CHAPTER 2

REVIEW OF LITERATURE

2.1 PRODUCTION OF BIOETHANOL

Vuuren and Meyer (1982) have investigated the production of ethanol from sugar molasses by using Zymomonas mobilis. They have reported that Zymomonas mobilis strains were compared with Saccharomyces cerevisiae for the production of ethanol from sugar molasses. The effect of pH and temperature on ethanol production by Zymomonas mobilis was also studied and it was found that at higher sugar concentrations, the yeast produced more ethanol than that of the Zymomonas mobilis.

Patil et al (1986) have investigated the effect of various additives on the rate of ethanol production from sugar cane molasses under batch fermentation conditions. They found that the skim milk supplementation enhanced the rate of ethanol production of about 6.0% (w/v). The ethanol was being formed in 48 hours from cane molasses containing 13.5% fermentable sugars when compared to a period of more than 72 hours in the absence of the additive.

Doelle and Doelle (1990) have investigated the two different qualities of sugar cane molasses containing a total sugar content of 48% to 50% and 35% to 42% by using Zymomonas mobilis. They have reported that molasses concentrations up to 250g/l were successfully fermented, but higher molasses concentrations led to fructose accumulation. They have suggested
that the addition of sucrose to a final sugar concentration of 15% increased the efficiency of the ethanol conversion.

Shojaosadati et al (1996) have investigated the modifications of the conventional ethanol fermentation process by using biomass and stillage recycle. They have reported that the biomass recycle method resulted in a reduction in the use of approximately 8% raw material (molasses). The recycle of 15% to 70% of stillage (dealcoholised) from a previous fermentation was also tested successfully. They found that there was 13% to 47% less water consumption and there was about 13% to 47% reduction in stillage volume, which was more economical and best suited for further treatments.

Favela Torres and Baratti (1997) reported that flocculent strain of Zymomonas mobilis was used for ethanol production from sucrose. They have reported that the dilution rate of 0.5h\(^{-1}\) (giving 96% sugar conversion), the ethanol productivity, yield and concentrations respectively were 20g/l/h, 0.45g/g and 40g/l by using a medium containing 100g/l sucrose. At a sucrose concentration of 150g/l, the ethanol concentration reached 60g/l. This fermentation was conducted at a range of conditions from 30°C to 36°C and from pH 4.0 to pH 5.5.

Sheoran et al (1998) have studied the fermentation system for the continuous ethanol production from sucrose and molasses by using calcium alginate immobilized Saccharomyces cerevisiae strain. They have reported that sugarcane molasses containing 15% total sugars was fermented in column reactor to produce 6.0% v/v ethanol in continuous system. They also suggested that yields could be improved to 7.0% with overall 11% increase in fermentation efficiency with the use of acid-clarified sugarcane molasses medium.
Perez et al (2002) have reviewed the recent advances in various biological treatments that can turn the lignocellulose biopolymers into alternative fuels. In addition to this, biotechnological innovations based on natural delignification of pulp and paper manufacture were also outlined.

Badger (2002) has discussed the production of ethanol from different feedstocks such as sugar, starch, cellulose etc. He reported that sugar molasses was observed as the main source for ethanol production. He also outlined the production of ethanol from cellulose through various methods.

Ghose and Ghose (2003) have investigated the renewed interest in bioethanol technology in view of its large potential as a transportation fuel. They have reported that bioethanol can be produced from lignocellulosic biomass. They have also analyzed in terms of feedstock availability, pretreatment strategies, efficient hydrolytic agents, availability of recombinant ethanologens and process economics with a focus on Indian research efforts.

Hiroyuki Inoue et al (2004) developed an efficient and economical ethanol production technology from woody biomass by using a new non acid pretreatment based on mechanical milling. In their study they discussed the effects of mechanical milling treatment of woody biomass on enzymatic hydrolysis and fermentation.

Michael Knauf and Mohammed Moniruzzaman (2004) preferred the thermochemical pretreatment method to reduce the cost of ethanol production and enzymatically hydrolyze the pretreated material to fermentable sugars that can be converted in to ethanol. Pretreatment research was focused on developing processes that would result in the reduction of bioconversion time, lower cellulase enzyme usage and higher ethanol yields. Cellulase research efforts were focused on developing a cost effective, highly thermostable, synergistically acting enzyme mixture that would meet the end
user’s needs. Fermentation microorganisms were also developed for conversion of biomass sugars to ethanol and to other bioproducts.

Li et al (2004) proposed the combination of NaOH treatment and homogenization which was used as a pretreatment to enhance the enzymatic hydrolysis of corn stover. The combined pretreatment method increased the enzymatic hydrolysis of corn stover five times compared to that of the conventional method. The effectiveness of such pretreatment process was found to be a function of NaOH concentration and particle size. Within the NaOH concentration range of 0.1N to 1.0N, best performance of this combined pretreatment was achieved at 0.3N NaOH. There is a significant effect of homogenization and NaOH treatment. Among the three particle sizes tested (the particle size was not directly measured but it was passed through screens with openings of 2mm, 0.707mm, and 0.25mm respectively), 2mm particle size was found to have the higher economic benefit for pretreatment process.

Vasudevan et al (2005) have reported an overview of the liquid fuel from biomass. They have reported the current and futuristic trends with respect to production and utilization of alcohols, vegetable oil based biodiesel.

Ojumu and Ogunkunle (2005) described the production of glucose from hydrolysis of lignocellulose under low acid and high temperature condition by pretreating the sawdust by auto-hydrolysis. The maximum glucose yield obtained was 70% for the pretreated sawdust at 210°C in the 18 minutes, which is 1.4 times greater than that of the untreated sawdust used under the similar condition. The glucose yield gradually decreases after the 20 minutes of reaction due to its decomposition.

Anneli Nilsson (2005) described the substrate feeding rate to fermentation of lignocellulose hydrolysate for production of ethanol. During
hydrolysis of lignocellulose, inhibitors were formed and affected the activity of the microorganism. To make the hydrolysate fermentable, the inhibitors were often removed by detoxification prior to fermentation. To get a successful fermentation the substrate feed rate was controlled and hence severe inhibition was avoided, which helped to obtain the maximum production of ethanol.

Badal Saha and Michael Cotta (2006) discussed the production of ethanol from wheat straw. In their study, the wheat straw contains 44.24% ± 0.28% cellulose and 25.23% ± 0.11% hemicellulose. Alkaline H₂O₂ was used as pretreatment and enzymatic saccharification was used for conversion of wheat straw cellulose and hemicellulose to fermentable sugars. The concentration of ethanol (per L) from alkaline peroxide pretreated enzyme saccharified wheat straw (66.0g) hydrolyzate by recombinant Escherichia coli strain FBR5 at pH 6.5 and 37°C in 48 hours was 18.9g ± 0.9g with an yield of 0.46g per g of available sugars (0.29g/g straw).

Yan Lin and Shuzo Tanaka (2006) discussed the broad overview of the current status of ethanol fermentation including biomass resources, microorganisms and technologies. They reported the promising prospects of ethanol fermentation which includes the fermentation technology, conversion of xylose to ethanol, utilization of cellulase enzyme in the hydrolysis of lignocellulosic materials, immobilization of the microorganism in large systems, simultaneous saccharification and fermentation (SSF) and sugar conversion into ethanol.

Dandan et al (2007) have reviewed the production of starchiness based fuel ethanol. Different technologies were discussed and their energy consumptions were analyzed to find out the best technical route for the producers based on the statistics. They have suggested that there are five steps
to manufacture ethanol. Among which liquefaction and distillation are the important ones which consumes more energy than that of the others.

Cazetta et al (2007) have investigated the effect of temperature and sugar concentration on ethanol production from sugar molasses using Zymomonas mobilis. They have reported that the best conditions for ethanol production were 200gL\(^{-1}\) of total reducing sugars in the molasses, temperature of 30°C, static culture, fermentation time of 48 hours, achieving 55.8gL\(^{-1}\).

Siqueira et al (2008) have studied the production of bio-ethanol from soybean molasses by Saccharomyces cerevisiae at laboratory, pilot and industrial scales. They Saccharomyces cerevisiae was used and fermentation were carried at laboratory scale, reactor. The kinetic parameters such as ethanol productivity, ethanol yield, biomass yield were determined. They reported that the residue of bio-ethanol production called soybean vinasse did not posses any environmental problem because it could be used as raw material for energy co-generation.

Liu and Shen (2008) have analyzed the influence of operating variable on bioethanol fermentation from stalk juice of sweet sorghum using immobilized Saccharomyces cerevisiae (CICC 1308). Orthogonal experiments method was used to investigate the influence of variables such as, fermentation temperature, agitation rate, particles stuffing rate and pH on ethanol yield and CO\(_2\) weight loss rate. They concluded that best conditions for bioethanol fermentation were determined as fermentation temperature of 37°C, agitation rate of 200rpm, particles stuffing rate of 25% and pH of 5.

Pattra et al. (2008) have evaluated the hydrolysis of SCB using H\(_2\)SO\(_4\) at various concentrations (0.25–7.0% volume), reaction times (15–240 min) and at temperature of 121°C, operating pressure of 1.5 kg/cm\(^2\). An
increase of acid concentration from 0.5% to 1.0% H₂SO₄ there is no significant changes in the glucose concentration, whereas H₂SO₄ concentration was between 1.0 and 5%, glucose concentration was decreased. Optimal conditions were found to be 0.5% H₂SO₄ and 60 min, under the optimum conditions the highest glucose concentration was obtained.

Najafi et al (2009) have investigated the production of bioethanol from agricultural residues such as wheat, barley, sugar cane, corn and rice. They reported that the agriculture wastes could be efficiently utilized, for the bio-ethanol production. They reported that the producing bioethanol from the agriculture wastes could replace 25% of total gasoline fuel consumption of Iran. They suggested 5 % ethanol could be use for SI engine without major modification in engine.

Mohanty (2009) have investigated the bioethanol production from mahula (Madhuca latifolia L.) flowers by solid-state fermentation. They reported that the moisture level of 70%, pH of 6.0 and temperature of 30°C were found optimum for maximum ethanol concentration (225.0 ± 4.0 g/kg flower) obtained from mahula flowers after 72 h of fermentation. They also suggested that the further studies are needed to find out the comparative economics of fuel ethanol production from mahula flowers and sugarcane/beet molasses.

Sanchez et al (2010) have discussed the Carob pod as a feedstock for the production of bioethanol in Mediterranean areas. They reported that carob pod is a suitable feedstock to produce fuel – grade ethanol because its high sugar content around 50%. The recoveries of these sugars were easy using water as a solvent with agitation times less than 30 min. The solid waste of the extraction process was hydrolyzated with sulphuric acid, phosphoric acid and sodium hydroxide. The best results were obtained with sulphuric
acid at 2% v/v. Simultaneous acid and extraction processes were also tested and total sugar extraction yields were lower than those obtained with water extraction due to degradation reactions of sugars in acid media. The fermentation of the aqueous extracts was done achieving yields of 47.5% of ethanol.

Tang et al (2010) have studied the Continuous ethanol fermentation from non-sulfuric acid-washed molasses using traditional stirred tank reactors with the flocculating yeast strain KF-7. They proposed a new molasses feeding method that separately supplies molasses and tap water. Their method was confirmed to be effective for the control of bacterial contamination during long-term continuous fermentation. A two-stage fermentation process was studied to achieve a high ethanol concentration and to make the ethanol production more economical. By feeding yeast cells with high metabolic activity to the second reactor, a two-stage continuous fermentation process that yielded a high ethanol concentration of 80 g/l as well as high ethanol productivity of 6.6 g/l/h was successfully operated for more than one month. This fermentation process was applied to ethanol distilleries in which traditional tank reactors are used.

Mussatto et al (2010) have studied the technological trends, global market, and challenges of bioethanol production. They reported that the some of the current and promising technologies for ethanol production considering aspects related to the raw materials, processes, and engineered strains development. Currently, worldwide ethanol production is in high levels and corn is the main raw material used for this purpose, but this scenario may change due to technological improvements that are being developed for production of low cost cellulosic ethanol, as well as for ethanol production from microalgae. They finally suggested that the use of various wastes (such
as wood and agricultural wastes) and unconventional raw materials (such as microalgae) can solve the problem without sacrificing food demands.

Cardona et al (2010) have investigated the Production of bioethanol from sugarcane bagasse. Sugar cane bagasse was considered as the future feedstock for ethanol production because of its low cost and its huge availability. They reported the current and potential transformation to sugars and ethanol, pretreatment technologies, detoxification methods and biological transformation. They found that the cost of ethanol production from SCB was relatively high based on current technologies and also pretreatment process was considered as most important step in ethanol production.

Moon et al (2011) have studied the simultaneous saccharification and continuous fermentation of sludge-containing mash for bioethanol production by Saccharomyces cerevisiae CHFY0321 from cassava. They have reported that the raw cassava powder was liquefied and then it was used directly in a continuous process without sludge filtration or saccharification. A fermentor consisting of four linked stirrer tanks was used for Simultaneous Saccharification and Continuous Fermentation (SSCF). The dilution rate was chosen on the basis of the maximum saccharification time, the highest volumetric productivity and ethanol yield were observed at a dilution rate of 0.028 h\(^{-1}\). They found the volumetric productivity, final ethanol concentration, and % of theoretical ethanol yield were 2.41 g/L h, 86.1 g/L and 91% respectively.

Zhang et al (2011) have prepared bioethanol from raw sweet potato by Saccharomyces cerevisiae at laboratory, pilot and industrial scales. They reported that the xylanase efficiently reduced the viscosity of raw sweet potato mash in fermentor during simultaneous saccharification and fermentation. The maximum ethanol concentration, average ethanol
productivity rate and yield of ethanol after fermentation in laboratory scale (128.51 g/L, 4.76 g/L/h and 91.4%) were satisfactory with small decrease at pilot scale (109.06 g/L, 4.89 g/L/h and 91.24%) and industrial scale (97.94 g/L, 4.19 g/L/h and 91.27%). They also concluded that sweet potato is an attractive feedstock for bioethanol production from both the economic standpoints and environmentally friendly.

Shen et al (2011) have prepared the bioethanol from sweet sorghum stalk juice with immobilized yeast. They reported that the experiments of ethanol fermentation from sweet sorghum stalk juice with immobilized yeast were carried out in 250ml shaking flasks at different conditions, including temperature, pH, particles stuffing rate and initial substrate concentration. They found the suitable conditions were determined as fermentation temperature of 33°C, pH of 4.5, particles stuffing rate of 25% and the initial sugar concentration of 218.1 mg·ml⁻¹.

2.2 PRODUCTION OF BIODIESEL

Edward Crabbe et al (2001) have investigated biodiesel production from palm crude oil. They have reported that molar ratio of methanol to oil, amount of catalyst and reaction temperature affected the yield of methyl ester (biodiesel) from crude palm oil. They have concluded that 40:1 methanol/oil (mole/mole) with 5% H₂SO₄ (volume/weight) reacted at 95°C for 9 hours gave a maximum methyl ester yield of 97%.

Lang et al (2001) have studied the preparation and characterization of bio-diesels from various bio-oils. They have reported that ethyl, methyl, 2-propyl and butyl esters were prepared from canola and linseed oils through transesterification by using KOH or sodium alkoxides as catalysts. In addition, methyl and ethyl esters were prepared from rapeseed and sunflower
oils by using the same catalysts. It was observed that the viscosities of bio-diesels were much less than that of the pure oils and were twice greater than that of diesel fuels and their gross heat contents of approximately 40 MJ/kg were 11% less than that of the diesel fuels.

Hak-Joo Kim et al (2004) have studied the use of heterogeneous base catalyst to produce biodiesel from vegetable oils. They have stated that Na/NaOH/-Al₂O₃ heterogeneous base catalyst was developed and used for production of biodiesel from vegetable oils. A study was made to optimize the reaction parameters such as reaction time, stirrer speed, oil to methanol ratio and the amount of catalyst. They also found that the heterogeneous catalyst showed the same results of the conventional NaOH catalyst.

Veerabhadra Reddy and Reddy (2004) have conducted experiments for the determination of kinetic data of the transesterification reaction. This was achieved by conducting the reactions at various temperatures and molar ratios. They also found that acid catalysed transesterification process was slower than that of the alkali catalyst transesterification process.

Delfort et al (2004) have compared homogenous and heterogeneous catalytic systems for transesterification of oil. They have reported that homogenous catalyst process required mild operation condition, while heterogeneous catalyst process required high temperature of reaction and higher methanol to oil ratio.

Verma and Patel (2004) have investigated the existing process and its limitation to the production of biodiesel. They have studied the conversion, yield and separation of unwanted products and purification of biodiesel. They suggested that enzymes could be used for maximum yield of production of biodiesel and also indicated that genetic engineering inputs provided the high yield oil species for biodiesel.
Karmee and Anju Chadha (2005) have studied the preparation of biodiesel from pongamia pinnata by transesterification method. They have reported that methonal was used as solvent in the presence of KOH catalyst for transesterification process. They found that pongamia oil resulted in high conversion of 92% (oil to ester) in 1.5 hours at 60°C with a molar ratio of 1:10 (oil: methanol).

Sukumarpuhan et al (2005) have prepared the biodiesel from mahua oil by transesterification process by using sulphuric acid with a catalyst 5% weight/weight, 20:1 molar ratio of ethanol to mahua oil at a temperature of 70°C to 75°C for a period of 5 hours. They reported that ester was washed with salt water (5% NaCl solution) and the product was dried at 110°C in an oven for an hour to remove the moisture.

Encinar et al (2005) studied the preparation of biodiesel from frying oil by transesterification process. They have reported that methanol was used as solvent and sodium hydroxide, potassium hydroxide, sodium methoxide and potassium methoxide was used as catalysts. They also suggested the optimum parameters for best biodiesel properties such as methanol/oil molar ratio (6:1), catalyst (1% potassium hydroxide) and temperature (65°C).

Demirbas et al (2005) have studied the biodiesel production from vegetable oils via catalytic and non-catalytic supercritical methanol transesterification methods. They reported that more than 350 oil bearing crops were identified, among which only sunflower, safflower, soybean, cottonseed, rapeseed and peanut oils are considered as potential alternative fuels for diesel engines. Methanol is the commonly used alcohol in this process. They also found that the most important variables affecting the methyl ester yield during the transesterification process were molar ratio of alcohol to vegetable oil and reaction temperature.
Meher et al (2006a) have investigated the optimization of alkali catalyzed transesterification of Pongamia pinnata oil for production of biodiesel. They reported that optimum reaction conditions for the process as 1% KOH as catalyst, 6:1 methanol/oil molar ratio and 65°C reaction temperature. They found that maximum methyl ester yield of 97% at 6:1 methanol/oil molar ratio after 3 hours.

Meher et al (2006b) have investigated the technical aspect of biodiesel production by transesterification process. They have reported about the various methods of preparation of biodiesel with different combination of oil and catalysts. They also reported the technical tools and processes used for monitoring the transesterification reactions.

Serio et al (2006) have studied the transesterification of soybean oil by using heterogeneous basic catalysts. They reported the possibility of using magnesium oxide and calcined hydrotalcites as catalysts for the transesterification of soybean oil with methanol. They found that the strongest basic sites (super-basic) promote the transesterification reaction at very low temperature (100°C), while the basic sites of medium strength require higher temperature to promote the same reaction.

Alamu et al (2007) prepared the biodiesel from palm kernel oil by transesterification process. They reported that KOH was used as a catalyst with 10grams of ethanol and 100grams of palm kernel oil at a temperature of 60°C for a period of 100 minutes to produce a maximum yield of biodiesel (92%).

Malaya Naik et al (2008) have studied the biodiesel production from high fatty acid karanja oil. They reported that high free fatty acid mainly depends on the moisture content in the seed during collection, oil expelling and storage condition. The conventional alkali-catalyzed route of biodiesel
production does not worked out effectively with high FFA upto 20%. They found the dual-step process of transesterification using acid-catalyzed and followed by base-catalyzed reaction method proved effective in producing the appropriate quality of biodiesel. The high FFA karanja oil gave a maximum yield of 96.6 to 97%.

Gui et al (2008) have analyzed the feasibility of edible oil, non-edible oil and waste edible oil as biodiesel feedstock. They reported that biodiesel has high potential as a new and renewable energy source in the future, as a substitution fuel for petroleum-derived diesel and can be used in existing diesel engine without modification. Currently, more than 95% of the world biodiesel was produced from edible oil which is easily available on large scale from the agricultural industry. However, continuous and large-scale production of biodiesel from edible oil without proper planning may cause negative impact to the world, such as depletion of food supply leading to economic imbalance. A possible solution to overcome this problem is to use non-edible oil or waste edible oil (WEO). All these issues addressed in this paper by discussing the advantages and disadvantages of using edible oil, non-edible oil and WEO as feedstock for biodiesel production. They also discussed the various aspects ranging from oil composition, oil yield, economics, cultivation requirements, land availability and also the resources availability.

Bhatti et al (2008) have prepared the biodiesel from waste tallow. They analysed the effect of various process parameters such as amount of catalyst, temperature and time. They reported that optimum amount of H$_2$SO$_4$, temperature and time were 1.25g, 50°C and 24 hour for production of ester from chicken fat oil, and 2.5g, 60°C and 24 hours for production of ester from mutton fat oil. Under optimal conditions, chicken and mutton fat methyl esters formation of 98.29% and 97.25% were obtained.
Sarin et al (2009) have studied the biodiesel synthesis and process optimization of Guizotia abyssinica L. oil. They reported that ester conversion mainly depends on temperature, oil: methanol ratio, catalyst type and catalyst concentration. The biodiesel was synthesized from crude Niger seed oil with more than 3% FFA in a single step base catalyzed transesterification with 98.7% of ester conversion. The synthesized product was blended in diesel at 5–20% ratios and evaluated for physico-chemical properties.

Patil et al (2009) have optimized the biodiesel production from edible and non-edible seeds. The production of fuel quality biodiesel from low-cost high FFA jatropha and karanja oil was investigated. A two-step transesterification process was used to convert the high FFA jatropha and karanja oil to its esters. They found that the high FFA oils could not be transesterified with the alkali catalyst transesterification process.

Hamed et al (2009) have reported that salmon oil was used as a feedstock for the biodiesel production transesterification in a two step process. They found that due to the high acid value of salmon oil, alkaline catalyzed transesterification was not an effective method for producing biodiesel from salmon oil. Therefore a two step process was applied in which a sulpheric acid catalysed pretreatment was used in the first step to reduce the acid value from 12 to 3 mg of KOH per litre of oil and then, in the second step, KOH catalyzed transesterification was applied. All the experiments were performed at a temperature of 52°C with a mixing intensity of 600 rpm. Based on the total weight of salmon oil used, the maximum biodiesel yield of 99% was achieved with a total methanol/molar ratio of 9.2% and 0.5% (w/w) of KOH.

Yang et al (2009) have prepared the methyl ester biodiesel from refined I. polycarpa fruit oil by using methanol and potassium hydroxide in an
alkali-catalyzed transesterification process. The experimental variables investigated in their study were catalyst concentration (0.5–2.0 wt. % of oil), methanol/oil molar ratio (4.5:1 to 6.5:1), temperature (20–60 °C) and reaction time (20–60 min). They found that the maximum yield of 99% of methyl esters in *I*. *polycarpa* fruit oil biodiesel was achieved using a 6:1 molar ratio of methanol to oil, 1.0% KOH (% oil) and reaction time for 40 min at 30°C.

Kansedo et al (2009) have prepared the biodiesel from Cerbera odollam (sea mango) oil. The first part focused on the extraction of oil from the seeds of C. odollam fruits, whereas in the second part they focused on the transesterification of the extracted oil to fatty acid methyl esters (FAME). The transesterification reactions were carried out using three different catalysts; sodium hydroxide (NaOH) as a homogenous catalyst, sulfated zirconia alumina and montmorillonite KSF as heterogeneous catalysts. They also found that the seeds contain high percentage of oil up to 54% while the yield of FAME reached up to 83.8% by using sulfated zirconia catalyst.

Lin et al (2009) have prepared the biodiesel from crude rice brain by transesterification. They analyzed the process in two steps. Firstly, the acid value of RBO was reduced to below 1 mg KOH/g by two-steps pretreatment process in the presence of sulfuric acid catalyst. Secondly, the product prepared from the first process was carried out esterification with an alkaline catalyst. The influence of four variables on conversion efficiency to methyl ester, i.e., methanol/RBO molar ratio, catalyst amount, reaction temperature and reaction time, was studied. The content of methyl ester was analyzed by chromatographic analysis. They found that the optimum reaction conditions for the transesterification were obtained: methanol/ RBO molar ratio 6:1, usage amount of KOH 0.9% w/w, reaction temperature 60°C and reaction time 60 min and the maximum conversion efficiency was 98.7%.
Amish P. Vyas et al (2009) have prepared the biodiesel from jatropha oil through transesterification with methanol using KNO$_3$/ Al$_2$O$_3$ solid catalyst. The catalyst with 35 wt% KNO$_3$ loaded on Al$_2$O$_3$ and calcined at 500°C for 4 hour. They reported that the reaction was carried out at 70°C, with a molar ratio of methanol to Jatropha oil of 12:1, a reaction time of 6 hour, catalyst amount of 6% and a agitation speed of 600 rpm. The highest conversion (84%) was reached at optimum conditions. The catalyst was recycled for reusability and they suggested that catalyst could be reused for three times.

Sahoo and Das (2009) have developed a method of preparation of biodiesel from non-edible oils such as Jatropha, Karanja and Polanga. They found that the conversion efficiency is strongly affected by the amount of alcohol because an excess of alcohol is required to shift the reaction close to completion. They found the maximum yield of 93% jatropha methyl ester. They concluded that properties of biodiesel were relatively close fuel property values to that of diesel.

Sharma and Singh (2010) have prepared the biodiesel from non-edible oil plant namely Kusum (Schleichera triguga). The acid value of the oil was determined by titration and was found to 21.30 mg KOH/g which required two step transesterification. Molar ratio of 10:1 (alcohol to oil), 1% v/v H$_2$SO$_4$ and 1 hour reaction time for 50 ± 0.5°C was optimum to bring down the acid value and this resulted in high yield after alkaline transesterification. The optimum conditions for alkaline transesterification reaction were 8:1 molar ratio, 0.7% (w/w) catalyst for 1 hour reaction time at 50 ± 0.5°C. They found that the high yield of biodiesel (95%) was obtained under optimized reaction conditions.
Chung (2010) prepared biodiesel by transesterification with methanol on alkali catalysts from Camellia japonica and Vernicia fordii seed oils. The composition and physicochemical properties were investigated in the raw seed oils and the biodiesel products. The fatty acid methyl ester contents in the biodiesel produced from the seed oils were above 96% on KOH catalyst in the reaction. The major constituent in the biodiesel products was oleic acid. The oleic acid and palmitic acid increased significantly after the reaction in the composition of the produced biodiesels. The properties of the produced biodiesels also matched with the biodiesel qualities.

Martin et al (2010) have identified Jatropha curcas as the most promising oil seed for biodiesel production in Cuba after comparison with various non-edible oil seeds because of the high oil yield of Jatropha at about 50%. Since Jatropha oils consist of mainly oleic and linoleic acids which are unsaturated fatty acids, the biodiesel produced has desirable good low temperature properties. Although Jatropha oil also has high free fatty acid content, methods to overcome this high FFA are well developed. Thus, Jatropha curcas oil has been highlighted as a potential biodiesel feedstock among the nonedible oils.

Ritesh Kumar et al (2011) have studied the microwave assisted alkali-catalyzed transesterification of Pongamia pinnata seed oil for biodiesel production. They reported that the experiments were carried out using methanol and two alkali catalysts (sodium hydroxide and potassium hydroxide). The experiments were carried out at 6:1 alcohol/oil molar ratio and 60°C reaction temperature. They suggested that 0.5% sodium hydroxide and 1.0% potassium hydroxide catalyst concentration were optimum for biodiesel production from Pongamia pinnata oil under microwave heating. There was a significant reduction in reaction time for microwave induced transesterification as compared to conventional heating.
Satyanarayana and Muraleedharan (2011) have investigated the comparative study of vegetable oil methyl esters. They reported that rubber seed oil having high acid value of 48 mg KOH/g. The two-step pretreatment process was employed to reduce acid value of 1.72 mg KOH/g for the optimized variables of 0.75 v/v methanol-oil ratio, 1% v/v H₂SO₄ as acid catalyst, reaction time of 1 h and reaction temperature of 63°C. The optimized product was used as raw material for further transesterification. The optimum conditions were 0.3 v/v methanol-oil ratio, 0.5% w/v KOH as alkaline catalyst, reaction time of 40 min and reaction temperature of 55°C to get the maximum yield of methyl ester of 98-99% from rubber seed oil. For coconut oil methyl ester, optimum conditions were 0.25 v/v methanol oil ratio, 0.5% w/v KOH as alkaline catalyst, reaction time of 20 min and reaction temperature of 58°C to got the maximum yield of 98 to 99%. For palm oil methyl ester, the reaction temperature was 60°C and other conditions were same as coconut oil methyl ester to obtain the maximum biodiesel production of 98 to 99%.

Ragit et al (2011) have studied the standardization of transesterification process parameters for the production of methyl ester of filtered neem oil and fuel characterization for engine performance. The effect of process parameters such as molar ratio, preheating temperature, catalyst concentration and reaction time was studied to standardize the transesterification process for estimating the highest recovery of ester with lowest possible viscosity. Based on the observations of the ester recovery and kinematic viscosity, they found that filtered neem oil at 6:1 M ratio (methanol to oil) preheated at 55°C temperature and maintaining 60°C reaction temperature for 60 min in the presence of 2 percent KOH and then allowed to settle for 24 h in order to get lowest kinematic viscosity (2.7 cSt) with maximum ester recovery of 83.36%. They also concluded that the methyl
ester of neem obtained under the optimum condition was an excellent substitute for fossil fuels.

### 2.3 FUEL PROPERTIES, PERFORMANCE AND EMISSION CHARACTERISTICS OF ETHANOL-DIESEL BLENDS

Ali et al (1995a) have tested the use of 12 different blends of methyl tallowate, methyl soyate, ethanol and diesel fuel in a Cummins N14-410 diesel engine. They have reported that engine performance operated with blended fuels did not differ to a greater extent from engine performance operated with diesel fuel. It is also observed that most of the exhaust emissions were not affected by an increase in the amount of alternative fuel with the blends.

Ali et al (1995b) have tested the performance of engine and emissions of four fuel blends produced from diesel, methyl tallowate and ethanol in a Cummins N14-410 diesel engine. They optimized the blended ratio based on the engine performance and emission values. The emissions were found to be minimum with a 80:13:7 blend of diesel: methyl tallowate: ethanol, without a significant drop in power output of the engine (efficiency).

Ali and Hanna (1996) used methyl tallowate – ethanol – diesel blends in a Cummins N14-410 engine. They found that addition of methyl tallowate ethanol diesel blends did not affect the engine performance, but there was a small drop in the delivery of power and torque. They also reported a reduction in CO, HC and increase in smoke emission but there was no change in the NOx emission.

McCormick et al (1997) have investigated several oxygenates, n-octanol (C8), decanoic acid (C12) and methyl soyester (C17) in diesel fuel by using a 6V-92TA DEC II engine. They have reported that methyl soyester
and n-octanol produced 20% and 12% reductions in particulate matter respectively. They found that methyl ester increased NOx by 2% to 3%, while decanoic acid had no effect on NOx and octanol slightly decreased NOx emissions.

Donahue and Foster (2000) studied the effects of oxygen enhancement on the emissions from a DI diesel engine. They have reported about the reduction of particulate matters and NOx emissions which was mainly due to the molecular structure, temperature and oxygen content of the fuel due to the introduction of oxygenated compounds.

Abu-Qudais et al (2000) found that the optimum percentage of ethanol appears to be 20% for ethanol fumigation and 15% ethanol-diesel fuel blends operations. In both cases, brake thermal efficiency, CO and HC emissions were increased. At the same time, considerable reduction in percentage of smoke and soot mass concentration was also observed.

Caro et al (2001) reported that two additives (1-octylamino 3-octyloxy-2-propanol and 2-nitrato-3-octyloxy-propyl) were added at a level of each 1%, to be able to use 10% to 20% ethanol in diesel fuel. They found that 2% additives were suitable to adjust the fuel properties of the blends. In particular, the additives enhanced the phase, enhanced the stability and improved the cetane number of the blends. The presence of additives also improved the cyclic irregularities and delayed ignition.

Ahamed et al (2001) have investigated the use of ethanol-diesel blends with puranol additive in a heavy duty diesel engine in laboratory tests and field tests. They have reported that blends containing 83% to 94% of diesel, 5% to 15% of ethanol, 1% to 2% of additive and a small amount commercially available cetane improver in the mixture reduced the 41% of particulate matter, 27% of carbonmonoxide and 5% of NOx emissions.
Kass et al (2001) have studied the use of 10% of ethanol and 15% of ethanol and 2% of GE Betz additive with diesel blends as fuels in diesel engines. They stated that PM emission was reduced by 20% to 27% and 30% to 41% for 10% and 15% of ethanol respectively. The reduction of particulate emissions increases the flexibility to control NOx emissions at different engine operating conditions. They further reported that both decreased and increased the CO emission and HC emission substantially.

He et al (2003a) reported that ethanol–diesel fuel blends along with a solvent additive were used for avoiding phase separation, enhancing cetane number of the blends and improving the ignition characteristics of the engine. They have determined the reductions in smoke, NOx and CO\textsubscript{2} emissions with the increase in ethanol content with the blend for most of the engine operating conditions. However, CO, acetaldehyde and unburned ethanol emissions showed increasing and positive trends.

Hansen et al (2003) have conducted Laboratory test on an International 7.3L engine run with the fuel blend containing 10% ethanol, 1% GE Betz additive and 89% low sulphur diesel fuel. They reported that the engine performance was not affected, apart from the expected 4% decrease in power output.

Corkwell et al (2003) reviewed the exhaust emissions on compression ignition engines operating on ethanol- diesel fuel blends with a commercial additive. They reported that smoke and PM reduction was unanimous, but studies on the NOx and HC emission have no clear conclusion. They concluded that the emissions mainly depended on engine configurations and operating conditions.

Ozer Can et al (2004) have described the effects of 10% ethanol and 15% ethanol additions and 1% isopropanol with diesel fuel. Isopropanol
are added with the blends to satisfy the homogeneity and prevents phase separation. They reported that the addition of ethanol reduced CO emissions, Soot emissions, SO₂ emissions, considerable reduction in power and also increased the NOx emission.

Xing cai et al (2004) have found that the thermal efficiency was improved remarkably when diesel engine was fueled with 1.5% of solublizer and ethanol-diesel blends. They have also stated that NOx emissions and smoke emissions were decreased simultaneously and CO emission was increased due to the blends. They concluded that the effect of cetane improver had a positive effect on engine thermal efficiency, NOx, CO and smoke emissions.

Kowalewicz and Wojtyniak (2005) have reviewed the alternative fuels and their application in combustion engines including physicochemical properties of these fuels, their sources and technological aspects of production.

Subramanian et al (2005) have reported the utilization of liquid biofuels in automotive diesel engines in Indian perspective. They stated the importance of the liquid biofuels such as benefits to environment, energy self-sufficiency and boosting of the rural economy as well as measures related to implementation and barriers. They also suggested the transport and refinery scenario, land availability for production of biodiesel, potential sources for biodiesel and potential sources for ethanol. The availability of ethanol and estimations for its consumption as transport fuel were calculated and necessary remedial measures to increase the availability of ethanol in the country in future were also suggested.

De-gang Li et al (2005) have investigated the performance and emissions of diesel engine with 1.5% of solublizer and different ethanol-diesel
blends. They reported that the brake thermal efficiency increased with an increase in the ethanol contents in the blended fuel at overall operating conditions. They also reported that the smoke, CO, NOx emissions were decreased for the blends but the HC emission was increased considerably as compared to that of the diesel fuel.

Hansen et al (2005) reported the important properties of ethanol-diesel blended fuels. They stated that ethanol-diesel blends have much lower flash point than that of the diesel fuel and higher vapour formation potential in confined spaces, thus requiring extra precautions to ensure safe handling and use of these blends. They also reported that by adding ethanol to diesel fuel, it reduced the lubricity, lowers the viscosity and calorific value.

Shi et al (2005) have analyzed the emission characteristics of methyl soyate-ethanol-diesel fuel blends on diesel engine with three different blends (BE15, BE20, B20). They stated that particulate matter emission decreased with increase in the oxygenate content in the fuels but nitrogen oxides emission was increased. They also reported that the BE20 emitted lesser particulate matter and a lower smoke but the highest NOx emission and HC emission of B20 blend was less than that of the other two blends.

Shudo et al (2005) have studied the use of palm oil methyl ester and ethanol at different blending ratios (at 10% volume) in four-stroke single-cylinder open chamber diesel engine Yanmar NFD-12. They stated that ethanol blending significantly reduced the smoke emissions from the engine without deteriorating other emissions and thermal efficiency.

Demirbas and Balat (2006) have discussed the recent advancements in the production and utilization of bio fuels. They reported that bio fuels are important because they replace petroleum fuels. There are many benefits for
the environment, economy and consumers by using the bio fuels. They also stated that biofuels was used as a substitute for fossil fuels to generate heat, power and chemicals. And also upgrading the bio-oil to transportation fuel is technically feasible but needs further development.

Eliana weber de menezes et al (2006) reported that the use of ether additives in diesel slightly changed the fuel properties. But the ether/ethanol/diesel blends alter the properties of the blends due to the introduction of ethanol in the mixture. In these mixtures, the ETBE and TAEE ethers act as co solvents for the introduction of ethanol in diesel. Among the above co solvents, TAEE showed the best results in terms of the properties and engine test.

Shi et al (2006) have investigated the emission reduction potential of using oxygenated diesel fuel blend on a heavy duty diesel engine. They stated that blend ratio used in this study was 5:20:75 (ethanol: methyl soyate: diesel fuel) by volume. They found that there was significant reduction in PM emissions and 2% to 14% increase in the NOx emissions. The change of CO emission was not conclusive and it depended on operating conditions. Total hydrocarbon from blended fuel was lower than that of the diesel fuel under most controlled experimental conditions. A small amount of ethanol was also detected in the exhaust from burning of fuel blend.

Magín Lapuerta et al (2007) have studied the stability of diesel bioethanol blends used in diesel engines. They reported that bioethanol was an attractive fuel due to its renewable origin and its oxygen content, but it is not possible to be used directly in diesel engines. The main drawback was that ethanol is immiscible with diesel fuel over a wide range of temperatures, leading to phase separation. In many cases, the presence of a surfactant and co-solvent additive in the ethanol diesel blend becomes absolutely necessary.
They found that the stability of the blends was affected by three important factors such as temperature, water content and ethanol content.

Chen et al (2007) have investigated the combustion characteristics and particulate matter emission of diesel engine by using ester-ethanol-diesel blended fuels. They reported that the blends reduced the smoke and dry soot in particulate matter significantly. When more ethanol was added to the fuel, more smoke reduction was achieved, ignition time was delayed, combustion duration was shortened and flame luminosity was decreased.

Kwanchareon et al (2007) have investigated the solubility of a diesel-biodiesel-ethanol blend, its fuel properties and its emission characteristics from the diesel engine. They reported that the diesohol blend containing 5% ethanol had very close fuel properties compared to that of the diesel fuel. The blend of 80% diesel, 15% biodiesel and 5% ethanol was the most suitable ratio for diesohol production. As for the emissions of blends were concerned, they found that CO emission and HC emission were reduced significantly at higher engine load, whereas NOx emission was increased, when compared with that of the diesel.

Rakopoulos et al (2007) have studied the performance and emissions of a high speed direct injection diesel engine operating with 1.5% of emulsifier by volume with ethanol diesel fuel blends. They reported that the blends of E5D95, E10D90 and E15D85 were used. The exhaust gas temperature, exhausted smoke, exhaust regulated gas emissions such as nitrogen oxides, carbon monoxide and total unburned hydrocarbons were measured. The differences in the performance and exhaust emission parameters from the baseline operation of the engine with neat diesel fuel were determined and compared.
Magín Lapuerta et al (2008) have tested the emissions from a diesel–bioethanol blend in an automotive diesel engine by using 10% of anhydrous bioethanol blended with conventional diesel and no additives were added. They reported that there was no substantial increase in other gaseous emissions, which made it helpful for contributing to fulfill the European compromise for using more than 5.75% of biofuels in 2010.

Rakopoulos et al (2008) have investigated the effects on the performance and exhaust emissions of heavy duty DI diesel engine by using blends of 5% and 10% of ethanol and 1.5% of emulsifier with conventional diesel fuel. They reported that there was a reduction in smoke, NOx and CO emissions with the use of ethanol-diesel fuel blends with respect to the diesel fuel. This reduction was higher for the higher percentage of ethanol in the blend. The hydrocarbon emission was increased for the ethanol-diesel fuel blend as compared to that of diesel fuel.

Chen et al (2008) have tested the oxygenated biomass fuel blends on a diesel engine. They reported that vegetable methyl ester was added in ethanol-diesel blends to prevent the separation of ethanol from diesel. They found that both PM and smoke emissions were reduced. The CO emission was increased at lower loads and middle loads, whereas it was decreased at higher loads and full loads.

Cheung et al (2008) have investigated the regulated and unregulated emissions from a diesel engine fueled with ultralow-sulfur diesel fuel blended with ethanol as the oxygenate additive and dodecanol as the solvent at different engine load conditions. They reported about the blended fuels containing 6.1%, 12.2%, 18.2% and 24.2% by volume of ethanol, corresponding to 2%, 4%, 6% and 8% by mass of oxygen. The results indicated that with an increase in the ethanol in the fuel, there was a little change in the brake thermal efficiency. Regarding the regulated emissions,
HC and CO increased significantly at the lower engine load but decreased at the higher engine load. The NOx emission was slightly decreased at lower engine load but slightly increased at the higher engine load. For the unregulated gaseous emissions, unburned ethanol and acetaldehyde emissions were increased.

Balat and Balat (2009) have studied the recent trends in global production and utilization of bioethanol fuel. They stated that biofuels were important for the developing countries because they replace petroleum fuels. Bio-ethanol was the most widely used bio-fuel for transportation worldwide. They also reported that production of bio-ethanol from biomass was one way to reduce both consumption of crude oil and environmental pollution.

Chotwichien et al (2009) have studied the utilization of palm oil alkyl esters as an additive for ethanol (99.5%) - diesel and butanol -diesel blends. They prepared the two types of blends namely diesel-palm oil alkyl ester –ethanol and diesel-palm oil alkyl ester-butanol in their studies. They have analyzed the phase stability of the blends at different temperature (10°C, 20°C and 30°C) for the maximum of 7 days. They also found that butanol have higher solubility in diesel fuel.

Radimi et al (2009) have investigated blending of ethanol with sunflower methyl ester-diesel blend (diesterol). They reported that the flash point and viscosity of the blends were reduced by increasing the amount of biofuel in the blends. They found that NOx, CO and smoke emissions were reduced by increasing the biofuel composition of diesterol throughout the engine operating range.

Jha et al (2009) studied the emission characteristics of diesel-biodiesel-ethanol fuel blends on one used engine and two new engines. They reported that there was a significant reduction in NOx emissions in new
engines with increased ethanol concentration, whereas in the used engine under similar conditions, there was an increase in NOx emissions.

Subramanian et al (2009) studied the transport bus engine performance and emission characteristics using diesel with different proportion of methyl ester of pongamia oil and ethanol blends. Methyl ester of pongamia oil was mainly used for replacement of diesel compare to ethanol in their studies. They observed that the brake thermal efficiency of the engine operated with hybrid fuel was slightly higher than that of the diesel fuel. The smoke and NOx emissions were reduced but HC emission was increased as compared to that of the diesel fuel.

Rajasekaran et al (2009) have investigated the performance and emission characteristics of diesel- Jetropha methyl ester-ethanol hybrid fuel blends in a direct injection diesel engine. They reported that there was a reduction in NOx, smoke emissions and an increase in brake thermal efficiency for the hybrid fuel blends at all load conditions.

Cheung et al (2009) have carried out experiments on regulated and unregulated emissions from a diesel engine fueled with biodiesel and biodiesel blended with methanol on a diesel engine operating on Euro V diesel fuel, pure biodiesel and biodiesel blended with methanol. The blended fuels contain 5%, 10% and 15% by volume of methanol. Experiments were conducted under five engine loads at a steady speed of 1800rpm to assess the performance and the emissions of the engine associated with the application of the different fuels. They reported that an increase of brake specific fuel consumption and brake thermal efficiency when the diesel engine was operated with biodiesel and the blended fuels, compared with the diesel fuel. They expect that the blended fuels could lead to higher CO and HC emissions than biodiesel, but lower HC emission than the diesel fuel. They also observed simultaneous reductions of NOx and PM to a level below those of
the diesel fuel. Regarding the unregulated emissions, compared with the diesel fuel, the blended fuels generate higher formaldehyde, acetaldehyde and unburned methanol emissions, lower 1, 3-butadiene and benzene emissions.

Kim and Choi (2010) have studied the effect of biodiesel and bioethanol blended diesel fuel on nanoparticles and exhaust emissions from CRDI diesel engine. They studied the characteristics of the particle size distribution, the reaction characteristics of nanoparticles on the catalyst, and the exhaust emission characteristics when a common rail direct injection (CRDI) diesel engine is run on biofuel blended diesel fuels. The biofuel used was mixture of biodiesel and bioethanol. They observed that the engine performance under a biofuel-blended diesel fuel was similar to that under diesel fuel, and the high fuel consumption was due to the lowered calorific value that ensued from mixing with biofuels and the use of a biodiesel–diesel blend fuel reduced the total hydrocarbon and carbon monoxide emissions but increased nitrogen oxide emissions due to the increased oxygen content in the fuel. The smoke emission was reduced by 50% with the use of the bioethanol–diesel blend. They also observed that the use of biofuel-blended diesel fuel reduced the total number of particles emitted from the engine, however, the use of biodiesel–diesel blends resulted in more emissions of particles that were smaller than 50 nm, when compared with the use of diesel fuel. They concluded that the use of a mixed fuel of biodiesel and bioethanol (BD15E5) was much more effective for the reduction of the particle number and particle mass, when compared to the use of 20% biodiesel with diesel fuel.

Chen et al (2010) have used a bio-solution additive to reduce reducing emissions of both polycyclic aromatic hydrocarbons and PM from diesel engines. They found that when compared with P0 (premium diesel fuel as base fuel), E16P20 fuel (16 vol. % biosolution + 20 vol. %
palm-biodiesel + 64 vol. % P0, an additional 1 vol. % surfactant) saved 12.4% fuel consumption and reduced emissions of PM by 90.1%, total PAHs by 69.3%. They concluded that the emulsified palm-biodiesel with bio-solution can be considered as a clean and alternative fuel.

Zhu et al (2010) have investigated the emissions characteristics of a diesel engine operating on biodiesel and biodiesel blended with ethanol and methanol. They tested a four cylinder naturally aspirated direct-injection diesel engine with Euro V diesel fuel, pure biodiesel and biodiesel blended with 5%, 10% and 15% of ethanol or methanol. They conducted experiments under five engine loads at a steady speed of 1800 rpm. They observed that compared with EuroV diesel fuel, the blended fuels could lead to reduction of both NOx and PM of a diesel engine, with the biodiesel–methanol blends being more effective than the biodiesel–ethanol blends. The effectiveness of NOx and particulate matter reductions were more effective with increase of alcohol in the blends. With high percentage of alcohol in the blends, the HC, CO emissions could increased and the brake thermal efficiency might be slightly reduced but the use of 5% blends could reduced the HC and CO emissions.

Rokupoulos et al (2010a) have investigated the performance and exhaust emissions of a standard, fully instrumented, four-stroke, high-speed, direct injection diesel engine operating on 8%, 16% and 24% (by volume) of n-butanol with conventional diesel fuel. The series of tests were conducted using each of the above fuel blends, with the engine working at a speed of 2000 rpm and at three loads. They have stated that smoke density, NOx and CO emissions were reduced with the use of butanol-diesel fuel blends and also found that this reduction being higher with respect to the higher percentage of butanol in the blends. They also reported that HC emissions were increased with the use of butanol-diesel fuel blends and also increase in
HC depends on higher percentage of butanol in the blends. They also stated that a little higher specific fuel consumption was observed with corresponding slight increase of brake thermal efficiency and little lower exhaust gas temperatures.

Aydin and Ilkılıç (2010) have investigated the effect of ethanol blending with biodiesel on engine performance and exhaust emissions in a single cylinder four stroke direct injection diesel engine. They reported that 20% biodiesel +80% diesel (B20), 80% biodiesel+20% ethanol (BE20) and commercial diesel fuel were used. They found that specific fuel consumption for BE20 fuel was lower that that of B20 and was almost the same as that of diesel fuel. The exhaust temperature and NOx emissions were increased with the use of BE20. The CO₂ emission was decreased for the use of B20 fuel when compared with both diesel and BE20 fuel. The CO and SO₂ emissions were reduced with the use of both B20 and BE20 blends with respect to diesel fuel.

Rakopolous et al (2010b) have investigated the performance and emissions of a bus engine operating on butanol-diesel fuel blends. They used the n-butanol as a supplement to the diesel fuel at blend ratios of 8/92 and 16/84 by volume. They reported that smoke, NOx and CO emissions were reduced but HC emission was increased with the use of blends as compared to that of the diesel fuel. The reduction and increase in the emissions mainly depends on the percentage of butanol in the blends. They also found that a little higher specific fuel consumption was observed with a corresponding slight increase of brake thermal efficiency.

Sayin et al (2010) have studied the effects of injection pressure and timing on the performance and emission characteristics of a DI diesel engine using methanol (5%, 10% and 15%) blended with diesel fuel. They reported
that brake specific fuel consumption, brake specific energy consumption and NOx emissions were increased but brake thermal efficiency, smoke, HC and CO were decreased with increasing amount of methanol in the blends. They also concluded that best results were obtained at the original injection pressure and timing.

Lee et al (2011) have studied the performance and air pollutant emissions in a diesel engine generator fueled with water containing ethanol – biodiesel-diesel blends. They reported that the fuel blend mix containing 4% of water-containing ethanol, 1% butanol and 5 to 30% of biodiesel yielded stable blends after 30 days. They found that the blend (BD1041) composed of 10% biodiesel, 4% of water containing ethanol and 1% butanol demonstrated 0.45 to 1.6% increase in brake-specific fuel consumption as compared to conventional diesel. The better engine performance of BD1041 was as a result of complete combustion, and lower reaction temperature based on the water cooling effect. They also reported that which reduced emissions to 2.8 to 6.0% for NOx, 12.6 to 23.7% particulate matter and 20.4 to 23.8% total polycyclic aromatic hydrocarbons. They also suggested that blending diesel with water-containing ethanol could achieve the goal of more green sustainability.

Karabektas et al (2011) have experimentally investigated the effects of blends containing various alternative fuels and diesel fuel on the performance and emissions of a naturally aspirated, direct injection diesel engine. The blends of biodiesel, ethanol, methanol and vegetable oil with diesel fuel, each containing 15% alternative fuel in volume were prepared. They reported that blends containing alcohols have been kept for a long time, a partial phase separation has occurred. This problem has not been experienced in the blends containing biodiesel and vegetable oil. Among the blended fuels, the best engine performance and emission characteristics have
been obtained with the biodiesel blend. Methanol and ethanol blends have yielded lower brake power, higher specific fuel consumption and higher HC emissions, while they have resulted in slightly lower NOx emissions.

Randazzo and Sodre (2011) have investigated the effects of diesel oil-soybean biodiesel blends on a passenger vehicle exhaust pollutant emissions. They used blends of diesel oil and soybean biodiesel with concentrations of 3% (B3), 5% (B5), 10% (B10) and 20% (B20) as fuels. Additionally, the effects of anhydrous ethanol as an additive to B20 fuel blend with concentrations of 2% (B20E2) and 5% (B20E5) were also studied. They reported that increase in biodiesel concentration in the fuel blend, increased the carbon dioxide and oxides of nitrogen emissions, while carbon monoxide, hydrocarbons and particulate matter emissions were reduced. The addition of anhydrous ethanol to B20 fuel blend reduced the exhaust NO\textsubscript{X} and CO\textsubscript{2} concentration but it increased the CO, HC and PM emissions.

Qi et al (2011) have studied the effects of using diethyl ether and ethanol as additives to biodiesel/diesel blends on the performance, emissions and combustion characteristics of a direct injection diesel engine. The blends B30 (30% biodiesel and 70% diesel), BE-1 (5% diethyl ether, 25% biodiesel and 70% diesel) and BE-2 (5% ethanol, 25% biodiesel and 70% diesel) were used as the test fuels. They reported that the blends BE-1 and BE-2 showed better stability and can be used in the engine without any modification. The specific fuel consumption of BE-1 was slightly lower but BE-2 was almost same to that of B30. Drastic reduction in smoke was observed with BE-1 and BE-2 at higher engine loads. Nitrogen oxide emission was found slightly higher for BE-2. Hydrocarbon emission was slightly higher for BE-1 and BE-2, but carbon monoxide was slightly lower. They also found that the combustion characteristics for BE-1 and BE-2 were almost identical to that for B30.
Torres-Jimenez et al (2011) have discussed the physical and chemical properties of ethanol-diesel fuel blends. The tested fuels were neat mineral diesel fuel (D100), 5% (v/v) ethanol/diesel fuel blend (E05D95), 10% (v/v) ethanol–diesel fuel blend (E10D90) and 15% (v/v) ethanol-diesel fuel blend (E15D85). They reported that, for ethanol-diesel fuel blends, some additives were necessary to keep stability under low temperature conditions. The cold weather properties test, such as cloud point and pour point tests were negatively affected by phase separation. The rest of the properties, excepting flash point, were within diesel fuel standard specifications. They concluded that using additives to avoid phase separation and to raise flash point and also blends of diesel fuel with ethanol up to 15% was used for fuel in the diesel engines.

2.4 CONCLUSIONS FROM THE LITERATURE REVIEW

From the review of literature, the following are the major conclusions.

- Non conventional sources of energy are capable of solving the twin problems of energy supply in a decentralized fashion and simultaneously help in achieving the environmental sustainability.
- The four stroke compression engines are indispensable in major areas of transport, agriculture etc and it will be very difficult to replace it with any other type of power plant.
- Modification of the fuel is one of the best ways to reduce emissions without any modifications on the existing engines.
- Many authors used biodiesel for partial replacement of diesel in diesel engine. However the quantity of biodiesel available in the market is limited.
• Many authors studied the engine performance and emissions analysis by using the anhydrous ethanol derived from fossil fuel.

• It is found that the different researchers have not reported phase separation when anhydrous ethanol was used. It might be due to in absence of water.

• Bioethanol is produced from different kinds of raw materials such as corn, maize, sugar beets, sugar cane, molasses, cassava etc by means of fermentation.

• The use of straight ethanol as a diesel engine fuel is not promising.

• The small quantity of water in the diesel-ethanol blend will cause phase separation.

• The additive is used to avoid the phase separation in the diesel - ethanol blends. But commercially available additives are found to be costly and are also obtained from fossil fuels.

• The additive selection is based on the availability, easy produce ability, high cetane number and renewable one.

• The diesel-ethanol blends with suitable additive has different physical properties and hence it has different influence on engine performance and emissions characteristics.

• The relative density, viscosity, calorific value and flash point of the ethanol diesel blends are found to different depend on the properties and purity of ethanol used.
- The exhaust emissions namely particulate matter and oxide of nitrogen are decreased with diesel-ethanol blends as fuel.

- The performance and emission characteristics of diesel engine are mainly depends nature of blends used such as purity of ethanol and nature of additives used to blend with diesel.

From the analysis of literature, it is also noted that very limited work has been reported for the preparation of bioethanol and additives derived from the biomass. Hence in the present work is proposed to study the experimental investigations of different bioethanol-diesel blends with suitable additives. The problem definition, its objectives and sailent future of the present work are presented in the next chapter 3.