EMISSION CONTROL STUDIES OF CONVENTIONAL ENGINE FUELED WITH JATROPHA BIODIESEL, DIESEL AND THEIR BLENDS

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CERTIFICATE

Certified that the thesis entitled "Emission control studies of conventional engine fueled with jatropha biodiesel, diesel and their blends" being submitted by Mr. P. Suresh Kumar [P20109B015] in partial fulfillment of the requirement for the award of the degree of Doctor of Philosophy from University of Petroleum and Energy Studies is an authentic record of student's own research work carried out by him under my guidance and supervision. It is also to certified that this research work being submitted here as thesis, has attained the standard required for a Ph D degree from the University of Petroleum and Energy Studies. The results presented here have not been submitted to any other University/Organization or College, for any Degree, Diploma or Certificate.

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DECLARATION

It is hereby to declare that the Ph D dissertation entitled "Emission control studies of conventional engine fueled with jatropha biodiesel, diesel and their blends" which has been submitted to the faculty of College of Engineering (Mechanical Engineering Department), of the University of Petroleum & Energy Studies, , in partial fulfillment of the requirement for the award of the degree of Doctor of Philosophy, is an authentic record of my own research work. This research work has been carried out by me under the guidance of Dr. Pradeepta kumar sahoo. It is also to certify that this dissertation has neither been submitted for the award of any other Degree, in any other University/College, nor sent for publication to any organization.

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Executive Summary

Limited reserve of fossil fuel, fast depletion, unpredictable increase of crude oil prices, growing uncertainty over production and supply of crude oil are the current major concern in the area of use of fuels in IC engines. Keeping in view, the necessity of search for alternate fuel can cater the requirement of energy and environmental concerns. This fact becomes more important for the developing countries and the countries whose energy demands are met by some other countries. Majority of researches are centered towards generating the new source of energy in the form of alternative fuel based upon the physico chemical properties, emission characteristics, heating values etc. The existing engines are normally designed and manufactured in accordance with petro diesel as fuel. The suitability of fuel obtained from alternative source is yet to be studied whether the new source of fuel gives desired performance and emission characteristics. Currently jatropha based biodiesel is receiving attention as an alternative fuel for diesel engine.

In the present study a medium capacity IDI (indirect injection) diesel engine test setup was developed to study the performance and emission characteristics. The major objective of this study is to reduce the emission without compromising the performance of the engine fueled with biodiesel. Initially the physico chemical properties like viscosity, density and calorific value of jatropha biodiesel were evaluated. The experimental test rig consists of a diesel engine equipped with electrical

loading, emission measuring devices, sensors for temperatures and fuel-air measuring systems. To study the emission parameters of the test fuels of diesel, JB 20, JB 40, JB 60, JB 80 and JB100 at different sets of experimentation, the AVL Make was used. All the sets of operating conditions as decided to be undertaken for experimentation is grouped in a sequence so that the observations can be made at all those operating points in a gradual ascending or descending order.

The modifications in three important technical equipments considered are three way catalytic converter, EGR system and their combination. The engine is designed to operate at 0 to 40 % EGR rate with increasing the steps of 5%. In this study, the engine was operated for all the testing fuels of above EGR rates for all loads i. e. 0%, 25%, 50%, 75% and 100%. These sets of operating parameters were used in all the four cases, i.e. the unmodified engine was run for testing with diesel fuel, biodiesel and their blends ii. engine installed with three way catalytic converter iii. engine installed with EGR and iv. the combination of EGR and three way catalytic converter. In the process of experiment, initially the IDI diesel engine was operated with diesel fuel at 0% to 100% of rated load in steps of 25% and at all the part load. All the technical parameters such as the brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), emission parameters of CO, CO_2, HC, NOx and smoke were evaluated. The above process was repeated for EGR system, three way catalytic converter and with the combination of both. After completing the test cycle with diesel fuel, the engine was run with the biodiesel and their blends as fuel. The test parameters were noted for further analysis.

The properties of diesel, biodiesel and their blends which are of importance to affect the performance and emissions are compared. It has been found that the kinematic viscosities, density of JB 100, JB 80, JB 60, JB 40 and JB 20 are higher than the diesel. It has been observed that the calorific values of JB 100, JB 80, JB 60, JB 40 and JB 20 are 39,000KJ/kg, 39,530 KJ/kg, 39,937 KJ/kg, 40,141 KJ/kg and 40,852 KJ/kg respectively, in comparison to 42,000KJ/kg for diesel. The performance parameters NO_X emissions were calculated at all the specified loads and compared with all controlling methods.

At 15% EGR rate, 10.1% of NO_X emissions was reduced and brake thermal efficiency was decreased to 2.1% of diesel fuel. It may be due to the reduction of oxygen concentration in the intake air. At 25% EGR rate, 11.94% of NO_X emission was reduced along with 4.72% decrement of brake thermal efficiency for JB 20 fuel. It may be due to the increase the heat capacity and lowers the combustion temperature. At 15% EGR rate, 13.4% of NO_X emissions was reduced and brake thermal efficiency was decreased to 1.43% of JB 40 fuel. It may be due to the combustion reaction occurs at lower temperatures, since the NO_X emissions forming reaction is lower at lower temperatures, less NO_X emission is formed. At 20% EGR rate, 15.2% of NO_X emissions was reduced and brake thermal efficiency increased to 0.77% of JB 60 fuel. At 40% EGR rate, 19.81% of NO_X emissions reduced and brake thermal efficiency decreased to 2.1% of JB 80 fuel. At 5% EGR rate, 24.8% of NO_X emissions was reduced and brake thermal efficiency decreased to 1.25% of JB 100 fuel. It may be due to the decrease in flame temperature and the reduction of oxygen concentration in the combustion chamber. For all testing fuels at high loads there is a significant change of brake thermal efficiency.

The three way catalytic converter was proved to be the most effective method for reducing the NO_X emissions. Negligible reduction in brake thermal efficiency was also experienced. For JB 100 fuel, maximum amount of NO_X produced at full load and was recorded 882ppm. However, the maximum amount of NO_X produced in case of diesel at full load and was found to be about 643ppm. In case of the three way catalytic converter with open loop system, maximum amount of NO_X emissions reduction was found in diesel fuel and is about 24.4% with no change in brake thermal efficiency because Rh catalyst release the oxygen atoms stored in the NO_X in the reduction process and hence NO_X emissions to the atmosphere significantly reduced in diesel.

The brake thermal efficiency of biodiesel and their blends was found to be lower than the diesel when operated with EGR and catalytic converter. It may be due to lower calorific value and slightly higher viscosity of biodiesel. The CO_2 emissions of jatropha biodiesel and their blends are higher than that of the diesel. This is because biodiesel and their respective blends have high oxygen content and the carbon content is relatively lower in the same volume of fuel consumed at the same engine load. Consequently CO_2 emissions from the biodiesel are higher. Within the experimental range, the lowest CO emissions have been observed with jatropha biodiesel and their blends when compared to diesel fuel. Since biodiesel contains more oxygen than diesel, so more carbon monoxide is converted to carbon dioxide. The value of unburned HC emission from diesel engine in case of jatropha biodiesel is higher than the HC emission of diesel fuel at higher loads. The HC emission is lower at partial loads but tends to increase at higher load for all the test samples. This is due to the lack of oxygen, which is caused by engine operation at a higher equivalence ratio. The efficient combustion leads to reduction in CO emission and increase in CO_2 emission, thereby reducing the HC emission. For more power output, the smoke produced during operation was higher. For diesel fuel and JB 20 at higher load (100%) three way-catalytic converter helped in reducing the NO_X emission (reduction in 33.14% and 22.38% respectively) without any significant change in brake thermal efficiency when compared to other controlling methods. At other loads for diesel (75, 50, 25%) the combination of EGR (35 %) and three way-catalytic converter facilitated in reduction of the NO_X emission (reduction is 84-86%). At other loads for JB 20 (75, 50, 25%) the combination of EGR (40%) and three way-catalytic converter reduced the NO_X emission (reduction is 61-75%). For JB 40 fuel at higher load (100%) only EGR (15%) system reduced the NO_X emission (reduction is 18.58%) and less smoke without any significant change in brake thermal efficiency compared to other controlling methods. At other loads for JB 40 (75, 50, 25%) the combination of EGR (rate is 40%) and three way-catalytic converter reduced the NO_X emission (reduction is 69-75%). For JB 60 fuel at higher load (100%) only EGR 20% system reduced the NO_X emission (reduction is 15.2%) and less smoke with an increase in brake thermal efficiency when compared to other controlling methods. At other loads for JB 60 (75, 50, 25%) the combination of EGR (40%) and three way-catalytic converter reduced the NO_X emission (reduction is 54-69%). For JB 80 fuel at all loads the combination of EGR (rate is 40%) and three way-catalytic converter reduced the NO_X emission (reduction is 43-65%) and less smoke without any significant change in brake thermal efficiency compared to other controlling methods. For JB 100 fuel at all loads the combination of EGR (rate is 5%) and three way-catalytic converter reduced the NO_X emission (reduction is 26-37%) with less smoke opacity and without any significant change in brake thermal efficiency compared to other controlling methods. It may due to the combined effect of EGR and three way- catalytic converter.

It can be concluded from the experimental observation that the combination of exhaust gas recirculation and three way-catalytic converter method has proved to be the most effective of reducing the NO_X emissions for JB 100 and JB 80 test fuels. For JB 60 and JB 40 exhaust gas recirculation method is most suitable for reducing the NO_X emission effectively. For JB 20 and diesel fuel, only three way catalytic converter is necessary to reduce the NO_X emission effectively.

List of Symbols

@	at the rate
cm	centimeters
g	gram
g/cc	gram per cubic centimeter
m	meter
N	Newton
%	per cent
s	seconds
v	kinematic viscosity
μ	dynamic viscosity
ρ	density
λ	surface tension
°C	Celsius
f	frequency
°F	Fahrenheit
h	Hour
J	Joule
W	watt

ABBREVIATIONS

A/F	Air to fuel ratio
AC	Alternate current
API	American petroleum institute
ASTM	American society for testing and materials
JB 20	20 % biodiesel and 80% diesel
JB 40	40 % biodiesel and 60% diesel
JB 60	60% biodiesel and 40% diesel
JB 80	80% biodiesel and 20% diesel
JB 100	Pure biodiesel
BIS	Bureau of Indian standard
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
BTDC	Before top dead centre
Cal	Calorie
cc	Cubic centimeter
CI	Compression ignition
CO	Carbon monoxide

CO_2	Carbon dioxide
cSt	Centistokes
CV	Calorific value
DI	Direct injection
EGR	Exhaust gas recirculation
EFI	Electronic fuel injection
FFA	Free fatty acid
FIP	Fuel injection pump
GC	Gas chromatograph
HC	Hydrocarbon
HCL	Hydrochloric acid
HP	Horse power
IDI	In- direct injection
IVOP	Inlet valve opening pressure
JBD	Jatropha biodiesel
kCal	kilocalorie
kW	Kilo Watt
kWh	Kilo Watt hour
LPG	Liquefied petroleum gas
L	Stroke length
Min	Minute
MJ	Mega joule

ml	Milliliters
MTOE	Million tonne of oil equivalent
NO_X	Oxides of nitrogen
O_2	Oxygen
PM	Particulate matter
ppm	Parts per million
RPM	Revolution per minute
SVO	Straight vegetable oil
TDC	Top dead centre
TSP	Total suspended particle
UBHC	Un burnt hydrocarbon
V	Volume of cylinder
vs	versus

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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 worlds 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)

	Oil	**Natural Gas**	**Coal**	**Nuclear Energy**	**Hydro Electric**	**Total**
India	128.5	36.2	208.0	4.0	27.7	404.4
World	3952.8	2637.7	3177.5	622.0	709.2	11099.3

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 eliminat’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 1500^0F. 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 NO_2 [9]. These are normally collectively referred to as NO_X. 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_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% diese/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. CO_2 emission was low with neat biodiesel compared to diesel fuel. CO emission was low at higher loads for neat biodiesel when compared with diesel. NO_X 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 NO_X 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_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_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 rapseed 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 ($NO_{X,}$ 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 biodiese3l, 20% blends, and the base fuel were tested at two different loads (100 and 200%) and three injection timings (3^0 advanced, standard; 3^0 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 soyabeen and rapseed. 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 NO_X 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_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_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_X emissions in case of blended biodiesel JB20 and JB40 have 25% and 14% lower NO_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_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_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_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_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_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_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_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_X, CO and smoke of the exhaust gas were measured to estimate the emissions. Exhaust gas recirculation process (EGR) reduces NO_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_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_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_X emission without much adverse effects on the performance, smoke, and other emissions. P.V. Babu et al. [71] investigated reduction of NO_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_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 with15% EGR showed lowest NO_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_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_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 JB100 and diesel fuel without EGR rates and with EGR rates. The performance parameters and NO_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_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 280^0 C to 430^0 C during idle, even up to about 1000^0 C to 1100^0 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 NO_X 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 2500^0 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. NO_X 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 NO_X emission is favor, at the expense of CO and HC oxidation. Jonathan et al. [84] suggested that to reduce NO_X 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 NO_X 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_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_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_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 NOx 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 pollutents 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.

Chapter 3

Test fuel characterization

The detailed methodology for test fuel preparation characterization and blending are discussed in this chapter. Biodiesel was prepared by using of jatropha oil, methanol and potassium hydroxide as a catalyst. The selection of appropriate parameters which are essential for characterization of test fuel relevant to diesel engine are described here.

3.1 Test fuel preparation

Jatropha seeds are procured from Rajasthan. Oil was extracted using screw press expeller. The crude jatropha oil extracted by mechanical expeller has small traces of organic matter, water and other impurities. The pretreatment of crude vegetable oils carried out by using 11 micron filter paper. Then mixture of crude oil, methanol, sulphuric acid and toluene was stirred at a constant speed (300-350 rpm) and temperature of 65^0 C for 2 h in batch reaction. Then it was kept in settling tank for 24 hour to separate in different phase. After that three layers are formed. Upper layer is consisted of methanol – water fraction, organic matter, gum, toluene and other impurities which were separated from the lower layer (treated vegetable oil). The treated jatropha oil was transesterified with 200 ml methanol, 9.50 g KOH in one liter biodiesel reactor. The reaction was carried out at 65 ^{0}C and 350-400 rpm for three hours. After completion of reaction the mixer was kept for 12 hours in settling tank. Glycerol is separated from biodiesel. This Biodiesel has some impurities like excess of methanol, glycerol, and excess catalyst which is removed by washing with hot water.

As biodiesel is insoluble in hot water while impurities like methanol, glycerol and excess catalyst are soluble in water and easily removed in three step process. Moisture is removed using by silica gel, from 1 liter jatropha oil 700 ml of biodiesel is obtained. This biodiesel is analyzed according to fuel quality standards of ASTMD 6751 and found under standard limits. This biodiesel was blended with conventional diesel in different ratio and their physico-chemical properties were analysed.

3.2 Measurement of physico chemical properties of biodiesel

The Physico-chemical fuel properties of biodiesel, diesel and their blends has very important role in defining the emissions quality of the fuel. Therefore, properties such as density and calorific value of biodiesel, diesel and their blends of different properties are determined.

3.2.1 Measurement of density

The density of the biodiesel, diesel and their blends was found out in the laboratory with the help of hydrometer. The density meter is capable of finding out the specific gravity of the test fuel with an accuracy of 0.01. The detailed specification of the density meter is shown in table 3.1. Initially the 100 ml jatropha biodiesel was put into the beaker and a suitable hydrometer is selected to suit the requirement of specific gravity range. After selecting the hydrometer it was put into the beaker and was allowed to get stabilized. The reading was directly read on the graduated scale of hydrometer. After finding out the specific gravity of biodiesel the beaker was flushed with diesel. The 100 ml of diesel as a new test fuel was put into the beaker and again the suitable hydrometer was selected. After the selection the hydrometer, it was put into the beaker and allowed to get it stabilized. The reading was taken to find the specific gravity.

Table 3.1: Specifications of density meter

S. No	Particulars	Specifications
1	Make	HAMCO
2	Model	Dual speed - deluxe model
3	Weight approx.	2 kg
4	Dimensions	5.5x 3.9 x11.4 in
5	Rated voltage (volts)	230 volts
6	Sensor material	Stainless steel 316L, Ni-Span C, Hastelloy C22
7	Power supply	110-220V AC
8	Temperature range	0 ^{o}C to 50 ^{o}C (+ 32 ^{o}F to +122 ^{o}F)
9	Temperature accuracy	± 0.1 ^{o}C
10	Density range	0 to 3 g/cm^{3}
11	Density accuracy	± 0.0002 g/cm^{3}, ± 0.0005 g/cm^{3} ± 0.0001 g/cm^{3}

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3.2.2 Measurement of kinematic viscosity

The kinematic viscosity of the test fuels was determined with the help of digital rotary viscometer. The detailed specification of the visco meter is shown in table 3.2. The resistance offered by the fuel to the rotor due to viscosity is used for measuring the kinematic viscosity. The kinematic viscosity is displayed on the screen. It was found that the viscosity of petro diesel at 30^{0} C was 4.3 cSt. Similar process was used to find the viscosity of biodiesel at same temperature. It was found that the viscosity of biodiesel at 30^0 C was 4.9 c St. The viscosity of biodiesel was determined at different temperature to study the temperature at which the viscosity of biodiesel matches with viscosity of diesel at room temperature.

Table 3.2: Specifications of visco meter.

S. No	Particulars	Specifications
1	Make	Fungilab
2	Code	V300003
3	Kinematics viscosity	centistokes/stokes
4	controls	Touch key with 6 key
5	Accuracy or precession	±1% of full scale
6	Viscosity Reading	cP, mPa or cSt
7	Power supply	220-240V and 50/60 Hz frequency
8	Temperature range	0 to 100 deg C with ±0.1 deg C precision)
9	Temperature accuracy	± 0.1 ^oC
10	Internal memory	more than 10,000 data
11	Software	Data logger software as standard supply

3.2.3 Measurement of flash point

The detailed specification of the Pensky-martens closed cup flash point test is presented in table 3.3. In the Pensky-martens closed cup flash point test, a brass test cup is filled with a test sample (about 200 ml) and fitted with a cover. The sample is heated and stirred at specified rates. An ignition source is applied into the cup at regular intervals with simultaneous interruption of stirring until a flash that spreads throughout the inside of the cup is seen. The corresponding temperature was recorded as flash point.

Table 3.3: Specifications of Pensky-Martens closed cup flash point apparatus

S. No	Particulars	Specifications
1	Make	HAMCO
2	Model	Dual speed - deluxe model
3	Rated Out put	7.5 KVA at 1500 rpm
4	Rated Speed (rpm)	dual speed 90-120 rpm and 250 rpm
5	Rated voltage (volts)	230 volts
6	Rated Currents (Amps)	8 A
7	Power supply	230 V, 1 Phase, 50 Hz
8	Size	330mm X 310mm X 290mm
9	Weight	8.0 Kg

3.2.4 Measurement of calorific value

A bomb calorimeter was used to measure the amount of heat generated when a known amount of test fuel was burnt in a sealed chamber in an atmosphere of pure oxygen gas. The apparatus consists of Bomb, Water jacket, offset stirrer, Calorimeter vessel, bomb firing unit, vibrator, timer, illuminator with magnifier, pressure gauge on stand, gas release valve, pellet press, crucible and ignition wire. The chemicals used for determination of calorific value were benzoic acid, naphthalene, sucrose or cane sugar, standard alkali solution, methyl orange or methyl red indicator.

Chapter 4

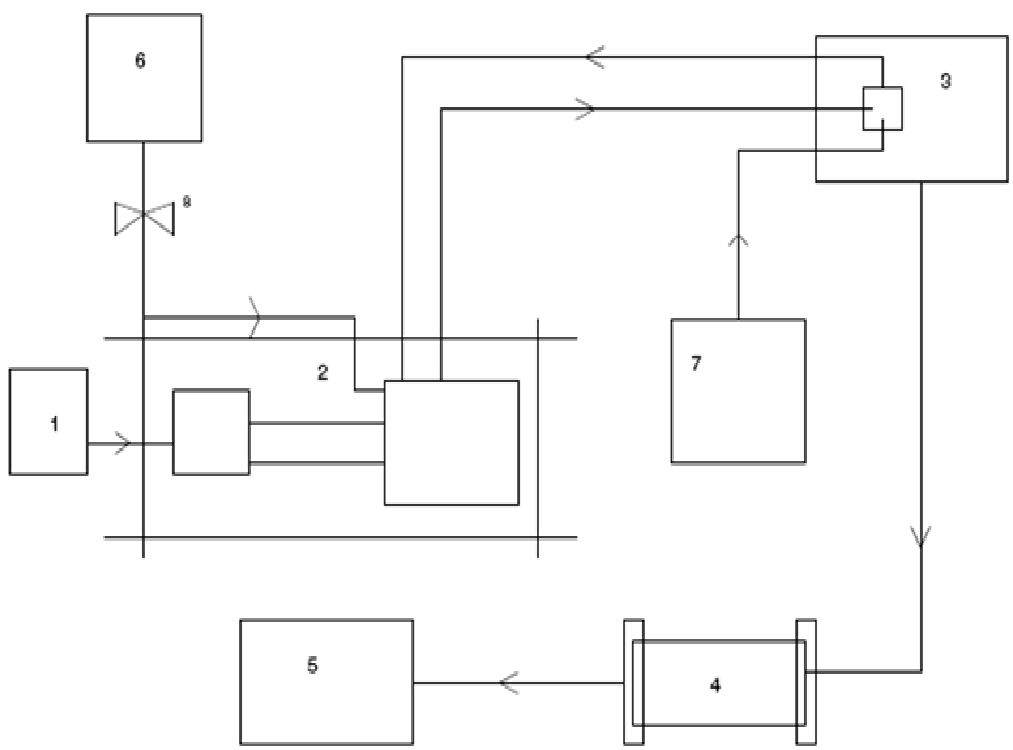
Engine experimental test rig

The complete experimental set up, test matrix and procedure for engine emission studies are discussed in this chapter. The main components of the experimental set up were fuel tank, fuel measuring unit. Electrical loading arrangement, voltmeter, ammeter, wattmeter, rpm meter, six channel temperature indicator, EGR rate indicator and emission equipments measurements are shown in the diagram (figure.4.1). The details of the experimental data acquisition are discussed below.

4.1 Engine

The engine used for experimental analysis is an indirect injection (IDI) low speed diesel engine. This engine is widely used mostly for agricultural irrigation purposes and also in many other small and medium scale commercial applications like producing electricity, running flour mills, oil expellers, rice mills etc. The engine was mounted on vibration isolators to avoid the excessive vibrations. The coupling of engine and generator is done by V-belt drive power transmission system. The diameters of the pulley mounted on engine and generator was so selected that the engine at designed rpm of 1000 at full load. The electrical loading arrangement was used for loading the engine. The study was carried out by loading the engine at 0%, 25%, 50%, 75% and 100% of its rated load. The integrated system of experimental set up is shown in figure 4.2. The technical specifications of the generator and engine are listed in table 4.1 and table 4.2 respectively.

The sub systems of the test rig are integrated and the schematic diagram of experimental test set up is shown below in figure 4.1.



1. Electrical loading 2. Single cylinder 4-stroke diesel engine & Alternator 3. Exhaust gas recirculation system 4. Three way catalytic converter 5. Gas analyzer & Smoke meter 6. Fuel tank and 7. Air drum.

Figure 4.1: Schematic diagram of experimental test setup.

Figure 4.2: single cylinder IDI diesel engine.

Table 4.1: Specifications of the alternator

S. No	Particulars	Specifications
1	Make	Field Marshal
2	Alternator Type	Single Phase, 50 Hz, AC
3	Rated Out put	7.5 KVA at 1500 rpm
4	Rated Speed (rpm)	1500
5	Rated voltage (volts)	230 volts
6	Rated Currents (Amps)	32 A
7	Power supply	230 V, 1 Phase, 50 Hz
8	Size	330mm X 310mm X 290mm
9	Weight	8.0 Kg

4.1.1 Engine load bank

After finalizing the procedure for data collection and procurement of the desired instruments, electrical heater, bulbs and switches were put on a control panel for engine loading. The control panel was assembled by installing instruments such as volt meter, ammeter, wattmeter, electrical load banks and their switches provided on the front side of the control panel as shown in figure 4.2. A voltmeter, ammeter, and wattmeter were connected between the alternator and load bank. A digital ammeter having range of 0 to 50 Amp and a digital voltmeter having range of 0 to 50 volt are connected to measure the current and voltage passing through the load. By varying the current at constant voltage difference, we are able to alter the load on the engine. The efficiency of the electric brake dynamometer is 80%.

Table 4.2: Specification of single cylinder IDI diesel Engine

S. No	Particulars	Specifications
1	Make	Field marshal diesel engines
2	Model	FM-4
3	Rated Brake Power BHP/kW)	10/7.35110
4	Rated Speed (rpm)	1000
5	Number of cylinder	One
6	Bore x Stroke (mm)	120x139.7
7	Compression ratio	17:1
8	Cooling system	Water cooled
9	Lubrication system	Forced feed
10	Cubic capacity	1580 cc
11	Nozzle	DL30S1202MICO
12	Nozzle holder	9430031264 MICO
13	Fuel pump	9410032034
14	Fuel Pump Plunger	9x03/323 MICO
15	Injection Pressure	145 kg/cm^2
16	Specific fuel consumption	265 gm /kWhr OR 195 gm / bhp /hr
17	Sump Capacity	4.5 Ltr
18	Lubricating oil Consumption	15 g /hr
19	Net weight	355 kg
20	Gross Weight	490 kg

Table 4.3: Current rating for part load estimation

Load (percentage of rated load of engine)	Current (Amp)
0%	0
25%	6.25
50%	12.5
75%	18.75
100%	25

The loading arrangement is capable of offering the load to the engine in the order of above requirements with accurately monitored on the indicator.

4.1.2 Engine control panel

The data display board was equipped with indicators connected to the thermocouples installed at different locations in the case of temperature indicator and the electrical voltmeter. The standard digital indicators having range as mentioned below were used to display the temperatures, voltage and current. Following are the indicators installed on display board. A burette was placed on the control panel to measure the volumetric fuel consumption of the engine.

4.1.3 Exhaust gas recirculation system

Exhaust gas recirculation system with engine have been developed for testing and measuring the parameters of selected test fuels to calculate performance characteristics and emission characteristics with use of this EGR system. The EGR system is developed to reduce the amount of oxides of nitrogen (NO_X) created by the engine during operating periods that usually results in high combustion temperatures. NO_X is formed in high concentrations whenever combustion temperatures exceed about 2500^0 F.

The EGR system reduces NO_X production by recirculation small amount of exhaust gases into the intake manifold where it mixes with the incoming air. By diluting the air mixture under these conditions, peak combustion temperature and pressure are reduced, resulting in overall reduction of NO_X output. The EGR system consists of EGR control valve, exhaust control valve, EGR cooler (water cooled type), exhaust cooler (water cooled type) and digital manometer. In the current research the exhaust gas coming out of the engine is passed to an exhaust cooler. The exhaust from the exhaust cooler after cooling is passed via a valve and digital manometer. The digital manometer is provided in order to find the total amount of exhaust gas flow (when the EGR control valve is closed) and valve controlling the flow. The digital manometer operates at a temperature range of $10\text{-}50^0$ C; this is the reason for cooling the exhaust gas after the EGR system. In the main exhaust line, a tapping is provided for EGR system. The exhaust gas from the tapping via a valve and is passed to the EGR cooler, where the exhaust gas is cooled before sending it to the engine. A digital manometer is provided at the inlet manifold of the engine in order to know the flow of exhaust gas to the engine. To allow desired percentage of EGR into the engine, the first step is to find the total flow of exhaust gas with the digital manometer provided after the exhaust cooler. If the flow is supposing 40mm is the 100% at some particular load. If to pass 10% EGR, the EGR control valve is slowly opened until it reach 4 mm reading in the digital manometer provided at the intake manifold of the engine. Simple software was programmed and designed by lab view to calculate the EGR percentage during experiments. The engine was tested at different loads (i. e. 0%, 25%, 50%, 75% and 100%) and various EGR rates of 5-40% (with 5% increment). Based upon the design parameters the EGR system was developed and the engine was modified by installing the EGR system to perform the experiments. The amount of EGR was calculated using the following equation.

$$EGR(\%) = \left[\frac{\text{Mass of air admitted without EGR} - \text{Mass of air admitted with EGR}}{\text{Mass of air admitted without EGR}}\right]$$

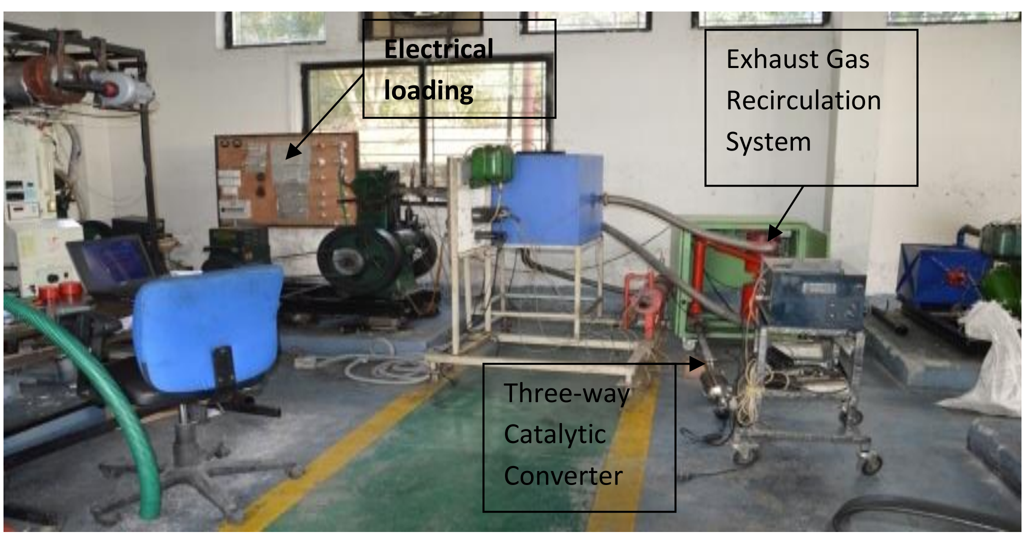


Figure 4.3: EGR system installed to the engine system.

After installing the EGR system on engine, the experiment was carried out by fuelling the engine with diesel, biodiesel and their blends. The engine was tested at different loads (i. e. 0%, 25%, 50%, 75% and 100%) and at various EGR rates of 5-40% (with 5% increment).

4.1.4 Catalytic converter

Three- way catalytic converter was fitted with engine for testing and evaluating the parameters selected of the test fuels. The converter has two basic components, an outer stainless steel cylindrical casing, which is housed a honeycomb matrix core consisting of many parallel channel passage ways through which the exhaust gas flows. The honeycomb passage ways are made from ceramic material, a highly porous aluminium (Al_2O_3) wash coat provides a rough surface finish and covers the passage ways walls to significantly increase the effective surface area exposed to the exhaust gas. The wash coat is impregnated by vapour deposition with the noble metals as catalysts, usually platinum (Pt), rhodium (Rh) and palladium (Pd). The Rh as a catalyst to release the oxygen atoms stored in NO_x in the reduction reaction. The oxygen atoms made available in the reduction process will simultaneously provide an oxidation environment to oxidise HC and CO. Therefore, the three main harmful exhaust species, namely HC, CO and NO_x are either oxidised or reduced when passing through the catalytic converter

Three- way catalytic converter can store oxygen from the exhaust gas stream, usually when the air fuel ratio goes lean. When the insufficient oxygen is available from the exhaust stream the stored oxygen is released and consumed. This happens when oxygen is derived from NOx.

The engine system with EGR and three way-catalytic converter is developed to reduce the amount of oxides of nitrogen (NO_X) created by the engine during operating periods that usually results in high combustion temperature, NO_X is formed in high concentrations whenever combustion temperature exceed about 25000F. After installing the EGR system and three way-catalytic converter on engine the experiment was carried out by fuelling the engine with diesel, biodiesel and their blends.

4.2 Measurement methods

Required data for performance and emission characteristics of the engine were obtained with the help of volumetric fuel consumption measuring unit, electrical loading arrangement, voltmeter, ammeter, tachometer, temperature indicator, smoke and exhaust gas analyzer. The performance parameter such as BTE and BSFC were evaluated from the fundamentals data generated during the experiments. Smoke opacity was also measured by AVL make gas analyzer along with $NO_{X,}$ CO, CO_2 and HC. The detailed procedure for data generation and analyzers are explained in the following sections.

4. 2. 1 Brake power

The brake power is among the most important parameter in testing of an engine. The power developed by the engine was measured with the help of an electric alternator type of dynamometer. The lamp load was connected in series with the generator to act as resistive load bank. The engine was started and engine was running for about 15 minutes to get stabilized. After that the voltage and current corresponding to all the operating points were recorded from the Voltmeter & Ammeter mounted on the control panel. The product of voltage and current gives the actual load on engine alternator system.

4.2.2 Measurement of temperature

A digital temperature indicator was provided on the control panel. The thermocouples were inserted into the flow line to a sufficient extent to capture the temperature correctly. The suitable fabrication work was done to accommodate the thermocouples at desired locations. The wires communicating the signals from thermocouples to the digital indicators were connected to the appropriate terminals rigidly. The range and the type of temperature indicators installed on data display board are as follows:

I. Exhaust gas temperature indicator: Range 500 ^{0}C (J 100 type)
II. Exhaust gas temperature indicator at heat exchanger outlet: Range 500 ^{0}C (J 100 type)
III. Cooling water inlet temperature indicator: Range 100^0 C (Type PT 100)
IV. Cooling water outlet temperature indicator: Range 100^0 C (Type PT 100)
V. Lubricating oil temperature indicator: Range 100^0 C (Type PT 100)
VI. Inlet air temperature at inlet to Air tank indicator: Range 100^0 C (Type PT 100)

4.2.3 Measurement of speed

The magnetic pickup produces a pulse for every revolution and a pulse counter accurately measures the speed. The instrument is capable of functioning in the range of 1 to 9,999 rpm with a sampling time of 1 second. For measurement, a nut was welded on the fly wheel face and sensor was mounted on a bracket near the fly wheel in such a way that the distance was less than 5 mm. The display unit is digital and mounted on the below the temperature measurement of the panel board.

4.2.4 Fuel flow measuring system

The fuel consumption of the engine was measured by determining the volume flow in a given time interval and multiplying it by the specific gravity of the fuel which was needed to be measured occasionally to get an accurate value. Another method is to measure the time required for consumption of a given mass of fuel. The test facilities were built up for measuring both diesel, biodiesel and their blends consumption rates. For this, one tank, one burette and two numbers of valves were provided on the panel. The time for 50 cc fuel consumed in recorded with the help of stopwatch.

4.2.5 Measurement of EGR rate

Data acquisition system was used for EGR system analysis of the engine. EGR system was used for acquiring EGR rate, using this interface the data is transferred from EGR system indicator to personal computer. Personal computer was used for analyzing the acquired data from EGR system with the help of software “Engine Soft”. This acquired data can be opened in any of the data processing software and various calculations were made. Figure 4.4 shows the acquired data and graphs on personal computer**.**

4.2.6 Measurement of air flow rate

The air flow measurement was achieved by a U-tube manometer and air chamber. It has an air chamber. The air chamber is equipped with an inlet orifice having coefficient of discharge 0.6. The pressure difference in the inlet manifold was measured by a normal U-tube manometer. Airflow was measured by taking the difference in heights of the water column in the two legs of the manometer and area of orifice of the surge tank.

Table 4.4: Capabilities of measurement AVL-437 smoke meter

Exhaust gas	**Measurement range**	**Resolution**
NO_x	0 – 4000 vol. ppm	1 vol. ppm
CO	0 – 10 vol. %	0.01 vol. %
CO_2	0 -20 vol. %	0.1 vol. %
HC	0 – 20,000 ppm	1ppm
O_2	0 – 22 vol %	0.01 vol %

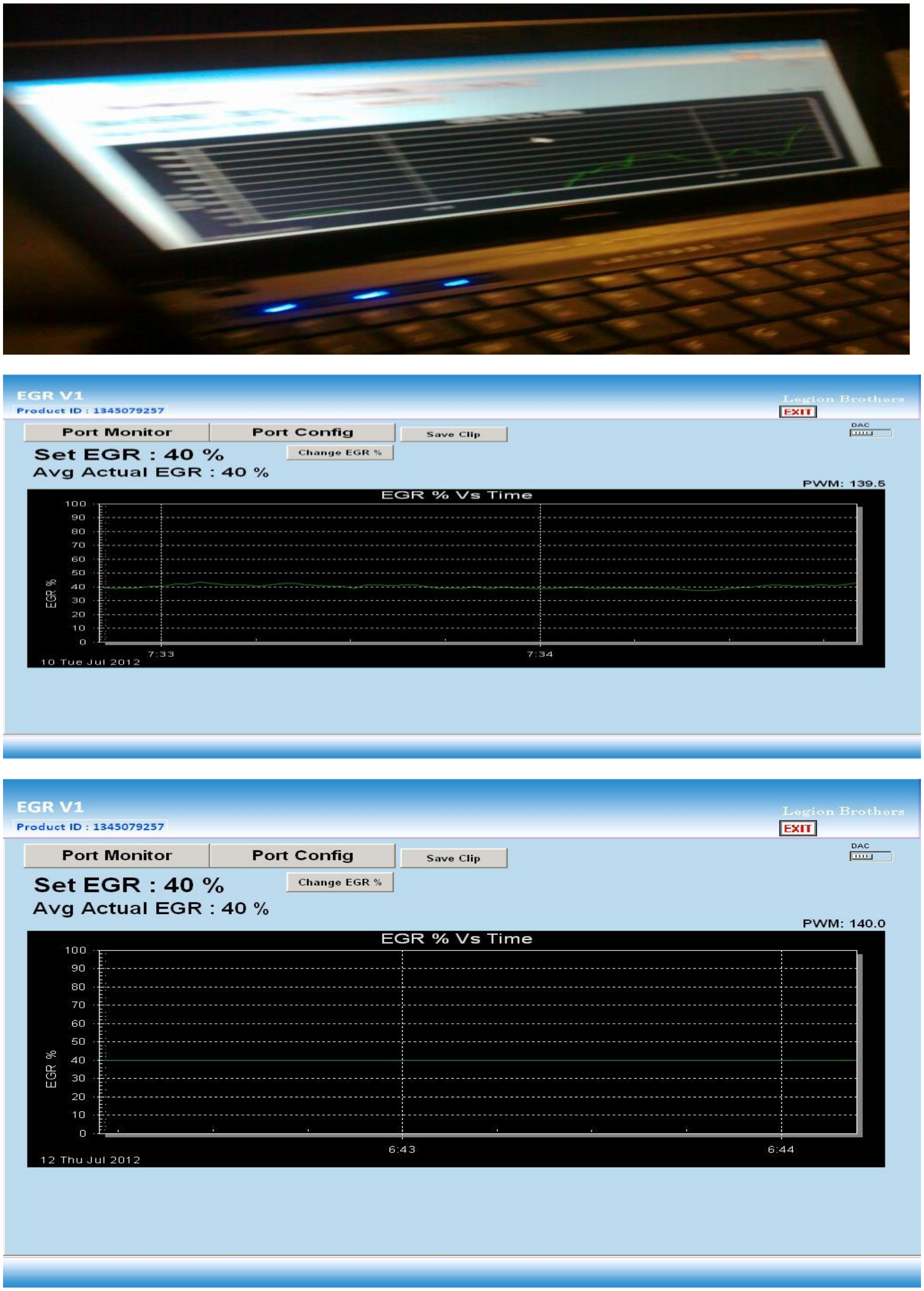


Figure 4.4: Un steady and steady EGR rate at (40%) on Computer monitor.

4.3 Measurement of emissions

The exhaust gas composition was measured using exhaust gas analyzer (AVL DIGAS-4000 model). The major emissions appearing in the exhaust of a diesel engine are the smoke, UBHC, CO2, CO and NO_X. This analyzer measures NOx, CO_2, CO, HC and O_2 in the exhaust gases. The basic principle for measurement of NOx, CO_2, CO and HC emissions is non-diffractive infrared radiation (NDIR) and electrochemical methods for oxygen measurement. For measuring the smoke opacity and emissions, smoke meter and analyzer were utilized respectively. Measurement range and resolution for different gases are measured by the use of exhaust gas analyzer. The smoke meter gave reading in terms of percentage opacity of the light beam projected across a flowing stream of exhaust gases, a certain portion of light is absorbed or scattered by the suspended soot particles in the exhaust. The remaining portion of the light falls on photocell, generating a photoelectric current, which is measure of smoke opacity. Smoke – meter consists of two identical tubes, a smoke type and a clean air tube. A pressure relief valve allows a regulated quantity of exhaust gas through the smoke tube. During smoke opacity measurements, a light source (halogen bulb) at one end of the smoke tube projects light beam through smoke, which at the other end falls on photoelectric cell. A clean air tube is used for initial zero setting. A 12-volt battery is used to supply power for the lamp and the clean air blower. A micro-voltmeter is connected to the photoelectric cell with its scale graduated 0-100, indicating the light absorbed in smoke meter unit. Zero reading corresponds to just clean smoke, where as reading of 100 refers to dense smoke, which allows no light to pass through it. This smoke meter measures the opacity of the polluted exhaust, in a particular diesel exhaust gases (in a measurement chamber of a defined measurement length). The effective length of the measurement chamber was 0.430 ± 0.005 m. The temperature of the exhaust gas to be measured was kept between 70 ^{0} C and 130 ^{0}C as per recommendations of the manufacturer as shown in the table. 4.4.

4.4 Engine test procedure

The unmodified engine was run with test fuels and data was tabulated as per the following test matrix. The fuel tank was flushed with diesel and then the tank was filled with diesel fuel. The engine was started and allowed to run for 15-20 minutes to get stabilized. The applied load on the engine was made zero by withdrawing the plates of loading system fully out and making the current flowing in load circuit to zero. Then the parameters like voltage, current, temperatures of all the 6 points, engine rpm, manometer reading and time for 50 cc fuel consumption is recorded. After recording these parameters the exhaust gas emission parameters like HC, NOx, CO_2 and CO were recorded by putting the probe of AVL gas analyzer into the exhaust pipe. For noting down the smoke (opacity) the exhaust gas was directed to AVL smoke meter and the opacity was recorded. After completing all the above data observation work the load on the engine was increased to 25% so that the current flowing through the load circuit is 6.25 Amp. The 6.25 Amp current corresponds to 25% load getting applied on the engine. The engine was allowed again to run for about 10-15 minutes to get stabilized. After this time duration all the process described in above para are repeated and careful recording of technical parameters were done at new engine operating point. Load on the engine was increased to 50%, 75% and 100% by adjusting the current flowing through the load circuit to 12.5 Amp, 18.75 Amp and 25 Amp respectively. The engine was run to attain the stable condition. After attaining the stable condition the observations were taken at all above mentioned operating points. The engine was run with remaining test fuels like biodiesel and their blends for generation of base line data.

The engine was run on different EGR rates 0 to 40% (with incremental value of 5%) for all the above test fuels and at the specified loads.

The engine was run with three way-catalytic converter for all the test fuels and at the specified loads. Then the engine was run with the combination of EGR and three way–catalytic converter. The maximum NO_X reduction is picked, when engine run with EGR, engine with three–way catalytic converter and engine with combination of EGR and three way catalytic converter.

Various performance and emission characteristics were recorded only when stabilized working conditions were achieved. The performance and emission data were duly corrected according to the procedure specified in IS: 10000 (Part IV) - 1980 for all test fuels.

Chapter 5

Results and Discussion

This chapter describes as well as discusses the results of all the investigations done, with respect to the physicochemical properties, engine performance and emission characteristics of diesel, biodiesel and their blends. The fuel properties were evaluated by the calibrated processional instruments, as described in earlier chapters and the results are discussed in this chapter. The role of these properties on performance of a diesel engine is briefly discussed. There after the engine performance like BTE, BSFC and emission characteristics are evaluated based upon the experiments conducted on existing engine operating with diesel, JBD and their blends as fuel. After the analysis and support from the literatures available, the importance and mechanism involved in desired emission reductions are listed. The results obtained from the engine experiments are analyses and compared with the results obtained from the conventional engine, in order to find out the optimum operating conditions.

5.1 Test fuel analysis

The important physico-chemical properties of jatropha biodiesel and their blends were determined by standard methods and compared with diesel as shown in Table 5.1. The results show that the calorific value of the vegetable oil and their blends is comparable to the diesel oil. However, the kinematic viscosity of jatropha biodiesel is higher than the diesel oil. The effects of these properties on engine performance are explained in the following sections.

Table 5.1 Physico-chemical properties of diesel and biodiesel

Properties	Diesel	JB 20	JB 40	B60	JB 80	JB100
Density (gm/cc at 30^0 C)	0.817	0.8379	0.8577	0.8769	0.8830	0.905
Kinematic Viscosity (cSt at 40^0 C)	2.211± 0.22	2.58	2. 96	3.79	4.01	4.84
Calorific Value (kJ/kg)	42000	40852	40141	39937	39530	39000

5.2 Effect of physico chemical properties on engine performance

5.2.1 Effect of kinematic viscosity on engine performance

Since viscosity of fuel has very important role in fuel atomization characteristics in combustion chamber which is essential phenomenon taking place before the fully established combustion process. The vegetable oil combustion studies have found that the biodiesel and their blends to be used as fuel for diesel engine has not been found suitable for DI engines whereas it gives good results in IDI Engine. It was reported that compared to commercial diesel fuel, all the vegetable oils were much more viscous, much more reactive to more oxygen and had higher cloud and pour points. The high viscosity of biodiesel is basic cause of poor combustion and atomization characteristics. The viscosity of JBD is about 10-12 times the viscosity of diesel.

Because of high viscosity the injector choking is one problem along with some others e.g. case of fuel injector, gum formation and piston sticking on long term, has tested the biodiesel for combustion analysis in IDI diesel engine and reported that high viscosity and density of vegetable oil led to problem in the injection system and combustion chamber of the engine for a long term usage and NO_X emissions are increased with the increase of biodiesel percentage. Fuels with high viscosity tend to form larger droplets on injection which can cause poor combustion increased exhaust smoke opacity and emissions and excessive carbon deposit takes place in combustion chamber. The high NO_X emissions problem has been solved in several ways such as using EGR system, three way- catalytic converter and the combination of EGR and three way- catalytic converter. The results are similar in trend in the literatures [(3), (7) and (8)].

5.2.2 Effect of density on engine performance

Fuel density has importance in diesel engine performance since the fuel injection system operates on a volume metering system. The density of JB 100, JB 80, JB 60, JB 40 and JB 20 were found 905kg/m^3, 883.6 kg/m^3, 876.0 kg/m^3, 857.7 kg/m^3 and 837.9 kg/m^3 respectively, whereas the density of diesel was 817 kg/m^3. Therefore though the volumetric fuel injection by the fuel injector will remain same in all the test fuel cases but the delivery of slightly greater mass of biodiesel and their blends will take place. A fuel with low energy content per liter will cause the engine to produce less peak power. However, this high density of biodiesel compensates the lower energy content, therefore the net energy supplied to the engine will be almost same in all the cases. Higher density of biodiesel and their blends will result higher mass of fuel particles injected in the combustion chamber. Because of higher mass the fuel particle will have higher momentum so the distance travelled by the fuel particle in the combustion chamber will also be higher. The results are similar in trend in the literatures [(6), (8) and (12)]. As we know the rate of fuel burning depends primarily upon the rate at which the product of combustion be removed from the combustion chamber and replaced by the fresh oxygen that is it depends upon the rate at which the burning droplet can move relative to the surrounding air. A heavier droplet will have higher momentum and hence higher relative velocity there by establishing efficient scavenging process. Therefore higher fuel density is advantageous in both the ways, one in supplying comparatively higher fuel energy in combustion chamber and second in improved combustion process due to efficient scavenging.

5.2.3 Effect of calorific value on engine performance

The increase of oxygen in biodiesel is related to the reduction of carbon and hydrogen, causes the lower value of energy content (or calorific value/ heat of combustion) of the jatropha biodiesel as compared to that of conventional diesel fuel, because the oxygen is ballast in fuel and carbon and hydrogen are the sources of thermal energy. The calorific value of JB 100, JB 80, JB 60, JB 40 and JB 20 were 39000 kJ/kg, 39530 kJ/kg, 39937 kJ/kg, 40141 kJ/kg and 40852 kJ/kg and the calorific value of diesel fuel is 42000 kJ/kg. The calorific vale of biodiesel and their blends were comparable with diesel fuel. Since the calorific value of biodiesel and their blends is marginally less than the diesel fuel but the density is high so the energy supplied by the fuel will remain almost same so the performance of the engine can be expected similar as if diesel fuel. The calorific value of diesel fuel is higher than the calorific value of biodiesel and their blends, whereas the density of JB 100,JB 80, JB 60,JB 40 and JB 20 (905kg/m^3, 883.6 kg/m^3, 876.0 kg/m^3, 857.7 kg/m^3 and 837.9 kg/m^3 respectively) is higher than the density of diesel (817 kg /m^3). The stoichiometric air-fuel ratio of biodiesel and their blends will be lower than that of diesel fuel due to presence of oxygen as a result improvement in combustion efficiency will be ensured. The results are similar in trend in the literatures [(3), (8) and (12)].

5.3 Effect of EGR rate on engine emissions

EGR rate decreases the combustion work and increases the pumping work. The results are similar in trend in the literatures. [(61), (66), (71) and (74)]. The decrease in combustion work could be due to the lower combustion temperatures and reduction in air- fuel ratio as a result of EGR use. This is expected due to the extra oxygen amount of biodiesel approximately 10-12% by weight, in accordance to previous findings of other researches in biodiesel fuel. This oxygen helps to improve the combustion efficiency, thus reduces the torque deterioration. The maximum NO_X reduction for JB 20, JB 40, JB 60, JB 80 and JB 100 fuels occurs at the EGR rates of 25%, 15%, 20%, 40% and 5% respectively; while, it is found to be at 15% EGR rate the maximum NO_X

reduction occurs for diesel fuel. The torque loss of JB 100, JB 80, JB 60, JB 40, and JB 20 were lower than that of diesel and at all loads.

5.3.1 Effect of EGR rate on BTE

From the following curves at 0% EGR rate it can be found that the brake thermal efficiency of biodiesel and their blends are lower than the diesel. The lower calorific value and higher viscosity of biodiesel and their blends compared to that of diesel are responsible for low BTE of biodiesels. The higher viscosity of the bio diesel is the cause for poorer mixture formation in the cylinder. JB 20 shows the maximum BTE among the blends. All other blends i.e. JB40, JB 60, JB 80 and JB 100 shows the general trend of decrease in thermal efficiency with increase in concentration of biodiesel in mineral diesel.

Figure 5.1 shows thermal efficiency of diesel, biodiesel and their blends at various EGR rates at 100% load. The thermal efficiency decreased with increasing EGR rates are compared without using EGR rate. The reduction in thermal efficiency with EGR is due to the dilution of the fresh charge with the exhaust gas which results in flame velocity and hence deterioration of the combustion and lead to incomplete combustion of fuel. In this study found the effective reduction of NO_X emissions at different EGR rates for each of test fuels and compare with the other controlling methods at specified loads. For the fuels Diesel, JB 20, JB 40, JB 60, JB 80 and JB 100 are at 15% ,25%, 15%, 20%, 40% and 5% EGR rates the higher the reduction in the NO_X emissions was observed respectively at specified loads. The BTE of test fuels at the above EGR rates are decreased compared to the base line value.

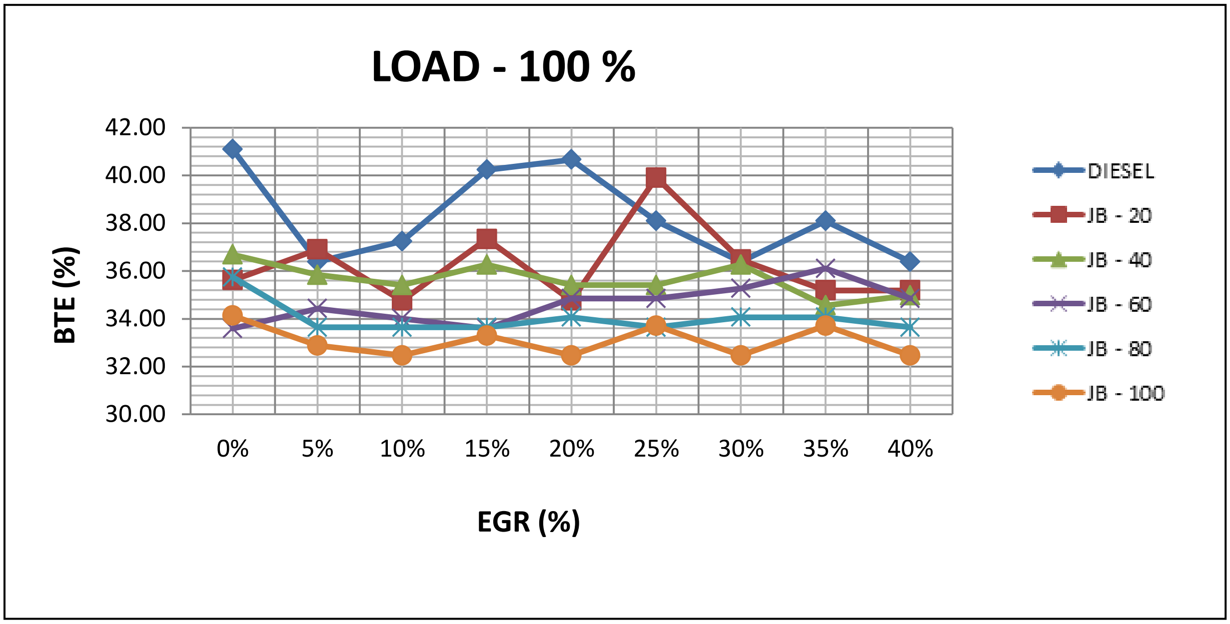


Figure 5.1: BTE variation with EGR rate

5.3.2 Effect of EGR rate on BSFC

The brake specific fuel consumption which directly governs the economy of engine utilization is very important to be evaluated under all operating conditions. The brake Specific fuel consumption was also found to be higher in case of JB 100 and their blends than diesel. With biodiesel the brake specific fuel consumption increases as biodiesel is substituted in increasing proportion. This is mainly due to the combined effects of the relative fuel density, viscosity and calorific value of the blends. As the volume of biodiesel is increased in diesel, the density of different blends also increase which results in no more discharge of fuel for the same displacement of the plunger in the fuel injection pump, thereby increasing BSFC. Figure 5.2. shows the BSFC of biodiesel, diesel and their blends at various EGR rates and specified loads. Biodiesel and their blends has high BSFC than diesel, this is at comparable with high thermal efficiency found at lower BSFC. At 0% EGR, the BSFC of biodiesel and their blends was slightly higher than that of diesel fuel. This is due to the higher calorific value and densities of biodiesel and their blends, compared to diesel fuel as shown in table 5.1. The BSFC was increased with increasing EGR rate due to dilution of charge. Upon sending exhaust gases along with the intake air, the amount of intake air will be decreased and lead to high fuel consumption. It is increased rapidly, beyond 20% EGR rate. The possible reason is the significant reduction in BTE with in a limit of 25-40% rate at all specified load, in this study found the effective reduction of NO_X emissions at different EGR for each of test fuels and compare with the other controlling methods at specified loads. For the fuels diesel, JB 20, JB 40, JB 60, JB 80 and JB 100 are at 15% ,25%, 15%, 20%, 40% and 5% EGR rates the higher the reduction in the NO_X emissions was observed respectively at specified loads. For JB100 fuel at 5% EGR, there is no significant change in BSFC. The other test fuels like diesel, JB 20, JB 40, JB 60 and JB 80.The possible reason is the significant reduction in torque output within a limit of 15-40% EGR rate.

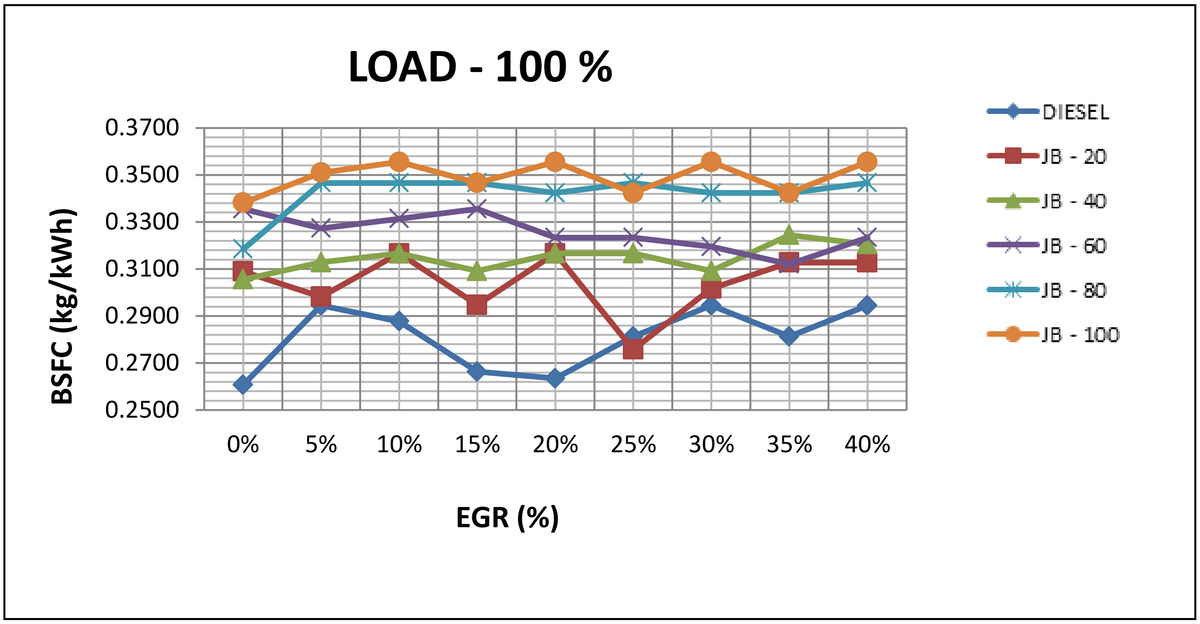


Figure 5.2. BSFC variation with EGR rate

5.3.3 Effect of EGR rate on NO_X emissions

The NO_X emissions of diesel, JBD and their blends are shown in Figure 5.3 results show that, for the test fuels, the increased engine load promoting NO_X emission, since the formation of NO_X is very sensitive to temperature. This is responsible for thermal NO_X formation. Kinetics of NO_X formation is governed by Zeldovich mechanism. The principle source of NO_X formation is the oxidation of atmospheric nitrogen at sufficiently high temperatures. NO_X are formed in cylinder areas where high temperature peaks appear mainly during the uncontrolled combustion. The NO_X emissions of biodiesel and their blends have been found higher than diesel at all loads. It is quite obvious, that with biodiesel addition in diesel more amount of oxygen is present in the combustion chamber, leading to formation of higher quantity of

NO_X in biodiesel fuelled engines. For biodiesel and their blends the maximum amount of NO_X produced at all loads. The reason is may be due to the boiling point of biodiesel and their blends is higher than that of diesel because this biodiesel maintains liquid phase for more duration, facilitating more droplet penetration into the combustion chamber, this can lead to increase in the fuel consumption, late burning of biodiesel and their blends during expansion, peak temperature and higher NO_X emission with respect to diesel may be due to sustained and prolonged duration of combustion associated without reduction in combustion temperature. This is the most important emission characteristics of biodiesel and their blends as the emission is the most harmful gaseous emissions from engines and this emission can be reduced by following methods. The main objective of the research work was to effectively reduce the NO_X emissions with three different controlling methods. Exhaust gas recirculation system (EGR), three-way catalytic converter and combination of EGR and three-way catalytic converter. Results related to NO_X emissions are very much similar to earlier studies reported by Nabi et al. [4]. The NO_X emission increases with increasing combustion temperature, which in turn is indicated by the prevailing, exhaust gas temperature. The NO_X emission increased with increasing biodiesel amount in the diesel. The NO_X emissions in case of biodiesel blends are higher than diesel due to higher temperatures in the combustion chamber and oxygen availability was also the major reason. The NO_X emission of all fuels decreased, when EGR was operated. The degree of reduction in NO_X emission at higher loads. This may be due to reduction in NO_X emissions using EGR in diesel engines are reduced oxygen availability and decreased the flame temperatures in the combustion chamber. It is observed from the figure 5.7. JB 20, JB 40, JB 60, JB 80, JB100 and diesel fuels have lower NO_X emissions at 25%, 15%, 20%, 40%, 5% and 15% EGR respectively.

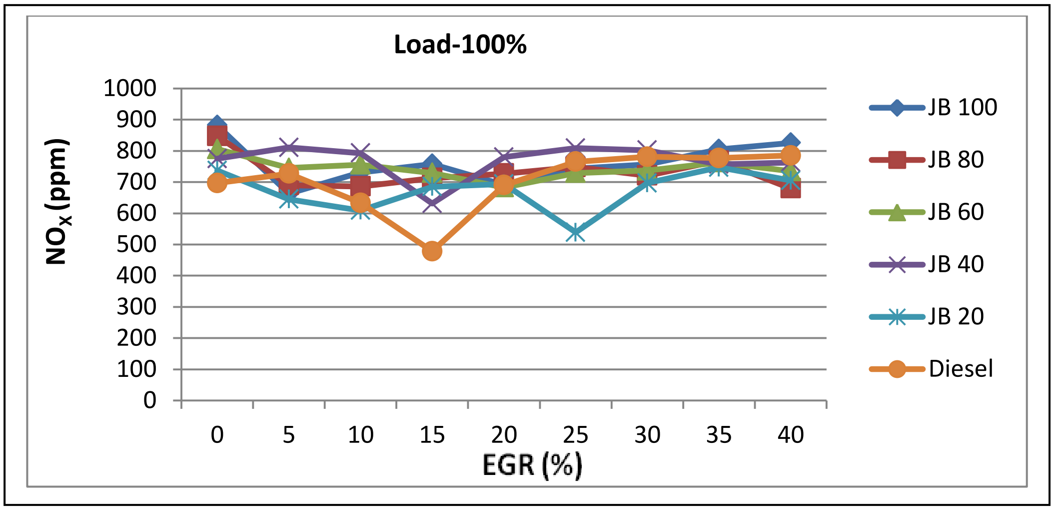


Figure 5.3: NO_X emission variation with EGR rate.

5.3.4 Effect of EGR rate on CO emissions

Generally, CO emission is forming due to incomplete combustion of fuel. If the combustion is complete, CO is oxidizing to CO_2. Usually CO emission of diesel engine is low, because diesel combustion occurs with lean mixture. The figure 5.4 clearly indicates the CO emissions at different loads for biodiesel, diesel and their blends. For all test fuels and their blends, CO decreases. But as the load is increased for a particular test fuel, there is an increase in CO emission. The increase in CO emission levels at higher load is due to rich mixture at higher load condition than those of lower load which results in incomplete combustion of fuel. Within the experimental range, the lowest CO emissions have been observed with biodiesel and their blends. This is possible because of complete combustion of biodiesel. Since biodiesel and their blends contain more oxygen than diesel much more CO is converted to carbon dioxide. In consequence it caused less carbon monoxide generated during the combustion, due to the presence of much more oxygen locally. The maximum value of carbon monoxide present in JB 100, JB 80, JB 60, JB 40 and JB 20 at 100% is 0.02%, 0.02%, 0.03%, 0.04% and 0.04% respectively. The corresponding value of diesel is 0.09% which is much higher than biodiesel and their blends in any of the case. Figure 5.4 shows the plots of CO emissions at various EGR rates and loads for diesel, biodiesel and their blends. The CO emission increased with increasing EGR rates. The possible reason may be reduction in the oxygen availability for combustion process, lower oxygen concentration results in rich air fuel mixture at different locations inside the combustion chamber. With EGR rate increases, it contributed to decrease the air fuel ratio and consequently CO emission eventually increased [35]. In this thesis the main aim is found the effective reduction of NO_X emissions at different EGR rates for each of test fuels and compare with the other controlling methods For the fuels diesel, JB 20, JB 40, JB 60, JB 80 and JB 100 are at 15%, 25%, 15%, 20%, 40% and 5% EGR rates the higher the reduction in the NO_X emissions was observed respectively at specified loads. The carbon monoxide of test fuels at the above EGR rates are increased shown in annexure compared to the base line value. Carbon monoxide for biodiesel and their blends with above EGR rates is noticed to be lower than that of diesel. This is expected due to extra oxygen amount of biodiesel molecules, which complete the fuel combustion and helps to oxidize carbon monoxide to carbon dioxide [56]. The values of CO emission were low because the compression ignition engines operate on lean side of the stoichiometric and therefore produce very little CO emission. The results are similar as mentioned in the literatures [(51) and (59)].

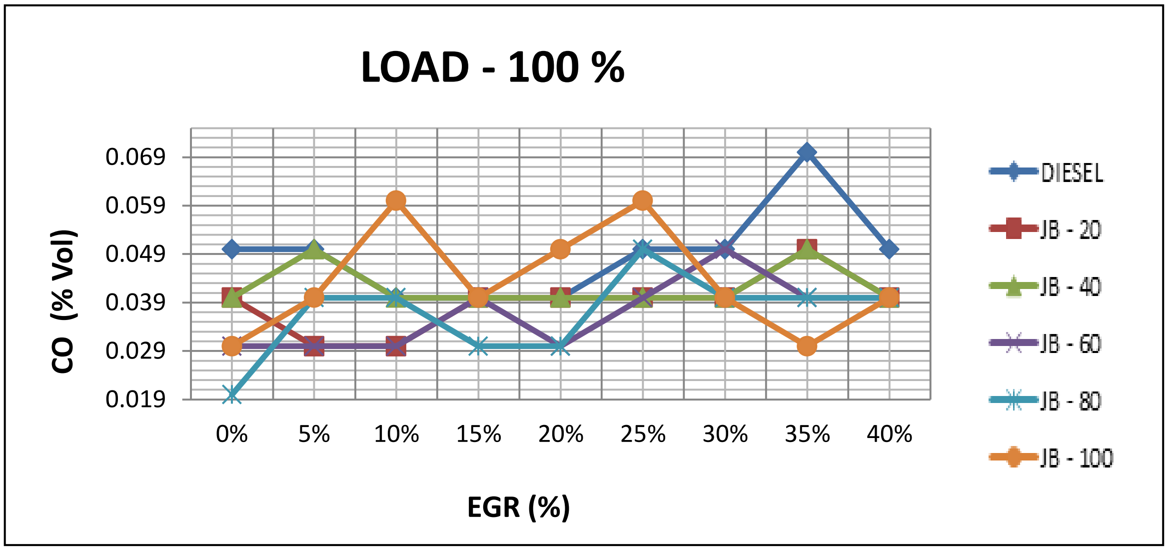


Figure 5.4: CO emission variation with EGR rate.

5.3.5 Effect of EGR rate on CO_2 emissions

In internal combustion engines high carbon dioxide in exhaust is an indication of the complete combustion of the fuel. Figure 5.5 shown below clearly indicates the variation of carbon dioxide emission with the specified loads for diesel, biodiesel and their blends. In the range of all specified loads, the carbon dioxide emissions of biodiesel and their blends are all higher than that of diesel. The highest carbon dioxide emissions have been in case of JB 100. The carbon content is relatively lower in the same volume of fuel consumed at the same engine load because of more oxygen content in JB 100 and their blends [33]. There was considerable increase in carbon dioxide emission with all biodiesel and their blends. Carbon dioxide emission increases as the proportion of biodiesel increases in mineral diesel i.e. it increases with JB 20, JB 40, JB 60, JB 80 and JB 100. In addition, CO_2 is threatening the human health, at its high concentration (toxicity) in the air. It can cause unconsciousness and death. The plots of carbon dioxide emissions with distinct EGR rates at specified loads. Carbon dioxide emissions increased with increasing EGR rate for all the test fuels. The higher increase in carbon dioxide emission was observed, at 35 to 40% EGR for all the test fuels. The reason is possibly due to the oxygen availability for combustion process decreased with increasing EGR rates. Thus, the phenomena for oxidizing carbon monoxide to carbon dioxide decreased. For the fuels diesel, JB 20, JB 40, JB 60, JB 80 and JB 100 are at 15% ,25%, 15%, 20%, 40% and 5% EGR rates the higher the reduction in the NO_X emissions was observed respectively at specified loads. CO_2 emissions for biodiesel and their blends with above EGR rates are noticed to be higher than that of diesel. This is because biodiesel and their respective blends have high oxygen content and the carbon content is relatively lower than in the same volume of fuel consumed at the same engine load. Consequently CO_2 emissions from the biodiesel are higher at all specified loads High CO_2 emission in exhaust is an indication the complete combustion of JB 40 fuel.

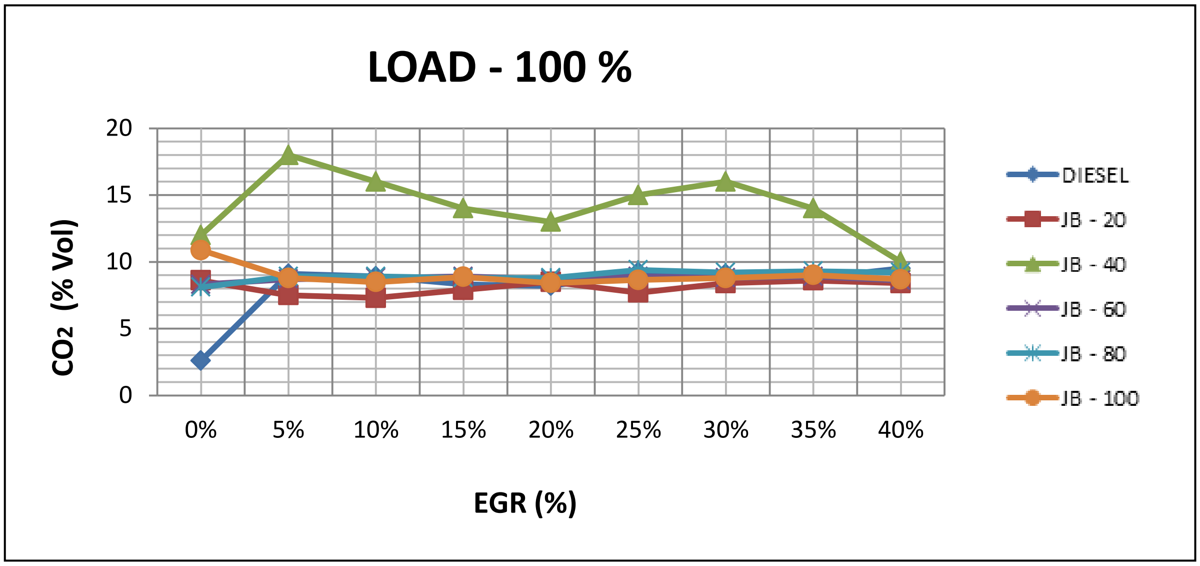


Figure 5.5: CO_2 emission variation with EGR rate.

5.3.6 Effect of EGR rate on UBHC emissions

Figure 5. 6 represents the variation of UBHC emissions with respect to load at distinct EGR rates. The UBHC emission increases with increase in load and EGR rate. This may be due to lower oxygen content available for combustion i. e. the increasing of EGR rate lower the oxygen concentration results rich mixture due to that incomplete combustion takes place and results higher hydro carbon emissions. In this thesis, the main aim is found the effective reduction of NO_X emissions at different EGR rates for each of test fuels and compare with the other controlling methods at specified loads. The UBHC emissions of test fuels at the above EGR rates are increased as shown in tables 5.2 to 5.7 compared to the base line value except JB 100 fuel. For JB 100 fuel the best NO_X emission reduction observed at the 5% of EGR rate. At this stage lower in UBHC emissions is observed for JB 100 test fuel for all the loads. The possible

reason due to that the oxygen availability not much change for combustion process with 5% of EGR rate. The UBHC emissions of other test fuels at the above EGR rates are increased compared to the base line value. The increase in UBHC emission was observed, at 15 to 40% EGR rate for above test fuels, because of lower oxygen content available for complete combustion of fuel.

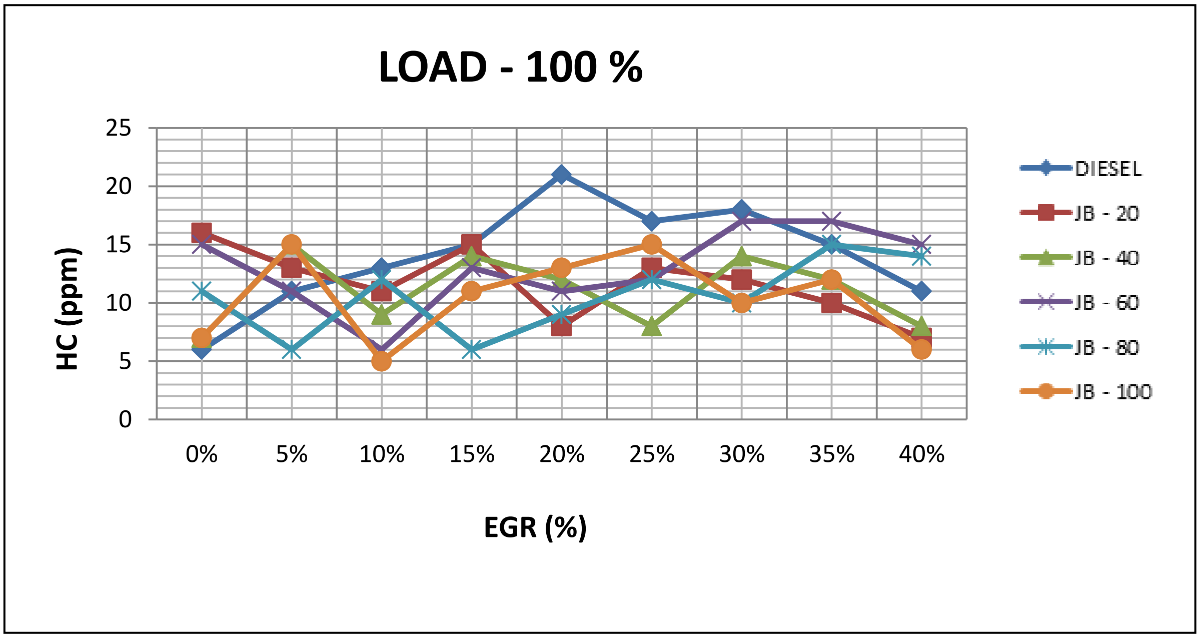


Figure 5.6: HC emission variation with EGR rate.

5.3.7 Effect of EGR rate on smoke

It can be noted that smoke is high mainly at higher outputs. High loads imply that more fuel is injected into the combustion chamber and hence incomplete combustion of fuel is amplified. Reduction of smoke emissions for different biodiesel-diesel blends in comparison to diesel fuel for all loads. With an increase of biodiesel in biodiesel-diesel fuel blends, smoke decreases at most of the operating conditions. However, the maximum smoke reduction has been observed in case of JB 100. The reduction in smoke can be explained by the presence of less carbon with biodiesel based fuels as compared to diesel. In addition to that, biodiesel has more oxygen content contrary to diesel, which has almost no oxygen. The presence of oxygen in the biodiesel is in favor of carbon residual oxidation, which leads to reduction in smoke opacity. The smoke is produced mainly in the diffusive combustion phase, the addition of oxygenated fuel such as biodiesel leads to an improvement in diffusive combustion. It is also observed that, the diesel fuel at all loads showed a higher level of smoke than that of biodiesel and their blends. This increase in soot emission is due to the higher boiling point and thermal stability of the aromatic hydrocarbons present in the diesel fuel. It is also observed that biodiesel and their blends are emitting lower levels of smoke as compared to that of diesel fuel under all specified loads. This is probably because of the combined effect of the higher cetane number and presence of oxygen in the biodiesel and their blends, which improves the combustion. Therefore, it is concluded that, the increase of oxygen in the biodiesel and their blends tends to reduce the smoke opacity for all specified loads. Figure 5.7 represents the variation of smoke with respect to load at distinct EGR rates. The smoke opacity was lesser for biodiesel and their blends compared to diesel at all specified loads. This may be due to the oxygen amount in the blends which contributes to complete and stable combustion process. When percentage of biodiesel amount in the blends increases, smoke opacity decreases. Smoke opacity increases with increase of load and EGR rate for all test fuels due to reduction oxygen available for fuel combustion and lead to incomplete combustion [55]. The increase in smoke opacity occurred, at high loads and higher EGR rates beyond 15%. The possible reason due to the increase in EGR rate lead to significant reduction in oxygen amount sucked into the combustion chamber. The smoke opacity of test fuels at the above EGR rates are increased compared to the base line value. Soot emission for biodiesel and their blends with above EGR rates is noticed to be lower than that of diesel. The molecule of biodiesel contains more oxygen than diesel, due oxygen complete combustion takes place and this may be a possible reason for lower soot emission.

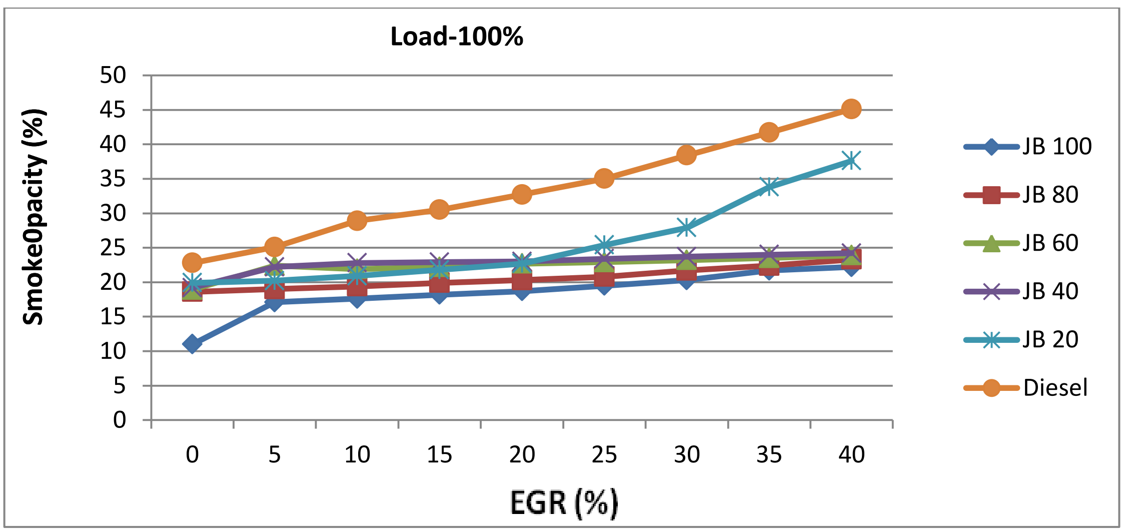


Figure 5.7: Smoke variation with EGR rate.

5.4 Effect of catalytic converter on engine performance

A three way catalytic converter has three simultaneous tasks, 1. Oxidation of carbon monoxide to carbon dioxide 2. Oxidation of un-burnt hydrocarbons to carbon dioxide and water and 3. Reduction of nitrogen oxides to nitrogen and oxygen. These three reactions occur most efficiently when the catalytic converter receives the exhaust gas from an engine running slightly above the stoichiometric point. Combustion efficiency is not affected by attaching the three way catalytic converter in an open-loop system [(82) and (83)]. According to this negligible reduction in brake thermal efficiency was experienced. For all testing fuels at all loads there is no significant change of brake thermal efficiency. Three-way catalytic converter store oxygen from the exhaust gas 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_X reduction is unavailable. The three way catalytic converter with open loop system, the maximum amount of NO_X emissions reduction was found in diesel fuel compared to other test fuels and with no change in brake thermal efficiency because Rh catalyst release the oxygen atoms stored in the NO_X in the reduction process and hence NO_X emissions to the atmosphere significantly reduced in diesel.

5.4.1 Effect of catalytic converter on BTE

From the above table 5.2 it can be found that the brake thermal efficiency of biodiesel and its blends was found to be lower than diesel, which may be due to lower calorific value and slightly higher viscosity of biodiesel. Combustion efficiency is not affected by attaching the three way catalytic converter in open loop method. Negligible reduction in brake thermal efficiency was experienced. For all testing fuels at all loads there is no significant change of brake thermal efficiency.

Table 5.2 Effect of catalytic converter on BTE at full load.

Test-fuels	Diesel	JB 20	JB 40	JB60	JB 80	JB100
Existing engine BTE (%)	41.09	39.91	36.69	33.59	35.74	34.13
Existing engine and 3-way CC BTE (%)	41.09	38.62	33.70	33.17	35.74	33.71
Change in BTE (%)	0	1.29	2.99	0.42	0	0.42

5.4.2 Effect of catalytic converter on BSFC

Table 5.3 Effect of catalytic converter on BSFC at full load.

Test-fuels	Diesel	JB 20	JB 40	JB60	JB 80	JB100
Existing engine (BSFC kg/kWh)	0.2607	0.2757	0.3056	0.3355	0.3185	0.3381
Existing engine and 3-way CC (BSFC kg/kWh)	0.2607	0.2849	0.3326	0.3397	0.3262	0.3423
Change in (BSFC kg/kWh)	0	0.0092	0.027	0.0042	0.007	0.0042

From the above table 5.3 it can be found that the variation of BSFC with the three-way catalytic converter at specified loads. For all loads, the BSFC of biodiesel and its blends was found to be more than the diesel fuel, which may be due to the biodiesel contains more percentage of oxygen and consequently less percentage of hydrocarbons and calorific value than that of diesel fuels shown in table 5.1, due to lower value of calorific value of biodiesel, this behavior of more fuel consumption was expected for all specified loads. Combustion efficiency is not affected by attaching the three way catalytic converter in open loop method. Negligible reduction in BSFC was experienced. For all testing fuels at high loads there is no significant change of BSFC.

5.4.3 Effect of catalytic converter on NO_X emissions

Table 5.4 Effect of catalytic converter on NO_X emissions at full load.

Test-fuels	Diesel	JB 20	JB 40	JB60	JB 80	JB100
Existing engine NO_X (ppm)	697	737	775	806	848	882
Existing engine and 3-way CC NO_X (ppm)	466	572	633	672	731	755
Reduction percentage of NO_X (ppm)	33.14	22.38	18.3	16.6	13.79	14.3

Table 5. 4 shows that the reduction of NO_X emission of diesel, biodiesel and their blends with three-way catalytic converter. Three- way catalytic converter was used in an open loop system. Rhodium (Rh), platinum (pt) and palladium (pd) noble metals acts as catalysts. Platinum and palladium metals were designed only to convert HC, CO to CO_2 and H_2O through exothermic oxidation reactions. Rhodium as a catalyst to release the oxygen atoms stored in the NO_X in the reduction reaction. The oxygen atoms made available in the reduction process was utilized to oxidised the HC and CO. Hence, the emission of NO_X reduced significantly with the three way catalytic converter.

The NO_X emission increases with increasing combustion temperature, which in turn indicated by the prevailing exhaust gas temperature. The NO_X emission increased with increasing biodiesel amount in the blends. The NO_X emission in case of biodiesel blends are higher than diesel due to higher temperatures in the combustion chamber and oxygen availability was also the major reason for increasing NO_X emission. The NO_X emission of all fuels reduced, when three-way catalytic converter was operated. When the engine is operated at low loads the concentrations of exhaust gases are low. Hence, changes in the catalytic activity or the accumulation of reactive species in a catalyst affect the dynamic behavior of the converter consequently low reduction of NO_X emissions. The degree of reduction in NO_X emission was higher at higher loads. This may be due to a higher load the engine is running with excessive fuel (rich mixtures), at rich mixtures the reduction in NO_X emissions is in favour, at the expense of CO and HC oxidation. When the engine load increases, the three way catalytic converter reaches the 'light-off' with less time hence NO_X emission reduction is more at higher loads for all test fuels. The reduction percentage of NO_X emission for diesel fuel has high when compared to biodiesel and their blends. This is may be due to that all the active sites are react with adsorbents, which enables the efficient mass transfer between diesel fuel exhaust and active catalytic surface to achieve the maximum reduction of NO_X emission compared to other test fuels , rate as a function of temperature. It is observed from the annexure the JB20, JB40, JB60, JB80 and JB100 have lower NO_X emission reduction when compared to diesel fuels at all specified loads.

5.4.4 Effect of catalytic converter on CO emissions

Table 5.5 Effect of catalytic converter on CO emissions at full load.

Test-fuels	Diesel	JB 20	JB 40	JB60	JB 80	JB100
Existing engine carbon monoxide (%)	0.09	0.04	0.04	0.03	0.02	0.02
Existing engine and 3-way CC Carbon monoxide (%)	0.05	0.03	0.03	0.03	0.02	0.02
Change in carbon monoxide (%)	0.04	0.01	0.01	0	0	0

From the above table 5.5 it can be found that the carbon monoxide of biodiesel and its blends was found to be lower than diesel at all specified loads, which may be due to complete combustion on account of higher oxygen content of biodiesel. Carbon monoxide emission from a diesel engine generally depends upon the physical and chemical properties of the fuel. Combustion efficiency is not affected by attaching the three way catalytic converter in open loop method. Due to higher fuel-air equivalence ratio, significant reduction in emissions of CO was observed at full load conditions for diesel fuel with three-way catalytic converter. While the difference in CO emissions are insignificant for the biodiesel and their blend fuels at all load conditions, when the existing engine CO emissions compared with the three way catalytic converter engine. This may be due to higher oxygen content of biodiesel leads to possible complete combustion. Engine with the three-way catalytic converter the oxygen atoms made available in the reduction process will simultaneously proved an oxidation environment to oxidize carbon monoxide.

Due to this, insignificant change in carbon monoxide was experienced. For all biodiesel and their blends at all loads there is no significant change of carbon monoxide.

5.4.5 Effect of catalytic converter on CO_2 emissions

Table 5. 6 Effect of catalytic converter on CO_2 emissions at full load.

Test-fuels	Diesel	JB 20	JB 40	JB60	JB 80	JB100
Existing engine Carbon dioxide (%)	2.6	8.6	12	8.3	18.6	11
Existing engine and 3-way CC Carbon dioxide (%)	9.2	9.1	16	9.1	17.3	8.5
Change in Carbon dioxide (%)	6.6	0.5	4	0.8	1.3	2.5

From the above table 5. 6 it can be found that the carbon dioxide of biodiesel and its blends was found to be higher than diesel at all specified loads, which may be due to complete combustion on account of higher oxygen content of biodiesel. Carbon dioxide emission from a diesel engine generally depends upon the physical and chemical properties of the fuel. Combustion efficiency is not affected by attaching the three way catalytic converter in open loop method. Due to higher fuel-air equivalence ratio, significant rise in CO_2 emissions was observed at full load conditions for diesel fuel with three-way catalytic converter. This may be due to when insufficient oxygen is available from the exhaust stream the stored oxygen released and consumed and complete the oxidation of carbon monoxide to carbon dioxide. While the difference in CO_2 emissions are insignificant for the biodiesel and their blended fuels at all load conditions, when the existing engine CO_2 emissions compared with the three way catalytic converter engine. This may be due to higher oxygen content of biodiesel leads to possible complete combustion. For biodiesel and their blends due to more oxygen content CO_2 formation may be reached just saturated level without three way catalytic converter. Then the remaining oxidation of carbon monoxide to carbon dioxide occurs in three-way catalytic converter. This may be the possible reason for biodiesel and their blends have insignificant change in CO_2 emissions by three-way catalytic converter. For all biodiesel and their blends at all loads there is no significant change of carbon dioxide.

5.4.6 Effect of catalytic converter on UBHC emissions

From the above table 5.7 it can be found that the UBHC emissions are high at high loads. The UBHC emissions of biodiesel and its blends was found to be lower than diesel, which may be due to the oxygen weight content is higher in biodiesel and their blends.

Table 5.7 Effect of catalytic converter on UBHC emissions at full load.

Test-fuels	Diesel	JB 20	JB 40	JB60	JB 80	JB100
Existing engine -HC (ppm)	14	12	12	11	11	10
Existing engine and 3-way CC-HC (ppm)	12	11	11	7	10	8
Change in –HC (ppm)	2	1	1	4	1	2

Combustion efficiency is not affected by attaching the three way catalytic converter in open loop method. At all specified loads, the three-way catalytic converter reaches the regeneration temperature. Oxidation of un-burnt hydrocarbons to carbon dioxide and water occur most efficiently when the catalytic converter receives the exhaust gas from the engine running at high loads. The possible reason due to the three-way catalytic converter light of temperature is reached easily at these high loads. The reaction rate is proportional to the number of active sites, at high loads the active sites are more compared to low loads. It is found that for all test fuels less UBHC emissions percentage was observed at high loads by using three-way catalytic converter. The reduction of UBHC emissions at specified loads for all test fuels is shown in above tables.

5.4.7 Effect of catalytic converter on smoke

Table 5.8 Effect of catalytic converter on smoke at full load.

Test-fuels	Diesel	JB 20	JB 40	JB60	JB 80	JB100
Existing engine - smoke (%)	22.8	19.9	19.2	18.9	18.6	11
Existing engine and 3-way CC smoke (%)	20.3	16.7	17.2	15.7	17.3	8.5
Change in - smoke (%)	2.5	3.2	2	3.2	1.3	2.5

From the above table 5.8 it can be found that the smoke opacity is high at high loads. The smoke opacity of biodiesel and its blends was found to be lower than diesel, which may be due to the oxygen weight content is higher in biodiesel and their blends. Combustion efficiency is not affected by attaching the three way catalytic converter in open loop method. At all specified loads, the three-way catalytic converter reaches the regeneration temperature. This causes chemical reaction which raises the three way catalytic temperature to the level required to convert soot into the CO_2. It is found that for all test fuels CO_2 percentage is more less smoke opacity percentage was observed at all the specified loads by using three-way catalytic converter.

5.5 Effect of catalytic converter and EGR rate on BTE

Figure 5.8 shows thermal efficiency of diesel, biodiesel and their blends with the combination of distinct EGR rates and three-way catalytic converter of specified loads. The thermal efficiency decreased with the combination of EGR rate and three-way catalytic converter are compared without using EGR rate and three way catalytic converter at different loads. The reduction in thermal efficiency only with EGR due to the dilution of the fresh charge with the exhaust gas which results in flame velocity and hence deterioration of the combustion and lead to incomplete combustion of fuel. Three-way catalytic converter is connected to the engine in an open loop model due to this no effect on brake thermal efficiency. For JB 100 fuel the best NO_X emission reduction observed at the combination of 5% of EGR rate and three way catalytic converter. At this stage insignificant change in brake thermal efficiency is observed for JB 100 test fuel. For other test fuels like JB 80, JB 60, JB 40, JB 20 and diesel fuels the best NO_X emission reduction observed at the combination of 35% to 40% of

EGR rate and three-way catalytic converter. This may be due to increasing of EGR rate leads to incomplete combustion of fuel.

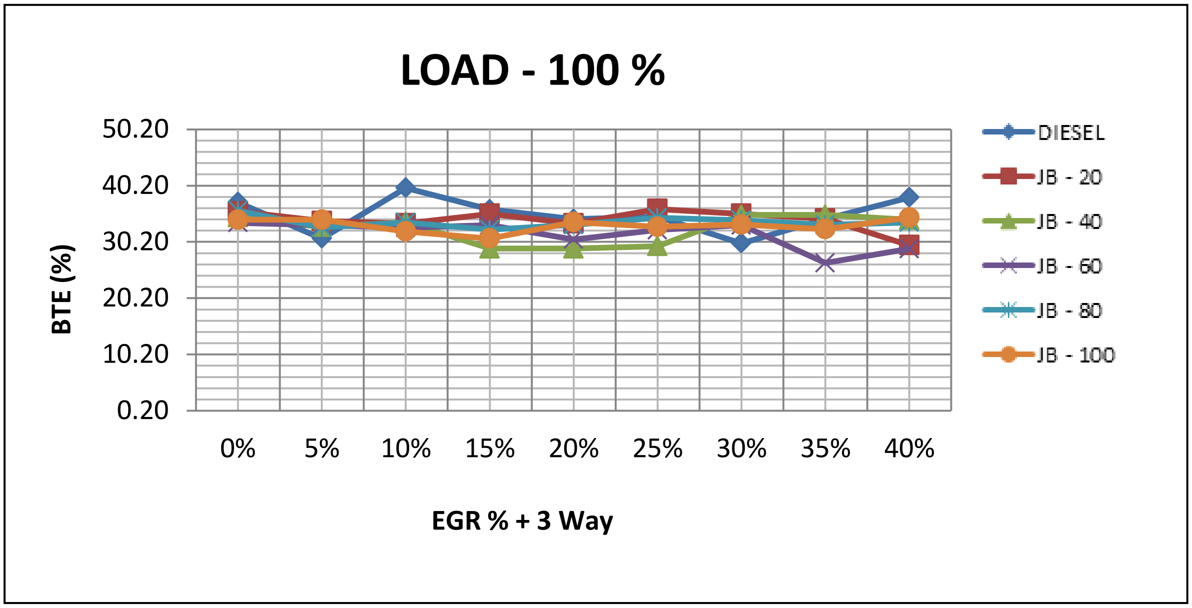


Figure 5.8: BTE variation with catalytic converter and EGR rate

5.5.1 Effect of catalytic converter and EGR rate on BSFC

Figure 5. 9 shows brake specific fuel consumption of diesel, biodiesel and their blends with the combination of distinct EGR rates and three way catalytic converter of specified loads. The specific fuel consumption with the combination of EGR rate and three-way catalytic converter are compared without using EGR rate and three way catalytic converter at different loads. The increase in BSFC only with EGR due to lower calorific value and high viscosity. Three-way catalytic converter is connected to the engine in an open loop model due to this no effect on brake specific fuel consumption. For JB 100 fuel the best NO_X emission reduction observed at the combination of 5% of EGR rate and three way

catalytic converter. Here no significant change in BSFC. For other test fuels like JB 80, JB 60, JB 40, JB 20 and diesel fuels the best NO_X emission reduction observed at the combination of 35% to 40% of EGR rate and three way catalytic converter. Hence, the BSFC changed for the above test fuels. This may be due to increasing of EGR rate leads to incomplete combustion of fuel.

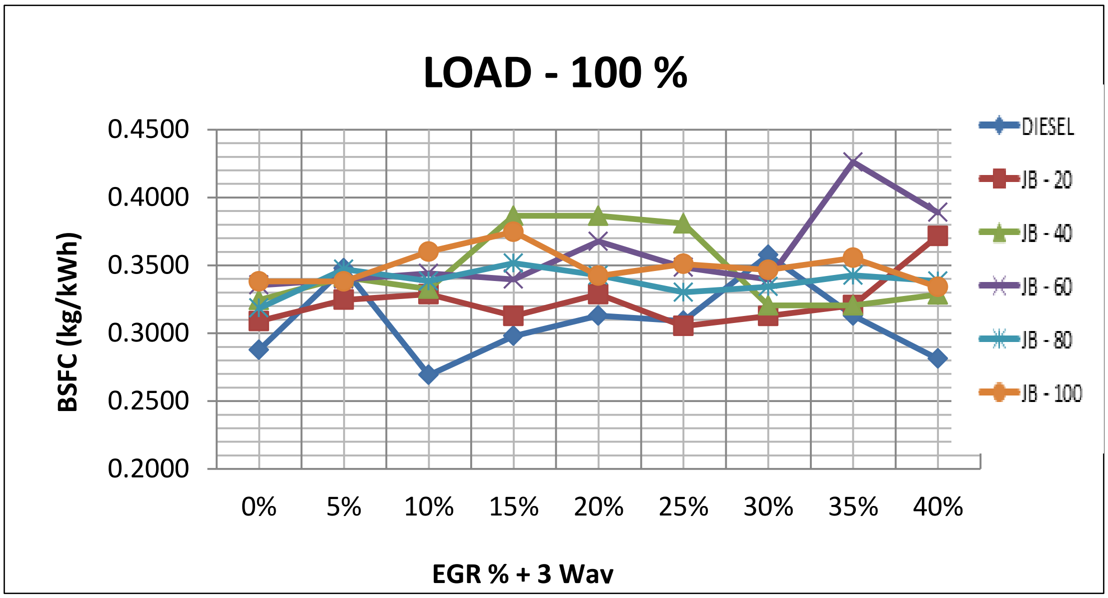


Figure 5.9: BSFC variation with catalytic converter and EGR rate

5.5.2 Effect of catalytic converter and EGR rate on NO_X emissions

Figure 5. 10 show NO_X emissions of diesel, biodiesel and their blends with the combination of distinct EGR rates and three-way catalytic converter of specified loads. The NO_X emissions with the combination of EGR rate and three- way catalytic converter are compared without using EGR rate and three - way catalytic converter at different loads. The combinations of EGR and three-way catalytic converter have proved to be the most effectively reducing the

NO_X emissions. In this study EGR connected to engine manifold and then followed by three way catalytic converter. Here EGR acts as pre-catalyst. The location of the pre-catalyst connected to the engine's exhaust manifold enables decreasing the pollutant concentrations, during the engine's operation. This allows reduce the burden on the in three way catalytic converter. Hence rare materials present three-way catalytic converter (platinum, palladium and rhodium) are conserved. For JB 100 fuel the best NO_X emission reduction observed at the combination of 5% of EGR rate and three way catalytic converter. For other test fuels like JB 80, JB 60, JB 40, JB 20 and diesel fuels the best NO_X emission reduction observed at the combination of 35% to 40% of EGR rate and three-way catalytic converter. This may be due to increasing of EGR rate leads to incomplete combustion of fuel, usually when the EGR rate is more the fuel air ratio goes lean. Then the three-way catalytic converter can store oxygen from the lean air fuel exhaust gas stream. When insufficient oxygen is available from the exhaust stream the stored oxygen is released and consumed. This happens either when oxygen derived from NO_X reduction. This may be the reason for the maximum amount of NO_X reduction occurs by using of EGR and three-way catalytic converter controlling method. The reduction percentages of the test fuels are shown in the tables.

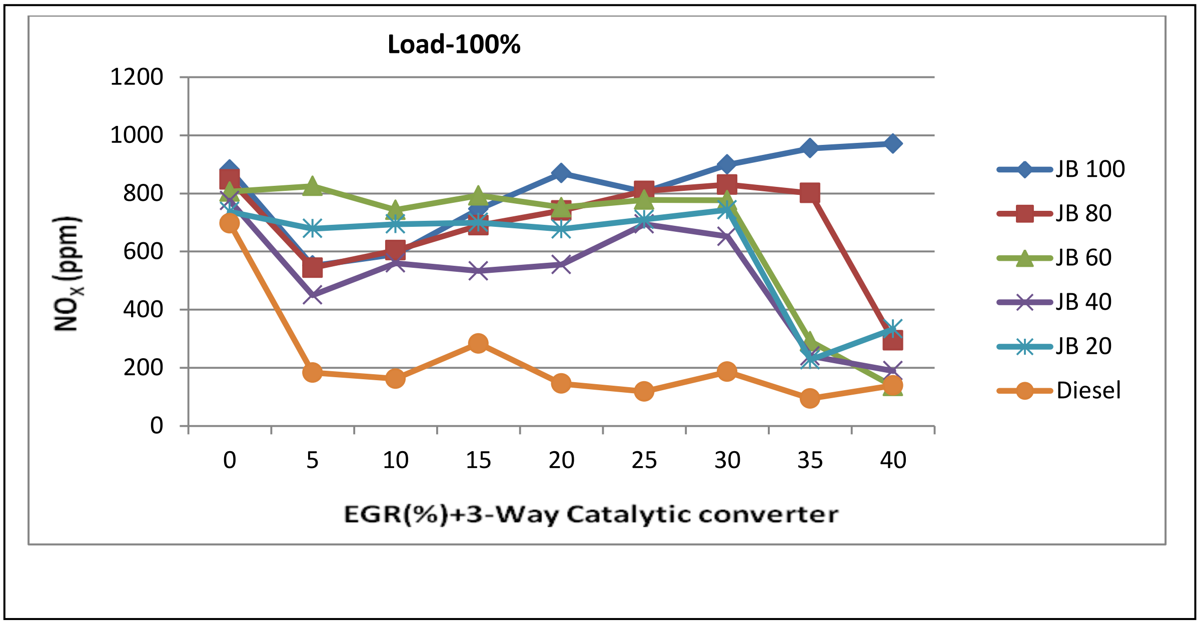


Figure 5.10: NO_X variation with catalytic converter and EGR rate

5.5.3 Effect of catalytic converter and EGR rate on CO emissions

Figure 5. 11 shows CO emissions of diesel, biodiesel and their blends with the combination of distinct EGR rates and three-way catalytic converter at specified loads. In this study EGR connected to engine manifold and then followed by three way catalytic converter. Here, EGR acts as pre-catalyst. The location of the pre-catalyst connected to the engine's exhaust manifold enables decreasing the pollutant concentrations, during the engine's operation. This allows reduce the burden on the in three-way catalytic converter. The CO emissions with the combination of EGR rate and three- way catalytic converter are compared without using EGR rate and three-way catalytic converter at

different loads. The combination of EGR and three-way catalytic converter have proved that insignificant change in the reducing the carbon monoxide emissions for diesel, biodiesel and their blends. The values of CO emission were low because the compression ignition engines operate on lean side of the stoichiometric and therefore produce very little CO emission. For JB 100 fuel the best NOX emission reduction observed at the combination of 5% of EGR rate and three-way catalytic converter. At this stage insignificant change in carbon monoxide emission is observed for JB 100 test fuel foe all the loads. For other test fuels like JB 80, JB 60, JB 40, JB 20 and diesel fuels the best NO_X emission reduction observed at the combination of 35% to 40% of EGR rate and three- way catalytic converter. At the same point of NO_X reduction, carbon monoxide emission is changes from 0.02 to 0.04% for the above test fuels. This may be due the CO emission of diesel engine is low. Hence, the combination of EGR rate and three way catalytic converter controlling method is not much effect on CO emission reduction for diesel engines.

5.5.4: Effect of catalytic converter and EGR rate on CO_2 emissions

Figure5.12 shows CO_2 emissions of diesel, biodiesel and their blends with the combination of distinct EGR rates and three-way catalytic converter at specified loads. The location of the pre-catalyst connected to the engine's exhaust manifold enables decreasing the pollutant concentrations, during the engine's operation.

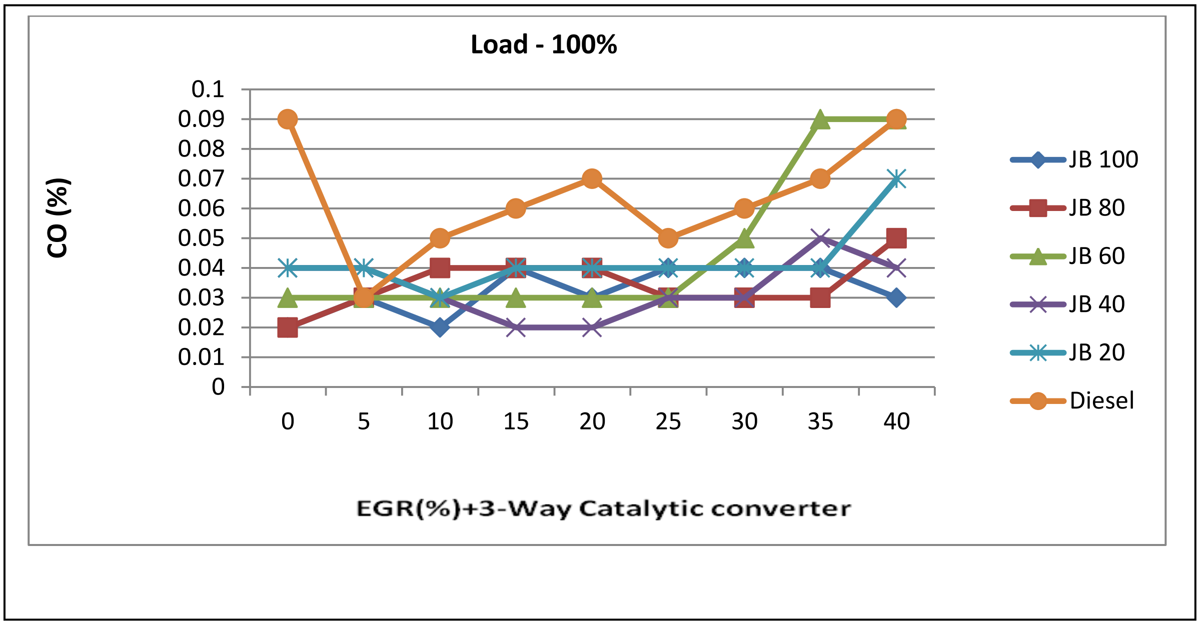


Figure 5.11: CO variation with catalytic converter and EGR rate

The CO_2 emissions with the combination of EGR rate and three way catalytic converter are compared without using EGR rate and three way catalytic converter at different loads. The combinations of EGR and three-way catalytic converter have proved that significant change in the carbon dioxide emissions for all test fuels except JB 100 fuel. For JB 100 fuel the best NO_X emission reduction observed at the combination of 5% of EGR rate and three way catalytic converter. At this stage insignificant change in carbon dioxide emission is observed for JB 100 test fuel for all the loads. The possible reason due to that the oxygen availability not much change for combustion process with 5% of EGR rate. For other test fuels like JB 80, JB 60, JB 40, JB 20 and diesel fuels the best NO_X emission reduction observed at the combination of 35% to 40% of EGR rate and three-way catalytic converter. At the same point of NO_X reduction, the carbon dioxide emission has significant changes occurs for the above test fuels. The higher increase in CO_2 emission was observed, at 35 to 40% EGR rate for above test fuels. This may be due to that complete combustion of fuel. This supports the higher value of exhaust temperature. Then the exhaust gases passing through the three way catalytic converter to complete the oxidation task i.e. oxidation of carbon monoxide to carbon dioxide. The combination of biodiesel blends and diesel produces carbon dioxide. Which are getting accumulated in atmosphere and leads to many environmental problems. The combination of EGR rate and three way catalytic converter controlling method is not much effect on CO_2 emission reduction for diesel engines.

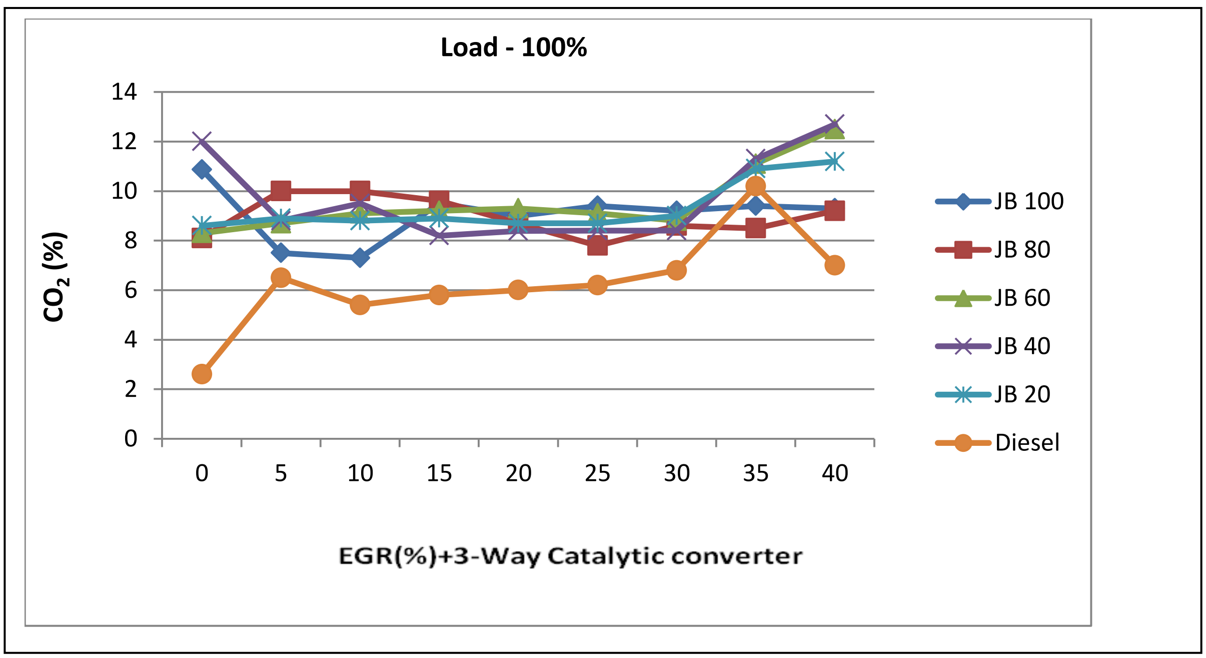


Figure 5.12: CO_2 emission variation with catalytic converter and EGR rate

5.5.5 Effect of catalytic converter and EGR rate on UBHC emissions

Figure5.13 shows that UBHC emissions of diesel, biodiesel and their blends with the combination of distinct EGR rates and three-way catalytic converter at specified loads. The UBHC emissions with the combination of EGR rate and three- way catalytic converter are compared without using EGR rate and three-way catalytic converter at different loads. In this study found the effective reduction of NO_X emissions at different EGR rates and three-way catalytic converter for each of test fuel and compare with the other controlling methods at specified loads. For the fuels diesel, JB 20, JB 40, JB 60, JB 80 and JB 100 are at 35%, 35%, 40%, 40%, 40% and 5% EGR rates and three-way catalytic converter the higher the reduction in the NO_X emissions was observed respectively at specified loads. The UBHC emission of test fuels is increased at the above EGR rates and three-way catalytic converter as compared to the base line values. For JB100 fuel at 5% EGR and three-way catalytic converter, there is no significant change in UBHC emissions. This may be due to that at 5% EGR rate the dilution of the charge is less and the available oxygen contributes to complete and stable combustion process. For other test fuels like JB80, JB60, JB40, JB20 and diesel fuels the best NO_X emission reduction observed at the combination of 35% to 40% of EGR rate and three-way catalytic converter. The UBHC emissions of above test fuels at the above EGR rates and three-way catalytic converter are very high compared to the base line value. This could be due to the at higher EGR rates, the increase in re-circulated exhaust gas amount lead to significant reduction in oxygen amount sucked in to the combustion chamber. Then the three-way catalytic converter receives the exhaust gas from the EGR connected engine with diluted air fuel mixture. Thus the oxidation of un-burnt hydrocarbons to carbon dioxide and water reactions occur in efficiently. This results UBHC emissions level of above test fuels at all specified loads were more, at higher EGR rates and three-way catalytic converter.

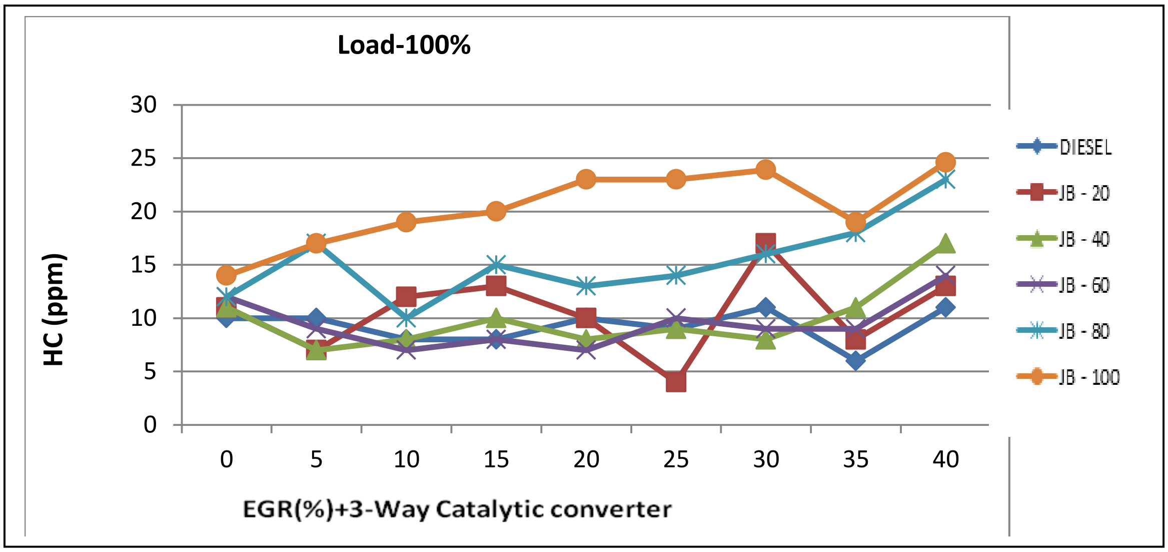


Figure 5.13: HC variation with catalytic converter and EGR rate

5. 5. 6 Effect of catalytic converter and EGR rate on smoke

Figure5. 14. shows smoke opacity of diesel, biodiesel and their blends with the combination of distinct EGR rates and three-way catalytic converter at specified loads. The smoke opacity with the combination of EGR rate and three-way catalytic converter are compared without using EGR rate and three-way catalytic converter at different loads. In this study found the effective

reduction of NO_X emissions at different EGR rates and three-way catalytic converter for each of test fuel and compare with the other controlling methods at specified loads. For the fuels diesel, JB 20, JB 40, JB 60, JB 80 and JB 100 are at 35%, 35%, 40%, 40%, 40% and 5% EGR rates and three-way catalytic converter the higher the reduction in the NO_X emissions was observed respectively at specified loads. The smoke of test fuels is increased at the above EGR rates and three-way catalytic converter. For JB100 fuel at 5% EGR and three-way catalytic converter, there is no significant change in smoke opacity. This may be due to that at 5% EGR rate the dilution of the charge is less and the available oxygen contributes to complete and stable combustion process. For other test fuels like JB 80, JB 60, JB 40, JB 20 and diesel fuels the best NO_X emission reduction observed at the combination of 35% to 40% of EGR rate and three-way catalytic converter. The smoke opacity of above test fuels at the above EGR rates and three-way catalytic converter are very high as compared to the base line value. This could be due to the at higher EGR rates, the increase in re-circulated exhaust gas amount lead to significant reduction in oxygen amount sucked in to the combustion chamber. Then the exhaust emissions passing through the three-way catalytic converter and very less amount of soot were converted into CO_2. Thus, the smoke opacity level of above test fuels at 100% loads was unacceptable, at higher EGR rates and three-way catalytic converter. This may be the reason at higher loads (100%) the EGR and three-way catalytic converter controlling method was not suggested.

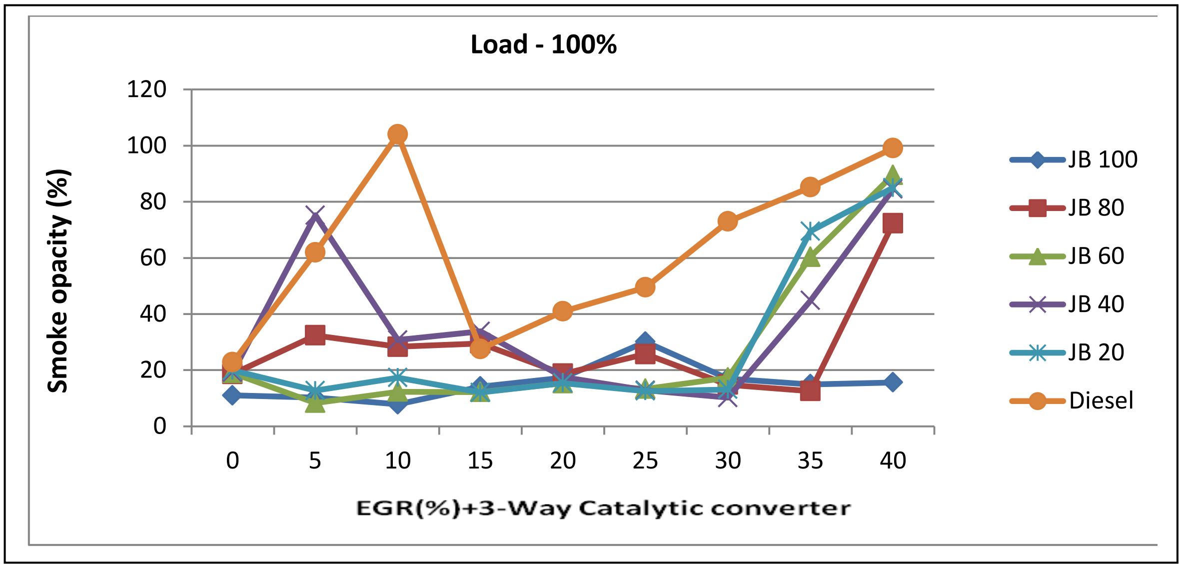


Figure 5.14: Smoke variation with catalytic converter and EGR rate

5.6 Operating conditions optimization

Experiments were carried out with an objective of reduction of NO_X emissions of IDI diesel engine when biodiesel, diesel and their blends fuelled in it with the controlling methods of EGR, three- way catalytic converter and the combination of EGR and three-way catalytic converter. For a test fuel like JB 100 having lower NO_X emissions at 5% EGR and three-way catalytic converter and other emissions are in acceptable range without specific changes of brake thermal efficiency compared to other controlling methods. Similarly other test fuels are discussed below.

5.6.1 JB 100-Fuel

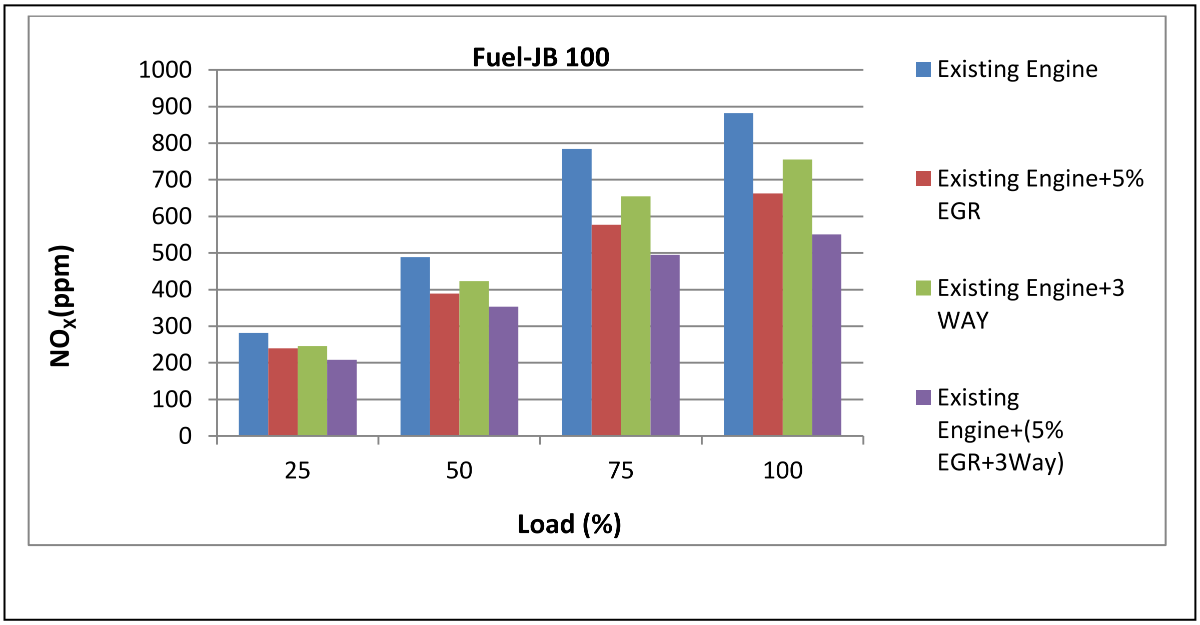


Figure5. 15: Variation of NO_X for JB 100

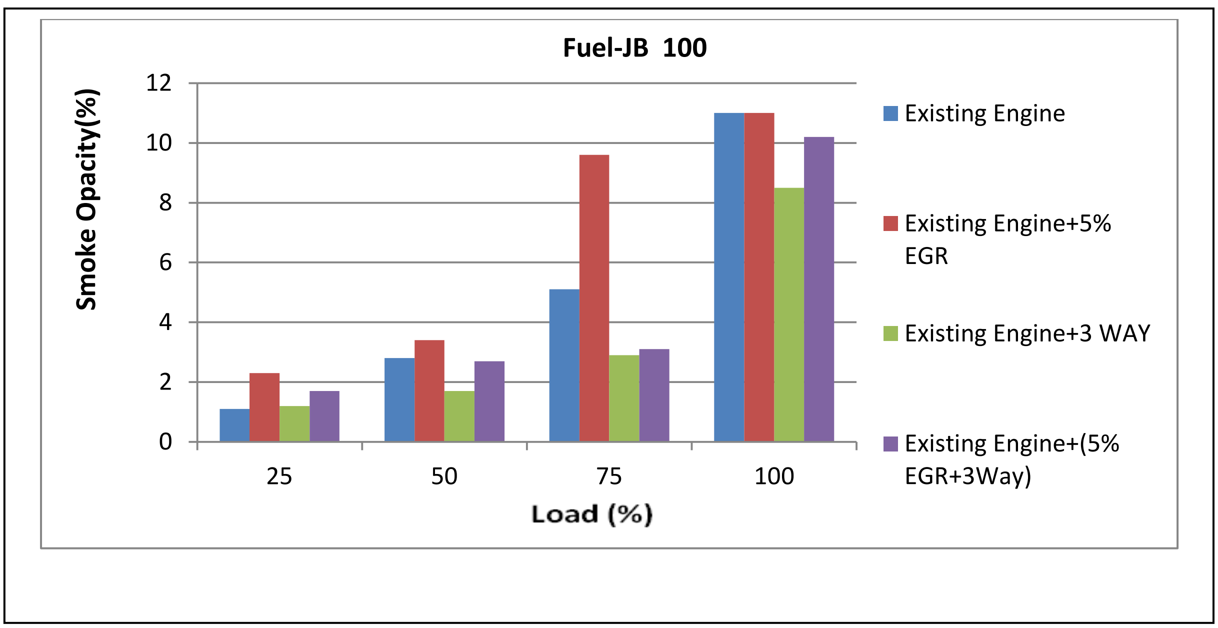


Figure5. 16: Variation of smoke for JB 100

Figure 5.15 and 5.16 shows that NO_X emission effectively reduced by using the EGR (rate at 5%) and three-way catalytic converter at all specified loads compared to other controlling methods. At this stage smoke opacity was an acceptable range by using of EGR (rate at5%) and three-way catalytic converter control method. From the tables 5.2 to 5.7 it was observed that the remaining exhaust emissions are also acceptable range and without any significant change in brake thermal efficiency. As discussed before, it may due to the combined effect of EGR and three-way catalytic converter. EGR (rate at5%) and three-way catalytic converter controlling method may be suggested for JB 100 fuel for all specified loads.

5.6.2 JB 80-Fuel

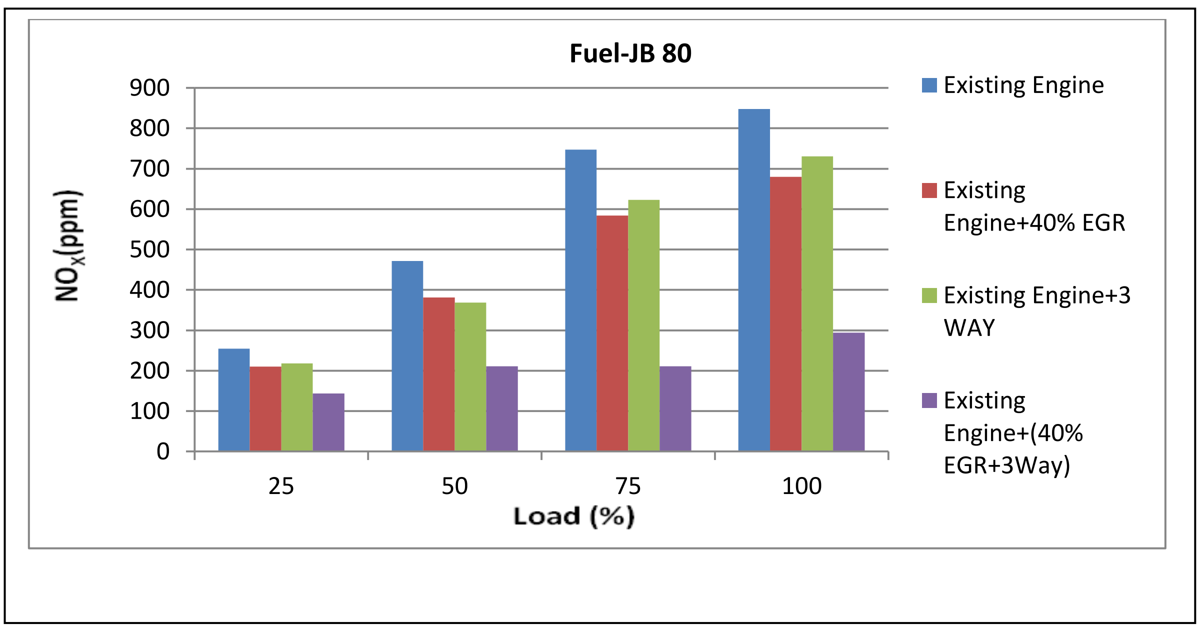


Figure5 .17: Variation of NO_X for JB 80

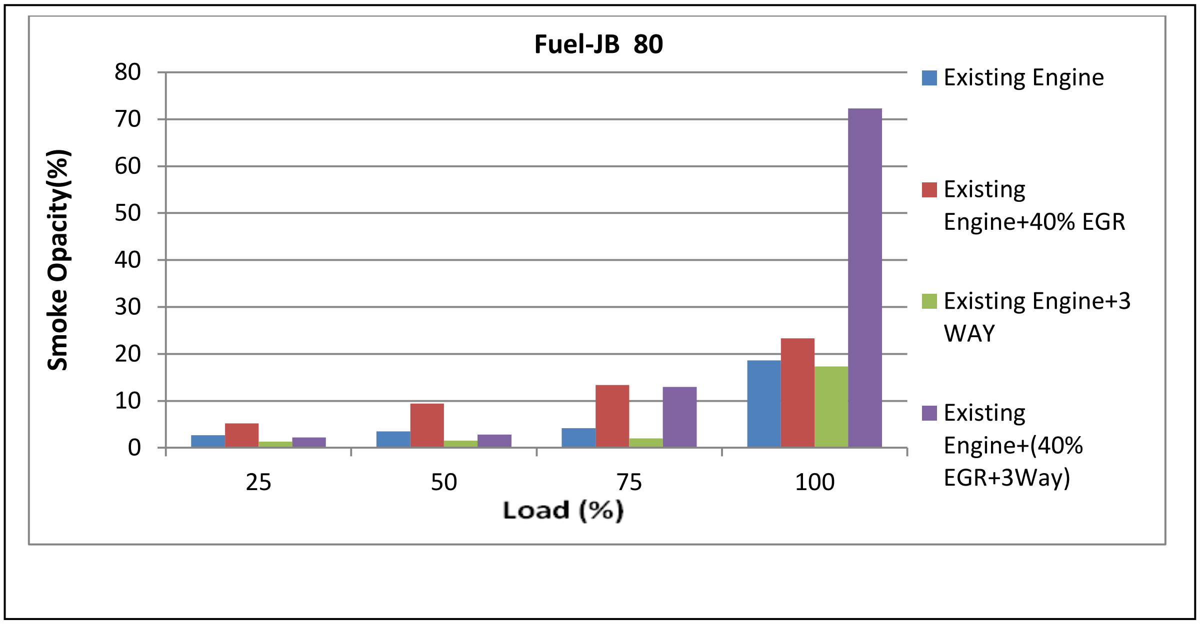


Figure5 .18: Variation of smoke for JB 80

Figure 5.17 and 5.18 shows that NO_X emission effectively reduced by using the EGR (rate at40%) and three-way catalytic converter at low loads compared to other controlling methods. For this test fuel at higher load (100%), it was observed that only three-way catalytic converter system reduces the NOX emission (reduction is 13.79%) effectively with less smoke opacity and without any significant change in brake thermal efficiency as compared to other controlling methods. At other loads for JB 80 (75, 50 and 25%) the combination of EGR (40%) and three way-catalytic converter controlling method was suggested due to effectively reduces the NO_X emission (reduction is 43-71%) with the acceptable range of smoke opacity compare to other controlling methods.

5.6.3 JB 60-Fuel

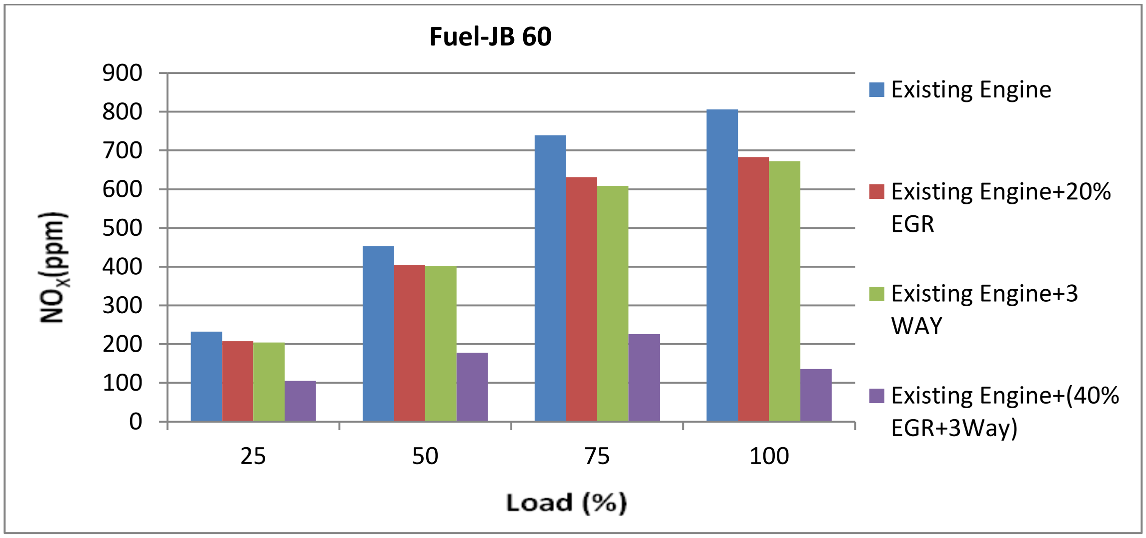


Figure 5.19: Variation of NO_X for JB 60

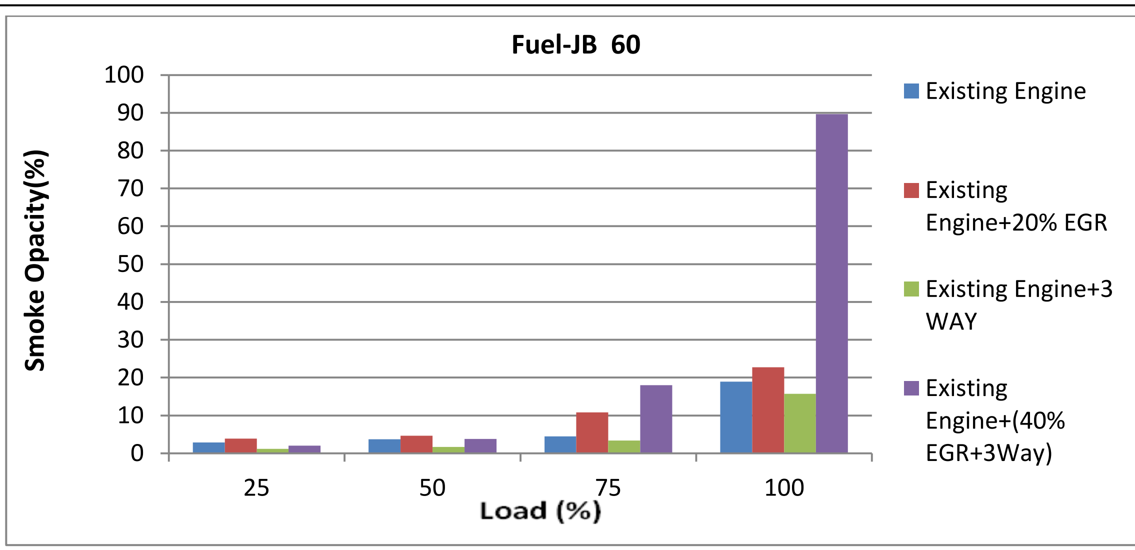


Figure 5.20: Variation of smoke for JB 60

Figure 5.19 and 5.20 shows that for JB 60 fuel at higher load (100%), only EGR (rate is 20%) controlling method may be suggested, due to that the NO_X emission reduces to 15.2% and less smoke opacity with an increase in brake thermal efficiency as compared to other controlling methods. The increase in brake thermal efficiency may be due to re-burning of unburned hydro carbons which enters the combustion chamber with the re-circulated exhaust gases. At other loads for JB 60 (75, 50 and 25%) the combination of EGR (40%) and three way-catalytic converter controlling method was suggested due to effectively reduces the NO_X emission (reduction is 54-69%) with the acceptable range of smoke opacity compare to other controlling methods.

5.6.4 JB 40-Fuel

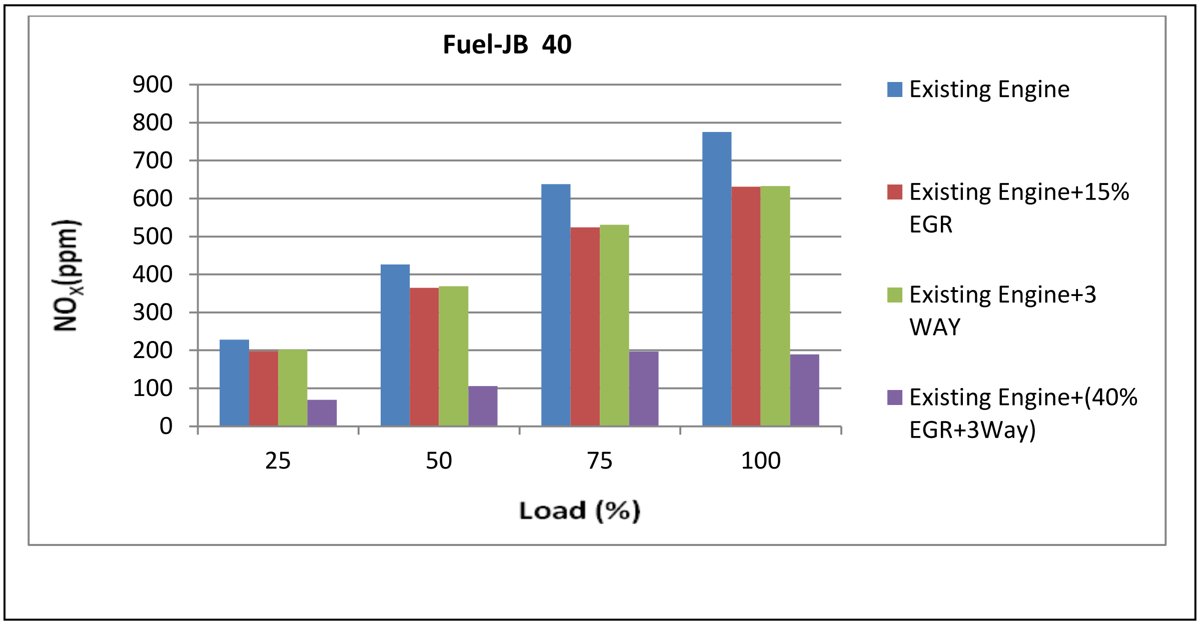


Figure 5.21: Variation of NO_X for JB 40

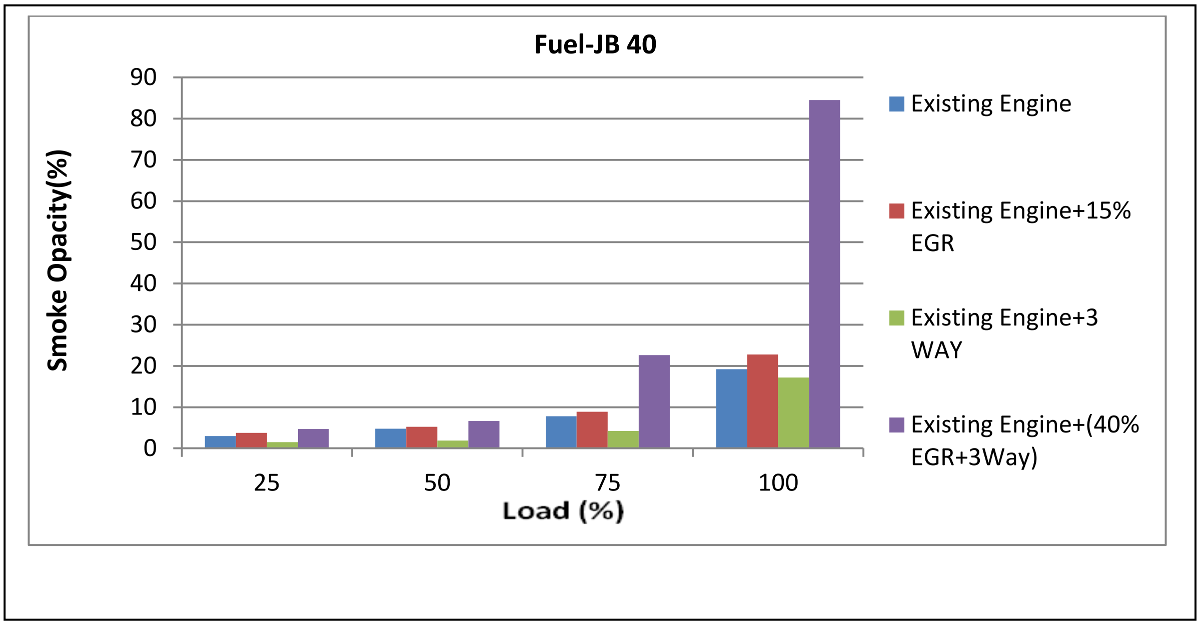


Figure 5.22: Variation of smoke for JB 40

Figure 5.21 and 5.22 shows that for JB 40 fuel at higher load (100%), only EGR (rate is 15%) controlling method may be suggested, due to that the NO_X emission reduces to 18.58% and less smoke opacity without any significant change in brake thermal efficiency as compared to other controlling methods. There is no change in brake thermal efficiency may be due to the amount of re-circulated exhaust gas mix well with fresh air helps to complete the fuel combustion. At other loads for JB 40 (75, 50 and 25%) the combination of EGR (40%) and catalytic converter controlling method was suggested due to effectively reduces the NO_X emission (reduction is 69-75%) with the acceptable range of smoke opacity and insignificant change in brake thermal efficiency compare to other controlling methods.

5.6.5 JB 20

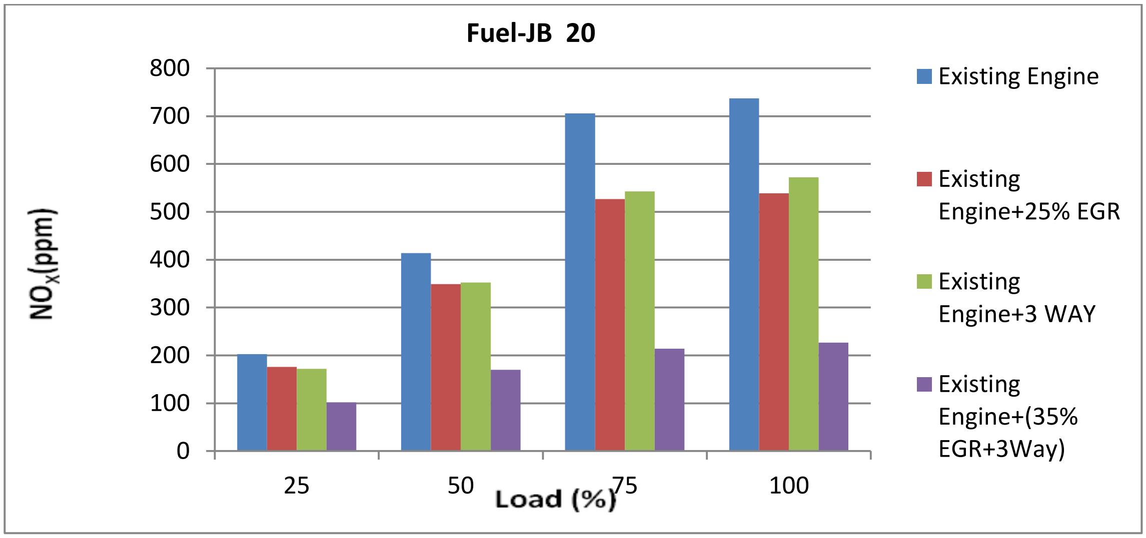


Figure 5.23: Variation of NO_X for JB 20

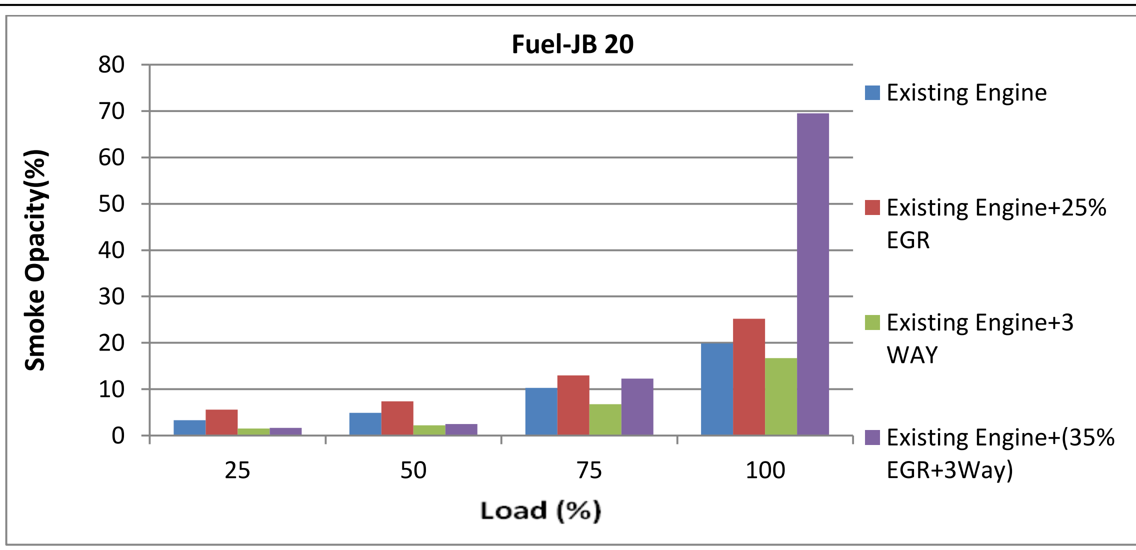


Figure 5.24: Variation of smoke for JB 20

5.6.6 Diesel

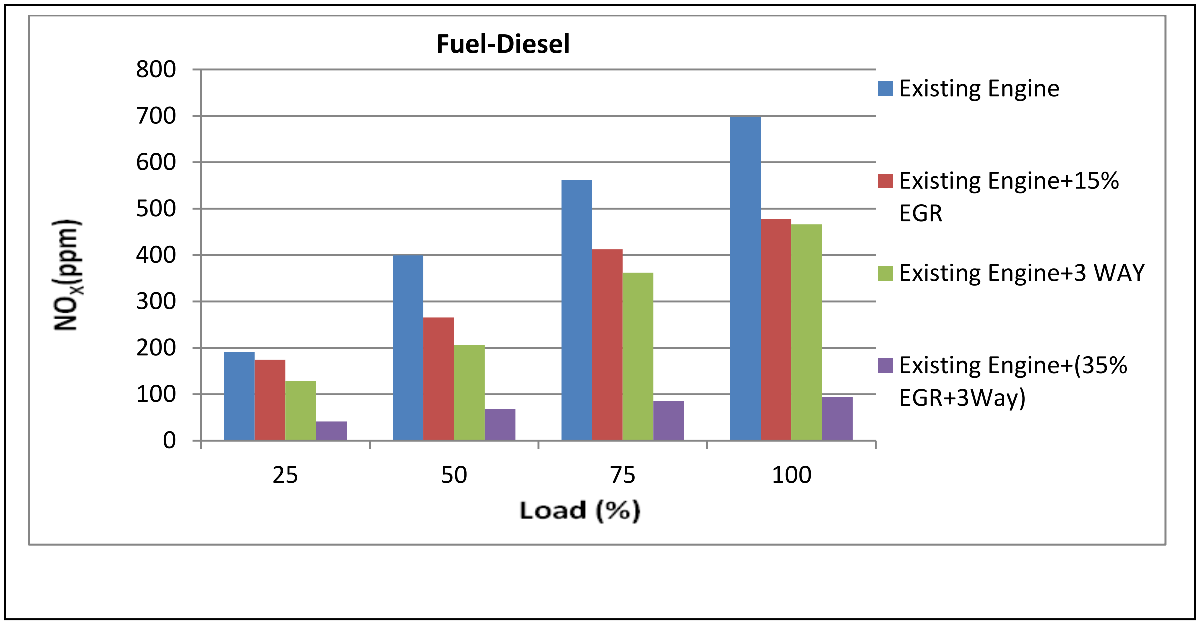


Figure 5.25: Variation of NO_X for diesel

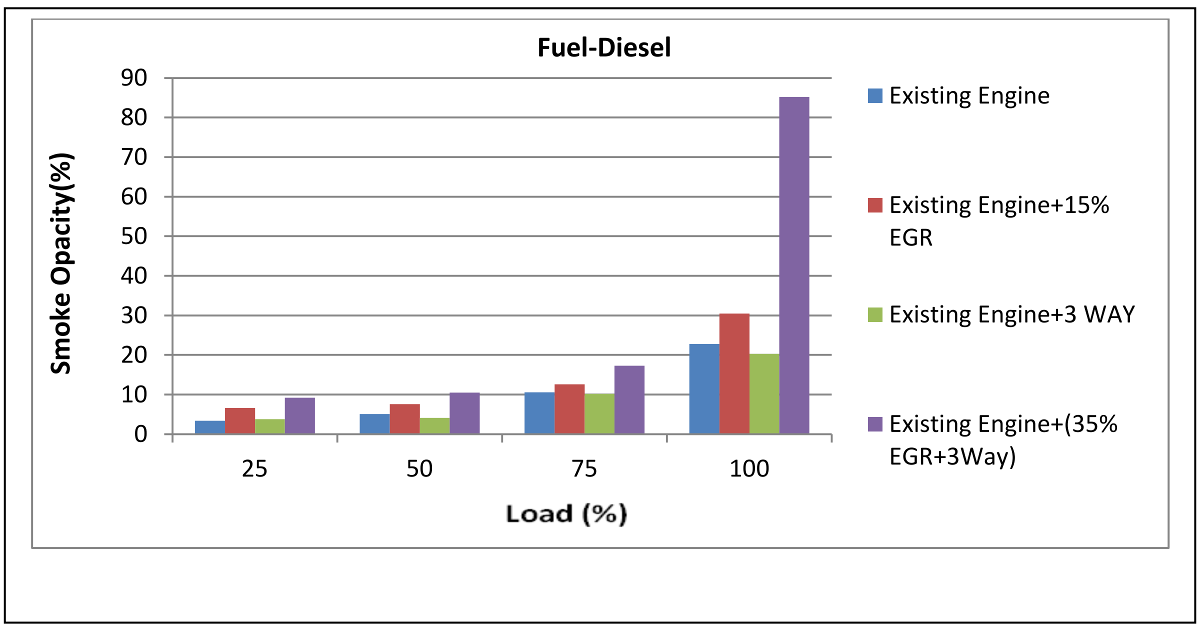


Figure 5.26: Variation of smoke for diesel

From the above figures, it shows that for JB 20 and diesel fuels at higher load (100%), only three-way catalytic converter controlling method may be suggested, due to that the NO_X emission reduces to 22.38% & 33.14% respectively and less smoke opacity without any significant change in brake thermal efficiency as compared to other controlling methods. There is insignificant change in brake thermal efficiency may be due to the amount of re-circulated exhaust gas mix well with fresh air helps to complete the fuel combustion. At other loads for JB 40 (75, 50 and 25%) the combination of EGR (35%) and three way-catalytic converter controlling method was suggested due to effectively reduces the NO_X emission (reduction is 61-75%) with the acceptable range of smoke opacity and insignificant change in brake thermal efficiency compare to other controlling methods.

Chapter 6

Conclusions

The objective of the research work was to meritoriously reduce the NO_X emissions with three different controlling methods. Such as exhaust gas recirculation system (EGR), three-way catalytic converter and combination of EGR and three-way catalytic converter. These controlling devices are connected to the IDI diesel engine to analyse NO_X emission when diesel, biodiesel and their blends are fuelled in the engine at all specified loads (0%, 25%, 50%, 75% and 100%). The data of existing engine was considered as a baseline and analysis was done by comparing the baseline data of engine with emission controlling devices. However, various conclusions derived can be summarized below.

i. Diesel fuel have lower NO_X emissions at all loads (25%, 50%, 75% and100%) when compared to biodiesel and their blends. It is quite obvious, that biodiesel addition to diesel implies more amount of oxygen present in the combustion chamber, leading to formation of large quantity of NO_X in biodiesel and their blends fueled engines. For biodiesel and their blends (JB 100, JB 80, JB 60, JB 40 and JB 20) the maximum amount of NO_X produced at full load (i.e. 882, 848, 806, 775 and 737 ppm respectively) is much higher to diesel fuel (697 ppm). Biodiesel has more density compared to diesel, facilitating more droplet penetration into the combustion chamber which may lead to increase in the fuel consumption, peak temperature and higher NO_X emission.

ii. An increase of biodiesel in biodiesel- diesel fuel blends, smoke decreases for most of the operating conditions due to the presence of less carbon with biodiesel based fuels as compared to diesel; In addition to that, biodiesel has more oxygen content contrary to diesel. The increase of oxygen in the fuel biodiesel and their blends tends to reduce the smoke emission for all power outputs. The presence of oxygen in the biodiesel is in favor of carbon residual oxidation, which leads to a reduction in smoke opacity. These results are in the similar trend with the results of reported by Choi et.al [69].

iii. The three-way catalytic converter is found to be the best effective controlling method for diesel and JB 20 at full load, which is responsible for reduction in the NO_X emission and smoke opacity. At the lower loads (75, 50 and 25%) for diesel and JB 20 the better trade-off between smoke opacity and NO_X emission can be attained with the use of 35% EGR and three way-catalytic converter.

iv. Acceptable performance and NO_X emission reduction was found at 15% EGR for JB 40 at full load. At other loads for JB 40 (75, 50 and 25%) the combination of 40% EGR and three way-catalytic converter was preferable to reduce the NO_X emissions.

v. The JB 60 blended biodiesel fuel at full load together with 20% EGR system was found to be useful in improving brake thermal efficiency and reduction in the NO_X emission with lower smoke opacity as compared to other controlling methods. At other loads (75, 50 and 25%) for JB 60 fuel the combination of 40% EGR and three way-catalytic converter controlling method was proven for minimum NO_X emissions with insignificant change in brake thermal efficiency.

vi. Use of the three-way catalytic converter controlling method for JB 80 fuel at full load has shown the better brake thermal efficiency, NO_X emissions smoke opacity. The combination of 40% EGR and three way-catalytic converter controlling method at lower loads was found to have less NO_X emissions, smoke opacity. Any significant change in brake thermal efficiency was observed as compared to other controlling methods.

vii. Engine fueled with JB 100 fuel at all loads employing the combination of 5% EGR and three way-catalytic converter controlling method was able to reduce the NO_X emission with the insignificant change in smoke opacity and brake thermal efficiency due to the combined effect of EGR and three way- catalytic converter.

Chapter 7

Future Scope of the Work

The experiments were carried out with an objective of reducing the NO_X emissions of IDI diesel engine when diesel, biodiesel and their blends were fuelled in it. The possibility of using the biodiesel in IDI diesel engine will make the remotely established people using this engine self-dependent because they can cultivate the jatropha seeds in their land which is not in direct utilization of cultivating the edible grains. The use of such unproductive land will enhance the land utilization while improving their economic conditions. The problem of the farmers and also the people using small industry machines running to the market for diesel by paying ever increasing the ever increasing cost of the diesel will be redressed.

- The experiments were carried out with an objective of reduction of NO_X emissions, without significant change of brake thermal efficiency IDI diesel engine when diesel, biodiesel and their blends are fuelled in it.
- In the present study, exhaust gas recirculation, catalytic converter and both exhaust gas recirculation and catalytic converter has been adopted as the reduction of NO_X emissions, however, other routes such as

reduction of unburnt hydrocarbons, smoke and carbon dioxide may also be tried.

- Use of other emission reduction tools can be done to find the optimum engine emission parameters.
- Cheaper controlling methods with ultra-low emissions, may be assessed.

Chapter 8

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Annexure-1

Technical specification of AVL 437 Smoke Meter

S. No	Particulars	Specifications
1	Accuracy and Reproducibility	± 1% full scale reading.
2	Measuring range	0-100% capacity in % 0-∞ absorption m^{-1}
3	Measurement chamber	effective length 0.430 m ± 0.005 m
4	Heating Time	220 V …….approx. 20 min
5	Light source	Halogen bulb 12 V/ 5W
6	Colour temperature	3000 K ± 150 K
7	Detector	Selenium photocell dia. 45 mm Max. sensitivity in light,
8	In Frequency range	550 to 570nm.Below 430 nm and above 680 nm sensitivity is less than 4% related to the maximum sensitivity
9	Maximum Smoke	210^0 C Temperature at entrance.

Annexure-2

Technical specification of AVL Di-Gas Analyzer

S. No	Particulars	Specifications
1	Measurement principle CO, HC, CO_2	Infrared measurement
2	Measurement principle O_2, NO	Electrochemical measurement
	Operating temperature	+5…………+45^0 C Keeping measurement accuracy +1………..+50^0 C Ready for measurement +5…………+35^0 C with integral NO sensor (Peaks of +40^0 C)
3	Storage temperature	-20…..+60^0 C -20….+50^0 C with integrated O_2 sensor -10……+45^0 C with integrated NO sensor
4	Air humidity	90% max., non-condensing
5	Power drawn	150 V
6	Dimensions	432×230×470 mm (w×h×l)
7	Weight	16 Kg

Annexure-3

Technical specification of Three-way catalytic converter

S. No	Particulars	Specifications
1	Outer shell material	High quality of stainless steel (409)
2	Substrate material	Ceramic (cordierite)
3	Catalytic Substances	Platinium, Palladium, Rhodium
4	Total volume of substrates	851.24 cm^3
5	Overall length of substrates	153 mm
6	Cell density	400 cells/in^2
7	Substrate equivalent diameter	83.75 mm
8	Wall thickness	0.15 mm
9	Cell equivalent diameter	1.12 mm
10	Inside material	Ceramic catalyst
11	Inlet size	2”
12	Outlet size	2”
13	Substrate cross-section	55.64 cm^2
14	Porosity	0.78
15	Overall shell size	100-130 mm
16	Diameter	250-300mm

Annexure-4

Technical specification of Exhaust gas recirculation system

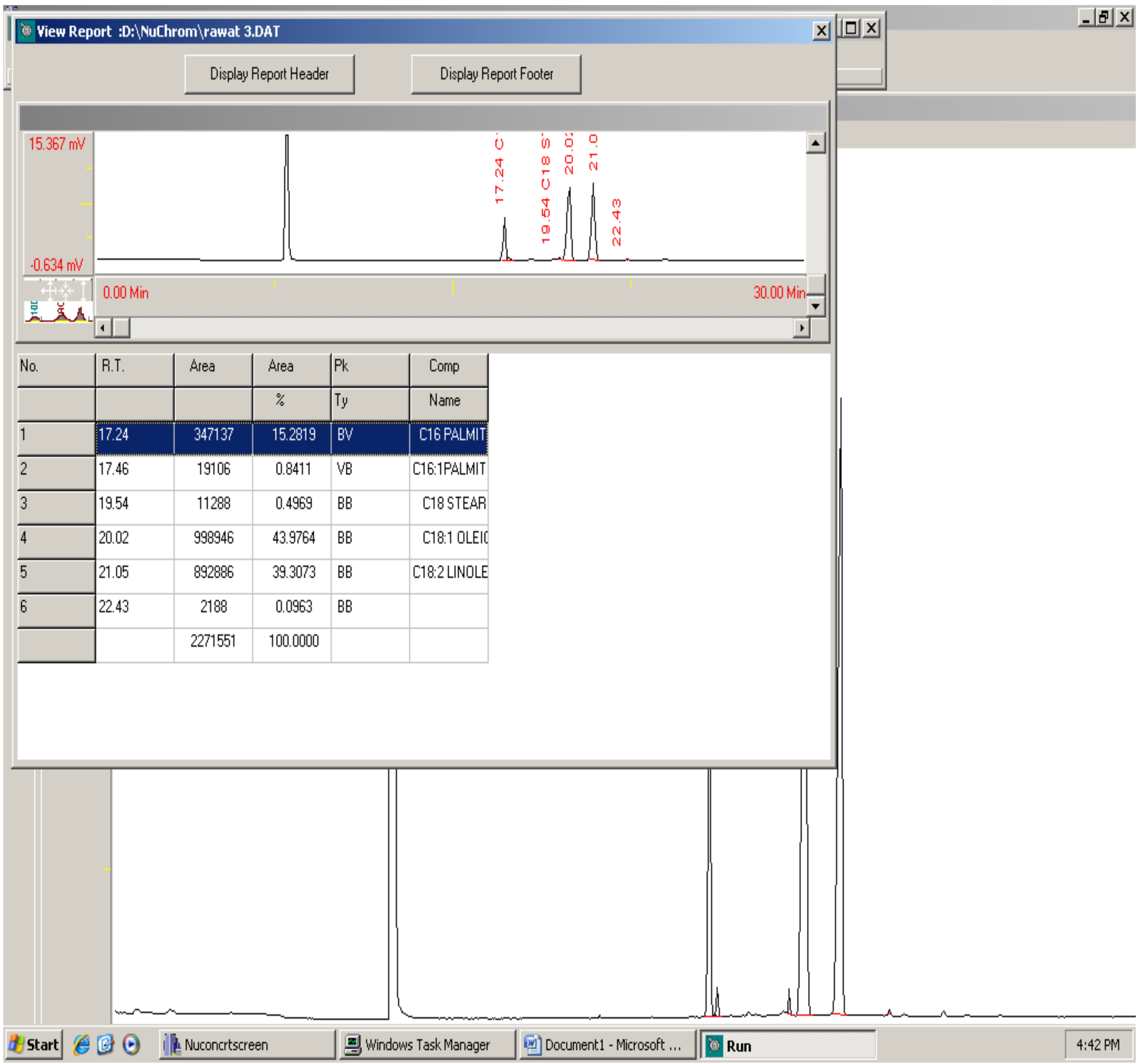
S. No	Particulars	Specifications
1	Surge tank Diameter Length	 220 mm 300 mm
2	EGR cooler Diameter Length Material	 60 mm 500 mm Stainless steel (1.5 mm thickness)
3	Control valve Stepper motor controlled	 12 V Operated
4	Power Supply	230 V AC
5	M S Piping Diameter Length	 25 mm 300 mm
6	Mounting Frame Square tube Length Width Thickness Connecting Hose	 2” 600 mm 600 mm 600 mm Quarter inch
7	Bellow Material Diameter Length Thickness	 Stainless steel 50 mm 1000 mm 0.7 mm
8	Pressure Sensor Method	± 0.1 bar Differential pressure
9	Software EGR Interface Cable	 Windows Based USB

Annexure-5

Instruments used for measuring physico- chemical Properties.

S. No	Test	Equipment	ASTM Test No	Instrument
1	Density/ API Gravity Measurement	Density Meter	D298	
2	Calorific Value	Bomb Calorimeter	D240	
3	Kinematic Viscosity	Kinematic Viscometer	D445	
4	Flash Point	Pensky Martene Flash Point Apparatus	D92	

Biodiesel Composition



No.	R.T.	Area	Area %	Pk Ty	Comp Name
1	17.24	347137	15.2819	BV	C16 PALMIT
2	17.46	19106	0.8411	VB	C16:1PALMIT
3	19.54	11288	0.4969	BB	C18 STEAR
4	20.02	998946	43.9764	BB	C18:1 OLEIC
5	21.05	892886	39.3073	BB	C18:2 LINOLE
6	22.43	2188	0.0963	BB	
		2271551	100.0000		

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Research Publications

1. P. Suresh Kumar, Prasanthi kumari and P. K Sahoo,(September24-25, 2010), Refrigeration & Air-conditioning of Group Housing Employing Vapour Absorption System by Using Renewable Energy Sources;

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