

Biodiesel fuel production from waste canola cooking oil as sustainable energy and environmental recycling process

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Abstract

The increase of petroleum price and environmental problems has triggered the finding of alternative and renewable energy. Biodiesel produced by transesterification of triglycerides with alcohol, is one of the energy forms that has attracted the attention of many researchers due to various advantages associated with its usages. Waste cooking oil is considered as the most suitable material due to its readily-availability and cost-effectiveness. In this study, the transesterification of waste canola cooking oil was carried out using lower alcohol to oil molar ratios to study its feasibility. Molar ratio of methanol, types and concentrations of catalyst were selected to obtain a high quality biodiesel fuel with the specification of American Standard for Biodiesel Testing Material (ASTM D 6751) and European Norm (EN 14214). The highest biodiesel yield was obtained (49.5%) under conditions of 1:1 volumetric oil-to-methanol weight ratio, 0.5% NaOH catalyst at 55°C reaction temperature and 250 rpm stirring speed. The results showed that biodiesel production from different oil to methanol ratio, catalyst types and concentration exhibited considerable differences. There was little difference in viscosity, acid value and chemical elements (Fe, Mg, Ca, Na, P etc.) at different parameters. The result showed that the optimal combination which gave the highest production of biodiesel in transesterification carried out for 2 hours by using methanol to oil molar ratio of 1:1 catalyzed by 0.5 % sodium hydroxide and produced biodiesel can be used as fuel in diesel engine.

Keyword: waste canola oil, biodiesel, viscosity, acid value, element content

Abbreviation: ASTM_American Standard for Biodiesel Testing Material; EN_European Norm; rpm_Revolutions per minute; NaOH_Sodium hydroxide; KOH_Potassium hydroxide

Introduction

The exponential growth of world population would ultimately lead to increase the energy demand in the world. Petroleum is a non-renewable energy source, which means that the resources of this kind of fossil fuel are finite and would be run out upon continuous use. Both of the shortage of resources and increase of petrol price have led to the findings of new alternative and renewable energy sources. Apart from these situations, environmental issues are also the driving forces for the development of alternative energy sources, since the burning of fossil fuels would cause various environmental problems including global warming, air pollution, acid precipitation, ozone depletion, forest destruction, and emission of radioactive substances (Dincer, 2000). The alternative energy sources of fossil fuels including hydro, wind, solar, geothermal, hydrogen, nuclear, and biomass (Demirbas, 2005). Among these alternative energy sources, biofuels derived from biomass are considered as the most promising alternative fuel sources because they are renewable and environmental friendly. Biofuels can be defined as any liquid or gaseous fuels that can be produced from biomass, including biodiesel, alcohol and biogas (Launhardt and Thoma, 2000).

Biodiesel is a biofuel that is gaining acceptance and market share as diesel fuel in Europe and the United States. The use of biodiesel has drawn attention in the last decade as it is a renew-

able, biodegradable, and nontoxic fuel, and has been industrially produced from vegetable oils in North America and Europe and from waste edible oils in Japan (Shimada et al., 1999). Various aspects of biodiesel such as production and properties was discussed in the following sections.

Oilseed rape (*Brassica* and related species, Brassicaceae) is now the second largest oilseed crop in the world, providing approximately 13% of the world's supply and occupying approximately 2% of the world's croplands (Leff et al., 2004). The name 'canola' was adopted in 1979 as a registered trademark of the Canadian Canola Association and referred to as rapeseed cultivars that produce seed oils with less than 2% erucic acid (22:1) and defatted meals with less than 30µmol/g of aliphatic glucosinolates. The world's canola commerce is mainly supplied by two species, *Brassica napus* L. and *B. rapa* L. which can produce seeds containing 40% or more oil. Among all species of *Brassica*, *Brassica napus* L. is the most productive species under cultivation (Pua and Douglas, 2004). Rapeseed now serves as the main feedstock in European countries for biodiesel production (Wardle, 2003).

The objectives of this study are to investigate the biodiesel production from waste canola cooking oil by using amount of alcohol lesser than the theoretical amount according to stoichiometric equation and to identify the standard parameters

Table 1. Variable and fixed parameters used in this study following the temperature 55 °C and 40 minutes in the water bath.

Variable parameters	Fixed parameters
Alcohol to oil molar ratio <ul style="list-style-type: none">• 1 : 1• 1 : 2• 1 : 3• 1 : 4	<ul style="list-style-type: none">• Types of alcohol: Methanol• Types of catalyst: NaOH• Amounts of catalyst: 0.5%• Reaction time: 2 hours• Mixing intensity: 250rpm
Types of catalyst <ul style="list-style-type: none">• KOH (0.5%)• NaOH (0.5%)	<ul style="list-style-type: none">• Alcohol to oil molar ratio: 1:1• Types of alcohol: Methanol• Amounts of catalyst: 0.5%• Reaction time: 2 hours• Mixing intensity: 250rpm
Amounts of catalyst, NaOH <ul style="list-style-type: none">• 0.5%• 1.0%• 1.5%	<ul style="list-style-type: none">• Alcohol to oil molar ratio: 1:1• Types of alcohol: Methanol• Types of catalyst: NaOH• Reaction time : 2 hours• Mixing intensity: 250rpm

like viscosity, acid value and metal content (Na, K, Ca, Mg, Pb etc.) that optimize the transesterification and appropriate for the use in diesel engine.

Materials and Methods

The canola cooking oil purchased from hypermarket and was used for frying to produce waste cooking oil. The waste cooking oil was then collected in a plastic bottle. After collection, the waste cooking oil was filtered by filter paper to remove bits of food residues. The filtered cooking oil was then collected in a clean conical flask and used for experiments.

An appropriate volume of alcohol was measured and poured into a 500mL conical flask. The catalyst in pellet form was weighed and mixed with alcohol. The mixture was then shaken for about 1 hour. Since alcohols evaporates easily, the flask was covered with aluminium foil during shaking to prevent the evaporation of alcohol. This covering could also prevent the alcoxide from absorbing water from the air.

Transesterification

Transesterification involves replacement of alcohol molecules from an ester by other alcohol molecules, and glycerine were produced as a by-product of this reaction. This process is similar to hydrolysis, except that alcohol is employed instead of water (Srivastava and Prasad, 2000). The stoichiometry of this reaction shows that 3 moles of alcohol reacted with 1 mole of triglyceride to give 3 moles of fatty acid ester and 1 mole of glycerine. The reaction rate of transesterification could be accelerated by using catalysts.

Biodiesel preparation

The filtered oil was heated up to a temperature of 55°C in water bath to melt coagulated oil. The heated oil of 100mL was poured into the conical flask containing catalyst-alcohol solution, and this moment was taken as the starting time of the reaction. The reaction mixture was then shaken by using shaker at a fixed speed of 250rpm. When the reaction reached the preset reaction time, shaking was stopped.

Separation of biodiesel from by-products

The product of reaction was exposed to open air to evaporate excess methanol for 30 minutes. The product was then allowed to settle overnight to produce two distinct liquid phases: crude ester phase at the top and glycerol phase at the bottom. There are a few methods to separate these 2 layers, including using the separating funnel and removing the biodiesel using pipette. The later was used in this experiment.

Biodiesel purification

The crude ester phase separated from the bottom glycerol phase was transferred to a clean conical flask. The biodiesel produced contains some residues including excess alcohol, excess catalyst, soap and glycerine. It was purified by washing with distilled water to remove all the residual by-products. The volume of water added was approximately 30% (volume) of the biodiesel. The flask was shaken gently for 1 minute and placed on table to allow separation of biodiesel and water layers. After separation, the biodiesel was transferred to a clean conical flask. The washing process was repeated for several times until the washed water became clear. The clean biodiesel was dried in incubator for 48 hours, followed by using sodium sulphate. The final products were analyzed to determine related properties including viscosity, total acid numbers (TAN) and element contents (Ma and Hanna, 1999). In this study, 3 experiments were carried out to study different parameters affecting biodiesel production, including alcohol to oil molar ratio, types of alcohol, types of catalyst, amounts of catalyst and reaction time. In each experiment, the parameters being studied were changed while other parameters were fixed. The experiments are summarized in Table 1.

Results

Biodiesel yields

The effect of different methanol to oil molar ratios on biodiesel yields was investigated. The volume of waste cooking oil used in this study was 100mL for each sample, thus the percentage of

Table 2. Acid value is shown in different parameters.

Experiments	Variable parameters	Acid value	Viscosity
Experiment 1	Alcohol to oil molar ratio		
	• 1 : 1	0.3a	2.8a
	• 1 : 2	0.4a	2.7a
	• 1 : 3	0.5ab	3.4b
Experiment 2	1 : 4	0.60b	3.5b
	Types of catalyst		
	• KOH (5%)	0.4a	2.9a
• NaOH (5%)	0.5a	2.8a	
Experiment 3	Amounts of catalyst, NaOH		
	• 0.5%	0.4a	2.8a
	• 1.0%	0.5a	3.2a
	• 1.5%	0.6b	5.3 b

biodiesel produced was equivalent to the volume of biodiesel produced. From figure 1, the highest biodiesel yield of 49.5% was obtained when the methanol to oil molar ratio was 1:1, and the methanol to oil molar ratio of 1:4 gave the lowest biodiesel yield of 18%. Generally, the biodiesel yields decreased with decreasing methanol to oil molar ratios.

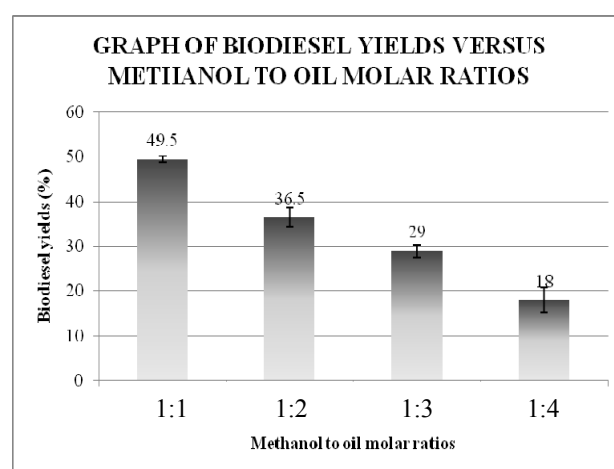
In this study, transesterification of waste cooking oil was catalyzed by using alkaline-catalyst, sodium hydroxide and potassium hydroxide (Figure 2). The result showed that the sodium hydroxide-catalyzed transesterification gave a biodiesel yield of 49.5%, which is higher than 33% in transesterification using potassium hydroxide. Three different catalyst concentrations were used in this study to determine the optimum catalyst concentration for transesterification of waste cooking oil using lower alcohol to oil molar ratios. The result showed that the biodiesel yield decreased with increasing catalyst concentrations; catalyst concentration of 0.5% gave the highest yield of 49.5%, whereas catalyst concentrations of 1% and 1.5% gave biodiesel yields of 27% and 17.5% respectively (Figure 3).

Biodiesel analysis

The result showed that the biodiesel with lowest viscosity was obtained when the methanol to oil molar ratio of 1:2 was used, and the methanol to oil molar ratio of 1:4 gave the highest biodiesel viscosity. Table 2 showed the effect of types of catalyst used on the biodiesel viscosity. It was shown that the sodium hydroxide-catalyzed transesterification gave a biodiesel viscosity higher than in transesterification using potassium hydroxide. In the Table 2, it was showed that the values of biodiesel viscosity increased with increasing catalyst concentrations.

Total acid number (TAN) determination

The result of TAN analysis showed that the TAN values of most samples were valid. The result showed that the biodiesel with lowest TAN was obtained when the methanol to oil molar ratio of 1:1 was used, and the methanol to oil molar ratio of 1:4 gave the highest TAN in produced biodiesel. Table 2 showed the effect of types of catalyst used on the biodiesel TAN value. It was shown that the sodium hydroxide-catalyzed transesterification gave a lower TAN than in transesterification using potassium hydroxide. In Table 2, it was showed that the values of TAN increased with increasing NaOH catalyst concentrations.



The effect of different methanol to oil molar ratios on biodiesel yield (oil was heated at 55°C for 40 minutes in the water bath).

Multi elements analysis

The elements measured in this study were iron, chromium, aluminium, copper, lead, tin, nickel, manganese, titanium, argentine, molybdenum, zinc, phosphorus, calcium, barium, magnesium, silicon, sodium, boron and vanadium. The result showed that the concentrations of all the elements were lower than 5ppm, except argentine and sodium (Table 3). In Table 4 it was shown the standard value of elements by ASTM and EN.

Discussion

Biodiesel yield

The result showed that the biodiesel yields of all the samples were low with a maximum average value of 49.5%. This result was expected since the amounts of alcohol used in this study were much lower than the theoretical optimum amount. One of the most crucial factors resulting in the low biodiesel yield was the soap formation. In this study, the raw material used for biodiesel production was waste cooking oil, which contains a large amount of free fatty acids. These free fatty acids might react with the alkaline catalysts to form soap. High soap formation leads to the formation of gels, which subsequently traps a large amount of esters within the glycerin layer and

Table 3. Element contents (ppm) in biodiesels produced from different alcohol to oil molar ratios

Elements	Ratios				NaOH (0.5%)	KOH (0.5%)	KOH (1%)	KOH (1.5%)
	MeOH 1:1	MeOH 1:2	MeOH 1:3	MeOH 1:4				
Fe	1	0.5	1.5	1	1.5	1	0.7	0.5
Cr	0	0	0	0	0	0	0	0
Al	0	0	0.5	0.6	0	0.5	0.5	0.5
Cu	0.5	1	0.5	0.4	0.5	1	1.5	2
Pb	0.5	0	4.0	0.4	0.5	0.5	0.5	0.5
Sn	4	2	3	3.5	4.5	7	0	0
Ni	3	2.5	0	0	3	3.5	2.5	2.5
Mn	0	0	2.5	7.4	0	0	0	0
Ti	1	1	2	3	1	1	0	0
Ag	8.8	6.5	5.5	6.5	8.5	7.4	9	9
Mo	2	1	0	3	2	3	0.5	0.5
Zn	0	0	2.3	2	0.5	0.5	0.6	0.5
P	3.5	3.5	1	1	0	3	0	0
Ca	2	2	3.0	4	2.5	2	6.5	6.5
Ba	0	0	0	0	0	0	0	0
Mg	1	1	1	0.8	1	1	2	2
Si	1.5	5.5	2.9	2.0	3.5	4	2.0	2.5
Na	4.3	6.2	7.5	8.0	4	3.5	9.4	9.4
B	3	2	2.5	2.0	0.5	1	1	1
V	1	1	0.8	0.9	1	1	1	1

leads to the loss of biodiesel (Stavarache et al., 2005). Besides that, soap dissolves in the glycerol layer since it contains one polar end. The dissolved soap increases the solubility of biodiesel in the glycerol, further decrease the recovery of biodiesel (Vicente et al., 2004). After transesterification, the washing step is necessary to purify the biodiesel. The presence of soap reduces the biodiesel yield in this step since it leads to the formation of emulsions which hinders the purification of biodiesel. This is because the soap presents in the esters phase tends to accumulate at the interfacial region between two immiscible ester and water layers. The amphiphatic nature of soap (one hydrophilic end and a long hydrophobic chain) orients the soap molecules perpendicular on the interfacial region, which collect the ester and water molecules to form emulsion (Stavarache et al., 2005). During the experiment, formation of emulsion was observed immediately once the water was added to biodiesels. In order to purify the biodiesels completely, all of the produced biodiesel were washed at least 3 times. During each washing step, small amounts of biodiesel were removed simultaneously with the emulsion, further leads to the loss of biodiesel.

Optimization of biodiesel production

Effect of alcohol to oil molar ratios on biodiesel yields

According to the stoichiometric equation of transesterification, 3 moles of alcohol reacts with 1 mole of triglyceride to give 3 moles of fatty acid ester and 1 mole of glycerine. In other words, an alcohol to oil molar ratio of at least 3:1 is required for complete reaction. Many researchers have reported an alcohol to oil molar ratio of 6:1 will be the optimal ratio, while Leung and Guo (2006) reported that the maximum biodiesel production was obtained at a molar ratio of 7:1 in transesterification of used frying oil. In this study, the alcohol to oil molar ratios used were much lower than the above

mentioned optimal ratios to study the feasibility of using low alcohol to oil molar ratios. In biodiesel production using waste cooking oils as raw materials, the main costs of materials are the costs of alcohol and catalyst. Since catalyst is required only in minute amounts, the primary cost would be the cost of alcohol. Therefore, if the use of alcohol can be reduced without significantly reduce the production of biodiesel, the biodiesel production cost would be less and the process would be more cost-effective. The result showed that the biodiesel yields were low for all four ratios used, and the yields decreased with decreasing methanol to oil molar ratio. Singh et al., (2006) suggested that higher methanol to oil molar ratios were better than lower ratios in terms of soap formation

Effect of types of catalyst on biodiesel yields

Vicente et al., (2004) reported that transesterification reaction carried out using sodium hydroxide and resulted in higher soap formation compared to that using potassium hydroxide due to the lower sodium hydroxide molecular weight. Thus, more methyl ester remains in the glycerol and less biodiesel can be recovered when sodium hydroxide is used. In terms of biodiesel quality, Tomasevic and Siler-Marinkovic (2003), reported that the use of 1% potassium hydroxide can produce biodiesel with better viscosities. Apart from that, biodiesel produced using potassium hydroxide also possessed a higher acid value. Since acid value is a measure of free fatty acid content in biodiesel, the transesterification catalyzed by potassium hydroxide is more effective than sodium hydroxide. The sodium soap sinks onto the glycerol layer at the bottom, resulting in a viscous glycerol layer. The potassium hydroxide is more commonly used in industrial processes compared to sodium hydroxide (Leung and Guo, 2006). Although most of the researchers reported that the use of potassium hydroxide could give a better biodiesel yield, the result obtained from this study showed that the biodiesel yields were higher when sodium hydroxide was

employed. Singh *et al.* reported that the soap formation was higher when potassium hydroxide was used compared to the use of sodium hydroxide. This phenomenon may explain the higher yield in sodium hydroxide-catalyzed transesterification than in potassium hydroxide in this study.

Effect of catalyst concentrations on biodiesel yields

Before the transesterification was carried out, the catalysts were dissolved in methanol first to produce methoxides. Since the amount of methanol used in this study was much lower than the theoretical amount required, the methanol added cannot dissolve the catalysts completely at catalyst concentrations of 1% and 1.5%. For methoxides with these two catalyst concentrations, the formation of soap was observed immediately after the filtered waste cooking oil was added to the methoxides, and this problem was more severe for methoxides with catalyst concentration of 1.5%. This phenomenon was expected because the sodium hydroxide which was not dissolved and reacted with free fatty acids present in the waste cooking oil to form soap. Soap formation was also observed for methoxides with catalyst concentration of 0.5%. Although the sodium hydroxide was completely dissolved by methanol to produce methoxide at this catalyst concentration level, the soap formation is inevitable since the feedstock contains free fatty acids. However, unlike sodium hydroxide which is a strong base, methoxide can reduce the soap formation because it behaves as weak Lewis base (Singh *et al.*, 2006). Thus, the amount of soap formed was less and soap formation occurred only during the process of shaking. The similar observation was reported by Singh *et al.*, (2006), in which the biodiesel yield did not increase linearly with increasing catalyst concentration but the formation of soap increased exponentially with catalyst concentration. Result showed that the biodiesel yield was lowest for catalyst concentration of 1.5%. This result is similar to the finding of Stavarache *et al.*, (2005) and Hossain *et al.*, (2009a). According to them, the yield of biodiesel produced using 1.5% (wt/wt) NaOH was very low due to the high soap formation. Ramadhas *et al.*, (2005) reported that the best conversion rate was obtained by using sodium hydroxide of 0.5%, which was in agree with the result of this study. However, the result of Rashid and Anwar (2008) showed that the maximum biodiesel yield was obtained by using sodium hydroxide concentration of 1%. Leung and Guo (2006) also reported that the optimum value of sodium hydroxide concentration for transesterification of waste canola oil was 1.1%. Phan and Phan (2008) concluded that the optimum catalyst concentration was strongly dependent upon the oil used (Hossain *et al.*, 2008, 2009b).

Viscosity

Formation of soap causes increase in the viscosity of biodiesel (Demirbaş, 2003). Therefore high soap formation rate may be the main reason causing high viscosity values of biodiesels in this study. Another reason that might be responsible for the high viscosity values is the long storage time. Mittelbach and Gangl (2001) studied the stability of biodiesel made from used frying rapeseed oil stored at 20 to 22°C under different storage conditions. They found that the viscosities of biodiesels increased slightly after a storage period of 170 days, from a value of 4.55cSt at day 0 to values ranging from 4.6 to 4.85cSt at day 170.

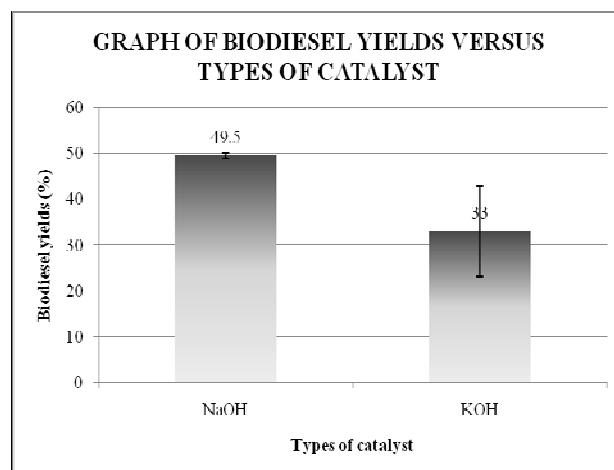


Fig 2. The effect of different types of catalyst on biodiesel yields

Sinha *et al.*, (2008) studied the effect of various parameters on the viscosity of the biodiesel produced through transesterification of rice bran oil. They found that the methanol to oil ratio does not cause significant variation in the viscosity of biodiesel. This result contradicted to the result obtained in this study; the difference between the viscosities of biodiesel produced using different methanol to oil molar ratio was significant in this study. This is because the amount of soap formed was significantly different in the biodiesels produced in this study, which eventually caused high variation between the viscosities of biodiesels produced.

Sinha *et al.*, (2008) used catalyst concentrations ranging from 0.5% to 1.25%. Their result showed that all of the biodiesels produced have similar viscosities and the values were lower than the ASTM limit of 5cSt, except for biodiesel produced using 0.5% sodium hydroxide. At this catalyst concentration, the transesterification may not be efficiently and completely catalyzed. Therefore free fatty acid content was higher and led to higher viscosity of the biodiesel. In this study, the soap formation increased with the catalyst concentrations. Hence the viscosities of biodiesels also increased in accordance with the increase of catalyst concentrations.

Total Acid Number (TAN)

In this study, the TAN values of most samples were valid except a few. These samples may be less chemical reactive or contain excessive acid value, which means that the acid contents of these samples were either too low to be detected or too high. Therefore the effect of different parameters on the values of TAN cannot be predicted. According to Tomasevic and Siler-Marinkovic, (2003), the alcohol to oil molar ratio has no influence on the acid value of biodiesel. The acid value mainly depends on the kinds of oil used as raw materials. It was also reported that the acid numbers of the biodiesel were influenced by reaction times, in which increasing reaction times causes increase in the value of acid number (Mahajan *et al.*, 2007). Vicente *et al.*, (2004) carried out alkali-catalyzed transesterification of refined sunflower oil. Their result showed that the acid values for biodiesels produced using sodium hydroxide were higher than those produced using potassium hydroxide (Hossain *et al.*, 2009a). Besides from viscosity,

Table 4. Characteristics of biodiesel with standard methods (ASTM D 6751 and EN 14214)

Property of FAME	Unit	Standard Method ^a	Value according to standard method
Viscosity	cSt at 40°C	ASTM D 6751	1.9 - 6.0
Acid number	mgKOH/g oil	ASTM D 6751	0.50 max
Group I metals (Na ⁺ K)	mg/l	EN 14214	5.0 max
Group II metals (Ca ⁺ Mg)	mg/l	EN 14214	5.0 max
Phosphorus content	mg/l	EN 14214	10.0 max

ASTM: American Standard for Biodiesel Testing Method; EN: European Norm

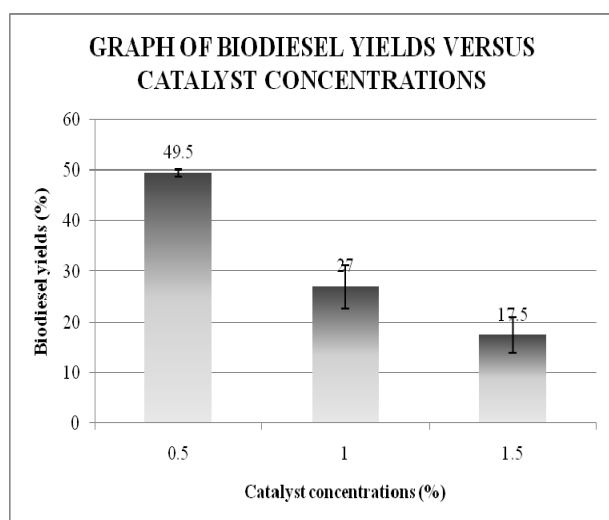
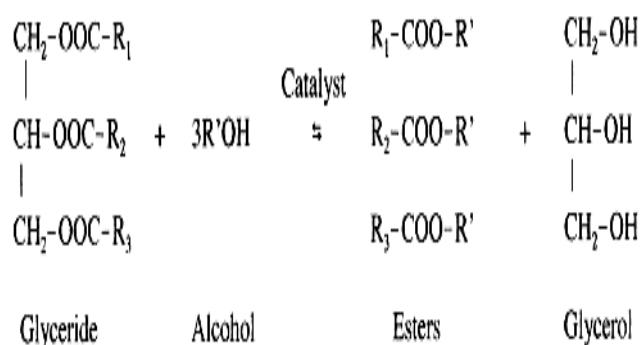


Fig 3. The effect of different catalyst concentrations on biodiesel yields

Mittelbach and Gangl, (2001) also studied the changes of biodiesel TAN values associated with a prolonged storage period. They found out that the values of acid number increased from 0.35mg KOH/g to values ranging from 0.38 to 0.54mg KOH/g after a storage period of 170 days.

Multi-element analysis

The presence of metals in the biodiesel is undesirable, as this may cause various problems, including promoting biodiesel degradation (Schober and Mittelbach, 2005), corrosion of engine, operability problems and environmental pollution. The elements whose quantities in biodiesel need to be controlled are sodium (Na) and potassium (K), which originated from the catalyst in biodiesel production, and phosphorus (P), which originated from the raw materials. The maximum permissible concentrations of Na and K in biodiesel are 5mg kg⁻¹, while P is 10mg kg⁻¹ (Korn et al., 2007). Apart from these elements, the levels of other elements such as magnesium (Mg), calcium (Ca), copper (Cu), iron (Fe), and zinc (Zn) should also be regulated. The metals in biodiesel can catalyze oxidation, especially highly-reactive species such as copper and zinc (McCormick et al., 2005). However the effect of presence of metals on oxidative stability is relatively less prominent compared to the



Transesterification reaction (Ma and Hanna, 1999)

effect exerted by presence of double-bonds (Knothe and Dunn, 2003).

Burning of biodiesel containing lead causes deposition in the motor parts, which helps to engine corrosion. Metals such as potassium, sodium, magnesium, and calcium present in biodiesel lead to injector, fuel pump, piston and ring wear, engine deposits, and filter plugging (McCormick et al., 2005). Since the catalysts used in this study were sodium hydroxide and potassium hydroxide, it is important to determine the values of these residual metals and make sure they are of safe level. Other metals such as copper and iron strongly increase the rate of gum formation, so as nickel and zinc, but to a lesser extent (Teixeira et al., 2007).

The metals present in the biodiesel can be removed by using chelators such as citric acid in order to attain desired concentrations. The chelators chelate the metals so that they can be removed by filtration (Gerpen et al., 2004).

Conclusion

It can be concluded that the optimal combination which showed the highest production of biodiesel in transesterification carried out for 2 hours by using methanol to oil molar ratio of 1:1 catalyzed by 0.5% sodium hydroxide. The production of biodiesel employing methanol to oil molar ratio of 1:1 was feasible in terms of biodiesel yield, since 6 times reduction of alcohol volume was used and resulted the 2 times decrease of biodiesel yield. It was also remarkable that sample cost and environmental pollution could be reduced by using used cooking oil.

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