Design of an updraft gasification stove and its performance test with cassava peel as fuel

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Abstract. In this study, an insulated updraft gasification stove for biomass has been designed and tested for cassava peel. The main components of the stove were forced airflow inlet, biomass bed and gasification chamber and ceramic wool-insulated stainless steel wall. Top lit method was used in the ignition and testing was performed by using water boiling test method. Cassava peel was fed at four levels of bulk densities and moisture content. The result showed that combustion rates were quite high. The bulk density of fuel tend to reduce the rate of combustion and ignition front speed. The cassava peel with moisture content of 8-10% showed reddish-purple flame and small amount of smoke produced while with moisture content above 15%, the fuel could not be ignited in a reasonable time. The thermal system efficiencies of this gasification stove were still quite low, which were between 5.88 to 8.79%.

1. Introduction

Cassava is one of agricultural commodities that is often consumed in processed form such as tapioca flour, cassava chips and other traditional foods. Cassava peel which is the dominant by-product (around 10-15%) in cassava processing is potential for further utilization such as feed or biomass energy source. In general, the cassava tuber consists of three parts namely the outer most layer (periderm), cortex and starchy flesh [1].

Usually cassava peel was not further processed. However, due to its composition cassava peel is potential to be used as biomass energy source for heating process such as cooking. This utilization may be fit with the circumstances that most of small-scale cassava processing units need cooking process. By doing this, the waste produced as well as the producers' expenditure on fuel can be reduced.

Gasification is a chemical reaction that converts carbon-containing materials such as biomass into fuels in the form of combustible gases such as CO₂ and H₂ and a small amount of CH₄ and hence it can be used for cooking process. The heart of the gasification is reduction reaction involving C, H₂O and CO, therefore, the most commonly used gasification medium is air, oxygen, and steam [2]. Air gives a lower heating value of the gas produced, but is easiest in application. Usually gasification is applied for low moisture content biomass.

One type of gasification reactors is an updraft fixed bed reactor. This reactor is considered as one of the simplest gasification reactor types [3, 4]. In this reactor, fuel flows in the opposite direction of the flow of the produced gases, where the gas originated from pyrolysis and gasification process is directed upwards. The principle of this reactor is very suitable to be applied in cooking stoves, namely top lit up draft (TLUD) stove. Usually to keep the continuity of the gas flow, the TLUD stove requires blower. However, the TLUD stove can also be used by natural draft flow [6].
Since the temperature is very important in gasification process, the stove was designed with insulation. The objective of this study was to design an insulated gasification cooking stove for household or small scale industry and to conduct performance test using the cassava peel as its fuel.

2. Methodology

2.1. The stove design

The gasification stove design was based on the top lit updraft gasification with air used as the gasification medium. Figure 1 shows the design of the stove consisting of fuel chamber, insulation, air inlet and outlet of gases. The wall of the fuel chamber was made of carbon steel and the insulation was ceramic wool. The diameter of the chamber was 25 cm, while the outside diameter (outer side of the insulation) was 40 cm and the overall height was 60 cm. The size of the stove chamber can contain about 2 kg of cassava peel.

![Figure 1. The 3D view of stove design](image)

Figure 2 shows schematically the parts of the stove system. The upper part of this chamber (above the fuel) is the space where the gasification process takes place. At the bottom of the fuel chamber is a steel floor with a hole in the air. The air flow is driven by a blower. The inlet and outlet diameter was 7.5 cm. The cassava peel was fed from the gases outlet located at the top of the furnace up to a height at which the empty space above the bed was about 5-10 cm. Then, the upper part of the bed was ignited and the blower was turned on to supply the air into the stove.

2.2. Performance testing

Performance testing was performed by boiling water or known as the water boiling test (WBT). After the fuel inside the stove was ignited, a pot containing 5 kg of water with ambient temperature was put at the top of the stove. The water temperature was measured by K thermocouple during the heating. Soon after the water has boiled, the rest fuel was weighed to find out the mass of the fuel consumed during the process.

The performance parameters determined from the experimental result included the specific fuel consumption, the rate of combustion of the fuel, the time of ignition, the efficiency of the furnace, the speed of the ignition front, the amount of smoke produced, and the color of the flame.
Figure 2. Schematic diagram of the gasification stove – pot system and temperature measurement points

2.3. Consumption rate and thermal system (stove-pot) efficiency

The rate of fuel combustion ($m_t$ in kg/s) can be determined by dividing the amount of fuel that has been burned ($m_{bb}$ in kg) by the time required to boiling the water (t in min) which can be stated as:

$$\dot{m}_t = \frac{m_{bb}}{t}$$  \hspace{1cm} (1)

The efficiency of the stove ($\eta$) is the ratio between the amount of energy used to boil water and the energy obtained from fuel. The energy to boil water is obtained by adding up the energy to raise the water temperature and the energy for water evaporation, while the the fuel energy was obtained from the product of the mass of the burned fuel and the lower heating value (LHV) of the cassava peel. The LHV of the fuel was measured using a bomb calorimeter at 10.18% moisture content and was repeated 3 times. The thermal efficiency is expressed as:

$$\eta = \frac{m_{avg} c_p (T_{boil} - T_i) + m_{vap} h_{fg,avg}}{m_{fuel} LHV}$$  \hspace{1cm} (2)

where $m_{avg}$ is the mass of heated water (kg), $m_{vap}$ is the mass of evaporated water (kg), whereas $m_{fuel}$ denotes the mass of the fuel burned out during the test (kg), $c_p$ denotes the specific heat of water heat (kJ/kg°C), $T_{boil}$ and $T_i$ each denotes the water temperature (°C) when boiling and its initial respectively, and $h_{fg,avg}$ denotes the latent heat of water vaporization (kJ/kg).

2.4. Ignition front speed and time of ignition

The ignition front speed was determined based on the time difference of the temperatures at the measurement points of the combustion bed (red dot in figure 2) when starting to increase. From the pre-experiment, it was determined that the time difference was performed at temperature of the points reached 300°C. Temperature was measured by using type K thermocouples. The distance between the measurement points was 6 cm.

The amount of smoke, and the color of the fire were determined by using visual observation. The ease of ignition can be determined by the time required to ignite the fuel until the flame was stable.
2.5. Fuel condition variation
Various levels of fuel bulk density and moisture content were used in this study, i.e. the testing was carried out 8 times, consisting of 4 test used fuels with almost uniform moisture content (at +10% w.b.) with different bulk densities and the other 4 tests used 4 levels of moisture content (8 to 15 % w.b.) with uniform bulk density. Differences in fuel densities can be obtained by pressing (manually) the cassava peel when it was filled into the fuel chamber.

The fuel density was calculated by simply dividing the mass of the fuel filled into the combustion chamber by the volume of the combustion chamber. The moisture content of the fuel was measured by gravimetry method. Different levels of moisture content were obtained by applying different duration of sun drying.

3. Results and Discussions

3.1. Physical appearance of the combustion process
In each test, the fuel was ignited by the top lit method. Soon after the ignition, the pyrolysis gases were produced and burned. In the beginning, the flame color of all of the test’s results were yellowish red. After a while the ignition front move down, gasification gases began to form at the top of the furnace and the combustion of the gases continued and this was shown by the color of the flame turn into bluish red (figure 3). The fuel at the top region form a charcoal bed due to the pyrolysis process that occurred. The ignition front will move slowly to the bottom of the stove until all the fuel became charcoal. When the gasification process has been occured, the flame produced by the stove was similar to the flame produced by natural draft gasifier stove using wood charcoal as the fuel [7]. Saravanakumar et al. [8] stated that the bottom lit updraft gasifier is a gasifier that burns charcoal and produces tar, while the top lit updraft gasifier (TLUD) is a gasifier that burns tar and produces charcoal.

![Figure 3. The flame produced by the stove](image)

3.2. Effect of fuel bulk density
Figure 4 shows the evolution of temperature at measurement points when combustion process was taking place for the fuel with bulk density of 108.8 kg/m³ and moisture content of 10.88%. The temperature at point 1 (upmost position) start to increase at 4 min followed by at point 2 (middle position) after 6 min and point 3 (lowest position) after 10 min respectively. The temperature increase took place from temperature near ambient up to more than 400°C in less than 1 minute. This shows
that below the ignition front, the temperature was low enough and hence the pyrolysis should had not been occurred yet.

![Temperature evolution at the measurement points in the fuel bed and the determination method of time required (showed by red arrow) of the ignition front to move between the measurement points](image)

**Figure 4.** Temperature evolution at the measurement points in the fuel bed and the determination method of time required (showed by red arrow) of the ignition front to move between the measurement points

Table 1 shows the rate of fuel combustion and the ignition front speed for four levels of bulk density ranged from 108.8 to 136.0 kg/m$^3$. The ignition front speed was ranged from 1.23 cm to 2.25 cm/min and it was significantly affected by the fuel density. It could seen that the higher the fuel bulk density, the slower the ignition front speed. Fuel combustion rate shows a similar pattern to the ignition front speed except for the lowest bulk density. In general, increasing density will reduce fuel porosity which will also reduce the amount of air from blowers that could pass through the fuel bed. The fuel rate was ranged from 0.065 to 0.079 kg/min and this is considered to be high a combustion rate for the small stove size.

**Table 1.** Experimental result of various bulk densities

| Bulk density (kg/m$^3$) | Fuel loaded (kg) | Combustion rate (kg/min) | Ignition front speed (cm/min) |
|-------------------------|------------------|--------------------------|-----------------------------|
| 108.8                   | 1.588            | 0.06583                  | 2.25                        |
| 121.2                   | 1.770            | 0.07970                  | 2.12                        |
| 131.0                   | 1.913            | 0.07487                  | 1.42                        |
| 136.0                   | 1.986            | 0.07122                  | 1.23                        |

### 3.3. Effect of fuel moisture content

Table 2 shows testing parameters especially the time of ignition, the amount of smoke formed, and the color of the fire formed with respect to the fuel moisture content. It can be seen from the data obtained that the higher the moisture content of the material the more difficult it is to ignite, the more smoke is formed, and the quality of the fire formed decreases visible from the reddish color of the fire. The red colour of flame indicate the incomplete combustion. Fuel with a moisture content of 15.06% could not even be ignited. This means that fuels with a moisture content above 15% could not be used because they are too wet and cannot be ignited. When the level of moisture content of a fuel is too
high, the energy required to evaporate is also high and then temperature increase of the fuel was too slow and becomes too difficult to ignite.

Table 2. Effect of moisture content to the time of ignition, smoke amount and color of the flame

| Fuel moisture content (%) | Speed of ignition (min) | Amount of smoke produced | Color of the flame  |
|--------------------------|-------------------------|--------------------------|---------------------|
| 8.24                     | 1                       | +                        | Redish purple       |
| 10.44                    | 2                       | +                        | Redish purple       |
| 11.94                    | 3                       | ++                       | Redish orange       |
| 15.06                    | -                       | -                        | -                   |

Note: + = a little
++ = moderate
+++ = much

3.4. Thermal system efficiency

Table 3 shows the fuel consumed and thermal system efficiencies for all experiments. It can be seen that the efficiency obtained was still relatively low, ranging from 5.88 to 8.79%. This low efficiencies were due to the stove chamber diameter which was quite large. An insulated stove (with rice husk ash) designed by Belonio [9] with rice husk as fuel has ignition front speed of 1-2 cm per min, with efficiency of 12.3-13.3%. According to Belonio [9] the reactor diameter is an important factor in designing a gasification stove. The diameter is directly proportional to the combustion rate. This explains why the flame formed is so large that a lot of heat is wasted and is not used for the boiling process (figure 5). The rate of combustion ranges from 66-80 g per minute shows the speed was quite large. Lotter et al. [10] tested forced draft stove with wood pellet with average rate combustion of 58.9 g per minute. The average wood pellet used to boil 5 kg of water was only 1088 g which is only around two-third of the fuel consumed in this study. Good insulation is also very important to prevent heat loss and improve furnace efficiency. Existing ceramic wool insulation was used to prevent heat loss from the combustion chamber.

Table 3. Fuel consumed and thermal system efficiency

| Experiment | Moisture content (%) | Amount of fuel consumed (g) | Thermal Efficiency (%) |
|------------|----------------------|------------------------------|------------------------|
| 1          | 10.11                | 1474                         | 8.79                   |
| 2          | 10.11                | 1594                         | 5.88                   |
| 3          | 10.11                | 1722                         | 6.34                   |
| 4          | 10.11                | 1638                         | 6.70                   |
| 5          | 8.24                 | 1685                         | 7.78                   |
| 6          | 10.44                | 1143                         | 7.46                   |
| 7          | 11.94                | 1395                         | 8.07                   |
| 8          | 15.06                | Not burned                   | Not burned             |
4. Conclusion

A small scale industrial gasification stove has been designed and tested with top lit updraft method for cassava peel as the fuel. In general, the combustion rates were quite high, i.e. more than 0.066 kg/min. The bulk density of fuel directly tend to reduce slightly the rate of combustion, and significantly the ignition front speed. The cassava peel with moisture content of 8-10% was easy ignited (less than 2 minutes) and showed reddish-purple flame and small amount of smoke produced. The cassava peel with moisture content above 15% could not be ignited in a reasonable time. The thermal system efficiency of this gasification furnace was still relatively low ranged from 5.88% to 8.79%, due to the incompatibility between the size of flame and the pot used.

5. References

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