

Process Development Studies on Biodiesel from Palm kernel, Palm and Gingelly oils

G. Kalyani, H.Joga Rao, Y.Prasanna Kumar

Abstract-Biodiesel is the name for a variety of ester-based oxygenated fuels derived from natural, renewable biological sources such as vegetable oils. Biodiesel operates in compression ignition engines like petroleum diesel thereby requiring no essential engine modifications. Biodiesel fuel can be made from new or used vegetable oils and animal fats. Biodiesel can be produced from oil bearing seeds of many plants like pongamia pinnata and that are grown in the wild like jatropha curcas and blended with high speed diesel for transport vehicles, generators, rail engines, irrigation pumps etc. As part of the research program on biodiesels, work has been initiated to develop processes for biodiesels reusing different feed stocks of vegetable oils including non-edible oils. The results of the research work on transesterification and evaluation of biodiesel samples are presented. The following variables were studied on laboratory scale transesterification of three vegetable oils, gingili, palm and palm kernel in presence of sodium hydroxide or potassium hydroxide catalyst- Mole ratio of vegetable oil to methyl alcohol and catalyst concentration. More over, the biodiesel samples obtained in the experimental studies have been evaluated determining the important physical properties like density, viscosity, distillation characteristics, cetane index, flash point, fire point, sulphur content and carbon residue. As observed from results, the yields of gingili, palm and palm kernel esters ranged from 90.3% to 95.7%.

Keywords-Biodiesel, ester-based oxygenated fuels, pongamia pinnata, jatropha curcas, cetane index, flash point, fire point, sulphur content, carbon residue, viscosity



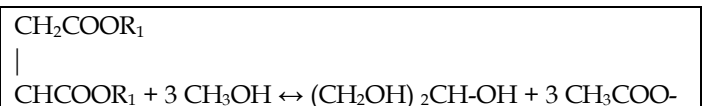
1 INTRODUCTION

Biodiesel is the name for a variety of ester-based oxygenated fuels derived from natural, renewable biological sources such as vegetable oils. Biodiesel operates in compression ignition engines like petroleum diesel thereby requiring no essential engine modifications. Moreover it can maintain the payload capacity and range of conventional diesel. Biodiesel fuel can be made from new or used vegetable oils and animal fats. Unlike fossil diesel, pure biodiesel is biodegradable, nontoxic and essentially free of sulphur and aromatics. Transesterification of a vegetable oil was conducted as early as 1853, by scientists E. Duffy and J. Patrick, many years before the first diesel engine became functional. Rudolf Diesel's prime model, a single 10 ft (3 m) iron cylinder with a flywheel at its base, ran on its own power for the first time in Augsburg, Germany on August 10, 1893. During the 1920s, diesel engine manufacturers created a major challenge for the biofuel industry. Diesel engines were altered to utilize the lower viscosity of the fossil fuel (petro diesel) rather than a biomass fuel (vegetable oil). The petroleum industries were growing and establishing themselves during this period. Some see a conspiracy here and argue that the business tactics and the wealth that many of these "oil tycoons"

already possessed greatly influenced the development of all engines and machinery. The alteration was the first step in the elimination of the production infrastructure for biomass fuels. Some see this as the first step in forcing the concept of biomass as a potential fuel base into obscurity, erasing the possibilities from the public awareness. However, others have pointed out that fossil diesel is simply cheaper than vegetable oil, and that no conspiracy is necessary to explain the move toward fossil fuels. Experiments with 50%, 100% biodiesel are underway.

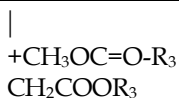
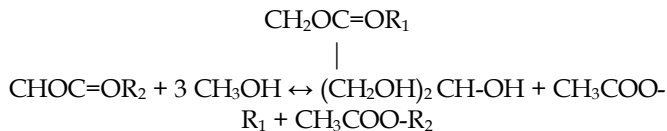
2 PRODUCTION OF BIODIESEL

Vegetable oils can be chemically reacted with an alcohol (methanol is the usual choice) to produce chemical compounds known as esters. Biodiesel is the name given to these esters when they are intended for use as fuel. Currently biodiesel is produced by a process called transesterification. The reaction may be shown as





Or



Triglyceride + Methanol \leftrightarrow Glycerine + Esters ; R_1, R_2, R_3 : Alkyl group.

The most common methods use vegetable oil, alcohol (ethanol) and sodium hydroxide (caustic soda), to produce biodiesel and glycerine.

Methanol recovery: The methanol is typically removed after the biodiesel and glycerine have been separated, to prevent the reaction from reversing itself.

Biodiesel refining: Once separated from the glycerin, the biodiesel goes through a clean-up or purification process to remove excess alcohol, residual catalyst and soaps. This consists of one or more washings with clean water. It is then dried and sent to storage. Sometimes the biodiesel goes through an additional distillation step to produce a colorless, odorless, zero-sulfur biodiesel.

Glycerine refining: The glycerin by-product contains unreacted catalyst and soaps that are neutralized with an acid. Water and alcohol are removed to produce 50%-80% crude glycerine. The remaining contaminants include unreacted fats and oils. In large biodiesel plants, the glycerine can be further purified, to 99% or higher purity, for sale to the pharmaceutical and cosmetic industries.

3 PRESENT INVESTIGATION

As part of the research program on biodiesels, work has been initiated to develop processes for biodiesels reusing different feed stocks of vegetable oils including non-edible oils. The results of the research work on transesterification and evaluation of biodiesel samples are presented. The following variables were studied on laboratory scale transesterification of three vegetable oils, gingili, palm and

palm kernel in presence of sodium hydroxide or potassium hydroxide catalyst:

- Mole ratio of vegetable oil to methyl alcohol.
- Catalyst concentration.

More over, the biodiesel samples obtained in the above experimental studies have been evaluated determining the important physical properties like density, viscosity, distillation characteristics, cetane index, flash point, fire point, sulphur content and carbon residue. The present study would be of considerable help in providing operating variables for a batch process as well as to design a continuous process for biodiesels.

Transesterification reaction without using catalyst

Saka and Kusdiana [1] experimented on the transesterification reaction of rapeseed oil in super critical method, without using any catalyst at high temperatures (350-4000C), high pressures 45-65 kPa and mole ratio of oil to alcohol 1:42. Saka [2] experimented in a batch type reactor using super critical methanol and found that this new supercritical methanol process requires the shorter reaction time and simpler purification procedure because no catalyst was used.

Kinetics of Transesterification

Avciao et al. [3] discussed the kinetics of transesterification of sunflower oil with ethanol at different temperatures in the presence of potassium hydroxide as catalyst. Pnov et al. [4] studied the kinetics and equilibrium of acid-catalyzed transesterification of acetates with alcohols in concentrated solutions evaluating different parameters like rate constants, activation parameters and equilibrium constants. Ginosar [5] worked on the process for producing alkyl esters useful in biofuels and lubricants by transesterification of glycerides or esterifying free fatty acids in a single critical phase medium for increased reaction rates, decreased loss of catalyst or catalyst activity and improved yield of desired products. Bikou et al. [6] studied the effect of water on kinetics of transesterification of cottonseed oil with ethanol and proposed a kinetic model for the transesterification of cottonseed oil with ethanol in the presence of catalyst presenting the dependence of the equilibrium constant and reaction rate constant on the water content. The results showed attainment of equilibrium within 30 minute reaction time in all cases. The increase in water content resulted in decrease of the conversion of the oil. By increasing ethanol/oil ratio the conversion of triglyceride has enhanced while the concentration of the mono and di-glyceride in the mixture reduced. Sermenov [7] presented a note that the

composition of the alternative fuel can be optimized by mixing biodiesel with light crude oil cuts. The first distillation curves are given for biodiesel, gas condensate, diesel fuel and the proposed binary alternative fuel.

Alternate fuel sources

Bhide [8] examined that the dimethyl ether is potential ultra clean diesel oil DME burns without producing the smoke associated with diesel combustion and can be manufactured from synthesis gas or methanol. DME has low viscosity, insignificant lubricity and can be blended with diesel fuel to obtain clearer burning fuels that retain satisfactory fuel properties. Joeng.G.Wi [9] discussed that the fatty acids and methyl esters show large potential applications as diesel substitutes also known as biodiesel fuel. He also investigated transesterification of rapeseed oil to produce the FAME. He found that the conversion ratio of rapeseed oil was enhanced by alcohol-oil mixing ratio and the reaction temperature.

Transesterification reaction using higher alcohols

Bhatia et al. [10] discussed the transesterification of jojoba oil with C3-10 alcohols and the products (shorter chain alcohol esters) were evaluated as a potential source for formulating lubricating oils. Shimada et al. [11] produced biodiesel using Isopropanol. The reaction time took more than 12 hours.

Biodiesel production by various different processes

Konear [12] concentrated mainly on a low waste process for the production of biodiesel. He explained that the production of biodiesel triglycerides of vegetable oils was contacted with methyl orange and a catalyst producing methyl ester and glycerin. Boerrichter et al. [13] experimented one of the promising routes to produce green fuels in the combination of biomass gasification and Fisher Tropsch (F-T) synthesis where the biomass was gasified and after cleaning the biosyngas was used for F-T synthesis to produce long chain hydrocarbons that are converted into green diesel. Hinnico [14] explained a process which involves comparison of fatty acids in three common vegetable oils, ester process description, overall material balance for rapeseed oil, case product properties, biodiesel based fuels in France and environmental advantages of biodiesel.

Studies on Engine performance with the use of biodiesel

Enchelmair et al. [15] studied the pressure less transesterification process and apparatus for the manufacture of rape oil methyl ester for use as fuel in internal combustion engines. Dunn et al. [16] presented a note on recent advances in the development of alternative fuels from vegetable oils and animal fats. Interest in utilizing vegetable oils and animal fats (triglycerides) as alternative fuels for compression-ignition (diesel) engine has increased in the past 10-15 yrs. Triglycerides have many fuel properties including heat of combustion, cetane number, high flash temperature and good lubricity that make them alternative fuels and extenders.

Storage of biodiesel

Very few people worked on the storage system of the biodiesel. This is also very important aspect to be taken in to account. Bondioli et al. [17] discussed about the storage system of biodiesel. Bondioli [18] examined the biodiesel stability under commercial storage conditions over one year. The results obtained from the long run storage study using eleven different biodiesel samples were presented.

4 EXPERIMENTAL SETUP

Three necked flat bottomed glass flask of 500ml capacity was used for transesterification reaction. A double coiled reflux condenser was fitted to a neck of the glass flask for condensing methanol vapours during the reaction. Ice cooled water was circulated through coils of the condenser. A thermo-well was fitted to the second neck of the flask. Thermo-well was filled with a thermometric liquid (ethylene glycol). A glass thermometer of 0-1000C range was placed in the thermo-well to measure the temperature of the reaction mixture. A plate heater with a magnetic stirrer was used for uniform heating of the contents of the flask. Oil, methanol and other chemicals were transferred through the third neck of the flask at the start of each experimental run using glass funnel and was stopped during the reaction. A constant temperature bath was provided to maintain the temperature of the contents in the flask in the range 60-630C.

5 DESCRIPTION OF THE EXPERIMENTAL SETUP

Hot plate with magnetic stirrer (220/230 V 50 ~ 1 ϕ AC Amperes 1.8), Magnetic element, Three necked flat bottom flask with neck size of 24/29 and 500 ml (made of borosil glass), Reflux coil condenser (joint size 24/29), Thermo-well filled with thermometric liquid (Ethylene Glycol), Thermometer of 0-100oC range. 500 ml (made of vensil glass), separating funnels and distillation setup.

6 PROCEDURE

Preconditioning of oil

Preconditioning of oil involved the removal of the moisture and neutralization of free fatty acids (FFA). Usually refined oils consist less than 5% of FFA but they need to be neutralized as they result in the formation of

soap. For determination of FFA present in the oil taken, we titrated the oil sample with 0.1N KOH solution with Phenolphthalein as indicator. Volume in ml of 0.1N KOH required to neutralize one gram of oil is called acid value. And with this we determined the amount of KOH needed to neutralize the FFAs in the oil. Thus by adding calculated amount of KOH, FFAs are removed in the form of soap. Removal of moisture involved heating the oil sample upto 105-110 °C and maintaining it there for few minutes so that all moisture gets evaporated. If required vacuum pump arrangement is used to remove the moisture present.

Transesterification reaction

In this step, calculated amount of catalyst (NaOH/KOH) is accurately weighed and dissolved completely in methanol. Calculated amount of oil sample is taken in the necked flat bottom flask and it is put over the flat plate heater and heated. To this methanol taken in 6:1 mole ratio (alcohol to oil) is gently added such that no amount of methanol gets evaporated. The condenser is readily fitted to one of the neck of the three necked flask. To the other neck, thermometric well is fixed and the third neck is closed with a stopper. Now the stirrer is put on, and the whole batch of oil and methanol are thoroughly mixed to attain uniform reaction. The temperature of the bath is maintained in the range of 60-63°C and the reaction is carried out for one hour. After the reaction time is over, the batch is withdrawn from the heater and cooled to room temperature on cooling formation of two layers is observed. This whole batch is poured into a separating funnel and allowed for at least 5 hour. To get clear separation of ester and glycerine. Glycerine formed at the bottom is taken out as a by-product. The obtained ester is subjected to further purification.

Purification of products and recovery of methanol

The ester was treated further, to remove the excess methanol and catalyst (NaOH) present. The excess methanol was recovered by distilling the ester and glycerine separately. For removing the catalyst present in the ester small amount of glacial acetic acid is added to get a neutral ester and then it is washed with hot distilled water to remove any traces of catalyst present. Washing is done with distilled water at 50 °C, 65 °C and 80 °C to remove traces of methanol or catalyst. Thus pure ester is treated with CaCl₂ or heated to 105-110 °C for 10 min. to remove any moisture present. Thus obtained ester is almost 100% pure.

Yields of esters

The yields of methyl gingili ester at 0.5, 0.75 and 1.0 wt% of sodium hydroxide catalyst were shown in table-4.1, the yields of methyl palm ester at 0.5, 0.75, 1.0, 1.25, 1.5, 1.75 and 2.0 wt% of potassium hydroxide catalyst and the yields of methyl palm kernel ester at 1.0, 1.5, 2.0 and 2.5 wt% of sodium hydroxide catalyst

7 EVALUATION OF BIODIESELS

The biodiesel samples prepared in the process development studies were evaluated by determining the physical properties mentioned below:

Density

Density of the sample was calculated by multiplying the specific gravity of the sample with density of water.

Specific Gravity

Specific gravity was determined using a 25 ml density bottle.

Kinematic Viscosity

Using Redwood viscometer, redwood seconds (t) were determined. The Values of the kinematic viscosity of the samples were calculated using the equation given below:

$$\mu/\rho = 0.00264 t_r - 1.79/t_r \quad t_r < 100 \text{ seconds (stokes)}$$

$$\mu/\rho = 0.00264 t_r - 0.5/t_r \quad t_r > 100 \text{ seconds (stokes)}$$

Distillation Characteristics

The distillation characteristics of each sample were calculated by finding the temperature recorded for distillate qualities of 10%, 50% & 90% by volume of the sample.

Cetane Index

Cetane Index was calculated using following equation.

$$\text{Cetane Index} = 175.4 \times \log (\text{mid boiling point } F) + 1.98(\text{API gravity}) - 496.$$

$$\text{API gravity} = \{(141.5/\text{specific gravity}) - 131.5\}$$

Flash Point

The flash point is the temperature at which the oil begins to evolve vapours in sufficient quantity to form an explosive or inflammable mixture with air.

Fire Point

It is defined as the temperature of the vapor at which the flame continuously burns.

Carbon Residue

Percentage of carbon residue was calculated using equation given below.

$$\% \text{ of Carbon Residue} = (x - y / 1000) \times 100$$

$$\text{Weight of the empty crucible} = y, \text{ in grams.}$$

$$\text{Weight of the empty crucible} + \text{Carbon Residue} = x, \text{ in grams.}$$

$$\text{Carbon Residue} = x - y, \text{ in grams.}$$

The physical properties of methyl gingili ester at 0.5, 0.75 and 1.0 wt% of sodium hydroxide catalyst, the physical properties of methyl palm ester at 0.5, 0.75, 1.0, 1.25, 1.5, 1.75 and 2.0 wt% of potassium hydroxide catalyst and the physical properties of methyl palm kernel ester at 1.0, 1.5, 2.0 and 2.5 wt% of sodium hydroxide catalyst.

8 RESULTS AND DISCUSSION

Preparation of Different Methyl Esters

Methyl esters of palm, gingili and palm kernel oils have been prepared in this work in fifty six experimental runs. The percent yield defined as grams of ester per gram oil for the preparation of different oils along with the details like mole ratio, catalyst concentration. As observed, the yields

of gingili, palm and palm kernel esters ranged from 90.3% to 95.7%. Irrespective of different mole ratios and catalyst concentrations, the yields were more or less same with about 3-5% variation. In case of methyl gingili ester, at 1:4.5 mole ratio and 0.5 and 0.75 wt% of catalyst (NaOH) the % yield was 95.7. In case of methyl palm ester, at 1:3 mole ratio and 1.5 wt% of catalyst, the % yield was 93.7 and with methyl palm kernel ester at 1:6 mole ratio and 2.0 wt% of the catalyst the % yield was 93.8. The yields must be more at higher mole ratios, but in our study we found that the yields were low at higher mole ratios this may be because of the large amount of loss in washings. The greater loss in washings occurred due to the unclear separation of the product and the wash water.

Cetane Number vs. Cetane Index

The Cetane number test method for diesel fuel was developed in the 1930s by the Cooperative Fuel Research (CFR) committee and later standardized by ASTM. The method involves running the fuel in a single cylinder engine with a continuously variable compression ratio under a fixed set of conditions. Although the method has been updated over the years, it is still based on the original engine design. Two specific hydrocarbons were chosen to define the cetane number scale: 1-methyl naphthalene (also called α -methyl naphthalene), which burns poorly in a diesel engine, was assigned a cetane number of zero and n-hexadecane(cetane), which burns well, was assigned a cetane number of 100. These hydrocarbons are the primary reference fuels for the method. The cetane number fuel defined as the volume percent of n-hexadecane in the blend of n-hexadecane and 1-methyl naphthalene that gives the same ignition delay period as the test sample. In other words, cetane number is a relative measure of the interval between the beginning of injection and auto ignition of the fuel. The higher the number, the shorter is the delay interval. The cetane number test method is difficult and expensive. If an engine is not available or the amount of fuel is insufficient for the engine test, two simple methods known as D 976 and D 4737 have come in to vogue to estimate the cetane number of the fuel. To differentiate them for the engine test, these estimations are called cetane indexes. D 976 uses the density of the fuel and its mid-distillation temperature to estimate the cetane number. D 4737 is an improved method over D 976. It uses the density of the fuel and the distillation temperatures at 10% vol, 50% vol and 90% volume recovery to estimate the cetane number. The values of cetane numbers estimated by D976 and D4737 are more conservative than the engine cetane numbers. In the present work, the cetane numbers of the bio-diesel samples were estimated using D976 methods because it is very simple. These values of cetane numbers are compared with the standard specifications.

Effect of Mole Ratio on Cetane Index and Kinematic Viscosity

The values of physical properties like density, kinematic viscosity, cetane index, flash point, sulphur content, carbon residue and distillation characteristics of methyl palm ester, palm kernel ester and gingili ester are presented in tables 4.4-4.6. As shown from the tables 4.4-4.6, cetane index decreases when the mole ratio of alcohol increases from a value of 1:4.5 to 1:9. The cetane index is calculated from the mid-boiling point temperature. It may attribute to the lower mid boiling point temperature obtained at the 1:9 mole ratio for the above mentioned esters. Calculations also give the mid-boiling point temperatures of different esters. It is evident that the purity of ester would be highest for the mole ratio of 1:9 as such it lowers the mid boiling point temperature. The values of kinematic viscosity are also in decreasing trend when the mole ratio is increased from a value of 1:4.5 to 1:9 in palm ester, palm kernel ester, and gingili ester. The variation in cetane indices with change in mole ratios are given in figures-4.1(a) to 4.1(c) and the variation in kinematic viscosities with change in mole ratios are given in figures-4.2(a) to 4.2(c).

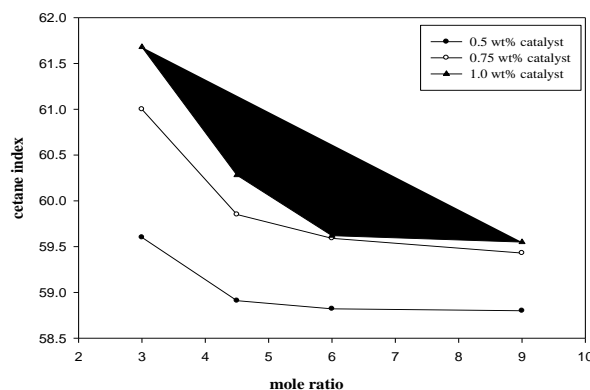


Figure-4.1(a): mole ratio vs cetane index at various catalyst concentrations for methyl gingelly ester with NaOH catalyst

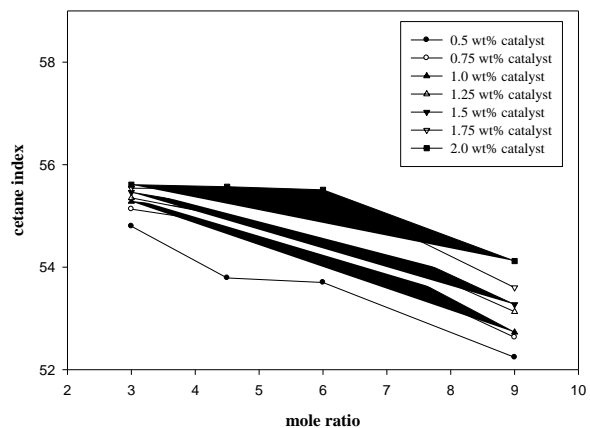


Figure-4.1(b): mole ratio vs cetane index at various catalyst concentrations for methyl palm ester with KOH catalyst

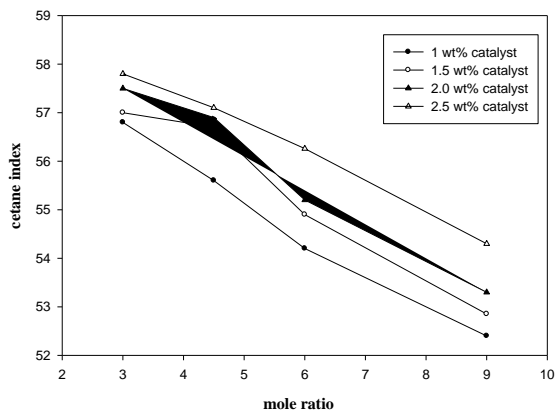


Figure 4.1(c): mole ratio vs cetane index at various catalyst concentrations for methyl palm kernel ester with NaOH catalyst

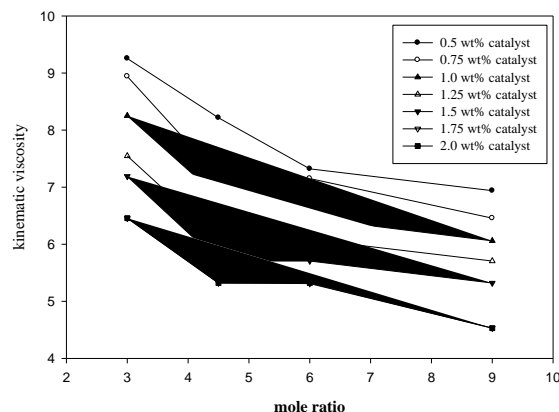


Figure-4.2(b): mole ratio vs kinematic viscosity at various catalyst concentrations for methyl palm ester with KOH catalyst

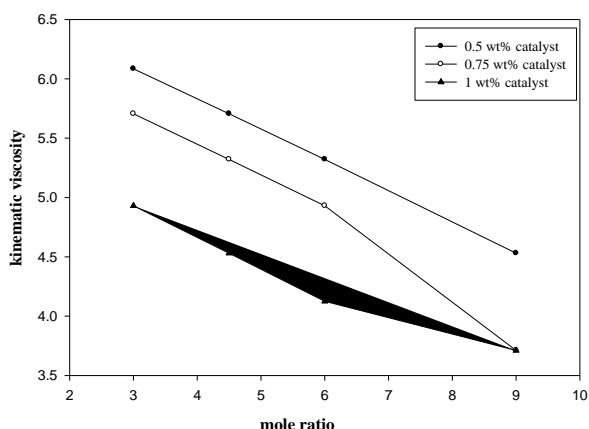


Figure-4.2(a): mole ratio vs kinematic viscosity at various catalyst concentrations for methyl gingelly ester with NaOH catalyst

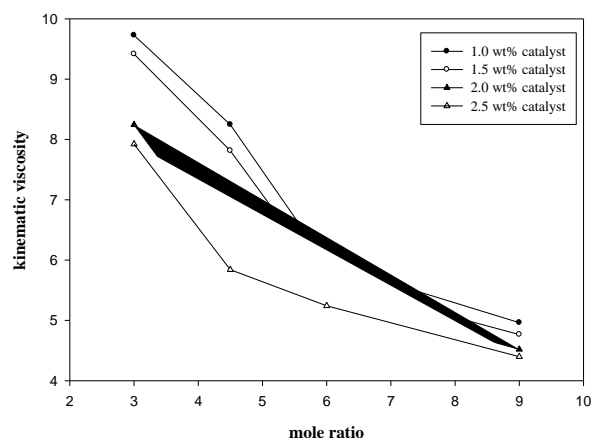


Figure-4.2(c): mole ratio vs kinematic viscosity at various catalyst concentrations for methyl palm kernel ester with NaOH catalyst

Effect of Catalyst Concentration on Kinematic Viscosity

From the results, it can be concluded that the lowest values of kinematic viscosities for palm ester, palm kernel ester and gingili ester at higher concentrations of the catalyst in the different mole ratios studied in the present investigation. At the same time, the concentration does not show any marked difference in the values of Cetane Index. The catalyst concentration has a profound effect on the values of both kinematic viscosity and cetane index for palm ester, palm kernel ester and gingili ester the values as calculated. For lower acid value oils, the experiments were conducted for the mole ratios from 1:3 to 1:9 and for the oils with greater acid values the experiments were conducted for the mole ratios from 1:3 to 1:9. The values of kinematic viscosities decreased when the catalyst concentration is raised from 0.25% to 1.0%. For the same increase of catalyst concentration, the cetane index is increased. It is clear from these results that the conversion of oil to ester is low even the concentration of the catalyst is raised from 0.25% to 0.5%. At the 1.0% catalyst concentration, the values of kinematic viscosity of the ester is significantly reduced indicating the fact that the minimum catalyst concentration

should be in the vicinity of 1.0%. Obviously higher values of density are recorded for the palm kernel ester because of low conversion of oil to ester. The variation in kinematic viscosities with change in catalyst concentrations are given in figures-4.3(a) to 4.3(c).

mole ratios 1:3 to 1:9. This sudden decrease in the flash points may be because that the esters at greater mole ratios become very volatile and that's why it is giving sufficient vapors at its volatile temperature which is very low compared to the esters which are less volatile. The variation in flash points with changes in mole ratios is given in figures-4.4(a) to 4.4(c).

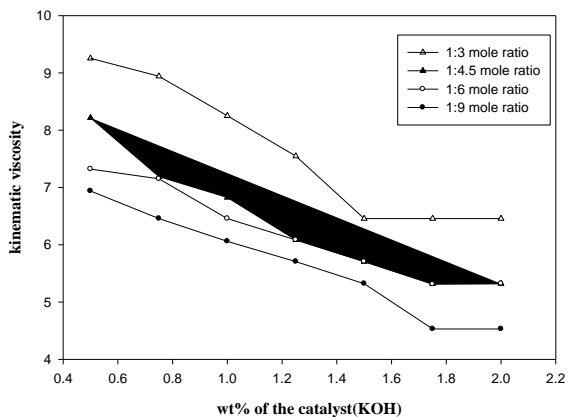


Figure-4.3(b): kinematic viscosity vs concentration of the catalyst for methyl palm ester with KOH catalyst

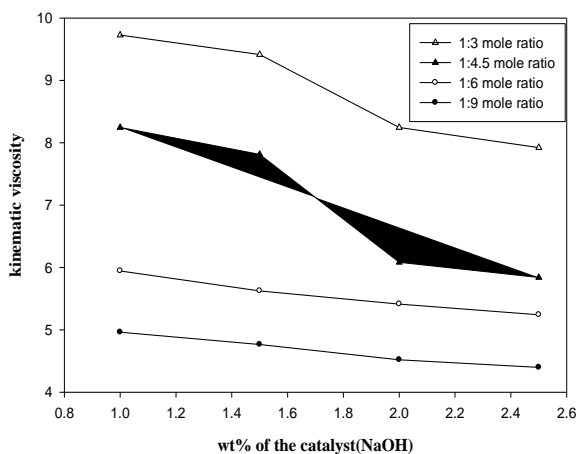


Figure-4.3(c): kinematic viscosity vs catalyst concentration at various mole ratios for methyl palm kernel ester with NaOH catalyst

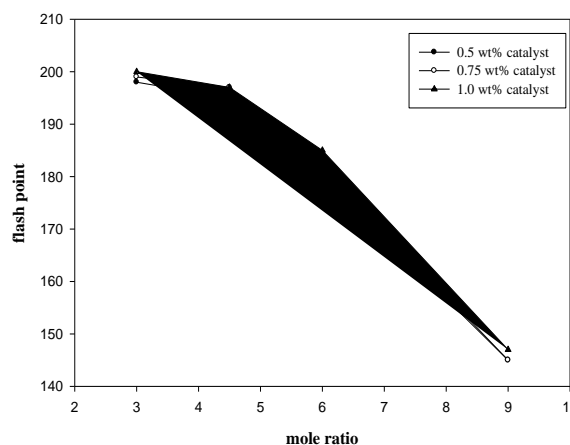


Figure-4.4(a): mole ratio vs flash point at various catalyst concentration for methyl gingili ester with NaOH catalyst

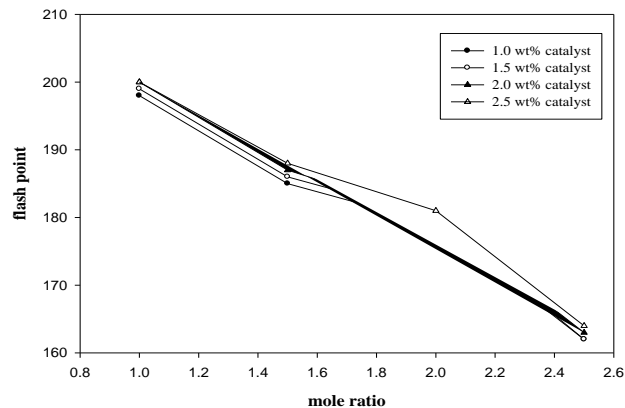


Figure-4.4(c): mole ratio vs flash point at various catalyst concentrations for methyl palm kernel ester with NaOH catalyst

Effect of Mole Ratio on Flash Point

The values of flash point of the palm ester, gingili ester and palm kernel ester are affected by the mole ratio. There is no significant change in the values of fire point for changes in mole ratio/catalyst concentration in the case of the esters mention above. Practically, the sulphur content and the values of carbon residue of these esters are found to be same. It may be due to the limitations in the analysis. The values of flash points gradually decreased for palm ester and palm kernel ester. But the change is very high in case of gingili ester particularly when approaching high mole ratios. A difference of nearly 30-40°C in case of palm ester, gingili ester and palm kernel ester is observed from the

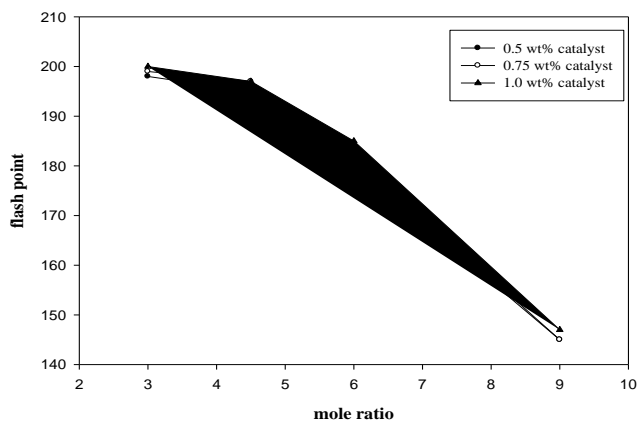


Figure-4.4(a): mole ratio vs flash point at various catalyst concentration for methyl gingly ester with NaOH catalyst

REFERENCES

- [1] Saka, S. and Kusdiana, D. Fuel.(Pub.2000), 80 (2), 225-231, 2001 (Eng) (Cited in Chemical abstract:Vol-134,No-7,2001)
- [2] Saka,S, Chorinkai and Saishin Gyutsu 7, 10-14, 2003, (Japan) Jasuko Repotosha.
- [3] Avciate, Ulvi, Teker and Murat, Chem Acta Turc. 20(2) 181-186, 1992, (Eng) (Cited in Chemical abstract: Vol-121, No-18, 1994)
- [4] Pnov, M. Yu., Garipova, U.K., Admiralova, L.V.Zh. and Obshch, Khim., 65 (80), 1381-1390,1995 (Russ) (Cited in Chemical abstract:Vol-124,No-15,1996)
- [5] Ginosar, PCT.Int.Appl. Wo, 0005327 (CL.CLO L1/18, 3rd Feb, 2000 US Appl. 94, 076, 24 July, 1998, 16 pp (Eng).
- [6] Bikou, Elina, Loulondi, Argiro, papayannakos and Nikas.Chemical Engg. Technl., 22(1) 70-75,1999 (Eng) (Cited in Chemical abstract Vol-8, 97,965, 1999)
- [7] Sermenov.V.G., Chemistry and Technology of fuels and oils (Translation of Khimiya I Tekhnologiya Topliv I Masel), 39(4), 192-196, 2003 (Eng).
- [8] Bhide, ICE (American Society of Mechanical Engineers), 40 (Design, applications of modern internal combustion engine systems and components) 207-215, 2003 (Eng).
- [9] Joeng Gwi, Applied Biochemistry and Biotechnology, 113-116, 747-758, 2004 (Eng) Humana press. Inc.
- [10] Bhatia, V. K., Kaul, S. and Kapoor, U.B., Jojobai Oil Technol. Assoc. India (Bombay), 26(1), 23-25, 1994 (Eng). (Cited in Chemical abstract: Vol-122, No-11, 1995)
- [11] Shimada, Yuji, Watanabe Yomi, Sugihara, Akio, Taminaga, Yoshio, Fukuda, Hidek and Noda, Hideo. PCT Int. Appl. 1 Sep, 1998; 29 pp (Japan) (Cited in Chemical Abstract: Vol-132, No-15, 2000)
- [12] Konear.E.Ahn, Scp.Sci.Technol, 30(79), 2021-2033, 1995 (Eng).
- [13] Boerrigher and Harald, Pyrolysis and gasification of biomass and waste proceedings of an expert meeting, Strasbourg, France, Sept 30,oct 1, 2002 (pub 2003).
- [14] Hinrico, Prepn. Pap-Am.Chem.Soc.Div.Fuel Chem., 40(4), 763-767, 1995 (Eng).
- [15] Dunn, R.O., Knothe, G. and Bagloy, M.O. Chem., 1, 31-56, 1997 (Eng) Trans World Research Network (Cited in Chemical abstract: Vol-26, 353581,1999)
- [16] Enchelmaier, Horst, Raschorn and Hans Juergen Ger.Offen.DE 4, 238, 195, 19th May 1994, April 12,1992(Cited in Chemical abstract:Vol-121,No-22, 1994)
- [17] Bondioli, Paolo, Gasparoli, Ada,Langeni, Armand,Fedeli,Enzo,Veronese, Serigo Sala and Moura, J., Am.Oil Chem Soc.72(6),699- 702,1995 (Eng) (Cited in Chemical abstract:Vol-123,No-10,1996)
- [18] Bondioli, European Journal of Lipid Sciences and Technology, 105(12), 735-741, 2003 (Eng)Wiley-VCH verlag GmbH.