

## Conversion of Waste Cooking Oil to Biodiesel

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### Abstract

Recycled waste cooking oil is harmful to health, but it is not environment friendly to dispose off used cooking oil. The best solution is to use it for industrial purposes, namely to convert it into biodiesel. Due to the awareness of adverse effects of conventional fuels to environment and the frequent rise in crude oil's price, the need for sustainable and environment friendly alternate source of energy has gained importance in recent years. Biodiesel is proved to be the best replacement for diesel because of its unique properties like significant reduction in greenhouse gas emissions, non-sulphur emissions, non-particulate matter pollutants, low toxicity and biodegradability. Cost of biodiesel produced from virgin vegetable oil through transesterification is higher than that of fossil fuel, because of high raw material cost. To minimize the biofuel cost, these days, waste cooking oil is used as feedstock. Catalysts used in this process are usually acids, base, and lipase. Since lipase catalysts are much expensive, the usage of lipase in biodiesel production is limited. In most cases, NaOH is used as alkaline catalyst, because of its low cost and higher reaction rate.

In the case of waste cooking oil containing high percentage of free fatty acid, alkaline catalyst reacts with free fatty acid and forms soap by saponification reaction. Also, it reduces the biodiesel conversions. In order to reduce the level of fatty acid content, waste cooking oil is pre-treated with acid catalyst to undergo esterification reaction, which also requires high operating conditions. In this paper, the pre-treatment step, the physical and chemical properties of waste cooking oil, Esterification, Transesterification and production of Biodiesel from waste cooking oil by various methods and catalysts reported so

far and the factors affecting the process parameters reported have been summarized.

## **INTRODUCTION**

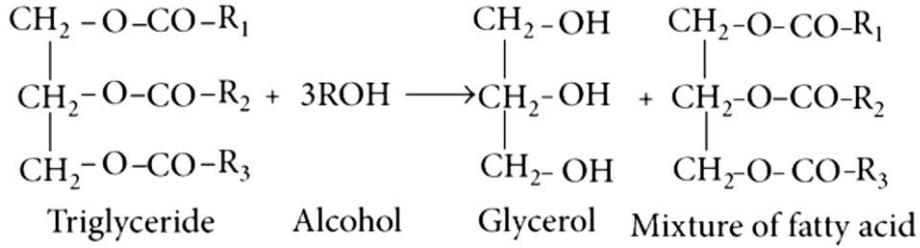
Biodiesel is an alternative diesel fuel derived from vegetable oils or animal fats. The main components of vegetable oils and animal fats are triglycerides known as ester of fatty acid attached to glycerol. One of the main driving force for biodiesel widespread is the limited greenhouse gas emission (CO<sub>2</sub> being the major one). The term waste cooking oil (WCO) refers to vegetable oil that has been used in the cooking of food and which is no longer viable for its further use in food production. WCO arises from many different sources, including domestic, commercial and industrial. WCO is a potentially problematic waste stream which requires proper management. The disposal of WCO can be problematic when disposed irresponsibly[1,2]. Any fatty acid sources may be used to produce biodiesel. Therefore, any animal or plant lipid should be ready substrate for the production of biodiesel. The use of edible vegetable oils and animal fats for biodiesel production has recently been of great concern because they compete with food material- the food versus fuel dispute. There are concerns that biodiesel feedstock may compete with food supply in the long term. From an economic point of view; the production of biodiesel is very feedstock sensitive. The cost of feedstock accounted for 88% of total estimated cost of production. Reusing of these waste oils and fats not only reduce the burden of the government in disposing the waste, maintaining public sewers, and treating the oily waste water, but also lower the production cost of biodiesel significantly. Biodiesel can be produced from any material that contains fatty acids, be they linked to other molecules or present as free fatty acids. Thus various vegetable fats and oils, animal fats, waste greases, and edible oil processing wastes can be used as feed stocks for biodiesel production. The choice of feedstock is based on variables such as local availability, cost, government support and performance as a fuel. The primary feedstock is a vegetable oil or animal fat. Biodiesel is generally considered to be renewable[1-4].

Since the carbon in the oil or fat originated mostly from carbon dioxide in the air, biodiesel is considered to contribute much less to global warming than fossil fuels. Diesel engines operating on biodiesel have lower emissions of carbon monoxide, unburned hydrocarbons, particulate matter, and air toxics than when operated on petroleum-based diesel fuel[23]. Neat (unprocessed) vegetable oil can not be used in the compression ignition engines as it is reported to cause several problems due to its high viscosity. Biodiesel which is accepted as an attractive alternative fuel[4,6], is prepared by transesterification of vegetable oils and animal fats with an alcohol in presence of a catalyst[3,21,22]. However, the land use for production of edible oil for

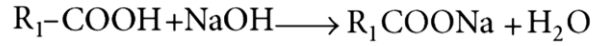
biodiesel feedstock competes with the use of land for food production. Moreover, the price of edible plant and vegetable oils is usually higher than petro diesel. The use of waste cooking oil as biodiesel feedstock reduces the cost of biodiesel production . Hence, the use of waste cooking oils and non-edible oils should be given higher priority over the edible oils as biodiesel feedstock[9].

Biodiesel is superior to fossil diesel fuel in terms of exhaust emissions, cetane number, flash point and lubricity characteristics, without any significant difference in heat of combustion of these fuels[17]. Moreover, biodiesel returns about 90% more energy than the energy that is utilized to produce it. Biodiesel mixed with conventional diesel in some proportions can be used to run any existing conventional compression ignition engine and does not require any amendments to be done to the engine[20]. Due to benefits like renewable in nature, low cost and green house gas reduction potential, biodiesel is nowadays incorporated all over the world especially in developed countries like USA, France, Brazil in different proportions with diesel[4,9]. It is also estimated that India can supplement 41.14% of its total diesel fuel consumption, if resources like waste cooking oil and other bio wastes were used as raw material for biodiesel production.

**3. Transesterification of waste cooking oil :** In transesterification reaction, the triglyceride component of oil reacts with the alcohol in the presence of NaOH or any other catalyst to give ester and glycerol as shown in the reaction-1. In general, there are three systems of transesterification with vegetable oil or an animal fat as a starting material, they are homogeneous, heterogeneous systems and enzymatic, based on the catalyst employed in the process[3,16,21,22]. Used vegetable oil is reacted with alcohol. In most of the cases methanol is used because of better efficiency[19]. However ethanol and isopropyl alcohol can also be used, Ethanol is used for animal fats. It has been reported that, transesterification process depends upon many parameters which are reaction temperature and pressure, reaction time, rate of agitation, type of alcohol used and molar ratio of alcohol to oil, type and concentration of catalyst used and concentration of moisture and free fatty acid in the feed stock waste oil[10,27,41]. The optimal values of these parameters largely depend on the physical and chemical properties of the feedstock oil for attaining higher conversion[17].

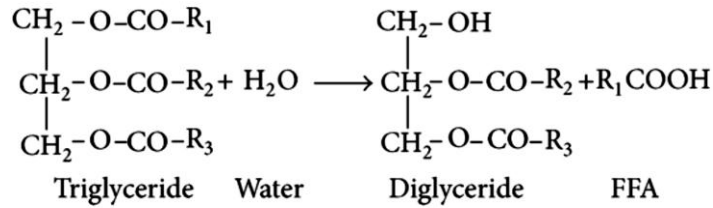


### Trans esterification reaction



FFA    Sodium hydroxide    Soap    Water

### Side reaction ( Saponification Reaction )



### Side reaction ( Hydrolysis reaction)

#### **Esterification: A schematic representation of the transesterification reaction.**

The production of majority of biodiesel today is done through homogeneous alkali-catalysed transesterification of edible vegetable oils[22]. Homogeneous catalysts are soluble during the reaction, they may be liquid or gaseous. They are of two types: Acidic and Alkaline. Acidic catalysts like H<sub>2</sub>SO<sub>4</sub> are used usually for Esterification while Alkaline catalysts like NaOH and KOH are used for transesterification. The benefits of homogenous catalysts are (i) they can catalyse reaction at lower reaction temperature and atmospheric pressure; (ii) high conversion can be achieved in less time, (iii) easy availability and its low cost . This process permits a good product quality in a relatively shorter reaction time .The effective use of Alkaline homogenous

catalyst is limited only for refined vegetable oil with less than 0.5 wt.% FFA or acid value less than 1 mg KOH/g. Moreover, the removal of these catalysts after the reaction is complete needs the washing of biodiesel with water which might result in loss of Fatty acid alkyl esters, energy consumption and generates large amount of waste water[11]. This also increases the overall cost of biodiesel production as it is difficult to recover the catalyst which may cause reactor corrosion. The triglyceride and alcohol should be anhydrous and a Low free fatty acid (FFA) content of raw material is necessary to avoid the soap production ( by alkaline catalyst consumption) and low product yields.

Heterogeneous catalysts are the solids and are insoluble during the reaction .Most of them are metal oxides like KBr/CaO, chitosan, SrFe<sub>2</sub>O<sub>4</sub>/SiO<sub>2</sub>-SO<sub>3</sub>H and catalyst derived from chicken bones. Heterogeneous (solid) catalysts are preferred over homogenous as they can be reused, allow a better separation, better quality of the final products and are economical[3,12]. Solid base catalysts are considered to be promising catalysts for transesterification as they have advantages such as easy removal of catalyst from reaction mixture, can tolerate high FFA, no washing is required, easy regeneration, less corrosive character, low in cost and it is a more environment friendly. However, there are also few disadvantages of the heterogeneous catalysts such as they require extreme reaction conditions (higher temperature and reaction times) for preparation compared to homogeneous process[22]. The calcinations temperature for catalyst obtained from chicken bones is 9000 ° C. Homogeneous catalysts might be required to be characterized by sophisticated equipment's techniques like Fourier Transform Infrared spectrometry (FTIR), X-ray Diffraction (XRD) and Scanning Electron Microscopy(SEM) techniques . Moreover, techniques like Response Surface Methodology (RSM) using Central Composite Design (CCD) need to be employed to study the effects of process variables on the reaction yield.

Solid acid catalysts like zeolites, mixed oxides, sulphates, zirconia and ion exchange resins might be very exciting for the production of biodiesel from feedstocks with high FFA contents, but still their activity is low because it depends upon the reaction conditions and higher amount of catalyst consumption related to homogeneous catalysts[3]. Moreover in some of the cases, soap formation is also seen using heterogeneous catalyst and purification is required in most of the cases to ensure the needed quality of fuel. Enzymatic catalysts are becoming one of the most promising catalysts for the biodiesel production. They can stand high FFA and simultaneous Esterification and Transesterification take place in these reactions. Enzymatic catalysts[3] are recognised for being cost effective catalysts, smaller reaction time and lower reaction temperature. However reactions using enzymatic catalysts require more amount of catalyst and production yield is less compared to homogeneous and heterogeneous. Generally, heterogeneous base catalysts are made in different ways,

such as impregnation of amounts of base metals, precipitation, conversion to oxides by calcination, and co-precipitation. Borges and Díaz used potassium-loaded pumice material (K-Pumice) as the heterogeneous catalyst in the sunflower oil and waste oil transesterification reaction for biodiesel production, using a packed-bed catalytic reactor in a recirculation system[13]. Pumice particles (1.40–3.0 mm) were introduced into a potassium hydroxide time, 20:1 methanol/oil molar ratio, and an 8.2 cm catalytic packed-bed length, the value of the content of the biodiesel required by Standard UNE-EN 14124 (96.5 %) was achieved, reaching a 99.5 % value.

Roschat et al. undertook transesterification aqueous solution in order to attain potassium interchange, generating some basic sites on the natural material. The reaction rate increased slightly when the temperature was increased from 50 to 60°C[14]. However, using a 55°C reaction temperature, a 2 hr reaction, mixing WCO, palm oil, soybean oil and rice bran with methanol to make a biodiesel and glycerol by-product, using calcined waste coral fragments in solid form as the catalyst. Under optimum reaction conditions, coral fragments calcined at 700°C for 1 hr, a catalyst/oil ratio of 100 wt.%, a methanol/oil molar ratio of 15:1, and a reaction temperature of 65 °C with constant stirring, biodiesel with a yield of over 98 % in 2 hr can be formed. The synthesized mixed oxide catalysts comprising CaO and ZrO<sub>2</sub> mixed oxides with various Ca-to-Zr molar ratios were employed for the transesterification of WCO as the feedstock with methanol to produce biodiesel at 65 °C and 1 atm. The experimental results showed that the activity of synthesized catalysts increases with increase in molar ratio of Ca-to-Zr but at the same time results in decreased stability of the catalysts[15]. Under the appropriate transesterification conditions at 65 °C, catalyst loading 10 wt.%, methanol-to-oil molar ratio 30:1, and reaction time 2 hr, a biodiesel yield of 92.1 % could be attained over the CaO-ZrO<sub>2</sub> catalyst with a Ca-to-Zr molar ratio of 0.5. If the acid value of waste cooking oil exceeds 1-2 mg KOH/mg of feed stock, then pre-treatment of waste cooking oil is required before it gets reacted with alkaline base catalyst[16-19].

## **FACTORS AFFECTING BIODIESEL PRODUCTION**

The viscosity of the vegetable oil changes drastically due to process of transesterification. The removal of high viscosity component, glycerol, gives the product which has low viscosity like the fossil fuels. The biodiesel produced is completely miscible with mineral diesel in all proportions. After transesterification flash point of the biodiesel is dropped and the cetane number is improved. The yield of biodiesel in the process of transesterification is dependent on many factors such as reaction temperature, reaction time, catalyst, presence of moisture and free fatty acids (FFA), and molar ratio of alcohol and oil [41 and 27] .

**Temperature**

Yield of biodiesel is largely affected by the Reaction temperature. For example, higher temperature increases the reaction rate and reduces the reaction time as the viscosity of oils is decreased. However, if the reaction temperature is increased beyond the optimal level, it leads to decrease of biodiesel yield, as higher reaction temperature speeds up the saponification of triglycerides [28] and facilitates the vaporisation of methanol resulting in reduced yield [29]. So the transesterification reaction temperature should be kept below the boiling point of alcohol to prevent the evaporation of alcohol. The optimal reaction temperature may vary from 50°C to 60°C depending upon the nature of oils or fats used [28] which should be near the boiling point of the alcohol for faster conversion. Methyl esterification of the FFAs could be carried out appreciably at room temperature up to 78% conversion after 60 minutes but it might require a longer reaction time [30].

**Reaction time:** An increase in reaction time has been found to increase fatty acid esters conversion. In the beginning the reaction is slow due to mixing and dispersal of alcohol and oil, then after some time the reaction proceeds very fast and the maximum ester conversion has been found to be attained within 90 min. Further increase in reaction time does not cause any increase in the yield of biodiesel. Moreover, longer reaction time than this leads to the decrease in the yield of biodiesel due to the reversible nature of the transesterification reaction causing loss of esters as well as soap formation [28] and 31].

**Methanol to Oil Molar ratio:** Esterification reaction is reversible so in order to shift the reaction to the right i.e to increase the yield of biodiesel, either the use of excess alcohol or the removal of one of the products from the reaction mixture is recommended. The removal of one of the products is generally preferred for the reaction to proceed to completion. The reaction rate has been found to be highest when 100% excess methanol is used [32 and 29]. Amongst methanol, ethanol, propanol, butanol and amyl alcohol which can be used in the transesterification reaction, the methanol is used more frequently due to its low cost. Moreover, it is physically and chemically advantageous as it is polar and shortest chain alcohol. Whereas, in the transesterification process ethanol is preferred alcohol compared to methanol as it is renewable and biologically less invasive to the environment and could be derived from agricultural products. The effect of volumetric ratio of methanol/ ethanol to oil has been studied and it was observed that highest biodiesel yield was nearly 99.5% at 1:6 oil/methanol. But biodiesel yield using methanol has been found to continuously increase with increase of methanol molar ratio [33].

**Type and Amount of Catalyst**

Biodiesel formation is also depends on the concentration of catalyst. In the transesterification process, the type and amount of catalyst needed generally depend

on the quality of the oil or fat, alcohol and the method applied for the process. Sodium hydroxide (NaOH) or Potassium hydroxide (KOH) are the most commonly used catalyst for biodiesel production [28]. For pure starting materials, any type of catalyst could be used for the transesterification process. However, homogenous transesterification process is unsuitable for starting materials having high moisture and free fatty acids contents, as there is a great probability of occurrence of saponification process instead of transesterification process.

The yield esters usually increase with increasing amount of catalyst as there is availability of more active sites by additions of larger amount of catalyst in the transesterification process, but it is not profitable due to cost of the catalyst itself. So it is necessary to determine the optimum amount of catalyst essential in the transesterification process [33 and 31].

### **Mixing Intensity**

Mixing is very important in the transesterification process, as oils and alcohols are not completely miscible and reaction can take place only in the interfacial region between the liquids hence transesterification reaction becomes a slow process. Therefore, sufficient mixing between these two types of reactants is essential to stimulate contact between these two reacting materials in order to promote the transesterification reactions to take place [31] and [33]. Most of the studies show that the reactants initially form a two-phase liquid system during the transesterification reaction and the mixing has been found to play an important role in the slow rate of the reaction but as phase separation ends, effect of mixing becomes insignificant [35]. The intensity of the mixing may be changed depending on its requirement in the transesterification process. For sufficient and uniform mixing of the feedstock the mixing intensity is usually increased, especially if the vegetable oils with high viscosity are used as the feedstock, intensive mechanical mixing is required [31] and [33].

### **Free fatty acid and water content**

The free fatty acid and water content have substantial effect on the transesterification of glycerides with alcohol using catalyst. The high free fatty acid (FFA) content more than 1% w/w, will cause the soap formation and the separation of products extremely difficult, and leads to low yield of biodiesel product [36]. In addition to this formation of gels and foams also hampers the separation of glycerol from biodiesel [28]. For example, water content in waste cooking oil speeds up the hydrolysis reaction and simultaneously reduces the amount of ester formation [37]. To overcome this difficulty, supercritical methanol method was suggested as water has been found to have less influence in supercritical methanol method [28]. So, water content should not exceed 0.5% in order to obtain 90% yield of biodiesel and it is more dangerous for an acid-catalysed reaction than base catalysed reaction [38]. The reaction of FFAs



with alcohol produces ester along with water which hinders the transesterification of the glycerides. Thus water formation is the primary mechanism limiting the completion of the acid catalysed esterification reaction with FFAs.

### **Process I.**

Waste cooking oil may contain particulate matter and other impurities. Such impurities are removed by filtering the waste cooking oil. Feed stock oils are usually preheated to 60°C by heat exchangers. Alcohol and acid catalysts are properly mixed in mixer before they were allowed into the esterification reactor. The mixing temperature is usually maintained at 60°C. Catalyst mixture and preheated feedstock are allowed into the esterification reactor. Esterification reaction was carried out between 80 and 90°C and at 1 atmospheric pressure[39,40]. Products from esterification reactor were cooled to 45°C, and catalysts are removed or neutralized before moving into the settling tank to remove the methanol and water mixture[21,22]. From the top of the settling tank, methanol and water mixture is removed and taken to distillation column to separate methanol from methanol water mixture and methanol is reused. The bottom product of separating vessel is taken to process II for transesterification reaction .

### **Process II**

Catalyst and alcohol are mixed in the mixer and products formed from process are taken into the transesterification reaction column along with catalyst and alcohol mixture. Reactor temperature is usually maintained at 65°C, 1 atmospheric pressure, and 1 : 6 molar ratio of oil to alcohol. Products of transesterification reactor are moved into separator 2. From the separation tank, biodiesel and alcohol mixture is distilled to separate methanol and biodiesel. Methanol from distillation column is recycled and reused. Biodiesel obtained is then washed with hot water and moved to separator to separate water and biodiesel. From the third separator tank, biodiesel is moved to storage tank. Bottoms of second separator section are moved to the alcohol and glycerol distillation column [41,42]. From the top of distillation column methanol is recycled. Bottom product of distillation column is a by-product.

**Purification of Biodiesel:** Once the reaction is complete, the mixture of product is shifted to a separating funnel in which the mixture is allowed to settle down at room temperature or by centrifuging. The mixture gets separated into two layers in most of the cases. When ionic liquid is used as catalyst, the product formed separates into three layers based on the catalyst used [9,10]. The top layer is always biodiesel and the lower layer is glycerol. This separation is based on the difference in densities. Biodiesel is collected and washed with distilled water or ethyl acetate for removing minor impurities. The washed biodiesel is heated to remove any moisture present. It may also be treated with anhydrous sodium sulphate to remove water and yield the biodiesel which is a yellow liquid[43, 44].

**CONCLUSION:**

Biodiesel has attracted extensive attention in the world as it is a renewable, biodegradable, nontoxic and environmentally friendly new alternative transportation fuel. It can be made from different feedstock containing fatty acids such as animal fats, nonedible oils, waste cooking oils, by products of the refining vegetables oils and algae etc. Transesterification process is a commonly employed for its formation. Heterogeneous catalysts are recommended the best catalysts in biodiesel production. Cost of biodiesel can be reduced by using waste cooking oil as feed stock. High fatty acid content in waste cooking oil can be reduced by pre-treating waste cooking oil with acid catalyst. Water produced during the esterification process may inhibit acid catalyst. It can be removed by stepwise reaction mechanism. Methanol is the most suitable alcohol because of its low cost and easy separation from biofuel. But still there is need to improve the biodiesel process economically using environmentally friendly catalysts and selecting the best process technology.

**REFERENCES**

- [1] Kulkarni MG, Dalai AK. Waste cooking oil an economical source for biodiesel: a review. *Industrial & Engineering Chemistry Research*. 2006;45:2901-13.
- [2] Muhammad Farooq ,AnitaRamli b, Abdul Naeemc; *Renewable Energy* 76 (2015) 362e368.
- [3] Lam MK, Lee KT, Mohamed AR. Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: a review. *Biotechnology Advances*. 2010;28:500-18. Said et al. / *Journal of Mechanical Engineering and Sciences* 8(2015) 1302-1311.
- [4] No SY. Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: a review. *Renewable and Sustainable Energy Reviews*. 2011;15:131-49.
- [5] Lanzafame R. Water injection effects in a single-cylinder CFR engine. SAE Technical Paper No. 1999-01-0568; 1999.
- [6] Demirbas A. Biodiesel a realistic fuel alternative for diesel engines. London: Springer; 2008.
- [7] Soon LB, M. Rus AZ, Hasan S. Continuous biodiesel production using ultrasound clamp on tubular reactor. *International Journal of Automotive and Mechanical Engineering*. 2013;8:1396- 405.
- [8] Vashist D, Ahmad M. Statistical Analysis of Diesel Engine Performance for Castor and Jatropha Biodiesel-Blended Fuel. *International Journal of Automotive and Mechanical Engineering*. 2014;10:2155-69.

- [9] Bajpai D, Tyagi V. Biodiesel: source, production, composition, properties and its benefits. *Journal of Oleo Science*. 2006;55:487-502.
- [10] Abbaszadeh A, Ghobadian B, Najafi G, Yusaf T. An experimental investigation of the effective parameters on wet washing of biodiesel purification. *International Journal of Automotive and Mechanical Engineering*. 2014;9:1525-37.
- [11] Gabriel O. Ferrero , Manuel F. Almeida , Maria C.M. Alvim-Ferraz , Joana M. Dias; *Energy Conversion and Management* 89 (2015) 665–671.
- [12] Honglei Zhang, Jincheng Ding, Zengdian Zhao; *Bioresource Technology* 123 (2012) 72–77.
- [13] Kathleen F. Haigha, Goran T. Vladislavljevićca, James C. Reynoldsb,ZoltanNagya, BasudebSahac; *chemical engineering research and design* 9 2 ( 2 0 1 4 ) 713–719.
- [14] Kao-Chia Ho, Ching-Lung Chen, Ping-Xuan Hsiao, Meng-Shan Wu, Chien-Chang Huangc, Jo-Shu Chang; *EnergyProcedia* 61 ( 2014 ) 1302 – 1305.
- [15] Sneha E. Mahesh , AnandRamanathan b, K.M. Meera S. Begum , Anantharaman Narayanan ;*Energy Conversion and Management* 91 (2015) 442–450.
- [16] Ghaly, A.E., Dave, D., Brooks, M.S., Budge, S. (2010) Production of Biodiesel by Enzymatic Transesterification: Review. *American Journal of Biochemistry and Biotechnology* 6 (2): 54-76.
- [17] Refaat, A. A., Attia, N. K., Sibak, H. A., El Sheltawy, S. T., Eldiwani, G. I.(2008) Production optimization and quality assessment of biodiesel from waste vegetable oil. *International Journal of Environmental Science and technology*, 5 (1): 75-82.
- [18] Alnuami, W., Buthainah, A., Etti, C. J., Jassim, L. I., Gomes G. A. C. (2014) Evaluation of Different Materials for Biodiesel Production. *International Journal of Innovative Technology and Exploring Engineering*, 3(8), 60-65
- [19] Shahid, E.M., Jamal, Y., Shah, A.N., Rumzan, N., Munsha, M. (2012) Effect of Used Cooking Oil Methyl  
a. Ester on Compression Ignition Engine. *Journal of Quality and Technology Management*, VIII (II), 91–104.
- [20] Sarıbiyık,O.Y., Özcan, M., Serin, H., Serin, S., Aydın, K. (2012) Biodiesel Production from Ricinus  
a. Communis Oil and Its Blends with Soybean Biodiesel, *Journal of Mechanical Engineering*, 56, 811-816.
- [21] Demirbas, A. (2008) Comparison of transesterification methods for production of biodiesel  
a. from vegetable oils and fats. *Energy Conversion and Management*, 49:125–130.

- [22] Lam MK, Lee KT, Mohamed AR. Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: a review. *Biotechnology Advances*. 2010;28:500-18. Said et al. / *Journal of Mechanical Engineering and Sciences* 8(2015) 1302-1311.
- [23] Piloto-Rodríguez, R., Melo, E. A., Goyos-Pérez, L., Verhelst, S. (2014) Conversion of by-products from
- a. the vegetable oil industry into biodiesel and its use in internal combustion engines: a review. *Brazilian Journal of Chemical Engineering*, 31(02): 287 – 301.
  - b. *Journal of Chemical Engineering*, 31(02): 287 – 301.
- [24] Antony Raja, S., Robinson smart, D.S., Robert Lee, C.L (2011) Biodiesel production from jatropha oil
- a. and its characterization. *Research Journal of Chemical Sciences*, 1 (1), 81-87
- [25] Schuchardt, U., Sercheli, R., Vargas, R.M. (1998) Transesterification of Vegetable Oils: A Review *Journal of Brazilian Chemical Society*, 9(1), 199-210.
- [26] Jaichandar, S., Annamalai, K. (2011) The Status of Biodiesel as an Alternative Fuel for Diesel Engine – An Overview. *Journal of Sustainable Energy & Environment* 2, 71-75.
- [27] Highina, B.K., Bugaje, I.M., Umar, B. (2012) Biodiesel Production from Jatropha Caucus Oil in a Batch Reactor Using Zinc Oxide as Catalyst, *Journal of Applied Phytotechnology in Environmental Sanitation*, 1(2), 61-66.
- [28] Mathiyazhagan, M., Ganapathi, A. (2011) Factors Affecting Biodiesel Production, *Research in Plant Biology: Review Article*, 1(2), 01-05.
- [29] Anitha, A., Dawn, S.S. (2010) Performance Characteristics of Biodiesel Produced from Waste Groundnut Oil using Supported Heteropolyacids. *International Journal of Chemical Engineering and Applications*, 1(3), 261-265.
- [30] Ogbu, I.M. Ajiwe, V.I.E. (2013) Biodiesel Production via Esterification of Free Fatty Acids from Cucurbita Pepo L. Seed Oil: Kinetic Studies. *International Journal of Science and Technology*, 2(8), 616-621.
- [31] Jagadale, S. S., Jugulkar, L. M.(2012) Review of Various Reaction Parameters and Other Factors Affecting on Production of Chicken Fat Based Biodiesel, *International Journal of Modern Engineering Research*, 2(2), 407-411.
- [32] Gashaw, A., and Lakachew, A. (2014) Production of biodiesel from non edible oil and its Properties.

- [33] International Journal of Science, Environment and Technology, 3(4): 1544 – 1562.
- [34] Hossain, A.B.M.S., Boyce. A.N. (2009) Biodiesel Production from Waste Sunflower Cooking Oil as an Environmental Recycling Process and Renewable Energy. Bulgarian Journal of Agricultural Science, 15 (4), 312-317.
- [35] Kansedo, J.B. (2009) Synthesis of Biodiesel from Palm Oil and Sea Mango Oil Using Sulfated Zirconia Catalyst. Msc thesis, Universiti Sains Malaysia.
- [36] Shereena, K.M., Thangaraj, T. (2009). Biodiesel: an Alternative fuel Produced from Vegetable Oils by Transesterification. Electronic Journal of Biology, 5 (3): 67-74.
- [37] Berchmans, H. J., Hirata, S. (2008) Biodiesel production from crude *Jatropha curcas* L. seed oil with high content of free fatty acids. Bioresource Technology, 99: 1716–1721.
- [38] Arun, N., Sampath, M., Siddharth, S., Prasaanth, R. A. (2011) Experimental Studies of base catalyzed transesterification of karanja oil. Journal of Energy and Environment, 2( 2): 351–356.
- [39] Lotero, E., Liu, Y., Lopez, D. E., Suwannakarn, K., Bruce, D. A., Goodwin, J. G. (2005) Synthesis of biodiesel via acid catalysis. Industrial and Engineering Chemistry Research, 44(14): 5353–5363
- [40] Abdullah, N.H., Hasan, S.H., Yusoff, N.R.M. (2013) Biodiesel Production Based on Waste Cooking Oil (WCO), International Journal of Materials Science and Engineering, 1(2): 94-99.
- [41] Gude, V.G., Patil, P. D., Grant, G. E., Deng, S. (2012) Sustainable Biodiesel Production, Second world Sustainable forum, 1-14, www.wsforum.org.
- [42] Parawira, W. (2010) Biodiesel production from *Jatropha curcas*: A review. Scientific Research and Essays, 5(14), 1796-1808.
- [43] Colin J. Stacy, Cory A. Melick, Richard A. Cairncross; Fuel Processing Technology 124 (2014) 70–77.
- [44] Abdelrahman B. Fadhil , Mohammed M. Dheyab, Abdul-Qader Y. Abdul-Qader; Journal of the Association of Arab Universities for Basic and Applied Sciences (2012) 11, 45–49
- [45] Anildo Cunha Jr. , Vivian Feddern, Marina C. De Prá , Martha M. Higarashi , Paulo G. de Abreu , Arlei Coldebella ; Fuel 105 (2013) 228–234.

