Production of Renewable Liquid Fuels for Diesel Engine Applications – A Review

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Abstract— ***Today it is very much essential to use renewable fuels for power generation and transport applications because of energy security, environmental concerns, foreign exchange savings and socio-economic issues. The new process technologies developed during the last years made it possible to produce biodiesel from different vegetable oils comparable in quality to that of fossil diesel fuels with added attractive advantages. The transesterification process is well-established and becoming increasingly important, but there remain considerable inefficiencies in existing transesterification processes. There is an imperative need to improve the existing biodiesel production methods from technological, economical and environmental viewpoint and to investigate alternative and innovative production processes. In view of this, the review is carried out on biodiesel production and this study mainly highlights the different techniques used in the production of biodiesel from different edible and non-edible oils, advantages and limitations of each technique, and the optimization conditions for each process. The emerging technologies which can be utilized in this field of research are also investigated.***

Keywords: Biodiesel, Triglycerides, Supercritical, Ultrasonic, Microwave, Lipase, Enzyme, Transesterifcation.

I. INTRODUCTION

The process to obtain an alternative fuel from vegetable oils called biodiesel was developed as early as 1853 and the transesterification process for methyl ester production was first conducted by scientists E. Duffy and J. Patrick. The first biodiesel-powered vehicle was Rudolf Diesel's prime model that ran with this fuel for the first time in Augsburg, Germany on August 10, 1893. Later the great scientist Rudolf Diesel demonstrated his engine powered by peanut oil at the World Fair in Paris, France in 1900 [1].

Actually, the name biodiesel was introduced in the United States during 1992 by the National Soy diesel Development Board (presently national bio diesel board) **[2].** However during the 1920's, diesel engine manufacturers decided to alter their engines utilizing the lower viscosity of the fossil fuel known as petrodiesel. Due to petrodiesel commercialization, the use of biomass fuel production infrastructure slowly it was eliminated. [1]. But, on continuous use of fossil fuels for all energy applications since a last century, these fossil fuels are becoming slowly diminishing and also due to heavy emissions caused by fossil fuels and the countries which are not having fossil fuel reserves were facing a foreign exchange crisis, mainly due to the import of crude oil. Hence, it is necessary to look for an alternative fuels, which can be produced from materials available within a country. In addition, the use of alternative fuels like vegetable oil, bioethanol, biogas and producer gas as fuel is less polluting than petroleum fuels [2].

Today it is very much essential to use alternative fuel because of energy security, environmental concerns, foreign exchange savings and socio-economic issues [3]. Therefore, now days, many efforts have been made by several scientists and researchers to use renewable liquid and gaseous fuels as an alternative fuels in compression ignition (CI) engine. Vegetable oils have an advantages in terms of renewability, environment friendly, non-toxic and biodegradable, also has no sulphur and aromatics and has favorable heating value, higher cetane number, its chemical structure contains long chain saturated, unbranched hydrocarbons are the most favorable property for the use in conventional diesel engine [4, 5, 6, 7, 8, 9, 10]. But it has been found that neat vegetable oil poses some problems when it is used directly in an engine as a diesel substitute [4]. These are all due to large molecular mass, chemical structure of oil, higher viscosity, low volatility and poly unsaturated character of vegetable oil [4, 9]. These problems can be solved, if the neat vegetable oils are chemically modified to biodiesel, which is similar in characteristics to that of diesel fuel. In view of this, several techniques were explored by scientists and researchers to bring down the physical and thermal properties of vegetable oils close to mineral diesel oil. In this direction, many researchers have identified several methods to produce biodiesel such as base and acid catalyzed transesterification, two step s transesterification, supercritical methanolysis, microwave assisted transesterification, ultrasonic transesterification, and

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lipase catalyzed transesterification, biodiesel production by using heterogeneous catalysts [11 – 14]. Biodiesel is defined as a liquid hydrocarbon fuel composed of fatty acids monohydric alcohol esters whose molecular composition may change according to the type of feed stocks from different places for the fuel synthesis [15]. The main reason for the lower performance and emission characteristics of CI engine is due to oils physico – chemical properties. The presence of fatty acids greatly affects the properties of biodiesel. The different fatty acids present in the vegetable oils are palmic, steric, lignoceric, oleic and linoleic etc [16 - 21]. These fatty acids of oil increase the smoke emissions and also lead to incomplete combustion due to improper air-fuel mixing.

For the production of biodiesel, any source of fatty acids can be used. From the literature survey, it is observed that many countries around the world are using edible oils for engine applications. In USA and Europe, their surplus edible oils like soybean oil, sunflower oil and rapeseed oil are being used as feed stock for the production of biodiesel [4, 22, 23, 24]. Only renewable fuel from oil crops are not considered as sustainable. Because of growing population, there always exist a great demand for edible oil consumption and hence it becomes too expensive for engine and other applications. However, the use of second and third generation fuels leads to a sustainable development [4, 25]. During the investigation and with a suggested priority structure, biodiesel from non – edible oils and algae is found to be in the highest rank and better alternative fuel compared to first generation fuels. Also the use of renewable non-edible oils for diesel engine operation avoids the conflict between food and fuel security. Second generation biodiesel feedstock - Non-food energy crops such as Honge, Jatropha, Neem, and Rice bran oil represent the second generation biodiesel feedstock.

In view of this, the review is carried out on renewable liquid fuels (biodiesel) production and this study mainly highlights the different techniques used in the production of renewable liquid fuels, advantages and limitations of each technique, and the optimization conditions for each process. The emerging technologies which can be utilized in this field of research are also investigated.

II. RENEWABLE LIQUID FUELS WITH REFERENCE TO PROPERTIES

Researchers and scientists had determined various properties of different vegetable oils and its methyl esters and gaseous fuels. A brief review of about this has presented here.

A. Vegetable oil and Biodiesel Properties

Triglycerides are the main constituents of vegetable oils. The fatty acid contribution in vegetable oils varies from oil to oil. Many samples of same kind vegetable oils were taken from different places and reported that they vary in their Chemical structure. It depends on weather and soil conditions [26]. Vegetable oils contain different types of fatty acids and the fatty acids vary in their carbon chain length and in the number of unsaturated bonds they contain *[2,4, 27, 28]*. The different fatty acids present in the vegetable oils are palmic, steric, lignoceric, oleic and linoleic etc [29, 30, 31]. The biodiesel produced from chemically modified process have similar characteristics as that of diesel fuel. The transesterification process reduces the molecular weight to one-third that of the triglyceride and also reduces the viscosity by a factor of about eight and increases the volatility marginally. Biodiesel has viscosity close to diesel fuels. These esters of vegetable oils contain 10–11% oxygen (by weight), which is responsible for lower heating value of biodiesel. The cetane number of Biodiesel is around 50 -54. Biodiesel is considered clean fuel having no sulphur and no aromatics. The higher cetane number of this fuel improves the ignition quality even when blended in the petroleum diesel [2]. The composition of Jatropha Gossypifolia and Hevea brasiliensis seed oils was determined by ***Hosmani*** et al [32] using chromatography test. It shows presence of hydroxyl fatty acids. 2, 4- dinitrophenyl hydrazine (2, 4 DNPH) thin layer chromatography test and picric acid layer chromatography test indicates absence of cycloproenoid, keto and epoxy fatty acids. In their anther research work *(*2009), he determined saponification value, iodine value and cetane number of fatty acid methyl esters empirically. Some vegetable oils show non-newtonian behavior, therefore, ***Knothe*** [33] have determined dynamic viscosity rather than kinematic viscosity. ***Park*** et al [34] investigated the effect of temperature variation and blending ratios on biodiesel and biodiesel blended with ethanol fuel properties. They showed that cloud point of biodiesel- ethanol blend decreases when ethanol content in biodiesel mixture increases and they developed empirical equation for ethanol blending ratio and fuel temperature variation from the measured and calculated values of the density. Vegetable oils are of two types namely edible and non edible and are basically extracted from seeds. The seeds contain 40 to 50% semi drying oil extractable by using hydraulic press. The process of oil extraction involves drying, grinding, steaming, air-cooling, and oil extraction by hydraulic press and screening. Vegetable oils typically have large molecules with carbon, hydrogen and oxygen being present. There is a wide variety of vegetable oils available and their properties lie within a fairly close range [35]. Vegetable oils have cetane numbers of about 35 to 50 depending on their composition [36]. This is very close to diesel. The heating value of the vegetable oils is more than that of alcohols. But it is to be noted that the vegetable oils and diesel differ greatly in various other properties. The viscosity of vegetable oils is higher than diesel (about 10 times). Carbon residue of these oils is appreciably larger than diesel and is not desirable. Vegetable oil molecules are triglycerides generally non-branched chains of different lengths and different degrees of saturation. They have good ignition quality since they are non-branched and have very long chains. The heating value of vegetable oils is somewhat lower than diesel and is due to oxygen content. The viscosity and carbon residue are higher than diesel and is due to their larger molecular mass and chemical structure. The flash point of vegetable oils is much higher than that of diesel, and hence they are much safer to store than diesel oil. They are about 10% denser than diesel fuel [37]. Their cloud point is higher indicating problems of thickening or even freezing at lower ambient temperatures. It is evident that vegetable oils are much less volatile than diesel. This makes them to evaporate slowly when injected into the engine. Differences in the molecular structure of vegetable oil greatly influence the physical and chemical processes occurring during the atomization, vaporization, spray pattern and combustion of the fuel after it is injected into the combustion chamber [38]. The identification of properties such as acid value, viscosity, free fatty acid (FFA), moisture content etc are very important for selecting the suitability of transesterification process. It is essential to identify right transesterification process to get best results with high conversion [25].

III. PRODUCTION OF RENEWABLE LIQUID FUEL (BIODIESEL PRODUCTION)

Researchers and scientists had developed various methods for biodiesel production from different vegetable oils. A brief review of these methods has presented here.

The trasesterification process is mainly used to reduce the viscosity of raw vegetable oil. In which a known quantity of clean, moisture free and low free fatty acid (FFA) vegetable oil is mixed with mixture of 20% methanol (volume bases) and 1-1.5% base catalyst of sodium or potassium methoxide or hydroxide (NaOH or KOH). Then the total mixture is stirred (at 150 – 250 rpm) and heated (65 – 70^0C) simultaneously up to 1 – 3 hours. Finally, the reaction completed mixture is transferred to separating funnel and from which the biodiesel can be obtained. This method yields high conversion (98%) with minimal side reactions ***L.C. Meher***, et.al [39] and ***Vivek and Guptha*** [40]. The base catalyzed transesterification using virgin vegetable oils was found to be economical process; it requires low pressure and temperature and produces about 985 conversion yield. But this method requires more time for chemical reaction and separation of glycerin from biodiesel. ***Sanjeev Garg*** et al reviewed the research work of biodiesel production carried out by ***Freedman B*** et al (1986), ***Noureddinni*** et al (1984***), Ahn*** et al (1995), ***Ma*** et al (1999). ***Young choel bak,*** et al [41], ***Vivek and Guptha*** [39], ***L.C. Meher***, et.al [40], ***Laureano Canoira***, et.al [42], ***Eevera Alptekin***, et.al [43], T**.** ***Eevera*** et.al [44], ***Ferreira Silva*** et al [45] have developed a system for biodiesel production and conducted the process of transesterification using different non-edible oils and determined the optimum process parameters in terms of reaction temperature, molar ratio, amount of catalyst. ***Hideki Fukuda*** et al [46] studied the production of bio-diesel using different methods and shown their merits and demerits of each method and reported that among many methods, transesterification using alkali-catalysts give high levels of conversion of triglycerides to their corresponding methyl esters in short reaction times. ***Saka and Kusdiana*** [47] studied the biodiesel production of different non edible oils in supercritical methanol without using catalysts ***Marichetti J.M.,*** et al [48] studied different alternative methods of biodiesel production and showed their advantages and disadvantages for each method and for all methods kinetics model was developed. ***Demiribas***, [49] ***Huayang He*** et al [50] developed a system for biodiesel production using supercritical methanol and tube reactor. They found that free fatty methyl ester (FAME) was reduced with increase in temperature and showed that increasing the proportion of methanol, the reaction pressure and temperature can enhance the production yield effectively. ***C.R. Vera***, et.al [51] investigated the reaction of transesterification of triglycerides is carried out under supercritical conditions. ***Ramadas*** et al [52] have two step transesterification process for high free fatty acid rubber seed oil. ***L.C. Meher,*** et.al [40] ***Syed Ameer Basha***, et.al [53] and ***Dennis Y.C. Leung*** et.al [54] reviewed biodiesel production. ***Satoshi Furuta,*** et.al [55] have studied the biodiesel production with prepared **a**morphous zirconia catalysts, titanium-, aluminum-, and potassium-doped zirconias, and evaluated the transesterification of soybean oil with methanol at 250 °C.

Ali Keskin et al [56] studied biodiesel production from tall oil which is a product of pulp industry. ***Chongkhong*** et al [57] investigated the biodiesel production from palm fatty acid distillate. ***Cherng-Yuan*** et al [58] conducted experiments on soybean oil transesterification reaction and they have studied the method of peroxidation to improve the fuel properties of the biodiesel ***Carmen*** et al [59] discussed the batch transesterification of vegetable oil with methanol, in the presence of potassium hydroxide as catalyst, by means of low frequency ultrasound (40 KHz) aiming on intimate reaction mechanism. ***Xin Meng*** et al [60] had reviewed the biodiesel production from oleaginous microorganisms and reported that producing low cost microbial diesel requires biotechnology improvement. A highly efficient procedure has been developed by ***Xuezheng Liang*** et al [61] from vegetable oil and methanol using KF/mgo catalyst. He reported that this catalyst gave a yield of 99.3% at shorter reaction temperature and they have also studied the effect of catalyst, amount of catalyst (KF/mgo), methanol amount and reaction time on the biodiesel synthesis reaction. ***Ferella F.***, et.al [62] studied biodiesel production using surface methodology (RSM) and optimized the whole cell –catalysed methanolysis of soyabean oil for biodiesel production using response surface methodology. Still biodiesel production from micralgae has not yet been undertaken on a commercial scale. Biodiesel production from this micralgea avoids the conflict between food and energy security. ***Xiaoling Miao and Qingyu Wu*** [63] developed a method of biodiesel production from micro algal oil. They have reported that this method was combination of bioengineering and transesterification and which is biodiesel can be produced effectively. ***Vishwanath Patil*** et al [64] analyzed the integrated approaches for sustainable microalgal biofuel production. They have discussed mainly the method to produce microalgae production. ***Guan Hua Huang*** et.al [65] investigated the biodiesel production from microalgal biotechnology. Microalgal biotechnology appears to possess high potential for biodiesel production because a significant increase in lipid content of microalgae is possible through heterotrophic cultivation and genetic engineering approaches. ***Zhiyou*** Wen etal and ***Michael B. Johnson,*** [66] discussed the feed stocks for Biofuel Production and algae cultivation method. ***Sarmidi Amin*** [67] had reviewed the microalgae conversion processes and reported that properties of microalgae are same as vegetable oils. ***Clemens Postan*** etal [68] had reviewed the biodiesel production from microalgae and discussed the overall biomass – to – fuel system and microalgae production process alternatives. ***Sharif Hossain A.B.M. and Aishah Salleh*** [69] studied biodiesel fuel production from algae and developed the biodiesel production plant. They have used oedogonium and spirogyra species to produce the biodiesel and reported that oil extraction will be higher with oedogonium than spirogyra sp. ***Teresa M. M.,*** et al [70] had reviewed the biodiesel production from microalgae. ***Ehimen E.A.,*** et al [71] have described the reaction variables which are affecting the biodiesel production from non-edible microalgae. ***Guan Hua Huang*** et al [72] studied the biodiesel production from microalgal biotechnology and compared this biodiesel with biodiesel produced from conventional method. They have also discussed the biodiesel production advances and prospects of using microalgal biotechnology.

In a supercritical condition, the methanol becomes an excellent solvent and dissolves the feedstock so that the molecules of the reactants are in close proximity of each other and therefore react readily without a distinct catalyst. This biodiesel production method uses high pressure and temperature but the cost of production of the biodiesel is more or less same as that of the earlier process. The process can tolerate water in the feedstock; free fatty acids are converted to methyl esters instead of soap, so a wide variety of feedstock can be used. Also the catalyst removal step is eliminated. ***Naoko Ellis*** et.al [73] studied transesterification process and for monitoring the reaction progress, they have used an acoustic wave solid state viscometer to measure the in situ viscosity. ***Sivakumar A.***, et.al [74] and ***Joana M. Dias*** et.al [75] studied the transesterification process. ***Shivkumar A.,*** et.al [74] showed that the increase in reaction temperature, especially to supercritical temperatures, had a favorable influence on ester conversion. ***Dong Sheng Wen*** et al [76] had reviewed the supercritical fluid (SCF) technology for biodiesel production from vegetable oils via transesterification process, bio-hydrogen from gasification and bio-oil from liquefaction of biomass from SCF route. ***Ayhan Demirbas*** [77] has produced methyl and ethyl esters from linseed oil with transesterification reaction in non-catalytic supercritical fluid conditions. Microwave assisted transesterification method offers many advantages in terms of lower reaction time, reduced catalyst requirement and lower alcohol/oil ratio. In this method, less that 0.2% (weight basis) catalyst, 5:1 to 9:1 molar ratio was used. The process was conducted at 60 – 70^{0}C for 10 – 20 minutes. From which, about 95- 98% conversion can be obtained. ***Zlatica J. Predojević*** [78], ***Ahn, et al.*** [79] and ***Xin Deng***, et.al [80] produced biodiesel using two reaction process for different vegetable oils. ***Nezihe Azcan,*** et.al [81] studied microwave assisted transesterification of rapeseed oil. Their results indicated that microwave heating has effectively increased the biodiesel yield and decreased the reaction time. ***Y.C. Sharma,*** et.al [82] have studied the recent developments in biodiesel technology and characterization of biodiesel and they found that the biodiesel is the solution for future. ***Naoko Ellis*** et.al [83] studied the transesterifaication process and observed the progress of their reaction using in situ viscometer

Lin Lin et.al [84] reported that the long- and branched-chain triglyceride molecules are transformed to mono-esters and glycerin in the process of transesterification. Commonly-used short-chain alcohols are methanol, ethanol, propanol and butanol. Methanol is used commercially because of its low price. ***Kraai G.N***. et.al [85] studied the base catalyzed production of biodiesel (FAME) from sunflower oil and methanol in a continuous centrifugal contactor separator (CCS) with integrated reaction and phase separation. They have showed that the combined reaction–separation in the CCS and they observed that it eliminates the necessity of a subsequent liquid–liquid separation step. The lipase catalyzed transesterification method used enzymes as catalyst. This is less sensitive to free fatty acids (FFA) content. But in this method, instead of methanol, methyl acetate is used because methanol inactivates the lipase catalyst after one batch. ***Xin*** et al [86] have studied the biodiesel production from microbial lipids. They have reported that developing high lipid content microorganisms for biodiesel production is becoming a potential and promising way in the future. ***Wen-Hsin Wu*** et.al [87] conducted lipase catalyzed transesterification by using Tallow and grease. ***Hannu Aatola*** et al [88] reported that hydrogenation of vegetable oil is another way to produce diesel like fuel or alternative process of esterification for producing bio-based diesel fuels. ***A. Robles-Medina,*** et.al [89] studied the obstacles present in the enzymatic production of biodiesel. The have showed that this methodology may reduce both the biocatalyst cost and dependence on lipase manufacturers. ***Yun Liu*** et.al [90] studied the preparation of biodiesel from stillingia by enzymeic transesterification with methanol. The results showed that lipase type, reaction systems and operational parameters influenced the biodiesel yield. About 99% conversion was reported from ultrasonic transesterifcation. In which, the vegetable oil is being mixed with the methanol or ethanol and NaOH or KOH. The mixture is heated to about temperatures between 45 and 65^{0}C. Finally the glycerin is separated using centrifuges and the converted biodiesel is washed. This method reduces the reaction time and, helps to decrease the amount of catalyst and amount of excess methanol required [87]. ***Hoang Duc Hanh*** et.al [91] studied the transesterification process using triolein with various alcohols such as methanol, ethanol, propanol, butanol, hexanol, octanol and decanol was investigated at molar ratio 6:1 (alcohol: triolein) and 25^{0}C in the presence of base catalysts (NaOH and KOH) under ultrasonic irradiation (40 kHz) and mechanical stirring (1800 rot/min) conditions. He found that the rate of the alkyl ester formation under the ultrasonic irradiation condition was higher than that under the stirring condition.

The vegetable oils with higher free fatty acids (FFA) cannot be processed with the conventional transesterification technology based on the use of alkaline catalysts in the homogeneous phase that requires the use of highly refined oil as raw materials. Therefore, the use of heterogeneous catalysts promot the transesterification reaction even in the presence of free fatty acids and water, allowing the prompt separation of pure glycerol and not requiring expensive purification of this byproduct. The heterogeneous catalysts considered are both basic and acidic in nature, such as hydrotalcite, MgO, TiO_2 grafted on silica, vanadyl phosphate, and different metals-substituted vanadyl phosphate of the type $Me(H_2O)_xVO_{1-x}$ $PO_4 \cdot 2H_2O$, where Me is a trivalent cation such as Al, Ga, Fe, and Cr and where $x = 0.18-0.20$ [91]. The use of heterogeneous catalysts in biodiesel production can reduce its price and becoming competitive with diesel fuel. ***Martino Di Serio*** et al [92] reviewed the biodiesel production using both acid and basic heterogeneous catalyst and studied performances for biodiesel production. ***Rekha Sree***, et.al [93] have investigated the biodiesel production. In their study they have prepared the catalysts like Mg–Zr catalysts with varying Mg to Zr ratios. The catalytic activity of these catalysts was evaluated for the room temperature transesterification of both edible and non-edible oils to their corresponding fatty acid methyl esters. ***Xuczheng Liang*** et al [94] have developed highly efficient procedure for the synthesis of biodiesel from vegetable oil and methanol; they have replaced conventional homogeneous catalysts by environmentally friendly heterogeneous catalysis**.** ***Georgogianni. K.G***. et.al [95] have investigated the biodiesel production from transesterification process of rapeseed oil for the production of biodiesel using homogeneous (NaOH) and heterogeneous (Mg MCM-41, Mg–Al Hydrotalcite, and K+ impregnated zirconia) catalysis. ***Samios D***., et.al [96] studied the transesterification process by double step process — for biodiesel preparation from fatty acid triglycerides. ***Chantaraporn Phalakornkule,*** et.al [97] discussed a community-scale process of biodiesel production.

Ferenc E. Kiss et.al [98] discussed the economic and ecological differences of biodiesel production over homogeneous and heterogeneous catalysts in large-scale industrial plants. They showed comparative economic assessment of the two processes and reported that the advantage of heterogeneous process in terms of higher yield of biodiesel and higher purity of glycerin, lower cost of catalyst and maintenance ***A. B. M. S. Hossain***. et.al [99] investigated the impacts of alcohol type, ratio and stirring time on the biodiesel production from waste canola oil. ***Siddharth Jain***, et.al [100] studied the kinetics of acid base catalysed transesterification of Jatropha oil. Their results indicate that, both esterification and transesterification reaction are of first order with reaction rate constant of 0.0031/ min and 0.008 / min respectively. ***Man Kee Lam,*** et.al [101] reviewed, ultrasonication, microwave assisted, use of homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil), their study indicates that using heterogeneous acid catalyst and enzyme are the best option to produce biodiesel from oil with high free fatty acid (FFA) as compared to the current commercial homogeneous base-catalyzed process. ***Deepak Agarwal*** et al [102] investigated the performance and emission characteristics of linseed oil, mahua oil, rice bran oil and linseed oil methyl ester (LOME), in a stationary single cylinder, four-stroke diesel engine and compare it with mineral diesel. They have mainly showed the durability problems in using the straight vegetable oils in a diesel engine for long term. They have suggested the process of transesterification is found to be an effective method of reducing vegetable oil viscosity and eliminating operational and durability problems. ***M.H. Jayed*** at al [103] had reviewed the literatures on energy scenario of Malaysia and Indonesia and their renewable energy policies and challenges for coming decades**.** ***Shailendra Sinha and Avinash Kumar Agarwal*** [104] studied the transesterification of rice-bran oil methyl ester (ROME) and obtained through of crude rice-bran oil using methanol in the presence of sodium hydroxide catalyst. ***W.N.R. Isahak*** et al [105] studied the transesterification process using nano-calcium oxide as catalyst and optimized the reaction conditions in terms of type of catalyst, methanol :oil molar ration, catalyst wt% and reaction time for palm oil trnasesterification process. He showed nano- calcium oxide gave stronger activity and lower soap and emulsion.

IV. CONCLUSION

Researchers in various countries carried out many experimental investigations on various methods of biodiesel production using more or less advanced technologies and variety of vegetable oils. Based on their research work and present review study, some conclusions are made in the following paragraph.

1. Use of non-edible oils for biodiesel production avoids the conflict between food and energy security.

2. For short runs, a diesel engine can perform satisfactorily on vegetable oil and its blends with diesel without any engine hardware modifications. For long-runs, a biodiesel and its blends with diesel can be used satisfactorily. However, for neat vegetable oil or biodiesel mode of operation, optimization in terms of injection timing, injection pressure, compression ratio, swirl, combustion chamber design etc are required.

3. Base catalyzed transesterification was found to be the most favorable process because base catalysts perform better than acid catalyst and enzymes. Also this process is simple, low cost and yields higher conversion. Acid catalysts used for high FFA's oils and can catalyze esterification and transesterification simultaneously. However, it has some drawbacks such as high molar ratio,

high catalyst concentration and high temperature. Also reaction is slow.

4. Biodiesel produced-using advanced fuel processing technology such as supercritical methanolysis, enzyme catalysed, pressure reactor etc reduces the time of reaction and resources required. Pressure reactors improve the chemical reaction kinetics during fuel processing significantly. Therefore lower excess methanol and less catalyst are required for biodiesel processing. Ultrasonic, Microwave, Lipase and heterogeneous catalysed transesterification technologies offer greater advantages compared base catalysed transesterification, but, these technologies needs to be investigated for possible scale – up for industrial application.

5. Engine operation with neat vegetable oils and its blends with diesel give inferior performance with increased smoke, CO and HC emissions. However, many rsearchers have reported that chemically processed vegetable oils (biodiesel) and its blends with diesel fuel give a slightly improved performance. The NOx emission levels with vegetable oils and biodiesels mode of operation were lower than diesel mode of operation.

6. Diesel engine operated with vegetable oil and biodiesel and its blends and with an optimum parameters gives better performance and lower emissions.

The total performance of vegetable oil or biodiesel operated engine can be improved by ceramic coating (low heat rejection) of engine parts. This facility reduces the HC, CO and smoke opacity, but increases the NOx emission levels. This higher NOx emission level from diesel/ vegatble oil/biodiesel operated engine can be reduced by using exhaust gas recirculation (EGR) method.

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