A comparative investigation of biomass pyrolysis on connecting tube performance for liquid smoke production

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Abstract. Currently, optimizations of biomass pyrolysis processes become an exciting topic. This is due to the increasing requirement of energy. This study focuses on the optimization of the pyrolysis process of palm starch waste, especially liquid smoke product. The optimization of the liquid smoke product had conducted through the modification of connecting-tube between pyrolysis reactor and condenser. The connecting tube has differences in diameter, length, and material. The results of the study show variations in size and type of tube affect the product yield of the pyrolysis process. Stainless-steel pipes have better performance to produce liquid-smoke. The shorter the length of the pipe increases the quantity of liquid-smoke, but the smaller the diameter of the pipe decreases the quantity of liquid-smoke. This paper discusses in more detail the comparison of the performance of connecting tube by modifying the type of material, the length, and the diameter of the pipe.

1. Introduction
The home industry of palm processing at Bendo village, Klaten, Jawa Tengah, Indonesia, face problem in case of waste handling. There is 137 home industry of palm processing. The processing of palm trees produces waste that pollutes the environment. Each of home industry produces 600-700 Kg/day of palm starch waste (solid waste), and the waste is currently untapped and unwell-processed. Therefore, it made a problem for the environment at around the home industry area, for example smell, groundwater contamination, and blockage of river flow.

On the other hand, palm starch waste has the potential for energy generation. The previous study on palm starch waste has conducted through the biomass of Refuse Derived Fuel (RDF) [1] and gasification of palm starch waste [2,3]. The results showed that palm starch waste has the potency as a renewable energy source if found the match process of energy converter from waste to energy. Palm starch waste could be converted into energy through several methods, such as the direct combustion, gasification and pyrolysis process. Pyrolysis is one of common method that use to manage the waste to energy [4], due to the economic and sustainability implications [5]. The pyrolysis process is the best technology for processing biomass than direct combustion and gasification [6]. The main products of the pyrolysis process are liquid smoke (bio-oil), Syngas, and Char [7].
The pyrolysis of palm starch waste has similarity with wood pyrolysis [8], which is the main product is liquid smoke. Therefore, this study conducted the experiment to convert the palm starch waste to liquid smoke (bio oil) through the pyrolysis processes. However, the pyrolysis product has relation with the type of biomass [9,10]. In order to find the appropriate pyrolysis apparatus for biomass of palm starch waste, this study focuses on the investigation of the modification of connecting-tube between pyrolysis reactor and condenser. Heat transfer as one of the mechanisms that affects the process of pyrolysis, the effect of the heat loss to the surrounding affects the stability of required pyrolysis temperature, and this has to be minimized. One of the reductions in heat loss can be overcome through the selection of the right connecting tube design. The objective of this study is to optimize the pyrolysis process of palm starch waste especially liquid smoke product as shown in figure 1.

![Image](image_url)

**Figure 1.** Illustration of pyrolysis process of palm starch waste.

2. **Experimental setup and research method**

2.1. **Experimental setup**

The pyrolysis of palm starch waste (figure 2) conducted in fixed bed shell type model with a capacity of 38.5 liters, while liquid smoke condensation uses water fluid in a 150 mm vertical condenser equipped with finned pipes with the opposite fluid flow direction. Temperature readings at the reactor used a K type digital thermocouple with two reference points below the reactor used. The pyrolysis apparatus of palm starch waste biomass shown in figure 3.
2.2. Research method
The research method that applied in this study is experimental method. The fast pyrolysis was employed by using 200 grams of biomass and conducted at 400°C. The optimization of the liquid smoke product had conducted through the modification of connecting tube diameter, length, and material. This experiment had employed six types of connecting tube i.e. a) galvanism pipe ø 0.019m x 1m, b) galvanism pipe ø 0.019m x 0.5m, c) galvanism pipe ø 0.00635m x 0.5m, d) stainless steel pipe ø 0.019m x 1 m, e) stainless steel pipe ø 0.019m x 0.5 m, and f) stainless steel pipe ø 0.00635m x 0.5 m. Figure 4 shown the example of connecting tube.

![Connecting tube](image)

**Figure 2.** Biomass of palm starch waste

**Figure 3.** Pyrolysis apparatus.

**Figure 4.** Connecting tube
3. Results and discussion

3.1. The effect of the length of connecting-tube to the liquid smoke production

Figure 5a and 5b describe the effect of connecting-tube length on liquid smoke production at diameter 0.019 m. The liquid smoke was measured during the 60 minutes after the condenser valves start the production of liquid. The first fifteen minutes are a crucial point for different performance of connecting tube between length =0.5 m and length =1 m, for galvanized and stainless-steel material. At that time, connecting-tube length =0.5 m has the production rate of liquid faster than connecting-tube length = 1 m. Therefore, the production volume of connecting-tube length =0.5 m higher than connecting-tube length =1 m. The second fifteen minutes (elapsed time = 30 minutes) shows that the production rate of liquid smoke for connecting tubes length = 1 m increases rapidly but the production volume is still below the connecting tube length = 0.5 m. The third fifteen minutes (elapsed time = 45 minutes) shows that there is no increase in volume, both connecting tubes length = 0.5 m and length = 1 m. At that time the pyrolysis process has finished and the biomass of palm starch waste completely burned in the pyrolysis reactor.

Finally, the pyrolysis process of 200 grams biomass of palm starch waste by using connecting-tube length =0.5 m and length =1 m shows the slightly difference in volume of liquid smoke production. The galvanized material produced 83 ml of liquid smoke by using the connecting-tube length =0.5 m and produced 81 ml by using the connecting-tube length = 1 m. While, the stainless-steel material produced 85 ml of liquid smoke by using the connecting-tube length =0.5 m and produced 83 ml by using the connecting-tube length = 1 m. These results informed that the distance of the reactor and condenser at pyrolysis process (connecting tube length) affects the distribution of heat and energy loss. Furthermore, uniform heat distribution is significant for effective mass and energy transfer (effective thermal conductivity in axial and radial direction, wall heat transfer coefficient), and it is integral to valuable obtaining and narrow range of hydrocarbons, so operating conditions significantly affected results were obtained by any experimental pyrolysis set-up.

![Figure 5](image-url)

**Figure 5.** The comparison of liquid smoke products between connecting tube used 0.5 m and 1 m length for diameter 0.019m; a) galvanized material and b) stainless steel material.

3.2. The effect of the diameters of connecting tube to the liquid smoke product

In order to observe the effect of diameters of connecting tube to the liquid smoke product, the connecting-tube diameter = ¼ inch (0.019 m) and ¼ inch (0.00635 m) was employed. Figure 6 show that the results of the comparison of liquid smoke production between the connecting-tube Ø =0.019 m and Ø = 0.00635 for galvanized and stainless-steel material. The result shows have relation to the steam flow that occurs in site of the connecting-tube. The connecting tube Ø = 0.00635 m has the small cross-sectional area than the connecting-tube Ø =0.019. Therefore, the steam flow in site of the connecting-tube Ø = 0.00635 faster than connecting-tube Ø =0.019. When the steam flow became fast, the pre-
condensation processes at connecting-tube between reactor and condenser occurred in the short time. It causes the liquid smoke production in connecting-tube $\varnothing = 0.00635$ lower than connecting-tube $\varnothing = 0.019$.

![Comparison of liquid smoke products](image1.png)

**Figure 6.** The comparison of liquid smoke products between connecting tube $\varnothing = 0.019$ m and $\varnothing = 0.00635$ m diameters for length= 0.5m; a) galvanism material and b) stainless steel material.

3.3. The effect of the material of connecting tube to the liquid smoke product

The results of the effect of the material of connecting-tube to the liquid smoke product were shown in figure 7. Figure 7 reported the quantity of each variation of the connecting tube. The results was shown through the data sequence from the heights liquid smoke production i.e. stainless steel ($\varnothing = 0.019$ m and length= 0.5 m), galvanized ($\varnothing = 0.019$ m and length= 0.5 m), galvanized ($\varnothing = 0.019$ m and length= 1 m), stainless steel ($\varnothing = 0.00635$ m and length= 0.5 m), galvanized ($\varnothing = 0.00635$ m and length= 0.5 m), stainless steel ($\varnothing = 0.019$ m and length= 1 m). The results show that the stainless-steel connecting-tube $\varnothing = 0.019$ m and length= 0.5 m is suitable for supporting the pyrolysis of palm starch waste.

![Liquid smoke production](image2.png)

**Figure 7.** Liquid smoke production in different materials of tube.

4. Conclusions

The experiment of optimization of the liquid smoke product through the modification of connecting tube diameter, length, and material has been performed. The results have shown that the diameter, length, and material of connecting tube significantly affected the liquid smoke products of pyrolysis of palm starch waste biomass. The experimental results showed that both pipes produced the same liquid-smoke
quantity at a diameter of 0.00635 m with a length of 0.5 meters, but slightly more stainless-steel pipes at a diameter size of 0.019 m with a length of 1 meter and 0.5 meters although the difference was not significant. The graph shows the galvanized pipes and stainless-steel pipes, and the pipe length 0.5 more and more produces liquid-smoke than the 1-meter long tube. Based on the size of the diameter, the pipe 0.00635 m produces more liquid-smoke than 0.019 m both from galvanized and stainless steel. The study has recommendation for pyrolysis of palm starch waste biomass, especially to increase the liquid smoke products by using connecting tube Ø = 0.019 m, length = 0.5 m and stainless-steel material.

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