A Gasification Technology in Biomass & Coal based Integrated Gasification Combined Cycle Power Generation System: A Review

Rahul Srivastava[1] M. K. Chopra[2]
[1]M.Tech Student [2]Assistant Professor
[1,2]Department of Mechanical Engineering
[1,2]RKDF Institute of Science & Technology, Bhopal M.P., India

Abstract— Electricity generation through Non-renewable energy i.e;coal–thermal route is one of the most responsible for environment pollution through greenhouse gas emission, which has given rise to issue of climate change risk. Coal combustion results large pollution and affect the environment. The harmful gases affect the atmosphere and act opposite to the nature. Today India is more concentrated towards non-conventional energy sources. Currently, in India 20.1% of power is generated through non-conventional i.e.; renewable energy sources. And if we want an IGCC power plant for remote location then there be a requirement of small scale power plant. For small scale IGCC power plant there may have the installation of downdraft gasifer because Downdraft gasifier is very attractive for biomass gasification due to its easy fabrication and operation, and also due to low tar content in producer gas. Finally, a brief review of the literature on gasification of coal/biomass and also reviews on the fluidized bed technology to discuss the main process parameters and their influence on the product composition, quality of the fuel gas and the operability of the gasifier as well as blends in bubbling/circulating fluidized bed gasifiers has also been presented.

Key words: Biomass Energy Resources, Biomass Gasification, Co-Gasification, Downdraft Gasifier, Fludized Bed Gasifier, Plasma Gasication

I. INTRODUCTION

Among different alternatives of renewable energy, an important source is biomass-based energy. Utilization of biomass for energy production in coal-fired power plants is essentially in terms of partial substitution of coal feed with biomass. As on April.30, 2018 total installed capacity in India is 344002 MW. The contribution of state sector is 84517 MW, central sector 103975 MW, and private sector 155510 MW. Thermal power plants accounts for 64.8% of the installed electricity generation capacity. [1] Coal contributes 57.3%, gas contribution 7.3% and oil 0.2%. It means we are mostly dependent on coal which is conventional and may exhaust soon if we continue the use of coal with the same rate. Biomass gasification is a thermochemical process of converting biomass feedstock into a mixture of combustible and non-combustible gas (producer gas) in a gasifier. Depending on biomass feedstock and producer gas flow in the gasifier, fixed bed gasifier can be categorized as updraft, downdraft, and cross draft. In downdraft gasifier, biomass feedstock is fed from the top of the gasifier then subjected to drying, pyrolysis, oxidation, and reduction process during flowing downward in the gasifier as shown in Fig. 1. Producer gas, a product of gasification, exits the gasifiers through gas outlet at the lower part of the gasifiers. Typically, producer gas is a mixture of combustible gas such as CO, H2, and CH4 and non-combustible gas such as CO2 and N2. Quality of producer gas depends on its heating value and tar content. Good quality producer gas has high heating value and low tar content. The quality of producer gas from biomass gasification is affected by some important parameters, such as biomass characteristics, process parameters, and gasifiers design. Biomass characteristics which have to be considered in gasification are size, density, elemental composition (C, H, O, N which are obtained from ultimate analysis), fixed carbon, volatile matter, ash content, and moisture content (obtained from proximate analysis). Operating parameters in gasification are equivalence ratio, gasification temperature, and biomass consumption rate. Producer gas formed during biomass gasification can be applied as fuels for gas burner or Internal Combustion (IC) engine. Downdraft gasifier is more suitable for small-scale applications. Typically, downdraft gasifiers have a capacity of 10 kW–1MW. Some commercial applications for power generation are available from small to medium scale for woodchips feedstock. Downdraft gasifier is very attractive due to its easy fabrication and operation, and also due to low tar content in producer gas. However, drawbacks such as grate blocking, channeling, and bridging are found in downdraft gasifiers, typically for feedstock with low bulk density. Another disadvantage is the gasifiers only suitable for feedstock with low moisture content. Feedstock with moisture content higher than 30% produces low quality producer gas, thus low gasification efficiency. Feedstock with higher moisture content requires more heat for drying than feedstock with lower moisture content. This means that more heat energy from oxidation process is used for drying the feedstock with higher moisture content. Hence, insufficient heat is available for other endothermic reactions during gasification. To encounter these drawbacks, various modifications of basic design of downdraft gasifiers have been performed and reported by researchers worldwide.[2]

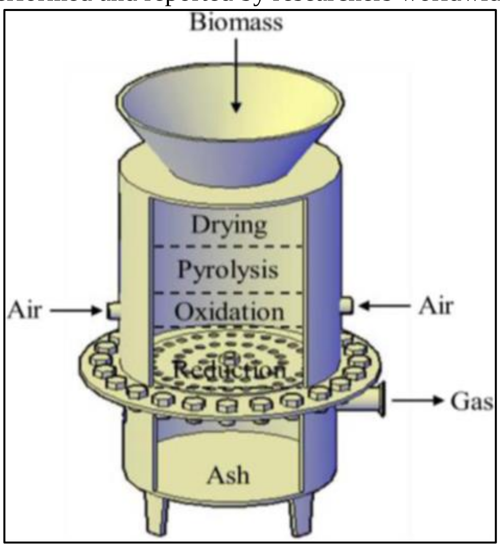

Fig. 1: Downdraft Gasifier [2]

Bioenergy is expected to become one of the major energy resources in the future because it is renewable and free from net carbon di oxide emissions. It is also the only sustainable source of organic carbon

ASPEN PLUS is a problem-oriented process simulation program that is used to facilitate the physical, chemical and biological calculations. It is often exploited to model chemical processes that involve solid, liquid and gaseous streams under defined condition by using mass and energy balance equations and phase equilibrium database. Over the years ASPEN PLUS has made model creation and upgradation easier and small sections of complex and integrated systems can be created and tested as separate modules before they are integrated. ASPEN PLUS is multipurpose and is used to simulate variety of processes, for example, methanol synthesis, indirect coal liquefaction processes, integrated coal gasification combined cycle (IGCC) power plants, atmospheric fluidized-bed combustor processes, compartment fluidized-bed coal gasifiers, coal hydrogasification processes and coal gasification simulation etc. [3].

Further a relatively new concept in coal gasification is the use of biomass and coal blends as feedstock. This concept has received wide attention of researchers, and large amount of the literature has been published in this area. Co-gasification of coal and biomass blends could be a bridge between energy production based on fossil and renewable fuels [4].

Co-gasification of coal and various types of biomass blends is done to improve biomass gasification by decreasing the tar content in the producer gas. In addition, minerals present in the ash of biomass catalyze the gasification of coal. An added advantage of this process is improvement in the H2/CO ratio in the produced gas, which is relevant from viewpoint of use of this gas for liquid fuel synthesis. Although the co-gasification is useful from a chemical point of view, various practical problems have also been associated with coal and biomass gasification on upstream, gasification, and downstream processes. In addition, during upstream processing, pre-treatment of biomass and moisture content are very important. The choice of gasifier operation parameters (temperature, gasifying agent, and catalysts) decides product gas composition and quality. The process of biomass and coal gasification occurs through three steps. The initial DE volatilization or pyrolysis occurs at lower temperature and produces volatile matters and char residue. Then, secondary reactions start involving the volatile products. Finally, the gasification reaction of the remaining carbonaceous residue occurs with steam and carbon dioxide. [4]

II. BIOMASS ENERGY RESOURCES

The positive aspects of biomass are narrated as follows: Biomass is an effective renewable energy source because the growth of new plants and trees replenishes the supply. Since most of the sources like manure, corn, switch grass, soya beans, waste from crops and plants are renewable, these crops can be replanted again and again continuously. It would help to reduce GHG emissions which may affect the climate change, provide environ- mental sustainability, improve health, increase agricultural productivity and also reduce the workload of women in households. The biogas technology is a practicable one and it is promising, reliable and successful also provider of a clean alternate energy globally.[5]

A brief negative environmental impact of biomass energy can be discerned under this section. The occupational injuries and illness associated with agriculture and forest biomass energy production systems are several times more than underground coal mining and oil mining operations. In terms of a million kilocalories of output, forest biomass has 14 times more occupational injuries and illnesses than underground coalmining and 28 times more than oil and gas extraction. A wood-fired steam plant requires 4 times more construction workers and 3–7 times more plant maintenance and operation workers than a coal-fired plant. Including the Labour required producing corn, about 18times more Labour is required to produce a million kcal of ethanol than an equivalent amount of gasoline. The safe harvesting practices a brief negative environmental impact of biomass energy can be discerned under this section. The occupational injuries and illness associated with agriculture and forest biomass energy production systems are several times more than underground coal mining and oil mining operations. In terms of a million kilocalories of output, forest biomass has 14 times more occupational injuries and illnesses than underground coalmining and 28 times more than oil and gas extraction. A wood-fired steam plant requires 4 times more construction workers and 3–7 times more plant maintenance and operation workers than a coal-fired plant. Including the Labour required to produce corn, about 18 times more Labour is required to produce a million kcal of ethanol than an equivalent amount of gasoline. The high rank of burden of disease is attributed to Bangladesh, India, Myanmar and Pakistan with percentage ranging from 3.2to4.6. Around 15% of the carbon released in the environment is due to deforestation. The actions have been already taken to save the world from such terrible effects of climate change [6].

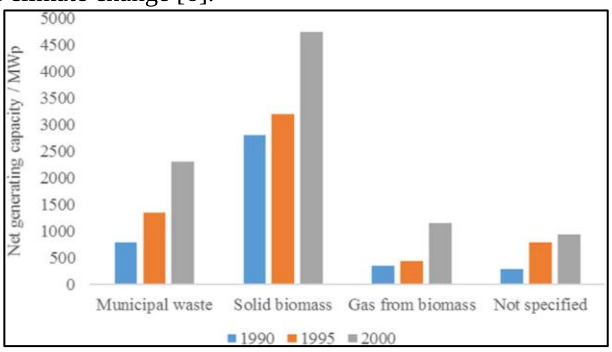

Fig. 2: Net Power Generating Capacity from Municipal Waste and Biomass in European Union (‘not specified’ refers to Renewables and Wastes out of the Mentioned Categories) [6]

From above figure no. 2 we can see the graph of Net power generating capacity from municipal waste and biomass.

III. BIOMASS GASIFICATION

A. Biomass

Environmental concerns are alerting the world to the imminent dangers of overdependence on fossil fuels as the drivers of industrialization, transportation, and other daily activities. Biomass is one of the choices of renewable energy sources that are now getting more attention, since the people are gaining more knowledge about the issue of sustainable energy and production. Although many options are available to convert biomass to useful energy, this study only considers the thermochemical pathway. There are three pathways of thermochemical conversion: pyrolysis, gasification, and combustion. Gasification involves the conversion of carbonaceous materials into synthetic gases in the presence of a limited amount of oxidation or oxidizing agent. The synthetic gas produced leaves the reactor with pollutants and therefore requires cleaning to satisfy engine requirements. Mixed with air, the cleaned synthetic gas can be used in an integrated gasification combined cycle (IGCC), where a combination of gas turbine, which is powered by the cleaned synthetic gas, and a steam turbine that utilizes the waste heat from the gas turbine, would further increase the efficiency of the turbine. This work focuses on reviewing the central process in the IGCC operation to keep track of the numerous findings of studies in this area.[6]

B. Gasification Process

Gasification is a thermochemical conversion process whereby carbonaceous materials (coal particle, oil shale, tire crumbs, municipal solid waste, etc.) undergo partial oxidation at a considerably high temperature to yield synthetic gases containing mainly carbon monoxide and hydrogen. During gasification, the carbonaceous matter is fed into a high-temperature pressurized container along with steam or carbon dioxide and a sub stoichiometric amount of oxygen, which is converted to combustible gases (mixture of CO, CH4, and H2), with char, water, and condensable tar as minor products. In the first step, pyrolysis, the organic matter is decomposed by heat into gaseous and liquid volatile materials and char (mainly a non-volatile material, containing high carbon content). In the second step, the hot char reacts with the gases (mainly CO2 and H2O), leading to product gases: CO, H2 and CH4. The producer gas leaves the reactor with pollutants and therefore requires cleaning to satisfy engine requirements. Mixed with air, the cleaned producer gas can be used in IGCC, gas turbines (in large-scale plants), gas engines, gasoline, or diesel engines. Producer gas is a mixture of carbon monoxide, hydrogen, and methane, together with carbon dioxide, nitrogen, and other incombustible gases. [6]

During gasification process solid coal mass converts into Char and further it transforms into various gases such as CO, CH_4, CO_2, and H_2O. Finally we can brief the Gasification such as follows:

Biomass gasification process involves three main stages: pyrolysis, a thermal decomposition of biomass into different products, gas phase reactions and gasification of the solid residue.

NOTE: As pyrolysis is the first stage before gasification, it is crucial to understand how this process occurs. Depending on pyrolysis conditions, the chemical species produced their yields and char characteristics are different. It can be noticed that pyrolysis is very difficult to be experimentally decoupled from gas phase reactions. The evolution of the gas phase in an inert atmosphere may also give important data for the understanding of gas phase behaviour in a gasification atmosphere. As well as the gasification behaviour of carbonaceous material like coal and biomass is a major function of their compositions. [4]

IV. CO-GASIFICATION

The key motive for co-gasification is the catalytic effect of alkali and alkaline earth metals in biomass on enhancing the gasification of char resulting from coal pyrolysis, which otherwise has slow kinetics. Coal ash has high silica (SiO2) content, which is an efficient catalyst for cracking heavy hydrocarbon molecules. As compared to coal, pyrolysis of biomass results in significantly higher quantities of tar due to higher content of volatiles. SiO2 in coal char can catalyze the thermal decomposition of these heavy hydrocarbons into lighter hydrocarbons such as methane or ethane. This results in enhancement of calorific value of the producer gas resulting from pyrolysis. [4]

Despite all the environmental advantages accomplished by the co-gasification of biomass and waste this process is not free from side products, some of them presenting harmful properties for animals, humans and the environment itself. In this chapter, main pollutant emissions will be addressed and some hints for their abatement or treatment will be given. [5]

V. DOWNDRAFT GASIFIER

Downdraft gasifier is more suitable for small-scale applications. Typically, downdraft gasifiers have a capacity of10 kW–1 MW. Some commercial applications for power generation are available from small to medium scale for woodchips feedstock. Downdraft gasifier is very attractive due to its easy fabrication and operation, and also due to low tar content in producer gas. However, drawbacks such as grate blocking, channeling, and bridging are found in downdraft gasifiers, typically for feedstock with low bulk density. Another disadvantage is the gasifiers only suitable for feedstock with low moisture content. Feedstock with moisture content higher than 30% produces low quality producer gas, thus low gasification efficiency. Feedstock with higher moisture content requires more heat for drying than feedstock with lower moisture content. This means that more heat energy from oxidation process is used for drying the feedstock with higher moisture content. Hence, insufficient heat is available for other endothermic reactions during gasification. To encounter these drawbacks, various modifications of basic design of downdraft gasifiers have been performed and reported by researchers worldwide.[2]

Typical producer-gas composition from commercial wood for downdraft gasifiers operated on low- to medium-moisture-content fuels

Component	[%]
H_2	12-20
CO_2	9-15
CH_4	2-3
CO	17-22
N_2	20-24

Table 1:

NOTE: Heating value 5–5.9MJ/m3

VI. PROCESSES IN DOWNDRAFT GASIFIER

In downdraft gasifier, sequence processes from top to bottom are drying, pyrolysis, oxidation, and reduction as shown in Fig. 1. During drying process, moisture in biomass is driven off by heat from oxidation process. Besides for drying, heat released during oxidation process is also used for pyrolysis and reduction processes Volatile gases are released during pyrolysis process. Producer gas is formed during reduction process and exits the gasifier through gas outlet.

A. *Drying*

Typically, temperature in drying zone is about 100–200 °C [6]. Conversion of moisture to water vapor occurs during drying process. The conversion takes place due to heat transfer between hot gases from the oxidation zone to biomass in the drying zone. The amount of moisture released is equal to water vapor formed and can be expressed in term of mass balance as in Eq. (1).

$$mH_2O(l) = mH_2O(g) \quad (1.1)$$

Where MH_2O (l) is the mass of moisture in biomass and $mH_2O(g)$ is the mass of produced water vapor. High moisture content biomass produces more water vapor and requires more heat for drying. One kilogram moisture in biomass uses 2260 kJ extra heat from the gasifier to vaporize a water [6] at atmospheric pressure. Normally, suitable moisture content in the biomass for downdraft gasifiers ranges from 5% to 35% [8].

B. *Pyrolysis*

During pyrolysis, biomass molecules are decomposed into condensable gases, tar, and char at temperatures between 200 and 700 °C in the absence of oxygen as shown in Fig. 2. The condensable gases in turns are decomposed into non-condensable gases (CO, CO2, H2, and CH4), liquid, and char [6]. The decomposition occurs between gas-gas phase (homogeneous reaction) and gas-solid phase (heterogeneous reaction). The condensable vapor is cracked into non-condensable permanent gases (CO and CO2). [2]

C. *Oxidation*

Heat released during oxidation is used for drying, pyrolysis, and other endothermic reactions during reduction. The oxidation temperature is about 800–1400 °C [6]. Partial oxidation of char (C) produces carbon monoxide and heat (Eq. (3)), while total oxidation of char produces carbon dioxide and more heat (Eq. (4)). Amount of heat released during total oxidation is three times more than during partial oxidation. Partial oxidation releases 111 kJ/mol heat and total oxidation results 394 kJ/mol heat.[2]

- Partial oxidation

$$C + O \rightarrow CO - 111 \text{ kJ/mol } 1 \quad (1.2)$$

- Total oxidation

$$C + O2 \rightarrow CO2 \quad (1.3)$$

D. *Reduction*

Main gasification reactions occur during reduction process [6]. Combustible gases in the producer gas are formed during reduction through the following reactions.

1) Bouduard reaction

$$C + CO2 \rightarrow 2CO + 172 \text{ kJ/mol} \quad (1.4)$$

2) Water-Gas reaction

$$C + H2O \rightarrow CO + H2 + 131 \text{ kJ/mol} \quad (1.5)$$

3) Water-Gas Shift reaction

$$CO + H2O \rightarrow CO2 + H2 - 41, 2 \text{ kJ/mol} \quad (1.6)$$

4) Methane reaction

$$C + 2H2 \rightarrow CH4 - 74, 8\text{kJ/mol} \quad (1.7)$$

Endothermic and exothermic reaction occur during reduction process. Bouduard and Water-Gas are endothermic reactions. Meanwhile, Water-Gas Shift and Methane reaction are exothermic reactions.[2]

VII. FLUDIZED BED GASIFIER

Fluidised-bed (bubbling, circulating and twin-bed): The gasifying agent is blown through a bed of solid particles at a sufficient velocity to keep the particles in a state of suspension. Fuel particles are introduced at the bottom of the reactor, are very quickly mixed with the bed material, and almost instantaneously are heated up to the bed temperature. As a result of this treatment, the fuel is pyrolysed very fast, resulting in a component mix with a relatively large amount of gaseous materials. Further gasification and tar-conversion reactions occur in the gas phase. Twin-bed gasification uses two fluidised-bed reactors. The biomass enters the first reactor, where it is gasified with steam, and the remaining char is transported to the second reactor, where it is burnt with air to produce heat. The heat is transported to the gasification reactor by the bed material, normally sand. The flue gas and the product gas have two separate exits.[8]

VIII. PLASMA GASIFICATION

A. *Plasma*

Plasma which consists of free electrons, ions, and neutral particles is defined as the fourth state of the matter. Although the presence of electrons and charged particles is the fact; the plasma is considered as neutral entirely. Plasma is thermally and electrically conductive due to the charged particles. Plasma can be partially ionized as well as fully ionized [4]. While English scientist Sir. William Crookes brought up the fourth of matter in 1879, American chemist and physicist Irving Langmuir defined ionized gases as plasma for the first time in 1929 [5]. Plasma can occur at different temperatures and densities. There should be sufficient energy in medium to form plasma from the gas. Also, energy in the medium should be continuous to sustain the plasma. If there is not enough energy to form plasma, the particles will turn to neutral gases. The energy to form the plasma can be electrical, thermal, ultraviolet light and etc. Nowadays, plasma in industry is used in many applications such as coating, thin film, gasification, flow control, sterilization, and etc.

B. *Classification of Plasma Depending on Thermal Equilibrium*

Plasma can also classified depending on the thermal equilibrium of species. If the species are in thermal equilibrium, all the species should be at the same temperature. In the case of hot plasma this occurs. Generally, hot plasma is in thermal equilibrium. The thermal equilibrium condition can only be provided for cold plasma when the plasma space has a high pressure. As a result of high pressure, the heat transfer between species can be enhanced and equilibrium can be provided. In the case of non-thermal plasma, the temperature of the species varies. As an example, the electrons having high temperature because of their low density are with the ions which are still in the ambient temperature. This is the signifying characteristics of cold plasma. It is known that conditions in plasma medium likewise pressure, the discharge length or distance between the electrodes and other design parameters affect the thermal equilibrium condition [5].

C. Plasma Gasification Methodology

Plasma gasification process is an all thermal process that consumes external power to heat up and sustain the high temperatures. In process, the materials decomposed to elements in an oxidant starved medium. Because of extremely high temperature, the higher conversion efficiency can be reached. Products are primarily syngas, slug and ash. Plasma with high temperature breaks down nearly all the materials to their elemental form excluding the radioactive materials [3]. As a result of high temperature, toxic compounds decompose to harmless chemical elements. In fact this is the serious advantage it offers in comparison with the conventional methods of gasification.

IX. CONCLUSIONS

A number of research papers, published in leading international journals, related to the biomass gasification were, and the important findings have been critically reviewed in this present work. From the all above stated review, it is too clear that, no progressive study is present on the evolution of gasification technology and effect of the process parameters especially effect of temperature, pressure particle size and shape of the biomass on the efficiency of biomass gasification. So, it is important to understand biomass gasification, varying of temperature, pressure particle size and shape.

Gas produced in the fluidized bed gasification process is not yet of the syngas quality. And that's why we focused towards co-gasification. In co-gasification takes place in the way to maintain tfe quality of exergy and affect the result positively. And main motive of this review paper is a platform to bring a track where we can see the evolution of gasifier from fixed to move bed style such as downdraft, updraft and plasma gasifier etc. Finally if we think the future work for gasification then a very great scope of establishing of small scale IGCC power plant with downdraft gasifier involving better CO_2 storage technique.

REFERENCES

[1] Ministry of power, Govt of India, http://powermin.nic.in/en/content/power-sector-glance-all-india retrieved at 30, April 2018
[2] A.A.P. Susastriawan, Harwin Saptoadi, Purnomo, Small-scale downdraft gasifiers for biomass gasification: A review, Renewable energy reviews 76(2017), 989-1003
[3] Priyanka Kaushal, Rakesh Tyagi (2018) Advanced simulation of biomass gasification in a fluidized bed reactor using ASPEN PLUS, 629-636
[4] Debarshi Mallick, Pinakeswar Mahanta and Vijayanand S. Moholkar (2018), Synergistic Effects in Gasification of Coal/Biomass Blends: Analysis and Review, 473-497
[5] G.M. Joselin Herbert, et. al ,2015, Quantifying environmental performance of biomass energy , Renewable and Sustainable Energy Reviews 59(2016)292–308
[6] International Energy Agency. Renewables for power generation, status & prospects.
[7] Basu P, Biomass Gasification and Pyrolysis
[8] Maria Puig-Arnavat, Joan Carles Bruno *, Alberto Coronas, Review and analysis of biomass gasification models Renewable and Sustainable Energy Reviews 14 (2010)2841–2851
[9] Sanlisoy, M.O. Carpinlioglu , international journal of hydrogen energy xxx (2016) 1-5,A review on plasma gasification for solid waste disposal