PERFORMANCE ANALYSIS OF A INVERTED DOWNDRAFT BIOMASS WOOD STOVE

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ABSTRACT

Biomass is a syngas fuel which can be used as a fuel for furnaces, stoves and vehicles in place of gasoline, diesel or other fuels. In the present investigation, syngas is used as fuel for biomass wood stove to meet the energy requirement for community and domestic level cooking applications. Water boiling tests were conducted to evaluate the biomass performance with respect to efficiency and fuel flexibility. The biomass wood stove was tested with Amla, Calotropis, Juliflora, Neem wood and Cashew nut shell. The properties of the biomasses were determined experimentally. It is seen from results that the thermal efficiency of neem wood is 56% higher than the other biomasses.

Key words: Syngas, Water boiling tests, Amla, Calotropis, Juliflora, Neem wood and Cashew nut shell.


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1. INTRODUCTION

In recent years, the interest in bio fuels has been increasing, motivated on the one hand by the need for reducing greenhouse gas emissions and on the other hand by the desire to improve energy security by reducing our dependence on imported fossil fuels. Biomass energy production does not suffer from the generation intermittency of solar and wind facilities. Biomass energy generation is effectively and can be utilized as a stable, reliable, on-demand source of base-load power generation. Yung-Chang Ko et al [1] have carried out a study which was aimed to assess the effects of changes in gas composition on burner performance and to propose suitable design or operational factors of domestic gas stoves burning natural gas with various heating values. A single gas burner, originally designed for burning natural gas with low heating value, is adopted to investigate the effects of variations in gas composition on the burner performance.

Using natural gas with high heating value instead of natural gas with low heating value results in a decrease in thermal efficiency (due to higher thermal input) and an increase in CO emission (caused by incomplete combustion). Smith et al [2] have investigated about the implications of changes in household stoves and fuel use. Persson et al [3] have carried out a study which investigates how electrically heated single-family houses can be converted to wood pellets- and solar heating using pellet stoves and solar heating systems. Four different system concepts are presented and system simulations in TRNSYS evaluate the thermal performance and the electrical savings possible for two different electrically heated single-family houses. Simulations show that the electricity savings using a wood pellet stove are greatly affected by the level of comfort, the house plan, the system choice and if the internal doors are open or closed. Installing a stove with a water-jacket connected to a radiator system and a hot water store has the advantage that heat can be transferred to domestic hot water and be distributed to other rooms. Pinar et al [4] have reviewed the flue gas emissions of carbon monoxide (CO), nitrogen oxides (NOX), sulphur dioxide (SO2) and soot from an improved space-heating biomass stove and thermal efficiency of the stove have been investigated. Rathore et al [5] have studied the wood gas stove in meeting cooking energy requirement using biomass gasification. The stove works on natural draft mode. The thermal efficiency of the stove was recorded at about 26.5% and it can be started, operated and stopped with very low emissions. Kariher et al [6] have studied 14 solid-fuel household cook stove and fuel combinations, including 10 stoves and four fuels, which were tested for performance and pollutant emissions using a WBT (Water Boiling Test) protocol. Results from the testing showed that some stoves currently used in the field have improved fuel efficiency and lower pollutant emissions compared with traditional cooking methods. Rashid et al [7] have carried out an experimental investigation using a multistage simple random sampling design, to determine the structural characteristics of the traditional cooking stoves, amount of wood fuel consumed. Kousksou et al [8] have carried out an experimental investigation by incorporating a TE (thermoelectric) generator with a multifunction wood stove. The TE generator has produced up to 9.5 W. Vigneswaran et al [9] have evaluated three types of forced draft cook stoves using fuel wood [10] and coconut shell. Carvalho et al [11] have carried out a field study investigating how modern wood-burning stoves operated in modern single-family houses, which showed that intermittent heat supply occasionally conflicted with the primary heating system and that chimney exhaust occasionally conflicted with the ventilation system causing overheating and particles in the indoor environment. On this background, it was
concluded that better combustion technology and automatics, controlling the interplay between stove and house, can make wood-burning stoves suitable for low-carbon dwellings and meet the remaining heat demand during the coldest period. Tonne et al [12] have compared fuel use between a low cost, improved wood stove and traditional three-stone stove. The performances of a wood gas stove with different biomasses such as Amla wood, juliflora, neem wood, calotropis, cashew nut shells have been discussed in this paper.

2. DESIGN AND FABRICATION OF BIOMASS WOOD STOVE
One of the fibres selected for this biomass wood stove is coconut fibre. Based on the properties of it, biomass wood stove was designed.

2.1. Energy needed
The amount of energy needed to cook food for a family of four members is estimated energy needed which is given by equation 1,

\[ Q_n = m c_p (T_2 - T_1) \]  

(1)

Where,
\( D \) - Reactor diameter (cm)
\( C_P \) - specific heat (KJ/kg)
\( T_1 \) - Initial temperature
\( T_2 \) - Final temperature

2.2. Fuel Consumption Rate
Fuel consumption rate is given by equation 2 as

\[ FCR = \frac{Q_n}{c_v \times \eta_g} \]  

(2)

Where,
\( Q_n \) - Energy Needed
\( c_v \) - Calorific value of coconut fibre
\( \eta_g \) - Gasification efficiency

2.3. Reactor Diameter

\[ D = \left( \frac{1.27 \times FCR}{SGR} \right)^{0.5} \]  

(3)

Where,
\( FCR \) - Fuel consumption rate (Kg/hr)
\( SGR \) - Specific gasification rate (kgm^{-2}h^{-1})

2.4. Height of the reactor:

\[ H = \frac{SGR \times T}{\rho_{coconut \ fibre}} \]  

(4)

Where,
\( T \) - Duty hour
\( \rho \) - Density of coconut fibre (kg/m^3).
Inverted downdraft biomass wood stove of height 40 cm, diameter 29 cm and thickness 3 mm as shown in Figure 1 has been fabricated using Mild steel in cylindrical shape.

![Photographic View of Biomass Wood Stove](image)

**Figure 1 Photographic View of Biomass Wood Stove**

3. **FEED STOCK FOR WOOD STOVE**

3.1. **Prosopis juliflora**

*Julliflora* is a shrub or small tree in the Fabaceae family, a kind of mesquite. It is native to Mexico, South America and the Caribbean. It has become established as an invasive weed in Africa, Asia, Australia and elsewhere.

3.2. **Cashew nuts shells**

It is a tropical evergreen that produces the cashew nut and the cashew apple. Officially classed as *Anacardium occidental*, it can grow as high as 14 meters. The cashew nut is served as a snack or used in recipes, like other nuts, although it is actually a seed. The cashew apple is a fruit, whose pulp can be processed into a sweet, astringent fruit drink or distilled into liqueur. The shell of the cashew nut yield derivatives that can be used in many applications from lubricants to paints, and other parts of the tree have traditionally been used for snake-bites and other folk remedies.

3.3. **Calotropis**

It is a large shrub growing to 4 m tall. It has clusters of waxy flowers that are either white or lavender in colour. Each flower consists of five pointed petals and a small, elegant "crown" rising from the centre, which holds the stamens. The plant has oval, light green leaves and milky stem. The latex of Caltop’s gigantean contains cardio glycosides, volatile fatty acids and calcium oxalate.

3.4. **Amla trees**

The tree is small to medium in size, reaching 8 to 18 m in height, with a crooked trunk and spreading branches. The branch lets are glabrous or finely pubescent, 10–20 cm long, usually deciduous; the leaves are simple, sub sessile and closely set along branch lets, light green, resembling pinnate leaves. The flowers are greenish-yellow. The fruit is nearly spherical, light greenish yellow, quite smooth and hard on appearance, with six vertical stripes or furrow.
3.5. Neem tree
Neem is a fast-growing tree that can reach a height of 15–20 metres, it is evergreen, but in severe drought it may shed most or nearly all of its leaves. The branches are wide and spreading. The fairly dense crown is roundish and may reach a diameter of 15–20 metres in old, free-standing specimens.

4. ESTIMATION OF MOISTURE
Moisture content of the sample is determined by drying it in a hot oven at a temperature of 102°C to 105°C for 5 hours. The hot oven is as shown in Figure 2.

![Hot Ovens](Figure_2_Hot_Ovens)

5. ESTIMATION OF TOTAL VOLATILE MATTER
Volatile matter content of the sample is determined by placing it in a electric furnace at a temperature of 550°C for 5 hours and cooling it in a desiccator. By determining the initial and final weight of the sample, the amount of volatile matter present in the sample can be estimated. The photographic view of electric furnace is shown in Figure 3.

6. ESTIMATION OF GROSS CALORIFIC VALUE:
Higher heating value (also called gross calorific value) is the theoretical maximum amount of energy that can be extracted from the combustion of the moisture-free fuel if it is completely combusted and the combustion products are cooled to room temperature such that the water produced by the reaction of the fuel bound hydrogen is condensed to the liquid phase. Gross calorific value is determined by using a bomb calorimeter which is shown in Figure 4.
7. WATER BOILING TEST

In the first phase, the cold-start in water, the tester begins with the stove at room temperature and uses a pre-weighted bundle of wood or other fuel to boil a measured quantity of water in a standard pot. The tester then replaces the boiled water with a fresh pot of cold water to perform the second phase of the test. The second phase, the hot-start in water the test, follows immediately after the first test while stove is still hot. Again, the tester uses a pre-weighted bundle of fuel to boil a measured quantity of water in a standard pot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. The third phase follows immediately from the second. Here, the tester determines the amount of fuel required to simmer a measured amount of water at just below the boiling point for a time span of 45 minutes.

8. FORMULAE USED FOR WATER BOILING TEST

8.1. Specific Fuel Consumption (SFC) for Water Boiling Test:

\[
SFC = \frac{(75||T_{\text{boil}} + T_{\text{start}}|) \times (\text{Mass}_{\text{mw}} \times (1 - \text{MC}) - \text{Mass}_{\text{w}}) - 1.5 \times \text{Mass}_{\text{char}}}{\text{Mass}_{\text{water remaining}}} 
\]  

(5)
8.2. Mass Of Fuel Wood Used To Evaporate Water:

\[
\text{Mass}_{fwe} = \frac{\text{Mass}_{\text{char}} \times \text{T}_{\text{boil}} - \text{T}_{\text{room}}}{\text{Net Calorific Value}_{\text{fuel}}} + 2257
\]  

(6)

Where,

- \text{Mass}_{\text{char}}: mass of the remaining charcoal after conducting WBT
- \text{Mass}_{fwe}: mass of fuel wood used to evaporate water
- \text{Mass}_{\text{mw}}: mass of water remaining in the pot at the end of the test
- \text{Mass}_{\text{mw}}: mass of the moist wood
- \text{MC}: mass of fraction moisture content of the fuel on the dry.
- NO\text{x}: oxides of nitrogen
- \text{T}_{\text{boil}}: the local boiling temperature
- \text{T}_{\text{room}}: the air temperature in the room.
- \text{T}_{\text{start}}: starting temperature of the water.

9. RESULTS AND DISCUSSION

9.1. Analysis of Properties of the Biomasses

From Figures 5, it is observed that the percentage of dry matter is higher for cashew nutshells, followed by amla wood, juliflora, and neem wood. Percentage of dry matter is very low for calotropis.

From Figure 6, it is can be seen that moisture content is low for cashew nutshells and is very high for calotropis. Since calotropis has very low percentage of dry matter, it has high moisture content. Cashew nut shells have higher percentage of dry matter, so it has lower moisture content. This shows that if the percentage of dry matter is high, then the moisture content will be low.

From Figure 7, it is clear that the percentage of ash content is maximum for calotropis and minimum for cashew nutshells. This is due to the reason that calotropis has high moisture content and cashew nutshells have low moisture content. This shows that if moisture content is high then ash content will also be high.
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Figure 6 Comparison of Percentage of Moisture Content for Various Biomasses

Figure 7 Comparison of Percentage of Ash Content for Various Biomasses
Figure 8 Comparison of Percentage of Volatile Matter for Various Biomasses

From Figure 8, it can be observed that the percentage of volatile matter is high for cashew nutshells and is very low for calotropis. This shows that if moisture content is high, then percentage of volatile matter of the biomass will also be high.

Figure 9 Comparison of Density for Various Biomasses
Figure 10 Comparison of Calorific Value for Various Biomasses

From Figure 9, it can be seen that the density is maximum for neem wood followed by calotropis, juliflora, amla wood and cashew nutshells.

From Figure 10, it can be observed that the calorific value is maximum for juliflora, and is minimum for calotropis. It is also figured that amla wood, cashew nutshells and neem wood also has higher calorific values

9.2. Performance Analysis of Various Biomasses

Figure 11 Comparison of Specific Fuel Consumption Of Various Biomasses
From Figure 11, it can be seen that, calotropis has higher specific fuel consumption due to its low calorific value and other biomasses have a specific fuel consumption of above 0.5. This shows that, if the calorific value is low, then the specific fuel consumption will be high.

![Figure 12 Comparision of Thermal Efficiency of Various Biomasses](image)

From Figure 12, it can be observed that, the thermal efficiency is very low for calotropis due to its lower calorific value and other biomasses have an efficiency value greater than 50%.

10. CONCLUSION
The properties analysis of the biomasses shows that, the percentage of dry matter is higher for cashew nutshells, moisture content is low for cashew nutshells and is very high for calotropis. The percentage of ash content is maximum for calotropis and minimum for cashew nutshells. The percentage of volatile matter is high for cashew nutshells and is very low for calotropis. The calorific value is maximum for juliflora, and is minimum for calotropis. The performance analysis of the inverted downdraft biomass wood stove shows that calotropis has higher specific fuel consumption due to its low calorific value and other biomasses have a specific fuel consumption of above 0.5. This shows that, if the calorific value is low, then the specific fuel consumption will be high. The thermal efficiency is very low for calotropis due to its lower calorific value and other biomasses have an efficiency value greater than 50%. This inverted downdraft biomass wood stove can meet the energy requirement for community and domestic level cooking applications.

REFERENCES

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