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Effect of Modification Perforated Plate for Combustion Temperature in Fluidized-Bed Combustor

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ABSTRACT

Perforated plates have been widely used for various applications, especially within the FBC combustion chamber. Investigation of combustion temperature with modification of perforated plates in FBC fuel chambers using palm oil biomass fuel is still very little found in the publication. Modifying the perforated plate in the FBC chamber aims to investigate the effects of combustion temperature. Three types of fuels, PKS, OPM, and EFB, are used to analyze the level of combustion temperature produced from within the FBC fuel chamber. Test results showed that PKS fuel had a higher combustion temperature level for all points tested. Each measurement's PKS maximum combustion temperature is M-1 896℃, T-2 987℃, T-3 864℃, and M-4 762℃. PKS fuel burn times are longer than OPM and EFB (57 minutes, 28 minutes, and 40 minutes) of the same fuel weight (2.5 kg). The overall PKS -fueled thermal efficiency level is higher than OPM and EFB. Thus, PKS fuel has a high calorific value and a longer burning time, making it suitable for electricity generation.

1. INTRODUCTION

Research on the use of perforated plates in various applications has been conducted. The perforated plate can be used to analyze bias sound suppression as the research results by Zhou et al. [1] and Fang et al. [2]. The results showed that the double-walled plate was modified, and the configuration was a key parameter for determining sound absorption performance. Investigation of bubble fluid campfires for particles in absorbent and CO_2 with modification of perforated plates has recently been conducted [3]. P-plate energy in ammonia-fueled micro-power systems against NOx emission behaviour has also been investigated [4]. The experiment results showed that the applied perforated plate can reduce NO emissions by up to 73.3% compared to those without perforated plates. In different studies, perforated plate quatrefoil (QPP) intended for the side of the shell heat exchanger shell-and-tube (STHX) has also been conducted [5]. The results of experiments conducted h/Δp heat exchanger with QPP comprehensively can be increased by 27% - 41%. The effect of hole size and position of perforated plates on flame and flow encroachment and oscillations at pressure explored in constant volume combustion chambers (CVCBs) using single-hole perforated plates has also been studied [6].

Fluidized-bed combustor (FBC) can be used in various applications, especially in industrial processes. FBC is used for fluidized catalytic cracking (FCC), forming catalysts, and other robust exothermal processes. Besides, it is also widely used for drying, solid fuel conversion, and gas-phase polymer production [7-9]. The main focus of the study was to analyze high-temperature processes, especially against the conversion of fuel in thermo-chemicals in fluidization campfires. Differences in thermochemical conversion routes to combustion, pyrolysis, gasification, fermentation, and anaerobic destruction have been investigated [10-12]. The fluidized coating is converted from solid waste fuels that have carbon, such as palm oil, biomass, wood, and coal. The high combustion temperature of the industrial process in producing hot steam, electricity, and hydrogen can be generated from the combustion process. Solid fuel inserted into the fluidized campfire serves to make heat and moisture.

FBC is widely used in various solid and liquid fuels that differ from the fluidized coating [13-15]. The use of fuel in solid FBC space generally uses solid biomass waste. The use of solid waste fuels such as palm oil biomass has begun to be in great demand in recent years. Palm oil biomass waste is one of the renewable energy sources that can be used as a substitute for fossil energy that will deplete in the next few years. The availability of palm oil biomass, especially in Southeast Asia, is very promising, as in the study [16, 17]. Also, the availability of renewable energy, especially in Indonesia, is very abundant, as presented in the study [18]. Technology for the utilization of renewable energy from various sources today availability has also been up-and-coming [19].

Meanwhile, an analysis of fuel availability and potential, especially in Aceh Province, has also been conducted [20, 21]. The analysis results using Software Aspen Plus show that the availability of renewable energy from solid waste biomass palm oil is quite promising. However, until now, research for temperature investigations in the FBC fuel chamber using palm oil biomass fuel is still very little found in the literature. As reported in the study, the examination of temperature and emissions in FBC fuel space is still dominated by coal fuel [22]. The research was conducted on 15 FBC boilers since 1980, and they can produce 300 MW of energy.

Investigations of combustion temperatures in the FBC fuel chamber using solid waste oil palm biomass fuel are still very few in the publication. The combustion temperature is almost the same as coal, and the energy produced is also auspicious. Modification of perforated plates in the FBC space aimed at investigating the level of combustion temperature using palm biomass fuel was the main objective of this study. The investigation of combustion temperature in the FBC chamber was conducted using three types of fuel such as palm kernel shell (PKS), oil palm midrib (OPM), and empty fruit bunches (EFB). The thermal efficiency levels of the three types of fuel are also analyzed in this work.

2. EXPERIMENT SETUP AND MATERIAL

The experiment conducted in this study was to analyze the effect of combustion temperature in fluidized-bed combustor (FBC) fuel using oil palm biomass fuel. Testing was performed three times with three types of PKS, OPM, and EFB fuels. Investigation of combustion temperature is carried out by modifying the perforated plate in the FBC chamber.

2.1 Experiment setup

The FBC combustion chamber design for the experiments in this study is fully shown in Figure 1. This combustion chamber is specially made for research tools with solid waste fuels such as palm oil biomass. The purpose of designing this tool is specifically to investigate the temperature level and combustion efficiency. Research using FBC using perforated plates has also been conducted by the researches [5, 23].

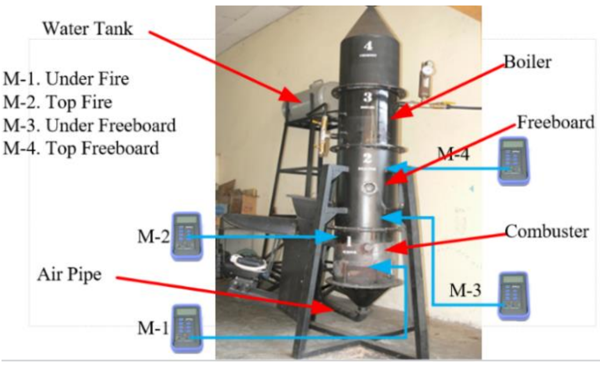

Figure 1. Schematic diagram for fluidized-bed combustor (FBC)

Figure 2. Modification of perforated plate with the addition of three spoons

In addition to the FBC combustion chamber for testing, the study also designed a perforated plate for wind control supplied by blowers with a pressure of 14.7 kPa. This perforated plate has 30 holes with three spoonfuls and one central hole in the middle of the plate. Modifying this plate aims to smooth the air entering the combustion chamber. Air supplied from blowers minimizes unburned fuel so that combustion is obtained efficiently. The modified design of the perforated plate made in this test is shown in Figure 2.

Furthermore, this study's steaming of combustion temperature uses Digital Thermometer HT-306, as shown in Figure 3. While the specifications of the Digital Thermometer HT-306 are presented in Table 1.

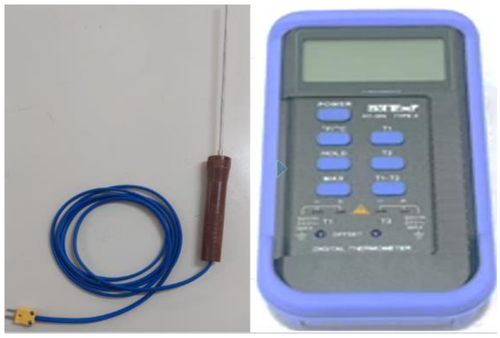

Figure 3. Digital thermometer merk HotTemp HT-306

Table 1. Specification thermometer digital HT-306

Component	Measurement
Response Time	15 Seconds
Power Supply	Baterai 6F22 9V
Resolution	HT-306:1°C/1ºF
Model HT-306	Dual Channel Input
Input Sensor	Thermocouple Type "K"
Wide Measuring Range	-50°C ~ +1300°C (-58ºF ~ +1999ºF)

The analysis conducted in this test is specifically to determine the maximum temperature level of the combustion process using palm oil biomass. Besides, the experiment in this study will also calculate the value of thermal efficiency. Calculating thermal efficiency in FBC fuel chambers with different fuels is performed using Eq. (1). Temperature analysis is performed to find out how high the combustion temperature of each type of fuel is used so that can be predicted the steam produced. The amount of combustion temperature obtained from a combustion process, the greater the vapour released. Large vapours can be converted into heating energy, especially electrical power.

$$\eta_{th} = \frac{ma\ Cp\ \Delta T}{mb\ LHV_{fuel}} \tag{1}$$

where,

ma = water (kg)

Cp = heat capacity (kJ/kg °C)

ΔT = end value - first value

mb = total fuel

LHV_{fuel} = lower heating value

2.2 Material

The type of fuel material for testing used in the study was sourced from solid waste of palm oil biomass such as palm kernel shell (PKS), oil palm midrib (OPM), and empty fruit bunches (EFB). The weight of each fuel used in this test was 2.5 kg, as shown in Figure 4.

Figure 4. Type of fuel used

3. RESULTS AND DISCUSSION

The experimental testing in this study aimed to analyze the level of combustion temperature in the FBC chamber with three different fuel types. The fuel used is palm oil solid waste biomass. Palm oil solid waste is one of the renewable energy sources that can produce energy. The result of energy conversion from palm oil solid waste can be used for heating, cooling, and electrical power. The availability of solid waste palm oil, specifically in Indonesia and the Southeast Asian region, is quite adequate. Renewable energy sources from palm oil are expected to reduce dependence on fossil energy, especially those used for electrical power [16, 17].

Experimental testing in the study was conducted on the FBC combustion chamber with four measurement points, as shown in Figure 1. Each topic is measured using the same three types of fuel. Combustion temperature measurements analyzed on M-1 showed the highest yield of 1,084°C was recorded on EFB fuel. The combustion temperature level when using PKS fuel is 896°C. While the test results using OPM fuel show the highest combustion temperature of 810°C. The average combustion time to reach the maximum temperature of the three fuels used is between 10-30 minutes, as shown in Figure 5.

Meanwhile, OPM fuel shows the fastest time compared to EFB and PKS. The amount of fuel used is the same as 2.5 kg. As for fuel, PKS has the longest combustion time. The combustion temperature produced in this study is higher, especially for EFB and PKS fuels, than in previous studies [24].

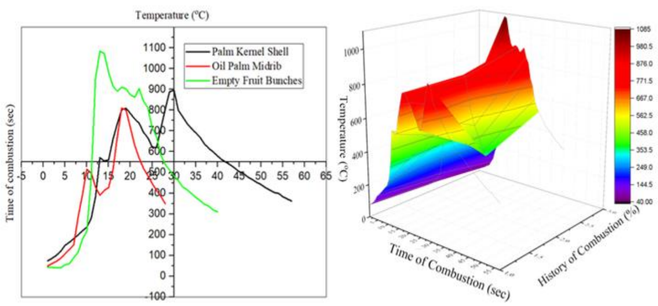

Figure 5. The combustion temperature effect of different fuels at the M-1 point

Figure 5 shows the combustion temperature with the 3D view adopted from Figure 5. Furthermore, the analysis results were conducted to measure the level of thermal efficiency based on the temperature resulting from combustion in the FBC chamber. Based on the results of the measurements, the thermal efficiency when using PKS fuel is higher than that of OPM and EFB, as shown in Figure 6. Calculation of thermal efficiency is done using Eq. (1). The results of thermal efficiency measurements conducted in this study are higher than the results in the study [25]. In their research, testing was conducted on vehicle engines with a fuel mixture between flaxseed oil and diesel. While the results of thermal efficiency analysis in this study are also higher than the measurements made by He et al. [26].

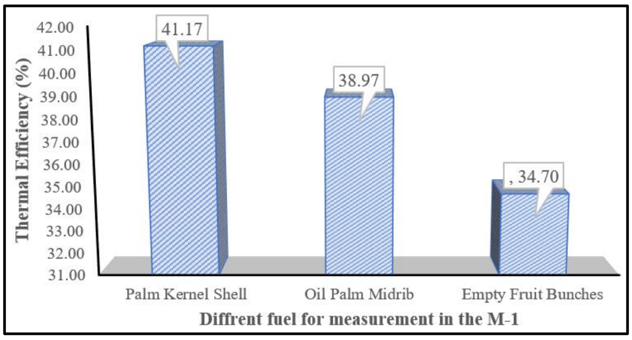

Figure 6. Thermal efficiency at M-1 points with different fuels

Furthermore, the analysis in this test was conducted on the M-2, the top end of the fire. The study aims to determine the maximum combustion temperature of each fuel used against the modified perforated plate. The measurements showed that the modification of the hole plate could provide a sufficient supply of air so that thoroughly the burn burned out and nothing was left. The highest combustion temperature reached 987°C recorded on PKS fuel, shown in Figure 7. As for EFB and OPM fuels, the maximum temperature produced was 935°C and 815°C. The results of experiments on M-2 used similar fuels in this study higher than [24, 27].

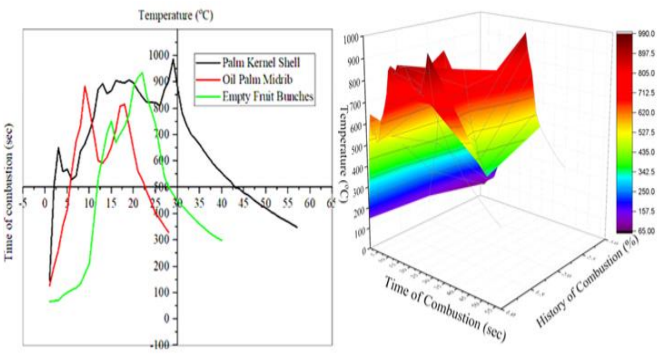

Figure 7. The combustion temperature effect of different fuels at the M-2 point

Based on the results of the combustion temperature analysis conducted, the thermal efficiency level of the combustion process is calculated for different fuels. Thermal efficiency measures aim to determine how much heat energy can be absorbed from the fuel. The results showed that PKS fuel is more dominant than OPM and EFB fuels. The thermal efficiency of the PKS fuel tested reached 31.81%. While thermal efficiency calculated from OPM and EFB fuel usage is 26.92% and 24.33%, respectively, shown in Figure 8. The measurements showed that the modified perforated plate in the FBC combustion chamber showed excellent results.

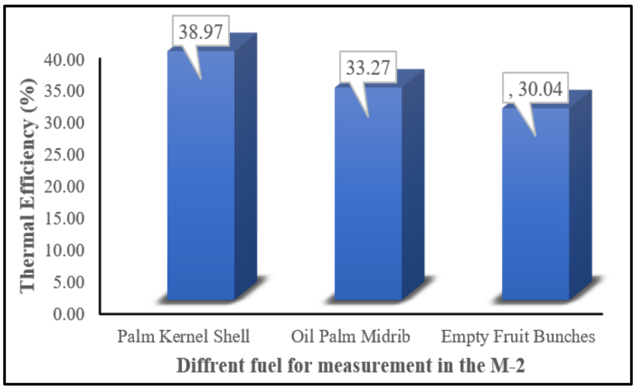

Figure 8. Thermal efficiency at M-2 points with different fuels

The results of tests conducted in this experiment for the M-3 highest temperature were recorded on PKS fuel 864°C at 28 minutes. While at the time of testing for OPM and EFB fuels, the recorded combustion temperature was lower than that of the PKS fuel. The highest temperatures of OPM fuel are 792°C and EFB 774°C. Combustion temperature levels using different fuels with modifications to the perforated plates are shown in Figure 9 (a). While the thermal efficiency of the measurements made on the M-3 with other fuels is slightly lower compared to the thermal efficiency of the M-1 and M-2. The efficiency levels of the three fuels used in the FBC fuel chamber are shown in Figure 10. While the combustion temperature is displayed, and the 3D form is presented in Figure 9 (b). The research results with similar fuels have also been carried out [28, 29].

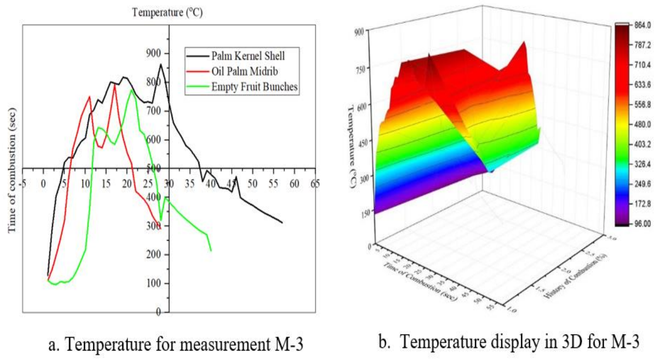

Figure 9. The combustion temperature effect of different fuels at the M-3 point

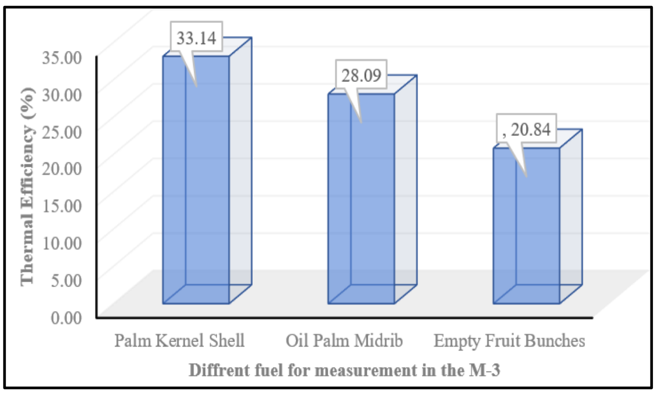

Figure 10. Thermal efficiency at M-3 points with different fuels

The last analysis is done on the topmost freeboard before reaching the boiler. The purpose of this analysis at the M-4 point is to determine the level of heat released on the boiler wall. This test is essential to know how long the water is in the boiler until it releases steam that can be converted into energy. The measurements made using The HotTemp HT-306 Digital Thermometer show that condensation can increase up to 120°C with a combustion temperature of 762°C within 12 minutes shown in Figure 11. Further analysis is carried out to measure the thermal efficiency of the combustion process. The analysis and measurement results showed that the thermal efficiency level of PKS fuel was slightly better than that of OPM and EFB fuels. Also, the PKS fuel burn period is more extended than OPM and EFB, as shown in Figure 12. While OPM fuel burns faster, the efficiency level is lower.

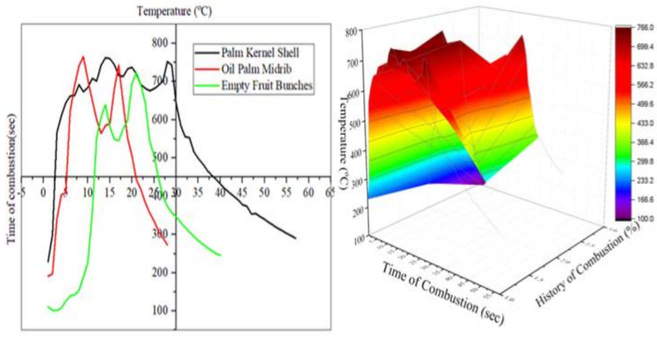

Figure 11. The combustion temperature effect of different fuels at the M-4 point

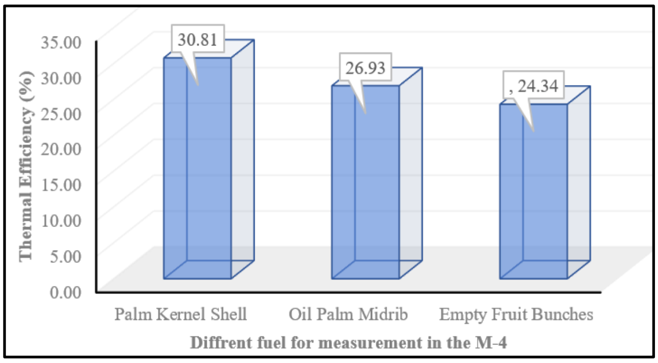

Figure 12. Thermal efficiency at M-4 points with different fuels

4. CONCLUSIONS

This study aims to measure the combustion temperature and thermal efficiency of different fuels having the same weight. Based on the results of the analysis and measurements carried out can be concluded as follows:

a. Overall, the four points measured showed that PKS fuel had higher temperatures than OPM and EFB. PKS maximum combustion temperatures for the four estimated points reached M-1 896°C, M-2 987°C, M-3 864°C, and M-4 762°C, respectively. While the temperatures obtained from burning OPM are M-810°C, M-2 885°C, M-3 792°C, and M-4 765°C. Meanwhile, the temperatures recorded from the EFB combustion products were M-1 1084°C, M-2 935°C, M-3 774°C and M-4 723°C, respectively.
b. PKS fuel has a long time, or about 57 minutes, compared

to 28 minutes for OPM fuel and 40 minutes for EFB with the same fuel weight (2.5 kg).
c. EFB fuel is slightly slower to burn but has a faster burn-out speed. However, it shows a better trend than OPM fuel.
d. The overall thermal efficiency level of PKS-fueled combustion is better than that of OPM and EFB. It is perfect for converting energy on a larger scale.

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NOMENCLATURE

EFB	empty fruit bunches
CO_2	generic functions
FCC	fluidized catalytic cracking
FBC	fluidized-bed combustor
M-I	measurement I
M-II	measurement II
M-III	measurement III
M-IV	measurement IV
NOx	height
NO	time index during navigation
OPM	oil palm midrib
PKS	palm kernel shell
STHX	shell heat exchanger shell-and-tube