



Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Response surface methodology for synthesis of bio-jet fuel from waste cooking oil using agitated ozone treatment

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ARTICLE INFO

Article history:

Available online 23 March 2022

Keywords:

Bio jet fuel
Cooking oil
Ozone treatment
RSM

ABSTRACT

Development of bio-jet fuel has gained much attention in the few years due to the carbon emission problem. Waste cooking oil (WCO) is an alternative raw material to produce medium chain of methyl ester which has similar properties with bio jet fuel. This research aims to investigate the Response Surface Methodology for synthesis of bio-jet fuel from waste cooking oil using agitated ozone treatment. In this study, bio jet fuel was produced using ozonolysis method with agitated ozone generator. The effect of reaction time, ozonolysis concentration and ozonolysis flow rate were optimized using response surface methodology (RSM) based on a central composite design (CCD). The optimum conditions obtained from RSM were 3% of ozonolysis concentration, 10 L/min of ozonolysis flow rate and 10 min of reaction time. Under this condition, the properties of bio-jet fuel met with the commercial standard of bio-jet fuel which are the density and %FFA conversion were 0.863 g/mL and 2.95%, respectively.

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1. Introduction

The global aviation industry is facing significant problems related to carbon emissions. This has been under public spotlight because of their contribution to the climate change. Annually, it produces about 2–3% of all human-induced carbon dioxide (CO₂) emissions which released to the atmosphere. Furthermore, the industry's reliance on the hydrocarbon fuels as a single product has also raised concerns over future feedstock, supply security and operational cost [1]. Therefore, development of bio jet fuel as the alternative fuel has gained much attention in the last few years.

Research on production of bio jet fuel from renewable resources has been conducted [2]. Several pathways during production of bio-jet fuel based on the raw material were studied. These pathways are lipids hydro-processing, alcohol-based biofuel, biomass pyrolysis to jet, gasification of biomass followed by Fischer-Tropsch process, and biomass upgrade utilizing the hydrothermal process. Moreover, the catalytic production of bio-jet fuels from

biomass was also reviewed [3]. Main technologies were studied in converting biomass into liquid hydrocarbon fuels specifically used as aviation fuels. Particular emphasis focuses on those routes involving heterogeneous catalysts. The production of bio-jet fuel from renewable lignocellulosic biomass has also been investigated [4].

This study demonstrated a novel transformation of biomass into bio-jet and diesel fuels. The transformation included following three reaction steps: (i) the catalytic pyrolysis of sawdust into low-carbon aromatics, (ii) the production of C₈–C₁₅ aromatics by the aromatic alkylation and (iii) the production of C₈–C₁₅ cyclic alkanes by the hydrogenation of C₈–C₁₅ aromatics. Another study has been showed by investigation on synthesis of bio-jet fuel from crude palm oil (CPO) using hydro-processing of esters and fatty acids [5]. However, the high paraffin content in this fuel affects the cold flow properties such as cold filter plugging point and cloud point. These properties are depending on the type of feedstock used [6].

Recently, the new material using waste cooked oil (WCO) for production of bio-jet fuel with catalytic process was proposed [7]. WCO is also composed of triglycerides and long-chain carbon

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fatty acids. Compared with vegetable oils, WCO is two to three times cheaper than virgin vegetable oils and become a promising feedstock in fuel production. The study investigated direct conversion on waste cooking oil (WCO) into bio jet fuel using a core-shell hierarchical USY@Al-SBA-15 zeolite-supported NiMo catalyst.

Hydrogenases in WCO during production of bio-jet fuel using ozonolysis had been develop [8]. Ozonolysis was performed in a bubble reactor to obtain the medium chain of methyl ester from WCO which specifically had 8–16 carbon chain. The results showed that the esterification products were met density and kinematic viscosity criteria of the commercial bio-jet fuel in which the density should be in the range of 0.775–0.840 g/ml for Jet A-1. The flowrate of ozone from generator also affected in the decreasing of density and acid value [9]. WCO is used in this study aims to utilize byproduct for producing an alternative fuel. Therefore, sustainability in renewable energy can be achieved. Moreover, the objective of this study was to optimize production of bio-jet fuel from WCO using agitated ozone treatment through response surface methodology (RSM). RSM is used in the experimentation as it is known as a reliable method in data optimization to study productivity of bio-jet process production. The combined effects of catalyst concentration, reaction time and flowrate on the production of bio-jet fuel were optimized using central composite design (CCD) in conjunction with RSM.

2. Material and methods

2.1. Materials

This research used aquadest, sulphuric acid, ethanol, nitrogen, potassium hydroxide, and methanol (MeOH) which were purchased from supplier CV. Jurus Maju Semarang. Waste cooking oil (WCO) was obtained from local fritters seller near Tembalang. Agitated ozone generator was used to produce bio-jet fuel from WCO. Fig. 1 shows the overview of agitated ozone generator which equipped with an inlet-outlet tubing, a temperature control, an agitated speed control and a power indicator. The ozonolysis generator could produce ozonide and aldehyde in fatty acid group.

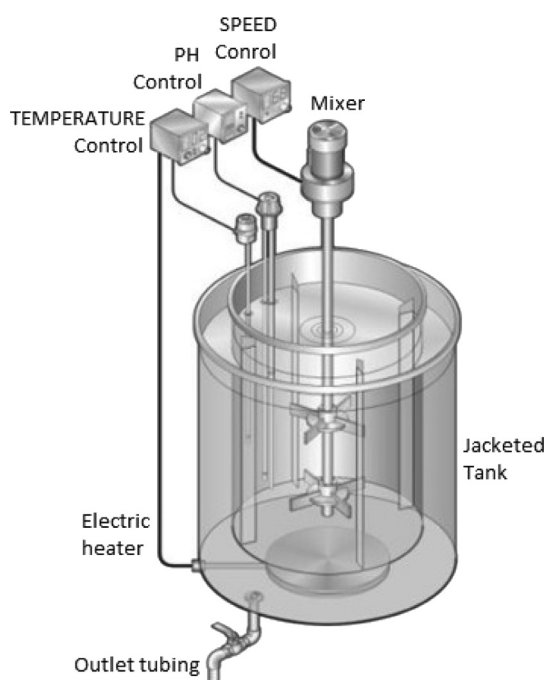


Fig. 1. Agitated Ozone Generator.

Therefore, high HC-chain can transform into short HC-chain. Addition of methanol as the co-solvent would lead the reaction product to medium HC-chain.

2.2. Production of bio jet fuel by ozonolysis process

The production of bio-jet fuel from WCO was produced by ozonolysis using MeOH as the co-solvent and potassium hydroxide as the catalyst, following the method reported by [4] and with some modification. The ozonolysis time were varied from 5; 10; 15; 20; 25; 30 min.

3. Experimental design and statistical analysis

RSM based on a central composite design (CCD) in this experiment was used to optimize the production of bio-jet fuel process from the WCO. It also aims to investigate the influence of different transesterification process variables on the % FFA conversion [10]. At 3 levels of independent variables ranging from - 1 to + 1, 16 experimental runs were carried out with the four independent variables: methanol-to-oil-molar ratio (A); catalyst concentration (B); reaction time (C); and co-solvent in methanol concentration (D). These variables were chosen due to their significant effects on the bio-jet fuel production. Methanol-to-oil-molar ratio shows the effect of co-solvent to raw materials while catalyst concentration indicates the influence of catalyst during production process. Further, reaction time and methanol concentration represent the kinetics of reaction.

4. Results and discussion

Bio-jet fuel from WCO was produced from ozonolysis in an agitated tank using ozone bubbling method in order to build shorter methyl esters. After the ozonolysis process completed, it was followed by free fatty acid (FFA) esterification process to obtain the ozonolysis product. RSM was applied to evaluate the relations between the response (%FFA conversion) and the three reaction variables. Sixteen experiments were performed in randomized orders. Table 1 shows the results of FFA conversion for each point base on the CCD experimental plans.

The effect of variable process on the FFA conversion were investigated by plotting three-dimensional surface curves against any two independent variables in which density was kept at their control (0) level. The 3D curves of response from the effect of independent variables are shown in Fig. 2 (a-b). Fig. 2 (a) illustrates the

Table 1
Experimental design of 3 independent variables and the 2 responses with observed and predicted values from transesterification of WCO.

Time [min]	Concentration [%]	Flow rate [L/min]	Density [g/mL]	FFA [%]
60	1	10	0.852	0.856
60	1	20	0.927	1.69
60	3	10	0.939	1.79
60	3	20	0.853	2.105
180	1	10	0.863	1.495
180	1	20	0.861	0.977
180	3	10	0.863	2.95
180	3	20	0.854	0.657
190.9	2	15	0.862	1.432
220.91	2	15	0.855	0.591
120	0.32	15	0.867	2.26
120	3.68	15	0.854	1.577
120	2	6.59	0.805	1.53
120	2	23.41	0.854	1.248
120	2	15	0.834	1.682
120	2	15	0.861	0.912

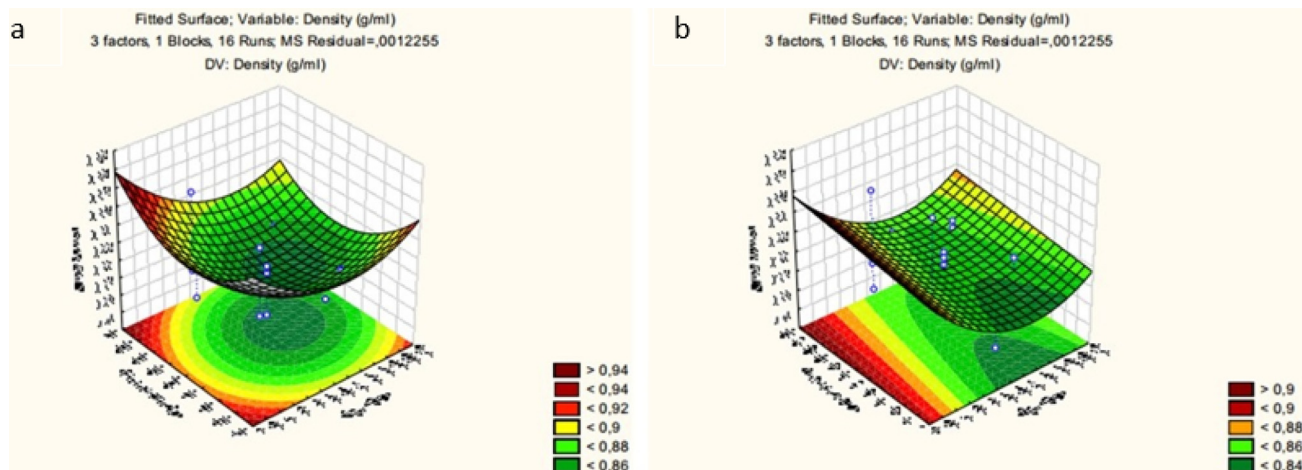


Fig. 2. Response surface plots elucidating the effects of (a) reaction time and ozonolysis concentration; (b) reaction time and flow rate of ozonolysis.

effect of reaction time and ozonolysis concentration on the density of bio-jet fuel at 60 min reaction time and 1% of ozonolysis concentration. The result reveals that the density of bio-jet fuel increases with increasing ozonolysis concentration and ozonolysis flow rate. Fig. 2 (b) exhibits the effect of ozonolysis flow rate and reaction time at 2% of ozonolysis concentration. The density of bio-jet fuel slightly increases with increasing of ozonolysis flow rate. The bio-jet product was validated by using Free Fatty Acid Method (FBI-A01-03). The highest FFA (2.95%) was resulted on variable 7th with a reaction time of 180 min, catalyst concentration of 3%, oxygen flow rate was 10L/minutes.

5. Conclusion

RSM was used to study the bio-jet fuel production from WCO using ozonolysis in agitated ozone generator with KOH as a co-solvent. The ozonolysis process provides high catalytic esterification for bio-jet fuel producing in terms of %FFA and density. These results indicate that ozonolysis process using KOH as co-solvent is able to improve the esterification of WCO for bio-jet fuel production.

Declaration of Competing Interest

The 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.

Acknowledgements

This research was supported by the Ministry of Research, Technology and Higher Education, Indonesia through Penelitian Terapan Unggulan Perguruan Tinggi 2019.

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