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BIOMASS GASIFIER: A REVIEW

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Abstract - *Biomass gasification is a thermo-chemical process in which solid biomass is converted into a combustible gas. 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. It has emerged as a new way to fulfill the increasing energy demands of the world as well as to reduce carbon pollutants which produced during the combustion of fossil fuel. The produced gas can be used in a generator set for the power generation, process heating, cooking or in an automotive vehicle as a single or dual fuel mode. In this paper, a detail mechanism of gasification process has reviewed. Also, this paper includes the types of various biomass gasifier, its relative merits and demerits, field application has been discussed.*

***Key Words*:** Downdraft Gasifier, Biomass, Gasification, Energy, Zones of Gasifier…

1. INTRODUCTION

This Modern agriculture is an extremely energy intensive process. However high agricultural productivities and subsequently the growth of green revolution has been made possible only by large amount of energy inputs, especially those from fossil fuels. With recent price rise and scarcity of these fuels there has been a trend towards use of alternative energy sources like solar, wind, geothermal etc. However these energy resources have not been able to provide an economically viable solution for agricultural applications [1].

Biomass is defines as the biological degradable fraction of the products, waste and residue from agriculture (including animals and vegetable materials), forestry and biological degradable fraction of industrial and household wastes.

Biomass is a renewable energy resources derived from the carbonaceous waste of various human and natural activities. Currently, the biomass sources contribute 14 % of global energy and 38 % of energy in developing countries. It is derived from the various sources, including the by product from timber industry, agricultural crops, raw material from the forest, major part of household waste and wood. Globally the energy content of biomass residue in agricultural based industries annually is estimated at 56 exajoules, nearly a quarter of global primary energy use of 230 exajoules. Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumes as a fuel. Its advantage is that it can be used to generate electricity with the same equipment or power plants that are now burning fossil fuels. It is an important source of energy and the most important fuel worldwide after coal, oil and natural gas [2].

The utilization of biomass is a very important source of energy in many parts of the world, especially for areas remote from supply of high-quality fossil fuels.

Biomass power has also grown significantly in a number of European countries and in several developing countries, including China, India, Brazil, Costa Rica, Mexico, Tanzania, Thailand, and Uruguay. China's capacity rose percent in 2009 to 3.2 Gigawatt (GW), and the country plans to install up to 30 GW by 2020.India generated 1.9 Terawatt-hours (TWh) of electricity with solid biomass in 2008. By the end of 2009, it had installed 835 Megawatt (MW) of solid biomass capacity fueled by agricultural residues (up about 130 MW in 2009) and more than 1.5 GW of bagasse cogeneration plants (up nearly 300 MW in 2009, including off-grid and distributed systems); it aimed for 1.7 GW of capacity by 2012. Brazil has over 4.8 GW of biomass cogeneration plants at sugar mills, which generated more than 14 TWh of electricity in 2009; nearly 6 TWh of this total was excess that was fed into the grid. As of 2007, the United States accounted for more than 34 percent of electricity from solid biomass generated in OECD (Organization for Economic Co-operation and Development) countries, with a total of 42 Terawatt-hours (TWh).

Japan was the OECD's second largest producer, at 16 TWh, and Germany ranked third, with 10 TWh. Although the U.S market is less developed than Europe's, by late 2009 some 80 operating biomass projects in 20 states provided approximately 8.5 GW of power capacity, making the United States the leading country for total capacity. Many U.S coal and gas fired power plants are undergoing partial or even full conversion to biomass by co-firing fuels in conventional power plants. Just over half of the electricity produced in the European Union from solid biomass in 2008 was generated in Germany, Finland, and Sweden. Biomass accounts for about 20 percent of Finland's electricity consumption, and Germany is Europe's top Producer [4].

Germany increased its generation of electricity with solid biomass 20-fold between 2002 and 2008. By early 2010, bioenergy accounted for 5.3 percent of Germany's electricity consumption, making it the country's second largest renewable generating source after wind power.

The substitution of conventional fossil fuels with biomass for energy production results both in a net reduction of greenhouse gases emission and in the replacement of non-renewable energy sources. Biomass energy conversion technologies especially pyrolysis and gasification have been substantially studied to promote renewable energy utilization and solving partially the environmental issues [4].

Biomass combines solar energy and carbon dioxide into chemical energy in the form of carbohydrates via photosynthesis. The use of biomass as a fuel is a carbon neutral process since the carbon dioxide captured during photosynthesis is released during its combustion. Biomass includes agricultural and forestry residues, wood, byproducts from processing of biological materials, and organic parts of municipal and sludge wastes. Photosynthesis by plants captures around 4,000 EJ/year in the form of energy in biomass and food. The estimates of potential global biomass energy vary widely in literature. The variability arises from the different sources of biomass and the different methods of determining estimates for those biomasses. Only in Asia, does the current biomass usage slightly exceed the sustainable biomass potential. Currently, the total global energy demand is about 470 EJ/year. It is estimated that, in the United States, without many changes in land use and without interfering with the production of food grains, 1.3 billion tons of biomass can be harvested each year on a sustainable basis for biofuel production. 1.3 billion tons of biomass is equivalent to 3.8 billion barrels of oil in energy content. US equivalent energy consumption is about 7 billion barrels per year. However, harvesting, collecting and storage of biomass adds another dimension of technical challenges to the use of biomass for production of fuels, chemicals and biopower [5].

In the context of India, Out of a total of 199,877 MW of installed capacity in the country, biomass accounts for 3095 MW. This includes 1952 MW of grid-connected cogeneration from baggage and 1143 MW of biomass based power from agro residue. A bulk of this capacity is from combustion technology. Power generation through biomass gasification contributes 148 MW, chiefly in off-grid rural and industrial settings. Clearly, when contrasted with its estimated potential of 18,000 MW annually, bioenergy is some distance from achieving its promise in India [5].

The availability of biomass in India is estimated to be about 1000 million tons per year covering residues from agriculture, forestry, and plantations. Major agricultural residues include rice husk, rice straw, bagasse, sugar cane tops and leaves, groundnut shells, cotton stalks, sunflower stalks, mustard stalks, pigeon pea stalks etc. It has been estimated that about 70-75% of these wastes are used as fodder, as fuel for domestic cooking and for other economic purposes leaving behind 120–150 million tones of agricultural residues per year which could be made available for power generation. Lot of Research and Development work has been carried in the country in the field of gasification to solve various operational problems like removal of tar, cooling of the gas to suit to work in IC engines, utilization of byproducts of gasification system, evaluation of IC engines on producer gas [6].

In developing countries like India, biomass is an important energy source for power generation (Table 1). By using these surplus agricultural residues, more than 16,000 MW of grid quality power can be generated with presently available technologies. In addition, about 5000 MW of power can be produced, if all the 550 sugar mills in the country switch over to modern techniques of co- generation. Thus, the estimated biomass power potential is about 21,000 MW. For the last 15 years, biomass power has become an industry attracting annual investment of over Rs.1000 crores, generating more than 9 billion units of electricity per year and creating employment opportunities in rural areas [6].

2. BIOMASS GASIFICATION

Gasification is the conversion of biomass, or any solid fuel, into an energetic syngas through partial oxidation at elevated temperatures. Gasification process is conducted by heat generated from carbon oxidant to conserve the reaction of gasification. Gasification agent or oxidant (air or oxygen) will be added to solid fuel and produce gasify fuel. Some of the gasification reactions involve the participation of water or steam. In addition, water or steam will be used to control reaction temperature. Studies on the development of gasification have long been carried out by many researchers to improve the efficiency, operability and the yield of the system. In general, the product yields and the composition of gases are dependent on several parameters including temperature, gasifying agent, biomass species, particle size, heating rate, operating pressure, equivalence ratio, catalyst addition and reactor configuration increase syngas yield and reduce formation of tar [7].

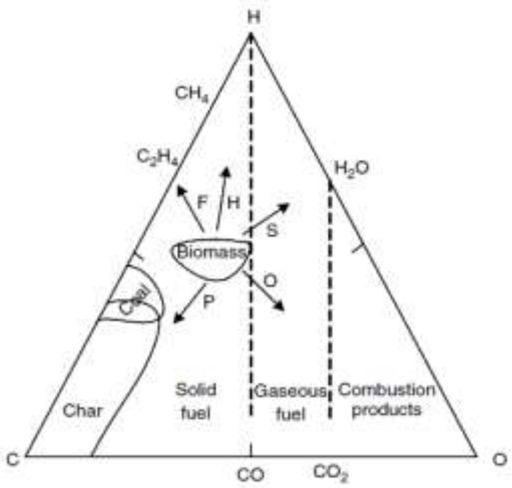

Fig -1: C-H-O Ternary gasification process.

Gasification is a thermo-chemical process which converts biomass materials into useful gaseous fuel. Gasification takes place at high temperature in the presence of an oxidizing agent (also called a gasifying agent). Heat is supplied to the gasifier either directly or indirectly which raises the gasification temperature of 600–1,000 °C. Oxidizing agents are typically air, steam, nitrogen, carbon dioxide, oxygen or a combination of these. In the presence of an oxidizing agent at high temperature, the large polymeric molecules of biomass decompose into lighter molecules and eventually to permanent gases, ash, char, tar and minor contaminants. Char and tar are the result of incomplete conversion of biomass. The results of gasification are the producer gases which contain carbon monoxide, hydrogen, methane and some other inert gases. The combustible gas comprises mainly of carbon monoxide (18-22%); hydrogen (15-20%); methane (1-5%); carbon dioxide (8-12%) and nitrogen (45-55%). The calorific value of producer gas is 1000-1200 kcal/Nm3.Whereas the conversion efficiency is 80 per cent. Reliable gasification systems related to the quality of the gas in terms of energy and the tar content and particulates in the gas. Though the poor energy conversion of solid fuel to the gas was acceptable, the higher particulate and tar content caused difficulties in using the gas for engine [8].

The conventional gasification technologies include fixed bed (updraft and downdraft), fluidized bed, and entrained flow reactors. 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. 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 [9].

2.1 Process Zones

Four distinct processes take place in a gasifier as the fuel makes its way to gasification. They are drying of fuel, Pyrolysis, Combustion and Reduction. Though there is a considerable overlap of the processes, each can be assumed to occupy a separate zone where fundamentally different chemical and thermal reactions take place [9].

2.2 Drying of Fuel

Wood entering the gasifier has moisture content of 10-30%. Various experiments on different gasifier in different conditions have shown that on an average the condensate formed is 6-10% of the weight of gasified wood. Some organic acids also come out during the drying process. These acids give rise to corrosion of gasifier. In order to prevent these adverse effects, moisture content must be removed from the biomass prior to gasification process. In this drying zone the main process is of drying of wood [9].

2.3 Pyrolysis Zone

Wood pyrolysis is an intricate process that is still not completely understood. The products depend upon temperature, pressure, residence time and heat losses. However following general remarks can be made about them. Upto the temperature of 2000C only water is driven off. Between 200 to 2800C carbon dioxide, acetic acid and water are given off. The real pyrolysis, which takes place between 280 to 5000C, produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between 500 to 7000C the gas production is small and contains hydrogen. Thus it is easy to see that updraft gasifier will produce much more tar than downdraft one. In downdraft gasifier the tars have to go through combustion and reduction zone and are partially broken down.

2.4 Combustion Zone

The combustible substance of a solid fuel is usually composed of elements carbon, hydrogen and oxygen. In complete combustion carbon dioxide is obtained from carbon in fuel and water is obtained from the hydrogen, usually as steam [9]. The combustion reaction is exothermic and yields a theoretical oxidation temperature of 14500C. The main reactions, therefore, are:

$C + O_2 = CO_2$ (+ 393 MJ/kg mole) (1)

$2H_2 + O_2 = 2H_2O$ (- 242 MJ/kg mole) (2)

2.5 Reaction Zone

The products of partial combustion (water, carbon dioxide and uncombusted partially cracked pyrolysis products) now pass through a red-hot charcoal bed where the following reduction reactions take place:

$C + CO_2 = 2CO$ (- 164.9 MJ/kg mole) (3)

$C + H_2O = CO + H_2$ (- 122.6 MJ/kg mole) (4)

$CO + H_2O = CO + H_2$ (+ 42 MJ/kg mole) (5)

$C + 2H_2 = CH_4$ (+ 75 MJ/kg mole) (6)

$CO_2 + H_2 = CO + H_2O$ (- 42.3 MJ/kg mole) (7)

Reactions (3) and (4) are main reduction reactions and being endothermic have the capability of reducing gas temperature. Consequently the temperatures in the reduction zone are normally 800-1000^{0}C. Lower the reduction zone temperature (700-800^{0}C), lower is the calorific value of gas [9].

3. TYPES OF GASIFIER

Since there is an interaction of air or oxygen and biomass in the gasifier, they are classified according to the way air or oxygen is introduced in it. There are three types of gasifier Downdraft, Updraft and Crossdraft. Gasifier equipments are generally classified as upward draft, downward draft and cross draft gasifiers, based on the direction of air/oxygen flow in the equipment. The choice of the gasifier largely depends upon the fuel, its final available form, moisture and ash content, volatile matter, calorific value etc. [10].

3.1 Updraft Gasifier

The oldest and simplest type of gasifier is the counter current or up-draught gasifier shown in below figure 2. Updraft gasifier has air passing through the biomass from bottom and the combustible gases come out from the top of the gasifier. Updraft gasifier has air passing through the biomass from bottom and the combustible gases come out from the top of the gasifier.

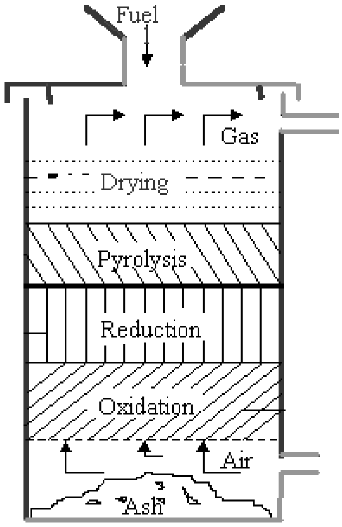

Fig -2: Updraft Gasifier

In the updraft gasifier as shown in the Fig. 2, the feed (biomass) is introduced from the top and moves downwards while gasifying agents (air, steam, etc.) are introduced at the bottom of the grate so the product gas moves upwards. In this case, the combustion takes place at the bottom of the bed which

is the hottest part of the gasifier and product gas exits from the top at lower temperature (around 500 °C). The producer gas has no ash but contains tar and water vapor because of passing of gas through unburnt biomass but, usually 5% to 20% of tars and oils are produced at temperature too low for significant cracking and are carried out in the gas stream and the remaining heat dries the wet biomass so that none of the energy is lost as sensible heat in the gas and the advantage of updraft gasifier over other gasifier is its high conversion efficiency up to 80% but it produces tar with producer gas which is the major feedback of updraft gasifier and its tar content producer gas cannot be used in engine application, it may corrode the engine parts like valve, piston and fuel line [10].

The air intake is at the bottom and the gas leaves at the top. Near the grate at the bottom the combustion reactions occur, which are followed by reduction reactions somewhat higher up in the gasifier. In the upper part of the gasifier, heating and pyrolysis of the feedstock occur as a result of heat transfer by forced convection and radiation from the lower zones. The tars and volatiles produced during this process will be carried in the gas stream. Ashes are removed from the bottom of the gasifier. The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high equipment efficiency, as well as the possibility of operation with many types of feedstock (sawdust, cereal hulls, etc.). The major advantages of this type of gasifier are its simplicity, Small pressure drop, good thermal efficiency, little tendency towards slag formation, high charcoal burn out and internal heat exchange leading to low temperature of exit gas and high equipment efficiency. This gasifier can work with several kind of feedstock ranging from Coal to Biomass. Major drawbacks result from the possibility of "channeling" in the equipment, which can lead to oxygen break-through and dangerous, explosive situations and the necessity to install automatic moving grates, as well as from the problems associated with disposal of the tar containing condensates that result from the gas cleaning operations. The latter is of minor importance if the gas is used for direct heat applications, in which case the tars are simply burnt. Major drawbacks are Great sensitivity to tar and moisture and moisture content of fuel, relatively long time required for start up of IC engine and poor reaction capability with heavy gas load. [10].

3.2 Downdraft Gasifier

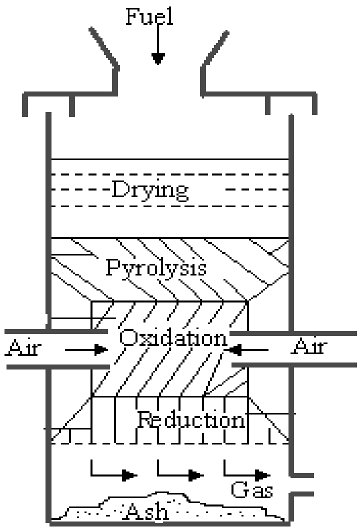

Fig -3: Downdraft Gasifier

A solution to the problem of tar entrainment in the gas stream has been found by designing co-current or downdraught gasifiers, in which primary gasification air is introduced at or above the oxidation zone in the gasifier. The producer gas is removed at the bottom of the apparatus, so that fuel and gas move in the same direction, In downdraft gasifier shown in Fig. 3, gas is drawn from the bottom of the reactor while the hottest reaction zone is in the middle. The volatile matter in the fuel gets cracked within the reactor and therefore the output gas is almost tar-free. However, the gas, as it comes out of the reactor, contains small amounts of ash and soot. After the air contacts the pyrolyzing biomass before it contacts with char and support a flame and the limited air supply in the gasifier is rapidly consumed, therefore that the flame gets richer as pyrolysis proceeds. Next to the end of pyrolysis zone, the gases consist mostly of CO_2, H_2O, CO and H_2 and the throat ensures that the gaseous products pass through the hottest zone someplace most of the tar cracked into gaseous hydrocarbon. So produces relatively clean gas. Designed for the application of producer gas in CI engine, downdraft gasifier is more suitable as it produces very less tar. Its advantages include Flexible adaptation of gas production to load and low sensitivity to charcoal dust and tar content of fuel. Its limitations include Design tends to be tall and not feasible for very small particle size of fuel. On their way down the acid and tarry distillation products from the fuel must pass through a glowing bed of charcoal and therefore are converted into permanent gases hydrogen, carbon dioxide, carbon monoxide and methane. Depending on the temperature of the hot zone and the residence time of the tarry vapours, a more or less complete breakdown of the tars is achieved. The main advantage of downdraught gasifiers lies in the possibility of producing a tar-free gas suitable for engine applications.

In practice, however, a tar-free gas is seldom if ever achieved over the whole operating range of the equipment: tar-free operating turn-down ratios of a factor 3 are considered standard; a factor 5-6 is considered excellent. Because of the lower level of organic components in the condensate, downdraught gasifiers suffer less from environmental objections than updraught gasifiers. A major drawback of downdraught equipment lies in its inability to operate on a number of unprocessed fuels. In particular, fluffy, low density materials give rise to flow problems and excessive pressure drop, and the solid fuel must be pelletized or briquetted before use. Downdraught gasifiers also suffer from the problems associated with high ash content fuels (Slagging) to a larger extent than updraught gasifier. Minor drawbacks of the downdraught system, as compared to updraught, are somewhat lower efficiency resulting from the lack of internal heat exchange as well as the lower heating value of the gas. Besides this, the necessity to maintain uniform high temperatures over a given cross-sectional area makes impractical the use of downdraught gasifiers in a power range above about 350 kW (shaft power) [10].

3.3 Crossdraft Gasifier

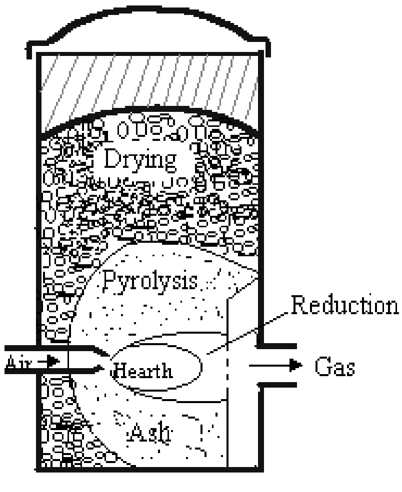

Fig -4: Crossdraft Gasifier

The Crossdraft gasifier as shown in Fig. 4, air enters at high velocity through a water cooled nozzle mounted on one side of the induces substantial circulation, firebox, and flows across the bed of char and fuel. The gas is produced in the horizontal direction in front of the nozzle and passes through a vertical grate into the hot gas port on the opposite side and this produces very high temperature in a very small volume and results the production of very low tar gas. However, the cross draft gasifier is not commonly used. The major advantages of cross draft gasifier are short design height, very fast response time to load and flexible gas production. It also has some limitations as Very high sensitivity to slag formation, high pressure drop etc. Cross-draught gasifiers, schematically illustrated in Figure are an adaptation for the use of charcoal. Charcoal gasification results in very high temperatures (1500 °C and higher) in the oxidation zone which can lead to material problems. In cross draught gasifiers insulation against these high temperatures is provided by the fuel (charcoal) itself. Advantages of the system lie in the very small scale at which it can be operated. Installations below 10 kW (shaft power) can under certain conditions be economically feasible.

The reason is the very simple gas-cleaning train (only a cyclone and a hot filter) which can be employed when using this type of gasifier in conjunction with small engines. A disadvantage of cross-draught gasifiers is their minimal tar-converting capabilities and the consequent need for high quality (low volatile content) charcoal. It is because of the uncertainty of charcoal quality that a number of charcoal gasifiers employ the downdraught principle, in order to maintain at least a minimal tar-cracking capability [10].

3. CONCLUSIONS

Presents paper highlights about overall biomass and bioenergy scenario in world and India. It also discovers about biomass potential, technological advancement, its development, utilization for various applications. It includes the in-depth information and basic concept about biomass gasification which play vital role for the generation of producer gas via different gasifier. Along with it also incorporates chemistry of gasification viz. drying, pyrolysis, and reduction processes. At the end, various types of gasifier, its relative merits and demerits as well specific application has been discussed.

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