

Development of bio-fuel from palm frond via fast pyrolysis

M D Solikhah¹, A A Raksodewanto¹, A Kismanto¹, F Karuana¹, Y Heryana¹,
Riza¹ and F T Pratiwi¹

¹Agency for the Assessment and Application of Technology, Build. 480 PUSPIPTEK,
South Tangerang, Indonesia.

Email : maharani.dewi@bppt.go.id

Abstract. In order to fulfill the fuel demand in the future, Indonesia has to find a sustainable alternative for its energy. Energy source in the form of biomass is a promising alternative since its availability is abundance in this tropical country. Biomass can be converted into liquid fuel via fast pyrolysis by contacting the solid biomass into hot medium in the absence of oxygen. Hot sand is the common heat carrier for fast pyrolysis purposes but it is very abrasive and required high pyrolysis temperature (450-600 °C). This paper will discuss on the equipment design and experiment of fast pyrolysis of palm frond using high boiling point thermal oil as heat carrier. Experiments show that by using thermal oil as heat carrier, bio-oil can be produced at lower pyrolysis temperature of 350 °C, compared to the one using hot sand as heating carrier. The yield of bio-oil production is 36.4 % of biomass feeding. The water content of bio-oil is 52.77 % mass while heating value is 10.25 MJ/kg.

1. Introduction

Indonesia is currently facing a big problem in fulfilling fuel demand. The increasing of fuel demand has reached almost 1.5 million barrels per day at 2015 while production is only nearly 0.8 million barrels per day and decreasing year by year [1]. The gap between demand and production is filled with fuel import that causes pressure on national economics. Therefore, it is required to obtain alternative fuel to find a sustainable alternative for its energy.

As a country that blessed with sunlight and produce a lot of biomass, converting biomass into fuel could become the best way. Biomass may be converted into liquid fuel via pyrolysis. Pyrolysis is a thermo-chemical decomposition process in which organic material such as biomass is converted into a carbon-rich solid (charcoal), liquid, and gaseous products by heating in the absence of oxygen [2]. The amount of each product can be adjusted by adjusting the temperature and residence time of the process [3]. Slow pyrolysis that occurs for hours up to days produce more char than fast pyrolysis. Fast pyrolysis process can give much liquid from the pyrolysis processes of the biomass feedstock and only occurred in order of seconds at higher temperature. Therefore, fast pyrolysis gives advantages on



producing liquid fuel. On the other hand, Gable and Brown [4] mentioned that bio-oil production on fast pyrolysis did not stop at 2 s and still produce until 42.4 s. These studies will be useful for the design of fast pyrolysis reactor.

Fast pyrolysis has been studied using various kind of reactor such as fluidized bed reactor, transported bed & circulating fluidized bed, rotating cone, and auger or screw [5]. Commercial scale pyrolysis reactor has been developed by Biomass Technology Group (BTG) of Netherland that using “rotating cone reactor” where biomass was heated by hot sands as heat carrier so that ablation and vaporization occurred [6]. Another commercial technology owned by Ensyn called “Rapid Thermal Processing” where biomass heated using hot sands in a fluidized bed reactor. Biomass will be vaporized and flowed up together with hot sands and char [7]. The vapor was separated from sand and char then condensed. Both technologies operated at temperature of 450 – 600 °C and can produced bio-oil of 55 – 75 % mass of biomass feeding. However, the hot sands caused abrasion on the equipment.

Other pyrolysis method has been studied by Jess, et. al. [8] that developed a fast pyrolysis process that using vacuum gas oil as a heat carrier. Jess *et al.* [8] produced bio-oil at lower temperature than Ensyn or BTG *i.e.* 320 – 400 °C with 60% mass of bio-oil production. This process is promising but vacuum gas oil is difficult to be found at open market. On the other hand, the similar heat transfer characteristics could be found on selected heat transfer oil that has high boiling point suitable for the operation temperature of the pyrolysis.

Pyrolysis process can utilize any kind of biomass. In Indonesia, the biggest source of biomass is oil palm plantation and industry since Indonesia has become the biggest producer of palm oil in the world. At 2014 Indonesia had more than 10 million hectares of oil palm plantation and almost 30 million tons of crude palm oil [9] that may produce biomass such as palm frond, palm trunk, fiber, shell, and empty fruit bunch. Palm fiber and palm shell has been widely utilized for own use power generation at palm oil mill while palm trunk only produced during replanting after 25 – 30 years. Empty fruit bunch’s production may reach 4.4 tons/(ha·year) and still not widely utilized but it has high moisture content, very tough to be chopped and contain high mineral content that may affect the reaction [10]. On the other hand, palm frond has low moisture content, easy to be crushed, and has a low utilizations. The production of palm frond from pruning can reach 10.4 tons/(ha·year) [11]. Therefore, palm frond has a good future for biomass utilization.

From above discussions, it was found that the use of liquid heat carrier could produce bio-oil at lower temperature at productivity that competitive with the one using hot sand as heat carrier. So, this paper will discuss on the equipment design and experiment of fast pyrolysis of palm frond using high boiling point thermal oil as heat carrier.

2. Method

2.1. Material

Biomass used in this experiment was palm frond that collected from palm tree in PUSPIPTEK, South Tangerang, Indonesia. The leaves were removed from the frond prior to chopping and powdering until size of 16 – 30 mesh. The size comparison is presented at Figure 1. The water content of the frond powder was measured. Thermal oil heater used in this experiment was Mobiletherm 605 (Mobil Oil Co. Ltd., Surrey, UK).



Figure 1. (a) Fresh palm frond (b) Palm frond after chopping (c) Palm frond after powdering

2.2. The Reactor

A continuous pyrolysis reactor was designed and equipped with electric heater, inclined screw feeder for torrefaction, thermal oil recovery (char filter and screw conveyor), and condenser for bio-oil collection. Condenser was using water as cooling media. All heaters were controlled using temperature controller. All parts of reactor were isolated using high temperature rock-wool insulation of 10 cm. The residence time of the reactor was design for 30 – 60 s. Figure 2 shows the 3D design and the actual reactor used in this experiment.

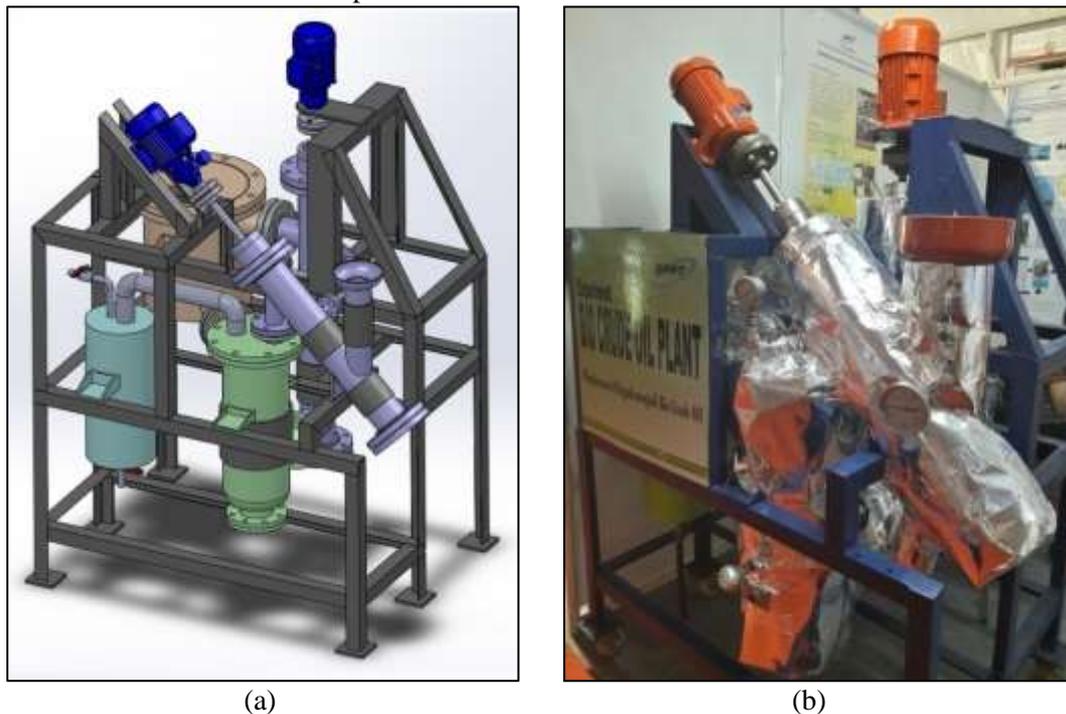


Figure 2. (a) The 3D design and (b) the actual Pyrolysis Reactor

2.3. Fast Pyrolysis Experiment

Thermal oil of 21 kg was heated until 350 °C in the reactor. Torrefaction section was heated until 200 °C prior to reaction experiment to remove the water contained in the biomass. After all temperature was reached, 5.5 kg of biomass fed into torrefaction section at flow rate of 150-200 grams per minute. Biomass was heated in torrefaction section and flowed into reactor trough screw feeder to perform fast pyrolysis reaction. When biomass contacted with thermal oil inside the reactor, vapor was developed. The vapor flowed out from the top of the reactor and condensed at the condenser then collected as

liquid at the output of condenser. This liquid was weighted and collected as liquid product. This reaction also produced char. To avoid char accumulation in the reactor, the char was removed from reactor using screw conveyor and transported into char filter. After char removal, heat transfer oil was circulated back into reactor. This circulation also enhanced heat transfer performance in the reaction, either from reactor wall into heat transfer oil as well as from heat transfer oil into biomass. The schematic diagram of the reactor is presented in Figure 3. The mass input and output from the experiment was measured to analyze the mass balance of the system. Furthermore the yield of bio-oil production was calculated as mass of bio-oil divided by mass of palm frond used in the experiment.

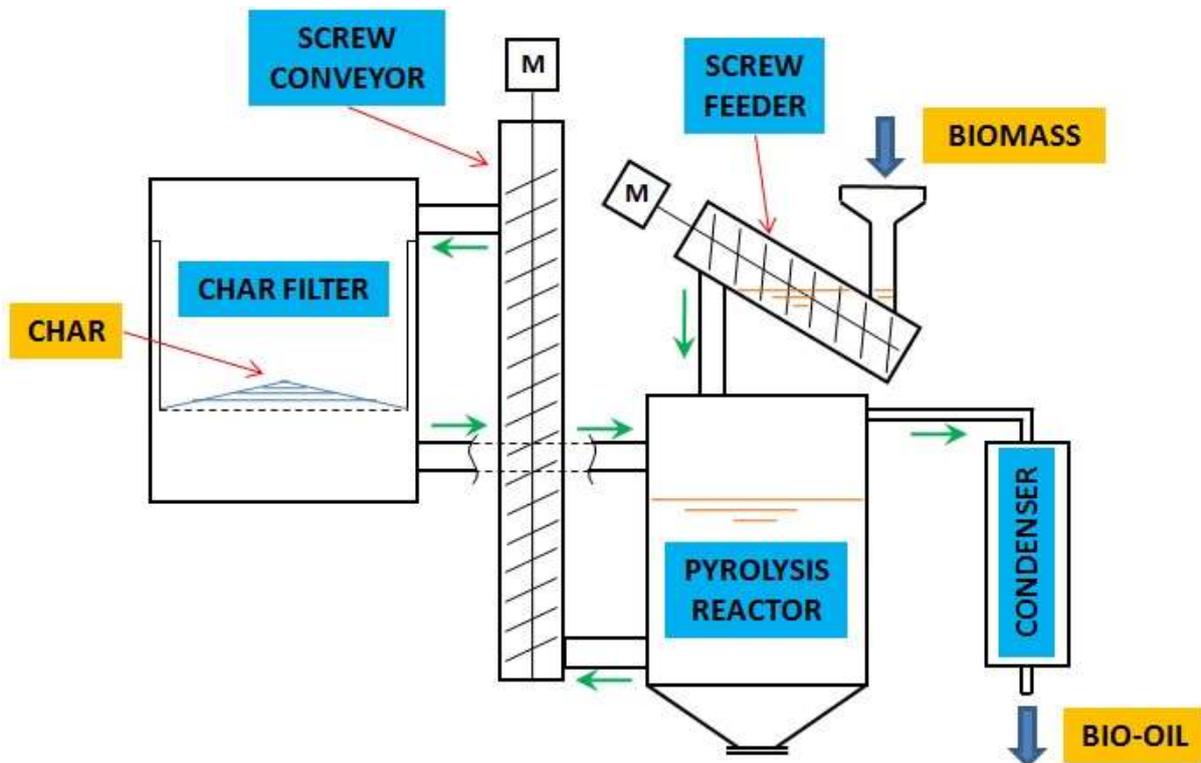


Figure 3. Schematic Diagram of the Fast Pyrolysis Reactor

2.4. Product characterizations

Liquid product collected from condenser formed in two phases: upper phase and bottom phase. The upper phase was in light color and water insoluble, called as sample A. The bottom phase was in dark color and water soluble, called sample B. Sample A and B was separated using funnel separator prior to analysis. Both samples were analyzed by GC/MS to determine the composition. A Shimadzu GC/MS QP 2010 (Shimadzu Corp, Tokyo, Japan) equipped with column of DB1 (30 m x 0.32 mm x 1 μ m capillary column) was used on the analysis. A 0.8 μ L sample was injected on the column that started at 40 $^{\circ}$ C and hold for 4 minute, after that, ramped at 5 $^{\circ}$ C/minute until 250 $^{\circ}$ C and then hold for 10 minute. Water content was analyzed on sample B using Karl Fisher KF200 (Mitsubishi Chemical Analytech Co.,Ltd., Kanagawa, Japan). Heating value was measured on sample B using Automatic Calorimeter AC500 (Leco Corp., Saint Joseph, USA). The pH analysis was performed on sample B using 848 Titrino plus (Metrohm AG, Switzerland).

3. Results and Discussions

3.1. Reactor Performance

Before filled into the reactor, the water content of frond powder was analyzed. The water content of palm frond was 11.54 % mass. The reactor was working well and can reach 350 °C after 1 h from ambient temperature. The liquid product produced from 5.5 kg palm frond powder was 5.38 kg (sample A + sample B). The mass balance of the reaction is presented at Table 1. This table shows that there is 7.9 % mass loss from the system. From observation during the experiments, some vapor has been loss from between flanges that may contribute to the mass loss. Therefore, prevention of leakage should be of concern in the further design of the reactor.

Table 1. Mass Balance on Bio-oil Production from Palm Frond

Input, kg		Output, kg	
Biomass	5.5	Liquid Product	5.4
Heating oil	21.0	Char	8.0
		Heating oil recovered	11.0
Total	26.5	Total	24.4

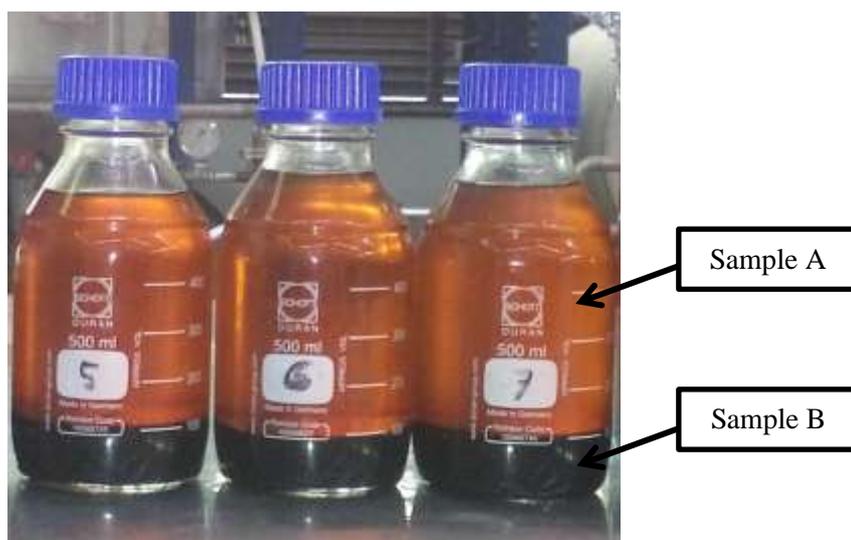


Figure 4. The appearance of liquid product from the reactor

3.2. Bio-oil Characterizations

Figure 4 shows the appearance of liquid product from the reactor. Liquid product was separate into two phases: water insoluble phase (sample A) and water soluble phase (sample B). GC/MS analysis was conducted on sample A, sample B, and heating oil for comparison. Figure 5 and figure 6 show the chromatogram of heating oil and sample A. From these figures, it is observed that both chromatograms are similar and most of sample A are heating oil. Therefore, it is concluded that sample A is not bio-oil.

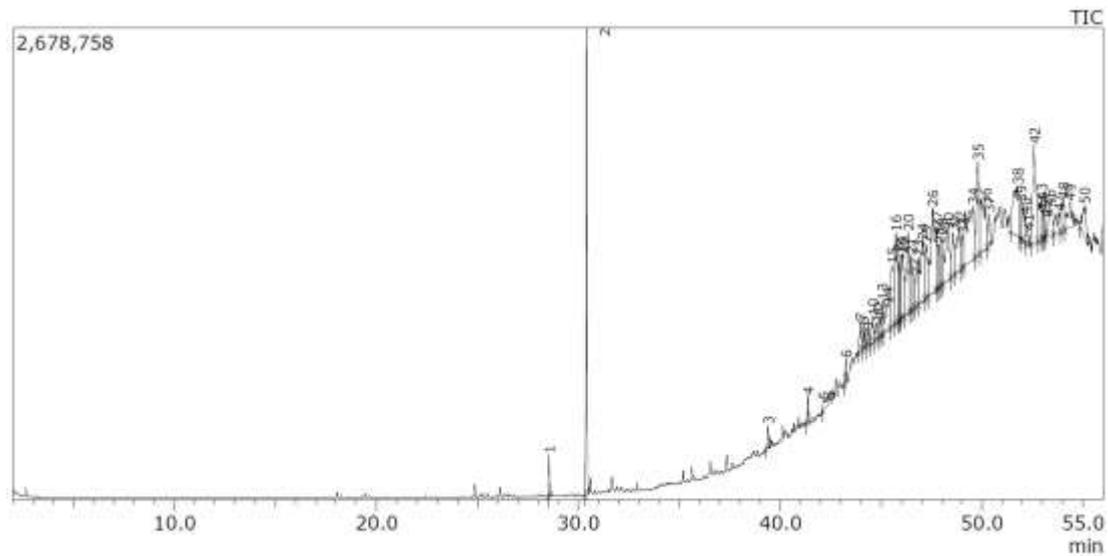


Figure 5. Chromatogram of Heating Oil (Mobileterm)

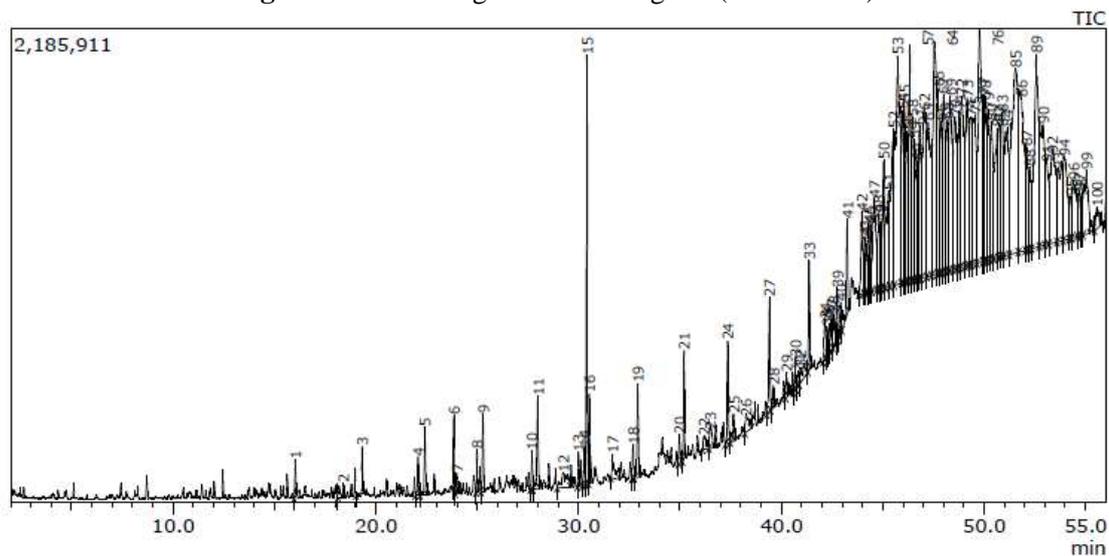


Figure 6. Chromatogram of Sample A (Water Insoluble Phase)

According to Bridgewater [5], pyrolysis oil typically is a dark brown, free-flowing liquid, and composed of a complex mixture of oxygenated compounds. By using this definition, sample B is the liquid that referred to as “bio-oil”. After separation from sample A, 2 kg of bio-oil was obtained from the liquid product. Therefore, the yield of bio-oil production was 36.4 % of biomass feeding. This result is still between the ranges of 16.6 – 43.5 % that mentioned by Abnisa *et al* [11].

The result of GC/MS analysis of bio-oil was presented at Figure 7. This figure shows chromatogram that is different from Figure 5 and Figure 6. The dominant component of bio-oil is presented on Table 2. This table shows that carboxylic acids, ketones, aldehydes, and phenol were indicated and most of the functional groups contained oxygen. The composition of bio-oil is in line with the result made by previous studies [12,13]. Presence of the above oxygenated components makes this phase becomes water soluble. The pH and water content of bio-oil was 2.2 and 52.77 % mass, respectively, that is in accordance to the work of Abnisa *et al*. [11]. Heating value of bio-oil was 10.25 MJ/kg that is lower than the result from Abnisa *et al*. [11]. This result may be caused by the high content of oxygenated

components especially acetic acid and phenol as showed in the GC/MS analysis that can reduce the heating value of bio-oil.

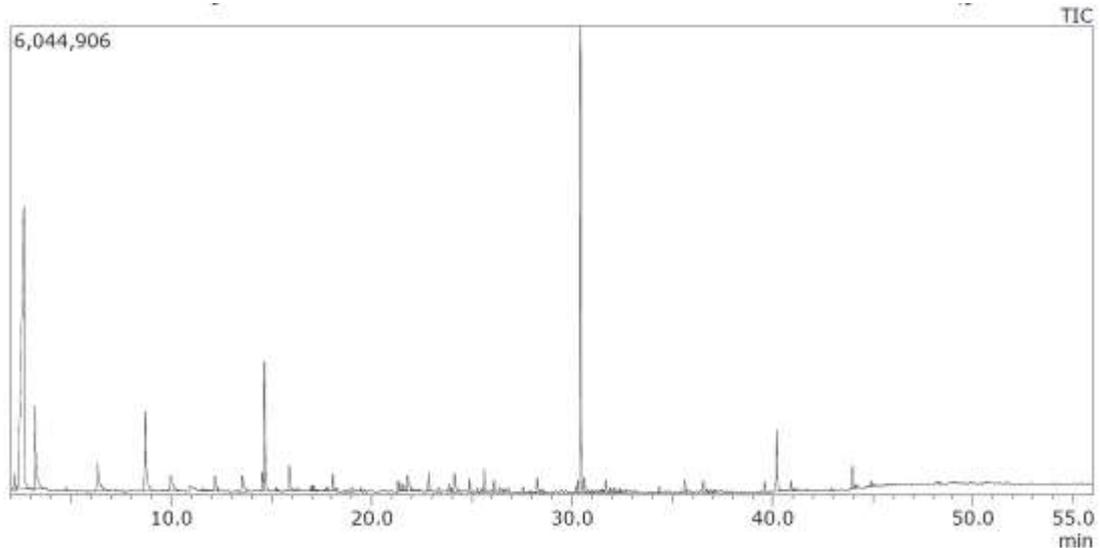


Figure 7. Chromatogram of bio-oil from palm frond

Table 2. The dominant component in Bio-oil

Components	% Area
Acetic Acid	30.20
2-Propanone (Acetone)	4.14
2-Furancarboxaldehyde (Furfural)	4.85
Phenol	5.70
Phenol, 2-methoxy-	0.75
2-Methoxy-4-methylphenol	0.46
Phenol, 2,6-bis(1,1-dimethylethyl)-	19.48
Palmitic Acid	3.09
Total	68.67
Others	31.33

4. Conclusions

The equipment design and experiment of fast pyrolysis of palm frond using high boiling point thermal oil as heat carrier has been conducted. The conversion of palm frond into bio-fuel via fast pyrolysis using heat transfer oil as heat carrier has been elucidated. This experiment shows that by using thermal oil as heat carrier, bio-oil can be produced at lower pyrolysis temperature of 350 °C, compared to the one using hot sand as heating carrier. Bio-oil has been characterized having heating value of 10.25 MJ/kg, water content of 52.77 %, and pH of 2.2. GC/MS analysis of bio-oil shows that it consisted of carboxylic acid, aldehydes, ketones, and phenols that caused bio-oil soluble in water. The most dominant component was acetic acid and phenol. The reactor can produce bio-oil at yield 36.4 % mass. However, 7.9 % of mass loss has been observed. Therefore it is suggested to improve the reactor by eliminate the vapor loss at flange connection and install a chiller condenser.

Acknowledgements

This research project is funded by “Badan Pengelola Dana Perkebunan Sawit” No. PRJ-30/DPKS/2015.

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