressures of the species and longer residence times due to lower volumetric flow. However, increasing the pressure means higher yields of carbon and methane and lower concentrations of hydrogen and carbon monoxide due to a shift in the equilibrium.

Aldén *et al.* (1997) conducted experiments to analyze the high temperature catalytic gas cleaning for pressurized gasification. Although their analysis is done with nitrogen as the gasifying agent (therefore pyrolysis) some of their result could bring some relevant information:

- Higher operating pressures produce less tar although the residence time also
- increased at higher pressures.
- Large pressures enhance soot formation and recarbonisation of the dolomite.

POWER GENERATION FROM BIOMASS GASIFICATION

Power production from biomass combustion is more common nowadays, using the exhaust gas to raise steam and using the steam in a steam turbine. However, this section focuses on power production from biomass gasification: type of cycles and equipment, advantages and problematic. Biomass gasification is in principle better suited for power generation than combustion allowing for higher electrical efficiencies.

Types of cycle: There are mainly two types of cycles suitable for biomass gasification power production, depending on the type of engine. If a gas turbine is used, the cycle is originally based on the Brayton cycle; if the product gas is used in a gas engine, internal combustion engine, then the cycle is based on the Otto cycle. Figure 8 and Figure 9 show the P-V and T-S diagram for each cycle.

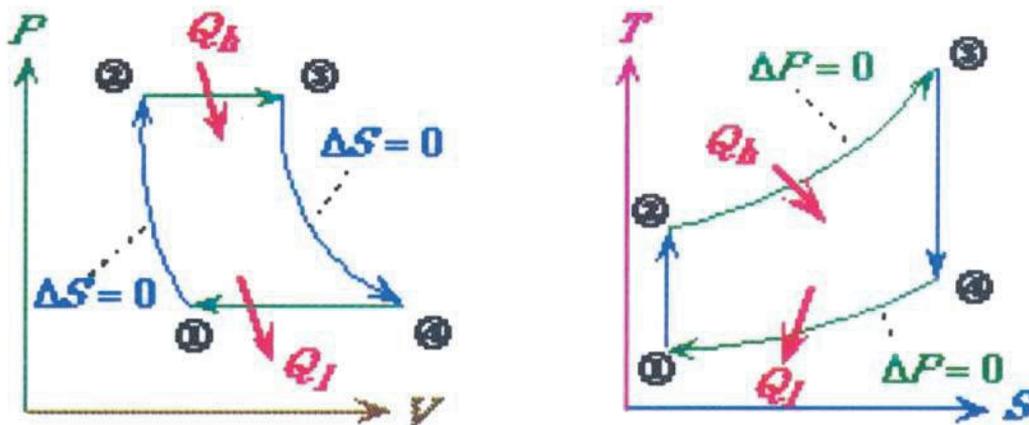


Figure 8: P-V and T-S diagram for the Brayton cycle (gas turbine)

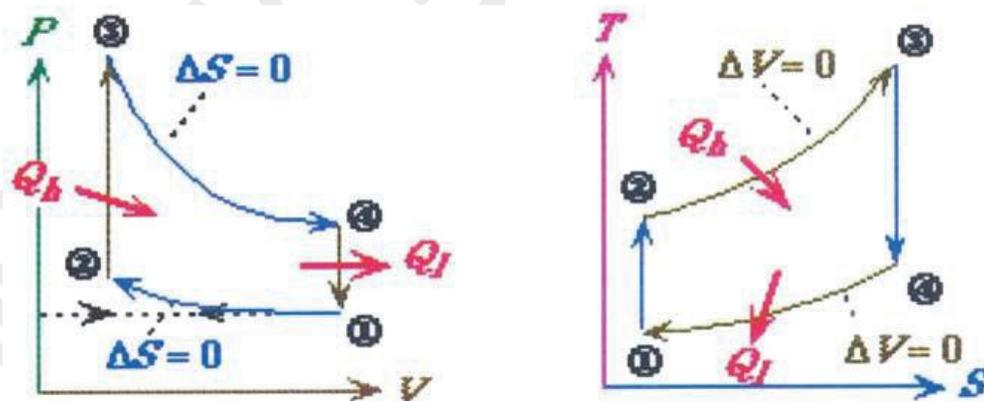


Figure 9: P-V and T-S diagram for the Otto cycle (internal combustion engine)

The gas turbine coupled with an air-blown gasifier creates a class of cycles known as Biomass Integrated Gasifier – Gas Turbine (BIG/GT) cycles (Booth and Elliott, 1993). BIG/GT technologies (with fixed bed) can convert a 60% of biomass energy into electricity and steam, being the gas turbine the one contributing the most for the electricity production

(Williams and Larson, 1996). In countries where biomass growth has low costs, BIG/GT can compete with coal-fired systems. Such units will be much smaller than conventional central-station power-generating units.

Finally, gas turbines can be used together with steam turbines in Integrated Gasification Combined Cycles (IGCC). Faaij *et al.* (1997) present a feasibility study of a combined cycle based on a gas turbine, using biomass as a fuel in an atmospheric gasifier with a secondary catalytic reactor and cold gas cleaning. They conclude that Biomass Integrated Gasifier/Combined Cycle (BIGCC) is a feasible process, whose cost is very sensitive to system efficiency but not that much to transport distance. Another problem with Biomass Gasifier Combined Cycle is that it requires certain size (30-50MWe) to be economical feasible (Wilén and Kurkela, 1997). According to Fredriksson and Kjellström (1996), gas turbines fired directly with wood power are economically attractive for cogenerating power plants up to 20 MWe.

Gas turbines for product gas: A gas turbine can achieve higher thermodynamic efficiency due to the peak cycle temperature of modern gas turbine compared to the steam turbine. Furthermore, gas turbines are being improved every day with new turbine blade materials and cooling technologies, allowing higher inlet temperatures and therefore, increasing efficiency. In addition, the unit capital cost for a gas-turbine system is relatively low and insensitive to scale (Williams and Larson, 1996). Figure 10 shows a simplified gas turbine system.

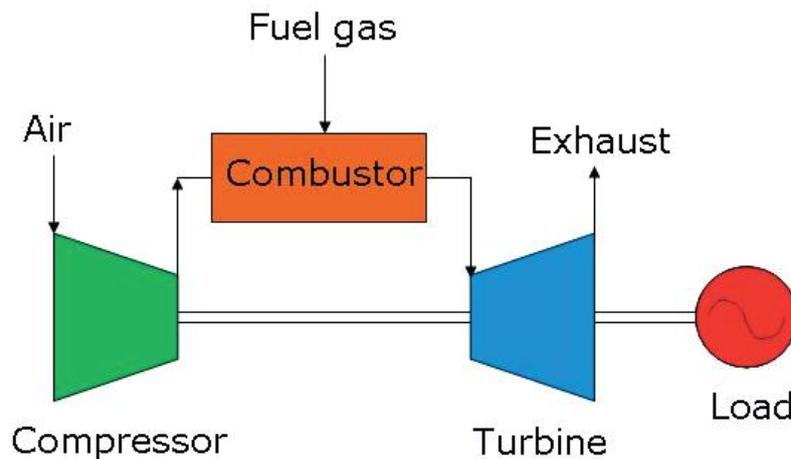


Figure 10: Gas turbine power generation system

CHALLENGES FOR BIOMASS GASIFICATION

Gasification is quite complex and sensitive process. There exists high level of disagreement about gasification among engineers, researchers, and manufacturers. Many manufacturers claim that their unit can be operated on all kinds of biomass. But it is quite questionable fact as physical and chemical properties varies fuel to fuel. Operation of diesel or gasoline engine is simple. Engine starts immediately and there is no trouble within the run. Handling of liquid fuel is also easy task. Anybody expecting something similar will be disappointed with operation of gasifier. It requires at least half an hour or more to start the system. Fuel is bulky and frequent refueling is often required for continuous running of the system. Handling

residues such as ash, tarry condensates is time consuming and dirty work. Driving with producer gas fueled vehicles requires much more and frequent attention than gasoline or diesel fueled vehicles.

Getting the producer gas is not difficult, but obtaining in the proper state is the challenging task. Gasoline and diesel have quite homogenous property. The physical and chemical properties of producer gas such as energy content, gas composition and impurities vary time to time. All the gasifiers have fairly strict requirements for fuel size, moisture and ash content. Inadequate fuel preparation is an important cause of technical problems with gasifiers. Gasifier is too often thought of as simple device that can generate a combustible gas from any biomass fuel. A hundred years of research has clearly shown that key to successful gasification is gasifier specifically designed for a particular type of fuel. Those interested in this technology must remember that it requires hard work and tolerance. Although technology is inconvenient, it is economical at many places and may lead to self-reliance in fuel crisis.

According to Maniatis (2000), it is a challenge to integrate the gasification technologies into existing or recently developed systems in order to demonstrate the attractiveness of the technology.

Another recent study about biomass conversion technologies (European Commission, 1999) presents the following conclusions:

- Biomass gasification is an interesting option because it allows the use of
- biomass in several sectors of the energy market.
- The quantities of biomass locally available will limit the capacity of future
- gasification plants.
- It is expected that the power generation by means of integrated gasification
- combined cycle plants (IGCC) using gas turbine will reach 45% efficiency.
- Combined heat and power applications will be preferred although the capacity
- will be limited by the local need of low temperature heat. Industrial heat receivers will be preferred to district heating because of their longer operation time.
- Biomass gasification for the production of liquid fuels (bio-oil) or synthetic natural gas (SNG) is not expected to become competitive in the near future.
- Future development should concentrate on reducing the cost of the gasification plant itself since it is the gasification plant the main cost factor.
- Gasification of biomass waste alone or co-gasification of biomass with waste and coal is encouraged and expected to improve the economics.

SAFETY CONSIDERATIONS AND FURTHER WORK

The operation of the plant involves certain risk because of the following circumstances:

- High temperatures (max.1000 °C),
- Extremely toxic and moderately flammable gases (CO, H₂),
- Carcinogenic compounds (tar),
- Gasses under pressure (N₂, air).

The flexible design allows for changes in the location of the air supply. By adding air at different heights simultaneously the temperature profile could be altered and the gas composition, tar and particle content may vary. The gas composition, namely the hydrogen content, can also be altered by substituting partially the air by steam as the gasification agent.

Finally, the tar content of the product gas should be reduced. It is expected that a more uniform high temperature at the pyrolysis front will have a positive influence.

CONCLUSIONS

Biomass gasification offers the most attractive alternative energy system for agricultural purposes. Most preferred fuels for gasification have been charcoal and wood. However biomass residues are the most appropriate fuels for on-farm systems and offer the greatest challenge to researchers and gasification system manufacturers. Very limited experience has been gained in gasification of biomass residues. Most extensively used and researched systems have been based on downdraft gasification. However it appears that for fuels with high ash content fluidized bed combustion may offer a solution. At present no reliable and economically feasible systems exist. Biggest challenge in gasification systems lies in developing reliable and economically cheap cooling and cleaning trains. Maximum usage of producer gas has been in driving internal combustion engine, both for agricultural as well as for automotive uses. However direct heat applications like grain drying etc. are very attractive for agricultural systems. A spark ignition engine running on producer gas on an average produces 0.55-0.75 kWh of energy from 1 kg of biomass. Compression ignition (diesel) engines cannot run completely on producer gas. Thus to produce 1 kWh of energy they consume 1 kg of biomass and 0.07 liters of diesel. Consequently they effect 80-85% diesel saving. Future applications like methanol production, using producer gas in fuel cell and small scale irrigation systems for developing countries offer the greatest potentialities.

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