Experimental Studies on Downdraft Biomass Gasifier

Pratik N Sheth[a], B. V. Babu[b*]

[a]Lecturer, Chemical Engineering Group, Birla Institute of Technology and Science (BITS), PILANI – 333 031 (Rajasthan) India; Email: pratik@bits-pilani.ac.in

[b]Dean- Educational Hardware Division & Professor of Chemical Engineering
Birla Institute of Technology and Science (BITS), PILANI – 333 031 (Rajasthan) India
Phone: +91-01596-245073 Ext. 259; Fax: +91-01596-244183
Email: bvbabu@bits-pilani.ac.in
Homepage: http://discovery.bits-pilani.ac.in/~bvbabu
* Corresponding Author:

Abstract

A process of conversion of solid carbonaceous fuel into combustible gas by partial combustion is known as gasification. The resulting gas, known as producer gas, is more versatile in its use than the original solid biomass. In the present study, a downdraft biomass gasifier is used to carry out the gasification experiments with the waste generated while making furniture in the carpentry section of the institute's workshop. *Dalbergia sisoo*, generally known as sesame wood or rose wood is mainly used in the furniture and wastage of the same is used as a biomass material in the present gasification studies. Experiments are carried out to study the effects of air flow rate and moisture content on biomass consumption rate.

Keywords: biomass; bio-energy; gasification; producer gas; downdraft gasifier; equivalence ratio.

Introduction

Biomass is the term used to describe all biologically produced matter and it is the name given to all earth's living matter [1]. It is a natural process that all biomass ultimately decomposes to its molecules with the release of heat. And the combustion of biomass imitates the natural process. So the energy obtained from biomass is a form of renewable energy and it does not add carbon dioxide to the environment in contrast to the fossil fuels [2]. The direct burning of biomass leads to the incomplete combustion of biomass, which generates a concern among the environmentalist, as it may produce organic particulate matter, carbon monoxide and other organic gases. If high temperature combustion is used, oxides of nitrogen would be produced. The biomass gasification has attracted the highest interest as it offers higher efficiencies compared to combustion and pyrolysis. Gasification is a process of conversion of solid carbonaceous fuel into combustible gas by partial combustion. The resulting gas, known as producer gas, is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. The producer gas is more versatile in its use than the original solid biomass. It is burnt to produce process heat and steam or used in gas turbines to produce electricity [3, 4]. Zainal et al. [5] performed experimental study on a downdraft biomass gasifier using wood chips and charcoal. Dogru et al. [6] carried out gasification studies using hazelnushell as a biomass. Jayah et al. [7] used a downdraft biomass gasifier using rubber wood as biomass in tea drying unit. In order to assess the potential of the saw dust as a biomass material, a fixed bed, downdraft, stratified and open top gasifier is used by Wander et al. [8].

In the present study, gasification experiments are carried out with the wood waste as a biomass material in a downdraft biomass gasifier. The biomass used in the present study is the waste generated in furniture making, collected from the carpentry section of the institute's workshop. Mainly two wood species are used to make furniture in the workshop namely *Dalbergia Sisoo*, generally known as sesame wood or rose wood and teak wood. Teak wood is costlier in comparison to sesame wood and also not easily available. Generally the furniture waste is used either for direct combustion or sold to pottery makers at a very cheap rate. Wastage generated while furniture preparation of sesame wood is collected and cut into appropriate sizes to feed the downdraft biomass gasifier. The effects of air flow rate and moisture content on biomass consumption rate are studied by performing experiments.

Biomass Gasification

The downdraft gasifier has four distinct reaction zones: (1) drying, (2) pyrolysis, (3) oxidation and (4) reduction. An Imbert downdraft biomass gasifier is used in the present study. It has throated combustion zone and different area of cross section for pyrolysis and reduction zone unlike stratified downdraft biomass gasifier in which gasifier cross sectional area is uniform through out the gasifier [9]. In downdraft gasifiers, pyrolysed gas generated in pyrolysis zone gets mixed with the moisture coming from drying zone and flow downwards. The pyrolysis gases pass through a combustion zone followed by a hot bed of char which is supported by a grate. Biomass is fed to the gasifier and oxidized in the zone where continuous air is supplied from two air nozzles. The heat generated in the combustion zone is transferred to the pyrolysis and drying zone. Released heat from the biomass combustion raises the temperature of the biomass particles resting above the oxidation zone and thus they get pyrolysed. The biomass particles are decomposed into volatiles and charcoal in the pyrolysis zone. The basic phenomena that takes place during pyrolysis are: (1) heat transfer from a heat source leading to an increase in temperature inside the fuel, (2) initiation of pyrolysis reactions due to this increased temperature leading to the release of volatiles and the formation of char, (3) outflow of volatiles resulting in heat transfer between hot volatiles and cooler unpyrolysed fuel, (4) condensation of some of the volatiles in the cooler parts of the fuel to produce tar, and (5) auto-catalytic secondary pyrolysis reactions due to these interactions [10-15]. Released volatiles from each of the biomass particles flow downward in the packed pyrolysis bed. The rate of volatiles release depends on particle size and temperature within the single particle. Due to high temperature of the combustion zone, tar of the pyrolysed gas mixture cracks into non-condensable gases and water. The cracked pyrolysed gas mixes with the carbon dioxide generated due to combustion and the inert N_2 present in the air. This gaseous mixture passes over the hot bed of charcoal and undergoes endothermic reduction reactions. The dimensional details of the biomass gasifier used in the present study and experimental procedure are reported in our earlier publication [16].

Results and Discussion

Biomass Characteristics

The biomass used in the present study is the collection of wood waste generated in the carpentry section of the workshop. The furniture waste of *Dalbergia sisoo*, is cut into appropriate size and used in the experimental studies. The physical properties, the proximate analyses, ultimate analyses and chemical analyses of the *Dalbergia sisoo* are listed in Table-1 [17]. Higher heating value is calculated using the empirical formula given by Eq. (1) reported in the literature [18].

$$\text{HHV (MJ/kg)} = 0.3536\ \text{FC} + 0.1559\ \text{VM} - 0.0078\ \text{ASH} \tag{1}$$

Biomass Gasification

Table-2 lists the details of the range of parameters varied in the present experimental study. The rate of biomass consumption is found to vary from 1.0 to 3.63 kg/h for an air flow rate ranging from 1.85 to 3.39 m^3/h. The moisture content is varied from 0.0254 to 0.164 wt fraction on wet basis. In order to reduce the number of parameters on which the performance of the biomass gasifier depends, an equivalence ratio is defined to reflect the combined effect of air flow rate, rate of wood consumption and the duration of the run. The equivalence ratio (Φ) for each run is calculated by Eq. (2) [16] and reported in Table-2.

$$\Phi = \frac{\left(\text{Flow Rate of Air} \big/ \text{Rate of Biomass Consumption}\right)}{\left(\text{Flow Rate of Air} \big/ \text{Rate of Biomass Consumption}\right)\Big|_{\text{Stoichiometric}}} \tag{2}$$

The stoichiometric ratio of air flow rate to the rate of biomass consumption is 5.22 m^3 air/kg of wood [19].

Table -1 Characteristics of *Dalbergia sisoo*

Physical Properties		
Size (mm^3)	Absolute Density (kg/m^3)	Bulk Density (kg/m^3)
25.4 x 25.4 x 25.4	1170	605
Proximate Analysis (% by wt. dry basis)*		

Fixed Carbon (FC)	Volatile Matter (VM)	ASH	Calculated HHV (MJ/kg)
15.70	80.40	3.90	18.06
Ultimate Analysis (% by wt. dry basis)*			
Carbon	Hydrogen	Oxygen	Nitrogen
48.6	6.2	44.87	0.33
Chemical Analysis (% by wt.)*			
Cellulose	Hemi-cellulose	Lignin	Extractives
36.75	11.30	43.65	8.30

*Source : Bhave [17]

Table 2 Details of the experimental runs for biomass gasification

Experimental No	Air flow rate (m^3/h)	Initial moisture content (wt fraction, wet basis)	Biomass consumption Rate (kg/h)	Equivalence ratio(Φ)
1	2.7765	0.1145	2.10	0.2533
2	3.3935	0.0437	3.63	0.1791
3	1.8510	0.0437	2.12	0.1673
4	2.7765	0.0437	2.67	0.1992
5	2.7765	0.073	2.59	0.2054
6	1.8510	0.10	1.00	0.3546
7	2.7765	0.1518	2.20	0.2418
8	2.1595	0.07	1.488	0.278
9	2.1595	0.164	1.0424	0.3968

Effect of Moisture Content

The effect of moisture content on biomass consumption rate is shown in Fig. 1. It is found that with an- increase in the moisture content, the biomass consumption rate decreases. For higher moisture content of biomass, the energy requirement for drying increases and reduces the biomass pyrolysis. The biomass moisture content greatly effects both the operation of the gasifier and the quality of the product gas. If moisture content of biomass is very high, water vapor released from the drying and pyrolysis zone condenses on the wall of the gasifier and flows to the oxidation zone, which may extinguish the combustion. The constraint of moisture content for gasifier fuels are dependent on type of gasifier used. Higher values of moisture content could be used in updraft systems but the upper limit acceptable for a downdraft reactor is generally considered to be around 40% on dry basis [6].

Effect of Air Flow rate

The effect of air flow rate on biomass consumption rate is shown in Fig. 1.It is found that with an increase in the air flow rate, biomass consumption rate increases. The increase in the air flow rate provides more oxygen to oxidize and higher amount of biomass would get combusted. The energy released will increase the rate of drying and pyrolysis. Biomass consumption rate increases not only due to a higher combustion rate, but also due to the enhanced pyrolysis and drying rate.

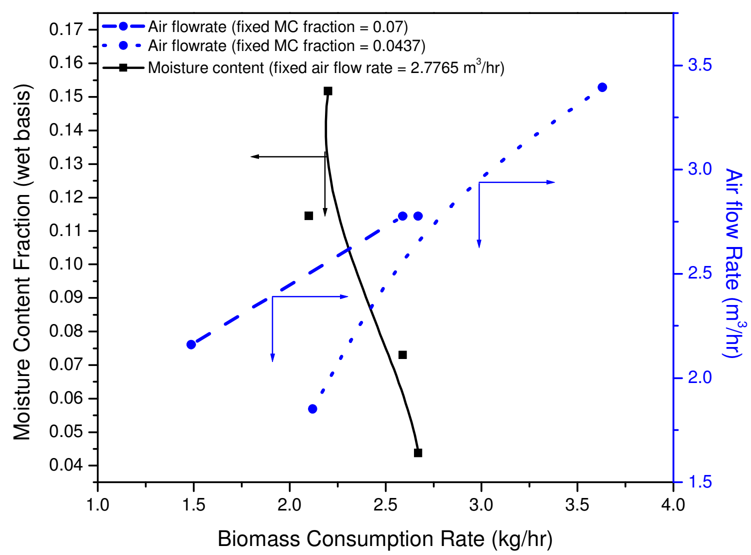

Fig. 1 Effect of Moisture content (for an air flow rate of 2.7765 m^3/hr) and of Air flow rate (for a MC of 0.0437 & 0.07) on Biomass consumption rate

Conclusions

Based on the results of this study, the conclusions drawn are:

- Wood waste can be successfully converted to generate the combustible gas, known as producer gas consisting of hydrogen, carbon monoxide, carbon dioxide, methane, nitrogen and water vapor, using an Imbert downdraft biomass gasifier.
- With an increase in the moisture content, biomass consumption rate decreases
- With an increase in the air flow rate biomass consumption rate increases.

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