CHAPTER-2
LITERATURE SURVEY

2.1 INTRODUCTION

Biodiesel, a renewable source is able to cater the needs of people at the same time it is helping towards clean and green environment. This has been possible by extensive investigations on renewable energy sources especially on the concept of biodiesel. Many researchers have carried out many investigations on usage of biodiesel in compression ignition engines. Problems encountered in usage of biodiesel were identified, many possible solutions have been suggested and published in many journal papers. This proved to be valuable source for many researchers, laying path for further research. A thorough reading has been done on sources of biodiesel especially on non-edible sources, production methods and usage of it as fuel in diesel engines. Transesterification process and catalytic cracking methods are implemented based on the literature survey and the biodiesel thus obtained is tested in diesel engine and results are reported. Out of many journal papers that have been gone through, few journal papers are quoted.

Ayhan Demirbas [1] in his paper detailed about biofuel, their sources, their effect on economy and future projections. With his briefing about biofuel and different products of biofuel presented their environmental effects and also socio-economic issues related to rural areas. Due to inherent advantages of biofuel related to environmental issues, he expressed that it would occupy a major share of automotive market in next decade and by 2050 he estimated that modern biomass energy contributes nearly one-half of the total energy demands of developing countries.

B. K. Barnwal et. al[2] expressed about necessity of alternative fuels. They proposed two methods for biodiesel production one was transesterification and other one was super critical methanol transesterification. Concluded that super critical methanol transesterification method gave good yield of quality biodiesel with very less conversion time. After economic feasibility study they expressed that biodiesel from non-edible oils are cheaper when compared to edible oils and that production of
biodiesel from vegetable oils will be economical and technically feasible only if cost of vegetable oils was less.

**S. Jaichandar** et. al[3] expressed their view that high viscosity and low volatility of vegetable oils are the problems to substitute diesel fuel. Biodiesel from vegetable oil can be produced by transesterification process there by reducing viscosity of vegetable oil. They expressed their view that acceptable thermal efficiency of CI engines can be attained with reduced emissions and more investigations are to be done to get full potential of biodiesel engines.

**O. O. Agbede**[4] investigated extracted oil from three fruit seeds (mango, tangerine, African star) for their worthiness for production of biofuel. It was found that fuel properties were similar to those of common seed oils which were already being used as biodiesels. Their low acid value signifies its potential to be used as feed stock in producing biodiesel. Concluded with need for further investigation of other fuel properties.

**S Savariraj**[5] worked upon reducing viscosity and increasing calorific value extracted mango seed oil with 1, 4 dioxane fuel additive. Transesterification of mango seed oil produced biodiesel that was mixed with additive in various proportions were tested. Optimal 10% additive added in biodiesel, fuel properties like viscosity reduced by 0.5% and slight improvement in calorific value. Further, little increment in brake thermal efficiency and reduction of 200 ppm in NOx emissions.

**Silvia Mironesas** et al.[6] studied physico-chemical, structural characteristics, content and quality of grape seed oil. Concluded that higher oil concentrations were obtained from the grapes that are grown in warmer climatic conditions. Oil content varies largely from 6.26 to 9.01% accordingly to grape variety and cultivation area.

**El Diwani** et. al[7] proved with results that ozonated vegetable oil(1% by weight) mixed biodiesels in comparison with biodiesel, contained more saturated carbon bonds in weight than that of unsaturated carbon bonds. When biodiesel was mixed with ozonated oil, oxygen content of biodiesel increases and helps in thorough reaction process there by reducing carbon residue. Higher combustion efficiency, high
heat of enthalpy and reduced emissions of particulate matter was observed. Finally ozone treated biodiesel showed better thermal properties and oxidation stability.

Murugu Mohan Kumar et. al[8] on analysis concluded that a minimum drop of thermal efficiency, little higher specific fuel consumption was noticed by using sunflower seed oil esters as fuel in diesel engine when compared to diesel fuel. This can be attributed to the low calorific value of sunflower oil ester.

Nilaj N. Deshmukh et. al[9] expressed that usage of biodiesel produced from food grains may lead to hike in food grain prices. Essentiality for non-food based biodiesel and their practicality to fuel diesel engines has been felt. Two different sources of bio-diesel one from food grain source and the other from non food grain are combined together in different ratios. Further physical and chemical fuel properties of resulting bio-diesel blends were tested for its suitability to fuel diesel engine. On successful test run of engine with mixed biodiesel it was found that engine performance was nearer to neat diesel with higher exhaust temperatures.

Ayhan Demirbas [10] detailed that alternate fuels are gaining significance towards their usage as fuel for diesel engines with decreasing petroleum reserves and also environmental concern are making these renewable fuels more attractive and fuel of future. Biodiesel was produced from transesterification process from both edible and non-edible sources thus produced fuel was producing nearly same brake thermal efficiency and lower emissions compared to diesel fuel to run diesel engines.

A. A. Refaat et. al.[11] intentions were to look for the possibility of conversion of waste vegetable oils into biodiesel to cut down production costs of biodiesel and to curb pollution caused by waste vegetable oils. Transesterification was done on three vegetable oils one with neat vegetable oil, second with domestic waste vegetable oil and third being restaurant vegetable oil. Yield percentage was more with neat vegetable oil, least with restaurant waste vegetable oil. Maximum yield percentage was obtained with methanol/oil molar ratio of 6:1 in the presence of catalyst potassium hydroxide(1%) maintaining process temperature at 65°C for a period of one hour.
S. Savariraj et. al. [12] conducted tests on four-stroke, single cylinder DI diesel engine with mahua biodiesel and also mahua biodiesel blended in different ratio's with diesel. Test results analysis show that brake thermal efficiency decreases and specific fuel consumption increases at all loads as the mahua biodiesel proportion increases in diesel. Reduction in brake thermal efficiency was only 14.3% with B100 at full load. With increase in quantity of mahua biodiesel in diesel, exhaust gas temperature decreases but smoke, NO and CO emissions increased at all loads.

Morvarid Yousef et. al. [13] investigated for physico-chemical properties of two types of shahrodi grape seed oils (Lal and Khalili) extracted by using Soxhlet method and petroleum ether as solvent. Their responsible variables such as fatty acid, peroxide value, soapy number, acidity, etc. were considered. Linoleic acid fatty acid content was nearly equal to 65.39% of all fatty acids which gives oxidation reaction resistance. Concluded that Lal variety was better than Khalili for their oil content and for low peroxide value.

Agarry, S. E et. al. [14] evaluated the citrus seeds (orange, grape, tangerine) oils for production of biodiesel. Transesterification process was carried out on the oils with ethanol and catalyst potassium hydroxide for producing fatty acid alkyl esters. Best yield of 90.6% was possible with grape seed oil compared to other two citrus seed oils. Fuel properties of all the three oils were evaluated. On analysis concluded that citrus seed oils can be used as biodiesel blended with petroleum diesel.

J.K. Heydarzaeh et. al. [15] describes an alternative energy for the replacement of fossil fuels has been developed. Biodiesel synthesis as a renewable energy was derived in a continuous packed column reactor. Free fatty acids (FFA) were esterified with ethanol in a heterogeneous catalytic reaction. The catalytic reactor had great potential as FFA introduced to the top of column, flow downward, reached to catalyst surface and interacted with ethanol on the active site. The ester product was instantaneously formed. In this catalytic reaction, effects of mass ratio of the free fatty acids to ethanol along with reaction temperature in the range of 150-250°C were considered, as reaction temperature increased esterification reaction was enhanced. From the data obtained it was concluded that optimal conditions of mass
ratio 3:5 and temperature of 250\(^\circ\) helped in conversion of 90% free fatty acids into ethyl esters.

**M. Canakci** et. al. [16] wanted to produce biodiesel from low cost oils for example animal fats, restaurant waste and frying oils. They converted two high free fatty acid content oils into biodiesel, one was soyabean oil and the other one yellow grease from animal fat with 9% free fatty acid. Turbo charged engine was tested with both biodiesel fuels and studied their effect on engine performance and emissions. They noticed that biodiesel energy conversion to work was similar to that of diesel but there was increase in unburnt hydrocarbon and NOx emissions.

**Ulf Schuchardt** et. al. [17] reviewed different process of transforming vegetable oils into biodiesel in the presence of various catalysts. They expressed their opinion that in near future usage of homogeneous catalysts in conversion process of vegetable oils might be replaced by heterogeneous catalysts due to their detrimental effects on environment. Many strong-base heterogeneous catalysts are in developmental phase one such good catalyst would be strong basic sites zeolites. Emphasized on the usage of guanidines but to avoid leaching of them, there was a need to double anchor them to polymers and also guanidines encapsulation in an inorganic matrix.

**C. M. Fernandez** et. al. [18] suggested that production of biodiesel from winery waste could be beneficial for wine production regions. Bringing into proper utilisation of 10 to 20% oil content in grape seeds. Two techniques were adopted to extract oil from grape seeds, one was solvent extraction technique and the second was pressing technique. Both processes were compared and concluded that Soxhlet solvent extraction process was better because when mixed with polar and non polar solvents produced oil with good oxidation stability and also with more oil yield. Transesterification of this oil with methanol and ethanol resulted in a good quality biodiesel but ethyl esters showed good flow properties in comparison with methyl esters.

**Sophi damayanti** et al. [19] identified, quantified linoleic acid as one of the main compounds of unsaturated fatty acids in grape seed oil. Successfully
transesterified linoleic acid in grape seed oil, one of the fatty acid in grape seeds available in abundant quantity which can be useful in production of biodiesel.

A. A. Refaat [20], tells about worthiness in continuing study and optimization of production procedures of bio-diesel due to its renewable nature and benefits to the nature. Heterogeneous transesterification method of producing bio-diesel was considered to be a green method as there was no need to recover catalyst nor need for aqueous treatment. This process requires severe operating conditions to get the high yield in comparison with theoretical value. Performance of heterogeneous catalysts when considered found to be lower to that of homogeneous catalysts. So to bring betterment in performance there has been extensive investigations on heterogeneous catalysts for biodiesel production. Emphasized on importance of catalyst selection and catalyst preparation, described various methods of solid catalyst preparation. Investigation was mainly concentrated on analysis of reaction conditions and leaching of catalysts.

Nurjannah Sirajudin et al. [21] explains that palm oil was a potential alternative energy source, which may replace the non-renewable fossil fuels, such as gasoline, kerosene and diesel oil. During utilization, biofuel produces fewer pollutants than fossil fuel. The research was conducted through a catalyst synthesis and the catalytic cracking process. The catalytic cracking process was accomplished in a fixed bed micro reactor with temperatures ranging from 350 – 500 °C and Nitrogen gas flow rates ranging from 100 – 160 ml/min for a period of 120 min. It was found that at 450°C and with Nitrogen flow rate of 100ml/min resulted in the highest yield of gasoline fraction of 28.87%, 16.70% kerosene and 1.20%. diesel oil. Concluded that synthesized HZSM-5 catalysts met the standards of a catalyst in producing biofuel by the catalytic cracking of vegetable oils.

Ogunsuyi. H. O [22] de hulled mango seeds soaked in n-hexane, later extracted oil from a soxhlet extractor which was refluxed with oil-solvent mixture. Mango seed oil was acid treated prior to transesterification due to high percentage of free fatty acid content. Kinematic viscosity and flash point values of produced biodiesel were in the range of specified standards of biodiesel. In conclusion it was
felt that proper encouragement is needed for biodiesel production from mango seed oil to convert discarded mango seeds from fruit into treasure.

M.M.Yunus et al. [23] extracted oil from african grape seed and tested its properties, compared them with recommended standards of biodiesel for its suitability as a fuel for running diesel engines. They expressed that wild grape seed oil has the potential to be used as input for biodiesel industry, which could become in near future one of the major exploitable sources of alternative fuels.

S Karthikeyan et al. [24] investigated use of aluminium nano particles mixed in blends of grape seed biodiesel fuel in a single cylinder diesel engine of horizontal type. Nano particles of alumina oxide in blends of grape seed oil improves flash point, calorific value and acts as oxygen buffers promoting longer and complete fuel combustion. Final conclusion was improvement in brake thermal efficiency and reduction in emissions with addition of nano particles of alumina oxide.

Guo. Y. Leung et al. [25] presented novel technology of producing biodiesel from local restaurants waste oils and grease trap oils. Transesterification of these oils produced biodiesel with seventy seven weight percentage and also with a purity of 96%. Produced biodiesel blended with petro-diesel was tested on light van under a chassis dynamometer. Results showed a significant reduction in smoke and hydrocarbon emissions while slight change in the NOx emission. With pure biodiesel(100%) there was unnoticeable drop in maximum engine power output.

Maryam Hassani et al. [26] describes preparation of catalyst from fine powder of zeolite, poly vinyl alcohol and kaolinite by pelletization method. Used it to synthesize fatty acid methyl ester (FAME) to get biodiesel from waste cooking oil containing considerable amounts of free fatty acids. The prepared catalyst was characterized by thermo gravimetric analysis, X-ray Diffraction, FTIR spectroscopy and BET surface area analysis. The zeolite based catalyst was employed to simultaneously catalyze the esterification of fatty acids and transesterification of triglycerides present in the waste cooking oil feedstock to biodiesel. The condition for biodiesel synthesis was optimized in terms of reaction temperature (50-85°C), methanol/waste cooking oil molar ratio (2.6-6.0) and reaction time (2-10 h).
Maximum triglyceride conversion of 46% was achieved at the near optimum conditions.

**A. Haiter Lenin** et al. [27] studied performance, combustion and emission characteristics of diesel engine using mahua methyl esters with two blends that was B25 and B50. Brake thermal efficiency of all blends of mahua biodiesel was higher compared to diesel at all loads. CO\(_2\) emissions of blends was similar to diesel but smoke and NO\(_x\) emissions were higher. On comparison of results with standards they concluded that B25 can be used without engine modifications.

**Kittiphoom S** et al. [28] reviewed mango fruit kernel seed oil for its fat content which can be used for various purposes. It consisted of both saturated fatty acids and unsaturated fatty acids. Major fatty acids are stearic acid and oleic acid. On analysis of results it was found that mango seed kernel oil as a good source of unsaturated fatty acids and also can be used as food oil.

**Ester Foppa Pedretti** et al. [29] investigated production of bio ethanol from hybrid varieties of grapes and also evaluated greenhouse gas emissions in comparison with European laws. Grape to ethanol production chain study gives a clear indication of its sustainability in terms of green house gas savings with reference to fossil fuel chain.

**Shalini Biswas** et al. [30] studied catalytic cracking of soya bean vegetable oil with Zirconium complex catalyst in the absence of hydrogen. They reported that with the use of complex catalyst they were able to produce liquid product without any non condensable gases and residue. Liquid product contained five fatty acids, aldehyde, alkane octadecane and one alkene. This was confirmed with GS-MS analysis. With increase in reaction temperature the alkanes content also increased.

**Belachew Tesfa** et al. [31] investigated the emission characteristics of turbocharged diesel engine with different fractions and types of biodiesel. Biodiesel from waste oil, rape seed oil, corn oil showed similar regulated NO\(_x\), CO, CO\(_2\) and THC emissions without much significant difference. They observed NO\(_x\) emissions increased by twenty percent with diesel engine running on different blends of
biodiesel at the same time CO, CO₂, THC emissions were reduced in comparison with diesel at different operating conditions.

**Jinlin Xue** et al. [32] investigated the reports on effect of biodiesel on diesel engines especially on their performance, durability and emissions. Their analysis on diesel engines fuelled with biodiesel were reduced power but it was recoverable with more fuel consumption, reduced carbon deposits, less wearing of engine parts due to inherent lubricity, reduced PM, CO, HC and increased NOₓ emissions due to their oxygen content. They concluded that blends with small part of biodiesel can well replace petroleum diesel to control air pollution and also eases pressure on scarce resources.

**N.Muthukumaran** et al. [33] studied catalyst performance and produced biofuel from Mahua oil using fixed bed catalytic cracking reactor. Produced biofuel was characterized by using FTIR and GC-MS. Blends of biofuel with diesel were fuelled to diesel engine to evaluate engine performance. After experimental investigation they reported that B25 Mahua blend gave higher peak cylinder pressure and heat release rates compared to other blends. NOₓ emissions were reducing with increasing blend percentage of biofuel where as CO and HC emissions increased at all loads.

**Le Thi Hoai Nam** et al. [34] stated that usage of liquid biofuels was good to environment as they were free from nitrogen and sulphur compounds and they have got good potential as an alternate fuel to fossil derived fuel. They compared the biofuel production from vegetable oil sludge by pyrolysis process with biofuel produced from catalytic cracking of vegetable oil with MC-ZSM-5/MCM-41 composite material. With its porous nature contributed to good catalytic performance in cracking reaction with higher conversion of vegetable oil sludge into biofuel compared to pyrolysis process.

**Mihai brebu** et. al. [35] studied about thermal degradation and pyrolysis of grape seeds at a temperature of 500 °C by TG-MSD. Composition of liquid products obtained was studied by GC-MSD analysis. It was found that maximum degradation of grape seeds occured at temperature of 390°C. The main elements of oil obtained from pyrolysis of grape seeds were fatty acids, followed by lignin-derived
compounds. Other derivatives identified were olefins and benzene, light carboxylic acids and homologous series of paraffin’s. Red Mud and FCC catalysts influenced the thermal behaviour and the pyrolysis yield was tested in liquid and vapour phase contact mode. It was identified that they improved the degradation and increased the product yield.

Chettha Jungjaroenpanit et. al. [36] investigated the factors that affect catalytic pyrolysis process with activated carbon supported magnesium oxide in a continuous reactor and wanted to find optimum conditions to obtain optimum liquid yield containing optimum amount of diesel fraction. They tested by increasing reaction temperature, used cooking oil flow rate, carrier gas flow rate and adding more amount of catalyst. At optimum conditions of reaction temperature 430°C, used cooking flow rate of 154.20 mL/hr, carrier gas flow rate 102.73 mL/min, catalyst loading of 60% wt produced an optimal liquid yield of 81.42% wt with 57.07% wt diesel fraction.

Jiratchaya Chuaykleang et. al. [37] studied catalytic cracking of refined palm oil with HZSM-5 catalyst into gasoline. By using response surface methodology studied effect of operating variables on oil yield. In addition to this, effect of operating variables on benzene and isooctane fractions was also taken up. With optimum conditions of temperature, weight of catalyst and with no effect of nitrogen flow rate organic liquid petroleum of 26.66% wt was obtained.

Momoh O.R. et. al. [38] investigated for the reaction parameters such as reaction temperature, time taken to complete reaction and oil to methanol ratio for production of biodiesel from alphonso mango seed oil. With high percentage of free fatty acid they had conducted three step esterification process to reduce percentage of free fatty acid to 0.547 mgKOH/gm. They reported that 60°C reaction temperature, 60 minutes reaction time and 1:4 oil to methanol ratio were optimum biodiesel yield parameters in a transesterification process. They also determined important properties like kinematic viscosity, density, cetane number etc. compared them with ASTM standards and concluded methyl esters of alphonso mango seed oil can be used as alternative or blended with petro diesel.
Omotola Babajide et. al. [39] investigated use of coal fly ash that was obtained by combustion of coal to produce electricity for a beneficial purpose. So for production of biodiesel from sunflower oil through transesterification process, class F fly ash was utilised as catalyst in the process. Catalyst was characterized using XRD and FTRI spectroscopy. They also investigated reaction parameters like reaction temperature, loading amount of active components, catalyst deactivation etc.. Synthesized biodiesel was tested for its fuel properties and found that they were comparable to ASTM biodiesel standards.

Jolius Gimbun et. al. [40] presented paper on the use of limestone based catalyst in transesterification of free fatty acid content of rubber seed oil. Oil extraction from rubber seeds using microwave method gave better yield compared to sohxlet method. Composition of minerals in the catalyst was characterized by XRF and XRD. Transesterification was performed with methanol activated clinker under reflux with continuous stirring. It was found that there was an efficient conversion of high FFA rubber seed oil to biodiesel, when tested biodiesel produced using limestone content catalyst derived from cement clinker was within the limits of ASTM standards.

Achmad Roesyadi et. al. [41] studied the effect of HZSM-5 catalyst with and without impregnation in a fixed bed micro reactor for catalytic cracking of palm oil. Synthesized catalyst was characterized using AAS and BET. Ni/HZSM-5 catalyst was recommended when compared to HZSM-5 catalyst with high selectivity given to gasoline.

Nakorn Tippayawong et. al. [42] tested the performance of CI engine fuelled with bio fuel from passion fruit seeds. Oil was extracted from passion fruit seeds, a by product of juice industry and biodiesel was produced with the transesterification process. Biodiesel was then fuelled to a diesel engine to test the engine performance. At constant engine speeds comparable performance results were obtained. Concluded that residues from fruit seeds as a renewable source of energy helping in improving energy efficiency and environmental sustainability.

Siddalingappa R. Hotti et. al. [43] studied about the optimization of production process of biodiesel from sugar apple seeds oil. They carried out the base-
catalyzed transesterification process for producing biodiesel and with optimized process parameters biodiesel yield was nearly 95.15%. They found biodiesel properties both physical and chemical were close to that of diesel fuel.

**S. Savariraj** et. al. [44] carried out experimental investigations on a single cylinder diesel engine fuelled with different blends of raw mango seed oil with diesel and also with different blends of mango seed biodiesel with diesel. It was analysed MSBD brake thermal efficiency was better than raw MSO, SFC of MSBD was less compared to raw MSO, smoke density of raw MSO and MSBD were higher to that of diesel at full load. B-25 blend gave better heat release rate compared to all other blends.

**Dessy Y. Siswanto** et. al. [45] studied the effect of operating conditions like O/C ratios, weight hourly space velocities (WHSV) to the feed conversion including optimum conditions for organic liquid product. On conducting catalytic cracking of palm oil using fixed bed microreactor with MCM-41 catalyst a highest yield of 60.73 weight percentage of organic liquid product consisting of gasoline, kerosene and diesel was obtained at a temperature of 450°C with oil to catalyst ratio of 32.50.

**H. Dewajani** et. al. [46] carried out the catalytic cracking process for production of biofuel from Indonesian crude nyamplung oil using ZSM-5 catalyst. This process was undertaken in two steps first step was to activate catalyst and in the second step catalytic cracking process. Studied about effect of addition of catalysts, reaction temperature and gaseous product. Concluded that using catalytic cracking process FFA of crude nyamplung oil can be directly converted into bio fuel and organic liquid product contained aromatic compounds that could improve octane number of bio fuel.

**Eduard Buzetzki** et. al. [47] in their conference paper provided the information regarding production of organic liquid products by catalytic cracking of TAG with different catalysts from renewable biomass energy sources. They mainly concentrated on synthetic and natural zeolites in the catalytic cracking process of rape seed oil. Comparison data like reaction temperature, yield, etc. of different catalysts are tabulated and finally it was concluded that zeolite catalysts were cheaper, easily
available and produced a better yield of liquid products with their porous structures and acidic sites.

Max J. A. Romero et. al. [48] studied about catalytic hydro treatment, an innovative process for production of bio fuels from non edible vegetable oils. This production process produced bio diesel with low density, high heating value and good flow properties compared to diesel but with a disadvantage of usage of hydrogen and metal sulphide catalysts. So they concentrated their work on decarboxylation process to eliminate usage of hydrogen and noble metal catalysts. On experimentation with jatropha curcas oil they obtained around 81% liquid bio fuel with high composition of hydrocarbons and also better heating value compared to diesel.

Hifjur Raheman et. al. [49] evaluated the engine performance fuelled with blends of biodiesel and high speed diesel including the soot formation on engine components. Biodiesel was mixture of two mahua and simarouba in equal percentages with blends prepared by mixing of HSD. B10 blend engine performance for 100 hr engine operation was better than other blend and soot formation on engine components reduced by 21% compared to that of HSD. Wear metals presence except manganese in the lubricating oil reduced nearly by 50% in comparison with HSD.

Deshpande DP et. al. [50] tried to obtain alternative fuel from palm oil using catalytic cracking process in the presence of calcium carbonate (CaCO₃) catalyst. Experiment was conducted with palm oil with different concentrations of calcium carbonate catalyst. With the increase in concentration of catalyst from 1% to 5% decrease in viscosity and density of oil was noticed. Maximum yield of hydrocarbons was noticed with 5% catalyst concentration.

Mohammad Nasikin et. al. [51] conducted both catalytic cracking and hydrogenation reaction in the presence of hydrogen simultaneously at atmospheric pressure to synthesize biodiesel from palm oil in a liquid phase batch reactor. During cracking process with the presence of NiMo/zeolite catalyst part of triglycerides were converted into smaller molecules and with FTIR analyses before and after reaction, occurrence of hydrogenation was noticed. With GC-MS analysis of bio gasoline, hydrocarbons consisted of C₈ to C₁₅.
Hyeon Su Heo et. al. [52] performed catalytic cracking process using three catalysts to convert biomass waste oil to bio fuel. To analyse liquid product Py-GC/MS direct analyses was done. With the use of mesoporous HY catalysts high yield of hydrocarbons in the range of gasoline were obtained similarly with the use of Al-MSM-48 catalyst high yield of diesel range oxygenated hydrocarbons were obtained. Finally addition of gallium to HZSM-5 catalyst increased aromatic content.

Sri Kadarwati et. al. [53] studied about the kinetics and mechanisms of cracking reaction of methyl esters of palm oil in the presence of Ni/zeolite catalyst in a fixed bed reactor of continuous type at atmospheric pressure. Wet impregnation method was used to prepare catalyst and characteristics of catalyst, porosity, crystallinity and acidity were evaluated. Hydrogen flow rate was varied during reaction and no considerable effect was observed on conversion rate and it was found that reaction followed pseudo first order kinetics. Light Hydrocarbon products of C6-C8 were derived after cracking reaction along with isomerization of the products and deoxygenation.

Martina Chiappero et. al. [54] studied about production of green diesel fuel by deoxygenation of methyl esters of vegetable oil. PtSnK/SiO2 catalyst proved to be best among tested catalysts and found to be good in converting vegetable oils and FAME to hydrocarbons. With the use of He in reaction process increase in olefin yield was noticed with little hydrogenation.

Suyanta Suyanta et. al. [55] carried out research work with an objective of developing an efficient catalyst in cracking palm oil to obtain liquid product of gasoline type. Synthesis of mesoporous alumina silicate AlMCM-41 was done by hydrothermal treatment and later converted into H-AlMCM-4 with good combination of catalytic properties of alumina and silica. A fixed bed reactor was used for catalytic cracking of palm oil in the presence of H-AlMCM-41 catalyst to produce organic liquid product of gasoline type.

G. Ramya et. al. [56] produced hydrocarbon fuels with superior characteristics from jatropha oil by using composite catalyst in catalytic cracking process. Composite catalyst core part consisted of HZSM-5 and shell prepared with varying percentages of AlMCM-41 was characterized using XRD and SEM
techniques. Mesoporous and micro porous AiMCM-41/ZSM-5 (25,15,10) composite catalyst converted nearly 99% of jatropha oil into bio liquid fuel with very high selectivity towards gasoline.

**Chettha Jungjaroenpanit** et. al. [57] studied catalytic pyrolysis of used cooking oil. In the investigation they used the catalyst magnesium oxide supported on activated carbon in a continuous reactor and found out the optimum conditions of the influencing parameters during catalytic pyrolysis process. Increasing reaction temperature and amount of catalyst increased the diesel fraction in the liquid yield where as increasing flow rate of used cooking oil and carrier gas flow rate increased liquid yield but decreased diesel fraction in the liquid yield. So at optimum conditions of reaction temperature, percentage weight of catalyst loading, used cooking oil and carrier gas flow rates a diesel fraction of 57.07% wt was obtained in liquid yield of 81.42%wt with several light hydrocarbons.

**Dilip Kumar Bora** et. al. [58] experimented the catalytic cracking process with two different catalysts for production of bio fuel from Mesua ferra L seed oil and compared it with fuel produced by fractional distillation process without any catalysts. Optimum operating conditions were identified for the catalytic cracking process for two different catalysts investigated. On analysis they found catalytic cracking process was faster in production of bio gasoline compared to fractional distillation. Catalyst calcium carbonate gave better results than alumina hydro silicate catalyst with respect to quality. Bio gasoline quality was very close to that of refinery gasoline.

**S.Ramkumar** et. al. [59] studied about the thermal cracking of pongamia pinnata oil for its direct use in CI engines as they expressed that with conventional transesterification by product glycerin was produced and its disposal was a matter of concern. They discussed about different methods of production of biodiesel. With thermal pyrolysis of vegetable oil pyrolyzate properties close to diesel. With TGA and DSC experimental analysis concluded that thermal cracking of pongamia pinnata oil at a temperature of 450°C gave 95% conversion rate of oil to gas that is suited for CI engine.
Divya R. Parapati et. al. [60] tested six catalysts in a continuous packed-bed reactor to produce organic fractions by implementing single stage hydro-processing of bio oil. With process parameters varied over a range, superior results were noticed with sulfided catalysts compared to reduced catalysts. Sulfided CoMo/γ-Al₂O₃ with its high catalytic activity produced organic fraction of higher heating value reducing oxygen content to a minimal in hydrocarbon fraction. Analysis of produced hydrocarbons was done and then compared with that of simulated distillation analysis.

Xianhui Zhao et. al. [61] studied the effect of ZSM-5 catalyst and its bifunctional Zn loaded catalyst in the catalytic cracking process for conversion of camelina oil to hydrocarbons. BET analysis showed reduced surface area, pore volume and increased pore size of ZSM-5 catalyst impregnated with zinc. Acidic sites increased in the bifunctional catalyst with impregnation that are responsible for good catalytic activity and increased hydrocarbon yield rate. Decreased density, oxygen content of hydrocarbons produced was noticed. Used catalysts can be recycled and reused in fixed bed reactor.

V.S.Hariharan et. al. [62] studied about engine characteristics of a diesel engine fuelled with sea lemon oil and its methyl esters. On analysis of results it was found that brake thermal efficiency of methyl esters of sea lemon oil was closer to diesel compared to sea lemon oil. An increase in ignition delay was observed for test fuels but combustion characteristics of sea lemon oils were closer to that of diesel. Decrease in engine NOₓ emissions was noticed for neat sea lemon oil with increase in smoke emissions compared to conventional fuel.

Vijittra Chalatlon et. al. [63] extracted jatropha oil from its seeds using simple screw press. By heating viscosity of oil was reduced and then blended with diesel to fuel the diesel engine. On testing engine characteristics with blends of jatropha oil, jatropha oil and diesel it was found that blends up to 20% of jatropha oil there was no reduction in brake thermal efficiency. With increase in blend percentage and load on engine CO₂ emissions increased nearly 20% and CO emissions increased for jatropha blends and jatropha oil with increase in loads compared to diesel.
K.Sivaramakrishnan et. al. [64] in their work developed an equation for finding higher heating value of vegetable oils and biodiesel based on properties like viscosity, density and flash point. Equation capability was to predict HHV with an accuracy of 0.949. They expressed that physical properties of biodiesel had a influencing effect on higher heating value.

Nwokedi I.C., Ude, C.N. et. al. [65] carried out both thermal cracking without catalysts and catalytic cracking in the presence of catalysts on palm oil to produce oleo chemicals. Catalytic cracking was found to crack palm oil in the presence of clay catalyst giving better yield of oleo chemicals which were similar to methyl esters of vegetable oil at very low temperatures compare to thermal cracking process.

I.M. Atadashi et. al. [66] studied about the effect of water presence during production of biodiesel and also technologies needed for refining it. Problems encountered with alkali catalyzed transesterification process were quality deterioration, corrosion of fuel supply system, decrement in heat of combustion etc. and due to this focus was on production and separation of biodiesel. possible remedies were usage of refined raw materials and usage of heterogeneous catalysts though themselves find first solution to be economically unviable, they were of the opinion that a need was there for more scientific research for production and refining of future fuel.

Endah Mutiara Marhaeni Putri et. al. [67] carried their research work on production parameters of biodiesel from kapok Randu seed oil by using transesterification process with calcium Oxide (CaO) as catalyst. Variables varied were oil to methanol molar ratio, reaction temperature and time. With GCMS analysis they concluded that reaction temperature of 60°C, reaction time of 1 hr and oil to methanol mole ratio of 1:10 biodiesel yield of 88.576% was obtained. Catalyst can be reused but when used for third time yield percentage decreased.

A.B.M.S. Hossain et. al. [68] studied about production of biodiesel from pure sun flower oil and waste sunflower cooking oil using alkaline-catalyzed transesterification process. They identified that with optimum conditions such as oil to methanol ratio of 1:6, reaction temperature of 40°C with 1% KOH catalyst and with a stirring speed of 320 rpm produced highest biodiesel yield of approximately
99.5%. Biodiesel produced from two oils were of good quality that could be used as fuel to diesel engines at the same time it was an opportunity to recycle waste oil.

**Yun Hin Taufiq-Yap** et. al. [69] studied and carried out work on production of biodiesel from palm oil using transesterification process with sodium hydroxide loaded alumina catalyst. Catalyst was prepared by impregnation of alumina with different amounts of aqueous solution of sodium hydroxide and further followed by calcination in air for three hours. Various technologies like XRD, BET were used to characterize prepared catalyst and optimum operational parameters were also studied. They were able to get 99% biodiesel yield with pour point closer to ASTM biodiesel standard.

**Maria I. Martins** et. al. [70] worked on production of biodiesel from soya bean oil using basic hydrotalcite catalyst in transesterification process. Hydrotalcite was selected for its strong basicity, pore volume and high surface area and it was synthesized with Mg/Al using co-precipitation method. With this prepared catalyst transesterification process was carried out that resulted in 94.8% FAME conversion. They expressed their view that proposed and tested solid hydrotalcite catalyst as a promising base catalyst under mild reaction temperatures for heterogeneous catalytic transesterification.

**M. Thirumarimurugan** et. al. [71] furnished experimental data on the production of biodiesel from waste sunflower cooking oil using transesterification with sodium hydroxide alkaline catalysts. Conducted experimentation by varying reaction time, catalyst concentration and oil to methanol ratio. At optimum conditions 80% of biodiesel yield was obtained and concluded that it can be a suitable option once production taken up on a large scale.

**Sanjaykumar Dalvi** et. al. [72] detailed about the production of biodiesel from undi seeds using in-situ transesterification a single step production process. This process eliminates the extraction of oil from seeds and usage of solvents like hexane. Seed powder was mixed with ethanol and methanol mixture, with continuous stirring and constant supply of heat of 60°C for a period of 1hr, after that solid cake and mother liquor was separated using vacuum filtration as a final step in producing
biodiesel solvent was separated using rotary evaporator. On GC-MS analysis of the product, found to be a good replacement to diesel.

**L. Nabilah Aminah** et. al. [73] studied about two processes, an alkali catalyzed transesterification and two phase solvent extraction for production of biodiesel from Garcinia Mangostana Linn. seeds. It was concluded that two phase solvent extraction was faster production process and in the other process sodium hydroxide catalyst was a cheaper catalyst compared to other catalysts of alkali transesterification process.

**Hwei Voon Lee** et. al. [74] studied about production of biodiesel from edible palm oil and non edible jatropha oil by using heterogeneous base type catalysts. Synthesized catalysts of alkali metal, alkaline earth metal oxide and mixed metal oxides were tested for chemical characteristics, texture, basicity profile etc. using XRD, BET, TPD-CO₂ and ICP-AES analysis. After conducting transesterification process with three different catalysts it was concluded that calcium based catalysts mixed with metal oxides and also with binary metal system solid base catalyst proved to be highly durable in transesterification process with low leaching of active metal for more number of cycles.

**P. M. Ejikeme** et. al. [75] in their paper reviewed about the different types of catalysts in the production of biodiesel using transesterification process. They concluded that in near future homogeneous catalysts were to be replaced by heterogeneous catalysts because of their impact on environment. Zeolites and lipases would be the catalysts of choice due to their advantages during pre-treatment processes of transesterification.

**T. Sathya** et. al. [76] implemented two step transesterification process for producing biodiesel from neem oil. This was implemented to overcome the problem of soap formation due to high content of FFA in oil. Initially acid transesterification was done to reduce percentage of FFA and then base catalyzed transesterification was adopted and nearly 92% biodiesel yield was obtained.

**Alnuami W** et. al. [77] evaluated different sources for production of biodiesel. About edible and non edible sources of oil, different biodiesel production methods,
pre treatment and post treatment of production process, its fuel properties, economics and standards were discussed. Best method of producing biodiesel was transesterification, non edible oils offer best cost reduction especially with reference to jatropha curcas and waste cooking oil.

Akhihiero E. T. et. al. [78] studied about process variables such as catalyst concentration of NaOH and CaO, methanol/oil molar ratio and their effects on transesterification of jatropha curcas to biodiesel. Optimum yield of biodiesel was obtained with 1% w/w NaOH catalyst concentration and 1:8 molar ratio but increasing them further favoured side effects rather than biodiesel. In case of CaO catalyst it was different with increase in catalyst concentration and molar ratio biodiesel yield was improved.

Theodore Dickerson et. al. [79] in their paper reviewed about fast pyrolysis with catalysts. Pyrolysis can convert wide variety of feed stock into liquid products or bio fuel but may not be readily utilised as transportation fuels so it becomes necessary to improve its properties which can be done by upgrading pyrolysis with catalysts. Many challenges were to be addressed for this up gradation, and the solution to them was zeolites and hydro deoxygenation but a lot of research has to be done to combine both of them into one catalytic fast pyrolysis reaction in a single unit or multi stage unit.

Y. Ashok Kumar Reddy et. al. [80] conducted experiment to test performance and emission characteristics of IDI engine fuelled with preheated jatropha methyl esters. With the help of electronic pre heating system JME were heated to different temperatures before injecting into the engine cylinder. It was found that with JME heated to 60°C gave a better thermal efficiency at 2.5kW load with overall improvement in performance and emission characteristics of engine compared to un heated biodiesel.

Ittipon Worapun et. al. [81] synthesized biodiesel from jatropha curcus oil using ultrasonic irradiation assisted two step transesterification process. With this method there was improvement in kinetic rate and mass transfer because of increase in interfacial area, activity of bubbles both at microscopic and macroscopic level. On
analysis of results it was noticed that reaction time was less and also high conversion rate was achieved compared to conventional method.

**Zoran Iličković** et. al. [82] studied about the effects of catalyst type and their amount in transesterification process of waste vegetable oils. In their conclusion they expressed that if FFA content was more it would lead to gel and soap formation so oils with high FFA content should be processed first with acid catalyzed transesterification and then with alkaline transesterification. Produced biodiesel was compared with industrial biodiesel as well with European biodiesel standards and found to be comparable. Finally they suggested blending of biodiesel with diesel or with biodiesel of rape seed oil for better usage.

**Mookan Rengasamy** et. al. [83] synthesized biodiesel from castor oil with nano sized iron particles as catalyst in transesterification process. Nano material catalysts known for their greater catalytic activity, less saponification, more specific surface area and also for their rigidity. Synthesized iron nano particles were characterized with X-ray diffraction, SEM, EDAX and TEM. Biodiesel so produced with nano material catalysts was proved to be better in quality compared to acid, base catalyzed transesterified biodiesel.

**Yanuandri Putrasari** et. al. [84] tested performance and emission characteristics of a two cylinder diesel engine at various engine loads fuelled with different percentages of ethanol blended with diesel. It was noticed that engine performance was increasing with increase in ethanol percentage in diesel and at the same time CO, HC and smoke emissions were found to be decreasing.

**Kavati Venkateswarlu** et. al. [85] studied effect of EGR and cetane improvers mixed biodiesel blends with diesel on engine performance and emissions. It was found that with 15% of exhaust gas recirculation to engine showed increment in brake thermal efficiency, reduction in specific fuel consumption. With both EGR and with cetane improver Di Tertiary Butyl Peroxide mixed with biodiesel fuelled to engine reduced NOx emissions by 25% with a slight increase in CO, HC and Smoke emissions.
J. Kanna kumar et. al. [86] studied effect of fuel temperature on performance and emissions of diesel engine fuelled with biodiesel of cotton seed and an additive. It was noticed that biodiesel mixed with additives had improved efficiency due to better atomisation of fuel with less viscous fuel. Preheating of fuel lead to decrease in NOx emissions due to lesser ignition delays. B20 blend biodiesel with 12% Ac2010a additive added comparatively gave better results.

Dr. G. R. K. Sastry et. al. [87] evaluated performance, vibrations and emissions of a diesel engine fuelled with three different blends of fish oil biodiesel. Diesel fuelled engine had higher mechanical efficiency, increased vibrational severity and lower SFC when compared to esters. CO and smoke emissions of esters were found to be lesser than diesel.

Puneet Verma et. al. [88] in their paper reviewed engine characteristics of diesel engine fuelled with biodiesel. On comparing fuel properties of biodiesel it was found closer to petroleum diesel. B20 blend of biodiesel was a suitable substitute for diesel. Biodiesel fuelled engine had slightly less BTE, higher SFC, higher NOx emissions but CO, HC and smoke emissions were lesser.

Murari Mohon Roy et. al. [89] studied about performance and emission effects of canola biodiesel on DI diesel engine. On experimentation they concluded with the following results on emissions. CO emissions with biodiesel at lower loads was lesser but with higher loads they increased by 5% compared to diesel. HC emissions were decreasing with increase in blend percentage of biodiesel but for all blends they were less than diesel. NOx emissions were slightly higher than diesel.

Li´lian Lefol Nani Guarieiro et. al. [90] studied about carbonyl compounds emitted by diesel engine fuelled by biodiesel and diesel. Carbonyl compounds known to be responsible for photo chemical smog. They found that with the use of biodiesel blends with diesel formaldehyde and acetaldehyde carbonyl compounds presented highest emissions but there was decrement in CC emissions with increase in blend percentage when they were considered in totality.

Sitaramaiah Naramsetty et. al. [91] investigated biodiesel of Mahua oil and with additive mixed diesel blends effect on engine performance and gaseous
emissions. Biodiesel was produced by esterification followed by transesterification process. Reported that B20 blend of biodiesel gave better results compared to other blends.

Gaurav Dwivedi et. al [92] experimented engine performance with biodiesel blended with diesel and methanol. Test results show that brake thermal efficiency of biodiesel blends up to B30 showed higher efficiency in comparison to diesel but after that it started decreasing and with B100 it was closer to diesel efficiency value. In case of specific fuel consumption B100 consumption was higher with nearly 14.8% compared to diesel fuel.

Ch.Narasimha et. al. [93] investigated engine performance and emissions fuelled with two additives (ethanol & ethyl hexyl nitrate) added to diesel blended methyl esters of rice bran oil. After experimentation it was found that blends with a maximum blend RBE45 showed higher brake thermal efficiency and decrease in specific fuel consumption compared to diesel. CO, HC and smoke emissions were also decreased for biodiesel blends with additive. Better performance was noticed with RBE35 of all other blends.

Vaneet Bhardwaj et. al [94] studied performance characteristics of CI engine fuelled with used cotton seed oil methyl esters. Biodiesel was produced by transesterification of used cotton seed oil with KOH catalyst and then three blends mixed with diesel B10, B15 and B20 were prepared and tested in diesel engine. Results indicate that B10 blend brake power, brake thermal efficiency were higher and specific fuel consumption, exhaust gas temperatures were lower compared to other blends.

Achuthanunni V et. al. [95] investigated a EGR system CI engine fuelled with diesel-biodiesel. Biodiesel on combustion produces more NO\textsubscript{x} emissions because of higher combustion temperatures. To lower combustion temperature and oxygen concentration 10% exhaust gas was re-circulated to reduce NO\textsubscript{x} emissions. On testing it was found that NO\textsubscript{x} reduced by 40% compared to without EGR. Apart from this engine performance at all loads was comparable to the performance of engine fuelled with diesel.
Magín Lapuerta et. al. [96] in their paper summarized the results based on analysis of scientific research papers on emissions from diesel engines fuelled with biodiesel. It was noticed an increase in consumption of biodiesel fuel by diesel engines to compensate efficiency due to their low heating value. With usage of biodiesel there was slight increase in NO\textsubscript{x} emissions, sharp reduction in particulate emissions, decrease in mean diameter of PSDs and also reduced THCs and CO emissions.

Z. Helwani et. al. [97] reviewed about green catalytic methods to produce biodiesel. For production of biodiesel the common method implemented was catalytic transesterification process. This can be done by usage of homogeneous liquids and heterogeneous solid catalysts. When compared to batch processing method continuous process production method was favourable with high production and low operating costs, for large scale production to get continuous supply.

Gerhard Knothe et. al. [98] gave a comprehensive report on fuel properties of Kenaf seed oil methyl esters. Biodiesel obtained by conventional method of base-catalyzed transesterification met the fuel property specifications of biodiesel standards and it uniqueness comes with small amounts of methyl epoxyoleate and cyclic fatty acid methyl esters. Kinematic viscosity was high may be due to the cyclic moieties.

Yogesh C. Sharma et. al. [99] in their paper discussed about advancement in solid acid catalysts based upon environment friendliness and economic viability. Different types of solid acid heterogeneous catalysts such as metal complexes, zeolites, tungstated and sulfated zirconia, etc., have been explored. Catalysts were able to bring about moderate to high conversion rates with improved yield. Reusability of solid catalyst was determined by their poisoning, deactivation and extent of leaching during reaction. Catalysts discussed were good at converting high FFA waste oils into biodiesel.

Umer Rashid et. al. [100] extracted oil from Citrus reticulata seeds and investigated its potentiality to be used as a feed stock for production of biodiesel. Sodium methoxide as a catalyst along with methanol, transesterification process was carried out to for producing biodiesel. Fuel properties like kinematic viscosity, pour
point, flash point etc. were determined and when compared with biodiesel ASTM standards found to be satisfactory. In their conclusion their opinion was that citrus seed oils can be of a potential source for producing biodiesel.

**Gregory S. Bugosh** et. al. [101] studied about emissions by conducting experiments on CI bench top engine generator using alternative diesel fuels. Engine exhaust emissions such as NO\(_x\), PM, HC, CO and CO\(_2\) from diesel engine fuelled with biodiesel fuels obtained from soybean, palm, canola etc. were measured and compared with Texas low emission diesel. It was found that NO\(_x\) emissions for biodiesel fuels were high at low loads but less at high loads whereas CO and HC decreased at low and high loads in general but it was different from one biodiesel fuel to other. Finally it was concluded based on reduced emissions from biodiesel they can be used in CI diesel engines without engine modifications.

**Yee Kang Ong** et. al. [102] presented summary about present and future of the catalytic cracking technology for production of biodiesel. Shape selectivity and acidity of the catalyst influence a lot on hydrocarbon yield. With the combination of microporous and mesoporous zeolites catalyst cracking activity can be enhanced and this process can be implemented in existing refineries with slight modifications saving investment costs for this technology.

**K S Babulal** et. al. [103] conducted experiment for the analysis of CI engine with biodiesel fuel. Tests were conducted using diesel, blends B40 and B100 of biodiesel mixed with diesel. On evaluation of test results it was noticed that B40 blend was a good alternative to diesel because BTE was closer to diesel, BSFC was only 8% higher and NO\(_x\) emissions were only 2% higher at full load operation of engine.

**Virin Kittithammavong** et. al. [104] made assessment of the impact of biodiesel production transesterification process on environment life cycle. They studied about two production processes one was transesterification and other was distillation process both of them have got their own advantages and disadvantages with respect to green house gas emissions. One process uses less energy but more water and on the other side the other process uses more energy less water with GHG
emissions in both the process. Finally if sufficient energy was available with less supply of water then distillation process was suitable compared to transesterification.

**Tan Yee Leng** et. al. [105] studied about conversion of palm oil using HZSM-5 catalyst into hydrocarbons. They used fixed bed micro reactor operating at atmospheric pressure with a temperature range of 360°C to 420°C and WHSV of 2 to 4 h⁻¹ to produce hydrocarbons by passing palm oil over HZSM-5 catalyst. Optimum reaction temperature of 400°C and space velocity of 2h⁻¹ gave a 40% wt yield of total product obtained that was of maximum gasoline range hydrocarbons.

**José Rodríguez-Fernández** et. al. [106] in their paper described about a new chemical process for utilization of glycerol and waste oils as reagents for production of fatty acid glycerol formal esters that can used as for blending in diesel. They evaluated properties for two FAGES blended with diesel one FAGE produced from cooking oil and the other from animal fat. Blends up to 20% were permissible as per present legislation based upon their fuel properties and NOₓ, particulate emissions in comparison with FAME.

**Dennis Y.C. Leung** et. al. [107] reviewed about three ways for reducing soap formation during transesterification process of high FFA content oils into biodiesel. First solution was esterification process with acid catalysts, second one was iodine as catalyst, third solution was with zinc chloride as catalyst adding glycerol to acidic feedstock and carrying out reaction process at high temperatures. First approach was more advantageous with one disadvantage of slow reaction rate. Glycerol produced in the transesterification process finds its usage in various industrial applications but before that it should be refined to 99% purity, for this hollow fibre membrane extraction found to be promising method for washing biodiesel.

**D.H. Qi** et. al. [108] made experimental study on combustion and performance characteristics of a DI engine with a fuel of biodiesel blends with diesel. Soy bean oil was transesterified with alkaline-catalyst to obtain methyl esters of soy bean oil and it was fuelled to diesel engine by blending with diesel in different ratios. It was noticed that BSFC and NOₓ emissions were more compared to diesel. NOₓ emissions increased due to increase in cylinder temperatures because of better combustion due to oxygen content present in biodiesel.
Avinash Kumar Agarwal et. al. [109] presented a paper summarizing particulate emissions in CI engines with biodiesel fuel. Use of biodiesel reduces total particle number emissions but there was increment in the nano size particle number. Higher ratio of elemental carbon to that of organic carbon combined with lower total PM mass emissions indicates that biodiesel was less toxic compared to diesel. Their opinion was that future investigations should be on the biodiesel particulates transformation in atmosphere with time.

H. Sharon et. al. [110] tested methyl esters of used palm oil in a diesel engine to check for performance and other characteristics of engine. B25 and B50 blends were giving better performance than the other two biodiesel blends and with B75 blend emissions were greatly reduced. It was also identified that ignition delay was less for biodiesel blends compared to diesel and overall results were encouraging to make use of biodiesel derived from used palm oil as a fuel to diesel engine.

Eric Cecrle et. al. [111] investigated emissions on single cylinder diesel engine when fuelled with biodiesel feedstock. They tried to identify biodiesel fuel properties in particular that could reduce NO\textsubscript{x} formation and wanted to use them to produce blends that can bring down NO\textsubscript{x} emissions. Seven biodiesel fuels were tested in single cylinder diesel engine and it was noticed that brake specific nitric oxide emissions were higher for biodiesel fuels at low loads compared to ULSD. Analysis of results they concluded that lower fuel density, lower poly unsaturation levels with higher hydrogen/carbon molar ratio's of fuel were significant in reducing nitric oxide emissions but without any change in NO\textsubscript{2}. Suggested that different ways can be tried to blend fuels with necessary properties to reduce nitrogen oxide emissions.

Sandun Fernando et. al. [112] presented paper on reduction techniques of NO\textsubscript{x} emissions that were graded as zone A hazardous compounds. Use of biodiesel in diesel engines reduces over all emissions except NO\textsubscript{x} emissions which were happened to increase slightly. Two techniques proposed to reduce these emissions were water injection and ignition timing retardation. These methods were found effective however with a slight decrement in engine performance.

M.E. Borges et. al. [113] presented paper on the recent heterogeneous catalysts for biodiesel production. They have got large applicability in biodiesel
manufacturing industry because of their easy separation, reducing no of stages in processes and wastages. They reviewed about latest solid acid type catalysts like CaO from eggshells, KNO$_3$/CaO, CaO/ZnO, etc., base type catalysts like WO$_3$/ZrO$_2$, SO$_4^{2-}$/ZrO$_2$, Kaolins etc., and bifunctional (both acid-basic) type catalysts like Quintinite-3T, MgO/TiO$_2$, Sr/ZrO$_2$ etc..

Niken Taufiqurrahmi et. al. [114] in their paper reviewed about catalytic cracking of both edible and non edible oils to produce bio fuels. This process was found suitable for producing bio fuel from biomass as well as from waste cooking oils. They covered different type of feed stocks, catalysts, cracking mechanisms, reactors for catalytic cracking process and also about bio fuel characteristics. With this process both fuels gasoline and diesel can be produced.

Tracy J. Benson et. al. [115] elucidated about catalytic cracking of unsaturated glycerides using solid acid catalysts. Unsaturated fatty acid side chains were cracked outside catalyst pores along with formation of mono-, di-aromatic compounds due to cyclization and aromatization inside the catalyst pores in the cracking mechanism. This process also forms propane, propylene and fatty acids by the cleavage of glycerol carbons. They proposed reaction mechanism for deoxygenation of lipids. Concluded that lipids can be transformed into transportation fuels with catalytic cracking process.

Gerhard Knothe [116] discussed about properties of biodiesel. Started with sources and availability of feedstock for production of biodiesel with transesterification , next with fuel properties such as cetane number and its role in combustion, viscosity, cold flow, lubricity, oxidative stability and finally ended discussion on improvements that could be done to overcome problems associated with usage of biodiesel.

María Jesús Ramos et. al. [117] studied about zeolite catalysts with different metal loadings in transesterification process. Three types of zeolites namely mordenite, X and beta were used and also influence of each catalysts with different metal loading for producing methy esters was also experimented. With metal loading, number of basic sites, basic strength and catalytic activity of parent zeolite increased in production process of methyl esters. Zeolite X had greater catalyst acitivity because
of high concentration of super basic sites compared to other two zeolites. On agglomeration of zeolite X with sodium bentonite binder it showed no difference in catalytic activity. Efforts had to be made for retaining active species of a catalyst from leaching so that catalyst can have long term stability because of which production process becomes more economical.

A. Demirbas [118] in his paper explained that though there were many different production processes for biodiesel, liquid fuel produced by pyrolysis method proved advantageous in comparison with transesterification process. Liquid fuel had similar chemical components in comparison with petroleum diesel. This process produces environmentally friendly liquid fuels consisting of gas, water, organic liquid product and coke. Hydrocarbons related to diesel, gasoline and kerosene were obtained from organic liquid product.

Wenlei Xie et. al. [119] carried out work for producing biodiesel by transesterification process from soy bean oil using a solid base catalyst like alumina loaded with potassium iodide. Catalyst was calcined for 3 h at a temperature of 773k to improve catalytic activity and also to increase basicity of catalyst for reaction. Reaction variables effect on transesterification process was also studied. A correlation for catalyst activity and its basicity was proposed for transesterification process and with optimum reaction conditions 96% conversion rate was achieved.

Magi´n Lapuerta et. al. [120] tested two blends of biodiesel from used waste cooking oil in a commercial DI diesel engine for particulate emissions. With increase in biodiesel concentration in fuel there was a sharp decrease in smoke, particle number concentration and particulate emissions. Concluded that there was no significant increase in small particle emissions by measuring particle size distributions.

Magín Lapuerta et. al. [121] tested three fuels for their bulk modulus of compressibility. It has impact on fuel hydraulic behaviour during injection process. All the three fuels were measured under same conditions by taking water as calibration fluid and it was found all of them showed lower isothermal bulk modulus compared to water. Biodiesel showed lower compressibility of all the test fuels because of high degree of unsaturation, presence of carboxylic groups and longer
mean carbon alkyl chain. Presented results could help in prediction and correction of effect of the fuel based on injection parameters like injection timing which influences NO\textsubscript{x} emissions in diesel engines.

**Melissa A** et. al. [122] experimented on reducing NO\textsubscript{x} emissions using reformulated soy bean biodiesel to find solution to strict environmental regulations. One reformulation technique was to convert fatty acid chain cis bonds to trans isomers of soy oil methyl esters and second technique was to transesterify polyol derivatives of soy bean oil to polyol fatty acid soy methyl esters. When both esters were put to test in diesel engine taking B20 blends NO\textsubscript{x} emissions increased with biodiesel produced using first method where as biodiesel produced by second method showed better reduction of NO\textsubscript{x} emissions.

**Syed Ameer Basha** et. al. [123] in their article reviewed about catalysts and additives for producing biodiesel and also effect of such produced biodiesel on engine characteristics. Summary of their findings was base catalysts were good at biodiesel production compared to acid type catalysts and on testing biodiesel produced using catalysts there was a very little variation of engine performance. Biodiesel with additives improved combustion characteristics because of reduced ignition delay and increased pre mixed combustion duration.

**Umer Rashid** et. al. [124] tested Moringa oleifera oil for the first time for its potentiality as biodiesel feed stock. Produced biodiesel from Moringa oleifera oil using two step transestrification process. Oil was rich in oleic acid so biodiesel produced had good oxidative stability and high cetane number of nearly 67 said to be one of the highest of available biodiesel fuels. With a concern of high cloud point still it can be well substituted for diesel and other biodiesels.

**Ma Zhihao** et. al. [125] experimented to study the emissions of a diesel engine with biodiesel-diesel blends. Engine was fuelled with Pistacia Chinensis Bunge seed biodiesel to check for the emissions. It was noticed that HC and CO emissions decreased with availability of oxygen for complete combustion. NO\textsubscript{x} emissions increased with increase in loads for all test fuels but for entire range of engine loads B10 & B20 biodiesel blends NO\textsubscript{x} emissions were lower to diesel. Exhaust smoke emissions decreased with increase in ratio of biodiesel in blends.
Defu Zhang et. al. [126] in their article reviewed about usage of biodiesel in marine engines. Analysis made by many researchers regarding advantages and problems associated to usage of biodiesel fuel were summarized. NO\textsubscript{x} emission reducing techniques suggested by other researchers like EGR, injection timing advancement and prevention of biodiesel oxidation by adding additives like citric acid were presented in their paper. With stringent emission norms being imposed on engine emissions biodiesel found to be a suitable fuel with its reduced emissions for engines of marine ships.

K. Sivaramakrishnan et. al. [127] studied about Cetane number an important parameter in evaluation of the quality of biodiesel fuel. Transesterification process converts highly viscous vegetable oils to biodiesel. Design of fuel system in CI diesel engines depends upon physical and chemical properties of fuel. Aim of their work was to create an equation to cetane number. With the help of other properties of fuel cetane number was calculated. When compared with measured cetane number values it was found that the results obtained were 90\% accurate.

C. Syed Aalam et. al. [128] produced biodiesel from Mahua vegetable oil through catalytic transesterification with potassium hydroxide as catalyst and ethanol. Biodiesel properties were tested to verify them for their compliance with ASTM standards. Advantages of biodiesels are renewable fuels, nontoxic, biodegradable and these have better properties than that of petro-diesel fuels. Mahua methyl esters viscosity, cetane number were slightly higher and calorific value was nearer to that of neat diesel fuel. Comparatively mahua methyl esters were more expensive than petro-diesel fuel. Recent hikes in petroleum prices and persistent uncertainties over petroleum fuel availability, created interest and necessity of biodiesel for diesel engines.

V.S. Yaliwal et. al. [129] reviewed about renewable liquid fuels for diesel engines. To overcome many socio economic issues usage of renewable fuels became essential for different applications. Biodiesel produced by different technologies offers quality comparable to fossil fuels. Fatty acid composition varies from one vegetable oil to other. Lot of variation in chemical structure was noticed when samples of same vegetable oil were collected from different places because of
determining factors like weather and soil conditions. Vegetable oils’ cetane numbers varied from 35 to 50 based on their composition. Vegetable oils and diesel fuel properties differed from each other such as higher viscosity of vegetable oils compared to diesel. Many techniques were explored by scientists and researchers to alter the physical and thermal properties of vegetable oils making them compatible to mineral diesel. Some techniques offered greater advantages in production of biodiesel with closer properties to diesel. Solutions to problem of increased NO\textsubscript{x} emissions with usage of biodiesel in diesel engines were summarized.

**Katsuki Kusakabe** et. al. [130] proposed production of both biodiesel and activated carbon from rubber seeds. Using in-situ transesterification process of oil extracted from rubber seed combined with n-hexane produced biodiesel. Only 98 \% FAME yield was obtained due to poor extraction of FFA from the rubber seed in n-hexane. Activated carbon produced by co-carbonization of the rubber seed residue and the crude glycerin showed improved pore properties and also ability of methylene blue adsorption.

**Gerhard Knothe** [131] in his paper compared biodiesel to that of renewable biodiesel. Renewable biodiesel, a kind of biodiesel similar to petro diesel produced from oil or fat by hydrodeoxygenation reaction with catalyst carried out at high temperature and pressure. Carbon renewability was one thing where both biodiesel and renewable diesel proved advantageous compared to petro-diesel. In terms of fuel properties, environmental issues and energy balance both fuels have got their own advantages and disadvantages. Renewable diesel promoted as ‘‘premium’’ diesel fuel offers some environmental benefits in the neat form rather than its blending with petro-diesel. Compared to biodiesel, environmental benefits of renewable diesel appears to be lesser. Lubricity to petro-diesel could be regained by blending it with biodiesel. To produce more biodiesel or renewable diesel remains as an issue.

**Atul Dhar** et. al. [132] studied about effect of particulate emissions from a transportation diesel engine fuelled with blends of karanja biodiesel. Detailed study on particulate number, their size, concentration and size to surface area distribution in the emissions at different engine loads and speeds were investigated. On observation of experimental results, increase in blend percentage of karanja biodiesel emitted
higher concentration of total particulate number and with karanja biodiesel blend of 10% the lowest concentration of particulate number was noticed. Blend percentage up to 20% was found effective in reducing particulate number emissions.

**J. Wall** et. al. [133] studied and investigated on waterless process of removal of soap and glycerine from biodiesel produced by transesterification process. To overcome problems associated with water washing process in getting pure biodiesel new alternatives such as use of adsorbents and ion exchange resins were tested. Filter paper separated precipitated soap in biodiesel with low methanol content and with increase in fineness in filter paper more soap could be removed. For lower soap levels in crude biodiesel ion exchange resins were found useful in removing soap by ion exchange method but at higher levels of soap both adsorbents and ion exchange methods were employed. Similar performance was noticed with gel and macroporous resins in removing traces of soap from biodiesel.

**Magín Lapuerta** et. al. [134] obtained methyl esters from spanish sunflower and cynara cardunculus crops. These esters were fuelled to diesel engine to study their effect on engine exhaust emissions. With necessary instrumentation fitted to a test engine, adsorbed hydrocarbons and their origin, sulphate content, mean particle diameter etc. were investigated. It was noticed that with increase in concentration of biodiesel soot mass was decreasing effectively but proportion of adsorbed hydrocarbons on the particle surface increased, sulphate content was reduced, there were no reductions in mean particle size nor increase in NOx emissions but at all engine loads soluble organic fraction was increasing. In Spain, reduced engine emissions from usage of sunflower and cynara methyl esters increased interest in utilisation of these energy sources as substitute fuel for conventional fuel.

**T.M. Yunus khan** et. al. [135] reviewed various engine parameters and their effect on engine performance with special attention given to electronic governing mechanisms of future automotive engines. A detailed explanation on engine variables like combustion chamber geometry, compression ratio, fuel injection pressure and timing, air swirl, spray behaviour etc. was provided. Concluded stating that best fuel economy with improvement in engine performance and reduced emissions could be achieved by optimizing engine variables using electronic control units.
Magín Lapuerta et. al. [136] tested blends of alcohol with diesel for viscosity, lubricity, stability and cold flow properties. Five types of alcohols blended separately in different ratios with diesel were tested. Stability of short chain alcohols was poor when blended because of which their usage was limited for lower concentrations. Any concentration of butanol and pentanol could be used because of very less loss in viscosity when blended with diesel. Lubricity of alcohols gets affected only at high concentrations with an exception to pentanol. Cold flow properties were improved for alcohols blended with diesel only at higher concentrations. Some limitations of alcohols could be overcomed by adding additives making them suitable for blending with diesel. Usage of alcohol blended diesel in engines ultimately reduces emissions.

David Kubic’ka et. al. [137] studied about conversion of vegetable oils to hydrocarbons over mesoporous alumina supported cobalt molybdenum catalysts. Higher activity of these catalysts was noticed during deoxygenation of triglycerides compared to cobalt molybdenum supported on silica and ordinary alumina catalysts. Deoxygenation process was carried out by two methods one was hydrodeoxygenation and other method was hydrodecarboxylation but both the processes level of reaction was based on reaction parameters and used supports. It was noticed that with increase in reaction temperature and with pressure decrease extent of hydrodecarboxylation increased and they expressed that there was a need for further research especially on type of supports and their properties.

Magín Lapuerta et. al. [138] studied about blending strategies and main properties of bio fuel produced by hydrotreatment of vegetable oil. Their usage in diesel engines have many advantages but with certain limitations. Cetane number, lubricity and cold flow properties were found to be causing some restrictions so certain solutions were found out based on extensive study. On consideration of cetane number and lubricity properties blending up to 50% was found to be permissible. Use of cold flow improvers were found effective, reduced soot formation and particulate matter would lead to filter durability, easier maintenance recommends usage of higher concentrations of hydrogenated vegetable oil.
Hitesh J. Yadav et. al. [139] investigated the effect of blends of diesel and karanja biodiesel on engine performance and emissions. It was found that brake thermal efficiency of karanja methyl ester and diesel was slightly better and specific fuel consumption was lower compared to diesel. Mechanical efficiency of certain blends was close to diesel. Exhaust emissions were higher for karanja biodiesel but for B20 blend they were near similar to diesel. Suggested use of B25 blend of karanja biodiesel and diesel in diesel engines without any engine modifications.

Magíñ Lapuerta et. al. [140] studied about different blending scenarios of soya bean derived fuels with diesel. To boost the blending possibilities depending on the desired fuel characteristics binary and ternary blends of diesel fuel, conventional biodiesel and hydrotreated vegetable oil (HVO), both derived from soybean oil, have been proposed as a means to increase the fraction of renewable energy in automotive fuels. Two scenarios were considered and in the first scenario a neutral fuel in terms of cetane number and sooting tendency was obtained with 25% vegetable oil and 75% petroleum oil blended with minor contents of biodiesel. Second fuel composed of 50% biodiesel and 50% HVO blended with base fossil diesel fuel was able to improve the cetane number from 45 to 65, approximately, and reduce soot by roughly 30%.

Rogelio Sotelo-Boya's et. al. [141] carried out experiments to produce renewable diesel called green diesel by using three bifunctional catalysts in hydrocracking of rapeseed oil. In catalytic reaction as well as in hydrogenation reaction, platinum zeolite catalysts were strong in catalytic activity because of strong acid sites. Nickel molybdenum and alumina catalyst were effective in hydrocracking of triglycerides and carbolic acids to produce highest yield of liquid hydrocarbons with high cetane number compared to that of fatty acid methyl esters. Temperature, pressure and strength of metal acid sites played a major role in converting triglycerides and fatty acids into hydrocarbons.

Jairton Dupont et. al. [142] discussed about latest catalytic process of triglycerides to produce biodiesel and hydrocarbons similar to diesel. Thermo catalytic cracking process for producing diesel like hydrocarbons and alcoholysis process to produce biodiesel were simple processes but they had their own drawbacks in terms of energy, water consumption and retrievability of catalyst. Heterogeneous
solid catalysts with reusability capability and ionic liquids were found to be promising in overcoming the draw backs associated with previous methods.

**Michael S Graboski** et. al. [143] reviewed about diesel fuels derived from fat and vegetable oils, their fuel properties and also engine performance and emissions. Disadvantage of using biodiesel was their high cost compared to petroleum fuels. Biodiesel miscible in petroleum diesel, superior lubricity, reduces particulate matter emissions considerably but increases NOx emissions significantly. Biodiesel fuel properties and air toxins available data were discussed in detail. Future research areas of focus suggested were identification of lower cost feedstock, heterogeneous catalysts, new processing techniques for production of biodiesel. Better understanding of chemical structure of biodiesel, acceptable levels of oxidative stability, flow improver additives, cetane improvers, presence of oxygenates on emissions.

**Michael J. Haas** et. al. [144] investigated on synthesis of FAME from a by-product of refining process of vegetable oil called acid oil. Acid esterification process was employed for conversion of free fatty acids and acylglycerols into FAME but could not completely eliminate triacylglycerides and diacylglycerides present in acid oil because of poor catalyses of sulphuric acid and formation of water. To get better conversion rates from HA acid oil prior treatment was done by passing steam with a pH value exceeding 11 but multiple water washing processes was to be optimised and this was done by centrifuging sample after first acid esterification, upper layer was collected and second esterification process gave a product with unacceptable acid value so another wash for one hour with sodium hydroxide reduced acid value and finally gave required fatty acid methyl esters.

**Gerhard Knothe** [145] made a comprehensive study on cetane numbers and evaluated influence of double bond position, compound structure and configuration of fatty acid methyl esters on them. Cetane numbers indicate ignition quality of fuels. Sometimes after experimentation also it would be difficult to get cetane number of some compounds but after extensive collection of CN determinations methyl oleate was taken as standard for finding cetane numbers. This made possible to predict cetane numbers for such compounds and also for biodiesel.
Ayhan Demirbas et. al. [146] studied and tested new ways to convert vegetable oils to alternate fuels. Many different process were adopted for producing biodiesel but they felt that there was a need for less expensive and direct process to produce biodiesel. Catalytic cracking process was tested by using zinc chloride as catalyst to convert vegetable oils into a quality biodiesel and they were able to get maximum yield of 79.9% at a temperature of 660 K from soya bean vegetable oil.

Venkata Ramesh Mamilla et. al[147] experimented production of biodiesel from karanja oil. Transesterification process with sodium hydroxide catalyst and methanol was adopted to convert karanja oil to biodiesel. Detailed about production process, tested fuel properties of biodiesel and compared them with ASTM and German biodiesel standards. Concluded stating advantages of using biodiesel.

María Jesús Ramos et. al. [148] studied about influence of composition of the raw material on biodiesel properties. Some ten refined vegetable oils were transesterificated to produce biodiesels, a correlation was established with critical parameters like oxidation stability, iodine value, cetane number and cold filter plugging point with the methyl ester composition of each biodiesel, according to long chain saturated factor and degree of unsaturation. Finally, a triangular graph was built based on the composition of polyunsaturated, monounsaturated and saturated methyl esters in order to predict the critical parameters of European standard for any biodiesel with known composition.

Maumita Chakraborty et. al. [149] investigated the prospects of terminalia oil for production of biodiesel. Kernal of terminalia contains nearly 43% oil and properties of oil were comparable to the other similar seed oils for production of biodiesel. Properties like calorific value and cetane number of biodiesel produced from this oil were within the standard limits and other properties were in par with other biodiesels. Suitability of terminalia oil for production of biodiesel would assist in national biodiesel mission and regeneration of forest areas in north eastern part of India.
Kyunghyun Ryu [150] investigated characteristics of a diesel engine fuelled with soyabean biodiesel mixed with antioxidants. Five oxidants were tested among them tert-butylhydroquinone antioxidant was best in providing oxidation stability to biodiesel. Brake specific fuel consumption of biodiesel mixed with antioxidants was less than that of antioxidant less biodiesel and also there was no such distinguishable change noticed in exhaust emissions with biodiesel fuel with antioxidants.

Amish P. Vyas et. al. [151] reviewed about various production processes of biodiesel taking into consideration popular feedstock source of biodiesel such as algae and most popularly practised biodiesel production process. They discussed about commonly used transesterification process but with various type of catalysts and also about other simple biodiesel production techniques to obtain better results compared to regular production method.

Junhua Zhang et. al. [152] conducted experimental study on production of biodiesel from high free fatty acid content raw feedstock using heterogenous catalysts. Two stage transesterification processes was implemented using ferric sulphate catalyst in the first stage and later with CaO catalyst for production of biodiesel from high free fatty acid content zanthoxylum bungeanum seed oil. Software was used for regression analysis of experimental data for plotting response surface. With optimal conditions nearly 96% and above feedstock conversion to biodiesel was achieved using acid and base catalyzed transesterification process.

Pedro Benjumea et. al. [153] studied effect of altitude on performance and combustion characteristics of a high speed direct injection diesel engine with fuelling of palm oil biodiesel. Injection timing and combustion timings of turbo charged engine were advanced with the effect of altitude and biodiesel fuel. With increase in altitude combined with fuelling of biodiesel combustion duration became less, higher in cylinder pressures and fuel air equivalence ratios were noticed. Results indicate that at high altitudes with fuelling of palm oil biodiesel better engine performance can be obtained.

Ekrem Buyukkaya [154] investigated DI diesel engine performance, combustion and emissions using a neat rape seed oil, its blends and diesel. Results indicate a higher brake specific fuel consumption, reduction in smoke opacity and CO
emissions with biodiesel. On analysis of combustion process shorter ignition delay was noticed with biodiesel. Concerned to increased engine NO\textsubscript{x} emissions with the use of biodiesel more research work had to be done to decrease them.

**T. Ganapathy** et. al. [155] proposed a methodology to determine optimum engine operating parameters with Taguchi's optimization technique. Simulation was done for jatropha engine performance considering ten parameters with an assumption of interactions between the parameter pairs. This helped in predicting Weibe's heat release constants, compression ratio and duration of combustion to be critical parameters affecting jatropha biodiesel engine performance.

**M. Gumus** [156] investigated combustion and heat release characteristics of hazelnut biodiesel fuelled to DI CI engine. Parameters of combustion like ignition delay, rate of pressure rise and heat release parameters like combustion duration, centre of heat release were considered for testing to see influence of biodiesel blends on these parameters of a diesel engine. Combustion duration extended with biodiesel blends and it was noticed ignition timing, injection pressure and compression ratio affected combustion duration of all test fuels and increasing these parameters led to improvement in combustion and heat release characteristics.

**J. Theo Kloprogge** et. al. [157] discussed about modification of clay minerals and conversion of expanded material into a permanent two dimensional structure called pillared clay. This material possessed porous structure with acidic properties similar to zeolites. These catalytically active materials with pores play an important role in cracking vegetable oils like canola into biodiesel. This catalytic cracking process produces organic liquid product better than biodiesel and similar to diesel.

**K. Muralidharan** et. al. [158] investigated variable compression ration engine characteristics fuelled with waste cooking oil biodiesel blends. With 50% load on engine and constant speed of 1500 rpm different compression ratios were tested to find out optimum compression ratio for best engine performance based on variations in fuel consumption, combustion pressures and emissions. B40 blend of methyl ester of waste cooking oil was found to give maximum thermal efficiency.
Md. Nurun Nabi et al. [159] investigated cotton seed biodiesel effect on engine performance and emissions. Biodiesel was prepared from cotton seed oil using transesterification process and conducted tests for getting good quantity of biodiesel by varying amounts of catalyst and methanol. Optimum conditions identified after tests were 20% methanol combined with 0.5% sodium hydroxide gave good percentage of biodiesel. On analysis of experimental results it was found that carbon monoxide, particulate matter, smoke emissions decreased with a slight increment in NO\textsubscript{x} emissions for all tested biodiesel blends.

M. Pugazhvadivu et al. [160] investigated engine performance and emissions of a diesel engine with preheated waste frying oil. Viscosity of waste frying oil was high so it was pre heated to two different temperatures and tested in diesel engine. It was noticed increase in engine performance and reduced carbon monoxide, smoke emissions with waste frying oil preheated to 135\textdegree C but it could be substituted for diesel only for short period of engine operation only.

Gerhard Knothe [161] reviewed about standards and other methods of analyzing biodiesel. Detailed discussion and standards to which biodiesel fuel properties should satisfy in order to be used as fuel in diesel engines were given. Various types of analysis of fuel properties were also provided and even justifications for specifications mentioned in standards were also mentioned.

Yogesh C. Sharma et al. [162] investigated conversion of biodiesel with high yield percentage from pongamia pinnata or karanja feedstock. Biodiesel was produced by acid esterification and later with alkaline transesterification because of high free fatty acid content in karanja oil. Fuel properties of biodiesel were tested and found to be within ASTM standards but oxidation stability of biodiesel was less than minimum specification so addition of antioxidants was necessary to increase deterioration time.

M. Senthil Kumar et al. [163] investigated usage of preheated animal fat oil in CI engine. Experimentation was carried out with preheated animal fat oil at various temperatures fuelled to diesel engine to test engine performance. It was noticed decrement in ignition delay, high peak pressures, high rate of
pressure rise and improvement in premixed combustion rate with increased preheating temperatures. HC and CO emissions were higher with lower temperature animal fat oil but decreased with fuel preheating compared to diesel. Concluded that preheated animal fat oil can be used in diesel engines without major loss in engine performance.

**M.P. Dorado** et. al. [164] studied about exhaust emissions from Perkins diesel engine operated at various steady state conditions with methyl esters of waste olive oil. Results indicate biodiesel engine exhaust emissions CO, CO₂, NO and SO₂ decreasing but NO₂ emissions increasing. Though combustion efficiency of biodiesel was constant a slight increase in brake specific fuel consumption was noticed compared to diesel. Concluded stating usage of waste frying oil for biodiesel would help in reducing dependence on fossil fuels and also help in protecting environment from pollution.

**N. Usta** [165] investigated performance and exhaust emissions of a methyl ester tobacco seed oil fuelled diesel engine. Turbo charged indirect injection diesel engine with tobacco seed biodiesel fuel showed a slight increase in power and efficiency, reduced CO, SO₂ emissions but a slight increase in NOₓ emissions because of combustion process well enhanced by presence of oxygen content in biodiesel.

**Mustafa Canakci** [166] compared combustion characteristics and emissions of a diesel engine fuelled with three different types of fuels. Two Test fuels were No.1, No.2 types of petroleum diesel fuels and third test fuel was biodiesel produced from soybean oil. Results showed that No.1 diesel fuel performed better with reduced emissions among tested fuels and biodiesel performed well with reduced emissions compared to No.2 diesel fuel. Concluded stating that an unmodified diesel engines could be fuelled with a blend of biodiesel and No. 1 type diesel.

**Y.D. Wang** et. al. [167] investigated diesel engine performance and gaseous exhaust emissions with vegetable oil blended in different ratios with diesel separately. Tests were conducted for different loads maintaining constant engine speed. Fuel consumption and power output of blends of vegetable oil were comparable to diesel
fuel. Emissions NOx, and CO emissions of vegetable oil blends were less than diesel except for HC emissions which were found decreasing up to 50% loading after that increase was noticed.

**James P. Szybist** et. al. [168] reviewed about biodiesel fuel combustion, emissions and their control. They noticed increase in NOx emissions in case of pump line nozzle fuel systems because of high bulk modulus of compressibility of soy bean biodiesel and also increase in NOx emissions with common rail engines. Conclude that adding cetane improvers and advancing injection timing they can be reduced. Oxygen content in biodiesel reduces particulate matter in soot.

**Md. Nurun Nabi** et. al. [169] investigated diesel engine emissions with conventional diesel and biodiesel. In comparison with conventional diesel, emissions such as CO and smoke were less with blends of biodiesel. There was increment in NOx emissions with blends of biodiesel but with exhaust gas recirculation they were slightly reduced. Neem oil methyl esters found to be environmentally friendly and it can be substituted to diesel as an alternate fuel.

**Abdul Monyem** et. al. [170] evaluated effect caused by oxidation of biodiesel on engine performance and emissions. Biodiesel known for its improved reduction in emissions but more prone for oxidation causing plugging of fuel filters with its gum forming nature and also for increasing acidity of fuel. Both oxidized and un oxidized biodiesel fuel were tested on John Deere 4276T turbo charged diesel engine. Decrement in CO and HC emissions was noticed with un oxidized biodiesel fuel compared to other test fuel but no noticeable change was found in NOx and smoke emissions with both fuels.

**Clayton V. McNeff** et. al. [171] investigated biodiesel production using continuous catalytic system. This process produces high quality biodiesel with very high yield. At a time both transesterification and esterification reactions were carried out without any need for modification of metal oxide surface to catalyze the reactions. Inexpensive feed stocks with high free fatty acids could be used for economical biodiesel production with minimal wastage eliminating usage large quantities of water. It was felt that in future this process could possibly produce biodiesel from vast
renewable energy resources in an inexpensive way reducing dependence on fossil fuels.

K. Dincer [172] in his paper briefed about reduced emissions from combustion of biodiesel. Biodiesel fuel properties were according to ISO norms, presence of oxygen brings about complete combustion process reducing CO, particulate matter and smoke emissions but leads to increase in NO\textsubscript{x} emissions. Due to less hydrocarbons chances of smog formation and ozone formation were reduced and sulfur oxide emissions were completely eliminated.

Abdullahi Isiyaku Kankia et. al. [173] reviewed about production, characterization of two non edible oils including process variables. Increasing Asian population and high prices of vegetable oils made to shift focus on non edible oils as feedstock for producing biodiesel. Two non edible oils neem and soap nut were concentrated and high level of free fatty acids necessitated implementation of two stage production process for biodiesel production. Analysis of process variables helps in conserving energy and in differentiating biodiesel based on quality, quantity and efficiency. Expressed their opinion that non edible oils would be an asset for developing and limited fossil fuel resource countries.

T. Elango et. al. [174] investigated diesel engine performance and emission characteristics with blend ratios ranging from 10\% to 50\% of jatropha biodiesel/diesel. On analysis of test results following conclusions were drawn. B20 blend specific fuel consumption was higher to diesel but closer than all other blends. Higher smoke opacity and NO\textsubscript{x} emissions for all blends compared to diesel. B20 blend brake thermal efficiency was very close to diesel. So B20 blend of jatropha methyl esters with diesel found to be viable source of fuel for unmodified diesel engine.

Xingcai Lu et. al. [175] investigated to bring about reduction of NO\textsubscript{x} and smoke emissions simultaneously for a diesel engine fuelled with biodiesel through port injection of ethanol. On analysis of heat release rate injecting ethanol delays injection timing resulting in smooth increase of maximum heat release rate. Increase in ethanol proportion for lean fuel/air mixtures slight increment in peak value of heat release rate was noticed and for rich fuel/air mixtures rapid increase in maximum heat
release rate was noticed and over all combustion event was completed at an earlier crank angle. Due to decrease in inside cylinder temperatures simultaneous high reduction in NOx and smoke emissions was noticed compared to that of neat biodiesel.

**Eduardo Santillan-Jimenez** et. al. [176] investigated catalytic deoxygenation of triglycerides and fatty acids through decarboxylation/decarbonylation in a semi batch auto clave. For fuel blending 20wt% Ni/C yielded lighter hydrocarbon products compared to 5wt% Pd/C. Higher acidity of Ni based formation favours adsorption of carbonaceous species and happening of cracking reactions. Catalytic performance was improved by presence of hydrogen and based on catalyst optimum hydrogen partial pressure was estimated. Triglyceride deoxygenation occurred through dearbonylation of fatty acid intermediates this was identified by analysis of reaction time at various reaction times.

**K. Srilatha** et. al. [177] investigated efficiency of solid acid catalysts for esterification of palmitic acid with methanol. Catalysts characterization was done using different techniques. Catalyst with 15wt% TPA/SnO$_2$ was found promising with highest fatty acid conversion and reaction parameters were also optimized. Recycled Catalyst showed consistent catalytic activity even after its usage.

**Omotoso** et. al. [178] reviewed about generation of biodiesel using non conventional heterogeneous catalysts from non edible seed oils. Non conventional catalysts were prepared from waste material like egg shells of golden apple snail, oyster shells, shells of mud crab etc. with high content of calcium oxide. These CaO catalysts possessed strong basic sites, their capability was enhanced with microwave irradiation in producing biodiesel. These catalysts were consistent in catalytic activity and maintained crystalline form even after five times repeated usage. Catalysts when synthesized from waste materials cuts down biodiesel production costs to a larger extent.

**Ahmet Necati Ozsezen** et. al. [179] evaluated performance and combustion characteristics of DI diesel engine fuelled with waste palm oil methyl esters and canola oil methyl esters. With methyl esters maximum engine torque decreased slightly and brake specific fuel consumption of engine increased. Decrease in ignition
delay period and advancement of fuel injection affected peak cylinder pressure and temperature as a result of this CO, HC and smoke opacity were reduced but CO$_2$ and NO$_x$ emissions increased. Research to be done on NO$_x$ reduction techniques during biodiesel combustion.

**Ming Zheng** et. al [180] investigated about effect of biodiesel low temperature combustion on performance and emissions of an engine. Biodiesel produced from soy, canola, yellow grease and ultra low sulphur diesel were tested on diesel engine for comparative study. With biodiesel NO$_x$ exhaust emissions of diesel engine were found higher so exhaust gas recirculation was implemented to bring about low temperature combustion. With throttling valve differential pressure was created to increase exhaust gas recirculation at low and medium load conditions as a result of this simultaneous reduction of NOx and soot in engine exhaust emissions was achieved. Research was done to implement this technology in biodiesel fuelled modern engines.

**Shahabuddin** et. al. [181] reviewed about ignition delay and its impact on combustion and emission characteristics of biodiesel fuelled diesel engine. Investigation of many papers it was clear that combustion characteristics of diesel engine fuelled with biodiesel slightly varied due to early SOC and shorter ID compared to conventional diesel. Fatty acid composition, lower compressibility and high cetane number value were found to be the primary causes for shorter ID and early SOC. Other reasons for variation in combustion process and engine emissions was due to lower heat release rate of biodiesel because of its low heating value, low volatility and higher viscosity of biodiesel.

**Kevin N Pethani** et. al. [182] experimented on CI engine using Mahua biodiesel blended with diesel mixed with additives for evaluating engine performance and gaseous emissions. It was identified additives showed positive effect on diesel engine characteristics. With increase in percentage of additives in biodiesel, increase in brake thermal efficiency, decrease in brake specific fuel consumption, decrease in exhaust gas temperatures along with decrease in CO and HC emissions was clearly evident on analysis of reported test data. For greener exhaust emissions, savings on
fuel and without comprise on engine performance mahua biodiesel blend added with additives could be an appropriate alternative fuel.

Pascal Ndayishimiye et. al. [183] tested palm oil based bio fuel in single cylinder IC diesel engine for its effect on engine performance and emissions characteristics. Test fuels were prepared using various methods and blended with different oils. Initial test was carried out with diesel fuel and later tests with prepared test fuels. It was noticed that heating value of all prepared fuels was lower to diesel fuel and increasing ratio of palm oil esters in diesel deteriorated heating value. Increase in brake thermal efficiency was noticed for PO/Diesel blends. For all test fuels HC emissions were lower with an exception for PO/Diesel blends but increase in CO emissions was noticed. NO\textsubscript{x} emissions were decreasing from low load to high load condition of engine fuelled with preheated palm oil but for engine fuelled with esters NO\textsubscript{x} emissions decreased from half load to full load.

K. Purushothaman et. al. [184] studied about CI single cylinder engine characteristics operated with neat orange oil. Longer ignition delay, higher combustion duration and high heat release rate was noticed for orange oil. At full load condition brake thermal efficiency and NO\textsubscript{x} emissions were higher for orange oil whereas CO, HC and smoke emissions were lower compared to diesel.

Olagunju Esther Olajumoke [185] studied about extraction of vegetable oil from mango seed and its characterization. Mango seeds were sun dried and powdered and then using Soxhlet extraction method with petroleum ether oil was extracted. Physiochemical properties such as oil content, specific gravity, acid value, iodine value etc. were tested and found to be comparable with other vegetable oils. Author felt that mango seed with its rich source of oil content could be exploited as a feedstock for biodiesel.

Sungyong Park et. al. [186] studied about exhaust emission characteristics and nano particle size distribution in particulate matter from diesel engines operated with blended biodiesel/diesel along with EGR and without EGR. Engine smoke emissions were reduced. CO and HC emissions were slightly reduced where as NO\textsubscript{x} emissions increased slightly for blend of biodiesel/diesel compared to diesel. With
EGR mass and particle number of PM reduced for blended biodiesel/diesel compared to diesel.

Chonglin Song et. al. [187] investigated about emissions concerned to carbonyl compounds from a heavy duty diesel engine operated with blend of diesel fuel and ethanol. Carbonyl compounds found to be hazardous to human beings and they were known to cause severe headache, irritation of skin, eyes and mucus membranes of respiratory system. From the experimental results carbonyl compounds such as acetone, acrolein, acetaldehyde, formaldehyde, propionaldehyde and crotonaldehyde were found to be dominant components. Individual carbonyl compounds were found to decrease with increase in engine load for constant speed test. It was noticed that carbonyl emissions for diesel fuel and ethanol blended diesel fuel increased at high engine speeds. In comparison with diesel fuel carbonyl carbon emissions for ethanol blended diesel fuel were found higher at all engine operating conditions.

S. Jindal et. al. [188] investigated about the effect of compression ratio and injection pressure on jatropha methyl ester fuelled diesel engine characteristics. Tests were conducted with varying compression ratios combined with varying injection pressure to find out best combination of the two parameters. When compression ratio and injection pressure were increased brake specific fuel consumption decreased and brake thermal efficiency of engine increased. Optimum compression ratio of 18 and injection pressure of 250 bar gave better performance and reduced emissions in small sized diesel engines used for agricultural applications.

In Kwon Hong et. al. [189] studied about prediction of fuel properties of biodiesel based on its fatty acid esters. Kinematic viscosity and higher heating value was analysed based on molecular property of fatty acid methyl ester. Both kinematic viscosity and higher heating value increased with presence of carbon double bonds in the molecular weight of esters. Oxidation stability was found inversely proportional to molecular weight and presence of carbon double bonds. With the help of equations predicted the values for fuel properties. Difference in error between predicted values and experimental values was in acceptable range. Obtained data could be used for optimal mixing of petro diesel with biodiesel for enhancing engine characteristics.
Niraj Kumar et. al [190] reviewed about biodiesel from different origins for their effect on performance and emission characteristics in a diesel engine. Some of the results were analysed and summarized. Nature of feedstock had an influential effect on engine characteristics. Shorter chain length saturated esters density was higher and produced more NOx emissions than longer chain saturated esters. Oxidation stability of unsaturated biodiesels was poor. With the usage of biodiesel in engine HC, CO and PM emissions decreased significantly. To genetically improve feedstock of biodiesel and to bring similar fatty acid composition among feedstocks lot of research work has to be carried out in future.

S. Saravanan et. al [191] investigated the usage of crude rice bran methyl ester in small duty diesel engine to analyze its combustion characteristics. Compared to diesel, delay period and rate of maximum pressure rise for blend of crude rice bran methyl ester was lower. It also required more crank angle duration to release heat and brake specific fuel consumption was slightly different from that of diesel. Based on result analysis authors concluded that blend of crude rice bran methyl ester can be used to fuel diesel engines as the measured parameters were slightly varied from that of diesel though its cost was high.

Jiafeng Sun et. al [192] reviewed about nitrogen oxide emissions from diesel engines fuelled with biodiesel. Various parameters such as ignition delay, adiabatic flame temperature and radiation heat transfer were found to be strongly influencing and were the cause for difference in NOx emissions. Ignition delay of biodiesel was affected by differences in heating value, vapour pressure and atomization. Amount of fuel-bound oxygen and number of double bonded species in biodiesel were found to be affecting parameters regarding adiabatic flame temperature. They also made comparative study on different size engines, different fuel systems, air systems and control systems for identification of the difference in NOx emissions between biodiesel and diesel.

N.L. Panwar et. al [193] evaluated performance of variable compression engine operated with methyl ester of castor seed oil. Transesterification process was adopted for converting straight castor seed oil into methyl esters of castor seed oil because of
its effectiveness in reducing viscosity and improving fuel properties. Tests were conducted with different blends of methyl esters of castor seed oil mixed with diesel and results were compared with that of diesel. Results were comparable to diesel but with increase in biodiesel blend percentage increase in exhaust gas temperature was noticed. On analysis it was found to be a suitable alternative to diesel because of its better brake thermal efficiency and reduced fuel consumption with lower blends of biodiesel.

K. Varatharajan et. al. [194] reviewed about the effect of composition and properties of fuel on NOx emissions of a biodiesel fuelled diesel engine. Factors such as increased premixed burning fraction, decreased spray cone angle, more stoichiometric burning, advanced injection timing, higher heat release rate, adiabatic flame temperature and less radiative heat transfer from soot were found to be the causes for NOx emission. Fuel properties such as density, surface tension, viscosity, liquid thermal conductivity, thermal diffusivity and vapour heat capacity were found to be significant in increasing NOx emissions. Presence of oxygen in biodiesel was cited as the reason by many authors for increased reaction temperature causing increase in NOx emissions.

Hu’seyin Aydin et. al. [195] investigated performance and emissions of a single cylinder diesel engine operated with five blends of methyl esters of cotton seed oil separately. Lower blends showed a slight increase in engine torque at medium and higher speeds. Emissions such as CO, NOx, SO2, and smoke opacity reduced considerably with increase in blend percentage of biodiesel. Engine showed similar performance with B5, B20 and diesel fuels.

Seung Hyun Yoon et. al. [196] studied about effect of biogas-biodiesel dual fuel on combustion, emission characteristics and performance of a diesel engine. For operating engine with dual fuel, intake system was modified and fuel was injected with the help of electronic controlled gas injectors. Test results at low loads showed slightly lower peak pressure and heat release with dual fuel operation compared to biogas-diesel operation but at 60% load it exhibited slightly higher peak pressure and heat release rate compared to diesel. Biogas-biodiesel showed shorter ignition delays
due to biodiesel higher cetane number, better reductions in soot emissions because of low sulfur content and absence of aromatics.

**P. McCarthy** et. al. [197] made an analysis of performance and emission characteristics of an internal combustion engine operated with various biodiesel fuels and also a comparative study with petroleum diesel. With both biodiesels due to their lower energy along with increasing blend percentage engine performance was reduced and also increase in fuel consumption was noticed. Some emissions like NO\(_x\), CO were found to be decreasing while other emissions like HC showed quite opposite trend. Finally it was noticed that each biodiesel had its own scale of effect on engine performance and emissions.

**Bernat Esteban** et. al. [198] studied about effect of surface tension on vegetable oils fuelled to diesel engines. Vegetable oils surface tension has to be reduced before it can be used as a fuel due to its higher value compared to that of diesel fuel. Tests were conducted by heating vegetable oils to different temperatures and then fuelled to engine to get optimum temperature at which it performs similar to diesel. An empirical relation was developed for surface tension in relation with density so that with density value known surface tension could be easily predicted.

**M. Mofijur** et. al. [199] evaluated physico-chemical properties of jatropha curcas methyl ester blends and their effect on engine performance and emission characteristics. B\(_{10}\) and B\(_{20}\) blends viscosity values were closer to diesel and oxidation stability of these fuels were within european standards. Brake power reduction was noticed when compared to B\(_0\) and reduction was increasing from B\(_{10}\) to B\(_{20}\). Reduction in HC, CO emissions and increase in NO\(_x\) emissions was noticed in blends compared with B\(_0\). Final conclusion was B\(_{10}\) and B\(_{20}\) blends could be used without any engine modifications to diesel engine.

**B. Bazooyar** et. al. [200] compared physical properties of methyl esters of different seed oils with petroleum diesel to evaluate their suitability as a fuel for diesel engines. Biodiesel was prepared from the rice bran, corn, olive, sunflower, soy and grape seed by implementing alkali-based transesterification with methanol and potassium
hydroxide. Biodiesel fuels properties like specific gravity, heating value, cetane number and flash point were determined using ASTM standards and were found comparable to each other except for viscosity. When cloud point and pour point were considered petroleum diesel was found to be most suitable fuel compared to methyl esters.

2.2 SUMMARY

The literature review suggests that the vegetable oils produced from numerous oils and seed crops have high energy content and reasonably good fuel properties, but they require processing to biodiesel for its safe use in compression ignition engines. It was reported that because of high viscosity, the neat vegetable oils can lead to thickening in cold climate, fuel flow problems, poor atomization and low efficiency. The vegetable oils therefore need to be converted into biodiesel, which has properties suitable for application in diesel engines. The available literature shows that the transesterification process is a conventional method for biodiesel production. This process is well suited if the FFA (free fatty acid) content is less but it does not go well if FFA is more because it results in saponification and biodiesel yield is affected. In such a case prior acid transterification process has to be implemented followed by conventional method. Second thing is about usage of water for separating biodiesel from glycerol in this process. Researchers are trying to find an alternative method for biodiesel production and they were able to find the solution from the already available cracking process in petro chemical industry with the help of catalysts. This process is called as catalytic cracking, the advantage of this process is it can easily crack down high FFA content of vegetable oil in the presence of catalysts at low temperatures into organic liquid product with major portion of it containing biodiesel. From the experiments and studies conducted by plenty of scientists and researchers on the biodiesel obtained by transesterification it has been observed that the biodiesel mostly causes reduction in engine power and torque, but some studies have reported higher engine power than conventional diesel fuel. Most of the studies showed lower carbon dioxide, carbon monoxide, hydrocarbons and smoke emissions with the biodiesel as compared to mineral diesel with a slight increase in NOx emissions. With the little available information on catalytic cracking process, biodiesel shows better engine
performance and lower specific fuel consumption in comparison with the biodiesel from transesterification process. After going through many papers in literature survey it is evident that an extensive work has been carried out on engine performance, emissions and combustion characteristics with biodiesel produced from both edible and non edible vegetable oils like sunflower oil, soya oil, jatropha oil, karanja oil, etc., but it can be noticed easily that a very little amount of work has been done on fruit seed oils to produce biodiesel. Present work is undertaken selecting two fruit seed oils one is grape seed oil and the other mango seed oil for production of biodiesel with catalytic cracking process and as a second part of the work, evaluation of performance and combustion characteristics, emissions of diesel engine fuelled with blends of biodiesel produced from these fruit seed oils is taken up. Undoubtedly a minimum betterment in engine performance is going to add up economic value to fruit seeds and also large quantities of water can be saved ultimately making it possible to have a better living with pollution free environment. Demand for energy is never ending increasing day by day and the present available energy sources are falling short in catering the increasing demand so future is all about biodiesel because of their abundant availability and suitability as an alternate fuel to diesel engine.
2.3 OBJECTIVES & METHODOLOGY

Many researchers proved with results that biodiesel is an alternate fuel. It is evident that two things are important, one is processing of vegetable oil to biodiesel and the other is testing obtained biodiesel in diesel engine for its compatibility as fuel to diesel engine especially the blend percentage that can give results similar to diesel. With the following objectives and methodology this work has been completed.

2.3.1 OBJECTIVES

1. To investigate biodiesel from fruit seeds as an alternate fuel to the conventional fuel.
2. To produce biodiesel from fruit seeds vegetable oil by conventional method and the other method by catalytic cracking based on literature survey.
3. To implement catalytic cracking process with three different catalysts for production of biodiesel from fruit seeds vegetable oil.
4. To test diesel engine with different blends of produced biodiesel fuels.
5. To present results based on engine performance, combustion characteristics and emissions.

2.3.2 METHODOLOGY

1. Vegetable oil from Grape & Mango seeds is selected for biodiesel production to give them an added economic value.
2. Transesterification process, a conventional biodiesel production method used for production of bio-diesel.
3. Bio-diesel obtained from conventional method is blended with diesel fuel in varying percentages and experimental investigations are carried out in a diesel engine.
4. Based on the literature survey, catalytic cracking process is employed in the current work and three different catalysts have been chosen for catalytic cracking process.
5. Thus obtained bio-diesel from catalytic cracking process is blended with diesel fuel in varying percentages and the experimental investigations are carried out in a diesel engine.
6. Experimental tests are conducted on Kirloskar TV-1, Single Cylinder Four Stroke DI diesel engine fuelled with biodiesel fuels produced by both production processes.

7. Engine performance, emissions and combustion characteristics of diesel engine of biodiesel are reported based on fruit seed oil, production method and catalyst for a well performing blend.