[Makara Journal of Technology](https://scholarhub.ui.ac.id/mjt)

Volume 21 | Number 3 Article 2

12-3-2017

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Recommended Citation

Faisal, Faisal; Setiawan, Adi; Wusnah, Wusnah; Khairil, Khairil; Luthfi, Luthfi; and Fajriana, Mona (2017) "Experimental Study of the Chimney Height Variation Against Double Pots Biomass Stove Performance," *Makara Journal of Technology*: Vol. 21 : No. 3 , Article 2.
DOI: 10.7454/mst.v21i3.3393
Available at: https://scholarhub.ui.ac.id/mjt/vol21/iss3/2

Makara J. Technol. 21/3 (2017), 109-114
doi: 10.7454/mst.v21i3.3393

Experimental Study of the Chimney Height Variation Against Double Pots Biomass Stove Performance

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Abstract

This research aims to get optimal chimneys height of double pots biomass stove. Optimal chimneys height needs to provide best performance of the stove. Experimental study was done by varied the chimney heights. Water boiling test as the standard method was used to obtained stove performance for each chimney height variation. The results showed that best performance stove was the one with 1.65 cm chimney height, with thermal efficiency at 37.66%.

Abstract

Studi Eksperimental Variasi Tinggi Chimney terhadap Kinerja Tungku Pot Ganda Berbasis Biomassa. Penelitian ini bertujuan untuk mendapatkan tinggi chimney optimum dari tungku biomassa pot ganda. Tinggi chimney yang optimal dapat memberikan kinerja terbaik dari tungku. Studi eksperimental dilakukan dengan variasi ketinggian chimney. Uji pendidihan air sebagai metode standar digunakan untuk mendapatkan kinerja kompor untuk setiap variasi tinggi chimney. Hasil penelitian menunjukkan bahwa kinerja terbaik tungku didapatkan saat ketinggian chimney 1,65 cm, dengan efisiensi thermal sebesar 37,66%.

Keywords: biomass, chimney, performance, stove

1. Introduction

Annual energy needs are increasing with population growth. Overall, almost 95% of its energy needs today met by fossil fuels, whereas fossil energy reserves are very limited and the growth rate of energy consumption is high at around 7% per year [1],[2]. Household is one of the sectors that use a lot of energy besides transport, industrial and commercial sectors. Energy needs for cooking is one of the highest energy consumption in the household sector [3].

The types of energy used for cooking in general are electricity, gas, oil and biomass. Biomass combustion accounts for approximately half of the total domestic energy use in many countries, and as much as 95% of use in the poorest countries. The use of biomass energy for cooking is one type of energy that is still widely used today, especially in rural areas [4].

Biomass energy usage generally is still so simple, not perfect with low thermal efficiency. Cooking by biomassstove is inconvenient and unhealthy; because of the smoke pollution as combustion results filled the kitchen [5]. The reasons why the people still use biomass energy are because they cannot afford to buy fossil fuels and the availability of cheap biomass fuel can even be obtained for free. Cooking with stove that use biomass for most households is aiming to save costs, and it is a tradition that is preferred. Some households prefer to use the stove with biomass energy in running the business because it is more profitable [6].

Some people who have used fossil energy but then switch back to use biomass energy due to the family economic difficulties. There are also many people who initially use biomass energy then switch to fossil fuels because of the economic conditions that are already capable ofand perceptions about social class distinctions that use biomass stove compared with modern cooking utensils. In contrast to the general trend for developed nations to move away from the use of crude biomass toward cleaner fuel sources, evidence shows that biomass fuel use in developing countries is actually increasing [7].

Because of the increasingly expensive price of fossil energy; some countries subsidize the use of fossil energyfor its people. If then more and more are turning to fossil energy, it will increasingly burden the state budget for subsidies [8]. It is also contrary to the government's program to encourage people to use diverse energy in accordance with the existing potential, so it is not dependent on one particular type of energy [9].

One of the ways to enable people to survive cook using biomass energy is to present the biomass stove that is more advanced, efficient, and comfortable as well as does not cause pollution of smoke in the kitchen [10]. Traditional stove that is placed in the kitchen usually exposed to the ambient air so that it has efficient combustion process but less efficient in heat transfers. Smokes as the result of traditional stove which temperature is still high enough for heating process is usually released spontaneously to the air and fulfills the kitchen so that, it needs two flames to heat two pots in the same time. The smokes, even though as the result of perfect combustion process, will also affects one's health [11].

Stove designs will influent the efficiency of biomass combustion [12] and heat transfer [13]. The stove was built with structural wall, which consist of some parts, i.e. combustion chamber; the channel, which redirect the combustion product of hot gas to the pot; and the chimney, as the channel to dispose the excess gas and also emerge natural draft to supply enough air to the combustion chamber. A good combustion process happened if there is an optimal turbulent mixing of fuel and air [14]. Improving heat transfer in the stove is usually done by maximally redirecting the combustion product of hot gas to the pot [15]. Chimney's height affects the natural draft rate, combustion efficiency and stove heat transfer [16]. The accumulation of combustion efficiency and heat transfer will effect thermal efficiency and other performance indicators of the stove. Based on that concerns, it needs to conduct experimental study to test the influence of chimneys height against this double pots biomass stove performance.

The background of biomass cook stove and chimney installation. Stove is a term that refers to a physical structure that serves to cook [17]. The burning process that occurs in the stove produces heat that is then directed towards a cooking target. The stove that produce clearer air combustion, not only indoor but also outdoor, is better and preferred [18].

Such a desirable, a stove provides additional benefits over a regular fire, such as increasing the overall thermal efficiency, reducing the production of harmful emissions, and improving safety [19]. Increased thermal efficiency means to reduce fuel consumption so that consumed energy costs will be lower.

A stove can be widely accepted must have a low enough cost so that people able to afford it. This is an expensive choice in between maximizing usability by optimizing the design [20]. Improving combustion efficiency not only made the stove consumed less fuel but also improved heat transfer efficiency to the pot [20],[21].

Non-governmental organizations in 1970, estimated that the population is increasing rapidly will cause the rate of fuel consumption of biomass (primarily wood from the forest) at a level that is not controllable, it is triggered by the availability of energy is limited, supply and demand are not suitable and poverty. Estimated biomass fuel combustion in 2000 was about 13% of global energy consumed. Most of them was at development countries, where 90% of rural household was still depending on biomass fuel for cooking and heating needs [22].

Unfortunately, most of biomass energy usage on traditionally cooking style was still inefficient, using more wood fuel then needed and caused air pollution. Concerns about the high fuel consumption of biomass that will cause logging and poverty intensified this as the first phase in the era that motivates the socialization improved cook stove and interference forestry policy in growing area [23].

A stove that have a chimney to dispose of exhaust gas from stove is installed in a dwelling or a kitchen [24]. Adding a chimney on wood-fuel stove is a good way [25]. Chimney will redirect the smoke and other emission outside the room and reduce the release of risky pollutant [26]. It had been proved that even for clean combustion stove, without chimney, it will cause harmful air pollution. The concept of chimney usage yielded a stove with clearer combustion and more heat transfer efficiency [27].

A chimney is used to emerge a natural draft, and mathematically relation between natural draft value and chimney dimension had been describe clearly [28]. Natural draft in the chimney emerged because of the pressure gradient that caused by temperature difference in the chimney [29].

2. Methods

Tested stove was double pots stove. First pot was directly on combustion chamber so that, directly received the heat from the combustion. The second pot reused the heat from excess gas flow of combustion before disposed outside through the chimney.

This research was conducted experimentally with statistical analysis. The research was begun by calculate the fuel humidity. Humidity is water vapor percentage contain by the fuel based on wet weight. Fuel humidity needs to know for concerning the caloric value of wood combustion.

Water boiling test methods then tested on the stove [30]. Water boiling test was conducted to obtain the performance of the stove based on varied height of the chimney. Water boiling test consist of high and low power. High power divided to cold start and hot start, while low powercalled simmer. Every stage involved some measurements and calculations. The variations of the chimney were 1.10 m, 1.45 m, 1.55 m, 1.65 m, and 1.85 m. The test was repeated three times for each chimney height.

The data obtained was then analyzed statistically to show stove performance for each condition and variation of the chimney height. The result obtained was then compared to get optimum chimney height for the best stove performance.

The height of chimney influence the draft inside the chamber and automatically affect the flow rate of air supply for the stove as well as combustion efficiency.

$$Q = C\,A\sqrt{2gH\frac{Ti\text{-}Te}{Ti}} \qquad (1)$$

Equation (1) explains relationship between the air flow rates (Q), height of chimney (H), temperature difference and chimney cross-sectional area (A) where T_i and T_e are respectively inlet and outlet temperatures of the chimney and C is discharger coefficient (0.65-0.70).

The amount of energy consumed at any variation of chimney height was calculated based on the amount of wood burnt (f_{cd}) multiplied by wood low heating value (LHV). Calculation of mass of wood burnt was made by considering the amount of energy required for releasing water vapor contained in the wood fuel and unburnt fuel. Equation (2) is used to calculate the mass of wood required for each tests.

$$f_{cd} = f_{cm}\, x\big(1\text{-}(1.12\ x\ m)\big)\text{-}\ 1.5x\,\Delta C_c \qquad (2)$$

Where f_{cm} is the mass of wood consumed for boiling the water which is the net between the initial weights of wood and the wood left after the test. The factor of (1-1.12 x m) is the mass of wood required to heat and vaporize m x f_{cm} grams of water. Assuming to heat up one kg water requires 2260 kJ (approximately 12% of caloric value of dry-wood), the effective amount of wood needed for heating the vessel is deducted by the factor by 1-1.12 x m the energy to boil the water is accounted differently.

A factor of 1.5 x ΔC_c is used to estimate the rest of energy left from unburnt char. Approximately, one and half of caloric value is equal to caloric value of char. Therefore, to estimate the unburnt char, the amount of heat required for heating-up the vessel is equal to 1.5 x ΔC_c:

$$\Delta C_c = C_c - k \qquad (3)$$

Where ΔC_c is the mass of char formed during the test. This is determined by separating carefully between unburnt char and ash after ending the test. There was a heat resistant vessel provided to collect hot-unburnt with the mass of vessel of k.

Measurement of fuel moisture. Initial testing conducted to obtain preliminary data on the moisture content of wood fuel as shown in Figure 1(a). The sample was weighed to obtain initial weight. Scales used to weigh the sample timber was scales with a precision of 0.001. The fuel used for this study was the pecan wood. Pecan wood is also commonly used to make a match and is also used as firewood with a calorific value of 21 840 kJ/ kg.

After the initial wet weight of the sample was measured, and then put in the oven. The oven was used for the drying process is the type Memmert oven to 250 ^{o}C temperature range. The process of drying in an oven to determine the moisture content was carried out with a constant temperature of 109 ^{o}C, as shown in Figure 1(b). The percentage of water vapor contained in the fuel timber by wet weight was 13%.

(a)

(b)

Figure 1. (a) Wood Samples and (b) the Drying ProcessUsing the Oven

Testing procedure. Stages of the boiling water test consisted of preparation, testing and data collection. The first preparation was the provision of wood fuel. Long and cross-sectional dimension of the woods has been made uniform. Average dimensions of this solid fuel were 50 cm in length and 10.35 cm^2 in cross- sectional area. Woods were dried and the humidity ensured uniform. Wood weighed and then tied with a fixed amount of mass that is easy to use and calculated mass amounts of used test of time. The woods were then wrapped to ensure moisture does not change due to environmental influences when stored.

Preparations were also made to the initial combustion materials (trigger) for the flame. The selected materials were kerosene and dried palm leaves. This material was chosen because the materials are normally used by the public when cooking using biomass stove. Next was to fill water into both of pots. Water is the medium that used as the material being cooked, where the energy is used to boil it. The amount of energy absorbed by the water is the amount of useful energy. The amount of energy absorbed by the water can be calculated based on sensible and latent heat. The amounts of useful energy were used as a parameter for determining stove achievement.

Next preparation was the installation of measuring devices on the stove to be tested. Installation of the measuring instrument was to determine the number of parameters as shown in Figure 2. Digital Thermometer (thermocouple) used to measure the temperature of the water in each pot, the ambient air temperature and the exhaust through the chimney. Scales were used to measure

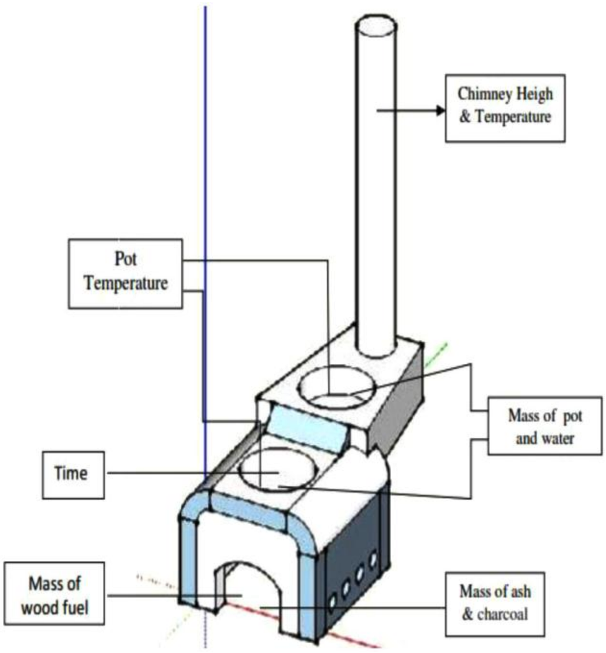


Figure2. Schematic of Double Pot Stove and the Measured Parameters

the mass of the fuel used in any combustion process, charcoal, water and mass of the pots. Mass of the fuel consumed was multiplied by the caloric value is the amount of energy supplied to the system. The amount of energy given the other parameters required to determine the performance of the furnace system being tested. Stop Watch was used as a counter of time. The tool used to determine the length of time was needed to heat water on the stove being tested.

3. Results and Discussion

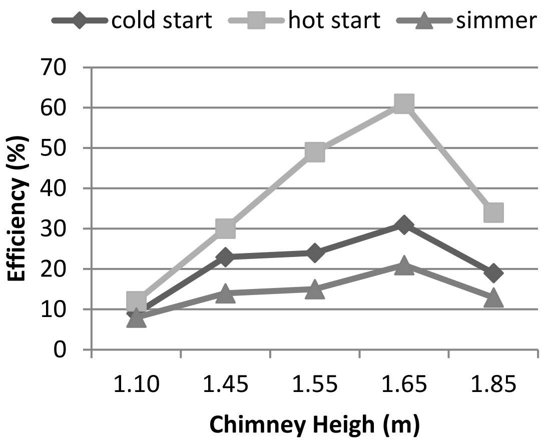
The variables observed in this study were time to boiling of pot 1, the rate of combustion, thermal efficiency, specific fuel consumption and fire power. Based on the achievement variable stove relationship to the chimney height variation is expected to be obtained optimal high chimney for the stove.

Effect of chimney height variations to stoves performance and water boiling time in pot 1. Stove performance can be known through the value of efficiency. The greater efficiencies gained the better of the performance of the stove. Changes of the efficiency of the chimney height variation are caused by air natural draft rate. Increasing the value of the air natural draft is caused by differences in air temperature in the chimney flue gas with ambient temperature around the chimney.

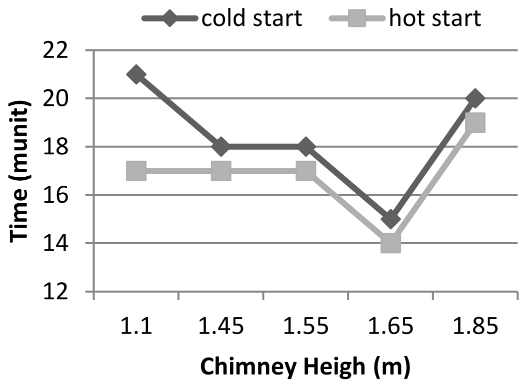
Figure 3(a) shows the efficiency of the stove data analysis on the condition of cold start, hot start and simmer for every chimney height variation. An increase in hot start conditions is caused due to the early heat generated from the combustion directly heats the pot, so the time taken to boil the water is not too long and the fuel consumption is not much compared to the cold start conditions. The decrease in efficiency on the simmer condition was lower than cold start conditions, because of the amount of fuel consumption and the length of time for maintaining the temperature of boiling water.

Figure 3(a) shows the continued improvement of the efficiency of each height of the chimney starting at 1.10, 1.45, 1.55 and 1.65 m. Stove testing with chimney height of 1.85 mwas decreased in efficiency. The decrease is happened because the natural draft air is too large, so the heat generated cannot be used to heat the pot and took a long time to boil water and the amount of fuel consumption. Best stove efficiency was shown at a height of 1.65 m chimney.

In pot 1, the time required to boil water with hot start conditions was faster than in cold start conditions. In conditions of cold start, the stove walls are still in a state of cold so the initial heat produced by burning directly absorbed to the walls of the stove, while in the condition of the hot start, wall of the stove has absorbed the heat so that the heat of combustion in the combustor directly heat the pot, as shown in Figure 3(b).



(a)



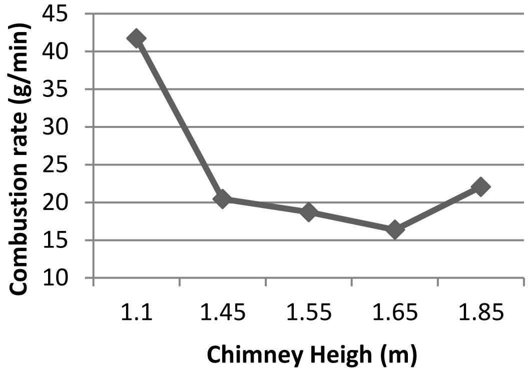
(b)

Figure 3. Graph of (a) Efficiency & (b) Water Boiling Time in Pot 1 to the Chimney Height Variation

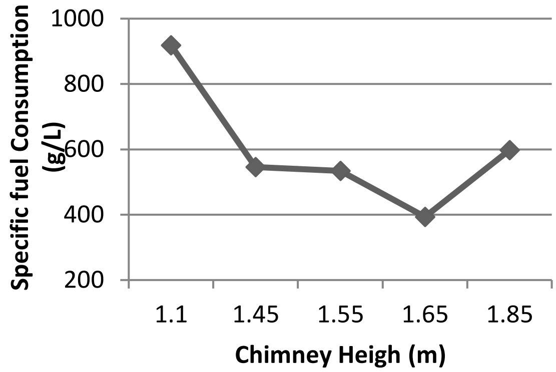
Effect of chimney height variations to combustion rate, specific fuel consumption and fire power. Figure 4(a) shows the average of combustion rate to the chimney height variation. Combustion rate is a measurement of the rate of consumption of wood to boil water. At the height of the chimney 1.65 m, fuel consumption and the time required to boil the water were not too long, resulting in a decrease in the rate of combustion.

Specific fuel consumption is amount of burning wood and unburning coal needed to vaporize the water. Figure 4(b) shows specific fuel consumption average against chimney height variation. More efficient the stove against the chimney's height, the lower specific fuel consumption.

Fire power is the comparation of wood energy consumed by the stove per second. The more fuel and time needed for boiling the water, the more fire power produced. Figure 4(c) shows fire power average produced by the stove based on chimney's height variation.



(a)



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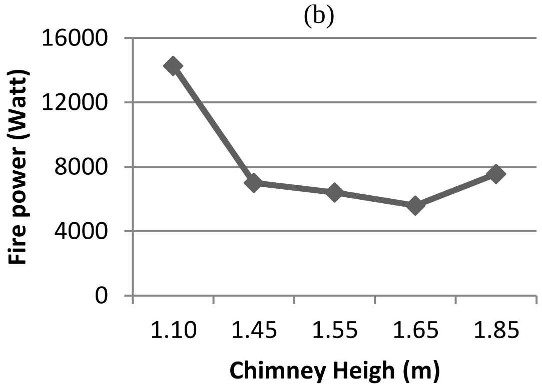

(c)

Figure 4. Graph of (a) the Average of the Combustion Rate, (b) Specific Fuel Consumption & (c) Fire Power to the Chimney Height Variation

Table 1. Chimney's Height for another Diameters

Chimney's height (m)	Surface area (m^2)	Diameter (cm)
26.23	19.62	5
6.82	38.46	7
2.00	90.25	9.5
1.34	86.54	10.5
1.12	94.98	11

The relation of chimney's height to diameter. Optimal chimney's height on this biomass stove was 1.65 m, with 10 cm diameters. On that height, chimney's draft resulted was 280.79 m^3/sec. Average temperature at the bottom of chimney was 265 °C and ambient temperature was 32 °C.

If 1.65 m chimney's height unfitted with the kitchen room, based on dimension and chimney's temperature correlation, chimney's height for another diameter can be calculated, as seen at Table 1. It was shown that the smaller the diameter, the higher the chimney, vice versa.

4. Conclusion

Based on the comparation of double pot biomass stove performance against the chimney's height, we concluded that the stove best performance, with 37.66% maximum efficiency, was at 1.65 m chimney's height. Natural draft resulted by the chimney had been successfully used for maximized the stove efficiency by utilizing excess gas heat potency on pot 2. The chimney dimensions are adjustable to the kitchen room size to get the same optimal natural draft as 1.65 m chimney.

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