Development and application of a biomass burner using nyamplung seed cake as feedstock for pyrolysis process

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Abstract. The main issue in running the pyrolysis plant for waste plastics and waste tire is how to operate the plant efficiently with the minimum energy required for heating the reactor. Therefore, the alternative heating source for the pyrolysis reactor should be applied to reduce the energy cost. Development of a novel biomass burner has been successfully fabricated, tested and applied for pyrolysis system. The experiments have been conducted to study the effect of air supply and fuel on the combustion performance of the burner. The results show that the thermal efficiency of the burner was higher by utilizing nyamplung seed cake as a feedstock compared to wood pellet. However, the maximum flame temperature of nyamplung seed cake was lower than that of wood pellet. This is due to the lower density of nyamplung seed cake compared to wood pellet which was lowering the combustion rate in the burner. The increase of the air supply generates the increase of the maximum flame temperature and the decrease of thermal efficiency. Moreover, the higher air supply the higher the flame length would be in which it will be one of the important parameters when designing larger scale of biomass burner and the pyrolysis reactor.

1. Introduction
Plastic waste has become a major stream in municipal solid waste increasing every year. This is due to the superior characteristics of plastics such as lightweight, corrosion resistant and good insulation properties. The characteristic of plastic waste that is different from organic waste is the difficulty of decomposing in the soil, it takes tens or hundreds of years to be completely degraded. To minimize the environmental impact of plastic waste, this material must be recycled to recover the material or to produce other products such as fuels and chemicals. There are several methods to recycle the plastic waste, namely mechanical recycling, feedstock recycling and energy recovery [1].

Feedstock or chemical recycling is a promising technology in which plastic waste is converted into smaller molecules in the form of liquid or gas with pyrolysis technology to produce fuels and chemicals. Pyrolysis is the process of thermal decomposition of polymeric materials by heating without involving oxygen in the process. It generally takes place at temperatures between 400-800 °C depending on the type of plastic and the product target. The product of this pyrolysis consists of gas, liquid and solid residue fractions. During the process, the long chain of hydrocarbons will be cracked
into short chains. This liquid product will later become fuel, both in the form of gasoline and diesel fuel. Some plastic waste has been pyrolyzed such as CD case [2], polypropylene (PP), polystyrene (PS) [3] and other materials. The liquid product has also been tested in a diesel engine as a partial substitute for diesel fuel [4].

Therefore, converting plastic waste into fuels with pyrolysis technology is a very prospective choice for plastic recycling which cannot be recycled mechanically due to economic considerations. The main issue in running the pyrolysis plant for waste plastics and waste tire is how to operate the plant efficiently with the minimum energy required for heating the reactor. Therefore, the alternative heating source for the pyrolysis reactor should be applied to reduce the energy cost.

Biomass is one of the alternative source for heating the pyrolysis reactor which is abundant in Indonesia. Biomass has the potential to become one of the main energy sources in the future, and the modernization of the bioenergy system is suggested as an important contributor to the development of sustainable energy in the future, especially for sustainable development in industrialized and developing countries [5]. As a result, there will be a massive mobilization of biomass supply in an effort to meet energy needs in each region [6].

One of the biomass source which has the potential as an alternative energy is nyamplung (*Calophyllum inophyllum*) mostly found in the southern Central Java province such as Cilacap and Kebumen. Utilization of nyamplung as alternative fuels has been carried out, especially nyamplung seed oil as a substitute for kerosene and diesel fuel [7]. The pyrolysis process has been used by some researchers to produced bio-oil from nyamplung [8][9][10]. The oil yield depends on some parameters such as moisture content and particle size [11]. Fuel oil production from nyamplung will generate the solid residual waste produced after pressing nyamplung in the machine. The nyamplung seed cake still has some energy content which can be used as fuel for burner.

The challenge in developing pyrolysis of plastic waste in developing countries such as Indonesia is how to design cheap and easily fabricated technologies, and use independent or abundant energy sources. The implementation of this technology is more focused on small and medium scale by looking at the current characteristics of plastic waste management that involve waste banks at the village.

The integrated plastic waste pyrolysis system consists of several main parts, namely the chopper machine, pyrolysis machine, charcoal pellet machine and burner. The complete scheme of this system can be seen in Figure 1. The chopper machine reduces the particle size of the plastic waste before it is put into the pyrolysis machine in order to maximize the reactor capacity. The energy source used to heat the pyrolysis machine is taken from the gas, residual solids from the pyrolysis and biomass.

![Figure 1. Integrated waste plastic pyrolysis system for small and medium scale application.](image-url)
2. **Materials and Methods**

2.1. **Materials**

The biomass used as feedstocks in these experimental works was nyamplung seed cake and wood pellet. Nyamplung seed cake was collected from nyamplung processing plant in Badan Usaha Milik Desa (BUMDes) Panggung Lestari, Bantul producing oil and raw materials for cosmetics and pharmacy industries. Wood pellet has been used as comparative feedstock supplied from PT. Mahya Bioenergi, Boyolali. The physical appearances of these feedstocks can be seen in Figure 2.

![Figure 2. Nyamplung seed cake and wood pellet samples used in the experiments.](image)

2.2. **Biomass burner design**

The burner has been designed for the application using solid fuel such as biomass and waste. The burner consists of hopper, feeding system, air intake and blower, ash removal and flame output. Burner lid was designed with a water seal to prevent the smoke and air coming out from this part. The feeding system can be used to prevent backflow of the air. The air supply was coming from the blower. A schematic design of the biomass burner used in these works is shown in Figure 3.

![Figure 3. Burner Design](image)

1. Fuel hopper
2. Fuel feeding system
3. Air intake
4. Ash removal
5. Flame output

One of the important part of the burner is ash removal system. This part was used to remove the ash produced in combustion of biomass. The ash would be dropped and collected to the bottom part of burner during the process. Water had been filled at the bottom to inhibit the ash from spreading into the air. This system was very important in continuous combustion system since the ash can block the flame during combustion if still remain in combustion chamber. Figure 4 shows the ash removal system used in the burner.
2.3. Experimental design
The experimental work had been carried out using nyamplung seed cake and wood pellet as burner fuels. This study aims to investigate the effect of air flow rate on the fuel consumption, thermal efficiency, and flame temperature of the burner for each feedstock. The air flow rate was measured using digital anemometer. The thermal efficiency was calculated based on water boiling test (WBT) method which commonly used for testing the cookstove. A temperature probe (K-type thermocouple) was put on the flame output to measure the flame temperature of each fuel and air flow rate.

The thermal efficiency of the burner was calculated based on WBT test method using the following formula:

\[
\text{Thermal Eff.} = \frac{4.186 \times (P_{cil} - P_c) \times (T_{cf} - T_{ci}) + 2260 \times (W_{cv})}{F_{ci} \times LHV} \times 100\% \quad (1)
\]

where:
- \( LHV \) = Lower Heating Value of biomass (kJ/kg)
- \( F_{ci} \) = mass of solid fuel (kg)
- \( P_{cil} \) = initial mass of pot and water (kg)
- \( P_c \) = mass of pot (kg)
- \( T_{ci} \) = initial mass of water (kg)
- \( T_{cf} \) = mass of water after testing (kg)
- \( W_{cv} \) = mass of water vapour (kg)

3. Results and Discussion
3.1. Effect of air flow rate on fuel consumption
The experimental works had been conducted at the air flow rate of 7, 10.5, and 15 m/s for each feedstock to study the effect of oxygen supply on the performance of the burner. The results show that the increase of the air flow rate will increase the fuel consumption of the burner for both feedstocks as shown in Figure 5. The reason is when the air flow rate increase, it means that the oxygen supply will also be increased. This condition will effect to more combustion reaction occured in the combustion chamber. As a result, the fuel combusted in the chamber will increase.
The figure also shows that nyamplung seed cake has higher fuel consumption rate compared to wood pellet. The density of the fuel might be the key factor for this trend. Nyamplung seed cake has lower density than wood pellet since it has not been mechanically pressed yet. The density of the fuel would affect the supplying of the feedstock into the chamber. This condition would reduce the feedstock rate to the burner.

![Figure 5. Effect of air flow rate on the fuel consumption of biomass burner.](image)

### 3.2. Effect of air flow rate on thermal efficiency

Figure 6 showed the thermal efficiency of the burner as the effect of air flow rate. From the figure, we can see that the maximum thermal efficiency of the burner can be achieved at the air flow rate of 10.5 m/s for both fuels. The lower and higher air flow rate will reduce the thermal efficiency of the burner. This is due to the lack of oxygen supply in the lower air flow rate which affected to the combustion process in the chamber. Some fuel may be not combusted completely. When the air flow rate increase, more oxygen will be supplied which lead to reduce combustion temperature since the oversupply of the air.

![Figure 6. Effect of air flow rate on the thermal efficiency of biomass burner.](image)
3.3. Effect of air flow rate on flame temperature

The most important thing when using burner for pyrolysis process is flame temperature. During the pyrolysis process, the minimum temperature is required to keep the pyrolysis reaction occurred. Figure 7 shows the flame temperature of burner using nyamplung seed cake at various air flow rate. It shows that the increase of air flow rate increase the flame temperature. More oxygen supply affect the reaction to become more intensive.

![Figure 7. Effect of air flow rate on the flame temperature of burner using nyamplung seed cake.](image)

The effect of air flow rate on the flame temperature of burner using wood pellet as a fuel is shown in Figure 8. From the figure, we can also see that the highest flame temperature can be achieved at the air flow rate of 10.5 m/s. When the air flow rate was increased to 14 m/s, the flame temperature was slightly reduced. The reason is that wood pellet has higher density compared to nyamplung seed cake. The high density of fuel will make the air more difficult to penetrate inside the pellet. Therefore, the reaction rate was lower than that of nyamplung seed cake.

![Figure 8. Effect of air flow rate on the flame temperature of burner using wood pellet.](image)

Figure 9 shows the comparison of the flame temperature between nyamplung seed cake and wood pellet. The result shows that wood pellet generate higher flame temperature compare to nyamplung seed cake. Higher density and higher heating value of wood pellet resulted in higher flame temperature. The figure also shows that the flame temperature of wood pellet was more stable than that of nyamplung seed cake. The uniform characteristics of wood pellet will make steady combustion process.
Figure 9. Comparison of flame temperature of burner using wood pellet and nyamplung cake seed at the air flow velocity of 10.5 m/s.

The maximum and average flame temperature of burner using nyamplung seed cake and wood pellet was summarized in Table 1. Wood pellet produced higher maximum and average flame temperature compared to nyamplung seed cake. The average flame temperature was high enough for pyrolysis process which requires the temperature around 400-500°C. The highest average flame temperature of burner by using nyamplung seed cake can be achieved at the air flow rate of 14 m/s.

Table 1. Flame temperature of burner using wood pellet and nyamplung seed cake.

| Feedstock            | Air flow rate (m/s) | Maximum temperature (°C) | Average temperature (°C) |
|----------------------|---------------------|---------------------------|--------------------------|
| Nyamplung seed cake  | 7                   | 818                       | 629.8                    |
|                      | 10.5                | 975.2                     | 783.9                    |
|                      | 14                  | 972.6                     | 792.1                    |
| Wood pellet          | 7                   | 887                       | 748.4                    |
|                      | 10.5                | 991.9                     | 859                      |
|                      | 14                  | 973.4                     | 837.5                    |

4. Conclusion
Development of a biomass burner has been successfully fabricated, tested and applied for pyrolysis system. The results show that the increase of the air flow rate would increase the fuel consumption of the burner for both feedstocks. Nyamplung seed cake had lower fuel consumption rate compared to wood pellet. The density of the fuel might be the key factor for this trend. The contrary results show that the thermal efficiency of the burner was higher by using nyamplung seed cake as a feedstock compared to that of wood pellet. However, the maximum flame temperature of nyamplung seed cake was lower than that of wood pellet. This is due to the lower density and lower heating value of nyamplung compared to wood pellet which lowering the combustion rate in the burner. The increase of air supply increase of the maximum flame temperature but decrease the thermal efficiency. The flame temperature of wood pellet was also more stable than nyamplung seed cake. The uniform characteristics of wood pellet would make steady combustion process.
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