CHAPTER 2

2.1 STATUS OF THE ART AND LITERATURE SURVEY

The studies on dual fuel system used in engines deserve much attention due to the series environmental impact by pollutants released during the combustion of fuels inside the engine. Apart from the above other factors like injection timing of the pilot fuel, injector opening pressure, pilot fuel quantity and intake temperature are of important to us. The poor combustion of the gaseous fuel at low loads results in emission of high carbon monoxide and unburned hydrocarbons. Preheating of the intake charge and the increase in pilot diesel quantity results in higher thermal efficiency. However, at high loads and high intake temperatures, increased admission of the gaseous fuel can result in uncontrolled reaction rates near the pilot fuel spray and lead to knock. The potential of different methods of improving the performance of dual fuel engines has to be evaluated to arrive at an optimum combustion.

According to Senthil kumar et al (2001) vegetable oil along with methanol induction in a dual fuel mode have cetane number and calorific value very close to diesel. However they brake thermal efficiency which is inferior to diesel. They also noticed that problems of high smoke, HC and CO emissions. This is due to the atomizing fuel and mixing it with air. Further gum formation and piston sticking under long term use due to the presence of oxygen in their molecules and the reactivity of the unsaturated HC chains are problems with vegetable oil.

Ramesh et al (1999) studied research on a dual fuel engine employing a primary fuel that is generally gas is mixed with air, compressed and ignited by
a small pilot spray of diesel as in a diesel engine. Results indicate dual fuel engines suffer from the problems of poor brake thermal efficiency and high HC emissions, particularly at low outputs. In this experimental work, the effects of intake charge temperature, pilot fuel quantity and throttling of the intake were studied. The gas and air is mixed in the gas-air mixer unit. It was also found out that in dual fuel engine at low loads when the gaseous fuel concentration is low, ignition delay period of the pilot fuel increases and some of the homogeneously dispersed gaseous fuel remains unburned and results in poor performance.

Studies on LPG based fuel with a low cetane number improve was carried out by Haruya Ohta et al (2002). The free radicals produced by the thermal decomposition of a cetane number improve in the pre ignition period of a diesel engine cycle have an important role in improving the ignition property.

Abd Alla et al (2001) investigated the effect of pilot fuel quantity on the performance of an indirect injection diesel engine fuelled with gaseous fuel. They found that the operation of dual fuel engines at lower loads suffers from lower thermal efficiency and higher unburned percentages of fuel. To rectify this problem, tests have been conducted on a special single cylinder compression ignition research engine (Richardo E6). Through experimental investigations, it is shown that, the low efficiency and excess emissions at light loads can be improved significantly by increasing the amount of pilot fuel, while increasing the amount of pilot fuel at high loads led to early knocking. Also an improvement in thermal efficiency was achieved by increasing the amount of pilot fuel, because of the corresponding high pressure and temperature while the combustion duration increased.

The increase in NOx emissions with increasing amount of pilot fuel was attributed to increase in the maximum temperature of the charge. The reduction in carbon monoxide and unburned hydrocarbon emissions were due to
general improvement in the combustion process. Increasing the amount of pilot fuel at high loads led to early knocking. It is therefore concluded that increasing the amount of pilot fuel is not effective in dual fuel operation at high loads.

Papagiannakis et al (2004) had conducted experimental investigations to examine the effect of dual fuel combustion on the performance and pollutant emissions of a DI diesel engine. From analysis of the experimental data, it is revealed that dual fuel operation results in lower peak cylinder pressure compared to the one under normal diesel operation, which is encouraging since no danger exists for the engine structure. At low load, the combustion duration under dual fuel operation is longer compared to normal diesel operation, while at high load, it is shorter.

Concerning total BSFC it is revealed that it becomes inferior under dual fuel operation compared to the one under normal diesel operation at the same engine operation conditions. At high load, the values of total BSFC under dual fuel operation is better than normal diesel operation. As far as pollutant emissions are concerned, the use of natural gas under dual fuel operation has a positive effect on NOx emissions, and thus, NOx concentration under dual fuel operation is lower compared to normal diesel operation. At the same time, there is a drastic decrease in soot emissions under dual fuel operation regardless of engine operating conditions, which is the most important finding. On the other hand, CO and HC emissions levels are considerably higher compared to normal diesel operation. Thus, it seems that dual fuel combustion using natural gas is a promising technique for controlling both NO and soot emissions even on existing DI diesel engines and requires only slight modification of the engine structure. The penalty in BSFC experienced is partially compensated by the lower price of natural gas.
Papagiannakis et al (2003) conducted experiments with diesel and natural gas as a fuel in DI diesel engine in the dual fuel mode mainly to reduce the particulate emissions and nitrogen oxides. Results revealed the effect of liquid fuel percentage replacement by natural gas on engine performance and emissions. It was observed a higher ignition delays compared to normal diesel operation. Furthermore the initial heat release rate is lower than the later. As far as pollutant emissions are concerned the use of gaseous fuel has a positive effect on NO emissions. The level of NO concentration under dual fuel operation is lower compared to the one under normal diesel operation. Their values increases with the gaseous fuel mass ratio and only at high engine load and high natural gas mass ratios a decrease was observed.

Ramadhas et al (2006) conducted experiments on the partial combustion of biomass in the gasifier generated producer gas that can be used as supplementary or sole fuel for internal combustion engines. Important findings on the engine performance and environmental aspects of electric power generation in dual-fuel mode of operation using coir-path derived producer gas-rubbed seed oil are highlighted. Further, existing diesel engine was capable of successful running in dual-fuel mode of operation with biomass. However, higher the capacity of the engine than the required capacity to be selected because the producer gas dual fuel engine could run only at maximum of 50-60% of maximum load condition.

Babu et al (2003) investigated that an unprocessed oil can be used in engines, but unlike diesel fuel, vegetable oil have different physical and chemical properties, some fuel property e.g., oxidation resistance, are markedly affected by fatty acid composition of vegetable oils. The large size of vegetable oil molecules (three or more time larger than hydro carbon fuel molecules) and the presence of oxygen in the molecule suggest differ from those of hydrocarbon fuels because of this physical and chemical property, vegetable oil accumulate and remains as
charred deposits inside the engine cylinder. Similar observations were made by Clevenger, et al. (1988) using vegetable oils and much attention has been paid on viscosities of oils on engine efficiencies.

Mary Kay Cardis Fishinger et al. (1981) conducted service tests with vegetable oil diesel blends and reported without any modification would run successfully on a blend of 20% vegetable oil and 80% diesel fuel without damage to engine parts. Compare to diesel fuels, all of the vegetable oils are much more viscous and are much more reactive to oxygen and has higher cloud point and pour point temperatures. Diesel engines with vegetable oils offer acceptable engine performance and emissions for short-term operations. Long term operations results in operational and durability problems. However the emission of pollutants was minimized.

The work of Karim (1981) on utilization of gaseous fuel such as methane, propane, acetylene, ethylene and hydrogen in diesel engine revealed that the maximum amount of gas consumption is limited due to the one set of knock. He reported that in dual fuel engines, at low load, when gaseous fuel concentration is low, ignition delay period of the pilot fuel increases and some of the homogeneously dispersed gaseous fuel remains unburned and results in poor performance. Pilot fuel quality, quantity, injection timing and intake temperature are important variables affecting the performance of dual fuel engine.

Gunea et al. (1998) conducted experiments on a four stroke single cylinder, direct injection, diesel engine, fuels with natural gas. Tests were conducted with diesel as the pilot fuel having different cetane numbers in order to study the effect of pilot fuel quality on ignition delay. They concluded that ignition delay of a dual fuel engine mainly depends on pilot fuel quantity and quality. High cetane number pilot fuels can be used to improve the performance of low cetane number gaseous fuel engines.
Liu and Karim (1998) studied the effect of admission of gaseous fuels and diluents into the dual fuel diesel engine. They reported that gaseous fuels and diluents would change the physical and chemical processes of the ignition delay period. The extent of the extension of the ignition delay period depends strongly on the type of gaseous fuel used and its concentrations.

Rao et al (1983) investigated the performance of diesel engine in dual fuel mode by indicating a small quantity of hydrogen in the inlet manifold. At higher loads, the efficiencies attained were closer to diesel with a notable reduction in smoke and exhaust gas temperature NOx emissions increased with increase in peak pressure.

Tomita et al (2000) investigated the induction of hydrogen in the intake port of the diesel engine. They found that NOx emission decreased because the combustion was lean and premixed. HC, CO, CO₂ and smoke emission also decreased with a marginal sacrifice in thermal efficiency.

Das (2002) suggested that hydrogen could be used in SI engine as well as in CI engine without any major modification in the existing system. He studied different modes of hydrogen induction carburetion, continuous manifold injection, timed manifold injection, low pressure direct injection and high pressure direct injection and suggested to use manifold injection method for the induction of gases to avoid undesirable combustion phenomenon (back fire) and rapid rate of pressure rise.

Saravanan et al (2009), carried out an experimental study on a single cylinder water cooled direct injection diesel engine using hydrogen in dual fuel mode. It was reported that the brake thermal efficiency increase from 23.59% to 29% with optimized start of injection and duration. The peak pressure increase
rapidly when using hydrogen in dual fuel mode. The emissions such as NOx, CO, CO₂ and HC are reduced drastically.

Ashok et al (2006), studied the suitability of acetylene in a spark-ignited engine along with an exhaust gas recirculation and reported that emission drastically reduces on par with hydrogen engines with a marginal increase in thermal efficiency.

Nathan et al (2008), conducted experiments in a CI engine by using acetylene as a fuel in homogeneous charge compression ignited mode along with preheated intake air. The efficiency achieved was very near to diesel, NOx and smoke level reduced considerably. However, HC level increased. They also adopted acetylene as a fuel for HCCI engine because of its moderate auto ignition temperature and high flammability limits. They varied intake charge temperature to control combustion phasing. They achieved brake thermal efficiency comparable to that of conventional CI mode by using proper intake charge temperature.

Cole et al (2001) investigated the particulate and NOx emissions in a 1.9 liter Volkswagen diesel engine with neat diesel and blends of diesel with ethanol. They reported that the tests were conducted on a engine dynamometer for five different speeds and five different torques using the standard engine control. It was concluded that a maximum of 75% reduction in particular emission and 84% reduction in NOx emission was achieved with diesel blended with ethanol when compared with neat diesel fuel.

Wang et al (2006) investigated the performance and exhaust emissions of a diesel engine operating on diesel fuel blended with vegetable oil. They reported that the engine performance, power output and fuel consumption were almost the same when the engine was operated with vegetable oil diesel blends.
and diesel fuel. The engine power increases with increase of engine load for all of the fuels. The differences of engine power output at different loads are very small with different blends of vegetable oil.

Swaminathan & Sarangan (2009) studied the reduction of NOx emission and to improve the performance of a diesel engine using bio diesel and bio diesel mixed with additives. They reported that the additives Di ethylene glycol mono methyl ether and Di ethylene glycol mono butyl ether were used with bio-diesel (POME) in various proportions. It was concluded that a 10 to 30% increase in reduction of NOx was achieved with bio fuel additive blends compared to neat diesel operation.

Herzog et al (1992) studied the NOx reduction potential of in cylinder charge condition, fuel injection system, exhaust gas recirculation, fuel formulation and exhaust gas after treatment of catalyst. It was concluded that based on these findings, various development options were derived and assigned to prescribe the future emission standards in USA, Europe and Japan.

Shundoh et al (1992) studied the effect of NOx and smoke in a diesel engine with respect to ignition delay period, pilot injection and high pressure injections. It was concluded that combination of both pilot and high pressure diesel injections have reduced NOx by approximately 35% and smoke by 60-80% simultaneously without worsening the fuel economy.

Konno et al (1993) investigated experimentally the reduction of both particulate and NOx emitted from direct injection diesel engines by a two stage combustion process. They reported that the primary combustion was made very rich to produce NOx and then the particulate was oxidized by strong turbulence generated during the secondary combustion. It was concluded that the NOx
reduction was significant while fuel consumption and particulate emissions remained at the same level.

Mohammed YE Selim (2005) had worked on the statistical analysis of the cycle-to-cycle variation of measured values obtained from a single cylinder Ricardo E6 engine working on dual fuel of diesel and LPG and compared to diesel methane and pure diesel fuel. They observed values of the combustion noise and their cyclic variability in dual fuel engines are strongly dependent on the type of gaseous fuels used and the concentrations in the cylinder charge. Dual fuel engine using LPG as main fuel exhibits higher combustion noise than that using methane. Advancing the injection timing of the pilot diesel fuel for duel fuel engine using LPG as main fuel resulted in an increase in the combustion noise, cyclic variation, and loss in IMEP. Injection timing of about 30-358 BTDC resulted in the least cyclic variations moderate combustion noise. Increasing the mass of pilot diesel fuel resulted in an increase in the IMEP, however, it increased the combustion noise, increasing the engine speed resulted in a decrease in the combustion noise and its cyclic variation.

Wenli et al (1989), experimentally investigated the performance and emission characteristics of C.I engine using hydrocarbons such as methane, ethane, butane and ethylene added with diesel. It was reported that the NOx emission was reduced slightly depending upon the concentration of these additives in the fuel. It was concluded that a constant carbon content ethane had greatest effect in the reduction of the NOx emission.

Dale Tree et al (1993) conducted experiments using Texaco Diesel Additive (TDA) as an in fuel emission reduction agent on a single cylinder, modified TACOM-LABECO engine. The experiments were conducted at a constant speed of 1500 rpm with two different loads using the base line fuel and as well as fuels with 1% and 5% additive by weight. It was further reported that
there were no difference in the emission level of the baseline diesel fuel and fuel with one percent TDA by weight. It was also concluded that there was a significant reduction in NOx with five percent additive and no significant changes in other measured emissions or fuel economy.

Alam et al (1999) investigated the performance of a direct injection diesel engine operated with neat dimethyl ether (DME) along with the catalysts designed for NOx reduction such as co-alumina and sn-alumina catalysts. They report that DME concentration in the exhaust gas was changed by adding extra DME before the catalytic reactor. It was found that the NOx reduction rate was not so high with DME addition. They concluded that the NOx reduction rate could be increased with increase in DME content and around 80% NOx reduction can be achieved with enough DME addition. It was also concluded that the NOx reduction rate could be increased with increase in reaction temperature up to around 300°C.

Chen et al (2000) investigated engine performance and emission characteristics using a small amount of Di-methyl ether (DME) mixed with diesel fuel to control the emission. They reported that the normal efficiency was higher than that of diesel fuel. It was also reported that the NOx emissions for lean DME component mixture were low. It was concluded that the start of the combustion was delayed in the presence low DME in the fuel mixture lowering the peak of the heat release rate.

Singh et al (2004), carried out the experimental and modeling analyses on the combustion and emission characteristics of a diesel /natural gas dual fuel engine. They reported that a diesel combustion model was developed to track the flame propagation. It was concluded that both emission and increased HC emissions with increased natural gas substitution. It was further concluded that
the NOx emission increased with increased intake charge temperature in both experimental and simulation studies.

**NOx REDUCTION THROUGH MODIFIED COMBUSTION**

Aoyama et al (1990) studied the various methods to control the formation of NOx in a diesel engine. They stated that NOx was mainly generated within localized high-temperature regions in the cylinder. They also stated that the temperature distribution measurement enabled the characterization of the NOx reduction mechanisms by two methods of injection control. i.e., injection timing retard method, the temperature throughout the combustion chamber was lowered which reduced the NOx formation as the spatial development of localized high temperature regions were controlled. In the pilot injection method, the development of high temperature in the compression region was lowered due to which the NOx formation is reduced.

Konno et al (1992) studied about the reduction of NOs in the diesel engine exhaust using copper ion-exchanged (ZSM-5) zeolite catalyst in the presence of oxygen with hydrocarbon as reducing agent. They reported that the NOx was reduced by 25% in normal engine process using ZSM-5 zeolite catalyst. They also stated that higher reduction of NOx was possible when hydrocarbons in the exhaust were increased. It was concluded that water in the exhaust gas decreased the NOx reduction efficiency while, oxygen and sulfur had only a small effect. It was also concluded that the NOx reduction was maximum at 400 °C irrespective of hydrocarbons species and did not decrease with space velocity up to values of 20,000 l/h.

Konno et al (1992) studied the effect of strong turbulence created by jets of burned gas from an auxiliary chamber installed in the cylinder during the combustion process of a diesel engine. They stated that the strong turbulence,
which was induced late in the combustion period, enhanced the mixing of air with unburned fuel and soot, resulting in a remarkable reduction of smoke and particulate; while NOx did not show any decrease with this system. It was further reported that the thermal efficiency showed improvements at higher loads. Experiments by introducing the EGR and water injection at a pressure of 0.3 MPa through the inlet manifold were also conducted. It was reported that the introduction of EGR and water reported a reduction in both smoke and NOx. It was also concluded that a remarkable NOx reduction of 72% was achieved with the water injection at high load condition and with the introduction of EGR at low load condition.

Alatas et al (1993) studied experimentally to the characterization of NO and soot evolution in an D.I engine with a square combustion chamber. They stated that to characterize NO evolution, a two dimensional laser-induced fluorescence was used and to characterize soot evolution a two dimensional laser induced incandescence (LII) and Mie scattering techniques as well as direct photography of the flame luminosity were used. It was stated that the engine operating parameters were set to provide optimum conditions for NO imaging. It was concluded that the NO formation was almost immediately after ignition and ceased not more than 40 degrees ATDC. It was also concluded that no soot images could be obtained before 20 degree ATDC in the technique adopted, since the soot concentration was very low.

Nehmer & Reitz (1994) investigated the effect of the rate-shaped and split injections on the soot and NOx emissions of a single cylinder version of the caterpillar 06 production engine. This engine was modified to accept an electronically-controlled, high-pressure common-rail injection system that offers a very high degree of flexibility in injection timing, split injections and rate shaping of the initial injection. It was reported that the rate shaped injection, when optimized for lowest BSFC, does not appreciably affect pressure rise or
peak cylinder gas pressures to be reduced by more than 45% and have a significant effect on the overall rate of pressure rise. It was also concluded that the split injections have a trend of reduced NOx as the quantity of fuel in the first injection is reduced, without increase in particulate emission.

Tow et al (1994) studied experimentally the effectiveness of using double, triple and rate shaped injections simultaneously to reduce particulate and NOx emissions in a single cylinder version of a caterpillar 3406 heavy duty D.I. Diesel engine using a common rail, electronically controlled injector that allowed flexibility in both the number and duration of injections per cycle. It was concluded that by varying the injection timing for each injection scheme, the particulate versus NOx trade off and fuel consumption were evolved.

Minami et al (1995) conducted experiments on a turbo charged direct injection diesel engine to study the effects of pilot injection on diesel combustion. They stated that the emissions from the engine were measured by varying the pilot injection quantity and timing and the combustion process was analyzed with an endoscope. It was concluded that the pilot injection at low engine load reduced the NOx and THC and showed a slight improvement in fuel consumption. Further, it was also concluded that the pilot injection reduced the average combustion gas temperature due to a restriction on premixed combustion and slower combustion during diffusion.

Hou and Abraham (1995) made a comparative study of computed and measured soot and NOx in a D.I diesel engine. They stated that a three dimensional model for flows, sprays and combustion in diesel engines was used for the computation and the auto ignition of the diesel spray was modeled using an equation for a progress variable which measures the local and instantaneous tendency of the fuel to auto ignite. It was stated that high temperature chemistry was modeled using a local chemical equilibrium model coupled to a combination
of laminar kinetic and turbulent characteristics. Further, it was reported that the soot formation was kinetically controlled, NOx was modeled using the Zeldovich mechanism and soot combination was represented by a model which has a combination of laminar kinetic and turbulent mixing times. It was also concluded that the soot oxidation was controlled near top dead center by mixing and by kinetics at the end of expansion.

Larsen et al (1996) studied the optimal use of filtered exhaust gas recirculation (EGR) to reduce the NO emissions of diesel engines. They stated that control of the particulate emissions and provisions for filtered EGR were achieved by an Aerodynamically Regenerated Trap (ART) collection efficiencies in the order of 99%. It was reported that EGR regulation was accomplished by monitoring the injection pump setting which was correlated to the fuel flow rate, the speed of the engine, the amount of EGR flow, and the ambient air temperature. It was concluded that NOx emissions was effectively reduced at 20% EGR, with a loss in fuel company by 8%. It was also concluded that with electrically controlled EGR valve, the NOx level was decreased by 30% while CO was increased by 30% without much loss in fuel economy.

Akira Murakami (1997) attempted to develop a new combustion chamber, in which a strong disturbance in the middle and late stages of combustion that enhanced smoke oxidation to achieve simultaneous reduction of NOx and smoke from diesel engines. It was reported that the initial combustion occurred in a fuel rich state in the pre chamber and the middle and late stages of combustion occurred in a lean state mostly in the main chamber. It was concluded that the NOx was reduced as the disturbance shortened the combustion duration.

Chen (2000) investigated the effect of pilot, post and multiple fuel injection strategies on engine performance and emissions on a
4-cylinder, 1-2 liter, small-bore, direct injection diesel engine equipped with a high pressure common rail fuel injection system. It was reported that the use of pilot injection did not lead to a simultaneous reduction of NOx and particulate. It was stated that post injection and multiple injections can reduce particulate emissions by more than 40% in some cases. It was concluded that, with the retarded main injection of fuel, simultaneous reduction of NOx and smoke were achieved and on further retardation of the main injection, the NOx emission could be further reduced.

Okude et al (2004) conducted experimental investigation in a single cylinder D.I diesel engine to reduce simultaneously the soot and the NOx by injecting the fuel into a combustion chamber in the vicinity of the top dead center. They stated that this type of injection was used to prevent the fuel from adhering to the wall and the formation of pre mixture which is formed shortly before ignition. It was stated that pre mixing reduces the over rich region of the mixture to reduce soot emissions, and at the same time lowers the combustion temperature by introducing a large amount of EGR to reduce NOx emissions. It was concluded that a maximum reduction of 62% NOx was achieved even in a high load operation.

Jarquin et al (2009) conducted experimental investigation in a furnace of 80MW boiler using natural gas for the reduction of NOx emission. It was reported that various methods such as the recirculation of smoke gases in the boiler furnace, injection of water in the burning zone, reduced supply of excess air into the burning zone and the combination of all the above methods were used in the investigation. It was reported that 15% to 40% of NOx reduction was achieved in the methods listed above. It was concluded that the combination of these methods were investigated for the maximum reduction of NOx emission.
NOx REDUCTION THROUGH AFTER TREATMENT OF EXHAUST GAS

Arand (1982) conducted experiments at two different temperatures i.e., 1355K and 1444K in a heavy duty diesel engine using ammonia as a reduction agent without introducing any catalyst. They stated that, for the same reduction of NOx, the lower temperature of urea injection caused a higher ammonia slip than at the higher temperature of urea injection. It was concluded that the ammonia slip was increasing with increasing value of NSR.

Epperly & Broderick (1988) studied the ammonia slip by injecting urea solution into coal fired boilers of 50MW and 150MW capacity. They stated that about 50% to 60% NOx reduction was achieved with the ammonia slip of 5ppm while the reduction of NOx was improved to about 65% to 75% with an increasing in ammonia slip of 20ppm. It was concluded that NOx reduction was higher while the ammonia slip was higher.

Jodel et al (1988) investigated the use of both ammonia and urea injection to They stated that some ammonia was released to the atmosphere as ammonia slip particularly at low temperature of injection regardless of the choice of primary reducing agent. It was concluded that the slip was very insignificant when ammonia was injected at 1173k and when urea was injected at a temperature of 1273 k and the same slip was noted.

Held et al (1990) studied the NOx reduction using copper exchanged zeolite catalysts on a lean-burn spark-ignition engine as well as diesel engine. They stated that a NOx conversion ratio of approximately 45% was achieved for S.I engine and a 65% NOx reduction was achieved in the case of diesel engine. It was also stated that copper exchanged zeolite catalyst converted nitrogen oxides
over a much wider range of fuel air ratios than noble metal catalysts. It was concluded that either ammonia or urea can be used as reducing agent.

Walker & Speronello (1992) investigated on a heavy duty diesel derived natural gas engine using ammonia injection for the reduction of NOx emissions from the engine exhaust to develop an exhaust gas treatment system. It was concluded that the NOx was reduced by 80% and an ammonia slip of less than 2ppm was achieved while the engine performance was reduced slightly.

Muramatsu et al (1993) studied the reduction of NOx from diesel engine exhaust using a newly developed copper based catalyst system. They stated that the fundamental interactions between NOx, oxygen and hydrocarbons over the copper based catalysts have been studied in relation to NOx reduction by hydrocarbon additions and hydrocarbon oxidation. It was stated that different NOx reduction characteristics of various hydrocarbons were studied. It was also concluded that the newly developed catalyst system combined with a diesel fuel or heavy saturated hydrocarbon spray system effectively reduced the NOx by 20%-30% over an exhaust temperature range of 350°C-550°C.

Kawanami et al (1995) investigated the performance of several Non-SCR catalysts and catalytic systems for the reduction of NOx. They stated that the performance of catalysts with respect to NOx was examined when secondary hydrocarbons were added as reducing agent directly in the exhaust gas stream. It was also stated that the effects of different catalyst formulations and secondary hydrocarbon additions on particulate emissions were also determined. It was concluded that there was a simultaneous reduction of about 12% NOx and 25% particulate over the transient cycle with 2-3% fuel penalty by the minor optimization of secondary fuel injection pattern and amount and choice of catalyst.
Metha et al (1994) studied the simultaneous control of particulate and NOx emissions from diesel engines. They stated that a trap that incorporated a high filtration efficiency ceramic honeycomb monolith was used to control particulate. It was stated that periodically the monolith filter was flushed by aerodynamic regeneration. It was further stated that the soot collected in a metallic chamber was either incinerated by an electric burner or removed by vacuum cleaner. Further, it was also reported that circulation of filtered exhaust gas (EGR) was used to reduce NOx emissions. It was concluded that the introduction of 20% EGR reduced the NOx emission by 50% at average loads.

Irfan (2007) conducted experimental investigation on a natural gas fired pilot scale isothermal reactor to determine the ammonia slip and the emission of N₂O using injection of aqueous urea solution at two different temperatures i.e. 1293K and 1423K. They reported that the ammonia slip was as much as 98ppm at lower injection temperature, while at higher injection temperature it was as low as 2ppm. It was stated that rising or declining trend of both NOₓ reduction and N₂O emission was almost similar with the temperature variation. It was concluded that the peak NOₓ reduction temperature was about 30K higher than that of peak N₂O emission temperature. It was also concluded that the ammonia slip was a function of reactor temperature.

Romero & Ciarlante (1997) studied about the NOx reduction on a tangential fired pulverized coal boiler of capacity 84MW with urea based SNCR system. It was reported that as much as 35% NOx reduction was achieved. It was also concluded that the NOx reduction as well as ammonia slip increased as the value of SNR increased.

Nag et al (1998) investigated the reduction of NOx and the effects of space velocity variation at peak activation temperature using copper ion exchanged x-zeolite with urea infusion. It was reported that, to minimize the
deactivation of zeolite caused by water, ammonium carbonate and ammonium sulphate were deposited on the copper ion exchanged x-zeolite. It was also reported that a maximum NOx conversion efficiency of 62% in the lean burn range was achieved. It was also concluded that the ammonia slip was more in case of urea infusion than ammonium salt deposition at higher temperatures.

Willand et al (1998) investigated on a heavy duty single cylinder research engine using aqueous urea as reducing species for the NOx reduction potential of an selective non catalyst reduction (SNCR) process as an alternative to catalyst exhaust treatment system. It was stated that the aqueous urea solution was directly injected into the combustion chamber. It was also concluded that a maximum NOx reduction of 65% was achieved at full load for an increased exhaust gas temperature.

Koebel et al (2000) studied the use of urea injection SCR for heavy duty automotive trucks. They stated that the catalytic volume was reduced without affecting the NOx reduction over a wide range of operating temperature. It was concluded that much shorter residence time of the exhaust gas in the catalyst would lead to secondary emission of ammonia.

Nam et al (2000) conducted NOx reduction experiments over a wide range of air/fuel ratios (20-40) on a diesel fueled single cylinder engine having a driven flow reactor using an initial NOx level of 530 ppm and for normalized stoichiometric ratios. They stated that an effective NOx reduction with urea was occurred over an injection range of 1100 to 1350k. It has been also stated that the NOx reduction increased with increasing NSR values and about 40%-60% reduction of NOx was achieved with NSR=1.5 TO 4.0. It was further stated that most of the NOx reduction occurred within the cylinder and head section only. It was concluded that relatively low NOx reduction was obtained due to the existence of higher levels of CO/UHC inside the cylinder and higher temperature
drops along the reactor. It was also reported that the injection of secondary combustile additives (diesel/c2h6) into the exhaust pipe promoted further substantial NOx reduction (5%-30%) without shifting the temperature windows. It was also concluded that the diesel fuel was found to enhance NOx reduction more than C2H6.

Lambert et al (2004) investigated the reduction of NOx with selective catalytic reduction technique using aqueous urea on a on board diesel vehicle. They stated that a diesel particulate filterwas fixed in the engine exhaust system before the SCR system to reduce the particulate matter and high way fuel economy test were performed to analyze the fuel economy and emissions at various exhaust temperature. It was concluded that the vehicle exhaust met the ULEV emission standard (0.2 g/mi NOx and 0.04 g/mi particulate matter (PM)).

Blakeman et al (2004) investigated the potential of urea based SCR for NOx reduction on a light duty vehicle. It was stared that a diesel oxidation catalyst was also incorporated, to deal with carbon monoxide, hydrocarbons and volatile organic fractions. They reported that the investigations were carried out to study the various effects by placing the oxidation catalyst at different positions in the system by varying the SCR catalysts composition and the rate of urea injections. It was concluded that, in the investigation, a best system was devised to achieve a maximum NOx conversion of 73%.

Gekas et al (2002) used a novel urea injection system, based on a mass produced digital pump combined with an electronic control unit specially developed for controlling the urea SCR process onboard the vehicles. They stated that the NOx conversion achieved was above 80% with ammonia slip below 10 ppm. It was concluded that with this novel 300 epsi urea injection systems, the SCR catalysts volume could be reduced to 2/3 compared to the 130 epsi catalysts.
Van Helden et al (2002) investigated the NOx reduction using vanadium catalyst with urea injection in heavy duty track diesel engine. They stated that with such system, 62% of NOx reduction was achieved. It was stated that upto 72% of the NOx reduction with a higher ammonia slip of 37ppm could be achieved. It was further reported that even after 60,000 km operation, NOx conversion and ammonia slip remained same. It was concluded that, such a catalysts arrangements with a temperature window extended to a lower temperature could be used to achieve an optimal NOx conversion in practical.

Nakatami et al (2002) investigated the simultaneous and continuous reduction of particulate matter and nitrogen oxide in diesel engine exhaust gas has been developing a new after treatment system, diesel particulate NOx reduction system (DPNR). It was concluded that more than 80% of both NO and particulate matter was achieved with DPNR developed.

Schar et al (2003) investigated the NOx reduction control of urea SCR catalytic converter system for a mobile heavy duty engine using titanium dioxide. They stated that 82% NOx reduction was achieved. It was reported that the average NH, slip was below 10ppm for the maximum reduction of NOx. It was concluded that the NOx sensor with cross sensitivity to NH3 allowed the design of a better feedback control loop.

Maunula et al (2003) developed an efficient exhaust gas after treatment system to operate at low temperature below 300°C with SCR catalyst coated with V$_2$O$_5$/TiO$_2$- wO3. It was stated that the SCR catalyst got evenly coated by open coating method with high cell density substrates and a new wash coat composition with platinum loading was used as pre oxidation catalyst which initiates the SCR reaction clearly below 300 °C. It was also stated that the coated mixer structure confirmed uniform urea hydrolysis and ammonia generation
particularly at low temperatures. It was concluded that the NH₃ slip was cut down by the optimization of urea injection and a small post oxidation catalyst.

Rusch et al (2003) investigated different particulate measuring technologies on the influence of parameters like the sulfur content of the fuel and the reducing agent. They stated that the SCR technology was effective in the reduction of both NOx and particulate emission. It was also reported that, apart from an effective reduction of the organic fraction of the PM, the system was also able to reduce the carbon fraction. It was also concluded that with the use of a SCR system, a clear decrease of the nanoparticulate emissions was achieved under all dosing conditions.

Zhihua Wang et al (2004) investigated the reduction of NOx in a bench scale drop tube furnace using ammonia, urea solution and ammonia salt solution as the reducing agent. They reported that 85% of NOx reduction was achieved using ammonium salt (NH₄) SO4 solution. It was stated that SCR technique with injection of ammonia and ammonia N-agents (ammonia chloride, ammonia carbonate, ammonia sulphate ) were tested in a heavy duty stationary diesel engine. N-agents were preferred over Urea and Ammonia due to its lower cost. It was reported that 60% of NOx reduction with ammonia and 81.3% NOx reduction with N-agents were achieved. It was also concluded that urea and ammonia were the best reducing agents.

Tennison et al (2004) studied the use of an oxidation catalyst to convert engine exhaust HC and CO upstream of the urea SCR system. They stated that aqueous urea was added to the exhaust using a Ford developed air assisted injection system. It was stated that a base metal/zeolite SCR catalysts was utilized to convert NOx to N2 under lean conditions. It was also concluded that the NOx level was reduced to the range of ULEV II levels.
Hyuk-Jin (2004) investigated the effect of various parameters including reaction temperature, oxygen concentration, NH3-to-NO ratio, space velocity, heating area, catalyst arrangement, and vanadium coating on the removal of nitric oxide, using the SCR technique with ammonia in a laboratory laminar flow reactor. It was stated that vanadium and pillared interlayer clay based monolithic honey comb catalysts were used. It was also stated that the investigation also aimed to study the concentration of the product species using Fourier transform infrared (FTIR) spectrometer. It was further stated that the major products were nitric oxide (NO), ammonia (NH3), nitrous oxide (N2O), and nitrogen dioxide (NO2). It was concluded that, for both catalysts, the removal of NO and NH3 were found to be high in the presence of a small amount of oxygen. It was also concluded that an increase in NH3-to-NO ratio increased NO reduction but decreased NH, conversions. It was also noted that the change of catalyst arrangements resulted slight improvement for NO and NH3 removals and also the catalyst with extra vanadium coating showed higher NO reduction and NH3 conversions than the catalysts without the extra vanadium coating.

Chi (2005) developed a dynamic model for simulating the transient performance of a NOx after treatment system using selective catalysts reduction with urea as a reducing agent. They stated that components of the urea-SCR after treatment system model include a urea dosing system, an exhaust pipe and a fresh vanadium based SCR catalyst. It was stated that the catalyst model was a 2 dimensional one that incorporates the heat and mass transfer characteristics of a monolith channel and the chemical kinetics of NOx conversion by ammonia. It was reported that the Nussell number, Sherwood number, and reaction probability were calculated as a function of axial position along the monolith channel. It was concluded that the results from a Cummins heavy duty engine was useful to calibrate the dynamic system model and parametric studies were
carried out to quantify the effect of ammonia storage capacity on NOx conversion and ammonia slip.

Schmieg & Lee (2006) investigated the selective catalytic reduction of NO using urea as one of the promising technique for removing NOx from diesel engine exhaust. They stated that the NOx in the engine exhaust was reduced by ammonia derived from urea over a catalyst to N₂. It was further stated that the effect of various reactor operating conditions on the NOx reduction and performance of three different catalyst formulations were studied to obtain useful guidance in the design and operation of urea SCR lean NOx emission control systems. It was further reported that the effects of NO-NO₂ ratio on the steady state NOx reduction activity at typical diesel engine exhaust temperatures from 150°C to 550°C also investigated.

Servati et al (2005) investigated the performance of a selective catalytic reduction after treatment system designed for diesel retrofit applications. They stated that the system consisted of a catalyzed diesel particulate filter, a SCR catalyst system and a diesel oxidation catalysts. It was stated that, as part of the system a compact air assisted dosing unit was developed for effective urea delivery and atomization. It was concluded that an overall NOx reduction of 70% was achieved.

Itabashi et al (2005) developed a system that simultaneously reduced NOx and particulate emission from diesel engine. They stated that the experimental system consisted two DPNR, catalysts arranged in parallel, each provided with an exhaust throttle valve downstream to control the exhaust gas flow to the catalyst, plus a fuel injector that precisely controls the air fuel ratio and the catalyst bed temperature. It was stated that the fuel injector supplied a rich mixture to the DPNR catalyst, and the exhaust gas was allowed to flow between the two catalysts by operating the exhaust throttle valves alternately. It
was found that there was an improvement in NOx reduction performance and a decrease in the loss of fuel economy from the NOx reduction. It was also concluded that the investigation had yielded basic data on the use of DPNR catalysts in commercial vehicles.

Nishioka et al (2006) developed a urea dosing device with two injectors to enhance the NOx reduction at low exhaust temperatures and also to lower the electric power consumption of the SCR system. They stated that the injectors were made to operate with a single phase urea solution, without air assistance. It was stated that one injector was located on the wall of the main exhaust duct for directly supplying urea to the exhaust and the other injector was used to supply urea to a bypass passage connecting the exhaust during low exhaust temperatures. It was also concluded that to overcome the problem of uniform spray distribution, a set of impact plates were used.

Acharya et al (2006) studied the impact of nitrogen dioxide on the ammonia consumption, production of nitrous oxide by developing a commercial urea selective catalytic reduction system having twin catalytic reactors used in series. It was stated that the aqueous urea solution was injected into the exhaust by using a twin fluid, air assisted atomizer. It was also stated that NO2 was used to oxidize particulate matter. It was concluded that a significant effect of NO2 on the overall performance and efficiency of the SCR system was achieved. It was also concluded that the urea SCR catalyst had higher selectivity for NO2 than NO and in the presence of NO2 the NH3 requirement for complete removal of NOx was changed.

Kawano et al (2007) investigated the NOx emission in a diesel engine using urea SCR system. They stated that, in order to get maximum reduction of NOx, enhanced insulation on diesel oxidation catalyst aggressive urea solution injection and idling stop installation were carried out. It was concluded that, with
the combination of these three measures, NOx was drastically reduced to the levels lower than 0.7 g/kWh, which is a NOx limit value of the Japanese 2009 emission regulation. It was also concluded that the unregulated harmful components NH3 and HCN were found emitted at very low levels.

Lee et al (2008) investigated the performance of urea SCR system using flow visualization techniques in a heavy duty diesel engine to determine the optimal urea injection condition. It was stated that a parametric study was conducted on gas temperatures, space velocity and aspect ratio. It was also stated that the urea injector was located at the opposite direction of exhaust gases emitted into an exhaust duct. It was further told that the optimal quantity of urea and its conversion efficient was estimated at each mode of ND-13 modes.

Murata et al (2008) investigated the performance of urea-SCR system combined with a diesel particulate filter system to reduce NOx and PM in a four liters turbocharged with intercooler diesel engine. They reported that significant NOx reduction was observed at low exhaust gas temperatures by increasing NOx reduction was observed at low exhaust gas temperatures by increasing NH3 adsorption quantity in the SCR catalyst. It was concluded that they have developed a urea SCR system that could reduce NOx by 75% at the average SCR inlet gas temperature of 158°C by adopting the NH3 adsorption quantity control.

Rajadurai (2008) studied the effect of compact, knitted, crimped wire mesh mixer fixed between the reducing agent injection and the urea SCR unit of a diesel engine. It was reported that the modified geometry and channel dimensions of the wire mesh provided zigzag path for the gas flow to obtain efficient mixing and it enhanced thermolysis of urea into ammonia and isocynamic acid. It was concluded that about concluded that the CFD model confirmed improved uniformity index from 0.94 to 0.99 within 35mm travel
length due to longitudinal and radial flow of the exhaust gas through the body of the wire mesh mixer.

Ken-ichi et al (2009) developed resistive electro chemical sensor based on vanadium oxide equipped with a pair of inter digital AU electrodes which can detect NH$_3$ gas selectivity at high temperature. It was stated that various electromagnetic sensors were used in the investigation. It was also stated that the NH$_3$ addition in a base gas increased the relative conductance. It was concluded that, among the samples tested. Al and Ce co doped sample was found to be the most suitable sensor. It was also concluded that the presence of water vapor did not markedly decrease the response magnitude but increased the response rate.

**PWEO AS AN ALTERNATE FUEL TO DIESEL**

Most of the research studies have indicated the need for research in the area of engine modification so as to suit the higher blends or pure biodiesel without any drastic change in performance, emission and combustion characteristics. In a similar research, repeated without any engine modification, pure biodiesel and its blends showed inferior performance, combustion and emission characteristics compared to the diesel fuel.

Karhale et al (2006) concluded that the thermal efficiency of the diesel engine fuelled with biodiesel is always less than that of diesel. Due to the variation in the basic properties of diesel and biodiesel the original design parameter of the diesel engine is not suitable for biodiesel fuel, for getting efficiency comparable to diesel. Therefore, engine modifications are needed in order to get the same efficiency comparable to diesel. Therefore, engine modification is needed in order to get the same efficiency for biodiesel as compared to diesel. The fuel air mixture formation and the ignition delay are the major factors which determine the overall efficiency of the engine. Hence,
modifying the engine parameters such as the injection pressure, fuel injection timing, compression ratio, injection rate and air swirl level of diesel engine have been reviewed in the following paragraphs.

Venkanna et al (2009) investigated the effect of injection pressure on direct injection diesel engine performance, emission and combustion characteristics using Honge oil blends. Four different injection pressures from 200 bar to 275 bar in the increments of 25 bar were employed for an experimental study. It was found that there was a significant improvement in performance, emission and combustion characteristics of diesel engine using 30% honge oil blend along with diesel at 225 bar injection pressure operation.

Sukumar Puhar et al (2007) studied the effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine at different injection pressure. The test results showed a reduction in CO, HC and smoke emission with a slight increase in NO emission at 240 bar injection pressure when compared to diesel. Similar brake thermal efficiency and shorter ignition delay was also observed when compared to diesel.

Several experimental studies have revealed that the injection timing influences the emission profile of the diesel engine while using biodiesel. Bari et al. investigated the effect of advanced injection timing of DI diesel engine using waste cooking oil and diesel. The results revealed that the advancing injection timing of 4 BTDC to 15 BTDC reduced the CO emission by 9.9% whereas NO emission increased by 77.6% for WCO compared to diesel. Aktas and Sekmen studied the effect of advanced injection timing on the CO, NO and HC emission of a DI diesel engine fuelled with biodiesel. Three different injection timings were used. When injection timing was advanced to 26 BTDC, lower CO and HC emission was noted but there was slight increase in NO emission from 4 to 11%.
Nwafor et al. (2000) investigated the effects of advancing injection timing on the HC emissions of a DI diesel engine using rapeseed oil. Advancing injection timing from 30 BTDC to 33.5 BTDC reduced the CO, CO2 and HC emission when compared to diesel. They also found that the longer delay period and slower burning rate of vegetable oil caused the late combustion in expansion stroke which was expected to be compensated by advancing injection timing. Furthermore, it was observed that a moderate injection advance was recommended for smooth engine operation at low speeds.

Narayana Reddy & Ramesh (2010) carried out an experimental investigation on a single cylinder, direct injection diesel engine fuelled with jartopha oil by varying injection timing, injection opening pressure, injection rate and air swirl level. They reported that advancing the injection timing from 30.5 BTDC to 33.5 BTDC and increasing injection pressure from 205 to 220 bar resulted in an improvement in brake thermal efficiency and reduction in hydrocarbon and smoke emissions. An improvement in the heat release rate and reduction in ignition delay was also observed at same operating conditions. But enhancing the swirl level did not improve brake thermal efficiency and slightly reduced HC and smoke emissions. It was reported that the injection timing was restarted from 33.5 to 32 BTDC with enhanced injection rate using 9mm plunger diameter, a significant improvement in brake thermal efficiency by 3.2% and reduction in HC, NO and smoke emission by 266ppm,608ppm and 0.7 Bosch smoke unit(BSU) respectively were noticed when compared with diesel.

Similar study was presented by Banapurmath et al (2009) with varying injection pressures and timings on a single cylinder DI diesel engine using honge oil, its ester and blends with diesel fuel. Experiments were carried out with three injection timing of 19 23 and 27 BTDC and five injection pressures of 205, 220, 240, 260 and 280 bar at various loads on a constant speed of 1500 rpm. Optimum injection pressure of 260 bar and injection timing of 19 BTDC exhibited better
performance characteristics and reduction in HC, CO and smoke emission for honge oil and honge oil methyl ester operation. However, a marginal increase in NO emission was also observed.

Ismet Celikten et al (2010) compared the performance and emission characteristics on four cylinder, diesel engine fuelled with diesel fuel, rapeseed and soybean oil methyl ester at different injection pressure from 250 bar to 350 bar in the interval of 50 bar. The reported that the performance and emission values of rapeseed and soybean oil methyl ester were found to be nearly same with those of diesel when injection pressure was increased to 300 bars. Rapeseed and soybean biodiesel have less carbon monoxide and smoke level than diesel fuel but have higher NOx emissions for all injection pressures.

Leung et al (2008) examined the effects of varying injection timing, plunger diameter and injection pressure on NOx particulate matter and HC emission of a single cylinder DI diesel engine fuelled with recycled oil biodiesel. The cross interaction effects of three parameters on combustion characteristics were also studied. The results revealed that larger plunger diameter and high injection pressure shorten the injection duration. Regarding fuel injection timing had an obvious effect on NOx reduction. The retarding timing and rapid diffusion combustion was found to be a suitable strategy to improve biodiesel fuelled engine performance and combustion characteristics. The multi parameter engine adjustment with the consideration of their cross interaction effects can keep the benefit of reducing PM and HC without increasing NOx emission and sacrificing fuel combustion efficiency.

Jindal et al (2007) studied the effect of compression ratio and injection pressure in a DI engine fuelled with jatropha methyl ester. Performance tests were carried out at three injection pressures and three different compression ratio for a constant speed of 1500 rpm. It was found that for all combination of
compression ratio and injection pressure, biodiesel showed the reduction in HC, NOx smoke opacity and exhaust temperature compared to diesel fuel. Based on lower emissions and better performance characteristics, the compression ratio of 18:1 with injection pressure of 250 bar was found to be optimum for biodiesel.

Peng ye & Andre L Boehman (2009) analysed the impact of engine injection strategy such as injection pressure, advancing injection timing and injection duration on the NOx emission from a common rail turbocharged DI diesel engine fuelled with soybean based biodiesel and its blend with ultra low sulfur diesel. They reported that either an increase of injection pressure or an advance of injection timing can significantly increase NOx emission with no significant difference in brake fuel conversion efficiency. Moreover, the heat release rate analysis showed a faster and premixed combustion at higher injection pressure which resulted in increased NOx emissions.

Raheman & Ghadge (2007) examined the performance of diesel engine with mahua indica oil based biodiesel and its blends at varying compression ratios and injection timing from 35 BTDC to 45 BTDC in the interval of 5 BTDC. They found that the performance of the engine such as brake specific fuel consumption, exhaust gas temperature increased whereas brake thermal efficiency reduced with increase in biodiesel percentage in the blend irrespective of all compression ratio and injection timing. At compression ratio of 20:1 and injection timing of 40 BTDC, pure mahua oil biodiesel produced comparable performance with diesel.

Cenk Sayin et al (2010) experimented on a DI engine using canola oil methyl ester diesel fuel blends with different timing from 15 BTDC to 25 BTDC in the interval of 5 BTDC. They reported that the canola oil methyl ester diesel blends exhibited reduction in smoke, CO, HC emission while increase in NO emission compared to diesel at standard injection timing of 20 BTDC.
Advancing injection timing of 25 BTDC showed a decrement in smoke CO HC and a significant rise in NO and CO₂ emission for canola oil methyl ester. Retarding the injection timing of 15 BTDC produced the minimum NO and CO₂ emission for all the blends. They also reported that the retarded injection timing of 15 BTDC leads to later combustion and therefore cylinder pressure increases only when cylinder volume becomes higher and results in a reduced effective pressure to do work.

2.2 SCOPE OF THE PRESENT WORK

The use of fossil fuel is increasing drastically due to its consumption in all consumer activities. The high utility of fossil fuel depleted its existence, degraded the environment and led to reduction in underground carbon resources. Hence the search for alternative fuels is paying attention for making, sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced now a days. The world wide reduction of underground carbon resources can be substituted by the bio-fuels. The SI and CI engines are the major contributors of the GHG.

The main researchers around the world are finding the alternate fuel that should have the least impact on the environmental degradation. Rudolf Diesel patented an engine design for used dual fuel system. The present fuel system involves the adaptation of Rudolf with diesel as a single fuel. The emission of COₓ is unavoidable in fuel combustion systems. This investigation has mainly focused to develop a three fuel system without additives in conventional C.I engines to achieve biofuel and to reduce emission of pollutants.

In addition to the above an attempt has been made to utilize purified waste engine oil combined with 30% diesel (PWEO) as an alternate to conventional diesel has to be explored due to the lack of information on PWEO
based fuels. Orhan Arpa (2010) has reported the use of PWEO with out blending with diesel and studied the engine performance and exhaust emissions. It is to be believed that the produced PWEO could be useful in diesel engines without any problem in terms of engine performance. The PWEO is expected to increase torque, brake mean effective pressure, brake thermal efficiency and decreases brake specific fuel consumption of the engine for full power of operation in comparison with results those reported earlier.

2.3 SUMMARY

A through literature survey has been carried out for the development of three fuel system to increase the efficiency of a engine with minimal emission of pollutants. The detailed survey explored that the utility of dual fuel system coupled with vegetable oils, use of metal catalyst and ion exchange bed catalyst effectively improved the engine efficiency. But they are viable for environmental concerns. Hence, experimentation will be carried out on the development of three fuel system and presented in chapter 3.