Technical Parameters Study of Coconut Shell Combustion as Heat Source by Using Fixed-bed Type Incinerator

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Abstract. The purpose of this study is to exploit the thermal energy of coconut shells via combustion. Coconut shell average size was maintained, whereas the flow rate of air requirements was varied to meet the equivalence ratio (ER) for combustion. The desired output is the highest average temperature of the product gas that can be achieved. A static grate packed-bed was used as the incinerator. The air is supplied from the bottom of the incinerator, under the grate by a 263 m^3/h of ring blower and monitored using a floating type air-flowmeter. The air flow rate was manually adjusted using air regulator valve. K-type thermocouples are used to detect temperatures inside the combustion chamber as well as the temperature of combustion gases at the cyclone exit and are visualized by utilizing a thermocouple reader. Experimental data showed that with the average size of the coconut shell (10 x 10) mm reached the highest temperature at primary combustion chamber of about 800 ^oC with product gas output temperature of about 390 ^oC at an equivalence ratio (ER) of 5.56.

Keywords: Coconut-shell, Incinerator, Combustion, Air-fuel ratio

1. Introduction

The exploitation of energy from solid biomass include coconut shells through the thermochemical process has been done for years. For instance, the coconut pyrolytic oil mixed with diesel fuel can be used to fuel internal cobustion engine [1]. A thermoelectric can also be employed to generate electricity by adsorbing heat of biomass combustion [2], [3], [4]. Indonesia posses abundant of biomass where thermochemical process can be an exat choice. One of them is combustion as an addition to gasification that can generate producer gas of about 3 MJ/m^3 by employing a simple downdraft reactor [5]. The energy contained in the coconut shell, which is still in the form of chemical bonds, can be converted into thermal energy, then it can be utilized as an energy source to produce electricity [6], [7]. Biomass can be burned in either stationary or moving grate packed beds [8]. Such combustion apparatus must be designed, operated, and maintained with a thorough understanding of the bed's burning process. The combustion technique using grate is the oldest, simplest, and most flexible because of the range of biomass fuel sizes used, ranging from small to large sizes. However, the limitation of this

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technique is in the production of thermal energy of 150 MWth, which is smaller than the fluid-bed and pulverized-bed techniques, which are able to produce thermal energy up to 300 MWth and 600 MWth, respectively.

Compared to incineration of packed bed type using wood-logs as feedstock, utilizing coconut shells is more suitable because there is no need to carry out treatment of the coconut shell size. Coconut shells already have a uniform size compared to wood which requires a machine to the size uniformization process before being used as feedstock. The collection and transportation of coconut shell biomass is also more efficient compared to another biomass. Another advantage is that incinerator units can be brought to locations where coconut shell sources are found to be abundant and their availability meets. In addition, it will create jobs for local residents. A biomass combustion unit usually requires units such as for treatment, handling, and transportation. However, the limitations of the equipment require the use of coconut shells as fuel without reducing the size.

This study examines the combustion of coconut shells to produce thermal energy contained in combustion fumes, which can then be used to generate electric power through a Rankine or organic Rankine system. A packed-bed type with a static grate incinerator is used to study the combustion characteristics of coconut shells. The temperature that can be achieved is used to study combustion performance. The size of the coconut shell is kept constant while the combustion air flow rate is varied to determine the exact ER required for complete combustion.

The use of biomass, including coconut shells as an energy source, has existed long time ago by burning. Tools that can be used such as conventional furnaces, incinerators, and boilers. Biomass absorbs CO_2 from the air and discharges it back during the combustion process, so biomass is called an environmentally friendly fuel because it is considered not to contribute to the addition of CO_2 emissions in the atmosphere. Therefore, until now the investigation into energy from biomass is developing rapidly, is widely researched, and has a bright future as stated by Mao, et al. [9]. During the combustion process, the temperature of the combustion gas product can reach 800-1200 ^{o}C, accompanied by the release of thermal energy [10]. The resulting thermal energy can then be converted into electrical energy through thermodynamic cycles [11], or it can be stored in the form of hot water for domestic use [12]. The potential thermal energy or heating value of 22.02 MJ/kg in the coconut shell can be exploited to the maximum by carrying out the right combustion process [13].

Knowing the optimum conditions in an incinerator is the most important thing. Many things can be done so that a combustion reaches optimum conditions. Investigations related to the most optimal conditions of an arson continue to be carried out by researchers. The type of biomass is related to the type of content in the biomass, especially in the inorganic fraction which plays a very important role in the case of precipitation (fouling, slagging, and agglomeration), namely the melting of the ash content which results in lumps above the grate which of course reduces the flow of combustion air. However, the conditions of intake and distribution of combustion air are the most important in an incinerator which greatly affects the emissions.

The efficiency of a biomass incinerator unit is largely determined by three main things, namely: (1) Characteristics of feedstocks such as; moisture, alkaline content, density, ash content, ash melting point. (2) Chemical properties through optimization and ultimation analysis, and (3) Operational parameters used such as; the size and geometry of the combustion chamber, the temperature of the combustion chamber, the distribution of air, and the feedstock sizes. The moisture in the feedstock is closely related to the calorific value that can be obtained during the combustion process, where the higher the water content value, the calorific value will decrease significantly [14]. In the process of burning biomass, it is sought that the moisture content is below 60%. The moisture content can be controlled by carrying out drying. The modern drying process can be done by flowing the combustion gas into the storage bunker instead of using solar heat.

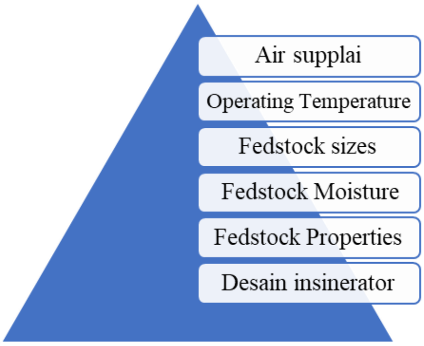

Fig. 1. Focus research on the incinerator development.

In a later 10-year-old study, researchers raced to improve the performance of the incinerators. From the data obtained, that almost 75% of studies focused on the study of the role of combustion air on the performance of incinerators. In this study, the researcher determined the novelty of the study based on the results of a review of previous research to date, where the main research priorities were more focused. Using the pyramid model as shown in **Figure 1,** the researcher found that the influence of air distribution became the most important in a combustion process. To date, the combustion air intake system into the incinerator has been the most researched and carried out. In addition, another purpose of research is developed to bring the situation closer to the real conditions where incinerator along with the biomass feedstock is located. Much research is done on a small size only and it is considered that the particle size of the feedstock is uniform. Meanwhile, large and non-uniform sizes such as coconut shells are still rarely studied.

The design or construction of the incinerator is not the main point in combustion process. Through computer simulation-based investigations, Kim, et. al concluded that the influence of incinerator geometry was not very significant on combustion performance [15], [16]. While the properties of biomass are highly related to corrosion problems due to the inorganic content of the feedstock [17], [18]. The moisture content and feedstock size do not greatly affect the performance of the incinerator, but greatly affect the carbon monoxide emissions. This happens because the higher the moisture content, the temperature of the combustion chamber decreases [19],[20]. In waste incineration, Yang, et al. [21] proved that a good distribution of air can lowering emission and improve combustion efficiency. By regulating the distribution of air in a wood-burning stove, Sornek, et al. [22] and Carvalho et al. [23] are also succeed in reducing greenhouse gas emissions. By placing an air distributor concentrically in a cylindrical biomass combustor, Simanjuntak, et al. found that the temperature of the flame reach of about 550 ^{o}C [24]. Caposciutti et al. [25] also studied fixed-bed combustor for commercial scale boiler by varying excess air to control the temperature.

In this study, the size and geometry of the incinerator have been established, while the feedstock size is attempted to be close to the actual size of the coconut shell to get closer to the actual situation. The inorganic content of coconut shells cannot be reflected because it has become innate or original properties. The proper distribution of combustion air is the main parameter because it guarantees complete combustion in the combustion chamber. Modifications to a single combustion air system are believed to improve the performance of an incinerator or boiler. The use of secondary air is very suitable for feedstocks with a high volatile content such as coconut shells. The purpose of this study is to investigate operational parameters by burning coconut shells using fixed-bed incinerators to obtain maximum thermal energy and low emissions. The coconut shell sample used is the actual size but the size is not uniform (non-uniform sizes).

2. Materials and Methods

2.1 Materials

Coconut shells was used as feedstock in this research. This biomass is found abundant around the research site and there is no special treatment was needed. Coconut shells are also known to have low moisture content (8%. dry wet) and require little time to prepare. This is done to bring the experimental situation closer to the real situation in the field where coconut shells are still considered worthless objects so that they are collected and placed in any place. Coconut shells are dried under sun exposure whose size assumed in the form of square of 10 x 10 mm. Incinerator of fixed bed type was used and is constructed in the form of a cube from refractory stone material coated with ceramic fibre as insulator. The size of the incinerator is 25 cm x 25 cm x 100 cm each for the length, width, and height respectively. The fuel is supported by a stationary grate, and is equipped with a glass door to facilitate cleaning and as observation window. The incinerator was fabricated at mechanical engineering workshop, faculty of engineering, Universitas Negeri Medan. A blower of 243 m^3/h is used to supply air combustion require. To obtain variations in the rate flow of combustion air is regulated through the floating air flowmeter with a capacity of 60 m^3/h.

2.2 Methods

During ignition start, a certain amount of woodchar was put into the reactor and sprayed with a little with kerosene and then ignited using a litter. After combustion took place, the woodchar became smoldering, and at that time the experiment began with the introduction amount of new fresh feedstock and regulating the air flow rate to a number of equivalence ratio (ER) required parameters. In this work, ER was calculated based on the feedstock mass and the air flow rates into the combustion zones. The following equation is used to calculate the ER.

$$\mathrm{ER} = \frac{(\mathrm{A/F})_{\mathrm{actual}}}{(\mathrm{A/F})_{\mathrm{stoichiometry}}} \qquad [1]$$

where $(A/F)_{actual}$ is the actual combustion air fuel ratio into the combustion chamber, whilst $(A/F)_{stoichiometry}$ is the stoichiometric air fuel ratio of the complete combustion with the value was about 6.25. During combustion, two important locations in the incinerator are measured in temperature, which are in the combustion chamber and the exhaust gas at the cyclone exit. Temperature measurements and recordings are carried out every minute. The experimental duration was set for one hour with the addition of fuel when the temperature in the primary combustion decreased to a temperature of 200 °C. Due to combustion and incinerator imperfection, it is common practice to use more air than the stoichiometric quantity to increase the chances of complete combustion or to control the temperature of the combustion chamber. For this condition, the combustion was carried out with supplement air or with excess air (ϕ), which is calculated using the following equation [26].

$$\Phi = \frac{V_{a,act}}{V_{a,st}} \quad [2]$$

that is the ratio between the actual air volume ($V_{a,act}$) and the stoichiometric air volume ($V_{a,st}$). An observation regarding flame color, which is described the combustion temperature, is performed through flame image captures.

3. Results and Discussion

3.1 Data Representation

Figure 2 shows the experimental test rig used, consisting of seven important units; (1) a blower, (2) an air-flow meter, (3) an air regulator valve, (4) a door with glass window, (5) a primary combustion chamber thermocouple port, (6) a cyclone, and (7) a product gas thermocouple port. Meanwhile, **Figure 3** shows the appearance of the fire inside the combustion chamber during combustion related to the ER used and also shows the color of the flame that relies on the ER. The red flame color has a higher temperature compared to the oranges and yellowish color. The red color indicates the highest combustion temperature that can be achieved in the incinerator unit, usually below 1000 °C. In this study, the highest combustion temperature that can be reached was about 780 °C at ER 5.6.

Fig. 2. Experiment test rig apparatus.

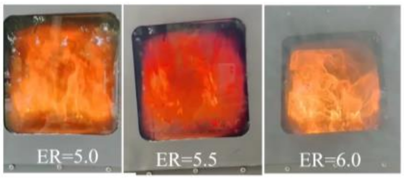

Fig. 3. Flame image captured during operation.

3.2 Temperature profile during operation

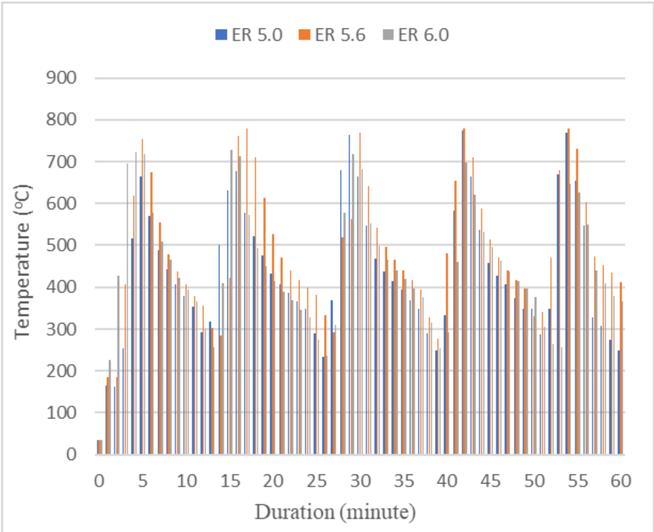

Fig. 4. Effect of ER on combustion chamber temperature.

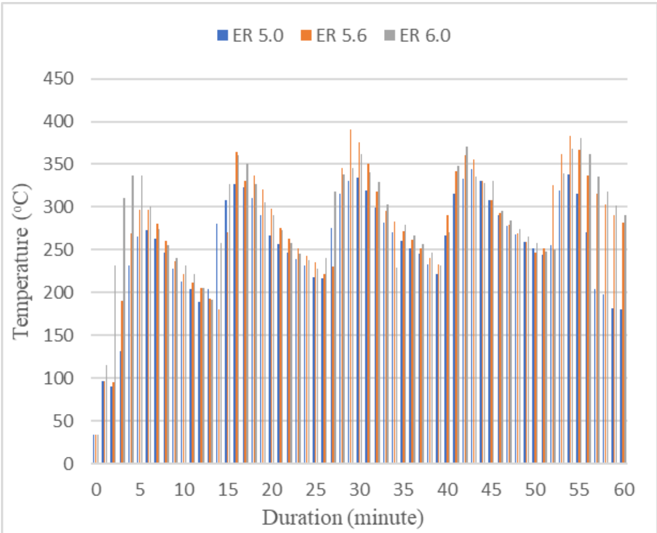

Fig. 5. Effect of ER on combustion gas product temperature.

The most suitable ER, which gives the maximum combustion chamber and product gas outlet temperatures of a packed-bed coconut shell cobustion was identified for each equivalence ratio (ER) through experimental simulation. The ER was varied by changing the supplied air combustion whilst the coconut size was maintained constant. At the beginning, both temperatures increase when ER is raised from 5.0 to 5.6, but then decrease when the ER raised to 6.0 as shown. In this study, it was found that the average temperature in the combustion chamber and product gases outflowing at the cyclone exit were 780 ºC and 350 ºC respectively as shown in **Figure 4** and **Figure 5** respectively. This finding is identic to the result found by Roy et al. [27], where they found that the temperature of the product gas produced was 215 ºC. This shown that the combustion reaction is very depend on the ER [27]. However, if the ER is increased, the temperature will decrease. This is because at ER 6.0, the amount of air intake is excessive so that there is a fire extinguishing in the combustion chamber and the gas product comes out diluted by a certain amount of nitrogen.

Figure 6 shows that ER largely determines the combustion performances. One of the important parameters in the combustion reaction is the burning rate. The higher the ER, the higher the burning rate, means that more fuel is consumed. This finding is in accordance with what was found by Simanjuntak et al. [24]. However, the high burning rate does not determine high temperatures of gas products.

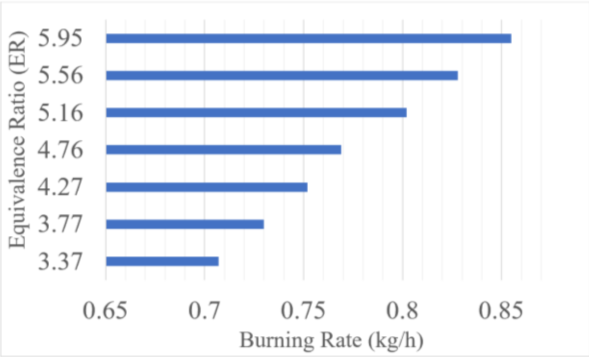

Fig. 6. Effect of ER on burning rate.

4. Conclusion

The operating parameter of the coconut shell incinerator of fixed bed static grate type has been conducted. The study revealed that the operating temperature of the incinerstor can be controlled by varying the air-fuel ratio. It is concluded that the exat air-fuel ratio (ER) of combustion resulted a high temperature in the combustion zone and the temperature of the product gas. In this study, with running duration of about one hour, a constant high temperature of the gas produtc (±380 ºC) was accieved which indicates that the high thermal energy in it. This energy can be recovered by utilized a recovery system such as Rankine cycle or organic Rankine cycle and can be converted to genegrate electricity which is the recomendation of this study.

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References

[1] Gunasekar, N.: Utilization of coconut shell pyrolysis oil diesel blends in a direct injection diesel engine. Materials to day: Proceedings. pp. 713-17 (2021)

[2] Montecucco, A.: A combined heat and power system for solid-fuel stoves using thermoelectric generators. Energy Procedia. pp. 597-602 (2015)

[3] Tambunan, B.H.: The use of thermo electric generator to utilize the waste heat from the biomass stove into electricity. Journal of Physics: Conference Series. IOP Publishing (2022)

[4] O'Syaughnessy, S.M.: Performance analysis of a prototype small scale electricity-producing biomass cooking stove. Applied Energy. pp. 566-76 (2015

[5] Simanjuntak, J.P.: Producer gas production of Indonesian biomass in fixed-bed downdraft gasifier as an alternative fuels for internal combustion engines. Journal of Physic : Conferences Series. IOP Publishing (2018)

[6] Schneider, T.: A review of thermochemical biomass conversion combined with Stirling engines for the small-scale cogeneration of heat and power. Renewable and Sustainable Energy Reviews. pp. 110288 (2020)

[7]. Simanjuntak, J.P.: Development of a Small-Scale Electricity Generation Plant Integrated on Biomass Carbonization: Thermodynamic and Thermal Operating Parameters Study. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences. pp. 79-95 (2022)

[8] Yang,Y.B.: Effect of air flow rate and fuel moisture on the burning behaviours of biomass and simulated municipal solid wastes in packed beds. Fuel. pp. 1553-62 (2004)

[9] Mao, G.: Research on biomass energy and environment from the past to the future: A bibliometric analysis. Science of The Total Environment. pp. 1081-1090 (2018)

[10] Singh, A. K.: Ash from coal and Biomass combustion, Springer (2020)

[11] Cheng, J.: Biomass to renewable energy processes, CRC press (2017)

[12] Simanjuntak, J. P.: Thermal Energy Storage System from Household Wastes Combustion: System Design and Parameter Study. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences. pp. 115-126 (2021)

[13] Raman, P.: Performance evaluation of three types of forced draft cook stoves using fuel wood and coconut shell. Biomass and Bioenergy. pp. 333-340 (2013)

[14] Safie, S.A.: Effect of hydrothermal and vapothermal carbonization of wet biomass waste on bound moisture removal and combustion characteristics. Applied Thermal Engineering. pp. 187-95 (2018)

[15] Kim, S.: Comparative evaluation of municipal solid waste incinerator designs by flow simulation. Combustion and Flame. pp. 241-251 (1996)

[16] Simanjuntak, J.P.: Hydrodynamic flow characteristics in an internally circulating fluidized bed gasifier. Journal of Research Technology. pp. 032001-8 (2018)
[17] Gulyurtlu, I.: The study of the effect of operating parameters on the PAH formation during the combustion of coconut shell in a fluidised bed. Fuel. pp. 215-223 (2003)
[18] Nunes, L.: Biomass combustion systems: A review on the physical and chemical properties of the ashes. Renewable and Sustainable Energy Reviews. pp. 235-242 (2016)
[19] Jenkins, B.: Combustion properties of biomass. Fuel processing technology. pp. 17-46 (1998)
[20] Bhattacharya, S., D. Albina.: Effects of selected parameters on performance and emission of biomass-fired cookstoves. Biomass and Bioenergy. pp. 387-395 (2022)
[21] Yang, X.: Effects of air supply optimization on NOx reduction in a structurally modified municipal solid waste incinerator. Applied Thermal Engineering. pp. 117706 (2022)
[22] Sornek, K.: Study of clean combustion of wood in a stove-fireplace with accumulation. Journal of the Energy Institute. pp. 613-623 (2017)
[23] Carvalho, R. L.: Wood stove combustion air retrofits: A low cost way to increase energy savings in dwellings. Energy and Buildings. pp. 140-152 (2018)
[24] Simanjuntak, J.P.: Performance improvement of biomass combustion-basedstove byimplementing internally air-distribution. Journal of Physic : Conferences Series, IOP Publishing (2021)
[25] Capociutti, G.: Experimental investigation on the fixed bed of a small size biomass boiler. Energy Procedia. pp. 468-473 (2017)
[26] Simanjuntak, J. P.: An operating parameter study of the biomass solid feedstock incinerator of fixed-bed type with two stage air supply. Journal of Physics: Conference Series, IOP Publishing (2022)
[27] Changkook R, Yao BY, Adela K, Nicola EY, Vida NS, Jim S.: Effect of fuel properties on biomass combustion: Part I. Experiments—fuel type, equivalence ratio and particle size. Fuel. pp. 1039-1046 (2006)