EXPERIMENTAL INVESTIGATION ON A DOWNDRAFT BIOMASS GASIFIER USING TREE WASTE AND SAWDUST PELLET

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Abstract. In this article, investigation and analysis of an experiment for downdraft biomass gasification has been conducted using two different feed stocks namely tree waste and sawdust pellet at different equivalence ratio. The different gas yield due to gasification mainly hydrogen, carbon monoxide, methane, carbon dioxide and nitrogen have been observed by the use of online gas analyser. The equivalence ratio of air has been varied from 0.3 to 0.4 for both of the biomass feedstock. On the basis of producer gas yield, the LHV of producer gas have also been calculated for different equivalence ratio and for both of the biomass. After that the LHV has been compared between the two biomass feedstock for equivalence ratios of 0.3, 0.33 and 0.4. The trend of LHV on the basis of different equivalence ratio has been examined and plotted.

Keywords: Downdraft biomass gasifier, Experimental Investigation, Effect of equivalence ratio

1. Introduction

The growing shortage of fossil fuels accompanied with increasing concerns about the environmental impacts resulting from combustion of such fuels has resulted in the adoption of renewable technologies throughout the world. Biomass gasification is one of the most promising technologies to provide sustainable energy solutions. Biomass can be defined as all the biologically produced matter. Biomass energy is harnessed from all the plant sources like wood from natural forest reserves and agricultural outputs. The energy generated utilizing biomass is renewable in nature and does not add to the carbon dioxide level in the atmosphere. Gasification is a process of conversion of solid bio-fuels into producer gas with a heating value. During the process of gasification the temperatures are maintained at a higher level so as to optimize the gas production. The producer gas comprises of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen.[1,2,3]Apart from the fact that it is carbon neutral, the advantages of the utilization of biomass is that it is readily available everywhere and is very suitable for distributed generation purpose using locally available feedstock. Biomass gasification when applied to power generation in distributed generation mode helps to achieve environmental impact mitigation, gainful utilization of domestic un-utilized resources, savings in economy, reduced energy dependency on grid, boost to agriculture, creation of local employment, replacement of fossil fuels and improving the energy security in areas located far away from the national grid. Among all the gasifiers available for the thermo-chemical conversion of biomass, the downdraft gasifier [4] is found to be the most suitable option for small scale power generation due to its simple construction, proven technology, easier operation and ease of maintenance. The carbon
conversion is also high combined with higher char and tar conversion rates. Downdraft gasifier has good fuel flexibility along with coupling up options with producer gas engines, solid oxide fuel cell and gas turbines. Due to high residence time of solids, the overall carbon conversion is higher. However to generate producer gas with optimum quality for turbines and internal combustion engines, it is pertinent to carry out proper selection of various parameters like gasifier type (updraft, downdraft), gasifier design, gasifying agent (air, steam), temperature range and equivalence ratio (ER). With an increased thrust placed on generation of sustainable energy means and reduction of carbon footprint, it is pertinent to focus our attention on further research and development of biomass gasification techniques and upgrading options so as to ensure a better future for the generations to come. Biomass energy has the potential to play a pivotal role in addressing the environmental concerns and energy security issues [5,6]. Many researchers throughout the world have carried out characterization studies on downdraft gasifier on the pilot as well as laboratory installations. Dong et al.[7] studied the variance of gas composition and tar generation by the varying equivalence ratio (ER) and biomass (corn stalk) feed rate in a three air staged fixed bed downdraft reactor. With biomass feed rate of 7.5 kg/h and ER at 0.25-0.27, the LHV (lower heating value) of the producer gas was 5400 kJ/Nm3 and cold gas efficiency was 65%. At increased ER of 0.32, the tar yield was 0.52 g/Nm3. With ER at 0.27, an increase in biomass feed rate from 5.8 kg/h to 9.3 kg/h, the LHV decreased from 5455.5 kJ/Nm3 to 5253.2 kJ/Nm3 and tar yield increased from 0.82 g/Nm3 to 2.78 g/Nm3. Ram et al. [8] designed and developed a 75 kWe downdraft gasifier integrated Internal Combustion (IC) engine with the key target to optimize overall system performance through proper selection of ER, increasing the biomass to gas conversion efficiency by minimizing the charcoal removal rate by incorporating a vibrating ash removal grate. Waste heat recovery system was also adopted comprising of heat exchanger and blower in order to supply pre-heated air into the gasifier so as to minimize the heat loss of the system and improve overall thermal performance. The power output varied from 65 kWe and 73 kWe. At ER of 0.35, the heating value of the syngas was 5.7 MJ/Nm3. Generally it has been observed from literature, gasifiers are designed for a specific biomass to be utilized in the gasification process. But in the present work, experimental investigation has been carried out in a downdraft gasifier using different biomass wastes. Effect of equivalence ratio on producer gas composition and its heating value have been reported and discussed.

2. Experimental Set up and Methodology
A complete experimental set up consist of gasifier unit along with its cleaning and drying system and associates accessories shown in Fig.1 (a&b).

![Fig. 1. (a) Schematic of experimental setup and (b) Photographic view of the experimental setup.](image-url)
Two types of biomass feedstock have been utilized in the present work: one is tree waste and another one wood waste (sawdust) shown in Fig. 2. Tree waste has been collected from Jadavpur University campus as twig and branches fallen from trees. Twig and branches are cut into proper size suitable for gasifier unit shown in Fig. 2 (a). Sawdust has been collected from nearby sawmills. But saw dust received from sawmills are not suitable for downdraft gasifier application due to its lower size. Saw dust pellet has been prepared by biomass pellet machine to provide required shape and size shown in Fig. 2(b). Proximate and ultimate analyses of the sample have been done. Proximate and ultimate analyses of the sample are presented in the table 1.

Fig. 2. (a) Tree waste 
Fig. 2. (b) Sawdust Pellet

| Biomass Feedstock | Proximate Analysis, % Dry basis | Ultimate Analysis, % by weight |
|-------------------|--------------------------------|--------------------------------|
|                   | Volatile Matter | Fixed Carbon | Ash | C  | H  | N  | O  |
| Tree Waste        | 80.2            | 15.3         | 4.5 | 45.1 | 6   | 1.6 | 41.6 |
| Sawdust Pellet    | 81.4            | 15.1         | 3.5 | 44.5 | 5.5  | 1.8 | 40.4 |

Table 1. Proximate and ultimate analysis of biomass feedstock.

3. Results and Discussions

Experiments have been carried out at different equivalence ratio by measuring the air supply using Rota meter. After stabilizing the gasifier run composition of the producer gas has been measured using an online producer gas analyser after successive intervals. Composition of the producer gas has been shown in Table 2.

| Biomass Feedstock | Equivalence Ratio | C0 | H2 | CO2 | CH4 | N2 |
|-------------------|-------------------|----|----|-----|-----|----|
| Tree Waste        | 0.3               | 17.5 | 16.5 | 11.5 | 0.85 | 53 |
|                   | 0.33              | 18.1 | 15.6 | 10.6 | 1.2  | 52 |
|                   | 0.4               | 18.8 | 15.2 | 10.3 | 1.3  | 51 |
| Sawdust Pellet    | 0.3               | 16.5 | 15.5 | 12.5 | 1.1  | 54 |
|                   | 0.33              | 17.1 | 15.1 | 11.6 | 1.2  | 53 |
|                   | 0.4               | 17.8 | 14.3 | 10.7 | 1.2  | 52 |

Table 2. Producer gas compositions at different equivalence ratio during trial run
The average of LHV for producer gas in the present study has been found 4.19 MJ/m³ on the other hand in the study of Sittisun et al. [10] the LHV of producer gas using same sawdust has been found 4.06 MJ/m³. Hence it can be concluded that the present study has found standard results as compared with the established literature. Through the experimental results it has been observed that the CO yield is more with the increase of ER from 0.3 to 0.4 for both of the feedstock. In case of tree waste it is ranging from 17.5 to 18.8 percent of the producer gas and in case of saw dust pellet it is 16.5 to 17.8 percent of the producer gas. On the other hand the production of H₂ has decreased with respect to the increase in ER. For tree waste the percentage decreases from 16.5 to 15.2 and for saw dust pellet it is from 15.5 to 14.3 percent. For CH₄ the production rate very nominal, it is increasing but the magnitude of percentage and increase is not that much prominent as it has been observed for the CO. The CH₄ percentage in case of tree waste is ranging from 0.85 to 1.3 and for saw dust it is 1.1 to 1.2. Therefore an increasing effect has been observed in the trend of LHV for both of the gas. Here the percentage of CH₄ production has played a very important role in the calculation of LHV. By the presented result the dominance of CO percentage in the gas composition is observed as compared to the H₂ and CH₄ production.
4. Conclusions
In this experimental study following observation has been made along with their conclusions.

- It is observed that the LHV of producer gas is increasing for tree waste sample with respect to the equivalence ratio. This kind of observation may be due to the fact of the increasing percentage of CO production as compared with the H2 and CH4 in the produced gas from tree waste sample, which has contributed nearly 12.63 times of its percentage in producer gas to LHV.
- On the other hand LHV for sawdust pellet has increased for the equivalence ratio 0.3 to 0.33 and remains constant form 0.33 to 0.4; This may be due to the same amount of CH4 nearly 1.2 percent of producer gas and decrease in H2 percentage, though there is an increase in CO percentage.
- Therefore on the basis of producer gas yield it is clear the percentage of CH4 and CO yield is the important contributor to the calculation of LHV. It is also concluded that the LHV is in the very near range of other experimental results of different literature.

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