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Research paper

Production of methyl esters from fried soybean oil using dimethyl carbonate with hydrobromic acid

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ABSTRACT

Energy demand is increasing dramatically because of the fast industrial development, rising population, and economic growth in the world. To fulfill this energy demand, a large amount of fuel is widely used from different fossil resources. Burning of fossil fuels has caused serious detrimental environmental consequences. The application of methyl esters has shown a positive impact in resolving these issues. The objective of this study, methyl esters were produced by transesterification of fried soybean oil with dimethyl carbonate using hydrobromic acid as catalyst. Optimized several factors that affected the reaction efficiency including the fried soybean oil to dimethyl carbonate ratio (1:4 v/v), 3.5 % v/v catalyst concentration, a reaction temperature of 80 °C for 50 min with 300 rpm agitation speed. The methyl esters yield was 94 % obtained using these optimized conditions. Methyl esters were purified by ion exchange resin amberlite-732, and purified methyl esters were analyzed by GC–MS. We then characterized important physical properties of methyl esters such as kinematic viscosity, density, flash point, cloud point, and pour point. These properties were found to have met with the quality standard defined under ASTM D6751-02 and compared with diesel fuel. In this research, a novel method was developed for the production of methyl esters under mild conditions using dimethyl carbonate and hydrobromic acid.

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1. Introduction

Global energy consumption is on an upward trend for the foreseeable future. However, energy sources such as petroleum and natural gas are non-renewable and relying on them for energy generation is not sustainable (Fauzi and Amin, 2013). Energy consumption augment is inevitable for human existence. There are various reasons for the search of environmentally acceptable, economically competitive, and readily available and basically as an alternative to fossil fuels (Fathy et al., 2015; Datta and Mandal, 2016). The consumption of global petroleum reserves together with ever increasing environmental concerns have stimulated the search for substitute renewable fuels that can meet the increasing demand for energy (Yang et al., 2014; Cai et al., 2015).

Alternative fuels have received significant attention in recent years for their promise of energy security and environmental benefits when compared to petroleum-based fuels (Singha et al., 2019). Biodiesel is a well-known renewable fuel with useful properties such as low emissions and high biodegradability (Uprety et al., 2016). Its physical properties are similar to those

of petroleum diesel, but is cleaner when burnt, thus making biodiesel a good alternative fuel (Tang et al., 2017; Xie et al., 2017; Debajyoti et al., 2019).

Methyl esters are a renewable fuel that can be produced from vegetable oils, non-vegetables oils, animal fats, and recycled restaurant grease for use in diesel vehicles (Fadjar and Shiro, 2015; Dharmaraja et al., 2019). Methyl esters are composed of long-chain fatty acids of alkyl esters and can be obtained from readily available renewable feed stocks, such as vegetable oils, and animal fats (Santana et al., 2017).

In general edible oils are expensive for methyl ester production process, as the raw material contributes up to 75% of the total production cost of the product. Consequently, less costly waste cooking oils are very significant source of methyl ester in developing countries (Das et al., 2014). Additionally, the use of waste cooking oil as a feedstock for methyl ester production is a substantial way to solve a waste-disposal problem as well (Lin et al., 2013). Generally, methyl ester is produced by conventional alkali catalysts (De et al., 2011). Waste cooking oil contains a significant amount of free fatty acids (FFA) and water, which leads to soap formation and results in separation problems (Zahoor et al., 2017), making standard homogeneous alkaline catalyzed unfeasible. Homogeneous acid catalysts are more suitable for biodiesel production from waste vegetable oil due to the fact that the waste vegetable oil has a great number of free fatty acids

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(Faizan et al., 2016; Panchal et al., 2017). Hydrobromic acid (HBr) catalyst is ideal catalyst for transesterification reaction because HBr acid has a higher tolerance for FFAs in oil. The HBr is a very strong acid, and but very corrosive, the stronger the acid the more corrosive and dangerous the substance.

Dimethyl carbonate (DMC) is achieving increasing importance in the chemical industry for its versatility as reagent and solvent, low cost, and its non-toxicity to humans and environment (Kim et al., 2010; Panchal et al., 2013, 2017). Additionally, DMC can be produced from methanol and carbon dioxide, and has low toxicological and ecotoxicological properties, thereby its production process is environmentally friendly (Dawodu et al., 2014; Alessio et al., 2017). For this purpose, DMC can be used as a transesterification reagent. The reaction is rather attractive because DMC is reputed to be a prototypical green reagent. In transesterification process DMC and oil can produce glycerol carbonate (GC) as a byproduct. Glycerol carbonate, one of the most attractive derivatives of glycerol, can be used as chemical intermediates for pharmaceuticals and as an environmental friendly solvent (Rongxian et al., 2016).

The objective of this research study was to optimize an environmentally safe method for production of methyl esters using DMC with HBr as a catalyst. In this research, we studied the effects of different parameters on the yield of methyl esters. The methyl esters were purified, characterized, and a number of important properties were determined. Purified methyl esters were compared with the ASTM D6751-02 standard.

2. Materials and methods

2.1. Materials

Fried soybean oil used in this study was obtained from the Hebei University of Engineering Handan, Hebei, China canteen. Food materials were fried at 110 °C for 2 h, after food materials fried oil filtered by 20 μm filter mesh. Hydrobromic acid and anhydrous sodium sulfate were purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA). Dimethyl carbonate and other chemicals were purchased from Alfa Aesar (Ward Hill, MA, USA).

2.2. Transesterification of fried soybean oil using DMC with HBr

The fatty acid composition of fried soybean oil was determined using GC–MS techniques as reported elsewhere in the literature (Zhang et al., 2010). Fried soybean oil was used as a reactant. Initially, the fried soybean oil was boiled at 80 °C until a uniform liquid formed and water was removed. The reaction was performed in a 500 mL glass batch reactor equipped with a heat exchanger to condense and return the DMC vapor to the reactor using a constant temperature paraffin oil bath. The ratio of fried soybean oil to DMC was varied from 1:1 to 1:5 v/v. The catalyst concentration was tested at 0.5 to 4.0% v/v of the DMC. The reaction temperature was varied from 40 to 90 °C for the batch operation under standard conditions, and agitation speed ranging from 100 to 400 rpm was applied. The reaction was allowed to run for various reaction times from 10 to 60 min. The sample was allowed to settle by gravity for 12 h after collection with a separating funnel; it settled into a clear, golden liquid of methyl esters on top of a light brown glycerol carbonate. To ensure a high purity of the methyl esters, a rotary evaporator was employed to remove excess DMC (DMC boiling point is 90 °C). The higher valued by-product glycerol carbonate (GC) was drained from the bottom of the separating funnel. GC and glycerol dicarbonate are also formed as byproducts but only in low concentrations. The methyl ester phase of biodiesel contains fatty acid glycerol carbonate (FAGCs) in addition to FAMEs. Glycerol carbonate and

glycerol dicarbonate (GDC) are also formed as byproducts but only in low concentrations. Since FAGCs are dissolved in the methyl ester-phase, the product can be used as fuel without separation (Kai et al., 2014). Overall mechanism of the transesterification as shown in Scheme 1. The crude methyl esters were purified by ion exchange resin amberlite-732. The purification by ion exchange resin amberlite-732 is promising for removing the contaminants present in the methyl esters. The efficiency of the process for the removal of methyl ester impurities was evaluated by determining the acid value and kinematic viscosity of the methyl esters. The results of the transesterification reaction were examined by thin-layer chromatography (TLC) (Ayten et al., 2013). 2 μL of the methyl ester was loaded on the TLC plate. The TLC procedure used a solvent containing hexane, ethyl acetate and glacial acetic acid at a ratio of 90:10:1 (v/v/v), respectively. Produced methyl ester showed higher vigor than did the fried soybean oil, as indicated on the TLC plate with a clear phase separating the biodiesel contents of methyl esters. The yield of methyl esters was calculated on the basis of the amount of methyl esters obtained and the amount of oil used and was estimated using Eq. (1). The methyl esters properties were determined by standard ASTM D6751-02 methods. All experiments in this study were conducted in three replicates, and the results were analyzed using ANOVA.

2.3. Reaction pathway of methyl ester and by-product production

Using of DMC in methyl ester production is a smart way of making its production viable because the by-products, GC currently have a higher market value. Triglycerides (TG) react with DMC to produce methyl glycerol dicarbonate (GDC) and fatty acid methyl ester (FAME), and then GDC further react to produce FAGCs and FAME. Finally, FAGCs rapidly undergo re-arrangement to form a cyclic compound which further reacts with DMC to produce GC upon decomposition of FAGCs since DMC normally contains residual water, mechanism of the transesterification is shown in Scheme 1.

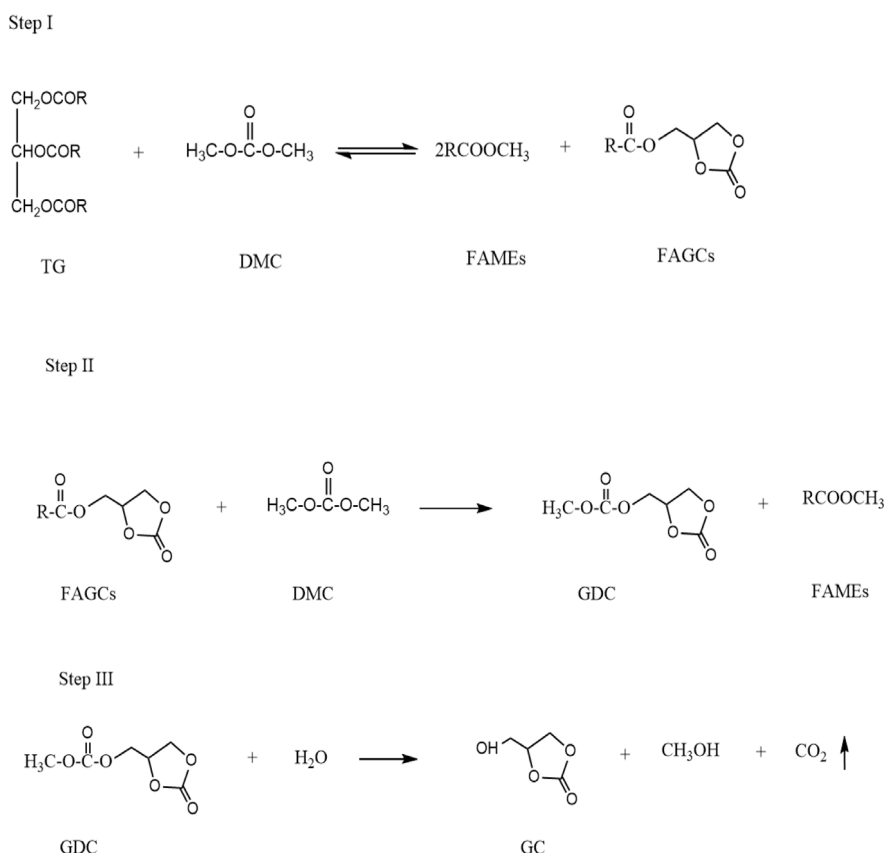
$$\text{Methyl ester yield (\%)} = \frac{\text{Mass of methyl ester produced (g)}}{\text{Mass of oil used (g)}} \times 100\% \quad (1)$$

2.4. GC–MS analysis of the purified methyl esters produced from fried soybean oil using DMC and HBr

The completion of the transesterification reaction was examined using thin-layer chromatography. Purified methyl esters were determined using a gas chromatography–mass spectrometry (GC–MS) system incorporated with an Agilent 5975 C MSD (Triple-Axis Detector, Agilent Technologies, Inc., Santa Clara, CA, USA) and an Agilent 7890 A, GC equipped with a capillary column (DB-23, 60 m 3250 lm 30.15 m nominal). The external standards calibration method was implemented to quantify the final product. Methyl esters Analyzer VC: Version 1.1 was used to estimate the properties of the prospective methyl esters.

2.5. Properties of the purified methyl esters produced from fried soybean oil using DMC and HBr

The properties of the purified methyl esters produced from fried soybean oil were compared with the ASTM D6751-02 specification. The density at 25 °C, kinematic viscosity at 40 °C, flash point (FP), cloud point (CP), pour point (PP), copper strip corrosion, and acid value were determined according to the ASTM D4052, ASTM D445, ASTM D93, ASTM D2500, ASTM D97, ASTM D130, and ASTM D664 standards, respectively (Rengasamy et al.,



Scheme 1. Stepwise conversion of triglyceride (TG) with DMC for methyl ester production using HBr catalyst. Fatty acid methyl esters (FAMEs), fatty acid glycerol carbonates (FAGCs), methyl diglycerol carbonate (GDC), glycerol carbonate (GC).

2014; Rathore et al., 2015). Flash point is the minimum temperature at which a volatile material can vaporize to form an ignitable mixture in the air. The cloud point is related to the lowest temperature at which the liquid forms a visible cloudy crystal solid as the fuel temperature decreases. Pour point is related to the temperature below which the fuel will no longer flow (Midiba et al., 2014).

3. Results and discussions

3.1. Fatty acid (FA) composition of fried soybean seed oil

Fried soybean seed oil contains linoleic acid (C18:2) (47.4%), oleic acid (C18:1) (25.5%), palmitic acid (C16) (9.0%), stearic acid (C18) (4.75%), and linolenic acid (18:3) (4.9%).

3.2. Optimization of transesterification of fried soybean oil using DMC and HBr

3.2.1. Effect of oil to DMC ratio on yield of methyl esters

The ratio of oil to DMC is one of the most significant factors affecting the conversion and yield of methyl ester as well as the production cost (Rathore et al., 2015). The reaction was carried out while varying the oil to DMC ratio. Oil to DMC ratios 1:1 to 1:5 v/v was tested to determine the effect on methyl esters production. These experiments were performed using a catalyst concentration as 3.5% v/v of DMC, a reaction temperature of 80 °C, with a reaction time of 50 min and agitation speed of 300 rpm. The methyl ester yield was increased from 30% to 94% when the oil to DMC ratio was increased from 1:1 to 1:4 v/v as shown in Fig. 2. The oil to DMC ratio of 1:3 v/v resulted in the lowest conversion to methyl esters with only a 76% yield. The highest methyl esters

yield, 94% was obtained for oil to DMC ratio 1:4 v/v. Generally, increasing the amount of DMC can increase the rate of reaction, resulting in better yield in a shorter duration (He et al., 2013; Kai et al., 2014). However, with further increases in the amount of DMC for oil to DMC ratio of over 1:5 v/v produced no significant differences in the methyl ester yield. Moreover, the excess DMC slowed the separation process (Jiahui et al., 2018). Therefore, oil to DMC ratio of 1:4 v/v is suitable for production of methyl esters from fried soybean oil and DMC using an HBr catalyst. This ratio is a very effective ratio and also economically viable because of small amount of catalyst concentration with short reaction time. Thus, oil to DMC ratio as 1:4 v/v was considered the optimal ratio for methyl esters production (see Fig. 1).

3.2.2. Effect of catalyst concentration on yield of methyl esters

The catalyst amount is an important parameter which affects the conversion of triglycerides to methyl esters (Chang et al., 2015). Selection of the catalyst is a crucial step in determining the outcome of methyl esters production. HBr acid catalyst is ideal catalyst for transesterification reaction because HBr acid has a higher tolerance for FFAs in oil. HBr has a larger atomic radius, and increased nuclear charge. As this topic of research is relatively new, production of methyl ester from fried soybean oil with HBr. The effect of HBr acid catalyst on methyl esters production was ascertained in 8 experiments in which the HBr to DMC ratio was varied in 0.5% v/v steps from as 0.5% to 4.0% v/v. All the experiments were employed the oil to DMC ratio of 1:4 v/v, an agitation speed of 300 rpm, a reaction temperature of 80 °C, and a reaction time of 50 min. The optimum yield of methyl esters (94%) was achieved using 3.5% v/v HBr acid catalyst concentration. The effect of the catalyst concentration on the yield of fried soybean oil methyl ester is shown in Fig. 3. The yield of methyl esters

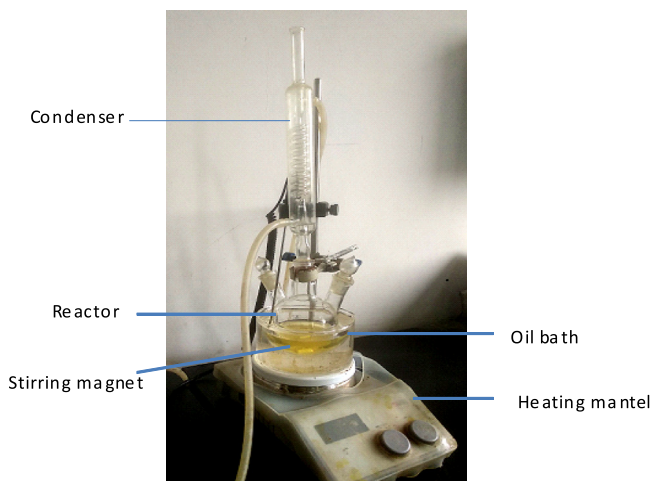


Fig. 1. Set up of the transesterification process.

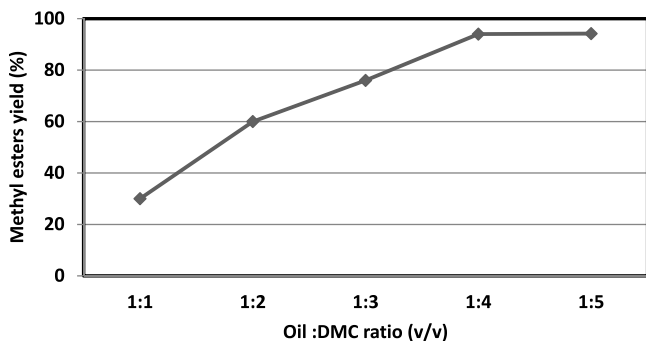


Fig. 2. Effect of oil to DMC ratio on fried soybean oil conversion yield of methyl esters. Reaction conditions; catalyst to DMC ratio of 3.5% v/v, reaction temperature 80 °C for 50 min, agitation speed 300 rpm and various ratio of oil to DMC. Data are represented as mean \pm standard deviation of triplicate observation.

increased from 0.5% to 3.5% v/v, until a yield of 94% was achieved. However, varying the catalyst concentration from 0.5% to 3.0% v/v on the DMC base did not result in any significant difference in the methyl esters yield. A catalyst concentration of 4.0% v/v produced same the methyl esters yield compared with the catalyst concentration of 3.5% v/v. The yield of waste cooking oil (WCO) methyl esters has been found to be 89.1% using ionic liquid, $\text{NaOH}_{0.75}$ catalyst (1 wt % [MorMeA] [Br] + 0.75 wt % NaOH) (Yuan et al., 2013). Thus, 3.5% v/v of the HBr acid catalyst concentration was considered to be the optimal catalyst concentration for methyl esters production.

3.2.3. Effect of the reaction time on yield of methyl esters

The reaction time plays a vital role in the transesterification of triglycerides in general (Zahoor et al., 2017; De et al., 2011), consequently influencing the yield of methyl esters. Experiments were carried out focusing on the reaction time to investigate its influence on the yield. In this phase of our study, reaction times were varied in 10 min steps from 10 to 60 min. The reactions were carried out using 1:4 v/v of oil to DMC ratio and 3.5% v/v of HBr acid concentration at 80 °C temperature with a 300 rpm agitation rate. Initially, the reaction is slow due to mixing and the dispersion of oil and DMC, but then proceeds very rapidly. Fig. 4, shows the yield percentage of methyl esters after 10 to 60 min reaction. The maximum methyl ester conversion was achieved within 50 min. Further increasing the reaction time to 60 min did not increase the methyl ester yield of 94%. In addition a longer

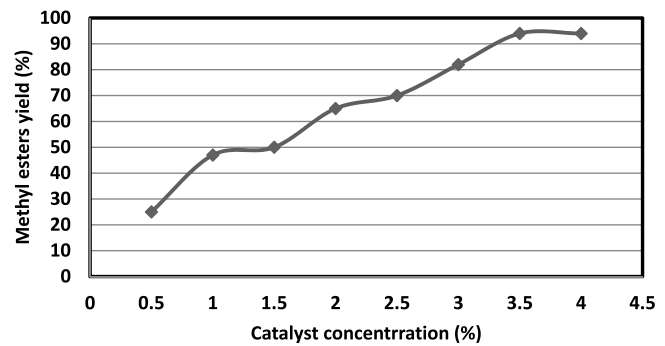


Fig. 3. Effect of catalysts concentration on fried soybean oil conversion yield of methyl esters. Reaction conditions; 1:4 v/v oil to DMC ratio, reaction temperature 80 °C for 50 min, agitation speed 300 rpm and various concentrations of HBr catalysts (0.5%–4.0% v/v on DMC basis). Data are represented as mean \pm standard deviation of triplicate observation.

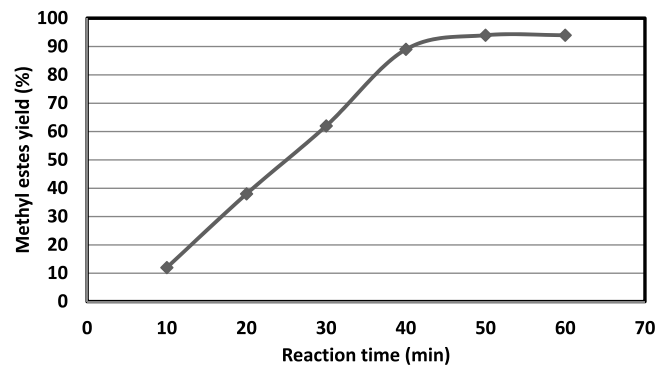


Fig. 4. Effect of reaction time on fried soybean oil conversion yield of methyl esters. Reaction conditions; 1:4 v/v oil to DMC ratio, 3.5% v/v of catalyst concentration, reaction temperature 80 °C, agitation speed 300 rpm and various reaction times (10 to 60 min). Data are represented as mean \pm standard deviation of triplicate observation.

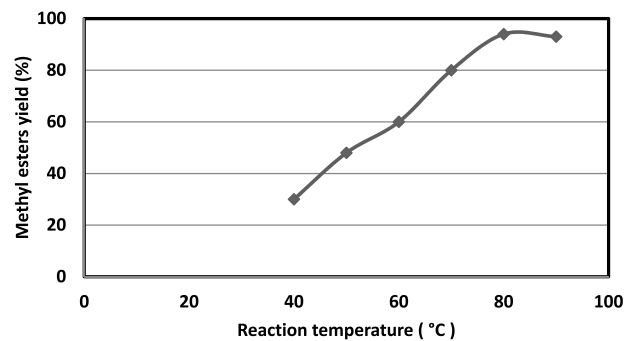


Fig. 5. Effect of reaction temperature on fried soybean oil conversion yield of methyl esters. Reaction conditions; 1:4 v/v oil to DMC ratio, 3.5% v/v of catalyst concentration (on the DMC basis), reaction time 50 min, and agitation speed 300 rpm and various reaction temperature. Data are represented as mean \pm standard deviation of triplicate observation.

reaction time leads to the reduction of the end product due to the reversible transesterification reaction, resulting in a loss of esters (Silitonga et al., 2017). Thus, the optimal reaction time for fried soybean oil-methyl ester production using HBr is 50 min.

3.2.4. Effect of the reaction temperature on yield of methyl esters

The reaction temperature is an important factor which can influence the reaction and yield of methyl ester production (Keon and Eun, 2018). Temperature can influence the reaction rate and

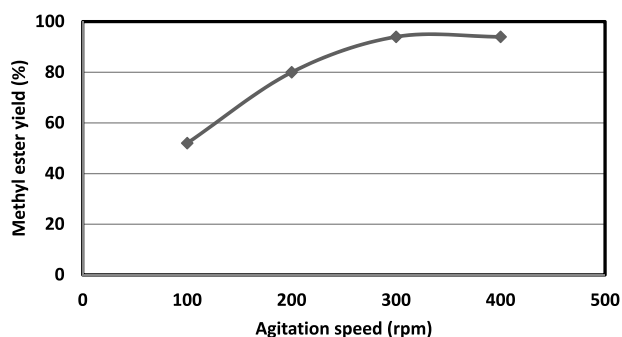


Fig. 6. Effect of agitation speed on fried soybean oil conversion yield of methyl esters. Reaction conditions; 1:4 v/v oil to DMC ratio, 3.5% catalyst concentration (on the DMC basis), reaction temperature 80 °C for 50 min, and various of agitation speed (100 to 400 rpm). Data are represented as mean \pm standard deviation of triplicate observation.

oil conversion, because the intrinsic rate constants are largely dependent on temperature (Zeng et al., 2017). In these experiments, the reaction temperature was varied from 40 to 90 °C, and the reaction was carried out with fried oil to DMC ratio of 1:4 v/v and 3.5% v/v of HBr acid concentration at 300 rpm agitation speed. Generally, the reaction rate increases with increasing temperature, and this effect of which is shown in Fig. 5. At a low reaction temperature of 40 °C, the yield to methyl esters was 30%. When the transesterification process was performed at 80 °C, the yield was 94%, which was slightly higher than the yield at 90 °C. The DMC concentration in the liquid phase decreased with increasing temperature, and consequently reduced the reaction rate at higher temperature (Kai et al., 2014). The conversion did not improve much with further increase in temperature up to 90 °C, which implies that the reaction reaches equilibrium at 80 °C. Additionally, the transesterification reaction temperature should be a below the boiling point of DMC to prevent its evaporation (Banihani, 2016). Thus, it can be concluded that the reaction temperature is a significant factor in the production of methyl esters (Chandrasekaran et al., 2017), and the optimum reaction temperature was found to be 80 °C.

3.2.5. Effect of the agitation speed on yield of methyl esters

The agitation rate can also act to determine yield in reactions involving viscous reactants (Baskar et al., 2018). Reactant mixing is important for the completion of the transesterification reaction and consequently, it increases the methyl esters yield (Sumit et al., 2017). In these experiments, the agitation speed was varied from 100 to 400 rpm, and the reaction was carried out using oil to DMC ratio of 1:4 v/v, and 3.5% v/v of HBr acid concentration at 80 °C with 50 min reaction time. The conversion of methyl esters at the agitation speeds of 100 and 200 rpm were 52% and 80% yield, respectively. The conversion of methyl esters at the agitation speed of 300 and 400 rpm were 94 and 94% yield, respectively. Due to the high yield 300 rpm was chosen as the optimum agitation speed. Fig. 6, shows the yield percentage of methyl esters at 100 to 400 rpm of agitation speed. The increase in the methyl esters yield with an increase in agitation speed indicate that the high agitation speed provides turbulence, leading to good reactant mixing. The higher agitation speed also minimizes the external mass transfer diffusion resistance, thereby increasing the rate of reaction and the methyl esters yield. Thus, agitation speed optimization is necessary for various feedstocks based on their different physical properties (Ajala et al., 2017).

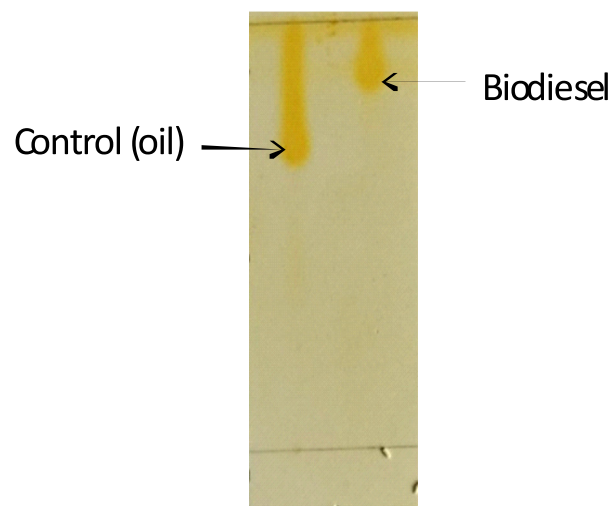


Fig. 7. Detection of methyl esters fried soybean oil conversion by TLC.

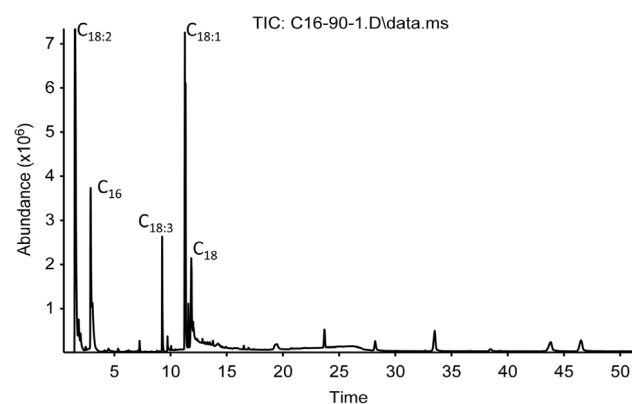


Fig. 8. Purified methyl esters of fried soybean oil analysis by GC–MS.

3.3. Analysis of the purified methyl esters produced from fried soybean oil using DMC and HBr by GC–MS

Thin layer chromatography is an analytical technique that allows a qualitative indication of methyl esters content in the mixture. The TLC procedure used a solvent containing hexane, ethyl acetate and glacial acetic acid at a ratio of 90:10:1 (v/v/v), respectively. Produced methyl ester showed higher vigor than did the fried soybean oil, as qualitative indicated on the TLC plate with a clear phase separating the biodiesel contents of methyl esters. Fig. 7, shows the TLC image for methyl esters from transesterification reactions with the oil to DMC ratio as 1:4 v/v, catalyst concentration as 3.5% v/v of DMC at 80 °C temperature, with a 300 rpm agitation speed for 50 min. GC–MS analysis was used to study the chemical composition of the produced methyl esters. Five major peaks were observed in the total ion chromatogram shown in Fig. 8. The identified methyl esters were verified by running standards under identical experimental conditions and comparing the respective retention times, which were confirmed by mass spectrometric analysis. In general, the chromatogram displayed very good peak shapes and the compounds were very well separated from each other. Five peaks were observed in the chromatogram; however, some of them could not be identified because their intensities were too low to be considered satisfactory. In the fried soybean oil methyl esters the most abundant esters were linoleic acid methyl esters (C18:2) (49.85%), followed by oleic acid methyl esters (C18:1) (22.95%), lenolenic acid methyl

Table 1

Methyl esters properties of fried soybean oil methyl esters were compared with standard ASTM D6751-02.

Sr. no.	Fuel properties	Units	ASTM 6751-02 method	Fried soybean methyl esters	ASTM D 6751-02
1	Kinematic viscosity at 40 °C	mm ² /s	D445	3.93	1.9–6.00
2	Density at 25 °C	gm/m ³	D4052	0.89	Report
3	Flash point	°C	D93	148	130
4	Pour point	°C	D97	1	Report
5	Cloud point	°C	D2500	4	Report
6	Copper strip corrosion	1	D130	1a	3 max
7	Acid value	mgKOH/g	D664	0.26	0.50 max

esters (C18:3) (5.95%), palmitic acid methyl esters (C16) (8.95%), and steric acid methyl esters (C18) (5.85%). The total content of fried soybean oil methyl esters was 94%, which may explained the high quality of the methyl esters produced by fried soybean oil with DMC and HBr acid catalyst.

3.4. Properties of the purified methyl esters produced from fried soybean oil using DMC with HBr

The kinematic viscosity of fried soybean oil methyl esters was found to be 3.93 mm²/s. Kochler kinematic viscosity bath equipment was used for kinematic viscosity determination. This kinematic viscosity meets the ASTM D6751-02 standards. Generally, the kinematic viscosity of methyl ester is slightly higher compared to diesel. Kinematic viscosity is a key fuel property because it enables atomization of the fuel upon injection into a diesel engine ignition chamber, and ultimately, the formation of engine deposits (Evangelos and Christos, 2018). The density is a physical property used to calculate the precise volume of fuel necessary to supply an adequate combustion (Ramirez and Luis, 2013). Anton paar DMA 4500M instrument was used for density determination. Methyl esters are denser and less compressible than the diesel fuel regardless of the feedstock (Silitonga et al., 2013). Properties of purified methyl esters are shown in Table 1. The FP of fried soybean oil methyl esters was found to be 148 °C. Protest clevel and close cup with automated flash point analyzer was used for flash point determination. The FP of fried soybean oil is within the specification in ASTM D6751-02. Generally, methyl ester have higher FP compared to diesel which is usually around 110 °C to 180 °C while conventional FP for diesel fuel is only 55 to 66 °C. This means that methyl ester is safe for transport, handling and storage purpose (Silitonga et al., 2013). Copper corrosion block bath instrument was used for determination of copper corrosion. The acid value determined by Titration of KOH. Fried soybean oil methyl ester produced using DMC and HBr has a PP of 1 °C and a CP of 4 °C. ISL CPP 5 Gs analyzer was used PP and CP determination. In general, methyl ester has higher CP and PP than diesel fuel (Torres et al., 2011). The PP is one of the important parameters associated with engine performance in cold weather conditions (Gaurav and Sharma, 2016), and is defined as the temperature below which a fuel no longer flows (Midiba et al., 2014).

4. Conclusions

The transesterification reaction of fried soybean oil and DMC with HBr acid was studied and optimized. It was observed that the use of HBr acid catalyst, which acts as a catalyst, significantly enhanced the yield of methyl esters. The methyl ester conversion was above 94% when the catalyst amount was 3.5% v/v on the DMC bases, the ratio of oil to DMC was 1:4 v/v, and the reaction temperature was 80 °C with 50 min reaction time and an agitation of 300 rpm. This research study demonstrates that the use of DMC is a promising alternative for efficient preparation of methyl esters. As this research topic is relatively new, there are few studies that focus on methyl ester production using DMC

and the lack of complete physical parameters, such as density and the kinematic viscosity are serious disadvantage for the industrial application of HBr acid at the moment. However, HBr are used in a smaller amount than the other catalysts. In fact, study on the economic potential of the methyl ester processes vis-a-vis the conventional processes indicated that the operational cost is significantly less and the gross profit margin is extremely high for the eco-friendly methyl ester synthesis processes. This favors possible industrial implementations in the near future. Fried soybean oil is cheaply available in China, the production of methyl ester from fried soybean oil can be scaled up to the industrial level.

Acknowledgments

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