An experimental investigation on utilizing cassava stalk as biomass sources in a gasifier

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Abstract. Many researchers focussed on the implementation of renewable energy sources with appropriate energy conversion technologies to replace conventional systems and overcome environmental issues. Among the various technologies used for producing thermal energy from biomasses without serious environmental impact, the thermochemical conversion process is considered as the viable one. Cassava is an important crop that is cultivated in the open region and also as an intercrop annually. A minor portion of the stalk is used as a source for the next cultivation and the major portion is dried and used for household cooking. Hence, in this paper, an experimental study is to be carried out on a cassava stalk and the gasification potential has been investigated. The composition, gas yield, higher heating value, temperature profile, and the efficiency of the gasifier has been studied. The result shows that the HHV and gas composition are 5.83 MJ/Nm³, and compositions of CO, H₂, CH₄, and CO₂ are 20-23%, 10-14%, 2.0-2.7%, and 15-18% respectively. All the observed results are better when the gasifier is operated with equivalence ratio (ER) 0.3. Moreover, the average producer gas yield, CO₂/CO ratio, and conversion efficiency are observed as 1.7 Nm³/kg, 0.65, and 78.73% respectively.

Keywords: cassava stalk; feedstock; biomass gasifier; producer gas; heating value; efficiency

1. Introduction

Most of the population in rural India receives the energy for cooking through various biomasses, such as crop residues, waste animation, fuelwood, and cow dung, etc. Besides, 64% of households use firewood for cooking purposes, and a further 26% use crop residue and animal waste [1]. However, it is documented that 80% of solid fuels are used for direct burning of fuel in the residential sector [2] in a comparative analysis of household energy use patterns in India and China. In addition to household applications, biomass is commonly used in various conventional and rural sectors, such as rice parboiling, hotels, restaurants, and pottery [3]. The methods of direct combustion are less efficient and, because of the toxic emissions, the system may not be a clean technology [4]. In this process, under partial high-temperature oxidation (800-900°C), biomass is converted into a combustible gaseous mixture with air, steam, or oxygen as the gasification medium [5]. Moreover, it is proposed that the thermochemical approach is a good option to substitute the direct burning of fuels in the future with high thermal efficiency with less CO₂ emissions [6, 7]. The downdraft gasifier from different
feedstocks such as woody biomass (waste from trees), agricultural waste (residues) was analyzed using an equilibrium model [8]. Using the species transport model, Murugan and Sekhar [9] used downdraft gasifiers with rice husk [10], and the feedstock available in rural areas [11] under normal atmospheric air as a gasifying medium and compared the result with their experimental value. The gas produced contains impurities and the usage of a natural bio-filter prevents the tar and char generated from the gasifier [12]. For the impurities, the gas generated from the gasifier is cleaned and can be used in IC engines to meet the energy required for the sawmill [13]. However, it is important to demonstrate the application for the use of non-food biomass as feedstock for energy products in order to better tackle the global problems facing a rising population and to create sustainable societies. [14]. After harvesting, the roots from the cassava plant have become an essential food resource for as many as one billion people in rural areas of Africa, Asia and Latin America, but the Cassava stalk is currently being wasted and not utilized properly[15]. The stems are removed as waste that is usually wasted or incinerated; only 10 to 20 percent is used for fertilizer application, cultivation development, or mushroom substrates [15]. Internationally, on the basis of a stem/root weight ratios of 42-50 percent [16,17] and estimated cassava root production in 2009-2013[15], the number of cassava stems can be estimated to be about 32-38 Teragram dry mass. The lack of understanding and consistency variance of the cassava stalk renders the feedstock an insignificant asset to date. An experimental study is therefore carried out to find the technical feasibility of using the proposed feedstock in a downdraft biomass gasifier to use the cassava stalk as an energy source. The gasifier’s performance quality, such as gas generation, calorific value, and CO₂/CO ratio, and gasifier efficiency, are studied.

2. Experimental Setup

The experimental setup as shown in Figure 1 is a downdraft biomass gasifier which consists of primary cooling and cleaning mechanisms to remove the unwanted particles from the producer gas. The secondary system is used to remove the moisture from the generated gas and the impurities. The feedstock used for the experimental study is weighed in a digital weighing scale with an accuracy of ±0.01%. The gas flowrate and quality of the producer gas are measured by using an appropriate devices having an accuracy of ±0.03 and ±0.02 respectively. Chromel-Alumel thermocouples are arranged at various points to monitor the temperature with the help of a data acquisition systems. The characteristics of the feedstock used in the experimentation is given in Table 1.

![Figure 1. Downdraft biomass gasifier used for the experimentation](image-url)
### Table 1. Ultimate and proximate analysis of cassava stalk

| Ultimate analysis (% w.b.) | Proximate analysis (% w.b.) |
|---------------------------|-----------------------------|
| Carbon 51.12              | Fixed Carbon 14.00          |
| Hydrogen 06.87            | Volatile Matter 79.90       |
| Oxygen 41.34              | Moisture 15.54              |
| Nitrogen 00.67            | Ash 06.01                   |
| Sulphur 00.00             |                             |

The operation of the gasifier is normally started by cleaning the wall of the gasifier to avoid the presence of tar and char. The insulation rope on the gasifier door and chamber is checked to prevent the leakage of gas. Cassava stalk is fed into the gasifier upto 50% and it is ignited by red hot charcoal. The gas is generated after 10 minutes from the start of experimentation. The gas coming out from the gasifier is at high temperature and is cooled by a venturi-scrubber. Later, the gas pass through the scrubber unit and multiple filters to obtain clean purity gas. To ensure the gas generation, the combustion nature of the gas was tested in the flare. Once the combustion quality was confirmed, gas samples were taken every 10 minutes of the experimental run and the average readings were plotted. The whole experimentation is done for 4 h and the average readings of gas composition, temperature and heating value of gas were noted. During the operation, the amount of ash formed is around 9-11% from the bottom tank. The final residues collected from the water tank is dried and used as fertilizer for agriculture.

### 3. Result and Discussion

The technical feasibility of using cassava stalk in a downdraft biomass gasifier is studied experimentally and the parameters such as gas composition, temperature distribution, heating value of gas, gas yield and the efficiency are discussed herewith after continuous operation of 4 hours and the average readings are plotted.

#### 3.1 Producer gas composition

![Figure 2. Effect of ER on gas composition](image-url)
Figure 2 depicts the producer gas composition on different equivalence ratio. The combination of gas such as carbon-monoxide, hydrogen and methane is known as producer gas. The trend for carbon-monoxide is increasing from ER 0.25 and it is maximum for ER 0.30 which is observed as 20-23%. However, the similar trend is also observed for hydrogen gas composition and the maximum gas composition is noted as 10-14%. The methane gas formation is almost more or less stable for all ER and it does not have much significance. Moreover, the carbon dioxide generation is higher at lower ER 0.20 and the CO$_2$ is observed to be very low composition at ER 0.30 [18]. It is proved partial oxidation of combustion has been taken place inside the gasifier. The nitrogen which is an inert gas is does not react with other combination of gases and observed as 47-52%. Better gas composition obtained from cassava stalk feedstock is when the gasifier is operated between ER 0.25-0.30 [19].

3.2 Higher heating value

The effect of higher heating value and the gas yield with respect to different ER is shown in figure 3. The CV of gas increases (5.83 MJ/Nm$^3$) with increase in ER from 0.20 to 0.30 and then it gradually decreases with increase in ER. This might be due to complete combustion of feedstock inside the gasifier with increase in air. Moreover, the formation of carbon dioxide to carbon-monoxide is higher at ER 0.30. The yield of producer gas obtained from the cassava stalk is maximum of 1.7 Nm$^3$/kg for ER 0.30. However, the gas yield from the feedstock are in the range of 1.4-1.7 Nm$^3$/kg for the ER 0.2-0.30 [19].

![Figure 3. Effect of ER on HHV and gas yield](image)

3.3 CO$_2$/CO ratio

The CO$_2$/CO ratio for different ERs is shown in Figure 4. The gas composition of the producer is positively linked with the ratio of CO$_2$/CO. The ER at 0.30 has a minimum CO$_2$/CO ratio among the different experiments as relative to the other experiments. For all instances, CO$_2$/CO is less than 1 and for an ER with maximum PG generation it is minimum. The influence of the CO$_2$/CO ratio follows the findings published in the literature of such a gasifier [11, 19], which ensures that the possibility of using cassava stalk as energy feedstock. The results from the study is validated with other feedstock (sugarcane bagasse) is listed in Table 2.
Table 2. Comparison of results with other feedstock from the literature

| Parameters     | Cassava Stalk (Present Study) | Rice Husk [18] | Sugarcane Bagasse [19] |
|----------------|-------------------------------|----------------|------------------------|
| CO (%)         | 20–23                         | 19–24          | 18–22                  |
| H₂ (%)         | 10–14                         | 8–16           | 9–16                   |
| CH₄ (%)        | 2–3                           | 2.5            | 2.4                    |
| HHV (MJ/Nm³)   | 4.2 – 5.83                    | 4.0 – 5.2      | 5.3 – 5.93             |
| PGY (Nm³/kg)   | 1.4–1.7                       | -              | 1.4–1.7                |

3.4 Temperature inside the gasifier

Figure 5 represents the temperature on the various zones of the gasifier. The temperature inside the gasifier is the main responsible parameter for the generation of producer gas [20]. Therefore, the temperature inside the gasifier should be clearly monitored. It is observed that the corresponding temperature at the various zones such as drying, pyrolysis, combustion and reduction zone are recorded as 140–170°C, 740–850°C, 1040–1160°C and 240–280°C respectively. Using the cassava stalk feedstock in a gasifier is safe and the temperature ranges are in the normal range as per the literature [9].
Figure 5. Recorded temperature on different gasifier zones

3.5 Efficiency of gasifier

The conversion efficiency rises from 76 percent to 78 percent and is optimum at the ER, 0.30 in Figure 6, which could be attributed to the decrease in the release of volatile matter during the oxidation reactions. Likewise, for the tested conditions of ER (0.20-0.40), the variation of Cold Gas Efficiency (CGE) is from 66 percent to 68 percent. Furthermore, the result indicates the highest efficiency of cold gas (68.56 percent) at an ER of 0.30 [19]. The increase in ER results in a sudden increase in the temperature of the gasification device and an increase in the sensitive heat of the air [8].

Figure 6. Effect of ER on efficiency of gasifier
Conclusion

The experimental observations have examined the technological viability of using the cassava stalk as feedstock in a gasifier. Based on the studies the following conclusions are drawn:

- The best heating value of producer gas is reported as 5.83 MJ/Nm$^3$ for the conditions studied, and CO, H$_2$, CH$_4$, and CO$_2$ compositions are 20-23%, 10-14%, 2.0-2.7%, and 15-18% respectively.
- The average producer gas yield at the ER of 0.3 is 1.7 Nm$^3$/kg, and the overall CO$_2$/CO ratio, cold gas efficiency and gas conversion efficiency values are respectively 0.65, 68.57% and 78.73%.
- The results show that compared to other biomass types, the proposed feedstock can be used as a feedstock in a gasifier.
- Hence, the cassava stalk available in the rural areas can be effectively used as feedstock in a gasifier for thermal and power applications.

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