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MODIFICATION OF PERFORATED PLATE IN FLUIDIZED-BED COMBUSTOR TO PROVIDE SUFFICIENT AIR SUPPLY IN THE COMBUSTION

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ABSTRACT

The modification of the perforated plate applied in this study aims to provide sufficient air access into the combustion chamber. Burning experiments were carried out with three different types of fuel (such as palm kernel shell (PKS), oil palm midrib (OPM), and empty fruit bunches (EFB). The purpose of the experiment with the modification of the perforated plate is to investigate the combustion temperature and the rate of heat transfer in the boiler. The fluidized-bed combustor (FBC) combustion chamber is used as the combustion chamber. Experimental results were obtained at four different points using a Digital Thermometer with a thermocouple. The experimental results show that the highest heat transfer rate is obtained from PKS fuel of 8.258 W/m for the M-1 measurement point. The measurement results on the M-2 highest heat transfer rate were recorded from OPM fuel of 7.392 W/m. The highest combustion temperature is obtained from OPM fuel, which is 884^{o}C for the M-1 measurement point. The combustion temperature of the PKS combustion process is slightly higher at 896^{o}C. However, the combustion temperature produced during the combustion of PKS shows a less good trend than OPM. Overall, the fuel used in this test can be completely burned and unsaturated by providing sufficient air supply into the combustion chamber. Modification of the perforated plate with the addition of air supply in the combustion chamber is a novelty found in this study.

Keywords: *Perforated plate, Heat transfer rate, Temperature, FBC, Combustion chamber.*

1. INTRODUCTION

Combustion research continues to this day using both solid and liquid fuels. The investigation of the combustion temperature of various types of fuels has been carried out to date. In general, combustion temperature analysis is performed on motor vehicle engines for example (Chaudhari & Deshmukh, 2020; Singh, Kumar, & Agarwal, 2020; Y. Wang, Liu, & Yao, 2021; Su, Zhang, & Chen, 2020). Temperature analysis on combustion engines uses many fossil fuels, diesel, petroleum, and also mixed fuels or additives (Chen, Ilies, Hansen, Pitsch, & Sarathy, 2021; Erdiwansyah, Mamat, Sani, Sudhakar, et al., 2019; Ma, Zhang, & Zheng, 2021; H. Wang & Zhang, 2021). While the analysis of combustion temperature using solid fuels such as palm oil biomass is still very rare in various publications. Palm oil biomass is a source of renewable energy that can be used as a substitute for fossil fuels that are depleting over time.

Perforated plates play a very effective role in the resistance of fire collected from the fuel provided (Nie, He, Zhang, Chen, & Zhang, 2011). The resistance of the perforated plate to the flame is the same as the metal mesh as described in the study by (Jin et al., 2017; Pang, Wang, Han, & Xu, 2015). The main function of the perforated plate is to provide the speed of the flame as described in the study (Chapman & Wheeler, 1926; Wan, Wang, Li, & Luo, 2020). Modified perforated plates can significantly lower the speed of flames downstream as discussed in the (Li et al., 2018; C. J. Wang & Wen, 2014; Wei, Li, Zhao, & Zhou, 2020). Perforated plates have the potential to extinguish flames.

Investigations into combustion temperatures using solid waste such as palm oil biomass in recent years have begun to be in demand by some researchers. However, the use of palm oil biomass as fuel to analyze combustion temperatures in the FBC fuel chamber is still very minimal and difficult to find in various publications. Palm oil biomass is a renewable energy source that can be used for heating, cooling, and electrical energy. The availability of renewable energy sources in Southeast Asia is also very adequate (Erdiwansyah, Mahidin, et al., 2019; Erdiwansyah, Gani, MH, Mamat, & Sarjono, 2022; Erdiwansyah, Mamat, Sani, & Sudhakar, 2019). The availability of renewable energy sources, especially in Indonesia today is very abundant. Availability of renewable energy sources as reported in the study (Erdiwansyah, Mahidin, Husin, Nasaruddin, Zaki, et al., 2021; Erdiwansyah, Mahidin, Husin, Nasaruddin, Khairil, et al., 2021; Loh, 2017; Shahidul et al., 2020; Wu et al., 2017). However, abundant energy sources cannot be utilized to the maximum.

Previous studies related to flame interactions have also been carried out. While the transition to flame acceleration and quenching has also recently been investigated (Wan et al., 2020). Investigations into combustion temperatures have also been widely presented in various literature. In general, investigations into combustion temperatures and heat transfer are generally conducted using fossil fuels, a mixture of alcohol and fuel additives. However, investigations of combustion temperatures and heat transfer in FBC chambers using solid waste

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biomass are still very rare in the literature. Therefore, to know the conditions of combustion temperature and heat transfer in the combustion chamber FBC conducted a series of experiments by modifying the perforated plate. Palm oil biomass solid waste fuel is used to investigate combustion temperature levels and heat transfer by providing sufficient air through a perforated plate.

2. EXPERIMENT SETUP AND MATERIAL

The experiment applied in this research is to analyze the level of combustion temperature and heat transfer rate on FBC through modification of perforated plates. Solid waste biomass fuel from renewable energy sources such as palm kernel shells (PKS), oil palm midrib (OPM), and empty fruit bunches (EFB) is used in combustion tests. The FBC burn chamber employed in this study is designed as short as shown in **Fig. 1**. The temperature data in the FBC room was analyzed using a HotTemp HT-306 Digital Thermometer. This digital thermometer can measure temperatures up to 1300°C. The redesigned perforated plate, as shown in **Fig. 2**, has a circle form with a hole and two clasps on the edge and one main direction right in the center. The perforated plate serves as an air source for the FBC chamber, allowing the fuel to be injected unsaturated due to the presence of incoming air to mix the fuel. **Table 1** lists the features of the HT-306 Digital Thermometer.

M-1. The tongue of fire under the combustion chamber
M-2. Tongue of fire over the combustion chamber
M-3. Bottom reactor measuring point
M-4. Upper reactor measuring point
5. Air supply blower
6. Air supply pipe to the combustion chamber
7. Burning kitchen
8. Reactor
9. Boiler
10. Water tank
11. Steam pressure gauge
12. Water vapor metering pipe
13. Smoke guide

Fig. 1 Schematic Diagram for FBC

Fig. 2 Perforated plate modification for access air

Table 1 Specification Thermometer Digital HT-306.

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

Fig. 3 depicts research into heat transfer rates in FBC fuel chambers using palm oil biomass solid waste fuels such as palm kernel shell (PKS), oil palm midrib (OPM), and empty fruit bunches (EFB) with perforated plates. Each of the fuels utilized is 2.5 kg in weight. **Fig. 1** shows data collection of heat transfer rate and combustion temperature at four different sites (Hani et al., 2020). The study's analysis for calculating heat transfer rates was used Eq. (1) (Bergman, Incropera, Lavine, & Dewitt, 2011; Holman, 1988).

Fig. 3 Fuel type of biomass palm oil

$$q = \frac{T1 - T5}{\frac{1}{hoAo} + \frac{\ln\left(\frac{ro1}{ri1}\right)}{k1} + \frac{\ln\left(\frac{ro2}{ri2}\right)}{k2} + \frac{\ln\frac{ro3}{ri3}}{k1} + \frac{1}{hiAi}} \quad (1)$$

Where:

$T1$	= The temperature flame
$T5$	= The temperature outer wall
$ro1$	= The outer radius of the combustor
$ri1$	= The mine radius of the combustor
$ro2$	= The outer radius of insulation
$ri2$	= The inner radius of insulation
$ri3$	= The radius of the cylinder
$k1$	= The thermal conductivity of the plate
$k2$	= The thermal conductivity of the insulation
ho	= The coefficient heat transfer rate from outer wall to air
hi	= The coefficient in the wall from the combustor chamber to the inner wall
Ao	= The outer cross-sectional area
Ai	= The inner cross-sectional area

3. RESULT AND DISCUSSION

The research in this work is specifically to analyze the heat transfer rate and combustion temperature level of the FBC indoor combustion process using palm biomass fuel (PKS, OPM, and EFB). The FBC combustion chamber is modified on a two-way hole and the main hole and steering wheel in the middle of the plate is shown in **Fig. 2.** Modify this perforated plate to provide air supply into the FBC fuel chamber so that the fuel incorporated can burn as a whole. Measurements of heat transfer rate and combustion temperature are analyzed at four predetermined points as shown in **Fig. 1.** The end of the analysis results at each point aimed to determine the level of combustion efficiency in the FBC combustion chamber with modification of the perforated plate.

Based on the results of measurements conducted with a Digital Thermometer brand HotTemp HT-306 shows that the heat transfer rate in M-1 reached 8.258 W/m recorded for PKS fuel. While the heat transfer rate obtained from OPM and EFB fuels reaches 7.493 W/m and 6.268 W/m respectively shown in **Fig. 3.** The high heat transfer rate produced by PKS fuel is due to the longer combustion time compared to OPM and EFB. The results of the combustion temperature analysis of the three fuels used showed varying results. Where the trend of combustion temperature from OPM fuel shows the best of PKS and OPM. The combustion temperature analyzed for PKS fuel is 948ºC higher than OPM and EFB respectively 884ºCand 776ºCshown in **Fig. 4.** Tests performed with EFB fuel and temperatures were shown to be more lopsided at the time until the end of combustion. This indicates that the modification of the perforated plate can work well. Modification of the perforated plate can supply enough air so that the fuel is thoroughly inserted and nothing is left shown in **Fig. 5.**

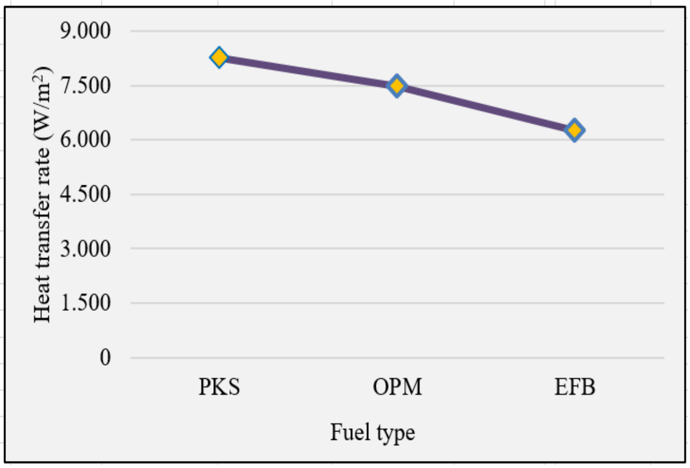

Fig. 4 Heat transfer rate for different fuel

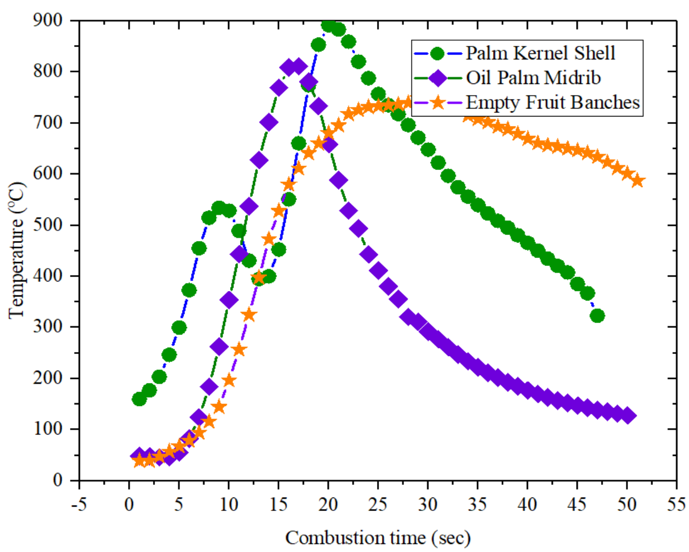

Fig. 5 Different fuel temperatures against time for M-I measurements

Analysis of heat transfer rate and combustion temperature measured on M-II showed that OPM fuel was higher than MILLS and EFB. When compared to the transfer heat rate on M-1 shows a difference. This is because the measurement on the M-2 is the end of the fire so when OPM has burned the fire immediately spouts upwards. While the fire burning with PKS and EFB is a little more ramped. The heat transfer rate recorded on OPM fuel reaches 7.392 W/m compared to the PKS of 7.232 W/m and 72.03 W/m for the EFB as shown in **Fig. 6.**

The combustion process with PKS fuel shows a higher temperature trend but is not optimal compared to OPM and EFB. While the combustion temperature trend for OPM and EFB burning materials shows an excellent trend. The maximum temperature obtained from OPM fuel reaches 874ºC for M-2, PKS 840ºC, and EFB 860ºC measurements shown in **Fig. 7.** The decrease in combustion temperature that occurs in PKS fuel is caused by an unstable air supply during combustion. The combustion temperature levels recorded in this study are higher than in previous studies (Hani et al., 2020).

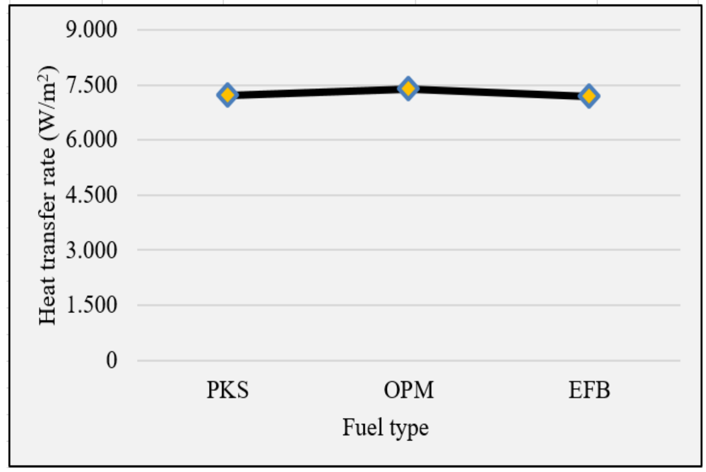

Fig. 6 Heat transfer rate for different fuel

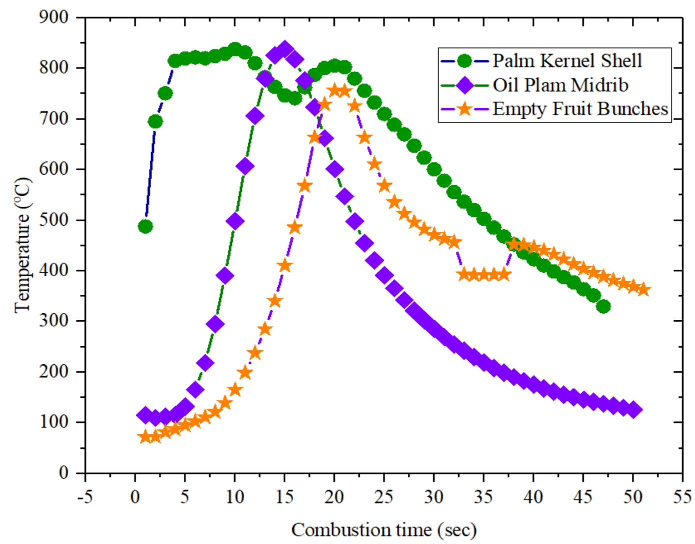

Fig. 7 Level of temperature for different fuel and combustion times **(9)**

Furthermore, analysis and measurements were performed on the M-3 for heat transfer rates for different fuels and combustion times. The heat transfer rate measured in M-3 shows that PKS fuel is 8.493 W/m higher than OPM and EFB at 6.274 W/m and 5.912 W/m respectively as shown in **Fig. 8.** This measurement is done on a freeboard that is above the combustor or in the room before reaching the boiler.

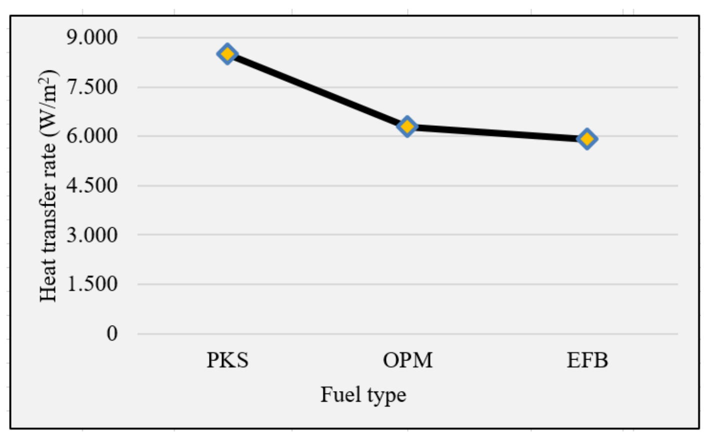

Fig. 8 Heat transfer rate (w/m) for different fuel

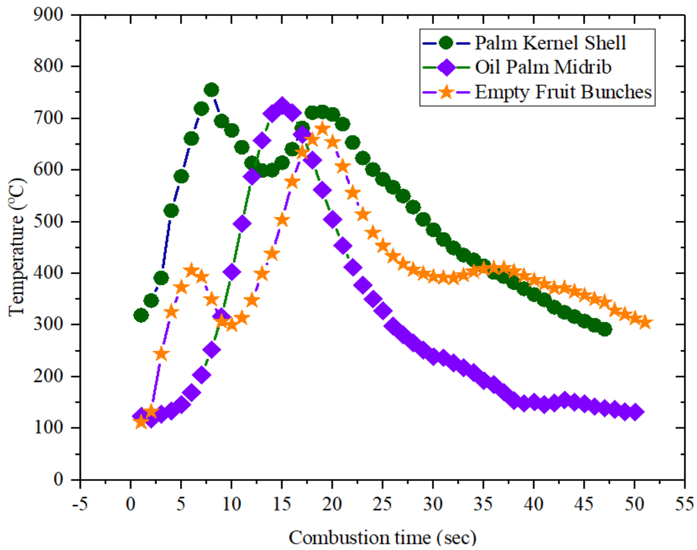

Fig. 9 Temperature for different fuel and combustion time

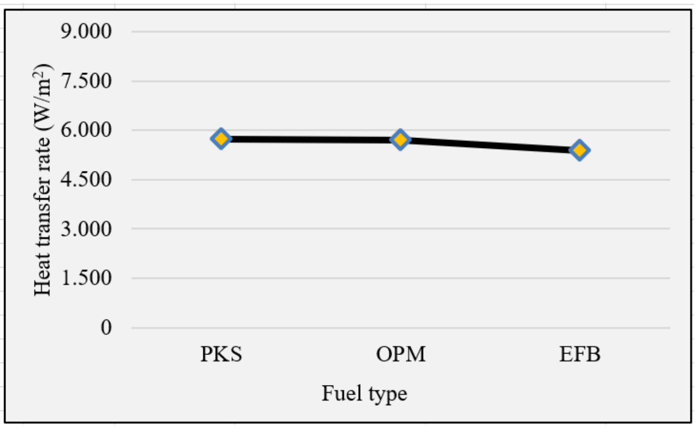

Fig. 10 Heat transfer rate for different fuel

The results of the combustion temperature measurement on the M-3 that OPM fuel show an excellent trend. The maximum combustion temperature of the OPM combustion process reaches 764°C slightly lower than the PKS 971°C. However, the temperature trend displayed from the PKS is not optimal. The trend of temperature is not optimal because the combustion fire from the PKS is uneven so the temperature is displayed up and down as shown in **Fig. 9**.

The latest analysis in this work for the measurement of heat transfer rate and combustion temperature was performed on a chimney (M-4). Measurements at this point are important to monitor the level of combustion temperature and heat transfer rate before reaching the boiler so that boiler heating and released steam can be known. If the combustion temperature gets higher, then the steam that can be converted into energy gets bigger. The results showed that PKS fuel showed a higher heat transfer rate than OPM and EFB. The heat transfer rates of the three fuels used reached 5.728 W/m, 5,695 w/m, and 5.394 W/m respectively shown in **Fig. 10.** However, the heat transfer rate in M-4 measurements was significantly lower than that of M-1, M-2, and M-3. While the combustion temperature in M-IV decreased significantly from M-1, M-2, and M-3 for all tests performed. The highest temperatures reached 699°C for PKS, 707°C OPM, and EFB 690°C as shown in **Fig. 11**. The combustion temperature trend of OPM and EFB fuels is better than that of PKS. The trend of combustion temperature from PKS fuel is unstable because the air entering the FBC fuel chamber is not enough. This is because the modified air hole is covered by fuel so that the air does not enter optimally. Based on the results of the overall analysis for heat transfer rates in this study is higher than the research conducted by (Liu, Wang, Li, & Wang, 2021; Tang & Zhang, 2020; Huang, Li, & Cheng, 2020). Where the research is conducted for analysis in utilizing geothermal energy efficiently. In addition, the results of the analysis conducted in their study showed that the combustion temperature was lower than in this study.

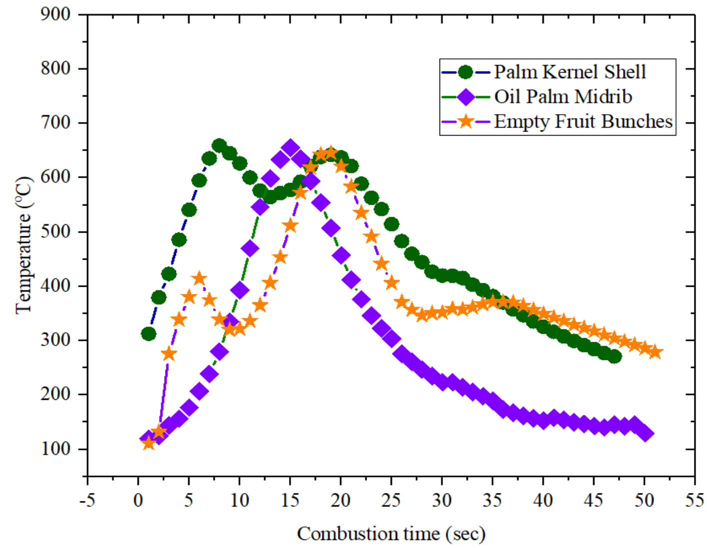

Fig. 11 Profile temperature for different fuel time combustion in the M-IV

Based on the results of the overall analysis that the heat transfer rate for PKS fuel is higher than OPM and EFB. While the combustion temperature of the PKS fuel experiment is higher than that of OPM and EFB.

4. CONCLUSIONS

Heat transfer rates and combustion temperatures in FBC fuels with oil palm biomass fuels such as PKS, OPM, and EFB were studied specifically in this study. Measurements are taken at four separate locations, with the heat transfer rate and temperature determined at each location. Based on the findings of the trials, the following conclusions can be drawn:

1. On PKS fuel, the heat transfer rate computed using M-I was 8.258 W/m. On the M-II, the greatest heat transfer rate of 7.392 W/m was observed on OPM fuel.
2. For all points studied, OPM fuel has a superior trend than PKS and EFB fuels in terms of combustion temperature. On M-I, the highest combustion temperature obtained with OPM fuel was 884°C. The temperature of the PKS combustion process, on the other hand, was greater at 896°C, but the trend was bad.
3. In M-I, the highest EFB combustion process had a heat transfer rate of 6.268 W/m. The greatest combustion temperature of the EBF is only 776°C.
4. In comparison to M-1, M-2, and M-3, the measurement findings for M-4 were the lowest.

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CONFLICT OF INTEREST

All authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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