Major Dissertation

Entitled

SIMULATION OF BIODIESEL FUELLED COMPRESSION IGNITION ENGINE

Submitted to the Delhi Technological University in fulfillment of the requirements for the award of the degree of

Master of Technology
In
Thermal Engineering
By

SAKET KUMAR
2K13/THE/21

Under the Supervision of

Dr. Naveen Kumar
Professor, Mech. Engg. Deptt.
Delhi Technological University
Delhi-110042

Dept. of Mechanical, Automobile, Production & Industrial Engineering
Delhi Technological University, Shahbad Daulatpur, Delhi-110042
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Declaration

I hereby certify that the work is being presented in this dissertation entitled “Simulation of biodiesel fuelled Compression Ignition Engine”, is submitted, and in the partial fulfillment of the requirements for Master’s degree in Thermal Engineering of Mechanical Engineering at Delhi Technological University is an authentic record of our own work carried under the supervision of Dr. Naveen Kumar. We have not submitted the matter embodied in this dissertation for the award of any other degree. Also, it had not been directly copied from any source without giving its proper reference.

SAKET KUMAR
(2K13/THE/21)

CERTIFICATE

It is to certify that the dissertation **“SIMULATION OF BIODIESEL FUELLED COMPRESSION IGNITION ENGINE”** submitted by **Mr. Saket Kumar** (Roll No. 2K13/THE/21) in partial fulfillment for the award of the Degree of **Master of Technology** in **Thermal Engineering** at Delhi Technological University is an authentic record of student’s own work carried out by him under our guidance and supervision.

It is also certified that the work embodied in this dissertation has not been submitted to any other Institute for the award of any degree to the best of my knowledge.

Dr. Naveen Kumar
Professor
Dept. of Mechanical, Automobile, Production & Industrial Engineering
Delhi Technological University
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Delhi-110042.

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SAKET KUAMR

(2K13/THE/21)

ABSTRACT

This project deals in Performance parameters and exhaust emissions of a diesel engine powered by diesel fuel and a biodiesels, namely Soybean oil methyl ester (SME) have been investigated using Diesel-RK engine simulation software. The performance of an engine whose basic design parameters are known can be predicted with the assistance of simulation programs into the less time, cost and near value of actual. Based on the DIESEL-RK software, an engine cycle simulation for a biodiesel fueled direct injection compression ignition engine was developed and used to study its performance and emission characteristics. The major objectives were to establish the engine model for simulation and then apply the model to study the biodiesel fueled engine and compare it to a diesel as well as biodiesel-fueled engine. The engine model used for carrying out experiments was single-cylinder Kirloskar make direct injection diesel engine. At selected engine operating conditions, sensitivities of engine performance and emission on engine load was investigated. Variations in cylinder pressure with bsfc, exhaust temperature, as well as emissions of nitrogen oxides, carbon monoxide, unburnt hydrocarbons were determined for both a biodiesel fueled engine and a conventional diesel fueled engine. Experimental result so obtained was compared with a thermodynamic analysis of the simulated engine to overall engine performance and emission characteristics.

Keywords: bsfc, SME, ubhc.

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NOMENCLATURE

ASTM	American Society for Testing and Materials
ATDC	After Top Dead Center
AVL-437	Smoke Meter
A/F	Air fuel ratio
BIS	Bureau of Indian Standards
BP	Brake power
BMEP	Brake means effective pressure
BSFC	Brake specific fuel consumption
BSEC	Brake specific energy consumption
BTE	Brake thermal efficiency
BSEC	Brake specific energy consumption
BTDC	Before Top Dead Center
^oC	Degree Celsius
cc	Cubic centimeter
CI	Compression Ignition
cm^{-1}	Per Centimeter
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EGR	Exhaust gas recirculation
FP	Frictional power
EXT	Exhaust temperature

ITHE	Indicated thermal efficiency
IMEP	Indicated mean effective pressure
IP	Indicated power
kW	Kilo Watt
kW-h	Kilo Watt Hour
MoEF	Ministry of Forests and Environment
NO	Nitric Oxide
Nos.	Numbers
NO_2	Nitrogen Di-oxide
NO_x	Oxides of Nitrogen
PPM	Parts per million
Vol. eff.	Volumetric efficiency

CHAPTER1

INTRODUCTION

1.1 ENERGY CONSERVATION

Improving the energy efficiency meets the dual objectives of promoting sustainable development and of making the economy competitive. Recognizing the formidable challenges of meeting the energy needs and providing adequate and varied energy of desired quality in a sustainable manner and at reasonable costs, improving efficiency have become important components of energy policy. In addition, the environmental and health burdens arising out of the use of hydrocarbons may also force mankind towards energy efficiency and clean energy systems. Energy conservation has also assumed enhanced importance with a view to conserve depleting energy resources. Bureau of Energy Efficiency (BEE), a statutory body under Ministry of Power in Government of India is responsible for spearheading the improvement of energy efficiency in the economy through various regulatory and promotional instruments. There are various measures have been taken out and they are (i) promoting energy efficiency in buildings by developing Energy Conservation Building Code (ECBC) in the 11th plan. This code sets minimum energy performance standards for commercial buildings having a connected load of 100 KW or above. (ii) Demand Side Management (DSM) measures in the energy sector to encourage installation of end use technologies that consume less energy, thereby reducing the customer’s overall electric bill. In the short term, DSM program can reduce energy costs for utilities, in the long term; DSM programs can help limit the need for utilities, to build new power plants, distribution, and transmission lines. In this context, Bureau of Energy Efficiency has launched a program for capacity building of DISCOMs. (iii) Agriculture Demand Side Management (Ag-DSM): Agriculture is an important sector of the Indian economy, according to ministry of Agriculture it accounts for 14% of India’s GDP, about 11% of its exports. This sector accounts for approximately 80 percent of India’s total water consumption, and pumps are the most vital element of the irrigation process, presently approximately 20 millions in numbers consuming 18 percent of total national electricity consumption of India. This sector is dominated by highly in-efficient pump sets having average efficiency range of 25-30 percent while efficiency level of star rated Energy Efficient Pump sets (EEPs) is 50-55 percent. In order to tap the energy saving potential, Agricultural Demand Side Management (AgDSM) scheme of BEE was initiated during XI plan in eleven DISCOMs of eight states which are agriculturally intensive and accounts for more than 70 percent of electricity consumption in this sector. The objective of these schemes is to reduce the energy intensity of agriculture pumping sector by carrying out efficiency up gradation of agricultural pump sets.

1.2 ENERGY SCENARIO

Primary energy consumption in India has more than doubled between 1990 and 2012, reaching an estimated 32 quadrillion British thermal units (Btu). The country has the second-largest population in the world, at more than 1.25 billion people in 2015, growing about 1.3% each year since 2008, according to World Bank data. At the same time, India's per capita energy consumption is one-third of the global average, according to the International Energy Agency (IEA), indicating potentially higher energy demand in the long term as the country continues its path of economic development. In the International Energy Outlook 2013, EIA projects India and China will account for about half of global energy demand growth through 2040, with India's energy demand growing at 2.8% per year.

India's largest energy source is coal, followed by petroleum and traditional biomass and waste. India's transportation sector, primarily fuelled by petroleum products, is set to expand as the country focuses on improving road and railway transit. The government plans to mandate some alternative fuel use, particularly with biofuel blends, and develop greater use of mass transit systems to limit oil demand growth.

India is the fourth-largest consumer of oil and petroleum products after the United States, China, and Japan in 2014, and it is also the fourth-largest net importer of crude oil and petroleum products. The gap between India's oil demand and supply is widening, as demand reached nearly 3.7 million barrels per day (bbl/d) in 2014 compared to less than 1 million bbl/d of total liquids production. EIA projects India's demand will more than double to 8.2 million bbl/d by 2040, while domestic production will remain relatively flat, hovering around 1 million bbl/d. The high degree of dependence on imported crude oil has led Indian energy companies to diversify their supply sources. To this end, Indian national oil companies (NOCs) have purchased equity stakes in overseas oil and gas fields in South America, Africa, Southeast Asia, and the Caspian Sea region to acquire reserves and production capability. However, the majority of imports continue to come from the Middle East, where Indian companies have little direct access to investment. Energy has undergone a major transition from a general field of study of technologies to an important issue in economic planning and international relations. Energy is the building block for socio-economic development of any country. 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 0.7 billion tonnes which are really very small (0.4 per cent of world's reserve). India accounted for 10.63 % of total primary energy consumption in Asia-Pacific region and 3.6% of world primary consumption in 2015. Per capita energy consumption remains low as 491 KGOE (Kilogram of oil equivalent) compared with a world average of 1,796 KGOE in 2005. The distribution of primary energy in India vis a vis world in 2006 has been shown in Table 1.1.

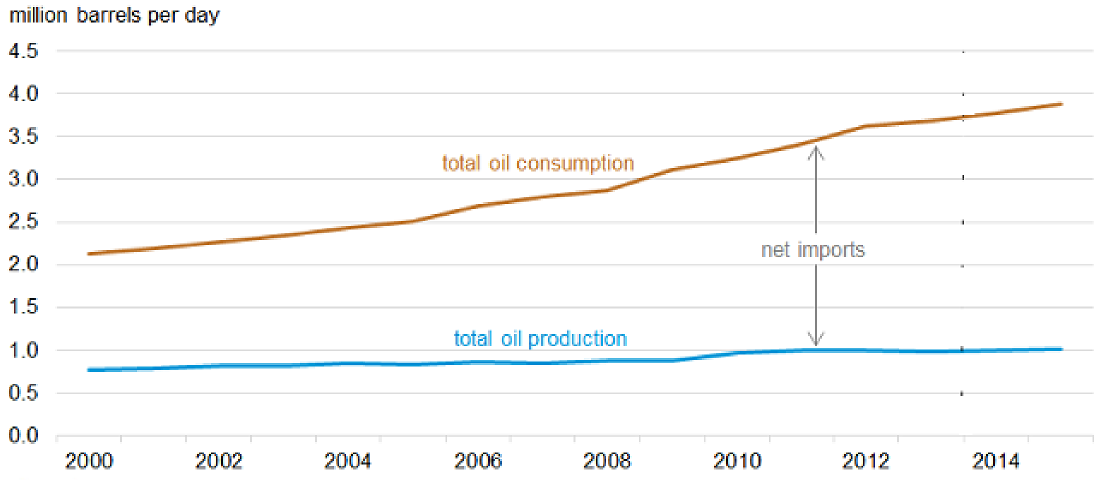


Fig 1.1.India's crude oil production and consumption according International Energy Statistics

India is fourth largest economy of world and has to extensively use energy to sustain its growth. Since India does not have huge reserves of petroleum products, it is heavily dependent upon the import of petroleum products to cater to its need for automobiles and other applications despite larger initiatives by government and exploration of new sources. Escalating prices, insufficient supply and limited reserves of petroleum have imposed an enormous burden on country's foreign exchange. In year 2006-07 the indigenous production of crude oil was 33.99 million tones whereas consumption was 144.88 million tones forcing to import 110.89 million tones. The country is spending Rs.2199.91 billion worth valuable foreign exchange towards import of crude petroleum which could otherwise be utilized for various other development works, that might ultimately prove to be more beneficial to Indian people. To improve the present energy crisis, future energy conversion in India should be sustainable which include increased share of renewable fuel, increased efficiency of fuel conversion, reduce environmental impacts, and increase knowledge. In this regard, the subsidy on traditional fossil fuels must be reduced in a phase manner and effort must be put to develop and promote the use of renewable sources of energy to meet the energy requirement.

1.3 ENERGY CRISIS

It is well known that transport is almost totally dependent on fossil, particularly, petroleum-based fuels such as gasoline, diesel fuel, liquefied petroleum gas (LPG) and natural gas (NG). In the last years, the world has been confronted with an energy crisis. The most used fuel, petroleum, is becoming scarce and its use is associated with the increase of environmental problems. Experts suggest that current oil and gas reserves would suffice to last only a few more decades. To exceed the rising energy demand and reducing petroleum reserves, fuels such as biofuel are in the forefront of the alternative technologies. Compression ignition has dominated the field of heavy-duty vehicles for a long time and is increasingly being applied in light-duty vehicles in the past 30 years. Compared to the gasoline engine, the diesel engine has considerably higher thermal efficiency due to its lean combustion, with a higher compression ratio, and lack of throttle. However, the major fuel source for diesel engine, the petroleum based fuel, is depleting at a very rapid rate. Of the 184 million metric ton(MMT)'s energy consumed in 2015 in India, 39% was from petroleum based fuels and 69% of that was consumed in transportation sector. The depletion of petroleum fuel and its increasing cost have raised much interest in looking for the alternate fuel for diesel engines. Tremendous effort to search for alternative fuels has been made in the past several decades;

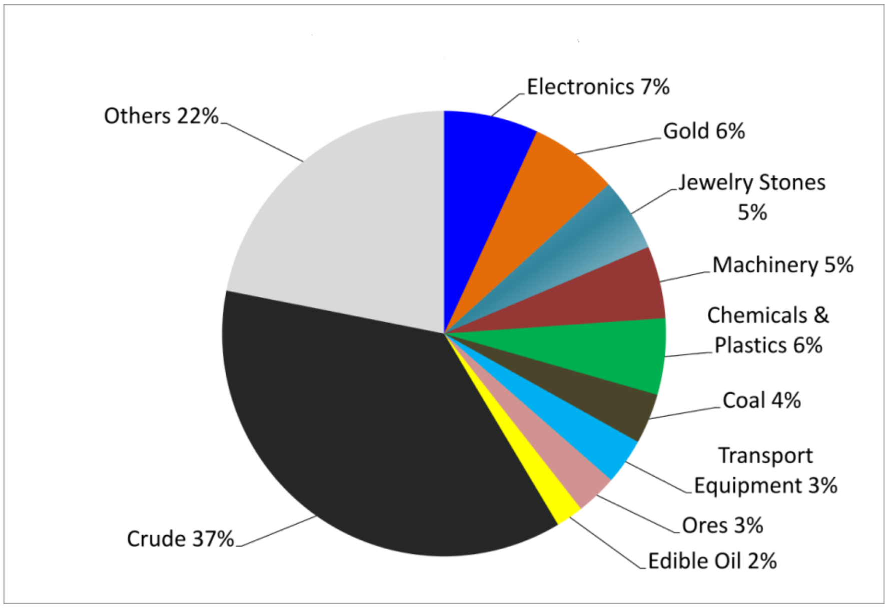


Figure 1.2: India's top imports in 2014-2015

Numerous alternative fuels have been studied and tested, including hydrogen, coal, dimethyl ether (DME), biodiesel, etc. However, due to several certain established end-use requirements, such as availability, supply, safety, cost-efficiency, etc., only a few candidates remain active for testing and research. Major candidates and their main advantages and disadvantages are summarized in table 1.1

Table 1.1: Candidates for biodiesel and its advantages and disadvantages

Candidates	Advantages	Disadvantages
Hydrogen	High lower heating value. Zero pollutant by emission. Potentially renewable energy source.	Refilling problem. Safety issue due to high pressure tank.
DME	Less PM &NOx emission. High Cetane number.	Worse lubrication than diesel. Safeety issue due to high pressure tank.
Coal	Large accessible reserve	Injection problem. Lubrication contamination.
Biodiesel	Low HC and CO emission. Potentially renewable energy source.	Low energy content. Uncertain effect on NOx.

1.4 NECESSITY OF ALTERNATIVE FUELS

It is clear from the above discussions that India is facing the twin problems of fast depletion of fossil fuels and environmental degradation. There is an urgent need to reduce dependence on petroleum derived fuels for better economy and environment. Adaptation of bio-origin alternative fuels can address both these issues. These fuels are essentially non-petroleum and result in energy security and environmental benefits. These fuels are available either in one form or other for more than one hundred years. Before the introduction of gasoline as a motor fuel in the late 1800s, vehicles were often powered by what are now considered alternative fuels. The first internal combustion engine designed, built, and demonstrated by Rudolf Diesel at the 1900 Paris World's Fair ran on peanut oil. This was the product of his dream–an efficient internal combustion engine, powered by crude oil or even vegetable oil.

Identification of alternative fuels for use in I.C. Engines has been subjected to studies throughout the globe. Performance tests have shown suitability of variety of alternative fuels such as hydrogen, alcohols, biogas, producer gas and various types of edible and nonedible oils. However, in Indian context, the bio-origin fuels like alcohols, vegetable oils, and biogas can contribute significantly towards the problems related to fuel crises.

1.4.1 RATIONALE OF BIOFUELS IN INDIA

The rationale of taking up a major Program for the production of bio-fuels for utilization in I.C. Engines in our country lies in the context of:-

- Ethanol and biodiesel being superior fuels from the environmental point of view,
- Use of Bio-fuels becomes imperative in view of the stringent emission norms and court interventions,
- Need to provide energy security, specially for the rural areas,
- Need to create employment, specially for the rural poor living in areas having a high incidence of land degradation,
- Providing nutrients to soil, checking soil erosion and thus preventing land degradation, addressing global concern relating to containing Carbon emissions,
- Reducing dependence on oil imports,

- Usability of biofuel in the present engines without any major modification,
- Use of biofuel not requiring major or time consuming studies or research.

1.5 ALTERNATIVE FUELS FOR COMPRESSION IGNITION ENGINE

With the indispensable position gained by diesel engine in recent years, the demand for conventional fuel and environmental degradation caused by fossil diesel combustion cannot be underestimated. As already elaborated, alternative fuels are immediately needed to deal the dual problem of fast depletion of fossil fuel reserves and environmental pollution. Such fuels should be renewable, should be suitable for use in existing engines and associated systems (such as fuel tank, pumps and hoses) as well other existing fuel storage, transportation and retail infrastructure. Since diesel engine plays an important and indispensable role in Indian economy and various sector of the country, fuels of bio-origin can provide a feasible solution to the problem. Some of these fuels can be used directly while others need to be transformed to bring the relative properties close to the conventional fuels. Ethanol is an attractive alternate liquid source for I.C engines since it can be produced from renewable sources such as grains. Given the widespread use of diesel fuels, in various sectors, the study on the performance of vegetable oils when used as a fuel in the neat or blended form is desirable**.** Since the viscosity of vegetable oils, hence of the fuel is of prime concern, the reduction in the viscosity is required which can be carried out by transesterification process.

1.5.1 Biodiesel as an alternative fuel

In the past few years, it has been found that biodiesel (esters derived from vegetable oils) is a very promising one. The most common blend is a mix of 20% biodiesel and 80% petroleum diesel, called “B20”.The widespread use of biodiesel is based on the following advantages:

- Biodiesel is potentially renewable and non-petroleum-based
- Biodiesel combustion produce less greenhouse gases
- Biodiesel is less toxic and biodegradable
- Biodiesel can reduce tailpipe emissions of PM, CO, HC, air toxics, etc
- Little modifications are needed for the traditional CI engine to burn biodiesel

Biodiesel also has some negative attributes:

- Lower heating value, higher viscosity
- Lower storage stability, material compatibility issue

- Slightly higher NOx emission

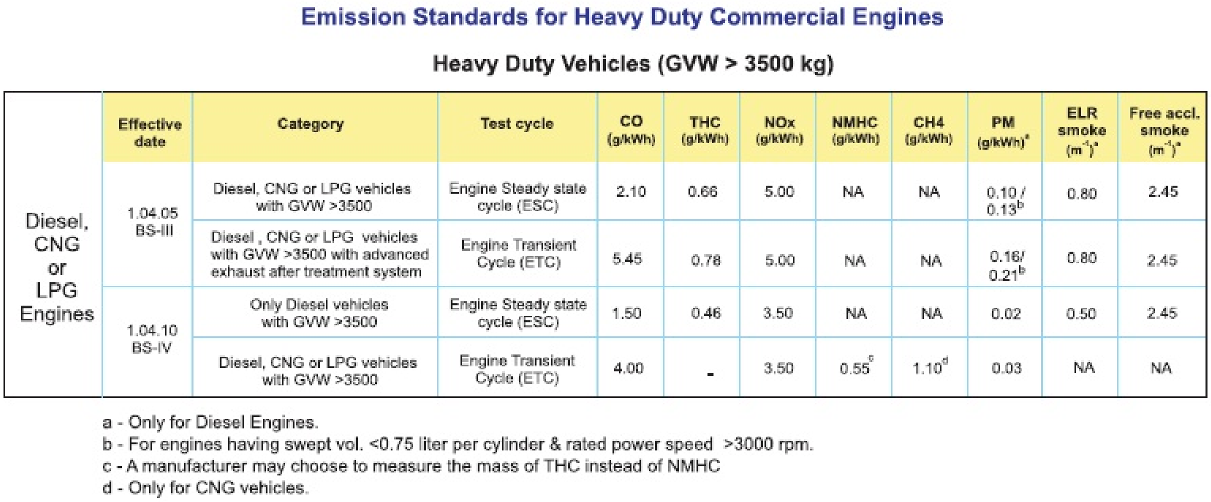
Among the above attributes of biodiesel, the higher NOx emissions from biodiesel fueled engines are a major concern due to more and restrict regulations, and therefore it serves as the major motivation of this work. There are vehicles and equipment that require absolutely no modifications to operate safely on biodiesel such as cars or buses.

The technical specifications of the new generation of diesel technology will be decided by the engineering and manufacturing departments of companies involved in the Diesel engine industry. In the area of alternative fuels, those engines and the, emissions control regimes packaged with them will need to be very versatile as the chemical makeup, quality, and quantity of biodiesel and blends of it vary across EPA regions. The Diesel engine is very versatile when it immediately comes to the actual fuel but, fuel of low quality, in the long run, can damage the fuel lines, lift pump, injection pump, injectors, and aftertreatment systems. Because of the widely varying chemical and physical specifications of biodiesel, the American Society for Testing and Materials (ASTM) and the European Committee for Standardization (CEN) have come up with standards for 100 percent biodiesel by volume (B100) and blends of it with various grades of diesel. The ASTM has developed and published the D6751 family of physical property standards for pure biodiesel itself. The 13th edition of the standard specifically targets the physical properties of biodiesel that, if out of range, can negatively affect the previously stated engine subsystems. Energy companies that offer blends of EPA ultra-low sulfur diesel (ULSD) at the pump and fatty-acid alkyl ester (FAAE) already ensure that their fuels conform to the ASTM D975-13 standard. The large chemical and qualitative variety of biodiesel directly stems from the fact that it is can be manufactured from a large number of glycerides, alcohols, use various transesterification methods, and bases. In the long run, the main challenge for engine designers is the identification of the appropriate type of biodiesel or blends to work with. There will come a period when injectors, injection strategy, combustion characteristics and piston bowl geometry will need to be redesigned to maintain performance, increase performance, and meet emissions and fuel consumption standards. There always has to be a balance between the solutions that alleviate emissions requirements issues, fuel consumption, and performance problems such as nozzle cavitation and customer or market wide satisfaction levels. Problems such as the food vs. fuel situation really only apply to a situation where there is a large scale production operation that utilizes virgin oil straight from field plant sources as feedstock. High quality biodiesel has been manufactured in large volumes using algae cultures and hemp oil. Currently, at the mass consumer level, a large volume of consistent blends of feedstock oils are needed along with a continuous production process instead of high volume batches. A mass movement to biodiesel really only requires that the selected oil and alcohol sources have high yield per acre if land is used to produce the feedstock and chemicals. There are several other plant-based fuel sources such as cotton seed oil. More advanced transesterification methods such as ultrasonication have been developed for high volume continuous production. Various research work has investigated several other methods of making biodiesel.

1.6 Emissions Standards in India

The modern applications of Diesel engines includes small-scale power generation, medium-scale power generation, light off-road equipment, medium off-road equipment, heavy off-road equipment, light-duty on-road vehicles, medium-duty on-road vehicles, locomotives, and all types of marine applications including pumping. The AUTOMOTIVE RESEARCH ASSOCIATION OF INDIA (ARAI) utilizes a system for classifying on-road engines by the model year and gross vehicle weight rating (GVWR). The allowable Emissions from heavy-duty Diesel-fueled engines in India have been on a consistent decline over the last 42 years as can be seen in figure. The emissions regulations on smaller vehicles are greater in number and tend to be more sophisticated.

Table 1.2: Emission standards for Heavy duty Commercial Engines



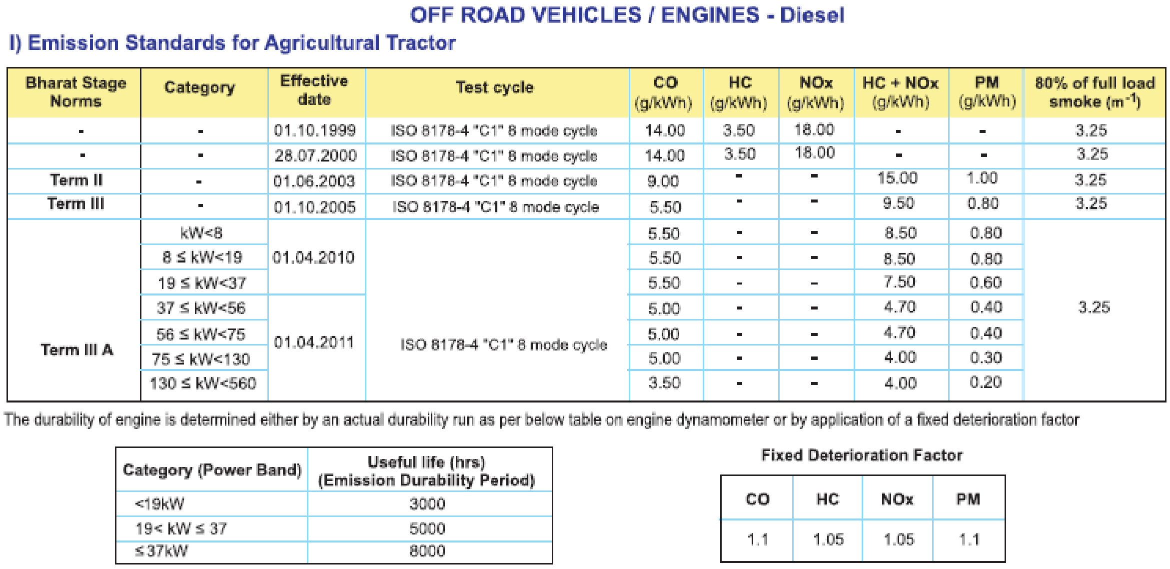
Emission Standards for Heavy Duty Commercial Engines

Heavy Duty Vehicles (GVW > 3500 kg)

	Effective date	Category	Test cycle	CO (g/kWh)	THC (g/kWh)	NOx (g/kWh)	NMHC (g/kWh)	CH4 (g/kWh)	PM (g/kWh)[a]	ELR smoke $(m^{-1})^a$	Free accl. smoke $(m^{-1})^a$
Diesel, CNG or LPG Engines	1.04.05 BS-III	Diesel, CNG or LPG vehicles with GVW >3500	Engine Steady state cycle (ESC)	2.10	0.66	5.00	NA	NA	0.10 / 0.13^b	0.80	2.45
		Diesel , CNG or LPG vehicles with GVW >3500 with advanced exhaust after treatment system	Engine Transient Cycle (ETC)	5.45	0.78	5.00	NA	NA	0.16/ 0.21^b	0.80	2.45
	1.04.10 BS-IV	Only Diesel vehicles with GVW >3500	Engine Steady state cycle (ESC)	1.50	0.46	3.50	NA	NA	0.02	0.50	2.45
		Diesel, CNG or LPG vehicles with GVW >3500	Engine Transient Cycle (ETC)	4.00	-	3.50	0.55^c	1.10^d	0.03	NA	NA

a - Only for Diesel Engines.
b - For engines having swept vol. <0.75 liter per cylinder & rated power speed >3000 rpm.
c - A manufacturer may choose to measure the mass of THC instead of NMHC
d - Only for CNG vehicles.

Table 1.3: Emission standards for Off Road Vehicles



OFF ROAD VEHICLES / ENGINES - Diesel

I) Emission Standards for Agricultural Tractor

Bharat Stage Norms	Category	Effective date	Test cycle	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	HC + NOx (g/kWh)	PM (g/kWh)	80% of full load smoke (m^{-1})
-	-	01.10.1999	ISO 8178-4 "C1" 8 mode cycle	14.00	3.50	18.00	-	-	3.25
-	-	28.07.2000	ISO 8178-4 "C1" 8 mode cycle	14.00	3.50	18.00	-	-	3.25
Term II	-	01.06.2003	ISO 8178-4 "C1" 8 mode cycle	9.00	-	-	15.00	1.00	3.25
Term III	-	01.10.2005	ISO 8178-4 "C1" 8 mode cycle	5.50	-	-	9.50	0.80	3.25
Term III A	kW<8	01.04.2010	ISO 8178-4 "C1" 8 mode cycle	5.50	-	-	8.50	0.80	3.25
	8 ≤ kW<19			5.50	-	-	8.50	0.80	
	19 ≤ kW<37			5.50	-	-	7.50	0.60	
	37 ≤ kW<56	01.04.2011		5.00	-	-	4.70	0.40	
	56 ≤ kW<75			5.00	-	-	4.70	0.40	
	75 ≤ kW<130			5.00	-	-	4.00	0.30	
	130 ≤ kW<560			3.50	-	-	4.00	0.20	

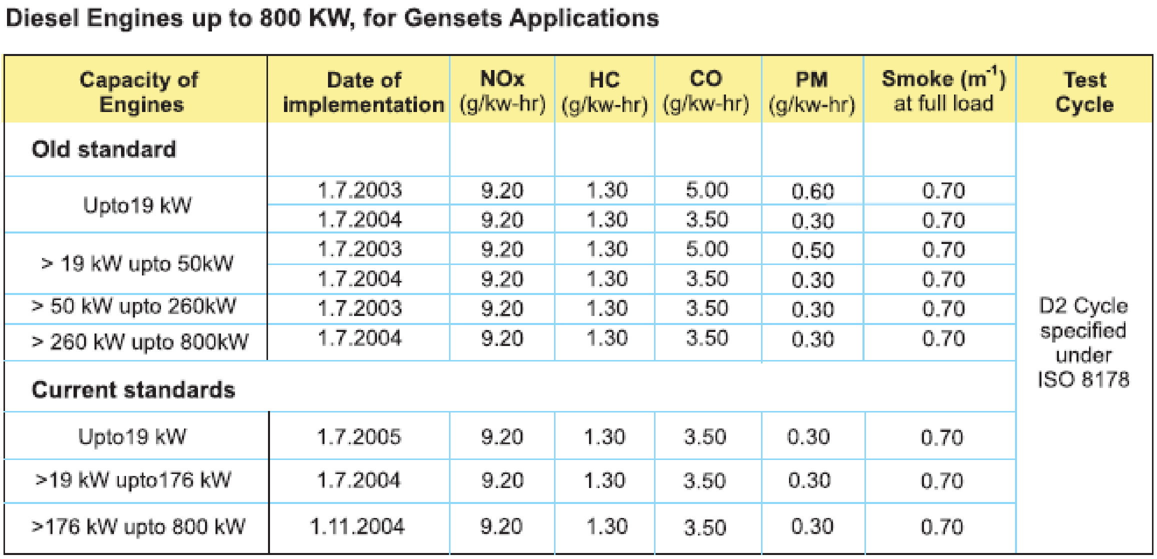
The durability of engine is determined either by an actual durability run as per below table on engine dynamometer or by application of a fixed deterioration factor

Category (Power Band)	Useful life (hrs) (Emission Durability Period)
<19kW	3000
19< kW ≤ 37	5000
≤ 37kW	8000

Fixed Deterioration Factor

CO	HC	NOx	PM
1.1	1.05	1.05	1.1

Table 1.4: Emission standards for Gensets



Diesel Engines up to 800 KW, for Gensets Applications

Capacity of Engines	Date of implementation	NOx (g/kw-hr)	HC (g/kw-hr)	CO (g/kw-hr)	PM (g/kw-hr)	Smoke (m^{-1}) at full load	Test Cycle
Old standard							D2 Cycle specified under ISO 8178
Upto19 kW	1.7.2003	9.20	1.30	5.00	0.60	0.70	
	1.7.2004	9.20	1.30	3.50	0.30	0.70	
> 19 kW upto 50kW	1.7.2003	9.20	1.30	5.00	0.50	0.70	
	1.7.2004	9.20	1.30	3.50	0.30	0.70	
> 50 kW upto 260kW	1.7.2003	9.20	1.30	3.50	0.30	0.70	
> 260 kW upto 800kW	1.7.2004	9.20	1.30	3.50	0.30	0.70	
Current standards							
Upto19 kW	1.7.2005	9.20	1.30	3.50	0.30	0.70	
>19 kW upto176 kW	1.7.2004	9.20	1.30	3.50	0.30	0.70	
>176 kW upto 800 kW	1.11.2004	9.20	1.30	3.50	0.30	0.70	

The reduction of regulated emissions output per engine comes after the introduction and mass implementation of several fuel and exhaust treatment technologies at various levels within the industrial and transportation technology sectors. Systems that have been implemented on most modern diesel engines for the reduction or elimination of harmful chemicals within high-temperature exhaust gas. Up until recently, the primary focus of engine development was the maintenance and insurance of critical system performance.

1.7 PRESENTWORK

In context to present work, use of the combustion simulation to study a biodiesel fueled Compression Ignition engine is carried. In modern engine research and study, using hardware experiments alone would be very expensive and time-consuming, and many cause and effect relationships implicit in the test results are often hard to interpret. On the other hand, modeling and simulation approaches, although less precise in predicting the outcome of a specific test, could effectively isolate one variable at a time and conduct parametric studies on it. Therefore simulation could point out cause-effect relationships more clearly, and a validated model could be a very useful tool to study new type of engines or engines running with new type of fuels. Since people still don't have a very clear understanding on the effect of using biodiesel on a diesel engine, together with experimental study, a simulation study of the biodiesel engine is necessary.

1.7.1 Motivation and Objectives

Compression ignition engines are used in many areas to support the logistical activities associated with industry. Diesel powered locomotives and heavy-duty trucks move unprocessed commodities, chemicals, intermediate materials between manufacturing processes, and finished goods to the places in which they are all needed. In the near future, several industrial pollution problems will have to be addressed. It will be possible to reduce some of the relatively high levels harmful emissions from the industrial sectors by using bio fuels. The circumstances resulting from the efforts of engine and heavy duty vehicle manufacturers to comply with increasingly more severe emissions standards around the world and demands of reduced fuel consumption, from governments as outlined by consumers, are the prime motivating factors for this work. The application of computational fluid dynamics (CFD) during the design of medium and heavy-duty diesel engines is the prime focus of this work. Numerical simulations of all types including kinematic and dynamic alike are necessary to simulate most aspects of engine operation quickly and efficiently with low cost. The key areas where CFD is widely applied during design iteration are the cooling system heat exchangers, the engine block water jacket, cylinder head lubrication systems, simulation of wall interactions between the piston rings and liner as demonstrated by intake flow, exhaust system flow, and flows occurring throughout the fuel delivery system including the injectors. The macroscopic features of combusting flows are modeled well with basic approaches in CFD. CFD models used to predict more detailed microscopic characteristics of reacting in-cylinder flows, harmful combustion emissions, and help in predicting fuel consumption across a wide variety of combustion regimes. CFD combustion models and codes allow engineers the ability to finely tune more advanced engine control models, maximize engine performance within constraints, and adapt the whole powertrain package to conform to outsourced original equipment requirements. Combustion models with higher numbers of species and higher fidelity will be possible to simulate widely in the future as access to computational resources such as, more specialized open-source codes, compute cloud rental, and cheaper high-performance cluster hardware becomes available to potential customers. Sophisticated solution techniques will also be incorporated into commercial codes as simulation becomes more popular for design. In this work, advanced reaction simulation on top of current in-cylinder flows will be used beyond the basic reaction mechanisms for predicting engine power and functional performance even more accurately.

CHAPTER2

LITERATURE REVIEW

2.1 INTRODUCTION

As already elaborated in preceding chapter, rapidly increasing prices and uncertainties concerning petroleum availability let the scientists work on alternative fuel sources. Bio-fuels is a promising alternative because it has several advantages—it is renewable, environmental-friendly and produced easily in rural areas, where there is an acute need for modern forms of energy. Obviously, the use of non-edible vegetable oils compared to edible oils is more significant because of the issue of food security. The idea of using vegetable oils as fuel for diesel engines is not radically new. Rudolph diesel used peanut oil to fuel one of his engines at the Paris Exposition in1900. In recent years systematic efforts have been made by several researchers to use vegetable oils as fuel in diesel engines. A review of recent biodiesel fueled engine research activities is presented here. Activities can be roughly divided into two aspects: engine experimental studies and numerical studies. Both of these types of studies focus on the performance and emission characteristics of biodiesel fuelled engines and comparison to the conventional diesel engine.

2.2 Previous experiment studies

[**1**] Used the biodiesel of Jatropha oil and its blends with diesel as fuel in a four cylinder, naturally aspirated indirect injection diesel engine. The results show slight increase in brake specific fuel consumption with increase in 5% of bio diesel in the blend and slight drop in the engine power. [**2**] Has investigated the CI engine of 5.2 kW rated power fuelled with preheated Jatropha oil methyl ester and diesel and found significant improvement in engine performance. [**3**] Developed a theoretical model for analysis of performance characteristics of CI engine fueled by biodiesel and its blends.

2.2.1 Effect of injection timings

In many papers reviewed, the start of injection (SOI) for biodiesel is advanced than those for conventional diesel engine. As an example, for the experiment done by **[3]**, an earlier start of injection for neat biodiesel fuels was found. The biodiesel fuel injected about 2.3^o earlier than diesel no.2, and the B20 (blend of 20% biodiesel and 80% diesel) were 0.25º-0.75º earlier than diesel no.2. According to **[4, 5]**, the SOI are majorly affected by changes in three physical properties: density, bulk modulus of compressibility, and speed of sound. Because of the higher bulk modulus of compressibility and speed of sound for biodiesel, there is a more rapid transfer of the fuel pump pressure wave to the injector needle, resulting in earlier needle lift and effectively a little advance in injection timing. However, this effect only exists in rotary/distributor-style fuel injection pumps, and not in common-rail fuel injection systems. In terms of NOx emission, advanced injection timing is considered by many authors as a major reason for change in NOx emission for biodiesel engine **[3, 5, 6]**. In the experimental study conducted by **[7]**, tests were done with a Yanmar L70 EE air-cooled, four-stroke, single cylinder DI diesel engine with a maximum power output of 5.8 horsepower, operating at high load and low load. The fuels include BP325 (baseline petroleum diesel fuel with 325 ppm sulfur), B20, B40, B100, and its blend with BP325. The results showed that brake specific and NOx emissions decrease with retarded injection timing at all loads. At high load, all the fuels demonstrate roughly the same NOx emissions as a function of fuel injection timing. This observation indicates that for these fuels the engine-out NOx emission differences are related to shifts in SOI timings.

3.1.2 Effect of ignition delay

Most of the studies observed that ignition delay for biodiesel is shorter than that of conventional diesel **[8, 9, 10, 11]**. **[8]** did experiments with a Cummins ISB 6.7L six cylinder engine with Bosch CRIN 3.0 HPCR fuel system. In these studies only one of the six cylinders is active and the others are unfired. The study investigated four fuels: Low Cetane Diesel, Low Cetane B20 Blend, High Cetane Diesel, and High Cetane B20 Blend. Results showed that at 1700 rpm low load condition, ignition delay for High and Low Cetane B20 are shorter than High and Low Cetane Diesel, respectively. The difference is 3º for Low Cetane case and 0.5º for High Cetane case. The decrease of ignition delay varies with different biodiesel feedstock. Some studies **[12]** found that ignition delay of CME (coconut oil methyl ester) is shorter than RME (rapeseed oil methyl ester) but longer than PME (palm oil methyl ester). The decrease of ignition delay also varies with engine operating conditions, i.e. engine speed and load. Experiments done by **[5]** indicated that compared with diesel fuel, ignition delay at 1300 rpm with B20 decreased by 5% at low load and 10% at high load , and at 75% load B20 decreased by 6.9% at load speed and 17.2% at high speed condition. Higher cetane number of biodiesel is generally considered as indication of its shorter ignition delay. Analysis in **[8]** indicated that ignition delay is affected by aromatic hydrocarbon content and is generally characterized by cetane number. In terms of NOx emissions, ignition delay is also considered by some investigators **[5, 7, 8]** to be an important part of the NOx emission difference between diesel and biodiesel. According to **[8]**, at light load, the relatively longer ignition delay for diesel fuel allow most or all of the fuel to be injected before combustion begins. This pre-mixing results in a more dilute combustion zone and in lower peak combustion temperatures. This in turn results in lower NOx formation in diesel engine compared with biodiesel engine. But **[8]** also indicated that at high load conditions where the combustion is dominated by a diffusion flame, the ignition delay effect is weak and there is only a small net combustion impact associated with burning biodiesel. The difference in NOxbetween either diesel fuel or its B20 blend is considerably less than the difference in NOx between the two commercial diesel fuels. 3.1.3 Effect of flame temperature and soot radiation. A lot of investigators **[8, 9, 13, 14]** hold that engines fueled with biodiesel have higher flame temperature than conventional diesel engines and the higher flame temperature is one of the major reasons for increased NOx emission from biodiesel engine. Results from **[8]** shows that the higher aromatic content in biodiesel produces higher flame temperatures and therefore higher NOx emissions. The author also indicated that this effect is most significant for modes of combustion dominated by diffusion burning, as is characteristic of higher load engine operation. In addition, the methyl ester compounds in the biodiesel have more double bonds than the base diesel fuel and these double bonds have the effect of increasing the flame temperature **[13]**. From a macroscopic point of view, advanced injection timing and shorter ignition delay produce a higher flame temperature during the diffusion burning period **[9]**. Also, for improved combustion the temperature in the combustion chamber can be expected to be higher **[14]**. Recent studies have shown that radiative heat transfer from soot could significantly affect the NOx formation during combustion **[15, 16]**. Some investigators have reported that the “cooling effect” of soot radiation may reduce NOx emission by approximately 25% **[15]**. Radiation from soot produced in the flame zone is a major source of heat transfer away from the flame, and can lower bulk flame temperature by 25 K to 125 K, depending on the amount of soot produced at the engine operating conditions. Such reductions in the flame temperature would accordingly decrease the NOx by the thermal mechanism by 12% to 50%. Thus, an in-cylinder soot-NOx tradeoff exists in diesel engines and this tradeoff appears to fit biodiesel emission data well **[13]**. As stated previously, biodiesel fuels in general produce less soot than petroleum diesel fuel, which is likely a consequence of the fuel bound oxygen. This reduction in soot would theoretically reduce the “cooling effect” via soot radiative heat transfer, and thus leave NOx formation unsuppressed. Also, soot radiation may explain the variation in NOx emissions between the different esters of which biodiesel consists **[13]**.

2.3 Previous simulation studies

Due to the intricacy and complexity of comparing biodiesel and diesel combustion in direct injection engines, numerical studies (engine simulations) have been applied in addition to experimental studies. The numerical study in **[13]** applied a so-called well-mixed balloon model to investigate the flame temperature and NOx formation of biodiesel combustion. Calculation were made using Cantera in a MATLAB environment. The well-mixed balloon is a model that simulates the time history of a jet of fuel into a combustion chamber containing oxidizer. In the well-mixed balloon, the mass output is zero and thus the balloon grows as mass flows in. In time the balloon grows and the fuel-air mixture in the balloon reaches the ignition conditions and then ignites. This leads to a sudden increase in temperature **[13]**. Two fuels, methyl butanoate and methyl trans-2-butenoate, were simulated, and the results showed that the double bonded methyl trans-2-butaneoate gave a 14 K higher flame temperature than the other fuel. The investigator believed that this change in temperature caused an increase in NOx emissions of 159 ppm **[13]**. Also, the author did the model sensitivity analysis on the influence of the various NOx mechanisms. Results revealed that the thermal NOx mechanism had the most visible contribution to the NOx formation (92%), comparing to other mechanisms such as N_2O mechanism (1%) **[13]**. Due to the over-simplicity of zero-dimensional model, and the long computational time of three-dimensional model, quasi-dimensional multi-zone models are increasingly applied by many investigators **[17, 18, 19, 20]**. The study in **[17]** developed a quasi-dimensional, multi-zone, direct injection (DI) diesel combustion model. The model was implemented in a full cycle simulation of a turbocharged engine. The combustion model accounted for transient fuel sprays evolution, fuel-air mixing, ignition, combustion and NO_x and soot pollutant formation. The results demonstrated that the model can predict the rate of heat release and engine performance with high fidelity, while more effort is needed to enhance the fidelity of emission prediction. Arsie et al. **[18]** reported that the model they developed successfully predicted engine performance and emissions. In addition, the constants in their sub models remained the same throughout the engine operating range, which enabled this quasi-dimensional multi-zone model to be used for prediction purposes. By using the GT-Power software, **[20]** also developed a multi-zone model to analyze the performance and emissions of different types of diesel and biodiesel fuels. The model was calibrated at a default case using normalized burn rate and it was then used to predict pressure diagram, heat release and NOx emissions for Soya bean based biodiesel, rapeseed based biodiesel and reference diesel. The results showed that three fuels gave almost the same pressure diagram, while the two biodiesel cases gave slightly higher heat release rate than that of diesel case. At two load conditions, results showed 60% higher NOx concentration from the two biodiesels fuel than that of diesel fuel. Since the model has not been well calibrated at all engine operating conditions, these results could be very preliminary. To obtain more detailed combustion insight, 3D simulation is still applied by some investigators. In **[8]**, a KIVA model was developed and calibrated using the engine data for diesel no.2 and B100 biodiesel. Good agreement between measured and predicted heat release is obtained with some discrepancies associated with the start of combustion. In terms of emissions, the author compared soot vs. NOx tradeoff between measurement and prediction and the agreement is also quite good. After completing the KIVA model validation, a detailed examination of the impact of engine controls settings on NOx formation due to the lower energy content of the B20 blends was conducted. Two test cycles (UDDS6K and HWY55) were conducted by the KIVA model. Final results showed that at higher speeds and loads, the change in engine control settings due to the lower energy content of the blended fuel led to a NOx increase on the order of 3-4%. The author believed that this accounts for the majority of the NOx difference between a B20blend and its base diesel fuel. The combustion of middle distillate fuels is complex and has to be simplified and approximated using surrogates. Farrell et al. [**23**] working at the National Institute of Standards and Technology (NIST) have made considerable effort to devise a surrogate database to ease the process of generating mechanism. Harper [24] introduced software using linked libraries to automatically generate mechanisms to user specifications. In experiments, the individual species concentrations must be measured accurately but, current technology uses limited spectroscopy techniques. [**25**] Mechanisms used in simulations are thus practically relegated to using models of surrogates for the purposes of verification. [**26**] Generating mechanisms is typically done by analyzing the pressure, thermal conditions, and analyzing the subsequent pathways of sub mechanisms for H_2, CO, methane, and more complex hydrocarbons.

Reactions can be combined depending on the products of chain initiating reactions. Typically several unimolecular reactions with high rates are used to initiate the breaking of the large surrogates into smaller chains and radicals such as hydroxyl. [**27**] Pyrolysis is naturally included in unimolecular reactions and offers a way to model soot formation in concert with PAH formation in detail. Biodiesel consists of several long chain methyl esters. Researchers and scientists at the Lawrence Livermore National laboratory have produced several detailed mechanisms for soy methyl ester (SME) and rapeseed methyl ester (RME) biodiesel. There are five main methyl ester components in biodiesel which are $C_{17}H_{34}O_2$ (methyl palmitate), $C_{19}H_{38}O_2$ (methyl stearate), $C_{19}H_{36}O_2$ (methyl oleate), $C_{19}H_{34}O_2$ (methyl linoleate), and $C_{18}H_{32}O_2$ (methyl linolenate). Theoretical model developed using single Wiebe function which does not predict the heat release rate during pre-mixed and diffusive phase of combustion separately. Above literature survey shows that efforts are being made on use of biodiesel and its blends with diesel in CI engine to address the issues related to the performance, combustion and emission characteristics experimentally and theoretically. Numerous studies have been performed to evaluate the effect of biodiesel blending ratio on the combustion, performance and emission characteristics of a CI engine. The brake thermal efficiency improves significantly with increase in percentage of biodiesel blending. Smoke opacity results show that biodiesel blending is relatively less pollutant as compared to petroleum diesel [4]. With the increase in blending ratio, the brake specific fuel consumption (BSFC) increases. This is mainly due to the presence of oxygen atoms in the biodiesel chemical structure, reducing its calorific value by 7–12% [3]. Many experimental studies shown that use of biodiesel increases the NOx emission by 2-5% compared to conventional diesel due to the presence of oxygen which advances the ignition timing [3, 5, 6]. The above studies are focused on experimental determination of performance or emission characteristics of biodiesel, which lacks the details of local in-cylinder processes

2.4 Literature Gap

Diesel engines occupy a prominent role in the present transportation and power generation sectors. There have been many methods tried and are in use to reduce pollutant emissions from a diesel engine. The main options to reduce pollutants are the usage of bio-fuels and adopting some modifications to the combustion process. The present study describes a performance and emission analysis of Diesel and its blends with biodiesel for CI Engine. It has been observed that the increase in the content of biodiesel in diesel-biodiesel blend decreases engine power. As reported this loss in engine power with the use of biodiesel is mainly due to the reduction in heating value of biodiesel compared to diesel. The same reason can be accounted for the increase in the brake specific fuel consumption. On the other hand, few researcher is of the view that compared to the fossil diesel fuel, biodiesel improves thermal efficiency as it gets injected earlier, resulting in an earlier start of combustion. Also, the shorter delay time of fuel combustion due to the higher cetane number of biodiesel provides more time for complete combustion. However, the low calorific value and high viscosity of bio-fuels again tend to decrease the thermal efficiency. Biodiesel and its blend have larger cetane number than that of diesel, resulting in earlier combustion. Due to this difference in cetane number, the use of biodiesels decreases the ignition delay period compared to pure diesel. The higher cetane number and the reduced ignition delay for the biodiesels tend to increase the in cylinder pressure. The higher oxygen content in biodiesels, leading to improved combustion may be another reason for this. In comparison with conventional diesel fuels, biodiesels promote more complete combustion and thus effectively reduce emissions of particulate matter (PM), carbon monoxide (CO) and smoke. However, the use of biodiesel increases the content of NO_x in the combustion products. This higher NO_x emission is due to the comparatively high temperature inside the cylinder owing to the combustion of biodiesel and higher oxygen content of the fuel. Direct use of biodiesel in CI engine may results in ring-sticking, injector coking or injector deposits problem in the long run. Therefore in practical application biodiesel is mixed with convention diesel fuel. The major limitation to the use of biodiesel is that it crystallizes at low temperature below 0ºC causing problem in fuel pumping and engine operation. Researchers have experimentally evaluated the performance characteristics of conventional diesel engines fuelled by biodiesel and its blends. However, experiments require enormous effort, money and time. A realistic numerical simulation model could reduce such effort. Numerical simulation based on mathematical modeling of diesel engine processes have long been used as an aid by design engineers to develop new design concepts Diesel engine simulation models can be used to understand the combustion performance; these models can reduce the number of experiments. The thermodynamic based model should be developed which could follow the changing thermodynamic state of the working fluid through the engine intake, compression, combustion, expansion and exhaust processes for predicting the performance of a diesel engine fuelled by diesel and also the different blends of diesel and biodiesel. The model should predict the performance of a CI engine in terms of brake power, brake thermal efficiency and exhaust emissions at different brake mean effective pressure for all the fuels considered. Fuel properties, the engine design and operating parameters could be specified as inputs to the model.

2.5 STATEMENT OF THE PROBLEM

It is clear from the above literature review that Biodiesel blends can be used either as an extender or complete replacement to diesel fuel. The present study describes a cycle simulation model. This thermodynamic based model follows the changing thermodynamic state of the working fluid through the engine intake, compression, combustion, expansion and exhaust processes for predicting the performance of a diesel engine fuelled by diesel and also the different blends of diesel and biodiesel. The model predicts the performance of a CI engine in terms of brake power and brake thermal efficiency for all the fuels considered for the present study. Fuel properties and the engine design and operating parameters are specified as inputs to the model.

The purpose of this project is to determine the effects of fuelling a diesel engine with diesel and bio-diesel fuel blends. The investigation has been done on 100% diesel fuel and 20% bio-diesel blend with diesel. The results are the compared with the results get from experimentations. Many researchers have reported difficulties encountered with use of vegetable oil in diesel engine. These difficulties are mainly attributed to high viscosity of vegetable oil. Soyabean is becoming a sustainable source for diesel replacement in India. However, its high viscosity issue is to be resolved for its long term utilization in diesel engine. Due to high viscosity, there are two strategies for using Soya bean oil as fuel for use in diesel engine. The first one is to modify the engine to adapt to the fuel and these condone is for processing the fuel to adapt to the engine. The literature indicates that modifying existing diesel engines to preheat Soya bean oil to reduce viscosity and could achieve the first strategy. The second option is modification of Soya bean oil to the existing engines. The adaptation of Soya bean oil to the diesel engine could be done by blending the Soya bean oil with diesel, producing methyl esters through transesterification process that could be used straight instead of diesel. However, it is essential to explore the possibility of development of a heat exchanger to preheat the neat Soyabean oil with the help of exhaust gases before entry to diesel engine in a dual fuel tank mode because fuel modification techniques such as transesterification process requires expertise and equipments and not easily understandable to rural community. The purpose of this project is to determine the effects of fuelling a diesel engine with diesel and bio-diesel fuel blends. The investigation has been done on 100% diesel fuel and 20% bio-diesel blend with diesel. The results are the compared with the results get from experimentations.

Therefore, the following objectives were envisaged for the present research work.

1. Comprehensive literature survey.

2. Some specific objects are to evaluate the performance of,
   - (i) Engine output.
   - (ii) Numerical Modeling results.
   - (iii) To predict the net heat release for B20.
   - (iv) To investigate the output parameters such as temperature, pressure, heat release etc.

3. Conducting exhaustive experiments on the test rig to evaluate performance and emission characteristics of Soya bean oil and compare with base line data of diesel.
4. Analysis of Results

CHAPTER 3

SIMULATION AND EXPERIMENTAL PROCEDURE

3.1 Overview of Compression Ignition Engines

The Diesel cycle was initially conceived by Rudolf C. K. Diesel in 1893, when he first introduced his thermodynamic theories. His goal was to create a new form of heat engine which didn't use steam or spark ignition to initiate combustion. The Diesel cycle is a four stage thermodynamic cycle based originally on the Otto cycle but with a few key changes. The four stages or strokes of the diesel cycle are induction, compression, injection/combustion, and the exhaust strokes. The main differences, particular to the Diesel cycle, are the lack of air throttling, the use of middle distillate fuels, and the employment of direct injection. The intake valve opens (IVO) just before the piston travels toward the crankshaft during the induction stroke. The intake valve closes near bottom dead center (BDC) and then piston travels away from the crankshaft. Nearing the end of the compression cycle, the average pressure and temperature is around 50bar to 80bar and 800K to 1100K respectively. Near top dead center (TDC), the injection valve needle lifts and a particular amount of fuel is introduced into the cylinder through the fine orifices. The axes of the several high precision orifices are positioned equi-azimuthally with negative elevation toward the piston crown and cylinder wall liner. The high pressure liquid fuel spray travels radially out in the form of jets. The swirling air deforms the fuel jets and they eventually break up into mists of fine droplets around the jet peripheries. The fine mist of droplets vaporizes when shear overcomes surface tension. Since there is no spark plug unlike the Otto cycle, the combustion reaction must ignite automatically. There is enough thermal energy in the air, after compression, to activate the combustion reaction. Ignition occurs automatically when an appropriate air and fuel according to a particular range of stoichiometric ratios is locally reached near the vaporized droplet. The rapid increase of average cylinder pressure comprises the combustion stroke. The expansion of cylinder volume is driven partially by the thermal and mostly the kinetic energies released during combustion of the charge. The combustion takes place around the crown of the piston. The violent action of the combustion process causes the remaining fuel to be mixed with the leftover air and the increase in cylinder pressure. The energy conversion process is facilitated by the piston, connecting rod, and crankshafts present orientation which is all a function of the crankshaft angular position, which is why injection timing is important. Finally, the exhaust valve opens (EVO) as the piston is moving away from the crankshaft again. At that time, the products of the reaction are expelled from the cylinder. When the operating conditions of the engines are optimum, the combustion process is self sustaining. The entire 4-stroke cycle is completely repeated for every two subsequent rotations of the crankshaft.

The hallmark of the diesel cycle is its relatively high thermal and mechanical efficiencies when compared to other reciprocating internal combustion (IC) cycles such as the Otto, Atkinson. The average light to medium duty reciprocating gasoline engine has an overall efficiency of 30%. Diesel engines can, depending on size and intake configuration can range from 27% to 40%. The largest Diesel engine in the world, the RTA96-C for maritime application, manufactured by Wärtsilä-Sulzer of Finland can reach an overall efficiency of 51.7%. This level of efficiency is reached because of some of the key idiosyncrasies of the diesel cycle. Unlike the Otto cycle, the atmospheric air inducted to into the engine is not throttled using a butterfly valve upstream of the intake valve situated in the cylinder head. Crankshaft angular kinetic energy, beyond losses imparted from inherent wall friction and fluid internal viscous forces, do not occur in the Diesel cycle because it is not throttled using a butterfly valve. The volumetric efficiency of diesel engines is thus higher because of the absence of those pumping losses. Also, diesel engine compression ratios are not heavily limited by the fuel and other thermo mechanical factors as they are in the premixed cycles. Compression ratio is not limited, in common diesel combustion regimes or strategies, because the fuel does not enter the combustion chamber in the premixed condition. Combustion knock, or the sudden detonation of the combustion charge before the ideal cylinder condition and corresponding crankshaft angular position, is not a highly relevant factor in diesel engine design. Overall pressure levels must be kept within ranges appropriate to the particular engine's structural strength. Typically, in reciprocating internal combustion engines, increases in compression ratio correlate with increases mechanical efficiency. Diesel engines rely on the autoignition phenomenon associated with high cetane number fuels, so they can take full advantage of turbochargers. Turbochargers use the wasted kinetic and thermal energy of the exhaust stream to increase the mass of air that reaches the combustion chamber. They have become a common aspect of modern diesel engine design. Turbochargers allow generous increases in combustion torque because of an increase in the mass of air that enters the cylinder. Because of the cylinder pressure levels (>100bar in many turbo-diesel engines), Diesel engines typically have heavy-duty components and relatively larger connecting rod length to crankshaft journal radius ratios, which limit their maximum crankshaft speed. The disadvantages to all this is that Diesel engines typically operate at fuel lean conditions. The amount of fuel injected into the cylinder controls the crankshaft speed and resistance to load. As engine speed increases with constant load, increasing amounts of fuel are introduced into the cylinder with less time to diffuse into air and combust. Spatially, within the cylinder, there are large variations in equivalence ratio and temperature which provide ideal conditions for the formation of several types of harmful pollutants. The Equivalence ratio is defined as the actual mass ratio of fuel to oxidizer over the stoichiometric ratio. Medium temperature (900K to 1700K) fuel-rich ($\Phi>1$) regions allow breakdown because of high heat without oxygen, of alkanes near the central axis of the fuel jet. Formation of sulfates and carbon particulates absorb intermediary hydrocarbons species leads to sulfuric acid formation and carcinogen exposure. High temperature (1800K to 2800K) fuel lean ($\Phi<1$) regions at jet are where oxides of nitrogen form which lead to nitric acid and smog. The small carbon particles, typically called soot, which are produced by the pyrolysis process leave the cylinder and exit the exhaust systems in large plumes. Pollution problems can be minimized with biodiesel fuels and the overall efficiency increased further, diesel engines can be taken advantage of during the quest to reduce the detrimental affects toward the biosphere.

3.2 Overview of Simulation software

DIESEL-RK software is designed for simulation and optimizing working processes of two- and four-stroke super- and turbocharged internal combustion engines. The program allows the computational research of all kinds of engines e.g. Diesel engines, SI petrol engines, SI gas engines including prechamber systems. For two-stroke engines the DIESEL-RK supports all kinds of scavenging.

3.2.1 Typical applications include:

- Torque curve and other engine performances prediction
- Fuel consumption prediction and optimization

- Combustion and emission analysis and optimization
- Knock prediction
- Valve timing optimization
- EGR analysis and optimization
- Turbocharger and bypasses matching and optimization
- Conversion of diesel engines into gas engines.

The program DIESEL-RK makes it possible to be carried out for simulating a working process of any type of internal combustion engines. Applied calculation models provide high accuracy of results and generality. The amount of empirical coefficients is not great, and they are strictly constant for any operating mode of engine and for any configuration. Calibrated calculation model provides accurate simulation of engine with identical values of empirical coefficients over whole operating range including part load and idling. The DIESEL-RK is a thermodynamic program: cylinders and manifold of an engine are considered as an open thermodynamic system. Parameters of gas in cylinders and in manifolds of an engine are defined by the step-by-step solution of the equations system of conservation of energy, mass, and also the equation of state and composition for open thermodynamic systems. Dependence of properties of gas on composition and temperature is taken into account. The used method of difference equations solving surpasses traditional in accuracy and speed in 5 times. It is assumed that all cylinders are identical. It allows increasing the computational rate in several times and makes possible the resolving the optimization problems and fast overall analysis of engines. Experience of CFD simulation of exhaust and intake manifolds fortifies the correctness of the assumption overwhelmingly. Gas flow in engine ports is considered as non-stationary. Design of ports is taken into account at heat transfer simulation. The mathematical model of gas exchange takes into account non-stationary flow of gas in ports, features of two-stroke ICE designs, influence of the adjacent cylinders and the design of the pulse converter. It makes it possible to carry out computational optimization of valve timing and also to determine the best configuration of two-stroke engine ports.

For calculation of combustion in petrol and gas engines, including engines with prechamber, the multizone model is used. Heat release rate is calculated by Wiebe's method. Optimization tools provide considerable increase in efficiency of computational research and reveal effective ways of improvement of engines. When solving research problems connected with a search for optimal combinations of several engine parameters, such as compression ratio, injection timing, diameter, number and direction of injector nozzles, combustion chamber shape, valve timing, turbocharging parameters etc., it is often difficult to schedule a new experiment and to process experimental results because of a great number of variable factors. Very effective means for the solution of like problems is multiparametric optimization when a search for the optimal combination of variable factors is laid on a formal procedure of nonlinear programming, and the researcher’s task is only to formulate the optimal search problem properly and to analyze the results obtained. The optimizing procedure uses the engine mathematical model to connect independent variables (optimization parameters) on the one hand with the goal function and with the restrictions on the other. Due to high operating speed of DIESEL-RK the computational optimization research can be carried out very fast and without large expenditures.

The taking into account of turbocharging units is carried out by different ways: Parameters of turbines and compressors may be set in an explicit form. Boost pressure and pressure before turbine may be calculated as functions of pressure ratio, efficiency, power balance. Parameters of turbines and compressors may be calculated by a method of the matching of their maps (SAE format) with the reciprocating engine. The technique of joint calculation of reciprocating engine and turbocharging units on various modes allows to predict performance maps, high-altitude and other characteristics of the super- and turbocharged engines. Selection of turbocharging units for matching of required characteristics of super- and turbocharged engines is possible.

Calculation of **NOx emission** is carried out by the newest technique with using the **Detail Kinetic Mechanism** for correct prediction of NO emission in an engine with large EGR, multiple injection and HCCI (199 reactions, 33 species); as well as using the Zeldovich's mechanism (18 species) for conventional diesels.

3.3 Specifications of the Simulated Engine

CASRAE lab at Delhi Technological University maintains several real time engines with different specifications and equipped with various accessories for the study of several regimes of combustion in compression ignition engines. A Kirloskar make, single cylinder, aircooled, direct injection, DAF8 model diesel engine was selected for the present research work, which is primarily used for agricultural activities and household electricity generations as shown in Plate 3.7.

FIG 3.1: Test Engine

It is a single cylinder, naturally aspirated, four stroke, vertical, air-cooled engine. It has a provision of loading electrically since it is coupled with single phase alternator through flexible coupling. The engine can be hand started using decompression lever and is provided with centrifugal speed governor. The cylinder is made of cast iron and fitted with a hardened high-phosphorus cast iron liner. The lubrication system used in this engine is of wet sump type, and oil is delivered to the crankshaft and the big end by means of a pump mounted on the front cover of the engine and driven from the crankshaft. The inlet and exhaust valves are operated by an overhead camshaft driven from the crankshaft through two pairs of bevel gears. The fuel pump is driven from the end of camshaft.

The detailed technical specifications of the engine are given in Table 3.1.

Table 3.1: Specifications of the Diesel Engine

Make	**Kirloskar**
Model	DAF 8
Base	Diesel
Rated Brake Power (bhp/kW)	8 / 5.9
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	95 x 110
Compression Ratio	17.5:1
Cooling System	Air Cooled (Radial Cooled)
Lubrication System	Forced Feed
Cubic Capacity	0.78 Lit Inlet
Valve Open (Degree)	4.5 BTDC
Inlet Valve Closed (Degree)	35.5 ABDC
Exhaust Valve Open (Degree)	35.5 BBDC
Exhaust Valve Closed (Degree)	4.5 ATDC
Fuel Injection Timing (Degree)	26 BTDC

For conducting the desired set of experiments and together required data from the engine,it is essential to get the various instruments mounted at the appropriate location on the experimental setup.

3.4 PARAMETERS SELECTION

The selections of appropriate parameters were essential for engine calculations, and parameters were selected very judiciously. The main parameters desired from the engine are listed below.

1. Power produced by the engines
2. Engine speed (Rev/min)
3. Fuel consumption

4. Temperature
5. Speed of the engine

With a view to calculate the parameters mentioned above, it was essential to pick up the following signals from the test bench.

1. Voltage generated by the alternator
2. Current generated by the alternator
3. RPM of the engine
4. Exhaust gas temperature at inlet and outlet of heat exchanger
5. Biofuel inlet and outlet temperature across heat exchanger
6. Fuel consumption rate
7. AVL 437 smoke meter
8. AVL Di Gasanalyzer

Once the parameters were selected, the essential instruments required for sensing these parameters were installed at the appropriate points in the experimental set-up.

3.5 Exhaust Emission Analysis

The major pollutants appearing in the exhaust of a diesel engine are the oxides of nitrogen. Exhaust gas analysis was done for exhaust smoke opacity, UBHC, CO, $CO_2$and NOx. For measuring the smoke opacity, AVL 437 smoke analyzer was utilized. This instrument 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 a photocell, generating a photoelectric current, which is a measure of smoke density. For measurement of UBHC, CO, CO_2 and NOx, AVL 4000 Light Di-Gas Analyzer was used.

3.6 BIODIESEL PROPERTIES

The biodiesel selected for carrying out experiments is Soya bean Methyl Ester (SME) B20 with following properties in table no. 3.2

Table No. 3.2 SME Physio-Chemical Properties

Cetane No	48.68
Heating Value (KJ/Kg)	41180
Viscosity(mm^2/s)	32.6 at 38^{o}c
Cloud Point (^{o}C)	-3.9
Pour Point (^{o}C)	-12.2
Flash Point (^{o}C)	254
Density (kg/m^3)	841
Sulfur fraction in fuel	0.00105
Apparent Activation Energy for the fuel auto ignition process (KJ/mol)	21
Molecular mass of fuel	211.5
Saturated Vapour Pressure at 480K	0.04326
Saturated Vapour Pressure at critical Temp. at 710 K	2.408

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The present work was done on off road vehicle diesel engine which was converted to run on a dual mode operation. The main objective of the study was to fuel the diesel engine with Biodiesel using shell and tube heat exchanger and performance and emission studies on the same at different bmep and compare the results with baseline data. Simulations of Biodiesel combustion were carried out for several parameters for validation purposes. All pertinent results are compared to the results from experimental data carried out on engine. The comparison is carried out further with the simulation result found at the Simulation software 'Diesel-RK'.

Combustion analysis involves the measurement of gas concentrations and temperatures for in-cylinder products, emissions checks and safety improvements. Parameters that are commonly examined include:

- • Oxygen (O2)
- • Carbon Monoxide (CO)
- • Carbon Dioxide (CO2)
- • Exhaust gas temperature
- • Soot(Particulate Matter)
- • Nitric Oxide (NO)
- • Nitrogen Dioxide (NO2)
- • Sulfur Dioxide (SO2)

When O2 appears in the flue exhaust, it usually means that more air (20.9 percent of which is O2) was supplied than was needed for complete combustion to occur. Some O2 is left over. or *Excess Air,* was supplied to the combustion reaction. When too little air is supplied to the burner, there is not enough oxygen to completely form CO2 with all the carbon in the fuel. Instead, some oxygen combines with carbon to form carbon monoxide (CO). CO is a highly toxic gas associated with incomplete combustion and efforts must be made to minimize its formation. This effort goes hand-in-hand with improving fuel efficiency and reducing soot generation.

As a rule, the most efficient and cost-effective use of fuel takes place when the CO2 concentration in the exhaust is maximized. Theoretically, this occurs when there is just enough O2 in the supplied air to react with all the carbon in the fuel supplied. Temperature of exhaust gases depends on heat leaving the exhaust flue with the hot gases is not transferred to do useful work. This heat loss becomes a major cause of lower fuel efficiency. Because the heat content of the exhaust gas is proportional to its temperature, the fuel efficiency drops as the temperature increases.

Nitrogen oxides, principally nitric oxide (NO) and nitrogen dioxide (NO2), are pollutant gases that contribute to the formation of acid rain, ozone and smog; Nitrogen oxides result when oxygen combines with nitrogen in the air or in the fuel. NO is generated first at high flame temperatures, and then oxidizes further to form NO2 at cooler temperatures in the stack or after being exhausted. The NO concentration is often measured alone, and the NO2 concentration is generally assumed to comprise an additional five percent of the total nitrogen oxides. The nitrogen oxide gas concentrations are sometimes combined and referred to as the NO_X concentration. Content of SO_x depends upon Sulfur dioxide combines with water vapor in the exhaust to form a sulfuric acid mist. Airborne sulfuric acid is a pollutant in fog, smog, acid rain and snow, ending up in the soil and ground water. Sulfur dioxide itself is corrosive and harmful to the environment. Sulfur dioxide occurs when the fuel contains sulfur and where the emission levels are directly related to the amount of sulfur in the fuel. The most cost-effective way to reduce sulfur emissions is to select a low-sulfur or de-sulfured fuel.

Soot is the black smoke commonly seen in the exhaust of diesel trucks, and is present whenever fuel oils or solid fuels are burned. Excessive soot is undesirable because it indicates poor combustion and is responsible for coating internal heat transfer surfaces, preventing good thermal conductivity. Over time, serious damage to the heat exchanger can occur. Soot is primarily unburned carbon, and is formed for the same reasons CO is formed—insufficient combustion air, poor mixing and low flame temperature. As with CO, it is usually impossible or impractical to entirely eliminate soot formation for some fuel types.

4.1 PERFORMANCE CHARACTERISTICS

The performance characteristics of the test engine on Diesel, Soya bean oil and simulation of biodiesel fuelled engine are summarized below.

4.2.1 Brake Thermal Efficiency

The variation of brake thermal efficiency of the engine with Soya bean oil at different bmep is shown in Figure 4.1 and compared with baseline data of diesel. From the test results it was observed that initially with increasing brake power, the brake thermal efficiencies of all the fuels were increased and then tended to decrease with further increase in brake power. The brake thermal efficiencies of the Soya bean oil were found to be lower than diesel fuel throughout the entire range. The possible reasons for this reduction are lower calorific value and high viscosity of the Soya bean oil as compared to diesel fuel. However, thermal efficiency of simulated result was higher than unheated Soya bean oil. This is due to the fact that simulated combustion works on ideal which result in increase in Brake thermal efficiency. The highest brake thermal efficiency was found in case of pre-heated Soya bean oil to 100ºC. The peak thermal efficiency for biodiesel blend through engine was 25.17% while simulated result was 26 but at different bmep, whereas the peak thermal efficiency of diesel was 28.51%.

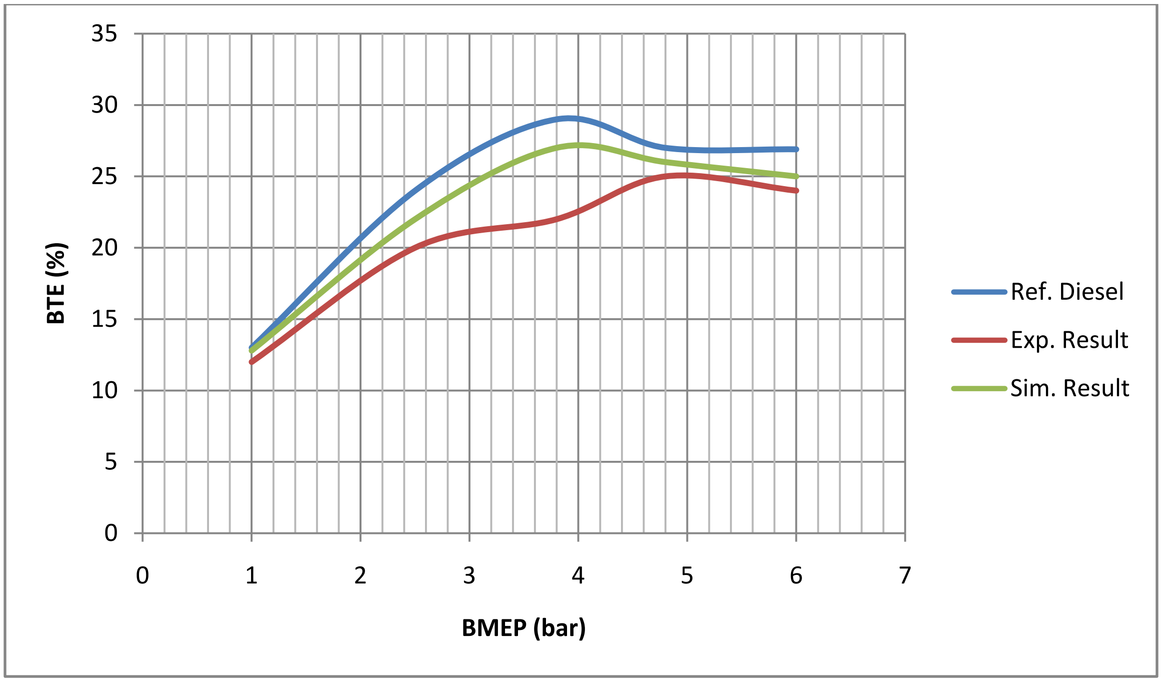


Figure 4.1: BTE Vs BMEP

4.2.2 Brake Specific Energy Consumption

Since Brake Specific Energy Consumption is not a very reliable parameters to compare the performance of two different fuels since density and calorific value of both the fuel are significantly different. Therefore, brake specific energy was taken as a parameter to compare the energy requirement for producing unit power in case of test fuels. The variation of BSEC vs. BMEP for the test fuels is shown in figure 4.2. It is clear from the figure that the brake specific energy consumption of Soya bean oil is higher than diesel which is due to high density and low calorific value of the fuel.

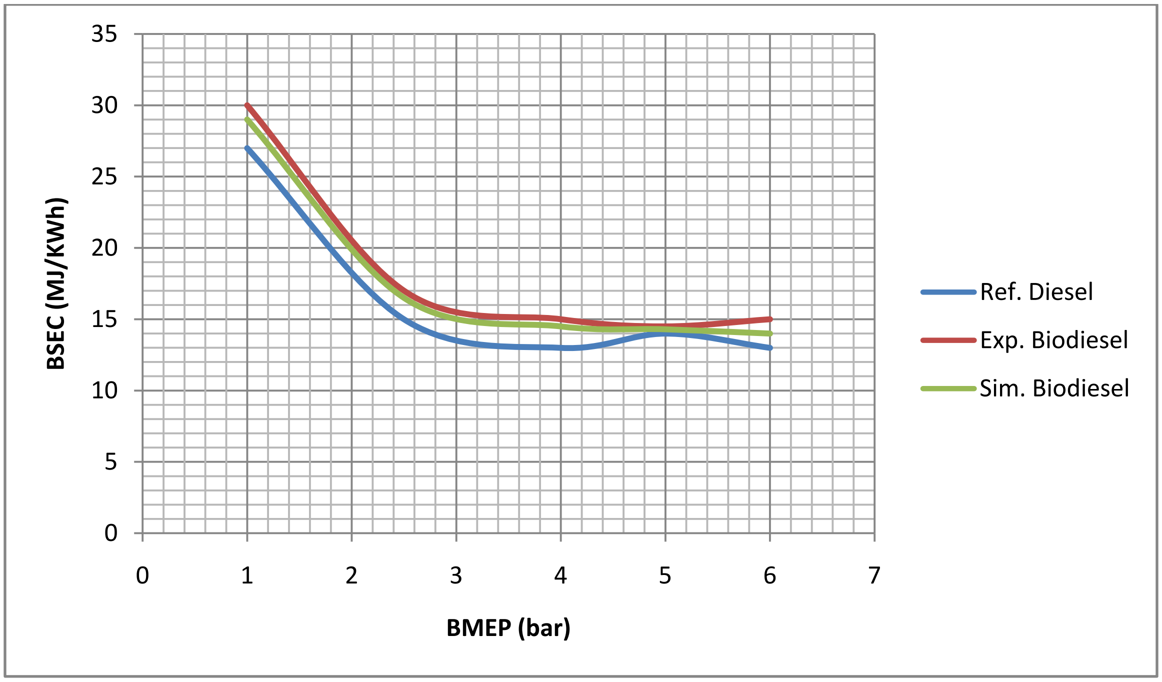


Figure 4.2: BSEC vs BMEP

4.2.3 Exhaust Temperature

Fig.4.3 shows the variation of exhaust gas temperature with brake mean effective pressure for diesel and Soya bean oil blends as B20. The results show that the exhaust gas temperature increased with increase in brake power in all cases. The highest value of exhaust gas temperature of 360°C was observed with the simulated combustion and the lowest was achieved with B20 blends of about 335°C where as the corresponding value with diesel was found to be 345°C. This is due to the poor combustion characteristics of the Soya bean oil because of its high viscosity. Though higher exhaust temperature with Soya bean oil is indicative of lower thermal efficiencies of the engine. At lower thermal efficiency, less of the energy input in the fuel is converted to work, thereby increasing exhaust temperature.

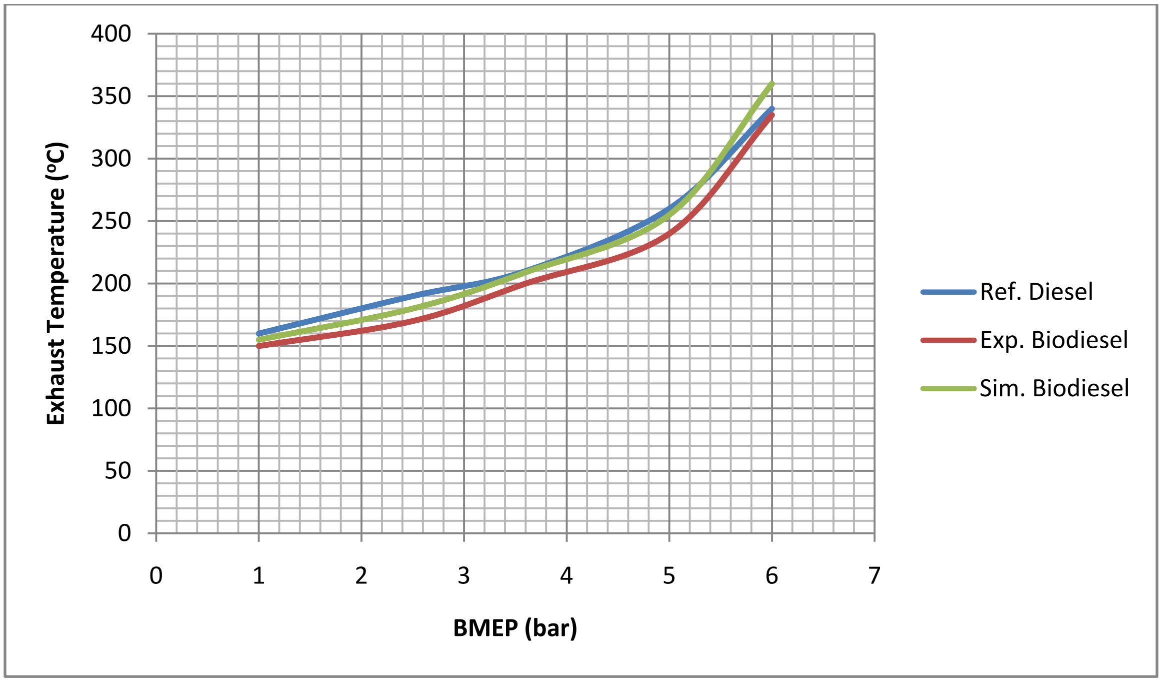


Figure 4.3: Exhaust Temperature vs BMEP

4.3 EMISSION CHARACTERISTICS

The emission characteristics of the test engine and simulated combustion on Biodiesel blends and diesel are given below.

4.3.1 NO_x Emissions

The variations of NO_x emissions for the entire test are shown in. Fig.4.4. The NO_x emissions increased with the increasing engine load, due to a higher combustion temperature. This proves that the most important factor for the emissions of NO_x is the combustion temperature in the engine cylinder and the local stoichiometry of the mixture. From Fig.4.5, it can be seen that within the range of tests, the NO_x emissions from the Soya bean oil are lower than that of diesel fuel but NO_x emissions increases as the fuel inlet temperature increased. For diesel, the highest NO_x emission is 1806 ppm. With Soya bean oil blends, the highest NO_x emissions are 1613 ppm. But in case of simulated combustion, the highest value of NO_x is 2636 ppm.

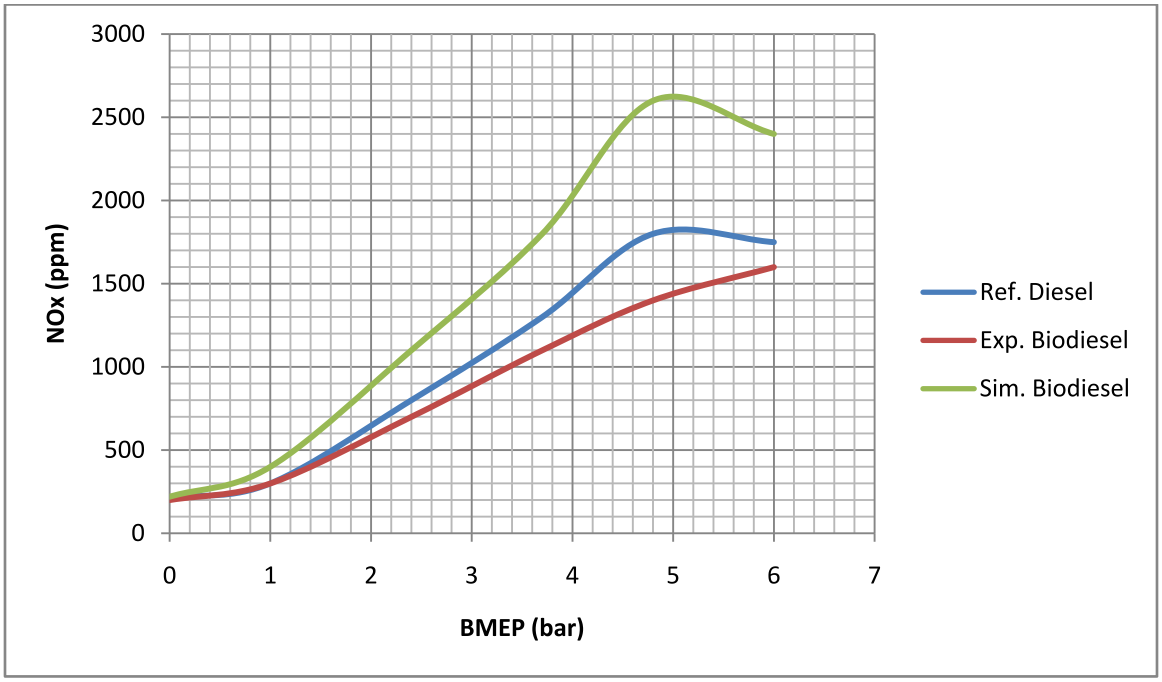


Figure 4.4: NOx emissions vs bmep

4.3.2 CO Emissions

Fig. 4.5 shows the comparison of the CO emissions for biodiesel blends at different engine load. Within the experimental range, the CO emission from the biodiesel blend is higher than that from pure diesel fuel. This is possible because of the high viscosity of vegetable oil. The higher the viscosity, the more difficult it is to atomize for the vegetable oil. This resulted in locally rich mixtures in the engine. In consequence it caused more carbon mono-Oxide generated during the combustion, due to the lack of oxygen locally. As already stated, the Soya bean oil viscosity decreases with increase in temperature, atomization of fuel droplets becomes good enough to reduce the concentration of CO in the exhaust emissions. The highest value of CO for diesel fuel is 0.42%.

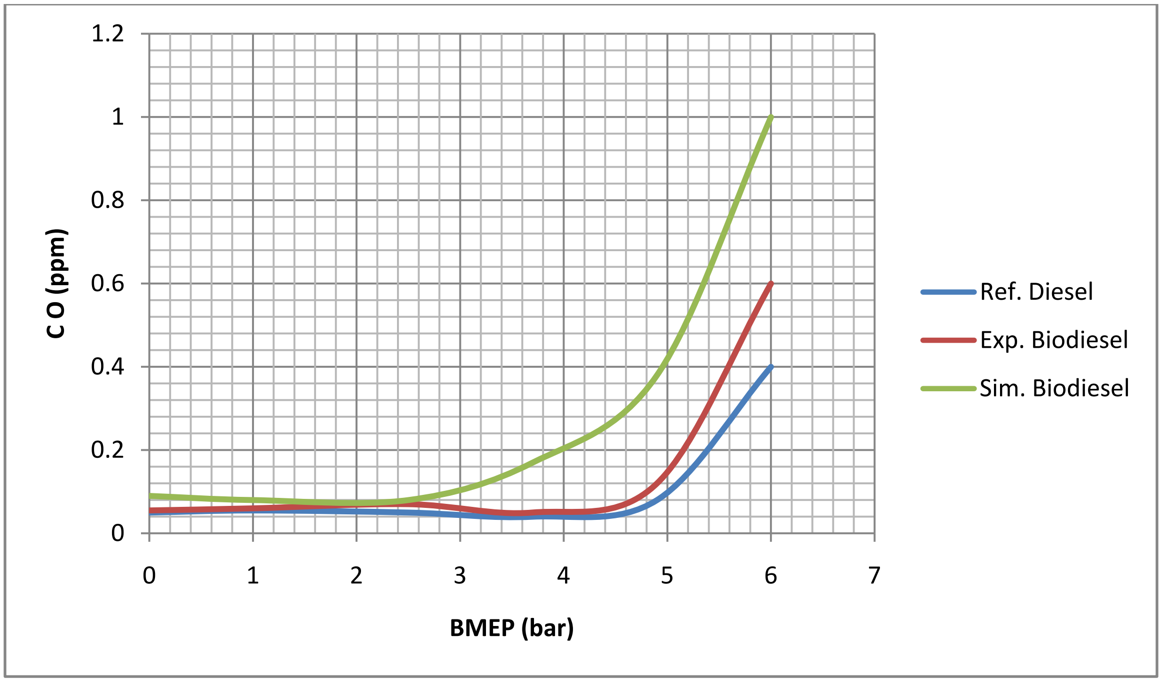


Figure 4.5: CO (ppm) vs bmep

4.3.3 CO_2 Emissions

The variations of CO_2 emissions of different fuels from the engine are shown in figure 4.6. In the range of whole engine load, the CO_2 emission of diesel fuel is lower than that of the other fuels. This is because vegetable oil contains oxygen element; the carbon content is relatively lower in the same volume of fuel consumed at the same engine load, consequently the CO_2 emissions from the vegetable oil and its blends are lower but with increase in temperature of Soya bean oil, combustion inside the cylinder becomes better. This better combustion results in increased value of CO_2. The highest value of CO_2 with diesel, biodiesel blend experimentally and simulated combustion at 100°C were 11.3%, 11.6% and 13.9% respectively. The result shows that there was a slight increase in CO_2 emissions when using plant oil and these results are in agreement with Agarwal et al. [52] in which he has reported increased CO_2 emissions.

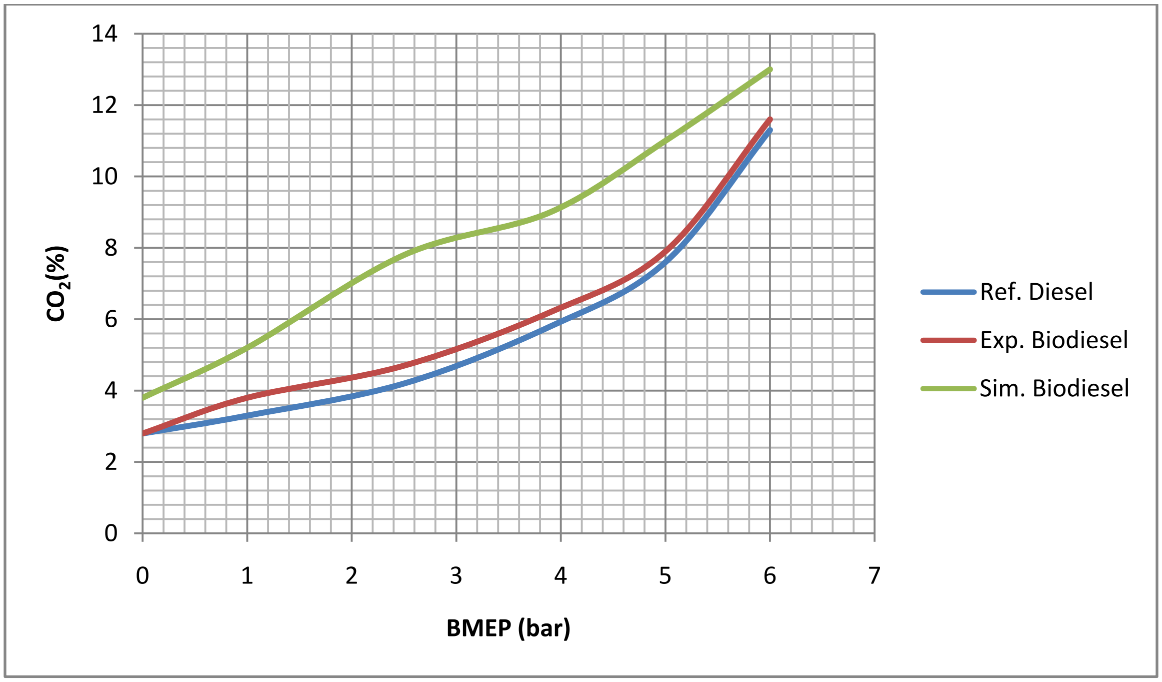


Figure 4.6: CO_2 vs BMEP

4.3.4 Un-burnt Hydro Carbon Emissions

The variations of unburnt hydrocarbon (HC) emissions for diesel and biodiesel blends are shown in Fig. 4.7. The HC emissions of all the fuels are lower in partial engine load, but increased at higher engine load. This is due to relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at higher engine load. Fig.4.8 shows that the HC emissions of Soya bean oil are higher than that of diesel fuel. The value of unburned hydrocarbon emission from the diesel engine running at constant speed from no load to full load is high in case of straight vegetable oil and less for pure diesel. HC emissions are lower at partial load, but tend to increase at higher loads for both the fuels. This is due to lack of oxygen resulting from engine operation at higher equivalence ratio.

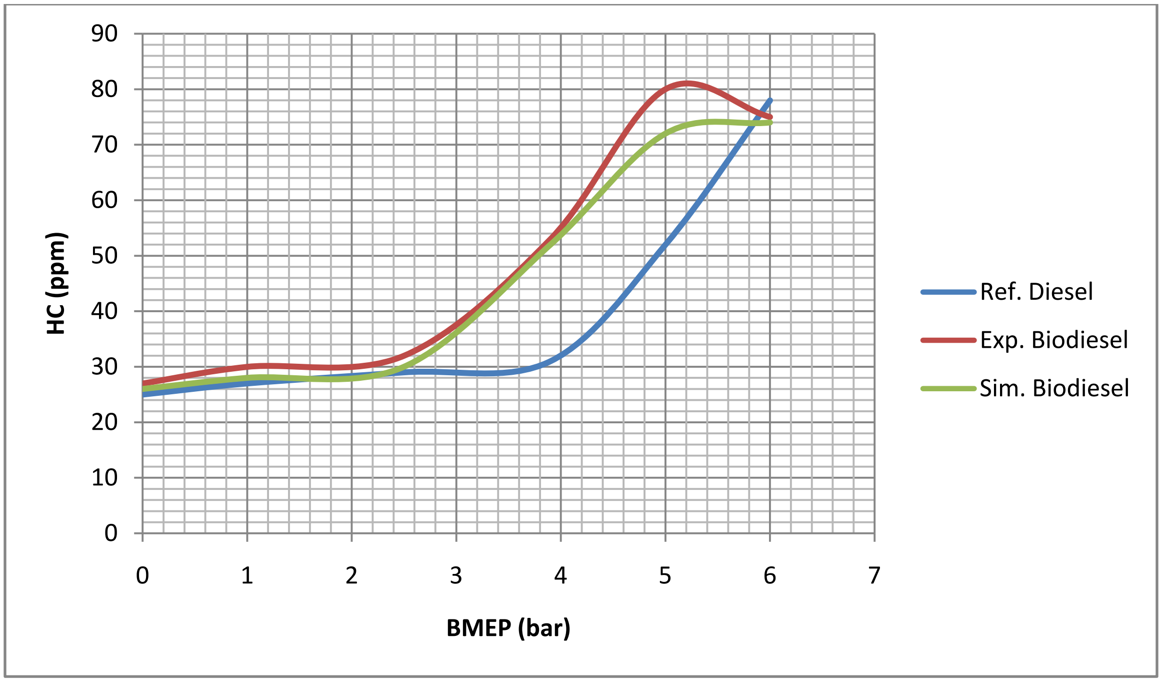


Figure 4.7: Unburnt hydrocarbons vs bmep

4.3.5 Smoke Opacity

Fig. 4.8 shows the comparison of smoke opacity for all the test fuels at different load conditions. Within the experimental range, the smoke opacity for Soya bean oil is higher than diesel fuel for no load and medium load conditions. However, at full loads smoke opacity is found lower than diesel fuel. This may be due to the fact that higher load, oxygen content of Soya bean oil may be responsible for better combustion and resulting into lower smoke opacity. This effect may be offset by high viscosity and density at lower load. When the fuel inlet temperature of Soya bean oil is increased, the smoke opacity decreases with the fuel in let temperature. This may be due to lower viscosity at higher fuel inlet temperature. It is relevant to mention that with increase in fuel inlet temperature, the brake thermal efficiency improved and all gaseous emissions in comparison to unheated Soya bean oil. However, it was experienced during the course of investigation that lubricating oil started leaking from engine at 1 00ºC. Therefore, it was found that fuel inlet temperature to 80ºC is good enough in reducing Kinematic viscosity to run the diesel engine without any adverse effect on engine

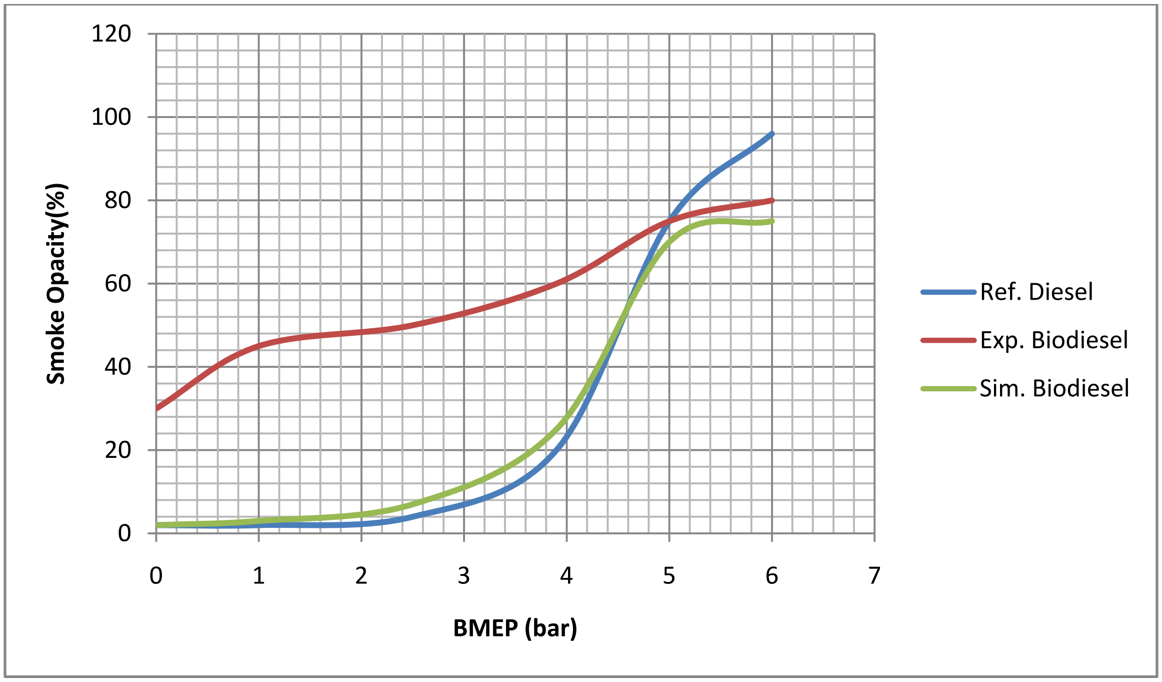


Figure 4.8: Smoke Opacity vs BMEP

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE WORK

5.1 Conclusions and future scope

An unmodified diesel engine model of a four stroke compression-ignition engine was used to study the engine performance and emission characteristics with both reference diesel fuel and biodiesel fuel. At five typical operating conditions, the engine model was calibrated for both diesel and biodiesel fuels. Performance characteristics curves and emission characteristics curves at these operating conditions were compared between simulation and experiments. The successfully predicted engine performance for both diesel and biodiesel fueled engine. Simulated curves at five operating conditions showed good agreement with experimentally determined results. The experimental results show that the engine performance with Soya bean oil is slightly inferior to the performance with diesel fuel. The thermal efficiency of the engine was lower and the brake specific energy consumption of the engine was higher when the engine was fueled with unheated Soya bean oil compared to diesel fuel. However, in case of Soya bean oil, these parameters were superior to unheated Soya bean oil. The oxides of nitrogen (NO_X) from Soya bean oil during the whole range of experiment were lower than diesel fuel. This is the most important gaseous emission characteristic of plant oil. However, for Soya bean oil, the NO_X emissions were increased. These NO_X emissions can be reduced by several methods such as EGR. The Carbon monoxide (CO), Hydrocarbon (HC), Carbon dioxide (CO_2) from the unheated Soya bean oil was found higher than diesel fuel during the whole experimental range. With Soya bean oil, the value of Carbon monoxide (CO), Hydrocarbon (HC) and smoke opacity were decreased and Carbon dioxide (CO_2) emissions were slightly increased. The results from the experiments suggest that Soya bean oil is potentially good substitute fuel for diesel engine and performance and emissions characteristics were found to be comparable to diesel fuel.

Due to the unknown characteristics of the biodiesel fuel, some observations from both the simulation and the experiment still cannot be well explained. Even with more advanced chemical kinetics modeling, direct experimentation to determine fuel properties is required for simple modeling techniques to have fidelity with real engine experimental data. Even with more advanced chemical kinetics modeling, direct experimentation to determine fuel properties is required for simple modeling techniques to have fidelity with real engine experimental data. The engineering value of biofuel combustion simulation is valuable for subsystem design, piston topology, and injection strategy decisions. The estimations of CO_2 and unburnt hydrocarbon data at EVO can be used to size and design aftertreatment subsystems if validated. With more accurate experimental data, recommendations for future work are,

1. Calibrate the model to match the emission data from experiment, especially the nitric oxides emission. Together with temperature profile, compare the results with diesel and biodiesel fueled engine and find out the cause of the difference if there is any.

2. It is a better improvement to include the compressor and turbine in the simulation as turbochargers and superchargers.

3. To get better understanding of biodiesel combustion in the cylinder, it would be useful to integrate the 3D computational fluid mechanics and detailed chemical kinetics into the current one-dimensional engine model. The simulation of intake/exhaust system could still be one-dimensional and the combustion in the cylinder could be simulated by 3D CFD and detailed chemical kinetics.

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