Downdraft fixed bed biomass gasifier: A review

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A B S T R A C T

Biomass gasifier is one of the promising technologies to fulfill the energy demand of India as well as world. It also significantly reduces biomass waste generated in developing countries. Biomass gasification is a chemical process that converts solid biomass into useful convenient gaseous fuel. In this paper, various aspects of research and modification in downdraft fixed bed gasifier system and parameters like equivalence ratio, operating temperature, moisture content, superficial velocity, residence time etc. are reviewed. Various applications and status of biomass and gasification are discussed.

Capsule Summary: biomass gasifier overview is reported in this paper.

INTRODUCTION

Biomass is non-fossilized and biodegradable organic material. Biomass derived from by product, residues and waste from agriculture, forestry and related industries. World’s energy consumption is increasing due to rapid industrialization and modernization in standard of living. Major energy consumption of India and world is from fossils fuel based causing environment and health concerns due to emission of carbon dioxide, sulphur dioxide, nitrogen oxide. After fossils fuel biomass is the fourth largest source of energy. It supplies about 11-12% of total world energy consumption. In developing countries it accounts 38% of their primary energy consumption and in rural area 90% of total energy supplies. As 90% of world population is expected to reside in developing countries by 2050, biomass energy is substantial energy source (Chopra and Jain, 2007; Küşçük and Demirbaş, 1997; Sims, 2003). Biomass has high but variable moisture content and it consists of carbon, hydrogen, nitrogen, oxygen and other inorganic elements. Biomass in comparison to fossils fuels content less carbon, oxygen and lower heating value in the range of 12-16 MJ/KG (Chopra and Jain, 2007; Jain, 1997; Mukunda et al., 1994).

GASIFICATION
Gasification is a thermo-chemical process which converts solid biomass into syngas. Gasification process results in producer gas that contains various gas compositions like methane, carbon monoxide, nitrogen, carbon dioxide, hydrogen and some other gases [1]. Gasification is a partial combustion of solid biomass that takes place at a temperature of about 1000°C. The device that performs this work is known as a Gasifier (Rajvanshi, 1986).

**DOWNDRAFT GASIFIER**

In downdraft gasifier, gasification air enters at or above the oxidation zone in the gasifier. The producer gas generated is flow out at the bottom of the Gasifier. The biomass fuel and syngas flow in the same direction, so this gasifier is also known as co-current gasifier (Virmond et al., 2013). Biomass is filled at the top of the gasifier in downdraft gasifier, due to heat flow from the lower part of the gasifier, in drying zone drying of biomass takes place. Oxidation zone is formed in downdraft gasifier, where air or oxygen is supplied in the gasifier. In reduction zone of the gasifier, the heat energy of biomass and charcoal is converted into chemical energy of producer gas. This type of gasifier is best suitable for those applications where moderate temperature is required up to 1100°C (Virmond et al., 2013).

**PROCESS ZONES**

In way to gasification of solid biomass four distinct processes take place inside the gasifier (Fig. 1):

1) Drying of fuel
2) Pyrolysis
3) Combustion
4) Reduction

**Fig. 1:** Schematic diagram of downdraft gasifier

![Diagram of downdraft gasifier](image-url)
1) Throat less downdraft gasifier:
Throat less gasifier is also called as "open core gasifier" or "stratified throat less gasifier". In this type of gasifier the top of the throat is exposed to the atmosphere and walls are vertical. It allows unrestricted movement of the biomass down the gasifier and this unrestricted movement is not possible in throated type gasifier. This type of gasifier is best suitable for finer fuels like rice husks (Virmond et al., 2013).

2) Throated down draft gasifier:
In throated downdraft gasifier cross sectional area is converge at throat and then diverged. Oxidation zone is at the narrowest part of throat and forces all of the pyrolysis process to pass through this narrow region. Air is entered through nozzles above the constriction. The movement of the whole mass of pyrolysis process through this narrow zone results in a equal temperature distribution inside the gasifier and allows most of the tar extraction (Virmond et al., 2013).

Modification in Design of Throat less gasifiers

To improve the performance of throat less gasifier and use it for heat and power applications various changes were made in design by allowing a varying air distribution in the gasifier, improving insulation and re-circulation of the gas in the gasifier (Mukunda et al., 1994). In this paper they developed an open top gasifier consisting of a vertical open top tubular reactor and provide a water seal at the bottom. The lower two-third part of the gasifier was lined with a ceramic material to protect from high temperature corrosion. The upper part of the gasifier made up of stainless steel with an annular jacket around gasifier. The producer gas was comes out from below the grate and taken through an insulated pipe to the upper annulus of the gasifier where part of the sensible heat of the gas to the cold wood chips inside the gasifier improves the thermal efficiency of the system. The re-circulating duct and the surface of gasifier was covered with aluminosilicate blankets (Barrio et al., 2001).

They used a small scale 30kw stratified downdraft gasifier for gasification of wood pellets at a feed rate 5 kg/h. The gasifier design allows for variation at the point of air injection along the cross-section of the gasifier. The grate was a perforated crank, it could be shaken manually. Equivalence ratio was 0.3, when air was taken in (80%) from the top and (20%) from the sides of the gasifier. It was 0.4-0.45, when 100% air was taken in from the top. The produced 12 Nm³/h of producer gas with a calorific value of 5MJ/Nm³ and CO and H₂ content of 20% each (Dasappa et al., 2004).

They developed a downdraft reburn reactor with open top, a cylindrical vessel with an inner lining of ceramic made of mild steel. Air nozzles were provided across the combustion zone. The distribution of air was achieved uniformly through the reactor by locating these nozzles at two different levels. The air entry –from two different levels and the nozzles – favored a high residence time for gases at evaluated temperatures thus eliminating the tar. The open top of reactor helped in loading of biomass. The biomass bed was supported on an ash discharging screw. The screw operation based on the ash content of biomass and the pressure drop across the reactor. Two discharging outlets were provided for extracting ash (Ojolo and Orisaleye, 2010).

They designed a 15 KW thermal downdraft gasifier. The gasifier was manufactured as a single piece having a water seal and cover. The gasifier was tested in both natural downdraft and forced downdraft mode. Ignition of the fuel beneath the grate, in natural downdraft mode wood shavings used as fuel, gas produced which burns with a blue flame for 15 minutes.

When fuel was ignited at the throat, using both palm kernel shells and wood shavings in the natural downdraft mode, the gasifier did not produced producer gas. In forced downdraft mode, fuel was ignited at the throat. Gasification was successful with the palm kernel shells, in forced downdraft mode, which produced gas that burns steadily with luminous flame for 15 minute per kilogram of biomass fed. Wood shavings experienced some bridging problems during the forced downdraft mode of operation. In forced downdraft mode the fuel conversion rate of gasifier using palm kernel shells was 4 kg/h. Forced downdraft mode of gasifier yields better results and is preferred operation of the gasifier (Ojolo and Orisaleye, 2010; Sivkumar et al., 2013).

They designed a 10 KW downdraft wood gasifier using empirical data and derived quantities. This gasifier was designed to run a diesel engine. This type of downdraft gasifier is throated downdraft gasifier. The fuel used in this gasifier is wood chips. Firing nozzle is used to start the combustion process. Gases and ash will passes through the grate. Ash will collected in the ash pit and the producer gas leave the gasifier through the gas outlet.

Main design parameters for gasifier

- High heating value of gas
- Moisture in feed stock should be between 10-30%
- Low content of tar
- Low pressure drop
- Unhampered down flow of the feed

Parameters to design throated downdraft gasifier

- Hearth load
- Specific fuel consumption
- Throat diameter
- Height and number of nozzles
- Hearth diameter
- Nozzle ring diameter

The wood downdraft gasifier has holding capacity of 12.8 kg/hr of wood (Martinez et al., 2012).

They found that the temperature inside the gasifier in the combustion zone is about 1000°C. They also indicates low heating value and the process cold gas efficiency for downdraft gasifier are around 4-6 MJ/Nm³ and 50-70% respectively. They found in their experiment that yield is the parameter that is usually used to determine the specific
producer gas production in cubic meters per mass of feedstock fed to the gasifier.

The yield is directly proportional to equivalence ratio in both fluidized bed and fixed bed gasifier. The overall performance parameter of downdraft gasifier i.e. composition of producer gas, its calorific value, conversion process efficiency and the yield, depends on process parameter such as the equivalence ratio which determine the temperature levels.

**Various parameters for gasifier performances**

**A) Equivalence Ratio (ER):**

Equivalence ratio is the oxygen-fuel ratio and is stoichiometric. It will determine the process takes place as combustion, gasification or pyrolysis. It also determines the composition of producer gas produced by gasification. High value of ER will result in low concentration of $\text{H}_2$ and $\text{CO}$, also in lowered tar production. ER ranges between 0.2-0.4 for several biomass. ER value of the gas produced was approximately 2 Nm$^3$/kg biomass, while the ratio of air to fuel flow was 1.5 Nm$^3$/kg biomass.

**B) Moisture Content**

The moisture content of biomass fuel is depends on its origin, type and treatment. High moisture content is major characteristics of biomass. It is desirable to use biomass fuel with low moisture content because heat loss is considerable before gasification due to evaporation and the heat budget of the gasification reaction is impaired. By increasing the pressure drop high moisture content puts load across filtering and cooling units because of condensing liquid. Thus pretreatment of biomass fuel is required to reduce the moisture content. Generally desirable moisture content for biomass should be less than 20% (Rajvanshi, 1986).

**C) Energy Content and Bulk density of biomass fuel**

The higher the energy content and bulk density of fuel, similar is the gasifier volume, as once charge one can get power for long time (Rajvanshi, 1986).

**D) Superficial velocity**

It is defined as a ratio of the syngas production rate at normal condition and the narrowest cross sectional area of the gasifier. A number of authors indicated that superficial velocity influences the gas production, gas energy content, power output and tar production rates. It is independent of gasifier dimensions with different power output. Low values of superficial velocity result in a relatively slow pyrolysis process, high yields of char and unburned tars. High value of superficial velocity causes fast pyrolysis process, decrease the amount of char and hot gases in the flaming zone in comparison to low value. However high value may decrease the residence time in the gasifier. In the region of 0.4-0.6 m/s superficial velocity, which gave low tar yield, the gas composition was suitable for operation of an I. C. Engine (Bhavanam and Sastry, 2011).

**E) Operating Temperature:**

To achieve high carbon conversion of the biomass and low tar content a high temperature greater than 800°C in the gasifier is recommended. High temperature results in increasing gas yield, combustible gas content, hydrogen, and heating value, while tar content decreased sharply. This showed that high temperature favorable for gasifier (Gao et al., 2009; Hanping et al., 2008; Luo et al., 2009). But from an overall process perspective reduction of ash agglomeration requires low temperature. This may limit gasification temperature up to 750°C (Salaices et al., 2010).

**F) Residence Time:**

It has significant effect on the composition and the quantity of produced tars. The quantity of oxygen containing compounds tends to decrease by increasing residence time. When the space time was augmented in biomass gasification with a bed of dolomite, a decrease in total tar content (Bhavanam and Sastry, 2011; Gao et al., 2009; Luo et al., 2009).

**APPLICATIONS**

1) Shaft power system
2) Direct heat applications
3) Chemical production

The shaft power systems major applications are in agriculture for driving of farm machinery like tractors, harvesters etc. Many manufactures providing to the on-farm machinery gasification system. Another useful application of it is in irrigation. This implies that it is the most important application in developing countries. Small scale power generation provide an attractive alternative application of this system.

Direct heat application is used for drying grains, green house heating, cooling systems and working of absorption refrigeration. It can be coupled to other renewable energy systems like solar for heat and power applications. It can also be used to running of Stirling Engines. These engines have high efficiencies and better option than internal combustion engine running on producer gas.

Production of methanol and formic acid by producer gas is recent phenomena. Another useful application of gasifier system may be used to run a fuel cell plant on producer gas. As compared to IC Engine the energy density of this type of plant would be high.

Above all applications the most important input is the availability of biomass fuel. Like in other alternative source of energy it is better to use hybrid system, in combination with other energy system. In specific case of chemical production like methanol, gasifier system should be used as separate one (Rajvanshi, 1986).
CURRENT STATUS OF BIOMASS AND GASIFICATION IN INDIA

Total installed capacity of biomass power in India is about 829 MW. Agriculture residue are produced in bulk in India. As per the estimates, 249.78 MT of surplus biomass was available in 2001 from all the sources like agriculture residues, forest residues, grasslands, roadsides, agro-forestry wastes etc. The abundance of biomass is predicted to raise to about 384.51 MT by 2015 (Bhoi et al., 2006; Pathak et al., 2004). To utilize the gasification technology in commercial uses, Ministry of New and Renewable Energy has started to established various research centre in India for developing the gasification technology a, as result of this India premier institute like Indian Institute of Science, Bangalore(IISc) . The Energy and resource Institute (TERI), Sardar Patel Renewable Energy Research Institute (SPRERI) have been working in the of biomass combustion and gasification technology. More than 350 TERI gasifiers have been installed within India successfully with capacity of about 13 MWth (Bhoi et al., 2006; Palit and Mande, 2007).

According to MNRE total biomass & gasification and bagasse cogeneration installed capacity is 4550.55 MW to grid-interactive and to off grid is 178.87 MW (including rural and industrial) by December 2015 (Khare et al., 2013).

CONCLUSIONS

Biomass has high potential to meet the energy requirement of India. Downdraft fixed bed gasifier is the most practical option for heat and power applications. The construction of downdraft gasifier is also simple. Downdraft requires shorter time to ignite. The downdraft gasifier are safer from environmental point of view. Applications like production of methanol, using of producer gas in fuel cell and irrigation system on small scale offers the great potential. It is one of the most attractive alternatives system of energy.

REFERENCES


