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On Gasifier Cookstove Operation Fuelled by Different Lignocellulosic Biomass Materials

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ABSTRACT

Gasifier based cookstoves are relatively clean and environmental friendly than that of direct combustion type. Though a few commercial designs are available, their capability in handling different biomass has not been known. The objective of this work was to characterize the basic operating properties of a gasifier-based biomass cookstove using different types of biomass fuels. The main characteristics evaluated were the efficiency of the stove. The biomass considered were oil palm fronds, dry leaves and pressed sugarcane. The efficiency of the stove was tested using standard boiling tests for 2.5 kg of water. The performance of each fuel was studied by analyzing the parameters involved during water boiling tests. It was demonstrated that the gasifier cookstove would be capable in handling different lignocellulosic biomass materials, although oil palm frond exhibited the highest thermal efficiency.

Keywords: *biomass; gasifier; cookstove; thermal energy; gasification.*

Introduction

Biomass is a valuable source of energy that exists in the form of organic matter, which is available on a renewable or recurring basis, including agricultural crops and trees, wood residues, plants, grasses, animal manure, municipal residues, and other residue materials [1]. In certain part of the world, especially in rural areas, biomass fuels are very important sources of energy especially for cooking purpose. It was estimated that over 20% of the world population

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were still relying on traditional use of biomass for cooking [2]. Most biomass fuel consumptions use inefficient energy conversion technology. The popular one is the indoor stove that applies direct combustion method, which is well known to result in serious adverse consequences for health and environment. This kind of stove does not have operating chimney or hoods, and this leads to high pollution levels inside the house.

The potential of extracting energy from biomass waste is very large. In the early nineties the accumulated potential of biomass energy in domestic cooking sector alone in seven top Asian producing countries was estimated to be at 152 million tons and 101 million tons in the forms of fuel wood and agricultural residues, respectively [3]. The opportunity to utilize energy from biomass in this clean and cheap way must be optimized by using efficient energy conversion method such as gasification process. Since most biomass consumers are from rural area of third world countries, switching from biomass cooker to much efficient cooker such as natural gas cooker is not easy. One of the ways to reduce the harmful effects of biomass utilization in household is by improving the method used; that is by using biomass gasifier cookstove. Gasifier based biomass cookstove is a reliable solution as its by-products are relatively clean.

Gasification of biomass is a process that converts an organically derived carbonaceous feedstock by partial oxidation into a gaseous product, synthesis gas or "syngas," consisting primarily of hydrogen and carbon monoxide, with lesser amounts of carbon dioxide, water, methane, higher hydrocarbons, and nitrogen [4]. The syngas can be combusted for extraction of thermal or electrical power, in a more efficient manner as compared to direct combustion. In theory, almost all kinds of biomass with moisture content of 5-30% can be gasified [5]. The content of syngas depends on the chemical composition of biomass fuels. However, design of the gasifier also depends on the nature of the fuels too, and therefore one gasifier design may not be able to handle all or many kinds of biomass feedstock.

The biomass cookstoves, which are basically compact gasifier-gas burner devices, have been utilized since mid-nineties for cooking applications. Many designs of gasifier cookstove are treated as updraft gasifier, and presently there are numerous biomass gasifier cookstoves in operation in countries such as China, India, Nepal and Indonesia. Gasifier based cooking systems have attractive features which include high efficiency, smoke-free clean combustion, uniform and steady flame, ease of flame control and possible attention-free operation over extended duration [6]. Traditional cookstoves in Asia have efficiencies in the range of 5-15%, while the efficiencies of gasifier-based biomass cookstoves are in the range of 25-35% [7]. The opportunity to utilize energy from biomass in clean and low-cost manner through utilization of the gasifier-based cookstoves can be broadened by increasing efficiency of existing designs.

Although widely available in the present market, basic characteristics of gasifier-based cookstoves especially the efficiencies and flexibility of fuels are not widely known. Reports on this information are very limited. In this work, basic operating properties of gasifier-based biomass cookstove using different type of biomass fuels were evaluated so that improvements could be made at a later stage. The cookstove evaluated was a gasifier-based biomass cookstove purchased from Indonesia. The study involved analysis of parameters around water boiling tests, which included stove efficiency, time required to boil 2.5 kg of water, stove ignition time and weight of fuel consumed.

Experiment Apparatus and Setup

In this work, the selected lignocellulosic biomass materials were oil palm fronds, sugarcane bagasse and dry leaves (from random tropical landscape trees). These biomass materials were selected because of their abundance, ease of collection and low cost. Gasification of oil palm frond has been quite recently studied and it was reported to be a highly potential feedstock [8-11]. The samples underwent indoor drying for two months at room temperature and with natural air circulation. The moisture content of each fuel was checked weekly. In general, the drying process for the dry leaves took the shortest time because their low initial moisture and also high area-to-volume ratio.

The selected biomass materials were previously characterised in the laboratory in order to determine their thermo-chemical properties; these were reported elsewhere by Sulaiman and Romli [12]. Their tests, which included the ultimate analysis, proximate analysis and also calorific value measurements, are summarized in Table 1. In general, the calorific contents of the three materials are shown to be quite typical to other common lignocellulosic biomass materials, although dry leaves are shown to display the highest energy content. In term of carbon and hydrogen contents, oil palm fronds displayed the highest value among the three. The percentage of volatile matter is shown to be the highest for sugarcane bagasse. In summary, each of the materials has its own advantage.

A commercial gasifier based cookstove of undisclosed manufacturer in Indonesia, as shown in Figure 1, was used in this work. When unloaded, the weight of the cookstove was about 23 kg. It consisted of five main components, which were an ash drawer, a fuel chamber, a grating plat, a cone and a secondary chamber. The stove was designed to be operated as an upside down downdraft gasifier. The ambient air temperature during the tests was 32°C. The biomass feedstock was filled inside the fuel chamber and the secondary chamber before being ignited with kerosene flame. At the point of ignition, the ash drawer was fully opened to allow complete combustion. When steady combustion was achieved inside the secondary chamber, the pot and its holder were placed on top of the secondary chamber. The ash drawer's opening was limited to 2 cm and thus limiting the oxygen supply; this changed the process from complete combustion to gasification. The stove was then ignited and water boiling test was conducted.

Table 1: Characterization results of the selected biomass [12]

Sample		Pressed Sugarcane	Dry Leaves	Oil Palm Fronds
Ultimate Analysis	% Carbon	43.2	48.2	61.5
	% Hidrogen	5.8	5.3	7.7
	% Nitrogen	0.067	1.719	0.336
	% Sulphur	traces	traces	traces
Calorific Analysis	Calorific Value (J/g)	16,821	19,237	17,787
Proximate Analysis	% Moisture Content	6.0	9.9	3.7
	% Volatile Matter	72.8	58.2	50.7
	% Fixed Carbon	14.9	26.7	40.1
	% Ash	6.3	5.2	6.3

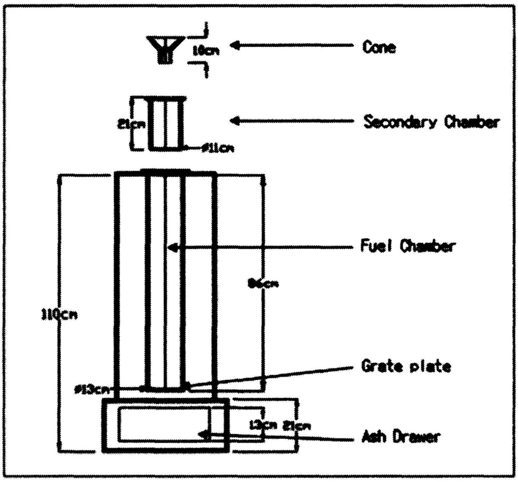

Figure 1: Schematic of the gasifier based cookstove

To test the cookstove's performance, a water boiling test was conducted. Water at 2.5 kg was boiled inside a 22 cm aluminium pot without lid. The efficiency and other parameters of the cookstove were obtained using the Water Boiling Test version 3.0 [13]. The cookstove was tested in three phases; i.e. cold start high phase, hot start cold phase and low or simmering phase. The first two tests were intended to determine the effects of initial cookstove conditions to its performance. The simmering phase test was intended to determine the ability of the stove to shift into a low power phase following a high-power phase in order to simmer water for 45 minutes using minimum amount of fuel. During each phase of water boiling tests the ignition duration, the duration to boil 2.5 kg of water, and the initial and final temperatures of the water were recorded. The efficiency or performance of stove was calculated by:

$$\eta = \frac{m_{wi} C_{pw} (T_e - T_i) + m_{w,evap} H_i}{m_f H_f} \tag{1}$$

where m_{wi} was the initial mass of water, C_{pw} was specific heat of water, $m_{w,evap}$ was mass of evaporated water, m_f was the mass of fuel burned, T_e was temperature of the boiling water, T_i was initial temperature of water (28°C), h_i was latent heat of evaporation at 100°C and 105 kPa and h_f was calorific value of the fuel measured [14].

Results and Discussions

The ignition process took about 15 minutes on cold start and 9 minutes if the cookstove was still hot. Shown in Figure 2 are photographs of the upper section of the cookstove. In Figure 2(a) white smoke is shown leaving the secondary chamber; this was due to the direct combustion process (sufficient oxygen), which was required to ignite the feedstock. As the feedstock was steadily combusted, it became a heat source and the process was then changed to gasification by limiting the amount of air flowing into the fuel chamber. The result was flow of syngas that was ignitable, as shown in Figure 2(b). It was observed that the design of the cookstove caused narrow space for air and syngas to circulate, and that was within the gaps in the biomass feedstock. Therefore, sufficient amount of syngas could not accumulate that the flame produced was intermittently disrupted. As a consequence, only small flame was produced, and hence long boiling time and low efficiency.

In this work, only high phases of water boiling tests could be performed. All the simmering phase tests failed. The requirement for simmering test was that the fuel must be able to supply enough heat to maintain water temperature inside pot within 6°C from the boiling temperature for 45 minutes after the start of boiling. All the selected biomass fuels could not supply enough syngas for the stove to pass through simmering phase, and thus the water temperature could not be maintained within the test requirement. In addition, the flame produced was disrupted, requiring an interval of between 2 and 7 minutes of attempts in order to re-ignite the flame. Apart from the poor air circulation problem, the failure was also observed to be attributed by the difficulty to control the cookstove's flame since adjustment of the opening of the ash drawer was not effective. It was proposed that adding gas vents and external blower could help to improve the cookstove's operation and efficiency.

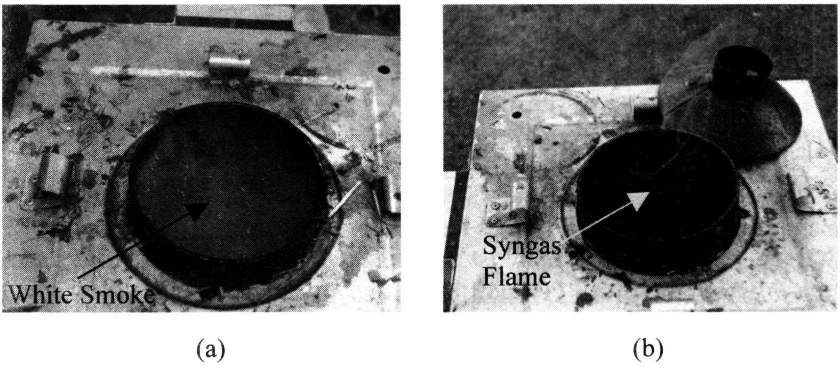

Figure 2: Photographs of the cook stove secondary chamber during ignition: (a) combustion prior to gasification (b) combustion of syngas after steady gasification

In comparison among the three biomass fuels, it was found that gasification of the dry leaves did not perform well since the resulting syngas was not enough to produce sufficient flame to heat the water. It was probable that gasification did not take place, in favour of direct combustion due to difficulty to adjust the air flow rate into the fuel chamber. Therefore, the dry leaves were mixed with oil palm fronds at a weight ratio of 1:1 in order to increase its ease the gasification process.

Shown in Figure 3(a) is comparison of duration to boil 2.5 kg of water heated by combustion of syngas resulted from gasification of different fuels and under different gasifier conditions; i.e. hot start and cold start. It is shown in the figure that the fastest time to boil water was achieved when using oil palm frond; i.e. 23.7 minutes for cold start and 18.3 minutes for hot start. This was followed by pressed sugarcane and mixture of oil palm frond and lastly the dry leaves. It is clear that although dry leaves have the highest calorific content among the three fuels it can be regarded as slow performer when gasified in the selected cookstove.

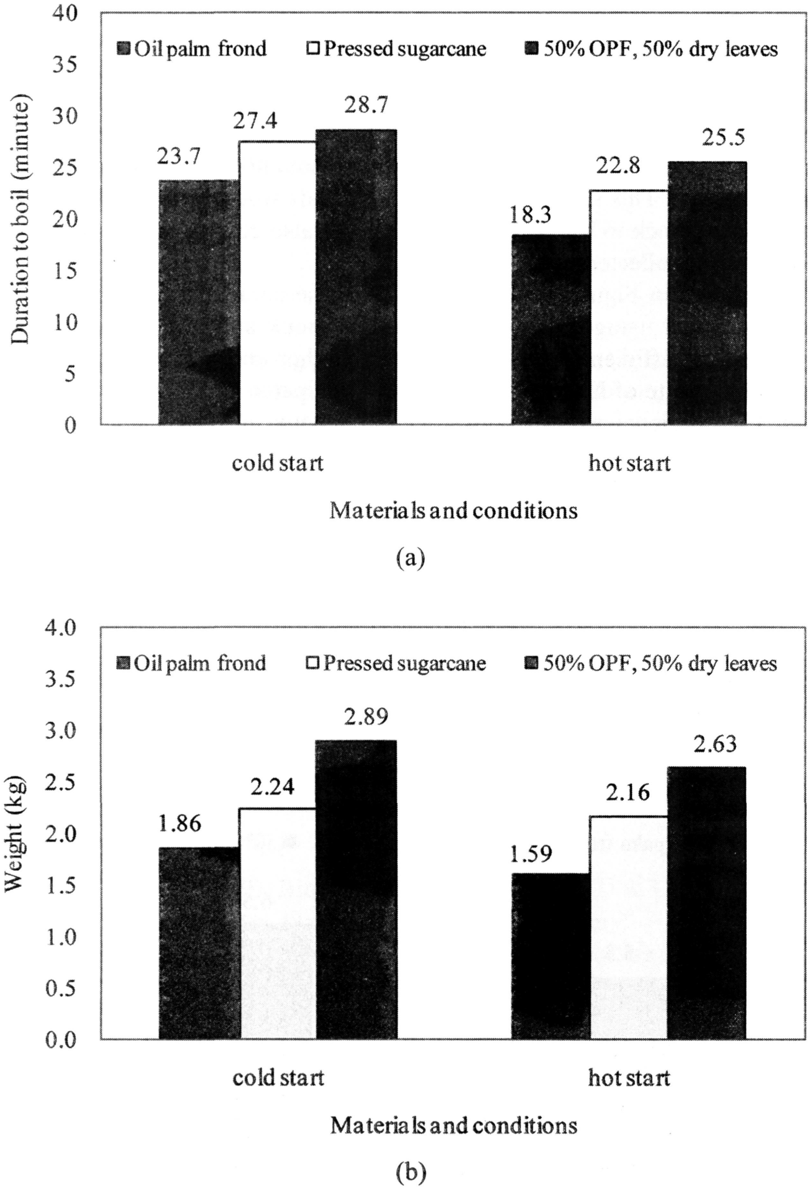

Figure 3: Cook stove performance in boiling 2.5 kg of water;
(a) duration to boil, and (b) weight of fuel consumed

Figure 3(b) shows similar comparison to that in Figure 3(a) but in term of weight of fuel consumed to boil 2.5 kg boil water. As expected based on the trends in Figure 3(a), oil palm frond is shown to consume the least amount of fuel. While the results in Figure 3(a) implies some difference (time taken were around 20 minutes or more), in Figure 3(b) it is depicted that the weight of oil palm frond was significantly lower (by up to about 40%) as compared to dry leaves mixture. This suggests that oil palm fronds would be a highly suitable biomass feedstock to be used in the cookstove, also considering its high bulk density when collected at site.

Shown in Figure 4 are efficiencies of the cookstove, using Eqn. (1), when operated using different biomass feedstock and test conditions. As expected, the efficiencies are shown to be higher under hot start condition since higher rate of heat losses would be anticipated when the cookstove is cold. The efficiencies of the cookstove range between 2.28% and 5.33% for cold start, and between 2.5% and 6.5% for hot start. As shown in Figure 4, oil palm frond had the highest efficiency at 5.3% for cold start and 6.5% for high start. The hot start phase efficiency is relatively higher because during the test, the stove was already hot and already at high fire bed temperature, which would help to increase the gasification process. The efficiency of similar stove was recorded elsewhere to be up to 35.4% [15]. Other cookstoves' efficiencies found in reports elsewhere were in the range of 25-35% [7]. The low efficiency of the cookstove in this work was likely to be related to the poor circulation of air due to design factor.

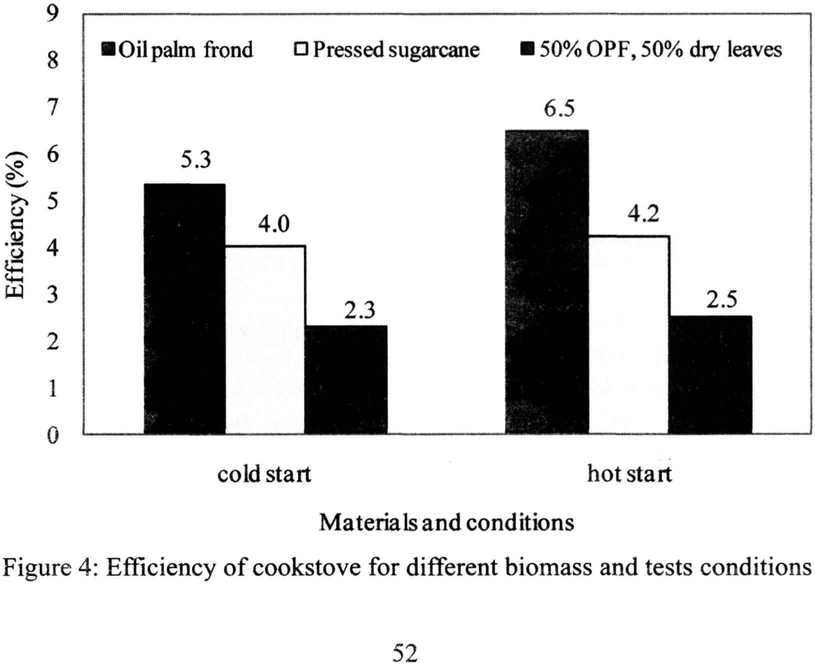

Figure 4: Efficiency of cookstove for different biomass and tests conditions

Overall, it is shown in this work that the efficiencies of the gasifier (at about 6%) were very low as compared to studies conducted elsewhere using different cookstoves [7]. Nevertheless, within the study itself, it is clearly shown that oil palm fronds would make the best fuel among the three materials tested. It is suggested that gasifier-based cookstove of a better design than the one used in the present study be used in order to assess the suitability of all the fuels tested.

Conclusions

In this work the basic operating properties of gasifier-based biomass cookstove using different types of materials were studied. The following conclusions could be drawn:

1. Of the three biomass materials used, oil palm frond was found to be the best in term of performance with efficiencies of 5.3% for cold start and 6.5% for high start.
2. The thermal efficiency of the cookstove was relatively low. Furthermore it failed the simmering phase of water boiling test. Improvements on the cookstove design would be required in order to increase its efficiency.
3. The main reason for low efficiency of the gasifier-based biomass cookstove was proposed to be due the poor air and syngas circulation inside the stove.

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