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Operating Characteristics of Gasifier Cookstove using Different Biomass Materials

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Abstract. Biomass energy technology such as gasifier is increasingly receiving attention as a promising renewable energy source because of the ever rising costs of fossils fuels especially diesel and kerosene. Gaseous products of gasifier based cookstove are relatively clean and environmental friendly than direct combustion cookstove. The objective of this workwas to characterize the basic operating properties of a gasifier-based biomass cookstove using different types of biomass fuels. The main characteristics evaluated were the efficiencyof the stove. The biomass considered were oil palm fronds, dry leaves and pressed sugarcane. The efficiency of the stove was tested using water boiling tests.Other characteristics such as its ignition duration and the time required to boil 2.5 kg of water were also observed. The performance of each fuel was studied by analyzing the parameters involved during water boiling tests. It was found that oil palm frond has the highest thermal efficiency among all the fuels tested.

Introduction

Biomass fuels had been crucially important for rural people especially for domestic cooking. The International Energy Agency through World Energy Outlook (WEO) estimates over 20% of global population relies on the traditional use of biomass for cooking [1]. The ever increasing price and depleting supply of fossil fuels are the main reasons for this increasing number.

Most of biomass consumptions use inefficient energy conversion technology which is direct combustion cooker that would give serious adverse consequences for health and environment. This kind of stove did not have operating chimney or hoods. This leads to high pollution levels inside the household. The World Health Organization estimates that more than 1.45 million people die prematurely each year from household air pollution due to ineffective biomass combustion [1].

Since most of 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 feasible. One of the ways to reduce the harmful effects of biomass usage in household is by improving method used by biomass stove. Gasifier based biomass cookstove is a reliable solution for this problem as products of gasifier cooker is relatively clean.

The opportunity to utilize energy from biomass in this clean and cheap way must be optimized by improving the efficiency of current gasifier. Despite the availability of gasifier based cookstove in current market, the basic characteristics of the stove such as the efficiency and best fuels to be used in it is not widely known. Report on this information is limited.

In this paper, basic operating properties of gasifier-based biomass cookstove using different type of biomass fuels were evaluated. The stove evaluated was a gasifier-based biomass cookstovepurchased fromChemaco, Indonesia. The study involved analysis of parameters of water boiling tests. The parameters include stove efficiency, time required to boil 2.5 kg of water, stove ignition time and weight of fuel consumed.

Gasifier-based Biomass Cookstove

Biomass is any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood residues, plants, grasses, animal manure, municipal residues, and other residue materials [2]. Potential of extracting more energy from biomass waste is very large. Biomass saving potential in seven Asian countries are 152 million tons of fuel wood and 101 million tons of agricultural residues, in the domestic cooking sector alone in early nineties [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. Biomass gasification is the conversion of 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]. Theoretically, almost all kinds of biomass with moisture content of 5-30% can be gasified [5].Constituents in the product gas and the gasification design are affected by the chemical composition of biomass fuels. Some may prove more costly or challenging to gasify and clean if the product gas must be very pure.

Gasifier based biomass cook stoves which are basically compact gasifier- gas burner devices have been tried since mid-nineties for cooking applications. Many current design of gasifiercookstove is treated as updraft gasifier. Currently, there were several hundred biomass gasifier cook stoves in operation in countries such as China and India. Gasifier based cooking systems have attractive features which are high efficiency, smoke-free clean combustion, uniform and steady flame, ease of flame control and possible attention-free operation over extended duration [6]. Traditional cookstove in Asian region has the efficiency of 5-15% and the efficiency of these gasifier cookers is in the range of 25-35% [7].

Experiment Apparatus and Setup

Three types of biomasses were chosen for this project, namely oil palm fronds, pressed sugarcane and dry leaves. Photographs of samples of these biomasses are shown in Figure 1. These biomass materials were selected because of their abundance, ease to collect and low cost. The samples underwent indoor drying for two monthsat room temperature and with natural air circulation.The moisture content of each fuel was checked weekly.

(a) (b) (c)

Fig.1:Raw biomass samples: (a) dry leaves, (b) oil palm fronds, and (c) pressed sugarcane

Shown in Figure 2 is the variation of moisture content with time for the three sets of samples.In general, the drying of dry leaves took the shortest time because their low initial moisture and also high area-to-volume ratio. Table 1 shows summary of ultimate analysis, calorific analysis and proximate analysis of the biomass fuels used [8]. Data from these analyses was used as reference data for water boiling tests.A Chemacogasifier based cookstove as shown in Figure 3 was used in this project. The weight of this cook stove was about 23 kg. It consisted of five main components which were an ash drawer, fuel chamber, grate plat, cone and secondary chamber. The stove operated as an upside down downdraft gasifier. The ambient air temperature was 32°C.

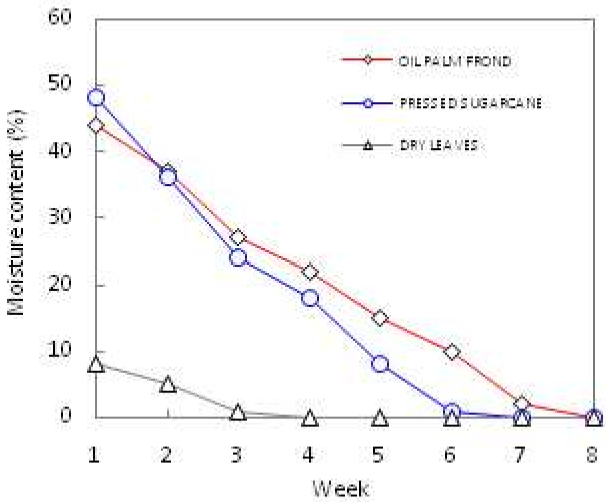


Fig.2:Variation of moisture content with time for different biomass materials

Table 1: Summary of Ultimate Analysis, Calorific Analysisand Proximate Analysis

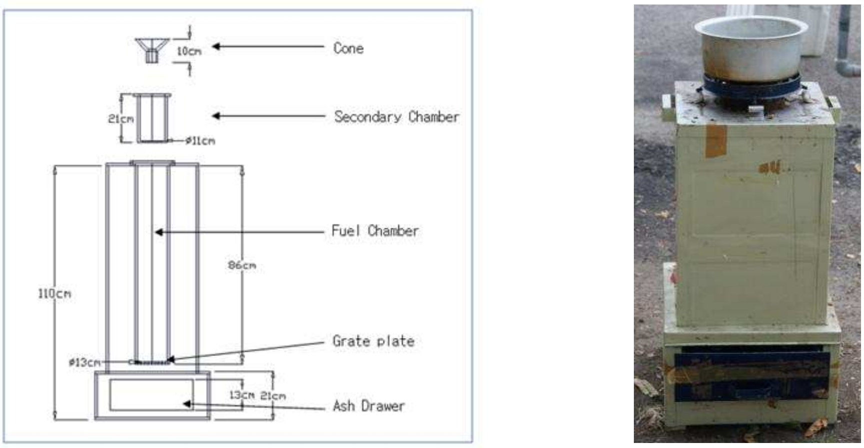
Sample		Pressed Sugarcane	Dry Leaves	Oil Palm Fronds
Ultimate Analysis	% Carbon	43.2	48.2	61.5
	% Hidrogen	5.8	5.3	7.7
	% Nitrogen	0.067	1.719	0.336
	% Sulphur	traces	traces	traces
Calorific Analysis	Calorific Value (J/g)	16,821	19,237	17,787
Proximate Analysis	% Moisture Content	6.0	9.9	3.7
	% Volatile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

The biomass fuel 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'sopening was limited 2 cm and thus limiting the oxygen supply; this changed the process from complete combustion to gasification. The ignition process took about 15 minutes on cold start and 9 minutes if the cookstove was still hot. The resulted syngas was burned at top of the stove. It was observed that the only space for air and syngas to circulate was within the gaps in the biomass feedstock. Therefore, sufficient amount of syngas couldnot accumulate that the flame produced was intermittently disrupted. Only small flame was produced, and hence the long boiling time and low efficiency.

The stove efficiency and other parameters were obtained using the Water Boiling Test version 3.0 [9]. The stove was tested in three phases, namely 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 stove conditions to the stove performance. The simmering phase test was intended to determine the ability of the stove to shift into a lowpower phase following a high-power phase in order to simmer water for 45 minutesusing a minimal amount of fuel.During each phase of water boiling tests the ignition duration, time to boil 2.5 kg of water, and the initial and final temperature of the water were recorded. The water was boiled inside a 22 cm aluminium pot without lid. The efficiency or performance of stove was calculated by:

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

where m_{wi} is the initial mass of water, C_{pw} is specific heat of water, $m_{w,evap}$is mass of evaporated water, m_f is the mass of fuel burned, $T_e$is temperature of the boiling water, T_i is initial temperature of water (28°C), h_i is latent heat of evaporation at 100°C and 105kPa and h_f is calorific value of the fuel measured [10].



(a) (b)

Fig. 3: Chemaco gasifier based cookstove: (a) schematicand (b) photograph

Results and Discussions

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 heat to maintain water temperature inside pot within 6°C from the boiling temperature for 45 minutes after start of boiling. All the three 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. The flame produced was also not continuous. Duration of between 2 and 7 minutes was required to re-ignite the fame. Apart from the poor air circulation problem, the failure was also contributed by the difficulty to control the stove's flame since adjustmentof the opening of the ash drawer was not effective. Adding gas vents and external blower could help to improve stove efficiency, and this could be considered in future work.

It was found that gasification of the dry leaves did not perform well as a fuel since the resultingsyngas was not enough to produce sufficient flame to heat the water. Therefore, the dry leaves were combined with oil palm frond to increase it thermal efficiency. Shown in Table 2 are the results for experiments for high-phase water boiling test.

Table 2: Experimental result of high power tests using Water Boiling Test version 3.0

Phase	Cold start, high power			Hot start, high power		
Fuel	100% oil palm frond (OPF)	Pressed sugarcane	50% OPF – 50% dry leaves	100% oil palm frond (OPF)	Pressed sugarcane	50% OPF – 50% dry leaves
Calorific value (kJ/kg)	17,787	16,821	18,512	17,787	16,821	18,512
Ignition duration	14 min 28 s	16 min 34 s	17 min 08 s	8 min 43 s	8 min 26 s	9 min 16 s
Initial water temperature (°C)	28	28	28	28	28	28
Final water temperature (°C)	98	99	99	99	99	99
Initial water mass (kg)	2.50	2.50	2.50	2.50	2.50	2.50
Final water mass (kg)	2.05	2.16	2.29	2.02	2.15	2.29
Mass of evaporated water (kg)	0.45	0.34	0.21	0.48	0.35	0.21
Time spent to boil water	23 min 43 s	27 min 24 s	18 min 43 s	8 min 17 s	22 min 48 s	25 min 32 s
Total fuel consumed (kg)	1.86	2.24	2.89	1.59	2.16	2.63
Efficiency	5.3%	4.0%	2.3%	6.5%	4.3%	2.5%

Shown in Figure 4(a) is comparison of time to boil water using different fuels. For both cold and hot start, the fastest time to boil water was when using oil palm fronds at 23.7minutes for cold start and 18.3minutes for hot start followed by pressed sugarcane and mixture of oil palm frond and dry leaves. In Figure 4(b) the weights of different fuels consumed to 2.5 kg boil water. It is shown that the least amount of fuel consumed was oil palm frond. This may be explained by its calorific value, which was the highest among the three fuels.

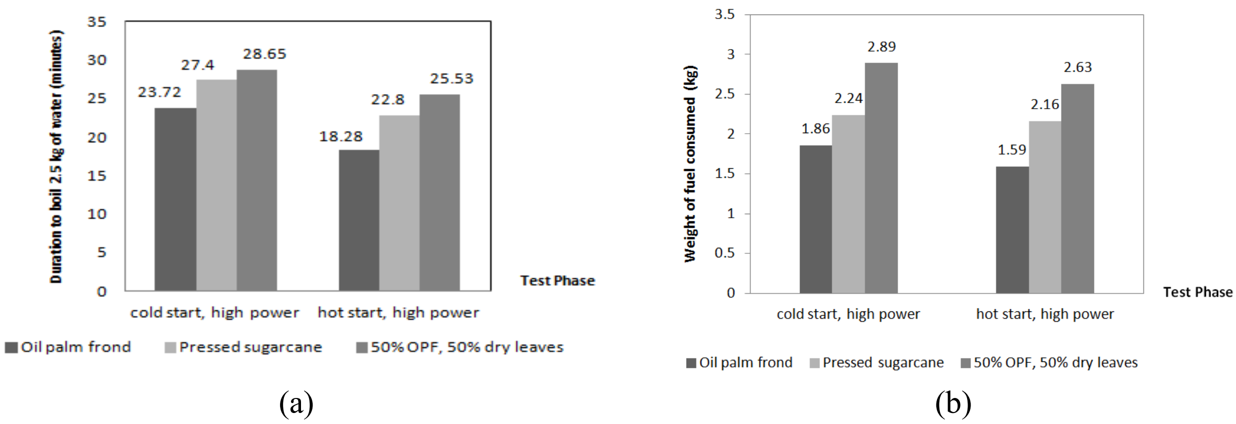


Fig.4:Cookstove performance in boiling 2.5 kg of water; (a) time duration, and (b) weight of fuel consumed

Shown in Figure 5 is the stove efficiency for different biomass feedstock and tests. The efficiencies of the stove range between 2.28% and 5.33% for cold start and between 2.51% and 6.48% for hot start. As shown in Figure 5, oil palm frond had the highest efficiency at 5.33% for cold start and 6.48% 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% [11]. Other similar stoves efficiencieswere in the range of 25-35% [7].The low efficiency of stove in this work was likely to be related to the poor circulation of air due to design factor.

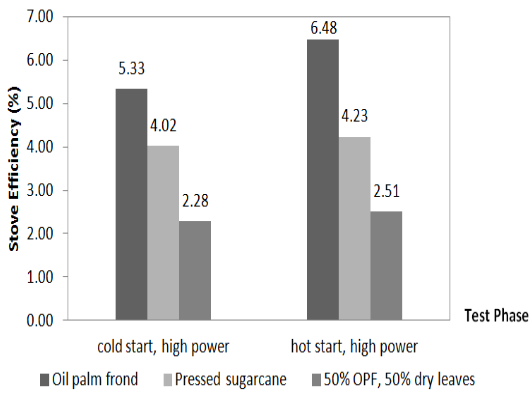


Fig. 5: Stove efficiency for different biomass and tests

Conclusions

The present work attempted to characterize the basic operating properties of gasifier-based biomass cookstove using different types of materials. From this work, the following conclusions can be drawn:

1. Among the three biomass fuels used, the best fuel to be used with Chemaco biomass was oil palm frond with 5.33% for cold start and 6.48% 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 needed to be done to increase its efficiency.
3. The main reason for low efficiency of Chemaco biomass cookstove was proposed to be due the poor air and syngas circulation inside the stove.

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