Chapter 1

Introduction

Energy has always played an important role in development of a country. It is considered as an index of economic growth and social development. The world primary energy consumption has increased very fast in recent past and the world energy demand could be 45% higher by 2030 than it is today. According to International Energy Agency (IEA) estimates 2008, Non-organization for Economic Cooperation and Development (OECD) countries are expected to contribute nearly 90% of total world energy demand growth. Fossil fuels are expected to provide the bulk of primary energy till 2030. Two factors are driving these figures population growth and mass. Estimates suggest that the global population will increase from today’s level of 6.7 billion to 9 billion by 2050. While short-term economic conditions may weaken global demand for primary energy temporarily where as the long term outlook remains one of substantial and sustained growth. Supply of energy is therefore, far less than the actual demand.

1.1 Energy state: Indian perspective

Although, India is rich in coal and abundantly endowed with renewable energy in the form of solar, wind, hydro and bio-energy. Its hydrocarbon reserve is only 0.7 billion tones which is very small (0.4 percent
of world's reserve). India accounted for 10.63% of total primary energy consumption. Per capita energy consumption remains low as 510 KGOE (Kilogram of oil equivalent) compared with a world average of 1820 KGOE. The distribution of primary energy in India vis a vis world has been shown in Table 1.1

Table 1.1: Distribution of primary energy in India and world (MTOE)

<table>
<thead>
<tr>
<th></th>
<th>Oil</th>
<th>Natural Gas</th>
<th>Coal</th>
<th>Nuclear Energy</th>
<th>Hydro Electric</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>128.5</td>
<td>36.2</td>
<td>208.0</td>
<td>4.0</td>
<td>27.7</td>
<td>404.4</td>
</tr>
<tr>
<td>World</td>
<td>3952.8</td>
<td>2637.7</td>
<td>3177.5</td>
<td>622.0</td>
<td>709.2</td>
<td>11099.3</td>
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Oil and gas sector is one of the key catalysts in fuelling the growth of Indian economy. With 1.2 billion population and an economy that has consistently at approximately 8 per cent annually, India’s energy needs are increasing fast and a robust demand for oil and natural gas is felt in the country. India has emerged as the 5th largest refining country in the world, accounting for 4 per cent of the world’s refining capacity. India exported 50 million tonnes (MT) of refined petroleum products during 2010-12. With our refining capacity increasing further, this figure is likely to touch about 70 MT by 2014, making India one of the world’s major exporters of petroleum products.
India is fourth largest economy of world and uses energy extensively to sustain its growth. Since, India does not have huge reserves of petroleum products, it is heavily dependent upon the import of petroleum to cater its need for automobiles, agriculture, industries and other applications despite larger initiatives by government and exploration of new sources. Insufficient supply and limited reserves of petroleum have imposed an enormous burden on country’s foreign exchange.

Indian economy is essentially diesel driven and the consumption of diesel fuel is four to five times that of motor-gasoline. This trend is characteristically different from several developed economies. Thus, there is an urgent need to look for exploration and utilization of renewable alternative fuels for diesel substitution.

1.2 Energy demand in remote areas

The energy requirements of human being not only in cities have hiked. In rural areas the energy requirements to meet the livelihood and agricultural needs has become critical. One needs to differentiate between the energy security of rural and urban areas because energy dynamics of both the areas are different. Energy security perhaps is more important for the rural people because they are very vulnerable, marginalized and lack access to most of the basic resources. Majority of rural households in developing countries like India still depend on traditional fuels
like firewood to meet most of their daily energy requirements, supplemented by small amounts of kerosene and electricity for lighting.

1.3 Necessity of alternative fuels

The world is confronted with the twin crises of fossil fuel depletion and environmental degradation. The indiscriminate extraction and consumption of fossil fuels have led to a reduction in petroleum reserves. Alternative fuels, energy conservation, energy management, energy efficiency and environmental protection have become important in recent years. The increasing import bill has necessitated the search for liquid fuels as an alternative to diesel, which is being used in large quantities in transport, agriculture, industrial, commercial and domestic sectors. Jatropha biodiesel has been considered a promising option due to its typical fuel properties similar to diesel.

1.4 Use of biodiesel in diesel engine

Amongst the various alternative fuels which could match the combustion features of diesel oil at a relatively low price and can be easily adopted for use in existing engine technologies with or without any major modifications is biodiesel. The development of biodiesel as an alternative and renewable source of energy has become very important due to the fact that it can help in attaining much needed energy security and being environment friendly [4].
The increase in demand of high speed diesel, the upsurge in prices of diesel fuel, reduced availability and more stringent regulations on exhaust emissions have created serious concerns world over. Thus biodiesel produced from locally available resources offer a great promise for future application in this country. With the dramatic growth in use of internal combustion (IC) engines in recent years, the demand of conventional petroleum fuel and environmental degradation resulting from engine combustion can no longer be ignored. To provide long lasting solutions to these twin problems, the use of alternative fuels have been effectively utilized for partial or complete substitution of conventional petroleum fuels in IC engines. However, a long term regular use of alternative fuels requires identification of large and long – term resource base to ensure availability and justify investment. Such fuels should be renewable, and compatible for use in existing engines.

The CI engine due its inherent fuel economy, ease in operation free maintenance and long life finds the wide usage in the fields of transportation, power generation, agriculture, earth moving machines and several industries. Diesel emission contains carcinogenic components, such as carbonyl compounds (formaldehyde), light aromatic hydrocarbons (benzene), poly aromatic hydrocarbons (PAHs) and nitro- poly aromatic hydrocarbons. Diesel particles mainly consist of carbonaceous material, soluble organic fraction (SOF), sulphates and traces of metals [6]. Biodiesel is substantially non-petroleum, yield energy security and has environmental benefits. Identification of alternative to
conventional petroleum based fuels has been subjected to studies throughout the world. Thermodynamic tests based on the engine performance evaluation have established the feasibility of using a variety of alternative fuels such as hydrogen, alcohols, biogas, producer gas and various types of oils. However, in Indian context, the vegetable oils derived fuels can contribute significantly towards the problems related to food crisis.

Vegetable oil fuels are nearly CO$_2$ neutral and an important characteristic in the effort to combat greenhouse gas emissions. They are also virtually free of sulfur, which does not contribute to acid precipitation. In case of utilization of biodiesel (a derivative of vegetable oil), no major modification is required in the design of diesel engines [7]. Biodiesel can play a dual role in greenhouse gas mitigation and other climate change initiatives. It can act as a source of sustainable energy to substitute mineral diesel.

**1.5 Formation of nitrogen oxides**

The higher the compression ratio in a diesel engine and higher energy content of diesel fuel allow diesel engines are to be more efficient. The same factor that cause diesel engines to run at a higher temperature leading to pollution problem, particularly the creation of nitrogen oxides [11]. Fuel in any engine is burned with extra air, which helps in eliminating’s unburned fuel from the exhaust. When air is compressed inside the cylinder of the diesel engine, the temperature of the air increase to more than 1500°F. The air expands pushing the piston down and rotating crank shaft. Some amount of the oxygen is used to burn
the fuel, but the extra oxygen is supposed to just pass through the engine unreacted. Nitrogen, since it does not participate in the combustion reaction, also passes unchanged through the engine. When the peak temperatures are high enough for long periods of time, the nitrogen and oxygen in the air combines to form new compounds, primarily NO and NO₂ [9]. These are normally collectively referred to as NOₓ. In order establish the fact that are relevant to biodiesel and the emissions, further literature are reviewed in the chapter 2.
Chapter 2

Literature survey and objective of the work

An exhaustive literature has been carried out from several national and international journals and other sources before identification of the research problem. A critical review of all the relevant literature is being summarized below.

2.1 Vegetable oil as engine fuel

Experimental investigations have been carried on the use of vegetable oil in diesel engine and these fuels were found supplementary to diesel fuel especially in rural areas where there is actue need of modern energy [14-17]. Vegetable oils have equivalent ignition quality and combustion characteristics to diesel fuel, but their viscosities are very high making them unsuitable for modern fuel pump [18]. Vegetable oils have comparable energy density, cetane number, heat of vaporization and stoichiometric air fuel ratio with mineral diesel fuel [19]. Many researchers have made attempt to use vegetable oil in neat form in diesel engines. The vegetable oil combustion studies have found that the jatropha biodiesel to be used as fuel for diesel engine has not been found suitable for DI engines. It was reported that compared to commercial diesel fuel, all the vegetable
oils were much more viscous, much more reactive to oxygen and had higher cloud and pour points. The viscosities of vegetable oils were found to be length from 10 to 20 times greater than diesel fuel [20-26].

Increased carbon chain length and reduced number of double bonds were associated with increased oil viscosity, cetane rating and gross heat content. It was found that except for castor oil, there was little difference between gross heat content of any of the vegetable oils. Heat contents were approximately 88% of that of diesel. The high viscosity of biodiesel is basic cause of poor combustion and atomization characteristics. The viscosity of jatropha is about 10-12 times the viscosity of diesel. The performance of a direct injection, 3-cylinder, 2600 series Ford tractor engine with 1:3 (v/v) blends of soybean oil and sunflower oil with diesel fuel for 200h has been evaluated. After the 200-h test it was concluded that as far as power output, thermal efficiency and lubricating oil data were concerned, the 1:3(v/v) blends of soybean oil and sunflower oil with diesel fuel performed satisfactory. However, when the general condition of the combustion chamber and fuel injectors after 200-h of operation were considered, the performance was not satisfactory. All combustion chamber parts and injector tips were coated with carbon deposits. They suggested that different operating conditions or modification of vegetable oils could help in improving the conditions of the engine.

The use of straight vegetable oils as a fuel for compression ignition engines is restricted by some unfavorable properties, particularly their
viscosity. The higher the viscosity of straight vegetable oils cause poor fuel atomization which leads to incomplete fuel combustion and carbon deposition on the injector and valve seat resulting in serious engine fouling. The inefficient mixing of oil with air contributes to incomplete combustion, leading to heavy smoke emission, and the high flash point attributes to lower volatility characteristics. These disadvantages, coupled with the reactivity of unsaturated vegetable oils, do not allow the engine to operate trouble free for longer period of time. The best way to overcome vegetables problems associated with use of vegetables in diesel engine is the catalytic transesterification of triglycerides with alcohols to form monoalkyl esters of long- chain fatty acids (or biodiesel), which has quite similar to hydrocarbon -based diesel fuels.

Ren et al. [60] reported problems of high emissions and low brake thermal efficiency with the use of vegetable oils in the diesel engine. Pramanik [54]. prepared blends of varying proportions of jatropha curcas oil and diesel and compared the performance characteristics with diesel fuel in a single cylinder CI engine. Acceptable thermal efficiencies of the engine were obtained with blends containing up to 50% volume of jatropha oil. Rakopoulds [55]. reported use of 25/75 and 50/50 blends (v/v) of olive and commercial diesel fuel in DI and IDI diesel engines with swirl combustion chambers. A small penalty in specific fuel consumption and essentially unaltered maximum pressures and moderate increases in the exhaust smoke were reported. There were moderate
decreases in emitted NO\textsubscript{X} and increase in HC as well as negligible increases in CO.

Forson et al. [56] used jatropha oil in proportions of 97.4% / 2.6%, 80% / 20% and 50% / 50% (diesel / jatropha oil by volume) in CI engine. It was found that the carbon dioxide emissions were similar for all fuel blends. The test further showed increases in brake thermal efficiency, brake power and reduction of specific fuel consumption for jatropha oil and its blends with diesel fuel but the most significant conclusion observed from the study was that the 97.4% diesel/2.6% jatropha fuel blend produced maximum values of brake power and brake thermal efficiency as well as minimum values of the specific fuel consumption. The 97.4%/2.6% fuel blend yielded the highest cetane number and even better engine performance than the diesel fuel. It was suggested that jatropha oil can be used as an ignition accelerator additive for diesel fuel.

2.2 Biodiesel as engine fuel

Vegetable oils are chemically complex esters of fatty acids. These are the fats naturally present in the oil seeds, and known as tri-glycerides of fatty acids. Biodiesel can be produced by different pathways. The transesterification methods both chemical and enzymatic have been reviewed extensively. The production of biodiesel can be carried out by base catalyzed transesterification or acid catalyzed transesterification process of vegetable oil or fat. However, base catalyzed transesterification reaction is generally preferred because of low temperature and pressure conditions, high yield with no
intermediate compounds. Some of the prominent aspects of utilization of biodiesel made from different vegetable oils in diesel engines is presented below [10].

Voleti. R. S et al. [27] the effects of jatropha on the performance and emissions of a single cylinder, water cooled diesel engine. Experimental results showed that the engine works smoothly on neat biodiesel with performance comparable to diesel fuel operation. Neat biodiesel results in a slightly increased thermal efficiency as compared to that of conventional diesel fuel. The exhaust gas temperature was decreased with neat biodiesel as compared to diesel fuel. CO₂ emission was low with neat biodiesel compared to diesel fuel. CO emission was low at higher loads for neat biodiesel when compared with diesel. NOₓ emission was slightly increased with neat biodiesel compared to diesel fuel. There was significant difference in smoke emissions when neat biodiesel was used. Smoke was increased with increased in brake power. Smoke emission was lesser for blended jatropha biodiesel compared to diesel fuel. When percentage of blend biodiesel increased, smoke density decreased, but smoke density increased for JB 50 and JB 75 due to insufficient combustion.

Rao et al. [28] used single cylinder, water cooled, DI diesel engine used to investigate the performance and emission characteristics of jatropha and other two types of non-edible oils on diesel engine. They observed slight drop in thermal efficiency with methyl esters when compared with diesel. Biodiesel gave less smoke density compared to petroleum diesel. When
percentage of blend biodiesel increases, smoke density decreases, but smoke density increased for JB80 and neat biodiesel due to insufficient combustion. Smoke, HC, and CO emissions at different loads were found to be higher for diesel, compared to JB 10, JB 20 and JB 40. Good mixture formation and lower smoke emission were the key factors for good CI engine performance. These factors are highly influenced by viscosity, density, and volatility of the fuel. For biodiesels, these factors are mainly decided by the effectiveness of the transesterification process.

Banapurmath et al. [29] carried out experiments by using a single cylinder, direct injection and air cooled diesel engine fuelled with neat biodiesel. The experiments result presented that was neat biodiesel had a thermal efficiency lower than diesel fuel. Also observed, neat biodiesel had slightly higher smoke emissions than diesel fuel.

Sahoo et al. [30] investigated that polanga biodiesel oil in a single cylinder diesel engine. The 100% biodiesel was found to be the best, which improved the thermal efficiency of the engine by 0.1%. The performance of biodiesel-fueled engine was marginally found better than the diesel-fueled engine in terms of thermal efficiency, brake specific energy consumption, smoke opacity and exhaust emissions including NOX emission for entire range of operations. They concluded that excess oxygen content of biodiesel played a key role in engine performance. Puhan et al. [31] tested mahua oil biodiesel and found specific fuel consumption higher than diesel and thermal efficiency lower than diesel. This was attributed to lower heating value of the ester. Exhaust pollutant
emissions are reduced compared to diesel. Carbon monoxide, hydrocarbon, smoke number, oxides of nitrogen were reduced 30%, 35%, 11% and 4% respectively, compared to diesel. They concluded that mahua oil methyl ester could be used as alternative fuels in a diesel engine instead of diesel fuel. They also found that NO\textsubscript{X} levels could be reduced without significant smoke increase when injection timing was retarded also the biodiesel fuel consumption was lower by 3% compared to operation without EGR.

Melisa et al. [32] tried reformulated soy-based biodiesel in diesel engine to reduce nitrogen oxide emissions. Using either isomerized soy biodiesel, at 20% blend level in petroleum diesel, nitrogen oxide emissions were elevated by between 1.5 and 3 percentage points relative to the combustion of a JB 20 blend of commercial diesel. Nitrogen oxide emissions were reduced in proportion to blend level during the combustion of biodiesel, with a 20% blend in petro diesel resulting in a reduction of about 4.5 percentage points.

Carraretto et al. [37] investigated use of biodiesel on six cylinders direct injection diesel engine, widely installed on local urban buses and found that performances are slightly reduced, while specific fuel consumption is notably increased using biodiesel. CO emissions are reduced but NO\textsubscript{X} are increased. They also concluded that due to the detergent properties of biodiesel tanks have to be carefully cleaned before storage, also some resistant materials like Viton or Teflon should be used since the fuel is not compatible with some plastic materials used in pipes and gaskets.
Szybist et al. [38] concluded in a review that more emissions of NO\(_X\) effect can be circumvented successfully by additization with cetane improver, shifting the injection timing to compensate for the advance caused by the fuel. Biodiesel, like other oxygenated diesel fuels, can reduce the amount of soot formed in the diesel spray flame and can lead to reduce the amount of soot formed in the diesel spray flame and can lead to reduced total particulate emissions.

Mustafa [39] found significant reductions in PM, CO, and unburned HC, while NO\(_X\) increased by 11.2\% in soybean biodiesel. Biodiesel had a 13.8\% increase in brake –specific fuel consumption due to its lower heating value. Caye et al. [35] prepared biodiesel through transesterification from wasted cooking oil and tested it in diesel engine. They concluded that JB 20 and JB 50 are the optimum fuel blends.

Ranja et al. [47] prepared methyl ester biodiesel from hazelnut soap stock or waste sunflower oil. Experimental results showed that the hazelnut soap stock or waste sunflower oil methyl ester can be partially substituted for the diesel fuel at most operating conditions in terms of the performance parameters and emissions without any engine modification and preheating of the blends.

Magin et al. [41] tested two different biodiesel fuels, obtained from waste cooking oils with different previous uses and under a set of engine operating conditions corresponding to typical road conditions on a direct injection diesel commercial engine either pure or in 30\% and 70\% v/v blends with
reference diesel fuel. They observed sharp decrease in both smoke and particulate matter emissions as the biodiesel concentration was increased, mean particle size was also reduced. Nwafor [18] investigated the influence of biodiesel from rapeseed oil on the injection, spray, and engine characteristics on a bus diesel engine with injection system and compared with mineral diesel under various operating regimes. They found that, by using biodiesel, harmful emissions (NO\textsubscript{X}, CO, Smoke and HC) was reduced to some extent by adjusting the injection pump timing. Kumar [19] investigated use of biodiesel produced from industrial grade rice bran oil using a two-step process. He found that biodiesel has better lubricity and ignition quality than petroleum diesel. He also found that brake power developed was lower than with biodiesel and fuel consumption higher as compared to diesel fuel.

Van Gerpen et al. [52] evaluated the impact of oxidized biodiesel on the engine performance and emissions. A Johan Deere 4276T turbocharged DI diesel engine was fueled with oxidized and un oxidized biodiesel and the performance and emissions were compared with diesel fuel. The objective of this Neat biodiesel, 20% blends, and the base fuel were tested at two different loads (100 and 200%) and three injection timings (3\textsuperscript{0} advanced, standard; 3\textsuperscript{0} retarded). The tests were performed at steady state conditions at a single engine speed of 1400 rpm. The engine performance of the neat biodiesel and their blend was similar to that of diesel fuel with the same thermal efficiency, but higher fuel consumption. Compared with un oxidized biodiesel, oxidized neat biodiesel
produced 15 and 16% lower exhaust carbon monoxide and hydrocarbons respectively. No statistically significant difference was found between the oxides of nitrogen and smoke emissions from oxidized and un oxidized biodiesel.

Madhumita Verma et al. [57] evaluate the suitability of using methyl ester of karanja oil in compression ignition engines. Physical and chemical properties of the karanja oil and that methyl ester have been determined.Maximum thermal efficiency of methyl ester has been determined and found to be slightly less than that of diesel.

Canakci.et al. [58] were chosen jatropha biodiesel as test fuel, because it is non-edible oil, which does not conflict with food industries. Jatropha biodiesel has good temperature property, compared to ordinary biodiesel feed stocks such as soyabean and rapeseed. Samion [59]. was focused to use jatropha biodiesel as a blend with conventional diesel to improve its properties to be close to ordinary diesel fuel The blending percentage was denoted by JB 5 and JB 20. The properties of diesel fuel and jatropha biodiesel blends were measured and determined. The brake specific fuel consumption of biodiesel of karanja is slightly as higher as compared to diesel. Carbon monoxide, hydrocarbon and NO emission of methyl ester and blends have been determined and compared to that of the diesel. It appears that methyl ester of karanja oil is a suitable substitute of petroleum diesel fuel.

Goering et al. [95] used hybrid fuels, formed by micro emulsifying aqueous ethonal in soybean oil, and evaluated it by burning them in a
diesel engine. They found that the blended fuels performed nearly as well as diesel despite having lower cetane numbers and less energy content. But they concluded that hybrid fuels are currently too expensive to compete with diesel fuel but could serve as an emergency fuel if petroleum supplies were interrupted. Van Gerpen et al. [91] investigated the effect of oxidized biodiesel on engine performance and emission parameters. Compared with un oxidized neat biodiesel produced 15 and 16% lower exhaust carbon monoxide and hydrocarbons respectively and reported decreases in smoke, HC and CO emission levels with oxidized biodiesel as compared to baseline diesel results. Krishnan et al. [96] studied biodiesel does not contain any aromatic components with low sulphur content produces low exhaust emissions, sulphur dioxide and lower aromatic HC emissions.

2.3 Engine emission with EGR

Tsolakisure et al. [45] studied the application of exhaust gas fuel reforming in engines fuelled with a mixture of 50% ultra-low sulphar diesel and 50% RME (B50). They found that REGR (Reformed Exhaust Gas Recirculation) addition to the biodiesel fuelled engine resulted in lower smoke emissions compared to engine operation with standard EGR. They also found that NOX levels could be reduced without significant smoke increase when the injection timing was retarded also the biodiesel fuel consumption was lower by 3% compared to operation without EGR.
Prasad et al. [46] conducted experiments on a single cylinder direct injection diesel engine fuelled with mahua methyl ester (MME) biodiesel combined with cold EGR to investigate the engine performance and exhaust emissions. The rating of EGR stopped at 15% where abnormal increase in CO and smoke was observed. Exhaust gas temperature has increased with increasing EGR rate. When the EGR system was used along with the MME, it would cause dilution of the charge as well as decrease in the intake air so that NO\textsubscript{X} decreased when EGR percentage increased. However, engine performance was unstable due to insufficient oxygen and CO and hydrocarbon (HC) emissions increased to high levels. At full load, MME along with 15% EGR has shown lowest NO\textsubscript{X}, but at that percentage, HC and CO emissions were higher.

Rajan et al. [47] study involved a twin cylinder, natural aspiration, water cooled, DI diesel engine that was used for conducting test with Sunflower methyl ester biodiesel blended with diesel fuel and combined with EGR technique. Higher amount of smoke in the exhaust was observed when the engine was operated with EGR compared to without EGR. Moreover, smoke and CO emissions were increased with increasing engine load and EGR rate. Observed NO\textsubscript{X} emissions in case of blended biodiesel JB20 and JB40 have 25% and 14% lower NO\textsubscript{X} emissions respectively with full load at 15% EGR, when compared to using diesel fuel without EGR. They concluded that engine operations with biodiesel while employing EGR were able to reduce 25% NO\textsubscript{X}
with expenses of reduction in brake thermal efficiency and increases in smoke, CO and unburned hydrocarbon were observed compared to diesel fuel.

Kim et al. [48] investigated the effect of variable EGR rate on engine performance and exhaust emissions. Experiments were carried out using a single cylinder, direct injection diesel engine fuelled with Soybean biodiesel. Experiments result showed that, EGR was effective to control NO\textsubscript{X} emissions. However, the EGR has brought about an increase in particulate matters (PM) resulting from the lowered oxygen concentration in the combustion flames. By comparing the combustion characteristics of diesel and biodiesel fuel under different EGR rate of 0% and 30%, biodiesel fuel showed less sensitivity to EGR on the combustion characteristics. Y. Y. shimoto et al. [49] investigated the effects of hot EGR combined with pure jatropha biodiesel (JB100) on engine performance and exhaust emissions. A single cylinder, water cooled, direct injection diesel engine was used for their experiments. The results showed that, at 15% EGR, the brake thermal efficiency at full load was found to be 30% and 32% for JB100 and diesel, respectively. Brake specific energy consumption of biodiesel was slightly higher for all levels of EGR compared to corresponding diesel values. Smoke opacity values higher than 60% were observed for EGR levels of 20% and 25% for both fuels. Higher values of CO were observed at full load for both fuels beyond 15% EGR. They concluded that hot EGR at 15% effectively reduced nitrogen oxide emission without much adverse effect on the performance, smoke and other emissions. A practical problem in fully exploiting EGR is that, at very high levels, EGR suppresses flame speed sufficiently that
combustion becomes incomplete and unacceptable levels of PM and HC are released in the exhaust. Therefore, by using EGR there is a trade of between reduction in NO\textsubscript{X} emission and increase in soot, CO, and HC emissions.

Pradeep et al. [50] investigated the effects of Hot EGR combined with pure jatropha biodiesel (JB100) on engine performance and exhaust emissions. A single cylinder, water cooled, direct injection diesel engine was used for their experiments. The results showed that, at 15% EGR, the brake thermal efficiency at full load was found to be 30% and 32% for JB100 and diesel, respectively. Brake specific energy consumption of biodiesel was slightly higher for all levels of EGR compared to corresponding diesel values.

Ramadhas et al. [51] reported that smoke opacity values higher than 60% were observed for EGR levels of 20% and 25% for both fuels. Higher values of CO were observed at full load for both fuels beyond 15% EGR. They concluded that hot EGR at 15% effectively reduced NO\textsubscript{X} emission without much adverse effect on the performance, smoke and other emissions.

Ren Y et al. [60] were observed that biodiesel blends produced higher BTE than that of diesel fuel, at all operating conditions. The BTE improved with increasing biodiesel amount in the blends. At 0% EGR the highest improvement of brake thermal efficiency was achieved with JB 20 compared to the baseline value. Choi et al. [61] uses EGR 5%, the BTE improvement may be due to re burning of un burned hydrocarbons which enters the combustion chamber with recirculated exhaust gases. From earlier studies, Mohan et al. [62] on performance of DI and IDI diesel engines with biodiesel, the experiments
results showed that the exhaust of IDI engine was less smoky when compared to DI engine. The lower pollution levels were achieved in IDI engine with biodiesel and IDI engine operation with biodiesel can be regarded as eco-friendly performance. IDI engine fuelled with biodiesel not only improves the BTE but also tremendously decreases the gummy particles. Hence, this thesis also used an indirect injection diesel engine for low production of smoke emission. It was investigated that the retarded injection timing is necessary when using jatropha biodiesel in order to reduce NO$_X$ emission without worsening other engine characteristics. Results indicate improved performance with the application of preheated biodiesel. The only penalty for using preheated biodiesel is the increase of smoke opacity. A significant reduction in CO and PM was obtained with JB 100 and JB 30 with an increase in NO$_X$ than diesel.

L. Yokoto et al. [64] reported on a single cylinder DI diesel engine with various combinations of EGR rates, fuel pressures, injection timing and intake gas temperatures affect exhaust gas emissions and they found that NO$_X$ reduction ratio has a strong correlation with oxygen concentration regardless of injection pressure or timing. NO$_X$ reduction ratio is indirect proportion to intake gas temperatures. EGR may adversely affect the smoke emission because it lowers the average combustion temperatures and reduces the oxygen intake gases, which in turn keeps soot from oxidizing. Also they suggested that for a given level of oxygen concentration the cooled EGR reduces more NO$_X$ with less EGR rates than does at hot EGR. S. Akther et al. [65] investigated that NO$_X$ emission
was slightly lower and carbon monoxide emission almost identical or slightly lower for biodiesel blends than that of diesel for distinct exhaust gas recirculation rate.

V. Pradeep et al. [66] investigated BTE of a direct injection diesel engine with biodiesel with hot EGR. At 15% exhaust gas recirculation rate gave the maximum reduction of NO\textsubscript{X} emission with minimum possible carbon monoxide, carbon dioxide, un burnt hydrocarbon and smoke opacity exhaust emissions and further increase in exhaust gas recirculation rate increases the NO\textsubscript{X} emission. H. Nagrajan et al. [67] studied on water cooled direct injection engine with distinct exhaust gas recirculation rates of hydrogen as a fuel, the results showed increase in BTE and lowered NO\textsubscript{X} emissions, smoke opacity level and particulate matter due to absence of carbon in hydrogen fuel.

Sinha et al. [68] conducted tests to investigate the usage of biodiesel and EGR simultaneously in order to reduce the emissions of all regulated pollutants from diesel engines. A two- cylinder, air-cooled, constant speed direct injection diesel engine was used for experiments. HCs, NO\textsubscript{X}, CO and smoke of the exhaust gas were measured to estimate the emissions. Exhaust gas recirculation process (EGR) reduces NO\textsubscript{X} from diesel engines by lowering the flame temperature and oxygen concentration in the combustion chamber. However, EGR results in higher particulate matter (PM) emissions. Thus, the drawback of higher NO\textsubscript{X} emissions while using biodiesel may be overcome by employing EGR. Qi. D. H et al. [69] performed series of test on various engine
performance parameters such as thermal efficiency, brake specific fuel consumption (BSFC) and brake specific energy consumption (BSEC), etc. were calculated from the acquired data. Application of EGR with biodiesel blends resulted in reductions in NO\textsubscript{X} emissions without any significant penalty in PM emissions or BSEC.

V. Panth et al. [70] investigated the effects of hot EGR along with JB 100 on the engine performance and exhaust gas emissions. A single cylinder, water cooled, direct injection diesel engine was used for experiments. The results showed that smoke opacity values were higher than 60%, 20% and 25% EGR rates for both fuels. At full load, higher values of CO were observed beyond 15% EGR, for both fuels. The study concluded that 15% of hot EGR rate effectively reduced NO\textsubscript{X} emission without much adverse effects on the performance, smoke, and other emissions. P.V. Babu et al. [71] investigated reduction of NO\textsubscript{X} from DI diesel engines fuelled with mahua methyl ester (MME) along with EGR. A single cylinder, DI diesel engine connected with cooled EGR system used for experiments. The results of experiments showed that at full load condition, abnormal increase in CO and smoke emissions occurred over 15% EGR rate. When EGR system was used with MME, NO\textsubscript{X} emission decreased with increasing EGR rates. The engine performance unstable due to insufficient oxygen, CO and HC emissions increased to high levels. At full load condition, MME along with 15% EGR showed lowest NO\textsubscript{X} and CO emissions were high.
S. Kumar et al. [72] studied the effects of EGR on the performance and emission characteristics of a compression ignition engine fuelled with sunflower biodiesel. The study involved a twin cylinder, natural aspiration, water cooled, DI diesel engine was used for experiments. Sunflower biodiesel was blended with DF different percentages, denoted by JB 20 (20% biodiesel by volume blended with 80% diesel fuel) and JB 40. When EGR was operated, it was observed higher amount of smoke emission in the exhaust compared to without EGR case. Smoke emission was increased with increasing engine load and EGR rate. At full load condition with 15% of EGR rate, JB 20 JB 40 emitted NO\textsubscript{X} was lower by 25% and 14% respectively compared to diesel fuel without EGR. The use of EGR with biodiesel was able to reduce NO\textsubscript{X} emissions at the expense of increase in smoke, CO and unburned HC emissions.

Thomas et al. [73-74] have studied the thermal efficiency decreased with increasing exhaust gas recirculation rate compared without using EGR rate for JB 5 and diesel fuel. The reduction in the BTE with EGR rate is due to the dilution of the fresh charge with exhaust gas which results in lower flame velocity and hence deterioration of the combustion. It was investigated that the effect of EGR system on engine performance and emission characteristics of JB 20, JB 40, JB 60, JB 80 and JB 100 and diesel fuel without EGR rates and with EGR rates. The performance parameters and NO\textsubscript{X} emissions are measured and recorded for diesel fuel, biodiesel and their blends. The results showed that at 15% EGR diesel, JB 20 at 25% EGR, JB 40 at 15% EGR, JB 60 at 20% EGR, JB
80 at 40% EGR and JB 100 at 5% the NO\textsubscript{X} emissions are effectively reduced by 10.1%, 11.94%, 13.4%, 15.2%, 19.85% and 24.8% respectively.

2.4 Catalytic converter emissions

Hans Bauer et al. [76] reported that the environmental degradation all over the world has led the researches to work towards the development of emission vehicles and ultra-low emission vehicles. Automobile vehicles emit substantial quantities of hydrocarbon (HC), Carbon monoxide (CO) and particulate matter. Oliver J et al. [77] in their experiments they reported that catalytic exhaust controls are generally recognized to be the most cost effective way to reduce emission. Catalytic exhaust control technology uses a precious metal catalyst to convert chemically the harmful components of the vehicle’s exhaust to harmless gases. This technology is capable of reducing HC and CO emissions in the range of 60 to 80 percent respectively and particulate matter more than 50 percent. The present generation of gasoline vehicles tested according the federal test procedure limits 70-80 percent.

Michael et al. [78] suggested that the performance of a three-way catalyst depends on numerous factors, the chemistry and the physics of the catalyst and the gas consumption, reaction temperatures and dynamic conditions. In order to create a catalyst with improved catalytic performance, while using less precious metal, it is essential to control the conversion reactions within the converter through surpassing the degradation of precious metals as much as possible. Stamatteols et al. [79] conducted tests to investigate that three-way
catalysts operate under at normal exhaust gas temperatures which in warmed-up gasoline engines, can vary from $280^\circ C$ to $430^\circ C$ during idle, even up to about $1000^\circ C$ to $1100^\circ C$, depending on the driving conditions. High operation temperatures should be avoided in order to prevent sintering of the precious metals and wash coat compounds. There are temperature and concentration gradients present in the catalytic converter, and the catalysts have to be thermally and mechanically stable against the physical and chemical changes to avoid deactivation. Zmudka et al. [80] reported that in automotive exhaust after treatment processes a range of advanced technologies is applied based on oxidation and three-way catalyst, adsorption, storage and filtration processes. This enables the reduction of carbon monoxide, hydrocarbons, nitrogen oxides and particulate emissions from a gasoline or diesel engine, to meet the demands of current and future exhaust emission regulations. Catalytic converters lower significantly toxic gases substance emissions as well as particulate mass in diesel engine exhaust gas up to 50% by destroying the organic fraction of the particulate.

Tomoaki Sunada et al. [81] described that an optimization of the catalyst structure that directs the flow of emissions using zone coating technology as a catalyst reaction control technology. According to them different coatings to different zones of the catalyst layer in order to convert the emissions of HC, CO and NOX from the engine with high efficiency. They also details the development of three-way catalyst degradation suppression control through catalyst zoning of the catalyst layer and the development of a carrier that dramatically suppresses Rh
grain growth. Robert et al. [82] investigated that the oxidation converter, the reduction catalyst converter helps eliminate hydrocarbons and carbon monoxide emissions and oxides of nitrogen emissions. Oxides of nitrogen emissions are produced in the engine combustion chamber when it reaches extremely high temperatures more than 2500°F, approximately. The concept of using catalyst near the engine manifold or in the vicinity of the vehicle fire wall to reduce the heat up time has been practiced.

Pesansky et al. [83] investigated the engines fitted with 3-way catalytic converters are equipped with a computerized closed loop feedback fuel injection systems, which is employing one or more oxygen sensors. While 3-way catalyst was used in an open loop system. NOX efficiency was lower by 28%. Within a narrow fuel air ratio band surrounding stoichiometry, conversion of all three pollutants is nearly complete. The reduction of NOX emission is favor, at the expense of CO and HC oxidation. Jonathan et al. [84] suggested that to reduce NOX on a compression ignition engine, the chemical composition of the exhaust must first be changed. They concluded that two main techniques are used selective catalytic reduction and NOX traps.

Kalpesh Chavda et al. [86] experiment is carried out on four stroke single cylinder compression ignition engine. The optimum values of exhaust emissions found at all load are HC (126 ppm), Carbon monoxide (0.03%). By using copper based catalytic converter it is found that HC is reduced by 33% and CO by 66% at full load. Manohar et al. [87] reported that emissions
of regulated compounds changed linearly with the blend level because conventional diesel fuel and biodiesel can be blended in every ratio. The known positive and negative effects of biodiesel varied accordingly and investigate the effect of catalytic converter emission performance with biodiesel blends.

Three way catalytic converters can store oxygen from the exhaust stream, usually when the air fuel ratio goes lean. When insufficient oxygen is available from the exhaust stream the stored oxygen is released and consumed. This happens either when oxygen derived from NO\textsubscript{X} emission reduction is unavailable or certain maneuvers such hard acceleration enrich the mixture beyond the ability of the converter to compensate. Rh as a catalyst to release the oxygen atoms stored in NO\textsubscript{X} in the reduction reaction. The oxygen atoms made available in the reduction process provide an oxidation environment to oxidize HC and CO. The three main harmful exhaust species, HC, CO, and NO\textsubscript{X} are either oxidized or reduced when passing through the catalytic converter.

The behavior of biodiesel in internal combustion engines is well documented in the literature. Engine performance is slightly lower when using biodiesel because of its lower heating value with respective to that of diesel fuel. The maximum NO\textsubscript{x} emissions were found for biodiesel fuel when compared to diesel and their blends. All biodiesel blends tests revealed that it can be safely used in the engine requiring no hardware modifications. Biodiesel has also showed interesting results when used three-way catalytic converter.
2.5 Need for present work

As the indirect injection medium speed diesel engine used in this work is primarily used by the farmers from long time in past. The affordability of the farmers for costly diesel is not good where as the need of diesel in increasing at rapid pace to meet the agricultural requirements. There are so many machines available by use of which the farming becomes easier so the farmers are attracted to use farming as their primary profession. These engines are significant contributors of oxides of nitrogen and particulate matter to ambient air pollutant inventories. The quantity of carbon monoxide and un burnt hydrocarbons is generally small. For this reason, the effect of biodiesel on particulate matter and oxides of nitrogen emissions is the primary concern. The emissions of particulate matter and oxides of nitrogen are more in jatropha biodiesel engines. The use of new technology and efficient methods are used to reduce the above pollutants and these machines will, increase the productivity which will enhance the prosperity of the nation.

All the machines used for forming or for the purpose of small scale industries established in rural areas need the engine to run it. The efficient utilization of jatropha biodiesel in those engines will facilitate the farmers to be self-dependent and increase their economy with lower emissions.
2.6 Objective of the research work

i. Test fuel characterization of jatropha biodiesel, diesel and their blends for a diesel engine with respect to emission reduction.

ii. Evaluation of exhaust emission of a diesel engine by using different blends of biodiesel, exhaust gas recirculation system and three-way catalytic converter.

iii. Comparative study and optimization of the operating condition for exhaust emissions of the diesel engine.