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A Performance Analysis of Bio Mass Gasifier

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Abstract - Biomass Gasification is a chemical process that converts biomass into useful convenient gaseous fuels or chemical feedstock. It has emerged as a promising technology to fulfill the increasing energy demands of the world as well as to reduce significantly the volume of biomass waste generated in developing societies. In this paper, various aspects of the research and development in biomass gasification in downdraft fixed bed reactors like advances in downdraft gasification systems, and the effect various parameters like equivalence ratio, operating temperature, moisture content, superficial velocity, gasifying agents, residence time on the composition of producer gas, yield and conversion are reviewed

Gasification is an efficient process to obtain valuable products from biomass with several potential applications, which has received increasing attention over the last decades. Further development of gasification technology requires innovative and economical gasification methods with high efficiencies. Various conventional mechanisms of biomass gasification as well as new technologies are discussed in this paper. In fact, the increasing attention to renewable resources is driven by the climate change due to GHG emissions caused by the widespread utilization of conventional fossil fuels, while biomass gasification is considered as a potentially sustainable and environmentally-friendly technology. Nevertheless, social and environmental aspects should also be taken into account when designing such facilities, to guarantee the sustainable use of biomass. This paper also reviews the life cycle assessment (LCA) studies conducted on biomass gasification, considering different technologies and various feedstocks.

Keywords-bio mass; gasification; process intensification; process combination; polygeneration

INTRODUCTION

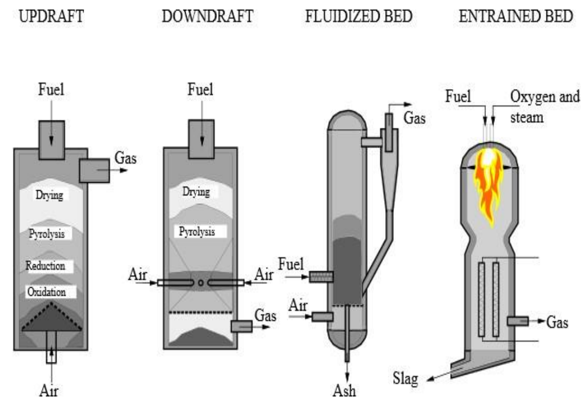
Gasification is conversion of solid or liquid carbonaceous feedtstocks into a gaseous fuel (synthesis gas, producer gas), principally CO, H2, methane, and lighter gaseous hydrocarbons association with CO2 and N2 depending on the process used. Gasification processes also produce liquids (tars, oils, and other condensates) and solids (char, ash) from solid feedstocks. Gasification processes are designed to generate fuel or synthesis gases as the primary product. Fuel gases can be used in internal and external combustion engines, fuel cells, and other prime movers. Gasification products can be used to produce methanol, Fischer-Tropsch (FT) liquids, and other fuel liquids and chemicals Gasification of solids and combustion of gasification-derived fuel gases generates the same categories of products as direct combustion of solids, but pollution control and conversion efficiencies may be improved.Climate change phenomenon or the global temperature rise caused by the emissions of CO2, NOx, and SOx pose a serious threat to mankind and the other species. According to the international energy outlook (www.eia.gov), world energy related CO2 emissions will increase from 30.2 (in 2008) to 43.2 billion metric tons in 2035. Since greenhouse gas (GHG) emissions from burning fossil fuels for power generation is a major contributor to climate change, a switch from conventional to renewable power resources, i.e., biomass, solar, wind, and hydroelectric energy generation, is vital (Sikarwar et al., 2016). Biomass has an advantage over the other renewable sources as it is more evenly distributed over the earth and is also abundantly available (Akia et al., 2014; Din and Zainal, 2016; Gottumukkala et al., 2016). In fact, biomass is the fourth-most important source of energy after coal, petroleum, and natural gas, and currently provides more than 10% of the global energy (Saidur et al., 2011). It is estimated that biomass and waste will contribute a quarter or third of global primary energy supply by 2050 (Bauen et al., 2009). The first confirmed application of gasification for electricity production was reported in 1792. However, the first successful gasifier unit was installed in 1861 by Siemens, while the fluidized bed gasifier (FBG) was only developed in 1926, leading to the establishment of the first commercial coal gasification plant at Wabash River in the USA in 1999.

As a consequence of unstable oil prices and concerns over climate change, biomass gasification has increasingly received interest since 2001 (Basu, 2010). Biomass gasification is a thermochemical partial oxidation process that converts biomass into gas in the presence of gasifying agents, i.e., air, steam, oxygen, carbon dioxide, or a mixture of these (Ruiz et al., 2013). The syngas product is a mixture of CO, H2, CH4, and CO2, as well as light hydrocarbons, i.e., ethane and propane, and heavier hydrocarbons such as tars. The quality of produced gas is affected by the feedstock material, gasifying agent, design of the reactor, the presence of catalyst, and operational conditions of the reactor (Parthasarathy and Narayanan, 2014).

The lower heating value (LHV) of the syngas ranges from 4 to 13 MJ/Nm3, as a function of feedstock, the gasification technology, and the operational conditions (Basu, 2013). The produced char is a mixture of unconverted organic fraction and ash (as a function of the treated biomass). The LHV of the char lies in the range of 25 to 30 MJ/kg depending on the amount of unconverted organic fraction (Molino et al., 2016). Biomass can be utilized as a substitute for fossil fuels in generating syngas, hydrogen, electricity, and heat, while syngas can be further processed into methanol, dimethyl ether, Fischer Tropsch (F-T) syncrude, or other chemicals (Leibbrandt et al., 2013; Petersen et al., 2015). Biomass gasification and subsequent conversions lead to several potential benefits such as sustainability, regional economic development, social and agricultural development, and reduction in GHG emissions (Demirbas and Demirbas, 2007). The gasification process still requires optimization to enhance the energy efficiency of the process by overcoming the main challenges such as tar production and moisture content of the biomass. New technologies have been developed as effective ways to utilize even toxic and wet biomass for power generation.

GASIFICATION TECHNOLOGIES

During the gasification process, biomass undergoes a combination of drying, pyrolysis, combustion, and gasification reactions. Biomass gasification has been developed as a waste valorisation method to obtain products such as syngas, H2, CH4, and chemical feedstocks. The conventional gasification technologies include fixed bed (updraft and downdraft), fluidized bed, and entrained flow reactors, as demonstrated in Figure 1. A wider variety of new gasification technologies have been further developed, including plasma gasification and gasification in supercritical water of wet biomass, to convert different feedstocks to gas products (Heidenreich and Foscolo, 2015; Sikarwar et al., 2016). Besides, process integrations and combinations aim to achieve higher process efficiencies, better gas quality and purity, with lower investment costs. Therefore, the so called "emerging technologies" have received increasing attention recently, such as integration of gasification and gas cleaning technologies, or pyrolysis combined with gasification and combustion. A summary of new technologies applied for biomass gasification



GASIFICATION OF BIOMASS

Gasification is basically a thermo- chemical process which converts biomass materials into gaseous component. The results of gasification are the producer gas, containing carbon monoxide, hydrogen, methane and some other inert gases

TYPES OF BIOMASS

Biomass may also be divided into two broad groups:

(a) Virgin biomass

(b) Waste

Primary or virgin biomass comes directly from plants or animals. Waste or derived biomass comes from different biomass- derived products. Table. I, list a range of biomass types, grouping them as virgin or waste. Energy crops [10], a virgin biomass are grown especially for the purpose of producing energy encompassing short- rotation or energy plantations: they comprise herbaceous energy crops, woody energy crops, industrial crops, agricultural crops, and aquatic crops. Typical examples are eucalyptus, willows, poplars, assorghum, sugar cane, soya beans, sunflowers, cotton etc. These crops are suitable to be used in combustion, pyrolysis, and gasification for the production of biofuels, synthesis gas and hydrogen. Large quantities of agricultural plant residues are produced

COMPONENTS OF BIOMASS

Cellulose, hemicellulose and lignin and extractives are found to be the major components of biomass. Raveendran et al. [12] has reported the composition of biomass in terms of these components. reproduces these results for different biomasses. Woody plant species are typically characterized by slow growth and are composed of tightly bound fibers, giving a hard external surface, whereas herbaceous plants are usually perennial, with more loosely bound fibers, indicating a lower proportion of lignin, which binds together the cellulosic fibers. The relative proportions of cellulose and lignin are two of the determining factors in identifying the suitability of plant species for subsequent processing as energy crops.

COMPOSITION OF BIOMASS

Every biomass type has carbon, hydrogen, and oxygen as major chemical constitutive elements. These element fractions can be quantified with the ultimate analysis. Ultimate analyses are reported using the CxHyOz formula where x, y, and z represents the elemental fractions of C, H, and O, respectively. To fully describe biomass characteristics, it is customary to provide the proximate analysis. Proximate analysis gives the composition of the biomass in terms of gross components such as moisture (M), volatile matter (VM), ash (ASH), and fixed carbon (FC). It is a relatively simple and inexpensive process. The ultimate analyses and proximate analysis of various biomass feed stocks are reported in Table.III, Table.IV respectively. Ultimate analysis is relatively difficult and expensive compared to proximate analysis.

CHEMISTRY OF GASIFICATION

In a gasifier, the carbonaceous material undergoes several different processes like drying, pyrolysis, combustion, gasification processes. The dehydration or drying process occurs at around 100°C. Typically the resulting steam is mixed into the gas flow and may be involved with subsequent chemical reactions, notably the water-gas reaction if the temperature is sufficiently high enough. Pyrolysis (or devolatilization) process occurs at around 200-300°C. Volatiles are released and char is produced, resulting in up to 70% weight loss for biomass. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char,which will then undergo gasification reactions. Combustion process occursas the volatile products and some of the char reacts with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions. The basic reaction here is

$$C + O_2 \leftrightarrow CO_2 \quad (1)$$

$$\Delta H = -393.5 \text{ kJ/mol}$$

Gasification process as the char reacts with carbon and steam to produce carbon monoxide and hydrogen, via the reaction.

$$C + H_2O \leftrightarrow H_2 + CO \quad (2)$$

$$\Delta H = 131.3 \text{ kJ/mol}$$

In addition, the reversible gas phase water gas shift reaction reaches equilibrium very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen.

$$CO + H_2O \leftrightarrow CO_2 + H_2 \quad (3)$$

$$\Delta H = -41.1 \text{ kJ/mol}$$

In essence, a limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be burned to produce carbon monoxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide. Further reactions occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide. This third reaction occurs more abundantly in reactors that increase the residence time of the reactive gases and organic materials, a well as heat and pressure. The ternary is a tool for representing the biomass conversion processes. The three corners of the triangle represent pure carbon, oxygen, and hydrogen- that is, 100% concentration. Points within the triangle represent ternary mixtures of these three substances. The side opposite to a corner with a pure component (C, O, or H) represents zero concentration of that component. For

example, the horizontal base in the diagram opposite to thehydrogen corner represents zero hydrogen that is, binary mixtures of C and O. A biomass fuel is closer to the hydrogen and oxygen corners compared to coal. This means that biomass contains more hydrogen and more oxygen than coal contains. Lignin would generally have lower oxygen and higher carbon compared to cellulose or hemicellulose. The diagram can also show the geological evolution of fossil fuel With age the fuel moves further away from the hydrogen and oxygen corners and closer to the carbon corner.

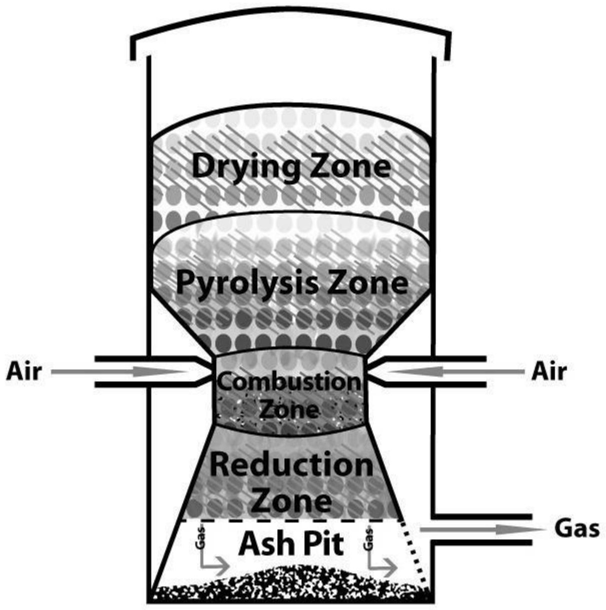


Diagram showing the different zones in the process of gasification in downdraft gasifier.

DESIGN OF DOWNDRAFT GASIFIERS

Downdraft gasifiers are one among the fixed bed gasification systems. Downdraft gasification technology has an increased interest among researchers worldwide due to the possibility to produce mechanical and electrical power from biomass in small-scale to an affordable price. There exist mainly two designs for downdraft gasifiers: the Imber gasifier (Throated or closed top gasifier) and the stratifiedgasifier (Throatless or open core gasifier). These gasifier have been used for gasification of bark, wood blocks, chip and pellets, straw, maize cobs, refuse derived fuel (RDF), an waste pellets with various gasifying media like air, oxygen Steam.

Types of gasifiers

Gasifiers can be classified based on the density factor, which is a ratio of the solid matter (the dense phase) a gasifier can burn to the total volume available. Gasifiers can be

(a) dense phase reactors, or

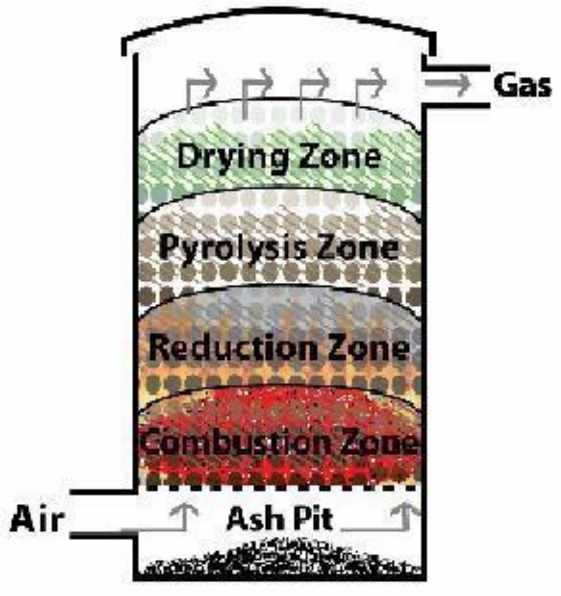
(b) lean phase reactors.

Dense phase reactors

In dense phase reactors, the feedstock fills most of the space in the reactor. They are common, available in different designs depending upon the operating conditions, and are of three types: downdraft, updraft, and cross-draft

Downdraft or co-current gasifiers

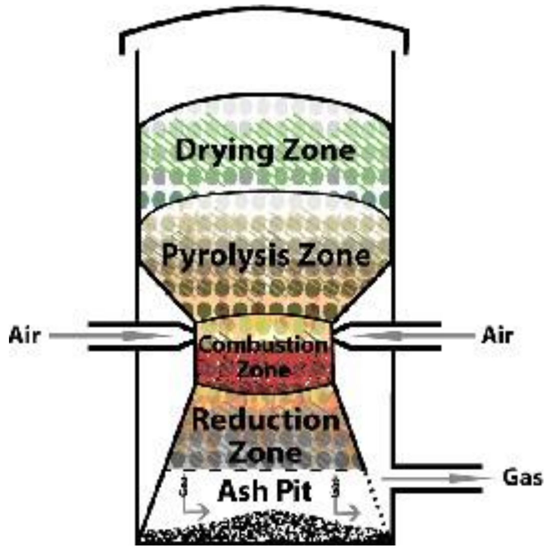
The downdraft (also known as co-current) gasifier is the most common type of gasifier. In downdraft gasifiers, the pyrolysis zone in above the combustion zone and the reduction zone is below the combustion zone. Fuel is fed from the top. The flow of air and gas is downwards (hence the name) through the combustion and reduction zones. The term co- current is used because air moves in the same direction as that of fuel, downwards. A downdraft gasifier is so designed that tar, which is produced in the pyrolysis zone, travels through the combustion zone, where it is broken down or burnt. As a result, the mixture of gases in the exit stream is relatively clean. The position of the combustion zone is thus a critical element in the downdraft gasifier, its main advantage being that it produces gas with low tar content, which is suitable for gas engines



Down draft gasifier

Updraft or counter-current gasifier

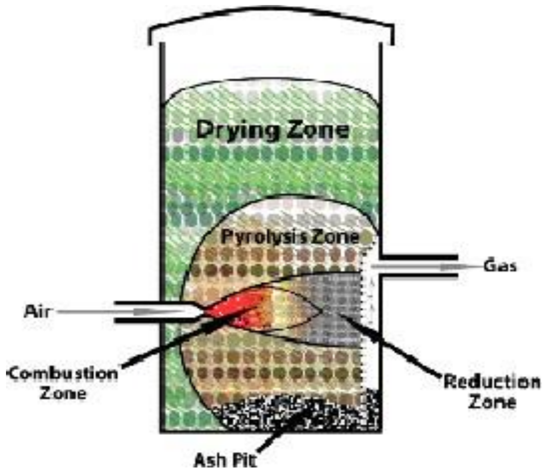
In updraft gasifiers (also known as counter- current), air enters from below the grate and flows upwards, whereas the fuel flows downwards. An updraft gasifier has distinctly defined zones for partial combustion, reduction, pyrolysis, and drying. The gas produced in the reduction zone leaves the gasifier reactor together with the products of pyrolysis from the pyrolysis zone and steam from the drying zone.



Updraft gasifier

CROSS-DRAFT GASIFIER

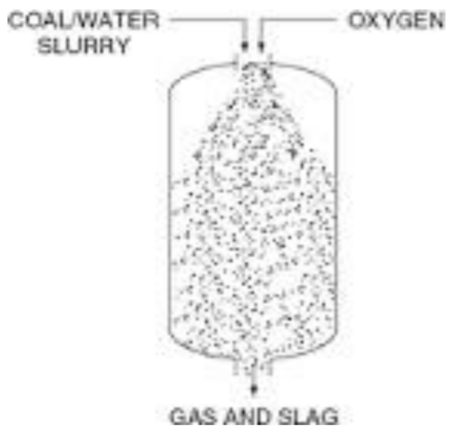
In a cross-draft gasifier, air enters from one side of the gasifier reactor and leaves from the other. Cross-draft gasifiers have a few distinct advantages such as compact construction and low cleaning requirements. Also, cross-draft gasifiers do not need a grate; the ash falls to the bottom and does not come in the way of normal operation.



Cross-draft Gasifier

ENTRAINED-FLOW GASIFIERS

In entrained-flow gasifiers, fuel and air are introduced from the top of the reactor, and fuel is carried by the air in the reactor. The operating temperatures are 1200–1600 °C and the pressure is 20–80 bar. Entrained-flow gasifiers can be used for any type of fuel so long as it is dry (low moisture) and has low ash content. Due to the short residence time (0.5–4.0 seconds), high temperatures are required for such gasifiers. The advantage of entrained-flow gasifiers is that the gas contains very little tar.



Entrained- flow gasifier

PRODUCER GAS APPLICATIONS

The producer gas obtained can be used either to produce heat or to generate electricity.

THERMAL APPLICATIONS

Producer gas can also be burnt directly in open air, much like Liquid Petroleum Gas (LPG), and therefore can be used for cooking, boiling water, producing steam, and drying food and other materials.

- Kilns: Firing of tiles, pottery articles, limestone and refractories, where temperatures of 800–950 °C are required.
- Boilers: Producer gas can be used as fuel in boilers to produce steam or hot water.

POWER APPLICATIONS

Producer gas can be used for generating motive power to run either dual-fuel engines (which run on a mixture of gas and diesel, with gas replacement of up to 85% of diesel) or engines that run on producer gas alone (100% diesel replacement). In general, the fuel-toelectricity efficiency of gasification is much higher than that of direct combustion: The conversion efficiency of gasification is 35%–45% whereas that of combustion is only 10%–20%. Generated electricity can be fed into the grid or can be used for farm operations, irrigation, chilling or cold storage, and other commercial and industrial applications.

WOODY BIOMASS:

- Pieces smaller than 5–10 cm (2–4 inches) in any dimension, depending on design
- Bulk density of wood or briquettes: less than 250–300 kg/m3

LOOSE BIOMASS:

- Pulverized biomass, depending on design
- Moisture content up to 15%–25%, depending on gasifier design
- Ash content below 5% preferred; with a maximum limit of 20%
- Bulk density of loose biomass is less than 150 kg/m3

CONCLUSION

Biomass has high potential to contribute to world energy needs. The fixed bed gasifier is the most practical option for production of a low calorific value gas for use in small-scale power generation schemes or thermal applications. The physical and chemical characteristics of biomass, capacity of gasifier and its intended application decides the choice of gasification system. The downdraft gasifier is suitable for both thermal and engine applications. The commercial installations for fixed bed gasification systems have come up in many countries. Although gasification technologies have recently been successfully demonstrated at small scale by the researchers and several demonstration projects are under implementation they still face economic and other non-technical barriers when trying to compete in the energy markets. This can be achieved via economic development through biomass systems integration

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