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Research paper

Product distribution from microwave pyrolysis of automotive paint sludge

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Abstract

Production of liquid, gas and solid from microwave pyrolysis of automotive paint sludge (APS) with addition of activated carbon as microwave absorber was investigated at different microwave (MW) power and amount of activated carbon. The microwave pyrolysis was conducted at three microwave powers of 600, 700 and 800 Watt (W) with 0 %, 10 % and 20 % (from automotive paint sludge weight) activated carbon. Increment of microwave power increased the gas yield with the highest yield was at 800 W due to high process temperature offered at high microwave power while the maximum solid and pyrolytic oil yields were obtained at 600 W due to low process temperature offered by low microwave power. However, highest solid yield at 600 W with 0 % activated carbon loading indicating incomplete pyrolysis process. The best amount of activated carbon loading was 10 % for the highest pyrolytic oil production whereas maximum gas yield was obtained at activated carbon loading of 20 %.

Keywords: *activated carbon; automotive paint sludge; microwave absorber; microwave power; microwave pyrolysis.*

1. Introduction

Pyrolysis has gained attention as a method of waste treatment for its ability to produce liquid, solid and gas fraction as the products by varying the parameters such as processing temperature and time depends on the products interest [1]. Besides that, pyrolysis is capable of improving the properties of a material such as the energy density and recovering high value chemicals, simultaneously [2, 3]. Unfortunately, application of pyrolysis as treatment technique becomes restricted for high moisture waste materials such as sewage sludge.

The limitation of having high moisture content in waste materials can be manipulated by using microwave during pyrolysis process. As compared to the conventional pyrolysis process, microwave pyrolysis has gained much attention due to the advantages of microwave as a heating source. Application of microwave pyrolysis on waste materials can eliminate or totally reduce the heat transfer resistance found in conventional pyrolysis process due to the radiation heating nature by the microwave. The microwave energy penetrates the waste materials and converts this energy to heat energy [4-6]. Thus, heat is generated throughout the volume of the waste materials which producing uniform and rapid heating of sample. Besides that, microwave pyrolysis gave high heating efficiency and heating rate, resulting to a great time saving during the process.

Introduction of microwave absorber during microwave pyrolysis process has been effectively proven to improve the microwave pyrolysis process by reducing the energy consumption [9]. Without microwave absorber, high energy consumption needed in order to achieve the necessary pyrolysis temperature. This is because microwave absorber absorbs microwave energy and transfers it to the waste. Furthermore, it has been found out that microwave absorber does influence the product yield from microwave pyrolysis process. Activated carbon has been used as microwave absorber due to its dielectric properties that capable to converts microwave energy into heat in a short period of time. The performance of activated carbon as one of a good absorber during microwave pyrolysis has been proven by previous studies [7–9].

The solid, liquid and gas fractions of the product from the microwave pyrolysis process were known to have the ability to be used as alternative fuels. High energy demand from the increasing worldwide population and limitation of fossil fuel sources such as coal and petroleum also urged more research to be performed on future alternative fuel [10, 11]. Many studies have been carried out on microwave pyrolysis of waste materials such as sewage sludge, waste cooking oil and waste engine oil [12–15]. However, limited information are available on microwave pyrolysis of automotive paint sludge especially with the application of activated carbon as microwave absorber.

APS was generated from automotive manufacturing industry and it has been classified as hazardous waste that contributes to major issue on environment and health. In Malaysia, automotive paint sludge is sent to Kualiti Alam which is an authorized body to handle the hazardous waste. Based on Environmental Quality (Scheduled Wastes) Regulations 2005, APS is categorized as Schedule Waste (SW) 416 due to its hazardous material [16].

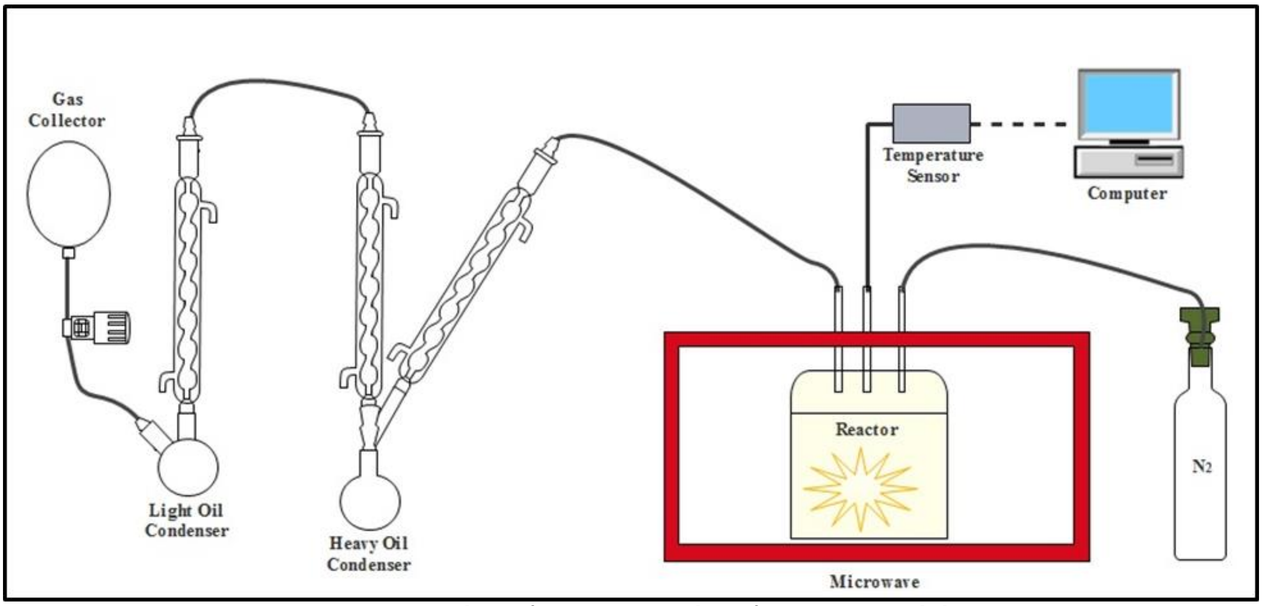

Fig. 1: Experimental setup for microwave pyrolysis of automotive paint sludge

High mass production of cars directly cause high amount of automotive paint sludge generated. It was reported by Ruffino and Zanetti [17] that 2.5-5.0 kg of paint sludge per painted car has been generated from Italian Automotive Paint Shop. It was also reported that about 100 000 tons of automotive paint sludge (APS) is produced every year regardless paint spraying process is done by robot or manually handled by people [18]. The estimation of APS generated was nearly 40% from 6 gallons of paint used to produce an exterior finish on vehicles [19]. Automotive paint sludge is known to have numerous hazardous constituents and at the same time, it contains valuable components that could be recovered [20-22]. Current method of treating automotive paint sludge is being dried in incinerator and finally dumped at landfill with no recovery being done. The application of incinerator is very limited due to the nature of APS that contains around 70% of water and this constraint has required another preliminary drying process prior to incineration [23]. Thus, microwave pyrolysis seems promising to treat the automotive paint sludge.

It is therefore, forms the basis to this study, to investigate the effect of microwave power and activated carbon loading towards products distribution in microwave pyrolysis of APS.

2. Materials and method

2.1. Materials

A constant weight of 200 g APS used in this study was collected from second largest automotive manufacturing company in Malaysia. Activated carbon (SYSTERM Chempur) has been used as microwave absorber. The amount of activated carbon used was 0 %, 10 %, and 20 % (from automotive paint sludge weight).

2.2. Microwave pyrolysis process

Fig. 1 shows the arrangement of microwave pyrolysis process used in the study. Activated carbon was placed in crucible while automotive paint sludge was placed in quartz reactor. The filled crucible was then placed inside the quartz reactor. The reactor was purged with 150 ml/min nitrogen gas for 20 minutes to ensure the system is free from any oxidative gas. It was continuously fed until the microwave pyrolysis process completed. Microwave power was set to be 600 W with 30 minutes radiation time. The process was triplicated. The whole process was repeated by changing the amount of activated carbon and microwave power as shown in Table 1. The solid, liquid and gas fractions of the products were collected. The liquid fraction comprised of the aqueous and oil phase. They were separated via liquid-liquid extraction by using hexane as the solvent. The amount of hexane used was based on the ratio 5:1 (hexane:liquid). All products yield were determined by using equation (1) to (5).

$$S\ (\%) = \frac{\text{weight of solid (g)}}{200\ g}\ x\ 100\ \% \quad (1)$$

$$L\ (\%) = \frac{\text{weight of liquid (g)}}{200\ g}\ x\ 100\ \% \quad (2)$$

$$G\ (\%) = 100\ \% - S\ (\%) - L\ (\%) \quad (3)$$

$$A\ (\%) = \frac{\text{weight of aqueous (g)}}{200\ g}\ x\ 100\ \% \quad (4)$$

$$O\ (\%) = L\ (\%) - A\ (\%) \quad (5)$$

where;

S represents solid yield, L represents liquid yield, G represents gas yield, A represents aqueous yield and O represents oil yield.

Table 1: Various microwave powers and activated carbon loadings (by weight of APS) adopted during microwave pyrolysis process

Microwave Power (W)	wt% activated carbon to automotive paint sludge
600	0
	10
	20
700	0
	10
	20
800	0
	10
	20

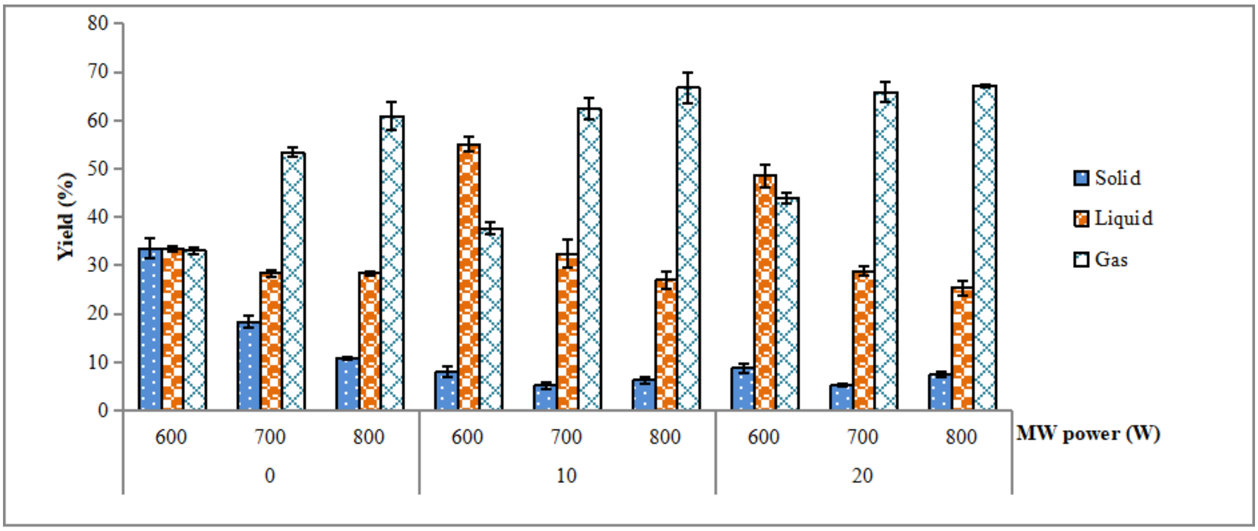

Fig. 2: Product distribution as result of microwave pyrolysis incorporating automotive paint sludge at different microwave powers.

3. Results and Discussion

3.1. Effect of microwave power

The effect of microwave power on pyrolytic products is shown in Fig. 2 and 3. Fig. 2 presents solid, liquid and gas yield. With the absence of activated carbon, the solid yield decreased while gas yield increased with increasing microwave power. There was only slight difference on liquid yield without activated carbon due to change of microwave power. It was observed that the solid fraction has not completely pyrolyzed (not fully turning into char), thus explains the high value of high solid yield. Based on visual observation, solid char at 600 W was in semi-coked form. Increasing the microwave power to 700 W and 800 W has led to reduction in liquid and increasing in gas yield with complete pyrolysis process. For the process with 10 % and 20 % of activated carbon, solid at all microwave power was in a form of char, indicating that pyrolysis process was fully completed.

Liquid faction was decreased with increasing microwave power. On the contrary, gas yield was increased with the increment of microwave power. High microwave power may be translated into high process temperature. According to Zhang *et al.* [24], the electric field strength intensity is weak at low microwave power level. Hence, polarization or vibration of molecules also slows which resulting in low heating rate of materials.

In contrast, at high microwave power, materials are heated rapidly since polar molecules vibrate vigorously due to high intensity of electric field. Thus, temperature increased rapidly, thus promoting the reduction in liquid yield and hence, increment in gas yield due to vigorous cracking process that produced non-condensable gases. Relationship between temperature and gas yield has been proven by Gao *et al.* [25] in the study of microwave pyrolysis of textile dyeing sludge that gas yield increased with the increment of process temperature from 450 °C to 750 °C .

They claimed that too high temperature promoted the cracking process of volatiles and reformed them into non-condensable gases. Hu *et al.* [26] has stated that increasing of microwave power from 750 to 2250 W increased the microwave density in its cavity and microwave energy absorbed by the Chlorella vulgaris. Hence, the vibrations of molecules also increased and heat was generated rapidly which led to secondary reaction to occur, releasing incondensable gases. Same phenomena could be used to explain the reduction in liquid phase and increment in gas yield as microwave power increased in this study.

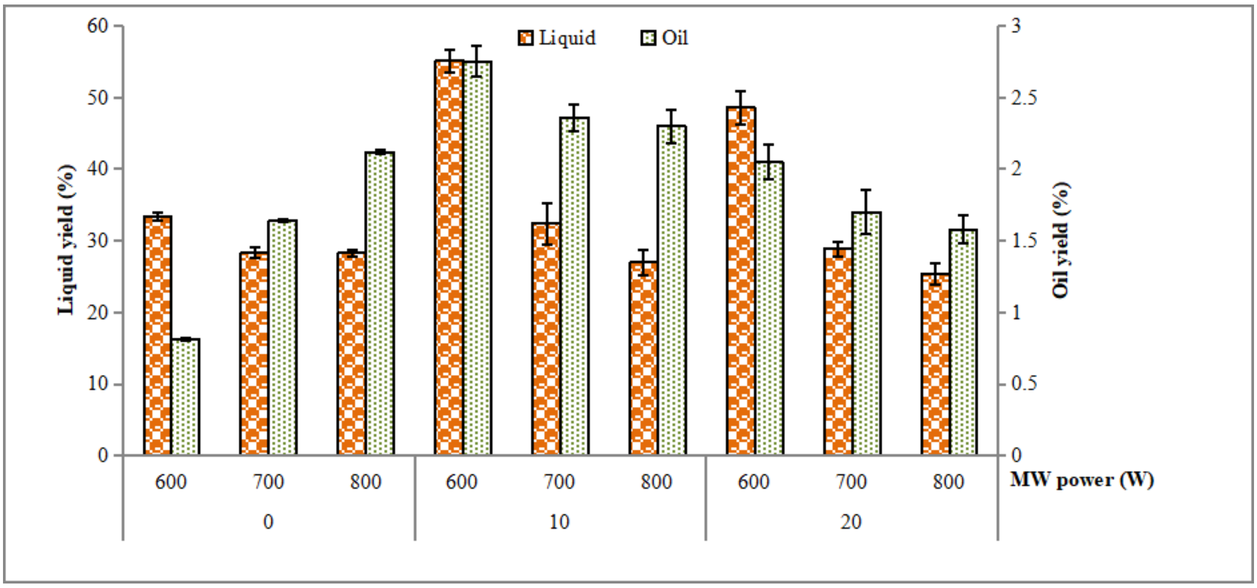

Fig. 3: Liquid and pyrolytic oil yield at different microwave power

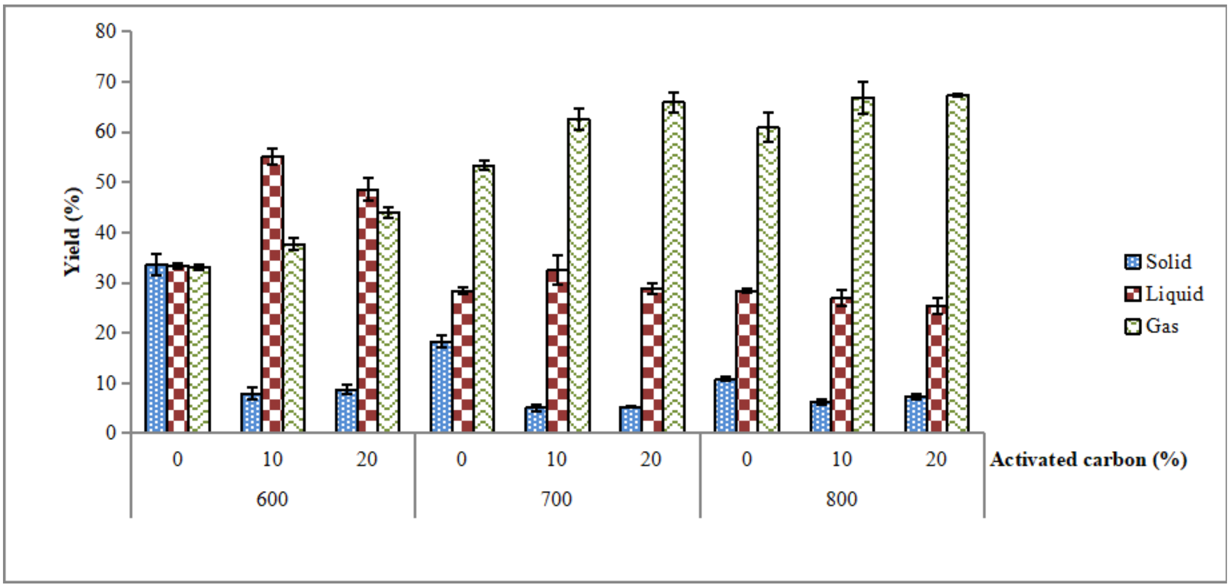

Fig. 4: Solid, liquid and gas yield at different activated carbon loading.

Liquid yield consisted of aqueous and oil which were separated through liquid-liquid extraction (LLE) process. Fig. 3 shows liquid and pyrolytic oil distribution. With the absence of activated carbon, the process with 600 W produced the lowest amount of pyrolytic oil as compared to the process with 700 and 800 W. Incomplete pyrolysis process may occur at 600 W resulting in the lowest pyrolytic oil yield since solid yield still containing volatiles compound. As mentioned earlier, increasing of microwave power led to high process temperature, promoting thermal cracking process. This phenomenon contributed to high pyrolytic oil yield.

Different observation was obtained for the process with addition of 10 % and 20 % activated carbon because it increased the process temperature as compared to the process temperature in the absence of activated carbon. Both liquid and oil yield were reduced as microwave power increased from 600 to 800 W. Although the increment of microwave power causes thermal cracking of the materials which contributes to high pyrolytic oil yield, nevertheless, the occurrence were limited since, secondary cracking could also take place at too high temperature caused, hence resulting in the production of non-condensable gases. High microwave power also promoted vaporized water molecules reacted with other pyrolysis product that later leaving the reactor in a form of non-condensable gases [27].

3.2. Effect of adding activated carbon

According to Fig. 4, high solid yield was obtained for pro-cess with 600 W with the absence of activated carbon due to incomplete pyrolysis reaction. As 10 % of activated carbon was introduced to the system, solid yield reduced and slightly increased when activated carbon increased to 20 %. When 10 % of activated carbon was used, liquid yield increased for process at 600 and 700 W. However, further increment of activated carbon to 20 % has reduced the liquid yield. Dissimilar to process at 800 W microwave power where the liquid yield slightly decreased as activated carbon increased from 0 % to 20 %. Reduction of liquid yield when activated carbon was increased from 0% to 10 % was due to increment of temperature that led to water released during process reacted with other pyrolysis product which left the reactor as non-condensable gases [27].

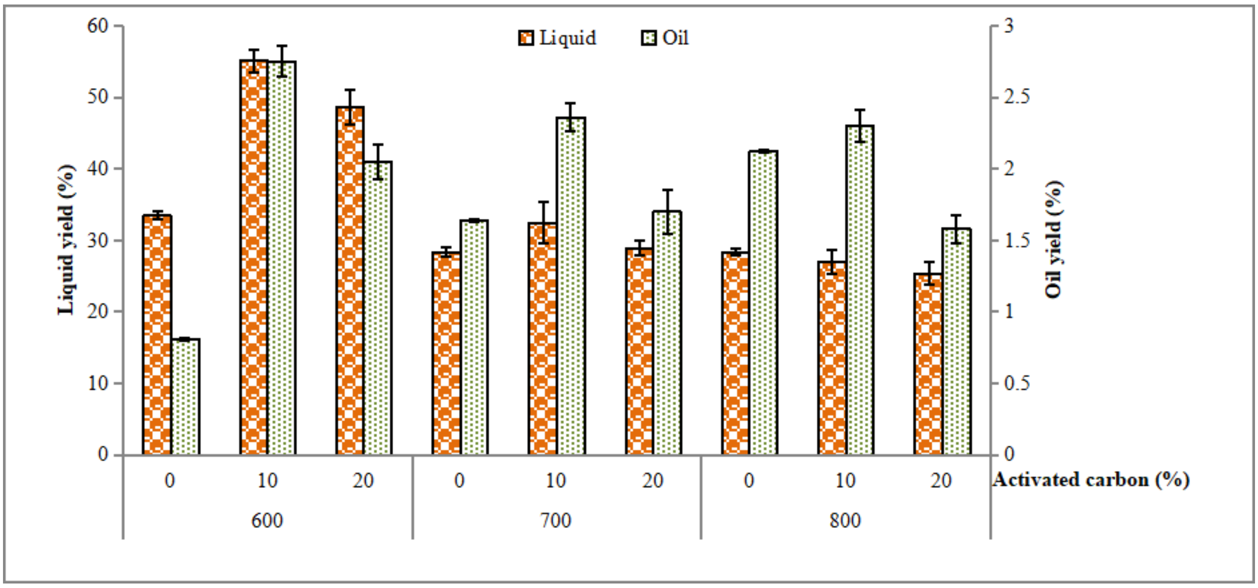

Fig. 5: Liquid and pyrolytic oil distribution at different activated carbon loading during microwave pyrolysis process.

However, further increment to 20 % has caused localized heating of activated carbon alone [28]. Similar trend of gas yield has been observed for 600 W, 700 W and 800 W where, the gas yield increased as activated carbon loading increased from 0 % to 20 %. Based on Fig. 5, the oil yield increased when activated carbon was increased from 0 % to 10 % and further increment of activated carbon to 20 % led to reduction in pyrolytic oil yield.

The presence of 10 % activated carbon has caused high impact towards products distribution of microwave pyrolysis of automotive paint sludge. Activated carbon absorbed microwave energy due to its high dielectric material properties and converted them into heat. Heat was then transferred to APS via conduction. At the same time, polar molecule such as water inside automotive paint sludge possessed dipole moment where the molecules tried to align with electric field induced in microwave. These electric fields were oscillating and the molecules try to realign with electric field. The continuous reorientation of these molecules created friction between them. Thus, heat was generated [29]. Due to this phenomenon, process temperature increased rapidly which promoted thermal cracking to occur. Relationship on reaction rate with activated carbon loading has been presented by Mushtaq *et al.* [30] in a review of fuel production from microwave pyrolysis of biomass and coal in which, reaction rate increased with addition of activated carbon.

Reduction in pyrolytic oil yield and slight increase of solid yield as the amount of activated carbon increased from 10 % to 20 % was due to non-uniform heating of automotive paint sludge. The results is in agreement with Abas *et al.* [31], where they observed that oil yield in-creased as amount of activated carbon increased from 37.5g to 75g and addition of activated carbon during the process led to reduction in oil yield. It has been claimed by Mushtaq *et al.* [32] that too high activated carbon would cause large temperature gradient between activated carbon and materials that being pyrolyzed. Indirectly, it led to hot spot phenomenon to occur which led to non-uniform heating of materials. This occurrence produced low pyrolytic oil.

4. Conclusion

From this study, it has been shown that selection of microwave power and application of activated carbon play an important role in products distribution of microwave pyrolysis of automotive paint sludge. Without addition of activated carbon, increasing of microwave power promoted complete pyrolysis process which increased the yield of gas, and liquid. In order to obtain high pyrolytic oil yield, higher microwave power than 800 W is required. Meanwhile, increasing of microwave power with addition of activated carbon led to increment of gas yield and reduction in liquid including pyrolytic oil yield due to secondary cracking reaction.

The highest gas yield was at 800 W due to high process temperature offered at high microwave power. The maximum solid and pyrolytic oil yields were obtained at 600 W due to low process temperature offered by low microwave power which prevents excessive cracking to occur. However, highest solid yield at 600 W with 0 % activated carbon loading indicating incomplete pyrolysis process. The best amount of activated carbon loading was 10 % for the highest pyrolytic oil production.

Acknowledgement

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