11-Performance improvement of biomass

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Journal of Physics: Conference Series

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Performance improvement of biomass combustion-basedstove byimplementing internally air-distribution

Performance improvement of biomass combustion-basedstove byimplementing internally air-distribution

J P Simanjuntak[1], E Daryanto[1], Baharuddin[1], B H Tambunan[1]

Mechanical Engineering Department, Universitas Negeri Medan, Medan 20221, North Sumatera, Indonesia

Corresponding author: janterps@unimed.ac.id

Abstract. This research aimed to enhance the performance of biomass combustion-based stove. Thermal performances were assessed in terms of power output (P_{out}), specific fuel consumption (SFC), thermal efficiency (η_{th}), and burning rate (BR). These performances were expected to meet the minimum standards established by the Indonesian biomass stove alliance regarding the use of a healthy and energy-saving of biomass stove in Indonesia. The stove tested was an improved stove with an advantage on the air distributor by adding a component to administrate air combustion needed placed on the centre of the combustion zones. This is a very effective way to distribute air for combustion required where the air could reach all the fuel and the combustion product that occupy entire the combustion zones to ensure high combustion zone temperature. Coconut shell was used as feedstock. This biomass was found abundant in Indonesia and was widely used as heat source by burning it directly. The coconut shell was sized uniformly about 5 cm x 5 cm, dried by utilizing sun energy. To estimate the stove performances, several combustion tests was carried out where the air flow rate into the stove (Q_a) and the amount of biomass fuel (m_b) referred as the air–fuel ratio (A/F) were considered. The Water Boiling Test (WBT) was performed to assess this improved stove. Parameter required such as initial mass of coconut shell, the mass of residual ash, the initial mass of water, mass of water after boiling, and the time required to boil as well as combustion flame temperature were recorded and used to determine the performance of the improved stove studied.

1. Introduction

Today and next 50 years, it is estimated that the world's energy resources is still derived from fossil fuels. Natural gas is still classified as the most practical, economical, affordable, clean, not corrosive, abundant and environmentally friendly so that its utilization is very widespread included in the electricity generation. However, about 35% of the world's population is currently using biomass for everyday energy sources for cooking and heating. This happens because there are still many remote areas which have not been connected to the electricity network, fuel oil, and gas.

It is undeniable that the fuel and gas price will continue to increase causes the people in the rural prefer to use alternative fuels, especially biomass. This amount will be increased by 2030 which will be almost half the human populations in the world using biomass as an energy source [1], and each family will need 2 tonnes of timber each year for cooking and heating purposes [2]. The timber can easily be obtained primarily by exploitating the forest.This will causes negative impact due to the importance of the forests to maintain the environmental system balance, especially to prevent global warming.

Biomass is usually burnt directly to obtain thermal energy, but this will greatly affect the human environment over a long period of time. Carbon dioxide (CO_2) as a result of combustion reactions will be detached into the atmosphere and may interfere with the human respiratory system. Sometimes carbon monoxide (CO) is also formed due to an imperfect combustion process and this CO is also one of the deadly pollutants [3].

Until now, the development of biomass combustion technology known as improved stove continuous to evolve. The improved stove hoped to reach the complete combustion and expected high performance at least near the performance of the stove using LPG or kerosene. However, complete combustion is theoretically possible, in reality it is not, mostly due to heat losses through carbon unburnt, pyrolisis product that leaving the stove before undergo combustion due to insufficient of air or even air flow prohibitive.

Usually, the biomass is burnt by utilizing ambient air as the oxidator. Ignoring combustion air requirements will produce emission gases and also smoke that is very bad for the user's environment. In addition, the heat energy generated from the fuel is not maximum and waste alot of fuel. The loss of heat energy from the stove is also yet taken into account so that it takes a lot of fuel only for a certain purposes. Traditional combustion method in open air using three–stones is very inefficient, low performances, and degrades air quality. The efficiency of a traditional three–stone stove typically ranges from 5% to 17% [4].

Combustion of biomass using atmospheric air becomes uncontrolled due to the instability of air flow around the stove. Sometimes, the air flow could be weak and could also too rigorous that can extinguish the fire because the air needs for combustion in accordance theoreticlly. Combustion process at near stoichimetric conditions achieve perfect combustion process with high thermal energy production and achieve efficiency estimated to be 20-30% [5]. Consequently, the temperature in the stove can be maintained during the proses.

According to previous research that the problem described can be solved by improving the air distribution in the combustion zones [6]. Using an internal air plennum looks like to be an effective way where this method allows for a good mixing between solid fuel and all the combustion products and the air in combustion zones. The most important is that the air could occupy entire the stove and prolong the reaction where the unburt carbon and the volatiles undergo complete combustion before leaving the stove. Air velocity into combustion zones need to be reduced to avoid particulate carry over. This is could be performed by implementing the internal plennum instead of single primary air distributor placed on the bottom of the stove and the secondary air at the top porson of the stove.

2. Literature study

Long time ago, to obtain energy from solid fuels especially biomass is carried out direct combustion. Biomass is collected, dried and burned using simple appliances often referred to stoves. The stove is very simply, i.e. three–stone with pan holder where an objects to be heated [7]. At that time the efficient combustion was not yet known and the combustion process was also very simple. The combustion process is carried out in an open area by utilizing the surrounding air as oxidizing. This makes the combustion process imperfect and produces alot of pollutant gases as well as fine particles that are very bad for health. Besides, the fuel wasteful, this stove also takes a relatively long time to boil at certain amount of water. The performance of this stove is also low with an efficiency of 5–10%, having the ability to boil water about 21.7 minutes, spending solid fuel of approximately 852 grams [8].

The combustion process using stove began to be known in the 1980 's, but the ability problem was not important. Until the 1990's began to learn the materials from the clay and sand, until the use of the chimney to overcome the problem of pollution. In improving stove capability, the knowledge of heat transfer also began to be considered until in the early 2000 robust stove material and heat transfer began to be taken into account.

Journal of Physics: Conference Series **1811** (2021) 012015 doi:10.1088/1742-6596/1811/1/012015

Developing a biomass burning stove refers to two things, namely designing a new stove or analyzing and evaluating the performance of existing stoves with the design of the already developed fiture. Combustion is the most important part of design and development and performance enhancement of stoves. Usually the performance is tested in two important things, the performance is thermally or often referred to as the performance of the stove and the emission factors caused. Thermal performance is measured in terms of power output equivalent (kWe), specific fuel consumption (SFC),and thermal efficiency (η_{th}) [9].

The final goal of a combustion stove development is to achieve minimal fuel usage for a particular purpose that will impact fuel efficiency and pollution effects in the level of recommendation. The thermal efficiency of biomass combustion is within 21–25% and might decrease in pollution when efficiency increased more[10]. Even Suresh et al. (2016) can increase the efficiency in the range of 30% to 37% [11]. Especially in the combustion method, researchers continually strive to perform and elevate the combustion process until it approaches the complete combustion. The combustion process perfectly produces maximum heat and reduces the emission gases. Some researchers study the combustion of biomass in the combustion stove to obtain an efficient stove

Raman et al. (2013) [12] evaluates the combustion of biomass in a combustion stove and tests several types of biomass as fuel. They tested and evaluated 3 pieces of forced air model stove with two types of biomass to determine the efficiency of the stove. Especially for coconut shell biomass, they found that the type of stove with a primary air supply at the bottom of the stove and a secondary air at the top of the stove can increase combustion efficiency. This occurs because with the presence of secondary air, the combustion process of pyrolysis occurs perfectly with the availability of oxygen from the secondary air.

The perfect combustion of biomass can acchieve temperature of 700 ^{0}C, so large chances of heat energy will disappear through the stove walls. With the technology related heat transfer, this problem can be solved. O'shaughnessy et al. (2015) [13] conducted a study of 5 small–scale biomass stove to produce electrical energy using thermoelectric generators (TEG). 3Wh of electrical power can be produced by utilizing the wasted heat energy from the stove walls. Vicente, et all. (2015) [14] conducted a study of 5 types of biomass in terms of emissions produced during the combustion process. They found that the biomass type also greatly affects the emissions and fine particles produced. In line with Vicence, L'orange et al (2012) [15] also investigates several types of stove and operating temperature used in the case of producing fine particles. They concluded that different stove designs would produce different fine particles. They also conducted a study of parameters against the biomass stove to determine which important parameters in the design and operation of a biomass stove. Ahiduzzaman and Sadrul (2013) [16] also conducted research on the combustion stove by using rice husks formed into briquette as fuel. They managed to optimize the stove to produce electricity energy of 6 kW.

Studies on improving efficiency of the stove are also developed continuously. Febriansyah et al. (2014) [17] conducted research on the efficiency of a biomass combustion stove of palm kernel shells. They managed to obtain a stove efficiency of 66.63% with a primary focus on the amount of air intake into the stove. With the opening of the 100% air control, they gained the highest stove efficiency. This occurs because the combustion process can approach stoichiometric with adequate air needed. Low efficiency of the stove results pollution by fine particles and smokes. Response to this, some researchers have conducted the study due to adverse effects of biomass stove. Michael et al. (2013) [18] conducted research on the influence of biomass use to produce heat energy against population settlements. Semmens et al. (2015) [19] also conducted research on environmental quality due to the influence of biomass usage.

Research on biomass combustion based stove is also widely conducted. It is known that this stove is very practical to produce thermal energy. Murrary et al. (2012) [20] conducting investigations on the emissions incurred when using briquette fuels. They found that CO, NO_x, and SO_2 are the most widely produced pollutant components. It has been informed by Vicente et al. (2015) [21] and also Suresh et all (2016) [22, 23] that the performance of the stove is highly depend on the availability and

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distribution of air combustion requirements entire the combustion zones. Performance of the stove should be improved to increase its efficiency and to reduce negative impact such as air pollution of carbon monoxide (CO) and fine particles. One of the way is to enhance the combustion process by suppling adequate of air for homogenous mixing of air and combustible gases to achieve complete combustion[24-26]. Some researchers tried to make modifications to the stove related to combustion air supply [27]. Combustion with a model of natural–draft has a weakness where the air intake is not continuous due to the accumulation of pressure in the stove. This resulted in bad mixing of the gas and oxygen to become imperfect, resulting in a discontinuous burning that can be seen on an uncontinuous flame

3. Materials and method

Improved stove prototype diagram with the advantage on the air distribution can be seen as shown in Figure 1. This stove is a cylindrical form made of iron plate material 0,5 mm thickness, fabricated in mechanical engineering faculty workshop, Universitas Negeri Medan. Two different cylinders in diameter are arranged concentrically. The outer and inner cylinders have diameter of 30 cm and 10 cm respectively. The inner cylinder on Fig.1 (b) acts as air plenum with the holes drilled equidistance along its wall with diameter of 1 cm. Space between the outer and the inner cylinder act as the combustion zones. The total height of the stove is 40 cm.

A small blower is used to supply air for combustion needed. The air flow rate is adjusted through an air control system and is measured using anemometer. Coconut shell is used as feedstock where this material is most widely used for cooking purposes. This biomass consist of 54.52% carbon, the rest are ash or other chemical objects [12]. Coconut shell is very easy to obtain because there are many household industries such as bakery industry where using coconut in bakery ingredients and produce coconut shell as waste. Water Boiling Test (WBT) version 4.2.3 [21] was applied in four replications. This procedure was frequently used by other researchers and designed principally to evaluate cook stoves performance.

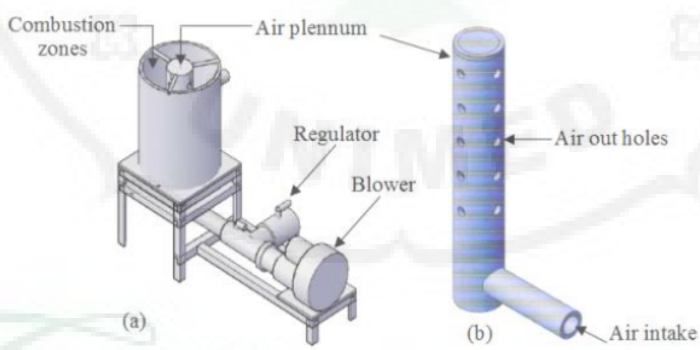

Figure 1.(a) Improved-Stove prototipe test-rig diagram, (b) internal air plennum

During the experiment, the temperature of the combustion zones is detected using a K– type thermocouple and displayed using a digital thermometer reader. Once the operating temperature is reached, the experiment begins and the operationg parameters are prepared. Amount of weighed coconut shell (m_{fuel}) and air flow rate (Q_u) are introduced into the stove according to the required air–fuel ratio (A/F). Performance parameters calculated for each A/F were thermal efficiency (η_{th}), firepower (kW), specific fuel consumption (SFC), and burning rates (BR). These parameters were calculated by using correlations found from several literatures[11-13, 15, 28-30]. The graph in **Error! Reference source not found.** shows the relationship between the fire power and the water time to boil using biomass as fuel theoretically. The mass of water and fire power greatly determine the time needed for boiling. Short time to boil at certain mass of water need high fire power. The more mass of water further, the more fire power requirement for certain time to boil.

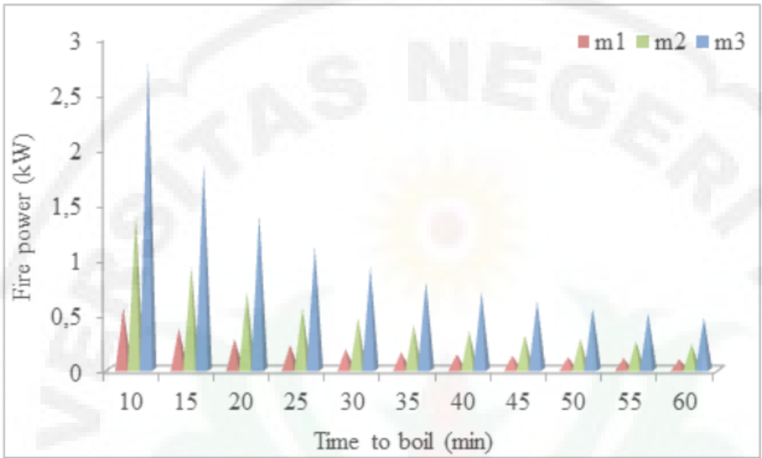

Figure 2. The relationship of fire power and time to boil of a biomass stove

Specific fuel consumption (SFC) is the ratio of fuel burnt during the WBT to the rest of water in the pan. This parameter is also an indicator used to determine the stove performance. The SFC found in this reseacrh in accordance to Indonesian standar biomass stove or Tungku Sehat Hemat Energi (TSHE) where the SFC = 1 kg/hr [31]

4. Results and discussion

In this study, the performance of the stove with an internally air distribution method measured with WBT cold start test were discussed comprehensively. Some of the stove performance parameters discussed as follows:

4.1 Effect of (A/F) on the temperature

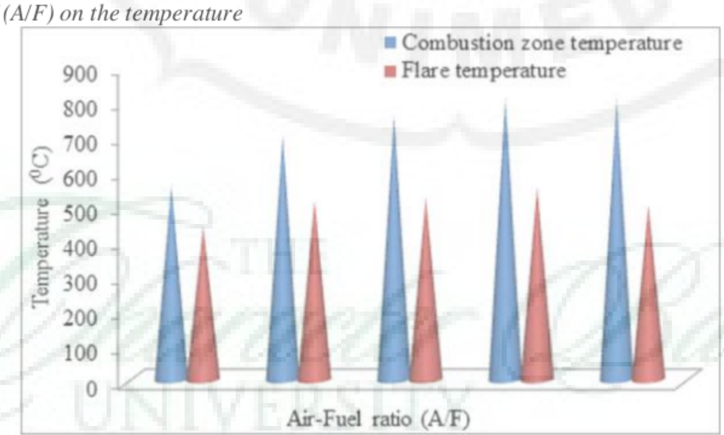

Figure 3. The effect of A/F on temperature

In a combustion, the main goal is to attain the temperature as high as possible that can be seen on the temperature indicator in the combustion chamber. The effect of A/F on the temperature in the combustion zones and the fire temperature as shown in Figure 3 below. It can be noted that the temperatures increased with A/F at certain extend, after that the temperature decrease slowly because by increasing air intake further, there will increase the nitrogen component also that dilute the fire caused the temperature decrease. The highest temperature obtained about 810 ^{0}C and 550 ^{0}C for combustion chamber and the flame respectively at A/F approximately. This finding is fairly good because the burning temperature is usually in the ranges 700–1400 ^{0}C [32], and typically the flame temperature about 500-650 C [33].

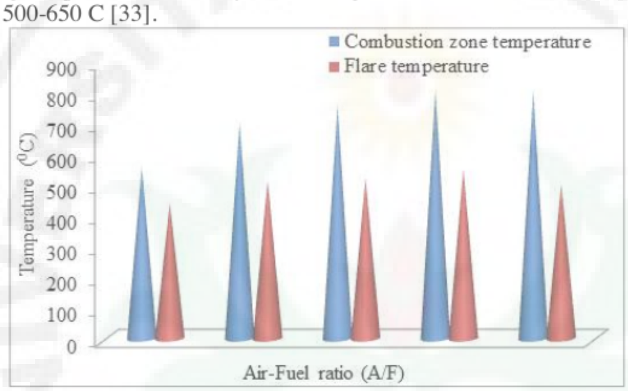

Figure 4. Effect of A/F on the temperature

4.2 Effect of A/F on the boiling time

The water boiling time depends on the amount of heat energy released that can be transferred to the water. The graph in **Error! Reference source not found.** shows the relationship between the A/F and the boiling time (min). It can be seen that the boiling time decreased with A/F. This is because the combustion have approached stoichiometric state by increasing the amount of air. About 10 minute is needed to boil 5 kg of water at the right A/F. This finding is good compare to the traditional stove where spend about 21.7 minutes to boil 1 kg of water [8]

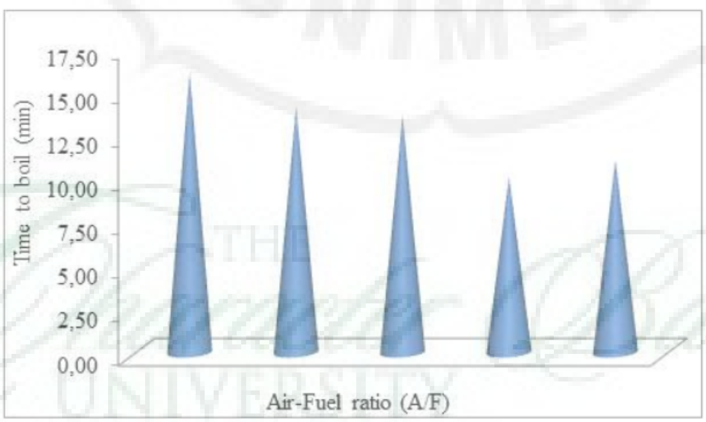

Figure 5. Effect of A/F on the boiling time

4.3 Effect of A/Fon the specific fuel consumption

The term specific fuel consumption (SFC) that indicates the amount of fuel used during experiment refer to Baldwin in Sutar et al. [7]. In this study, the SFC found ranges from 1.5 – 2.52. This value does not meet to the Indonesia's standard for biomass stove or Standar Nasional Indonesia (SNI) where the SFC is about 1 kg/h [31]. However, in this work, it's proven that the improved stove mainly intended to reduce the fuel utilization. By introducing adequate A/F, the fuel utilization goes to minimum level as shown in

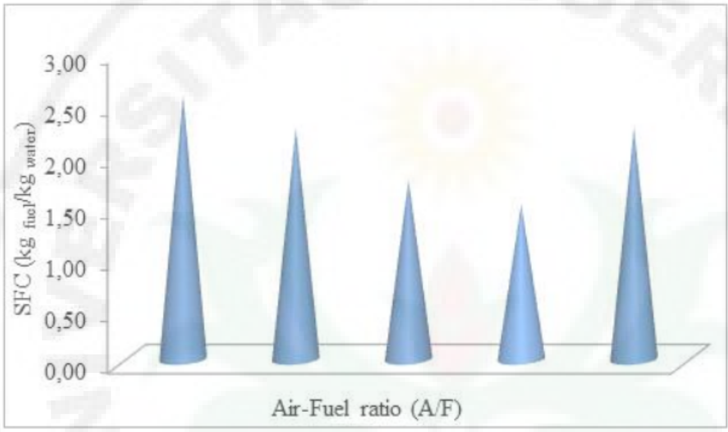

Figure 6. Effect of A/F on SFC

4.4 Effect of (A/F)on the thermal efficiency

Thermal efficiency is the amount of useful energy that can be transferred to water until it reaches boiling point assuming there is no energy loss. If the energy loss is very small then the heat efficiency of a stove will be high. An improved stove can achieve efficiency of up to 35%. By controlling air flow rate into combustion chamber wil lead to increase the thermal efficiency [34]. In this research the highest efficiency achieved is about 25%, after that decreased when A/F is raised. This is supported by Jain, et al. (2019) [30] stated that the stove efficiency decreases against airflow rates. This efficiency is higher compared to the stove studied by Parmigiani et al. (2014) [27], where they found efficiency of the stove using rice husk of averages 18%. However, this finding is very close to results found by Gogoi, et al. (2016) [35].

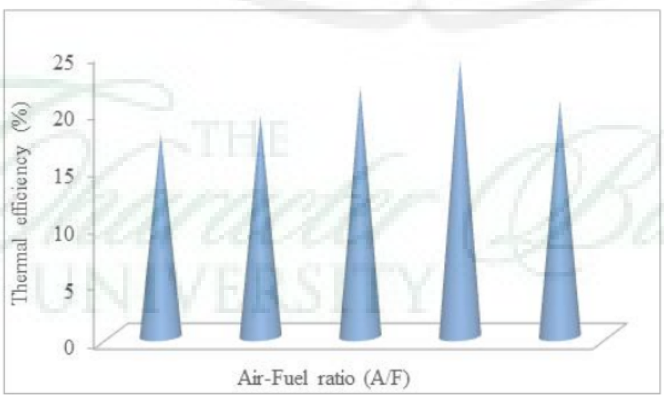

Figure 7. Effect of A/F on thermal efficienfy

4.5 Effect of A/Fon the burning rate

The burning rate pointed how quickly the fuel can burn in the stove in kg/hr. The combustion rate can differ from each stove according to its design and geometry. It was found that the burning rate increased with A/F as shown in **Error! Reference source not found.**. This result is in accordance with the study conducted by Jain, et al. (2019) [6, 30] where the burning rates linierly proportional to the air flow rate. The low burning rates result in relatively longer boiling time. However, high burning rates also does not guarantee to rapid boiling time, because by increasing A/F, the amount of air increased together with nitrogen that extinguish the fire. Thus, an optimum operation of air flow rate is needed to operate the stove effectively.

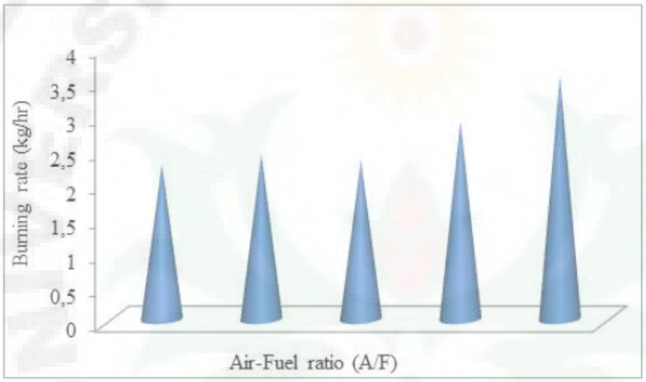

Figure 8. Effect of A/F on the burning rate

4.6 Effect of A/Fon the fire power

Stove power is an indicator of the ability of a biomass stove releasing heat during burn periode in a unit of kilowatt (kW). Refer to Fig.1 that the time needed to boil depends heavily on the fire power resulted by the stove. Theoretically, to ensure complete combustion required minimum amount of combustion air, and even have to supply excessive air to burn the rest of both carbon and gas products before leaving the stove. Results of this study explained that the power increase with A/F and then decrease caused by overmuch nitrogen in the air by increasing air flow further. This result in accordance with Indonesia's stove standard about 2,5–5 kW [31].

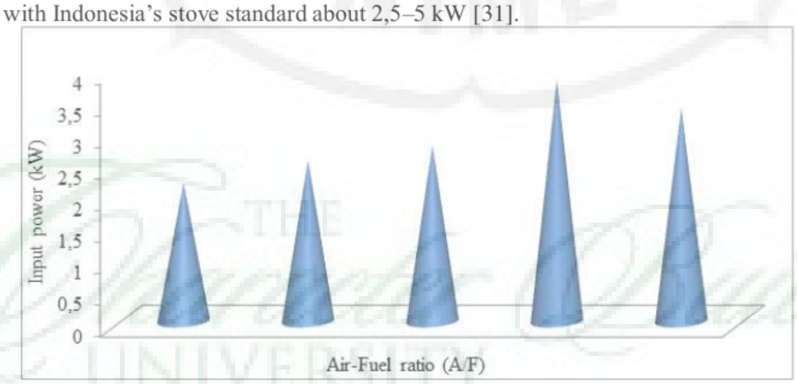

Figure 9. Effect of A/F on the fire power

5. Conclusion and future work

The improved cook stove with an advantage on air distribution performance study has been conducted. The study revealed that by introducing internal air plennum to equally distribute required air for combustion lead to improve significant the stove performance. Theoretically that the high performance lead to decrease the pollutan. However, the impact of internal air plennum on pollution is not yet evaluated. It is sugested to assess this condition to avoid a negative impact on the end user.

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Acknowledgements
The authors would like to acknowledge the Universitas Negeri Medan for financial support through DIPA with Contract Number 292D/UN33.8/PL/2019. The authors highly acknowledge support from mechanical engineering workshop members, and two final project students for their participation and contribution to this project.

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