A study on the Performance and Emission Characteristics of CI Engine using blends of Hydrogenated Rapeseed Biodiesel and neat Diesel as fuel

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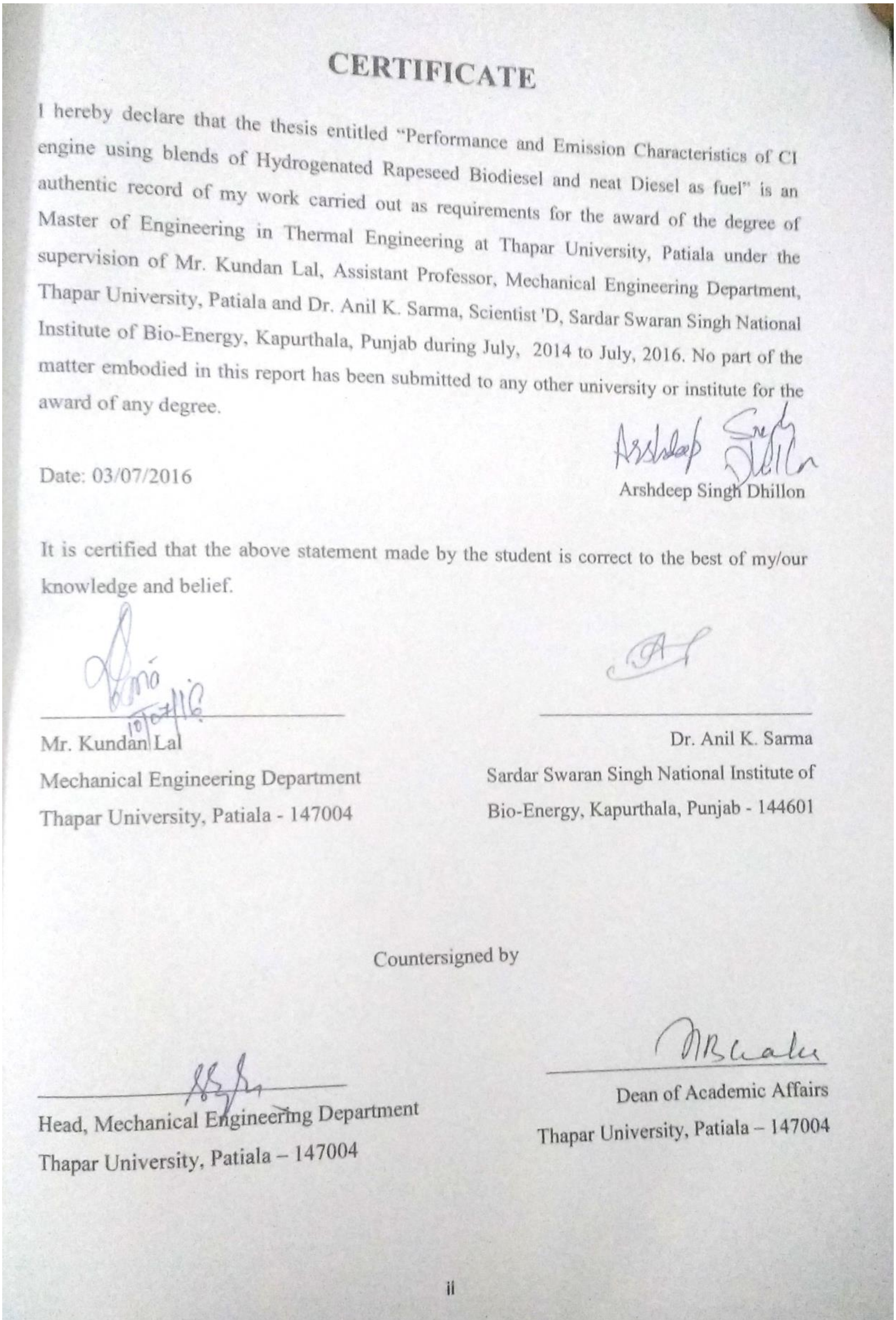

CERTIFICATE

I hereby declare that the thesis entitled "Performance and Emission Characteristics of CI engine using blends of Hydrogenated Rapeseed Biodiesel and neat Diesel as fuel" is an authentic record of my work carried out as requirements for the award of the degree of Master of Engineering in Thermal Engineering at Thapar University, Patiala under the supervision of Mr. Kundan Lal, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala and Dr. Anil K. Sarma, Scientist 'D, Sardar Swaran Singh National Institute of Bio-Energy, Kapurthala, Punjab during July, 2014 to July, 2016. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any degree.

Date: 03/07/2016

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It is certified that the above statement made by the student is correct to the best of my/our knowledge and belief.

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Dedication

I dedicate this thesis to my beloved father Gurcharan Singh and my mother Paramjit Kaur, who are an ever supporting and encouraging with their great patience. I also dedicate this to my brother Ramandeep Singh and to all my dearest friends.

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Abstract

Biodiesel is found to be an alternative fuel to conventionally available petro-diesels. Worldwide researchers are actively involved in the preparation of different types of biodiesel from edible and non-edible oils. The variety of the biodiesels is being tested for their performance and emission characteristics under actual conditions. As far as the performance of particular biodiesel is concerned, it largely depends upon the method of preparation and properties of the biofuel used. A detailed report on the preparation, performance and emission characteristics of CI engine using hydrogenated rapeseed oil methyl ester (HROME) and comparison of results of pure diesel with different blends of HROME in pure diesel has been presented in this report. Earlier reports suggested that hydro-treated vegetable oil can be easily transesterified to get superior quality biodiesel. Whereas, our investigations reveal that the biodiesel obtained after transesterification of rapeseed oil and subsequent hydroprocessing changes the properties remarkably. The rapeseed oil methyl ester has been prepared by alkali-catalysed transesterification by using Radleys Reactor for the reaction time of 2 hours at 78-80 °C by continuously stirring the sample at 650 RPM. The sample of hydrogenated rapeseed oil methyl ester is also prepared by hydrotreating biodiesel in a constant temperature and pressure reactor (CTPR) by passing hydrogen from rapeseed oil methyl ester at 360 °C (±2 ºC) temperature and varying pressure from 2 bars to 6 bars by continuously stirring the sample for the reaction time of 1 hour.

The variable compression ignition, single cylinder four stroke diesel engine has been used to conduct the experiments at constant compression ratio to investigate the performance and emission characteristics of HROME as compared to pure diesel. Experiments are conducted on variable loads from 0 to 15 kg on the engine. Different blends @ of 10 %, 20 %, 30 % and 40 % have been formed by mixing the HROME with the pure diesel. The experiments are conducted on the CI engine to evaluate their performance and emission characteristics. The properties like; calorific value and viscosity of different biodiesel blends are measured as per IS standards. Different parameters such as BSFC, fuel Consumption per hour, BTh Eff, BP, Mech Eff, NO_x, HC, CO and CO_2 have been compared for HROME blends and pure diesel. From the results it is concluded that blending of HROME not only improves the performance of CI engines but also reduces harmful emissions as compared to pure diesel.

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Nomenclature

ASTM	American society of testing and Petroleum
BMEP	Brake mean effective pressure
BP	Brake power
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
BTDC	Before top dead centre
CI	Compression ignition
CO	Carbon monoxide
CO2	Carbon dioxide
CTPR	Constant temperature and pressure reactor
CR	Compression ratio
DI	Direct injection
EGT	Exhaust gas temperature
HC	Hydrocarbon
HROME	Hydrogenated rapeseed oil methyl ester
IC	Internal combustion
NO, NO2 and NOx	Oxide of nitrogen
PM	Particulate Matter
PPM	Parts per million
RPM	Revolution per minute
SFC	Specific fuel consumption
TDC	Top dead centre
D100	0% biodiesel + 100% diesel (% by vol.)
B10	10% biodiesel + 90% diesel (% by vol.)
B20	20% biodiesel + 80% diesel (% by vol.)
B30	30% biodiesel + 70% diesel (% by vol.)
B40	40% biodiesel + 60% diesel (% by vol.)

Chapter 1

Introduction

1.1 Introduction

Biodiesel is defined as any fuel which can be an alternative to the convention petro-diesel and is derived from biological renewable resources. More precisely, biodiesel is defined as alternative of conventional petro diesel which is eco-friendly, non-toxic, oxygenated, biodegradable and sulphur-free [Prusty et al., 2008]. It can be defined chemically as a fuel which is composed of methyl esters or mono-alkyl esters of long chain fatty acids derived from different renewable sources, such as used cooking oils, animal fat and vegetable oils which is named as B100 in the research field and these fuels meets requirements of the European and ASTM standards to be used in the engines in the form of blends with the conventional diesel. For making edible and non-edible oils fit to use in engines without any change in the design these oils should be converted into biodiesel by using different techniques such as: transesterification, dilution, pyrolysis and micro emulsification to reduce the viscosity of the oil so that it can fit into the European and ASTM standards. The most common technique used for converting oils in biodiesel is transesterification which leads to methyl esters of the processed oils.

1.2 Need of Biodiesel

In the recent years number of vehicles has increased at very rapid rate in the modern world. This increase in number of vehicles has resulted in great demand of petroleum products. Our fossil fuels are also depilating with high pace due to this petroleum product prices are raising day by day. Transportation sector would have direct impact of price raise of petroleum products. To meet the demand researchers are looking for an alternative diesel fuels so as to substitute the conventional diesel fuel. Considering all this biodiesel seems to be very promising alternative fuel to conventional diesel fuel [Prusty et al., 2008]. Biodiesel is renewable in nature and has an advantage that it can be used directly in internal combustion engines without any change in design because of quite similar properties as conventional diesel fuels. India is one of the biggest petroleum product importing and consuming countries. In India only 30% of its petroleum demand is fulfilled by its own reserves and 70%

of petroleum product demands are fulfilled by importing products from foreign countries. The annual requirements of petroleum products of India are about 120 million metric tons, out of which consumption of diesel is 40 million tonnes approximately [Prusty et al., 2008]. Per day consumption of United States is about 21 million barrels, out of which, transportation consumes approximately about 65%, while per day consumption of world's oil amounts to 90 million barrels. For agricultural and transportation purposes heavy duty vehicles are used in which usually diesel engines are employed. It was reported that demand for diesel fuel in Turkey in 2006 is 12.07 million tonnes, which is approximately 4 times greater than its gasoline demand which is 3.88 million tonnes [Karabektas et al., 2008]. Many researchers had forecasted that demand of convention fuels in transportation sector all over the world will increase by maximum of 1.3% annually up to 2030 [Prusty et al., 2008]. If these forecasts are true then it means up to 2030 demand of conventional fuels per day will be around 18.4 billion litres (taking base year 2005-per day current demand is 13.4 billion litres) [The Royal Society, 2008]. Further it is seen that one of the major pollutant of atmospheric air now a day's is exhaust emitted by the automobiles. Major reductions in the emission of harmful gases has been done recently by research and development agencies, but the rate with which population and number of vehicles in the world are growing indicates clearly that the exhaust emissions will become very big problem for our environment in coming years. Therefore, an alternative fuel having fewer emissions as compared to conventional diesel is required. Biodiesel is a best alternative fuel because in recent researches clear reduction in unburned CO, HC and PM emissions are seen in case of using biodiesel as blends with conventional diesel [Di et al., 2009].

In recent researches it is seen that India is one of highest polluted countries in terms of atmospheric air in the world. According to the report 8.9 million vehicles were sold in India in 2005-06 and the number becomes 15 million within 5 years in 2010-11 [Sood, 2012]. India's capital city Delhi is reported as one of the ten most polluted cities of the world by the World Health Organisation. As per the Economic Survey of Delhi there are around 5.6 mission vehicles running on the roads of Delhi currently [Goyal et al., 2014]. In the industrialized countries like United States various laws were passed to limit the exhaust emissions in the atmospheric air and had issued proper guidelines up to specific allowable limits. Due to this in 1980s and 1990s various restrictions were applied on automobile engine development. For example, for passenger cars NO_x and PM emissions has reduced from 0.25 and 0.025 g/km to 0.10 and 0.005 g/km according to Euro 5 standards [Lapuerta et al., 2008]. There is very harmful effect of automobile emissions on human body. Gases from emissions of automobiles mix with atmospheric air which we inhale for breathing gives rise to contagious diseases. Different kinds of harmful gases are emitted by automobiles such as CO, HC, NO_x, CO_2 and PM causes serious health problems to human beings like nervous system disorder, nausea, cardio vascular disorder, vomiting and vision and judgment impairment. Along with this it also has very harmful effect on reproducing capability of human beings.

Table 1.1**:** Emission Standards for Petrol Vehicles (GVW ≤ 3,500 kg) in India, g/km [Sood, 2014]

Standards	Reference	CO	HC	HC+NOx	NOx
2000(year)	Euro 1	2.72-6.90	-	0.97-1.70	-
Bharat stage 2	Euro 2	2.2-5.0	-	0.5-0.7	-
Bharat stage 3	Euro 3	2.3 4.17 5.22	0.20 0.25 0.29	-	0.15 0.18 0.21
Bharat stage 4	Euro 4	1 1.81 2.27	0.1 0.13 0.16	-	0.08 0.10 0.11

It causes more severe problems in the body like irritation in throat, eyes and nose, cancer, impairment of lungs functioning and immune system disorder [Sood, 2014].

In order to encounter such problems we have to look for other alternative fuel to the fossil fuels for the environmental as well as economical benefits for the society. As per many researchers biodiesel is found to be best fuel to encounter the problems of atmospheric air pollution in case of internal combustion engines [Lapuerta et al., 2008]. Engine using biodiesel blended fuel emits less CO, HC and PM as compared to engine using pure diesel as fuel.

1.3 Biodiesel Properties

Following are some important properties of the biodiesel:-

1.3.1 Density

Generally biodiesel is denser as compared to conventional diesel. Specific gravity of biodiesel and pure diesel is 0.88 Kg/m^3 and 0.84 Kg/m^3 respectively. Then during mixing biodiesel with the conventional diesel for making different blends, biodiesel must be poured at the top of conventional diesel so as to ensure proper mixing [Sarkar, 1974].

1.3.2 Kinematic viscosity

Viscosity is one of the important physical properties of a diesel fuel. It is defined as a property which gives us information about the flow resistant nature of the fluid. Viscosity of the diesel fuel has a great impact on the performance of engine. If the viscosity of the fuel is too high it can cause jamming of injection valve and also causes problem in atomisation of fuel in combustion chamber causes incomplete combustion and if the viscosity of the fuel is too low it can cause leakage at the injection valve and also incapable of sufficiently lubricating Injector plungers and closely fitted pumps. Kinematic viscosity of biodiesel is approximately 1.5 times higher than diesel fuel. This is the reason why atomization of biodiesel fuel is less efficient which results in longer combustion duration and slower burning as compared to diesel fuel [Sarkar, 1974, Di et al., 2009].

1.3.3 Flash point and fire point

Minimum temperature at which the fuel generates just sufficient vapour to form inflammable mixture with air, indicated by the formation of flash of blue light i.e of momentary flame (flash) when needle having fire flame acting as an external source of fire is brought in contact with the vapour is known as flash point of the fuel. The minimum temperature at which fuel vapours continue to burn without external supply of flame is known as fire point of the fuel. Flash point of the fuel is lower as compared to fire point of the same sample of fuel. Fuel having value of flash point above 66 °C is regarded as safe fuel. As compared biodiesel fire point and flash point of petroleum based diesel fuel is lower. From this it is clear that in terms of storage biodiesel is safer fuel as compared to petroleum based diesel fuel [Sarkar, 1974].

1.3.4 Cloud point and pour point

On cooling the oil in a specific manner the maximum temperature at which oil becomes cloudy is known a cloud point. Cloud point is higher than the pour point in terms of temperature. Usually there is a difference of 5 °C to 6 °C between cloud point and pour point. The cloud point has much greater importance in diesel fuel as compared to pour point because if the temperature of fuel falls below cloud point, the formation of wax crystals in fuel can plug the filters of injection system and flow of the fuel stops automatically even if temperature of fuel is above pour point. On cooling the oil in the specific conditions and manner the temperature 2.8 °C higher than the temperature at which oil ceases the flow is known as pour point. Increase in viscosity of the diesel fuel is main reason behind cessation of flow. By adding lighter hydrocarbons in the diesel fuel, pour point can be reduced. Generally pour point and cloud point of biodiesel is higher as compared to convention diesel which results in poor performance in cold weather and difficulty in starting the engine in the temperate regions [Sarkar, 1974, Di et al., 2009].

1.3.5 Calorific value

Calorific value is defined as total quantity of heat liberated by completely burning of one unit mass of fuel. In another way it can also be defined as the amount of energy released when the substance is burned completely to a final state and has released all of its energy. Bomb calorimeter is the instrument with which we can measure the calorific value of fuel [Sarkar, 1974].

1.3.6 Ash content

Ash content in the substance is defined as the amount of inorganic contaminants such as the concentration of soluble metal soaps, abrasive solids and catalyst residues contained in a fuel sample. Ash is formed when these inorganic contaminants are oxidized during the combustion process. With the increase in ash content in the fuel, risk of engine damage also increases.

1.3.7 Carbon residue content

This is one of the important properties of fuel when the fuel has to be used in compression ignition engines. Carbon residue is defined as carbonaceous deposits formed by the decomposition of heavier complex compounds [Sarkar, 1974].

1.3.8 Cetane number

Cetane Number is the measure of ignition quality of the fuel. The fuel having higher Cetane Number has better ignition properties. For measuring the ignition quality of diesel fuel two reference fuels having Cetane Number 100 (high ignition quality, short ignition delay) and 15 (low ignition quality, long ignition delay)is used in the standard engine. Lowest Cetane Number is of alpha-methyl-naphthalene i.e 0 but hepta-methyl-nonane having Cetane Number 15 is used because it is more stable compound.

High Cetane number (45-50) is required in high speed engines having speed above 1500 rpm and for low speed engine Cetane Number in the range of 25-30 is sufficient. Generally biodiesel have higher Cetane Number (54-63) as compared to conventional diesel (51-52) and this result in higher combustion efficiency of biodiesel [Sarkar, 1974].

1.4 Specifications of biodiesel

For users, manufacturers and suppliers of bio-fuels standards play an important role. For evaluation of environmental protection, safety and risks approval standards are needed by authorities. To develop the codes and standards for products in one country it is conventional practice of analysing existing codes and standards of different countries in detail. While developing codes and standards for products in India a global survey of bio-diesel specification was done. The specifications are given below as:

Table 1.2: Properties of biodiesel according to ASTM standards

Fuel Properties	ASTMD6751 (Biodiesel)	Commercial diesel fuel
Density (kg/m^3)	------------------	750 - 840
Kinematic viscosity(mm^2/s)	1.9 - 6.1	1.9 - 4.1
Flash point (°C)	>130	67 - 85
Pour point (°C)	-15 to 10	19 - 13
Cloud point(°C)	-3 - 12	<10
Cetane Number	------------------	51
Higher heating value(kJ/kg)	>33000	42000
Ash content (%)	<0.02 max	0.008 - 0.010
Carbon residue (%)	< 0.05	0.035–0.040
Sulphur content (%)	0.05% by mass, max.	0.035–0.05
Water contents (%)	0.05% by vol., max.	0.02–0.05

The only purpose of such a large survey was to understand the objective behind specifications. Residual catalyst, reactant alcohol, residual vegetable oil, monoalkylesters, free fatty acids, dialkyl esters and free glycerine are the components which mainly represent the biodiesel quality. A specification (D6751) was issued by American Society of Testing and Materials (ASTM) in December 2001 for biodiesel (B100).

1.5 Performance and emission characteristics

1.5.1 Performance characteristics of C.I Engines

The degree of success with which job assigned to an engine is done by it is termed as the performance of an engine.

Following are the parameters on the bases of which degree of success is compared.

a. Brake Power (kW)
b. Indicated Power (kW)
c. Friction Power (kW)
d. Brake Mean Effective Pressure (bar)
e. Indicated Mean Effective Pressure (bar)
f. Brake Specific fuel consumption (kg/ kW-hr).
g. Fuel Consumption per hour (Kg/h)
h. Brake Thermal efficiency (%)
i. Mechanical efficiency (%)

Different parameters have their importance at different places according to the engine applications for example in case of marine engines specific power output is most important parameter and in case of industrial engines brake specific fuel consumption is most important parameter as compared to others.

1.5.2 Engine performance and emission characteristics of biodiesel

Calorific value of biodiesel is low as compared to conventional diesel on weight basis. It is mainly because in the biodiesel fuel oxygen is present in substantial amount but on the other hand specific gravity of biodiesel is more as compared to conventional diesel that are 0.88 and 0.85 respectively [Di et al., 2009]. Therefore, biodiesel has low energy content per unit volume due to overall effect of oxygen and specific gravity as compared to conventional diesel. Biodiesel operated engines have better thermal efficiency as compared to convention diesel operated engines. Biodiesel has much lower hydrocarbon emissions as compared to conventional diesel. Reason behind this is high oxygen content present in biodiesel which helps in complete combustion. If incomplete combustion takes place in the engine it gives rise to increase in CO content in the exhausts and CO is very toxic in nature, so biodiesel also helps in reduction in CO content in exhaust emissions. Since biodiesel does not contain sulphur so exhausts from biodiesel operated engines are free from sulphur and also it leads to reduction of particulate matter in the exhaust emissions. Problem of acid rain is also reduced with biodiesel because of sulphur free emissions. Lot of research is going on in this field and performance and emission characteristics of engines using biodiesel blends are evaluated by many researchers. Waste cooking oil methyl esters is investigated by Yage Di et al. [Di et al., 2009] in the diesel engine. In their investigation they found improvement in the engine performance and emission characteristics. Brake power showed significant improvement and at medium and higher loads slight increase in brake thermal efficiency was also seen in the case of biodiesel. In major emissions like CO and HC slight reductions were seen and ignition delay was also slightly shorter in case of blends but increase in NO_x emissions were recorded. Yage Di et al. [Di et al., 2009] results are shown in the following table.

Table 1.3: The performance and emissions of diesel and B100 [Di et al., 2009]

	NO_x (ppm)	HC (ppm)	BTE (%)	BSFC (g/kW-h)	CO (ppm)
Diesel	590	122	34.44	239.2	363
B100	680	80	36.81	260.7	316

1.6 Compression ignition engine [Heisler, 1995]

Fresh air is drawn into the cylinder by the compression ignition engine during the induction stroke and the compression of that charge takes place in the return stroke and compression goes on until temperature in the cylinder raises up to or above 550 °C. Usually compression ratio in compression ignition engines is in the range of 15 to 22. An accurately metered quantity of fuel is injected in the cylinder just before the end of compression stroke at the pressure of 350 bars or more. Then the atomisation of the fuel sprayed in the cylinder takes place and this atomised fuel mixes with hot air and it ignites due to high pressure inside cylinder and burns rapidly. Over the crank angle movement of 40 ° at 5000 rpm fuel is injected for 0.000133 min.

1.6.1 Classification of compression ignition combustion chamber

The following are the two categories of combustion chambers of compression ignition engines:

(a) Direct injection combustion chamber: Fuel is directly injected into the combustion chamber in these types of chambers. These chambers generally have its application in large commercial vehicle diesel engines of 10 to 16 litres size, having low and medium speed of not more than 2500 rpm. These engines have low fuel consumption and high torque output. Figure 1.1 shows direct injection volumetric combustion chamber.

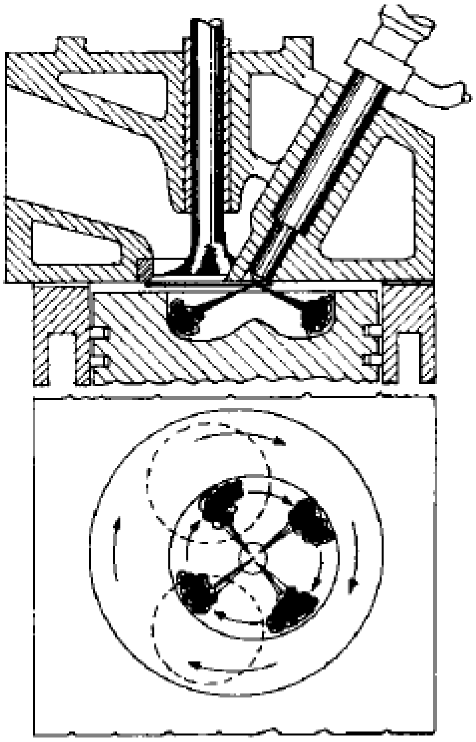

Figure 1.1: Direct injection volumetric combustion chamber [Heisler, 1995]

(b) Indirect combustion chamber: In the indirect combustion chambers combustion of the fuel takes place into the divided chambers. Generally such types of chambers have application in small engines having size 1.5 to 3.5 litres and speed not more than 5000 rpm. Such engines have low noise level and low smooth speeds. Fig below shows indirect combustion with swirl combustion chamber.

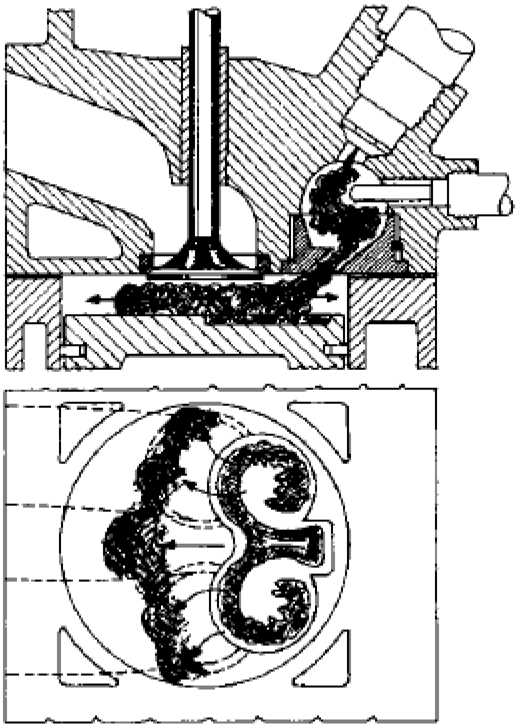

Figure 1.2: Indirect injection with swirl combustion chamber (Ricardo Cornet) [Heisler, 1995]

1.7 Hydrogenated biodiesel

For diesel engines hydrogenated biodiesel is best alternative fuel and also it has advantage of its eco-friendly and renewable nature over conventional diesel. If we talk about properties then hydrogenated biodiesel has higher Cetane Number, flash point and lower pour point, viscosity and density as compared to diesel and normal biodiesel fuel. Biodiesel has oxygen percentage 10-15% by weight and is considered as oxygenated fuel. But the oxygen present in hydrogenated biodiesel is more stable as compared to normal biodiesel. Normal biodiesel fuel has low energy content as compared to conventional diesel but hydrogenated biodiesel has almost similar energy content to convention diesel. This is due to presence of hydrogen in the fuel. Hydrogen atom has high energy content as compared to carbon atom. As per many researchers in order to improve the performance and emission characteristics especially particulate matter and NO_x hydrogenation of the biodiesel is necessary [Hemanandh et al., 2015].

1.8 Effect of hydrogenation on performance and emission parameters of CI Engine

1.8.1 Effect on performance [Hemanandh et al., 2015]

Hydrogenation of biodiesel increases the calorific value of biodiesel. Calorific value of biodiesel becomes approximately similar to convention diesel. Hydrogenation improves the oxygen stability of the biodiesel which result in lower BSFC and higher brake thermal efficiency.

1.8.2 Effect on emissions [Hemanandh et al., 2015]

Air pollution is increasing day by day with the rapid increase in number of vehicles in the world. Many researchers all around the world are working on this to reduce the emissions from the exhaust of the vehicles. To curve this problem of air pollution best alternative method is to use hydrogenated biodiesel in the form of blends with conventional diesel. In recent researches biodiesel blending with diesel found to be good alternative to reduce CO and HC emissions but NO_x which is also a harmful gas increases with biodiesel. To overcome this hydrogenation of the fuel is very necessary. Investigations show that use of hydrogenated biodiesel is very efficient in lowering emissions of compression ignition engines. Hydrogenation improves oxygen stability in fuel and ensures complete combustion which leads to reduction in unburned hydrocarbons. It also increases Cetane Number of biodiesel and it was found while investigation by researchers that NO_x emission of the fuel having high Cetane Number is low for the same BMEP in comparison with those fuels having low Cetane Number.

Chapter 2

Literature Review

2.1 Introductory comment

To formulate the problem many research papers were studied and a brief report on the papers has been presented in this chapter. Topic of the research is related to production of hydrogenated biodiesel and evaluation of performance and emission characteristics of compression ignition engine. This has been done by using hydrotreated biodiesel blends as fuel. Hydrogenation is done by passing hydrogen gas from the biodiesel fuel at constant temperature. To evaluate its performance and emission characteristics number of experiments were performed. Research papers related to preparation of hydrogenated biodiesel, effect of hydrogenation on biodiesel and its effect on performance and emission characteristics of compression ignition engines were studied. The research papers related to preparation of biodiesel, performance and emission characteristics of compression ignition engine using biodiesel were also reviewed.

Hemanand et al. (2015) evaluated the performance and emission characteristics of single cylinder, 4 - stroke, vertical, stationary direct injection diesel engine. Experiments were conducted at constant speed of 1500 rpm and at compression ratio of 17:1. Pure diesel and 25 % blend of diesel with hydrotreated refined sunflower oil (B 25) and pure hydrotreated refined sunflower oil (B 100) was used as fuel at varying load (0 %, 25 %, 50 %, 75 % and 100 %). Decrease in carbon monoxide (CO) by 9 % and 37 %, hydrocarbon (HC) by 42 % and 55 %, brake specific fuel consumption (BSFC) by 25 % and 12.5 %, nitrogen oxide (NO_x) by 10 % and 18.18 % was observed in case of B25 and B100 respectively as compared to pure diesel fuel. His results show the significant increase in brake thermal efficiency (BTE) by 10 % and 38 % in case of B25 and B100 respectively compared to diesel fuel.

Kim et al. (2014) conducted the experiments on 1.5 litre, 1496 cc, CRDi (350 bar) diesel engine of passenger car having constant compression ratio of 17.8. To evaluate its performance and emission characteristics pure diesel and 16 different blends (2 %, 10 %, 20 %, 30 % and 50 %) of pure diesel with biodiesel (BD), hydrotreated biodiesel (HVO) and isomerized hydrotreated biodiesel (Iso-HVO) were used. Biodiesel was extracted from vegetable oils such as palm and soybean. It was observed that isomerized hydrotreated biodiesel (Iso-HVO) has low density and almost similar calorific value as compared to pure diesel. It was found that isomerized hydrotreated biodiesel (Iso-HVO) has high Cetane number and oxygen stability as compared to normal biodiesel (BD) and hydrotreated biodiesel (HVO). It was observed that power produced by engine using blends of isomerized hydrotreated biodiesel (Iso-HVO) as a fuel was high as compared to power produced by it using blends of normal biodiesel (BD) and hydrotreated biodiesel (HVO) as a fuel. But it was observed marginally low in case of blends of isomerized hydrotreated biodiesel (Iso-HVO) when compared with power produced using petro-diesel as fuel. Fuel consumption was found to be low in the case of hydrotreated biodiesel (HVO) and isomerized hydrotreated biodiesel (Iso-HVO) as compared to both normal biodiesel (BD) and petro-diesel. Hydrocarbon (HC) and carbon monoxide (CO) emissions were found to be low in case of isomerized hydrotreated biodiesel (Iso-HVO) and hydrotreated biodiesel (HVO) as compared to normal biodiesel (BD). Particulate matter (PM) and nitrogen oxide (NO_x) emissions of both isomerized hydrotreated biodiesel (Iso-HVO) and hydrotreated biodiesel (HVO) were found almost similar to normal biodiesel (BD).

Young No (2014) had studied the application of hydrotreated vegetable oil (HVO) on compression ignition (CI) engines. Hydrotreated vegetable oil (HVO) was produced from different types of oils such as animal fat, algae, vegetable oil and waste cooking oil. In his study, he reviewed many papers of different researchers on performance and emission characteristics of compression ignition engines using various hydrotreated biodiesels as fuel. It was concluded that cold flow properties of the biodiesel fuel can be improved by using different methods such as addition of flow improvers, isomerization and reaction temperature control but isomerization is found to be most preferred and best method. It was observed that greatest advantage of hydrotreating the biodiesel over transesterification is reduction in nitrogen oxide (NO_x) emissions. But influence of hydrotreated vegetable oil (HVO) on nitrogen oxide (NO_x) emissions is not clear because different researchers had showed fluctuating results in this case. It was found that many researchers had observed decrease in carbon monoxide (CO), particulate matter (PM) and hydrocarbon (HC) in case of hydrotreated vegetable oil (HVO) as compared normal biodiesel (BD) without any major changes in the engine.

Singh et al. (2015) investigated the fuel consumption and emission characteristics of four stroke, 6-cylinder, direct injection, turbocharged, water cooled heavy duty diesel engine. Hydrotreated renewable diesel (HRD) and normal biodiesel (BD) extracted from jatrophacurcas oil was used as fuel. Investigation was carried out at varying loads (0 %, 25 %, 50 %, 75 % and 100 %) and speeds. Biodiesel (BD) was produced using transesterification reaction and hydrotreated renewable diesel (HRD) using hydro-deoxygenation reactions. Both hydrotreated renewable diesel (HRD) and biodiesel (B100) showed significant reduction in carbon monoxide (CO) by 16 % and 27 %, hydrocarbon (HC) by 16 % and 41 % and particulate matter (PM) by 27 % and 43 % respectively when compared with petro-diesel. But both biofuels showed increase in nitrogen oxide (NO_x) emissions by 26 % for hydrotreated renewable biodiesel (HRD) and 77 % for biodiesel (B100). Brake specific fuel consumption (BSFC) was found to be lowest in case of hydrotreated renewable biodiesel (HRD) followed by petro-diesel. Hydrotreated renewable biodiesel (HRD) has 29 % lower nitrogen oxide (NO_x) emissions as compared to biodiesel (B100). It was concluded that due to low brake specific fuel consumption (BSFC) and also other emissions within the limits of ASTM standards hydrotreated renewable biodiesel (HRD) is best alternative fuel to petro-diesel.

Moser et al. (2009) had examined exhaust emissions of 5.9 litres, 300 hp, 6 cylinder heavy duty engine at constant compression ratio of 16.5:1. Fuel properties of 20 % blend (B20) of partially hydrotreated soybean oil methyl esters (PHSME) and 20 % blend (B20) of soybean oil methyl esters (SME) with ultra low sulphur diesel fuel (ULSD) were also examined and compared with neat ultra low sulphur diesel fuel (ULSD). It was observed that blends (B20) of soybean oil methyl esters (SME) and partially hydrotreated soybean oil methyl esters (PHSME) have higher Cetane number (45.1 and 47.3 respectively) and kinematic viscosity (2.84 mm^2/s and 2.94 mm^2/s respectively at 40 ºC). Whereas in case of neat ultra low sulphur diesel fuel (ULSD) Cetane number and kinematic viscosity is found to be 41.4 and 2.67 mm^2/s respectively. Soybean oil methyl esters (SME) and partially hydrotreated soybean oil methyl esters (PHSME) showed improved lubricating capacity (182 μm and 197 μm respectively at 60 ºC) when compared with ULSD (lubricating capacity 538 μm at 60 ºC). But both Soybean oil methyl esters (SME) and partially hydrotreated soybean oil methyl esters (PHSME) has lower oxidative stability, sulphur content (8 ppm for both SME and PHSME) and inferior low temperature properties compared to ULSD. Whereas in case of neat ultra low sulphur diesel fuel (ULSD) sulphur content is found to be 10 ppm. B20 blends of soybean oil methyl esters (SME) and partially hydrotreated soybean methyl esters (PHSME) showed increase in nitrogen oxide (NO_x) emissions by 4.9 % and 4.8 % respectively. Reduction in carbon monoxide (CO) by 11.3 % and 11.1 % and particulate matter (PM) emissions by 27.9 % and 22.5 % respectively was shown by B20 blend of soybean oil methyl esters (SME) and partially hydrotreated soybean methyl esters (PHSME) when compared with ultra low sulphur diesel fuel (ULSD). Hydrocarbon shows marginal increase in case of soybean oil methyl esters (SME) by 0.6 % and significant reduction in case of partially hydrotreated soybean methyl esters (PHSME) by 19.8 % as compared to ultra low sulphur diesel fuel (ULSD). Brake specific fuel consumption in soybean oil methyl esters (SME) is more as compare to both partially hydrotreated soybean methyl esters (PHSME) and ultra low sulphur diesel fuel (ULSD) which has almost similar results in this case.

Papadopoulos et al. (2010) had optimised biodiesel (critical properties) produced from cotton seed oil by modifying its fatty acid methyl esters (FAME) composition by homogeneous hydrogenation. It was observed that by catalytic hydrogenation of fatty acid methyl esters (FAME) quality of biodiesel can be upgraded in the form of relative high oxidative stability and Cetane number of the processed fuel. Hydrogenation may worsen the cold flow properties of the fuel but it can be taken care of by controlled blending of the processed fuel in base fuel. $RhCl_3.3H_2O$ and STPP-TiOA were the catalysts used for hydrogenation of fatty acid methyl esters (FAME) of cotton seed oil. Iodine value (IV) of the partially hydrotreated fatty acid methyl esters (FAME) was found to be low as compared to unprocessed fuel.

Simacek et al. (2011) had performed experiments on production of renewable diesel by hydroprocessing sunflower oil. Experiments were performed at various temperatures ranging from 360 ºC to 420 ºC at constant pressure of 18 MPa in the presence of commercial hydrocracking catalysts in the fixed bed reactor. Concentration of n-alkanes was found to be 67 % by weight in the final product when processed at 360 ºC as compared to 20 % at 420 ºC. All the fuel properties of the product such as density at 15 ºC, kinematic viscosity at 40 ºC and cloud point processed at 420 ºC were found to be very similar to petro-diesel fuel. Particularly low temperature properties of hydroprocessed sunflower oil at 420 ºC showed excellent results contradictory to previous studies [6]. Cloud point and cold filter plugging point (CFPP) were found to be -11 ºC and -14 ºC respectively as compared to petro-diesel having cloud point -8 ºC (grade F diesel) and cold filter plugging point (CFPP) -15 ºC (grade E diesel). Various blends (10 %, 30 % and 50 %) of petro-diesel with the fuel processed at 400 ºC and 420 ºC were produced and their properties were evaluated. Low temperature properties of diesel fuel mixture having hydrotreated sunflower oil produced at 420 ºC as blend were found to be very good. Cloud point and cold filter plugging point (CFPP) were found to be -8 ºC and -15 ºC respectively and it was observed that cold filter plugging point (CFPP) can be further lowered to -25 ºC.

Simacek et al. (2009) had conducted tests for the production of renewable diesel by hydroprocessing rapeseed oil. The experiments were conducted at various temperatures ranging from 260 ºC to 340 ºC at constant pressure of 7 MPa in the presence of three Ni-Mo/alumina hydrorefining catalysts in laboratory flow reactor. Gas chromatographic methods were used to analyse the reaction products. It was observed that organic liquid product (OLP), water and hydrogen-rich gas were contained in reaction products and main components of organic liquid product (OLP) were found to be i-alkanes and n-alkanes, C_{17} and C_{18}. Experiments showed that organic liquid product (OLP) also contains triglycerides and free fatty acids at low reaction temperatures where as it contains only hydrocarbons at high temperature reactions above 310 ºC which are very similar to diesel fuel. It was concluded from this study that components present in the reactant product largely depends upon the temperature of reaction and catalyst used.

Hark et al. (1992) had studied the process of hydrogenation of fatty acid methyl esters (FAME) to convert it to fatty alcohols at supercritical conditions using solid catalysts and propane as a solvent. It was found that above 240 ºC temperature fatty acid methyl esters (FAME) were completely converted into fatty alcohols within 2-3 seconds. Proper concentration of hydrogen while processing plays a vital role in preventing the formation of by products such as hydrocarbons (HC). Experiments shows that hydrogenation catalyst deactivates rapidly when rapeseed oil was processed but in case of sunflower oil life of the catalyst was similar to that obtained in industrial processes. Researchers concluded that conversion of fatty acid methyl esters (FAME) to fatty alcohols is best method to produce fatty alcohols in efficient manner.

Simacek et al. (2010) had performed experiments on production of renewable diesel. Renewable diesel was produced by hydroprocessing rapeseed oil under four combinations of 310 ºC and 360 ºC temperatures and hydrogen pressures of 7 MPa and 15 MPa. Commercial hydrocracking Ni-Mo/alumina catalyst was used while production. Production of renewable diesel was done in the laboratory flow reactor. It was observed that n-octadecane and n-heptadecane accomplished with low concentration i-alkanes and n-alkanes were contained in the reactant products. Four different blends (5 %, 10 %, 20 % and 30 %) were formed by mixing reactant product obtained at 360 ºC temperature and 7 MPa pressure in mineral diesel fuel. It was found after evaluating the properties of the various blends that most of the standard properties are almost similar or better than the properties of the mineral diesel fuel. For example density (at 15 ºC) and kinematic viscosity (at 40 ºC) of 30 % blend were found to be low (816 Kg/m^3 and 2.76 mm^2/s respectively) as compared to mineral diesel (820-845 Kg/m^3 and 2-4.5 mm^2/s). But all the blends show worse low temperature properties when compared with mineral diesel fuel. For example cloud point and cold filter plugging point (CFPP) were found to be significantly higher (+3 ºC and -3 ºC respectively) as compared to mineral diesel having cloud point -8 ºC (grade F diesel) and cold filter plugging point (CFPP) -20 ºC (grade F diesel).

Kiatkittipong et al. (2013) demonstrated that hydrocarbons similar to petro-diesel can be produced by hydroprocessing of relevant refining palm oil. In the study three types of palm oils namely degummed palm oil (DPO), crude palm oil (CPO) and palm fatty acid distillate (PFAD) were converted into fuel similar to diesel fuel by the process of hydrogenation. These processes were performed under various conditions by varying reaction time, temperature and pressure in the presence of different catalysts such as Pd/C and NiMo/γ-Al_2O_3. It was observed that by treating crude palm oil (CPO) by hydrogen at 400 ºC temperature, 40 bar pressure and for the reaction time 3 hours in the presence of Pd/C catalyst provides highest diesel yield of 51 %. After converting crude palm oil (CPO) into degummed palm oil (DPO) by removing gum (phospholipid compounds) from crude palm oil (CPO) highest diesel yield of 70 % can be produced in the reaction time of only 1 hour. It was observed that by hydroprocessing palm fatty acid distillate (PFAD) at 375 ºC temperature and for the reaction time of half an hour maximum diesel yield of 81 % can be obtained. Liquid reactant products mainly consist of n-heptadecane and n-pentadecane which in reference to decarboxylation/decarbonylation pathways have one carbon atom less than fatty acids. It was found that while hydroprocessing fatty acids feedstock Pd/C showed good catalytic activity but showed less promising nature in case of triglyceride feedstock when compared with Ni/Mo/ γ-Al_2O_3.

Lapuerta et al. (2011) had studied the key properties and different blend strategies of hydrogenated vegetable oil. The study was conducted to efficiently use hydrotreated vegetable oil into the compression ignition engines without any change in the engine design. Ten different blends (10 %, 20 %, 25 %, 30 %, 35 %, 40 %, 45 %, 50 %, 55 % and 75 %) of ultra low sulphur diesel fuel (ULSD) with hydrogenated vegetable oil (HVO) were formed. Properties of blends were evaluated in order to formulate the blending strategies so as to efficiently improve the performance and emission characteristics of compression ignition engines. It was observed from the results that main limitations in case of blends are its lubricating capacity, Cetane number and low temperature properties. It was recommended that blending of ultra low sulphur diesel fuel (ULSD) with hydrogenated vegetable oil (HVO) below 50 % can be used in compression ignition engines which can run without any damage to the engine parts. On the account of density and viscosity no restriction on the blending was recommended. Because with increase in blending both density and viscosity decreases which also decreases brake specific fuel consumption (BSFC) proportionally that helps in economical saving. Up to 50 % blends decrease in calorific value per unit volume was found to be only 3 %. It was found that blending up to 50 % showed sharp reduction in shoot formation and particulate matter (PM) emissions.

Can (2014) evaluated the performance, emission and combustion characteristics of single cylinder, air cooled, four-stroke, direct injection diesel engine. The evaluation was done at constant compression ratio and speed (18:1 and 200 rpm respectively) and at four different loads (BMEP 0.48, 0.36, 0.24 and 0.12 MPa). Two blends (5 % and 10 %) of petro-diesel with waste cooking oil biodiesel were formed. It was found that ignition delay of the engine using blended fuel decreases at all the four loads (BMEP 0.48, 0.36, 0.24 and 0.12 MPa) because of high Cetane number of the biodiesel. With the increase in blending up to 10 % it was found that in cylinder pressure rise rate felled marginally and heat release rate and combustion duration increased as compared to neat diesel. But no effect on in cylinder maximum pressure was found with blending up to 10 %. Slight variation was found in indicated mean effective pressure (IMEP) which mainly depends upon the centre and time of heat release location and combustion duration. With the increase in blending of petro-diesel with waste cooking oil biodiesel up to 10 %, 2.8 % decrease in brake thermal efficiency (BTE) and 4 % increase in brake specific fuel consumption (BSFC) was found when compared with petro-diesel. In case of exhaust emissions with the increase in blending up to 10 %, decrease (5 % at low and medium loads and 29 % at high loads) in hydrocarbon (HC) and 8.7 % increase in nitrogen oxide (NO_x) was seen. Decrease in smoke was found with increase in blending up to 10 % in the observation in comparison with base fuel. It was found that at low and medium loads there was no change in carbon monoxide (CO) emissions but it decreased by 51 % at higher loads when compared with neat diesel. Very slight increase in carbon dioxide (CO_2) was found with increase in blending up to 10 % in comparison with neat diesel fuel.

Adaileh et al. (2012) investigated the performance and emission characteristics of four-stroke, single cylinder, diesel engine at variable speed (1200-2600 rpm). B5 and B20 blends (5 % and 20 %) of standard diesel with biodiesel extracted from waste cooking oil were used as fuel without any modification to compression ignition engine. For B20 blend increase in brake specific fuel consumption (BSFC) by 5.95 % and brake power (BP) (1.5-3.5 kW) was found as compared to standard diesel having brake power (BP) ranging between 1.23 kW and 3.47 kW. Brake specific energy consumption (BSEP) was found to be low (13-16.3 MJ/kW.kg) for B5 blend as compared to standard diesel (13.81-16.8 3 MJ/kW.kg). With the increase in blending up to 20 % decrease in carbon monoxide (CO) and hydrocarbon (HC) and increase in nitrogen oxide (NO_x) was found when compared with standard diesel. It was observed that with the increase in speed brake thermal efficiency, fuel consumption rate and exhaust gas temperature increased and carbon monoxide (CO) and carbon dioxide (CO_2) decreased. Biodiesel was also produced with the peroxidation process. It was found that carbon monoxide (CO) and carbon dioxide (CO_2) emission level decreased in case of peroxidation produced fuel compared to previous results. Peroxidation was recommended as the best method of biodiesel production.

Lapuerta et al. (2008) performed the experiments on the effect of two different alcohol types (methanol and ethanol) used in production of biodiesel on the performance and emission characteristics of 2.2 litre, 4 cylinder, common rail direct injection diesel engine. Experiments were conducted at constant compression ratio of 18:1 and biodiesel was extracted from waste cooking oil. B30, B70 and B100 (30 %, 70 % and 100 %) blends of standard diesel with methyl esters and ethyl esters were formed and tested in compression ignition engine and compared with reference fuel (standard diesel). In case of B100 14 % increase in brake specific fuel consumption (BSFC) was found as compared to reference fuel. B100 showed increase in nitrogen oxide (NO_x) emissions and particulate matter (PM) and sharp reduction in hydrocarbon (HC), particle emissions and smoke opacity as compared to standard diesel fuel. It was observed the nitrogen oxide (NO_x) and hydrocarbon (HC) emissions in case of methyl esters (B100) were found to be more as compared to ethyl esters (B100) but alcohols show inverse trend in case of particulate matter (PM).

Aslam et al. (2015) investigated the conversion of high free fatty acids (FFA) to liquid hydrocarbons. Conversion was done in the presence of hydrocracking catalyst and using biomass based thermal power plant fly ash (BBTPFS) and heterogeneous catalysts derived from biomass viz. Musa balbisiana Colla underground stem (MBCUS). Investigation was conducted in the bench scale reactor at 400 ºC temperature and (1-75 bar) hydrogen pressure for the reaction time of (1-4 hour) in the presence of catalyst ranging from 1 % to 5 % by weight. High free fatty acids (FFA) were extracted from vegetable oils such as Mesua ferrea L. and Jatropha curcas oil. It was found that reactant products of these reactions mainly consist of non-polar oxygenates, hydrocarbons and organic acids also known as biocrude. The dominant reactions in the process were hydrolysis, thermocatalytic cracking, decarboxylation and hydrocracking which results in the production of mixture of hydrocarbons having chain length C8-C19. Then reactant products commonly known as biocrude were fractioned into four parts as per ASTM D5236 and ASTM D2892 specifications within four different boiling ranges (35-140 ºC, 140-180 ºC, 180-370 ºC and 370-482 ºC). It was observed that quality of the biocrude depends upon the reaction conditions and properties of catalyst which directly affects the recovery of each fraction. It was concluded that biomass based thermal power plant fly ash (BBTPFS) is most efficient catalyst for biocrude with highest percentage (>65 %) of the product and lowest acidity in the liquid hydrocarbon range, and heteroatom and acidity removal.

Elongo et al. (2011) performed the experiments to evaluate the performance, emission and combustion characteristics of kirloskar, single cylinder, air cooled diesel engine. The experiments were performed at constant compression ratio and speed (17.5:1 and 1500 rpm respectively) and different levels of load. Five blends (10 %, 20 %, 30 %, 40 % and 50 %) of standard diesel with jatropha biodiesel and neat standard diesel were used as fuel. With the increase in blending of biodiesel in standard diesel decrease in cylinder peak pressure and increase in ignition delay was observed as compared to neat standard diesel. Brake thermal efficiency (BTE) of diesel (30.9 %) was found to higher as compared to all the blends (B50=26.1 %). But brake thermal efficiency and brake specific fuel consumption (BSFC) of B20 blend (BTE=29.40 %) was found closer to standard diesel. It was observed that exhaust gas temperature, nitrogen oxide (NO_x) emissions and smoke opacity (B50=35.7 %) increases. Reduction in hydrocarbon (HC), carbon monoxide (CO) and carbon dioxide (CO_2) emissions (B50=7.1 %) was found when compared with standard diesel having smoke opacity 26.2 % and carbon dioxide (CO_2) emissions 9.1 %.

Ketlogetswe et al. (2011) evaluated the performance characteristics of four-stroke, water cooled variable compression ratio (5:1-18:1) diesel engine. The experiments were performed at variable speeds (1000-2500 rpm), two different compression ratios (12:1 and 17:1) and load levels. Three blends (30 %, 50 % and 100 %) of petro-diesel with biodiesel extracted from cooking oil by transesterification process and neat petro-diesel were used as fuel. It was observed that engine torque produced by engine for compression ratio 17:1 is higher at all experimented loads as compared to 12:1. With the increase in blending of biodiesel in petro-diesel torque decreases, and brake power (BP) and brake specific fuel consumption (BSFC) remains almost similar when compared with standard petro-diesel.

Yang et al. (2013) investigated the performance, emission and combustion characteristics of in-line, four-cylinder, turbo charged, common rail, direct injection diesel engine. The experiments were conducted at constant compression ratio of 18.5:1, four different engine speeds (800 rpm, 1200 rpm, 2400 rpm and 3600 rpm) and three different loads (25 %, 50 % and 75 %). Two blends (10 % and 50 %) of standard diesel with biodiesel, neat biodiesel and petro-diesel were used as fuel. Biodiesel was extracted from waste cooking oil by transesterification process. It was observed that at partial loading conditions and low engine speeds brake specific fuel consumption (BSFC) of biodiesel blends was higher as compared to standard diesel. For example for biodiesel (B100) brake specific fuel consumption (BSFC) at 25 % load, and 800 and 1200 rpm increased by 42 % and 34.4 % respectively compared to standard diesel fuel. At higher loads (50 % and 100 %) brake thermal efficiency (BTE) of biodiesel blends (38.1 %) was found higher but at 25 % load inverse trend was seen when compared with diesel (36.3 % at 100 % load). Lower heat release rate and marginally shorter ignition delay was observed in the case of biodiesel blends compared to diesel fuel. Slight reduction in hydrocarbon (HC) and nitrogen oxide (NO_X) emissions were observed in case of biodiesel blends at higher loads (50 % and 100 %) but at 25 % load completely inverse trend was seen as compared to diesel fuel.

Luu et al. (2014) had studied the production of biodiesel extracted from Vietnamese Jatropha curcas oil having high content of free fatty acids (FFA) by two stage process. In the first stage esterification was done in the presence of 1 % H_2SO_4 and 30 % acetonitrite by weight as co-solvent and 6:1 molar ratio of methanol to free fatty acids (FFA) at 65 ºC temperature. First stage was completed in 60 min and reduced the concentration of free fatty acids (FFA) to 2 % from the initial value of 15.93. Then in the second stage, transesterification reaction was carried out in 30 min to covert free fatty acids (FFA) into fatty acid methyl esters (FAME) with 99 % efficiency. The reaction was carried out in the presence of 1 % KOH and 20 % acetone by weight as co-solvent and 6:1 molar ratio of methanol to oil at 40 ºC temperature. Final product was compared with EN 14214 and JIS K2390 standards and found that it meets all the given standards regarding free fatty acid (FFA), fatty acid methyl esters (FAME) and water contents.

Chapter 3

Research Gaps and Objectives

3.1 Introductory comment

Day to day increasing demand of petroleum products and its scarcity leads to large scale exploitation of our natural resources. Today we are in the need of an alternative fuels which can have superior lubricating properties, better emission characteristics, less toxic in nature and most importantly biodegradable in nature. Biodiesel come out as a best alternative fuel to satisfy above mentioned properties. The rapeseed oil is found to be good alternative fuel for the production of biodiesel because it is available easily in dry regions. Scientists throughout the world are doing research to improve the performance and emission characteristics of diesel engine using biodiesel as fuel. At the same time more emphasis is laid down to the treatment of biodiesel before using it in diesel engine.

3.2 Gaps in research

A lot of research has been done on the production methods of biodiesel so far to improve the yield and to improve the performance and emission characteristics of diesel engines. The various proportions of blends of biodiesel in pure diesel have been used at different compression ratios, loads and speeds. Mostly the researchers' are concerned about the higher emissions especially NO_x and lower performance of diesel engines in case of using biodiesel as fuel. But, now a day's scientists are giving emphasis on treatment of biodiesel before using it in diesel engine so as to improve the fuel properties, performance and emission characteristics of engine. A lot of work is being done in the field of improving the properties of biodiesel by using different additives like flow improvers etc. But limited study has been done to improve the properties of biodiesel by treating biodiesel with hydrogen at higher temperatures above 350 ºC and using its different blends with diesel as fuel in CI engines to evaluate its performance and emission characteristics.

3.3 Research objectives

The objectives of the present study have been analysed carefully after studying the literature. In the literature review different research work on performance and emission characteristics of CI engines using diesel biodiesel blends as fuel were studied. The main objective of present investigation will be to evaluate the performance and emission characteristics of variable compression ratio diesel engine using various blends of hydrogenated rapeseed biodiesel with diesel as fuel. Four different blends (B10, B20, B30 and B40) of hydrogenated rapeseed biodiesel with pure diesel will be prepared and it will be tested at constant compression ratio of 17.5 and at different engine loads (0, 3, 9 and 15).

Following are the steps in which objectives of the work will be carried out:-

1. Production of biodiesel from rapeseed oil
2. Hydrogenation of biodiesel at constant temperature
3. Evaluation of performance parameters
4. Evaluation of emission parameters
5. Comparison of performance and emission characteristics of different diesel-biodiesel blends with base fuel (diesel)

Chapter 4

Methodology

4.1 Introductory comment

Methodology for the preparation of rapeseed biodiesel and hydrogenation of rapeseed biodiesel has been discussed in this chapter. The processes with which the fuel properties of rapeseed biodiesel, hydrogenated rapeseed biodiesel and the blends of pure diesel (PD) with hydrogenated rapeseed biodiesel (HRD) (B10, B20, B30, B40) are modified have been discussed in this chapter. These four blends and pure diesel (PD) were tested in compression ignition engine at compression ratio of 17.5 and at four different loads. The performance and emission characteristics like brake specific fuel consumption, fuel consumption per hour, brake thermal efficiency, brake power, mechanical efficiency, volumetric efficiency, NO_x, HC, CO_2 and CO emissions of variable compression ignition engine are investigated. Performance and emission characteristics of compression ignition engine using blends of pure diesel with hydrogenated rapeseed biodiesel (HRD) are compared with same engine using pure diesel (PD).

4.2 Procedure

The work under taken is divided into following steps:

1. Production of biodiesel in Redlays reactor using Transesterification process
2. Evaluation of biodiesel fuel properties
3. Production of hydrogenated rapeseed biodiesel using constant temperature and pressure reactor
4. Evaluation of hydrogenated biodiesel fuel properties
5. Preparation of blends of pure diesel with hydrogenated rapeseed biodiesel (HRD)
6. Evaluation of Performance and Emission characteristics of blended fuel on variable compression ignition engine
7. Comparison of performance and emission characteristics of blended fuel with that of pure diesel

4.3 Production of biodiesel using Transesterification process

Rapeseeds were purchased from the shop at Bathinda and oil was extracted from the rapeseed through oil extracting mill. Transesterification process is used for the preparation of biodiesel using rapeseed oil. After testing the acid value of rapeseed oil, it was found that Transesterification can be done in single step. Biodiesel production was carried out in the laboratory at Sardar Swaran Singh National Institute of Renewable Energy (SSSNIRE) Kapurthala, Punjab (India) using materials like sodium hydroxide (NaOH) and methanol.

Various steps carried out for the production of biodiesel from rapeseed oil are discussed as below:

- First of all acid value of the required rapeseed oil was tested by titration method. Acid value of rapeseed was found to be 3.77 which is below 5. Therefore, it is concluded that Transesterification can be done in single step.

- Optimum percentage of methanol (250 ml) 6:1 molar ratio and NaOH (9 gm) 1% was mixed and stirred in a separate conical flask.

- Rapeseed oil (1000 ml) was poured into Radlays reactor and then stirred mixture of methanol (250 ml) and NaOH (9 gm) was added to it.

- After that sample was maintained at 78-80 ºC in Radlays reactor at constant stirring (650 rpm) for the reaction time of 2 hours.

- Then H_2SO_4 was added to reduce the pH of the sample and after that sample was washed with water several times to neutralise the pH.

- Then this stirred sample was poured into the separating funnel for layer separation and left for 24 hours to separate the glycerol from methyl ester. After 24 hours the glycerol was removed and separated to obtain the methyl ester. The yield of 89.4 % conversion was obtained.

- Now the methyl ester was poured into the beaker and kept in oven for 1 hour at 105 ºC so that unwanted water content can evaporate from the sample.

- Biodiesel is ready for the further processing.

4.4 Hydrogenation of biodiesel

Hydrogenation is the process of treating vegetable oils with hydrogen at constant temperature and pressure in the presence or absence of catalyst in the reactor known as Constant Temperature and Pressure Reactor.

Steps involved in hydrogenation of biodiesel are as follows:

- First of all prepared biodiesel was poured into the cylinder of Constant Temperature and Pressure Reactor and closed it tightly ensuring no leakage.
- Then hydrogen gas was filled in the cylinder of the reactor up to the initial pressure of 2 bars.
- After that biodiesel was maintained at 350ºC temperature at constant stirring (250 rpm) for the reaction time of 1 hour.
- Reactor was opened after 24 hours and the hydrotreated biodiesel was extracted from the reactor cylinder and poured into the jar.
- After that Hydrotreated rapeseed biodiesel was ready to be used in the compression ignition engine.

Figure 4.1: Constant Temperature and Pressure Reactor

4.5 Evaluation of fuel properties of biodiesel and hydrotreated biodiesel

The following properties of biodiesel were determined:

- Kinematic viscosity
- Flash Point
- Carbon Residue Test
- Calorific Value
- Freezing and Pour point
- Density

4.6 Apparatus used for evaluation of properties

The following apparatus were used successfully to evaluation of biodiesel properties.

4.6.1 Kinematic viscometer

Figure 4.2 shows the kinematic viscometer which was used to determine the viscosity of biodiesel. The equipment consists of a glass drum filled with water, heater, Vacuum pump and U tube. Water was maintained at 40 ºC with the help of heater.

Figure 4.2: Kinematic viscometer

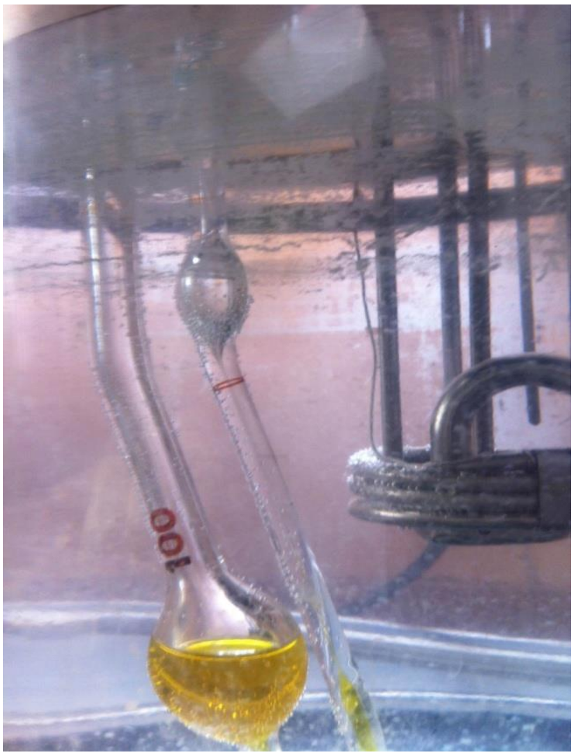

Figure 4.3: U tube filled with biodiesel

Biodiesel was poured into the side of U tube having bigger diameter and hanged in hot water for half an hour as shown in figure 4.3. Then from the side of U tube having small diameter biodiesel was sucked above the two reference points with the help of vacuum pump. Then the time in which biodiesel falls from the upper reference point to lower reference point was noted and multiplied with the U tube constant to get the desired viscosity of biodiesel.

4.6.2 Flash point apparatus

Figure 4.4 shows the flash point apparatus which was used to determine the flash point of the biodiesel. The equipment consists of brass cup, flame needle, CNG cylinder and heater. Biodiesel was poured into the brass cup and placed on the heater which is mounted on the flash point apparatus which heats biodiesel and raises its temperature continuously. The needle with flame passes over the cup continuously after every 2 ºC rise in temperature of the biodiesel.

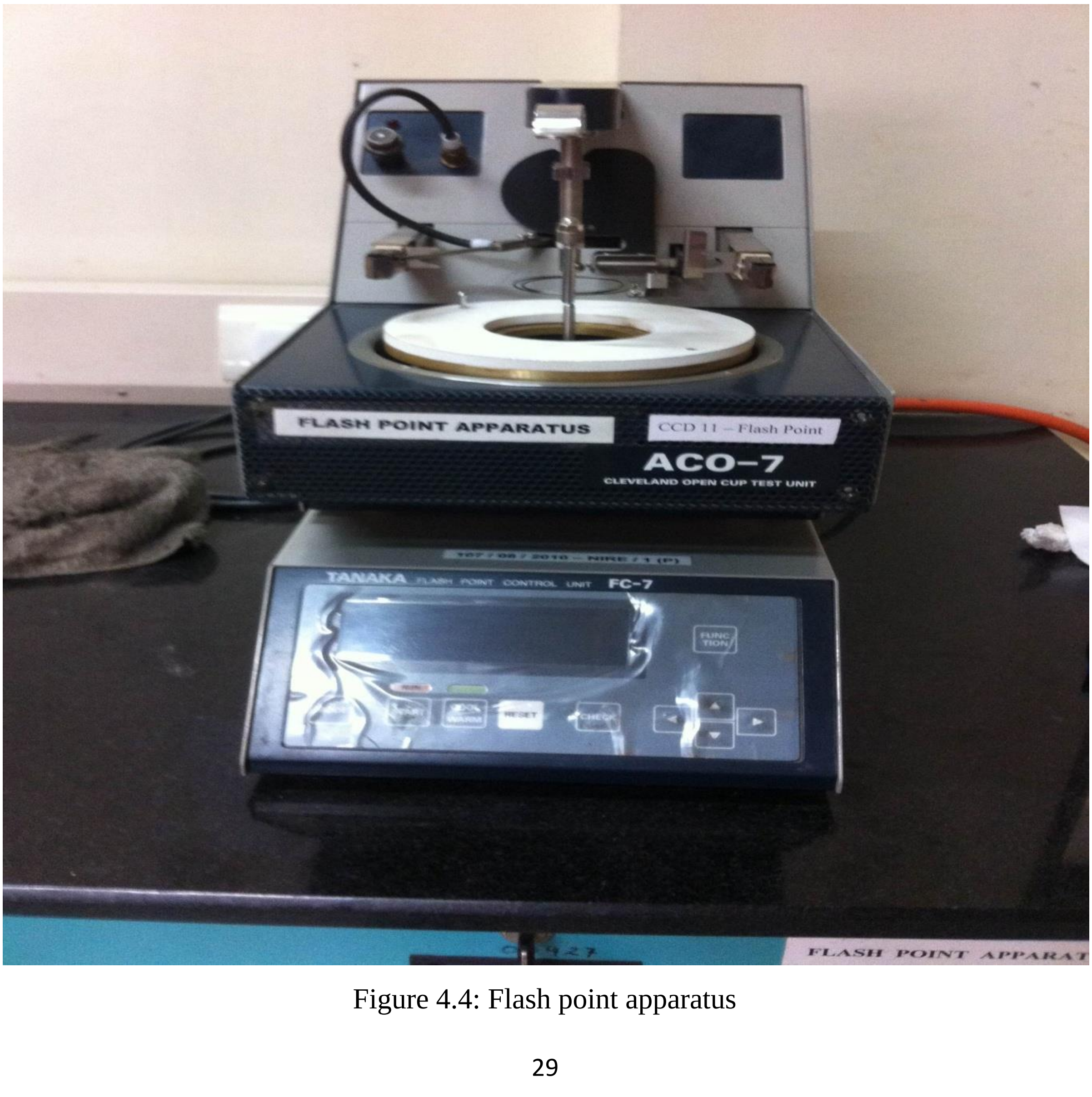

Figure 4.4: Flash point apparatus

Heaters are present on both resting sides of the needle to keep it burning. When the temperature of the biodiesel reaches the adequate level where sufficient vapours forms to ignite the fuel then a flash of blue light (momentary flame) forms while the fame needle is passing over the cup filled with biodiesel. This temperature of biodiesel is flash point.

4.6.3 Ramsbottom carbon residue apparatus

Figure 4.5 shows the Ramsbottom Carbon Residue Apparatus which was used to determine the carbon residue of the biodiesel. The equipment consists of Pyrex bottles, desiccator and heater. First the Pyrex bottles were heated at 550 ºC for half an hour in Ramsbottom carbon residue apparatus for sterilization of the bottles. Then bottles were cooled for 15 min in the desiccators as shown in figure 4.6. Then empty bottles were weighted with the help of weighting machine.

Figure 4.5: Ramsbottom carbon residue apparatus

Then 2.982 g of biodiesel was poured in the bottle and weighted. Then weighted Pyrex bottle having biodiesel was put into the Ramsbottom carbon residue apparatus at 550 ºC for 20 min. At this high temperature biodiesel in Pyrex bottle burned completely leaving behind only carbon. Then the bottle having carbon residue was weighted and percentage of carbon in biodiesel was evaluated.

Figure 4.6: Desiccator

4.6.4 Bomb calorimeter

Figure 4.7 shows the bomb calorimeter which was used to determine the calorific value of biodiesel. As per IS: 1350(PII), 1970 the gross calorific value of the fuel samples was determined with the help of bomb calorimeter. In the presence of oxygen 1 ml fuel sample was burned in the bomb of calorimeter. Electricity was used to ignite the sample. Rise in temperature and heat produced in the bomb was observed after the ignition of the fuel sample. Calorific value of the fuel was calculated using the equation given below:

$H_c = (W_c * \Delta T)/M_s$ … (1)

H_c = Heat of combustion of the fuel sample, Cal/g

W_c = Water equivalent of the calorimeter, Cal/ºC

Δ T = Rise in temperature, ºC

M_s = Mass of sample burnt

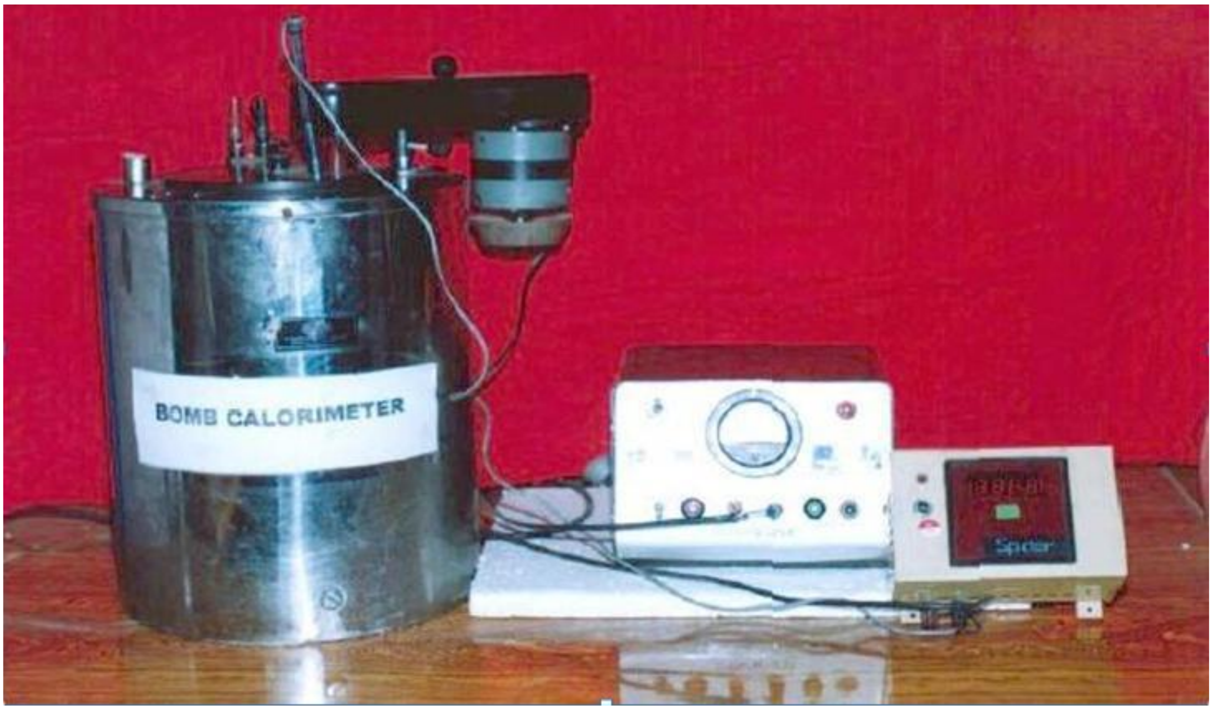

Figure 4.7: Bomb calorimeter

4.6.5 Freezing Point

Freezing point of the biodiesel was determined by pouring it in small plastic bottles and placed these bottles in the refrigerator. When the biodiesel freezes in the bottles its temperature was checked with the help of thermometer. This temperature is the freezing point of the biodiesel.

4.7 Preparation of hydrotreated biodiesel blends

Different blends were prepared by the addition of hydrotreated rapeseed biodiesel in pure diesel by volume. Four different blends B10, B20, B30 and B40 of hydrotreated rapeseed biodiesel were prepared.

4.8 Evaluation of performance and emission characteristics of hydrotreated biodiesel blends

Tests were performed on compression ignition engine in the lab at Sardar Swaran Singh National Institute Renewable Energy (SSSNIRE) for evaluation of performance and emission characteristics of the engine using pure diesel (PD) and its blends with hydrotreated rapeseed biodiesel (HRD) as fuel.

4.9 Equipment used for the evaluation of engine performance

For the present study single cylinder four stroke variable compression ratio diesel engine was used. The performance and emission characteristics of compression ignition engine using pure diesel and its blends with hydrogenated rapeseed biodiesel as fuel were evaluated. The experiments were executed at the constant compression ratio of 17.5 and variable loads. On 0, 3, 9 and 15 loads different parameters of compression ignition engine were evaluated. Loads were varied using eddy current dynamometer with the help of load cell sensors. For the measurement of load, fuel flow, air flow and temperature specific arrangements were provided. Rota meter was used to control the flow of cooling water. To evaluate the on line performance of the engine, software named "Enginesoft" was used. Figure below shows the variable compression ignition engine on which experiments were executed.

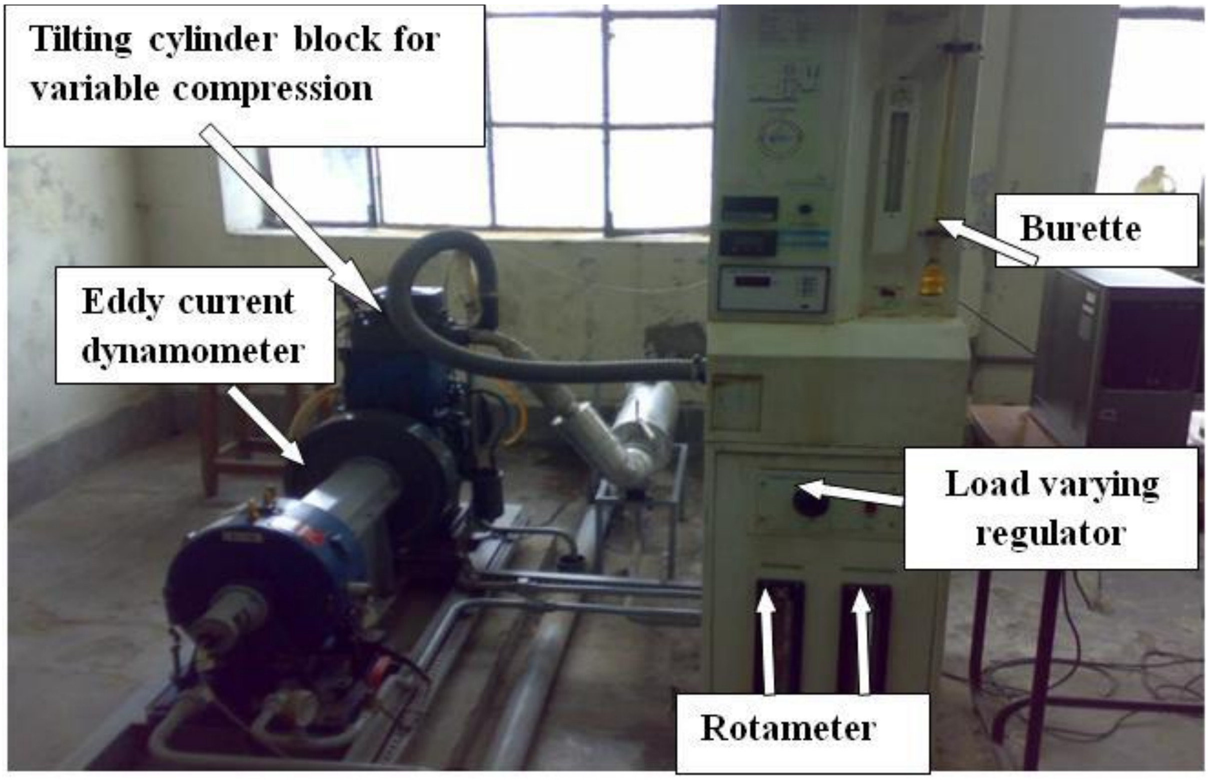

Figure 4.8: Single cylinder four stroke variable compression ignition engine

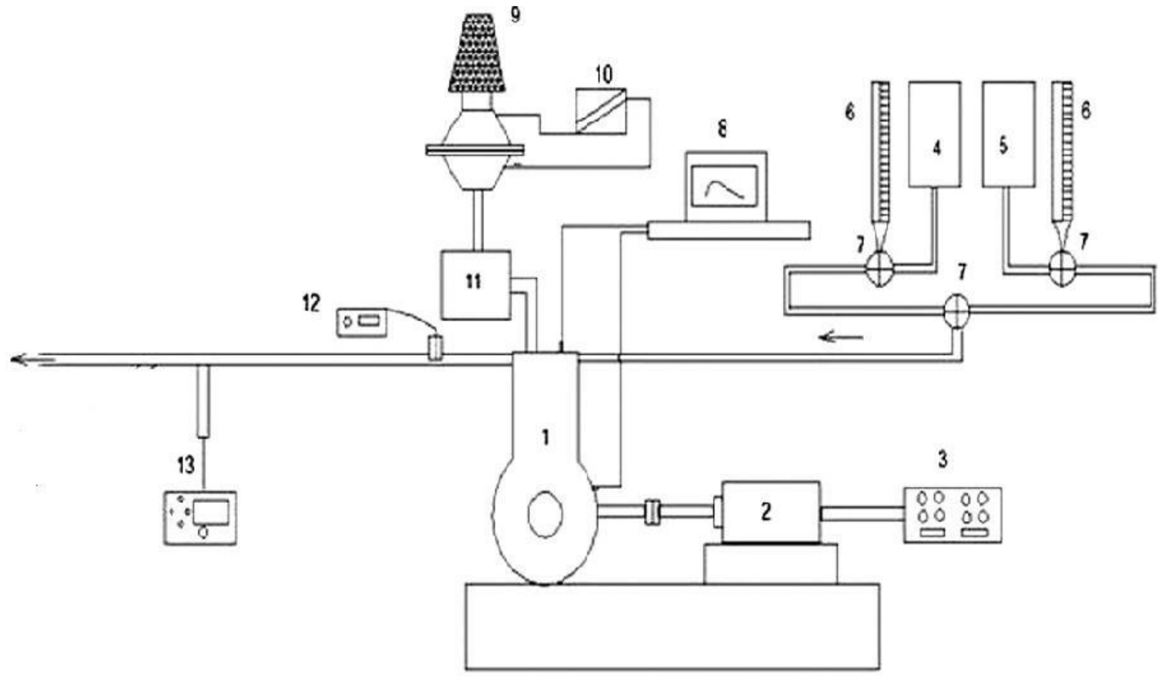

Figure 4.9: Schematic diagram of experimental system (MED Thapar University)

1. Variable compression diesel engine
2. Alternator
3. Loading device
4. Biodiesel tank
5. Diesel tank
6. Burette
7. Fuel control valve
8. Data control system
9. Air filter
10. Manometer
11. Surge tank
12. Exhaust gas temperature sensor
13. Gas analyser

4.10 Equipment used for the evaluation of engine emissions

Flue Gas analyser was used for the evaluation of exhaust gas emissions. It can determine CO, HC, CO_2, O_2 and NO_x.

4.11 Specifications of the Test Rig

Single cylinder four stroke variable compression ratio engine was used for conducting the experiments. Specifications are as following

Table 4.1: Specification of variable compression ignition engine

Make Type	Kirloskar
Rated Power	5.20 kW @ 1500 rpm
Engine Type	Single Cylinder, Four stroke , Constant Speed, Water Cooled, Diesel Engine
Bore	87.50 mm
Stroke	110 mm
Connecting rod length	234 mm
Compression Ratio	17.50
Swept volume	661.45 cc
Orifice diameter	20 mm
Orifice Coeff. Of Discharge	0.60
Dynamometer Arm Length	185 mm
Fuel Pipe diameter	12.40 mm
Cooling media	Water cooled
Load indicator	Range 0-50 Kg, Supply 230V AC, Digital
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Loading device	Eddy current dynamometer

4.12 Experimental procedure

For evaluating the performance and emission characteristics of compression ignition engine using pure diesel (PD) and blends of pure diesel (PD) with hydrogenated rapeseed biodiesel (HRD) following experimental procedure was followed.

4.12.1 Procedure of evaluating performance characteristics

1. Fill the biodiesel and diesel both in respective fuel tanks.

2. In the starting, compression ratio of the engine is automatically at 17.5:1, so no need to adjust it.

3. Adjust the flow of cooling water for engine and calorimeter after starting the water supply and ensure proper supply of water to dynamometer and piezo sensor for cooling.

4. Check all the electric connections before starting the electric-supply to the computer through the UPS.

5. For on screen performance evaluation of the engine parameters click on the lab view based "**Enginesoft**" software package.

6. Initially operate engine on diesel fuel for 20 minutes for flashing.

8. Set the calorific value and value of specific gravity of the fuel in the software. Then after selecting the run option, run the engine for 15 minutes under no load conditions.

9. Select log option in the software and assign the fuel supply by revolving the supply knob. Choose log option of the software. Before turn on the fuel supply knob, check that gas analyser is available there.

10. Display changes to input mode after 1 minute, then enter the values of water flow in calorimeter and cooling jacket. Now enter the name of file (applicable only for the first reading) in the software and insert the probe of gas analyser into the exhaust at appropriate place. Then it let for few minutes so that it could stabilize.

11. Logged the reading for no load conditions.

12. Repeat the experiment for different loads.

13. Save the readings for each load.

14. Bring the engine to no load condition at the end of experiment and turn off the engine and computer.

15. Turn off the water supply after few minutes of turning off the engine.

4.12.2 Procedure of evaluating emission characteristics

1. Insert the probe of the equipment into exhaust of the engine after starting the engine at no load condition.

2. Exhaust gases passes to the flue gas analyser through the sensors attached with it.

3. Readings were displayed on the digital screen of flue gas analyser after the entry of exhaust gases into it.

4. After a minute or 2 when the values were stabilized on the screen readings are noted down.

5. After every reading sensors were removed from the flue gas analyser so that the values on the screen settle down again to zero value.
6. Repeat the above procedure for different load and fuel conditions respectively.

4.13 Precautions and maintenance instructions

1. Always ensure that sufficient oil must be present in the oil tank before starting the engine.
2. There should not be any contamination in fuel lines and fuel tank.
3. Always make it sure before starting the engine that the supply of water is turned on.

4.14 Comparison of performance and emission characteristics of pure diesel blended with hydrogenated rapeseed biodiesel (HRD) and that of pure diesel (PD)

Data obtained after the experiments on compression ignition engine for all the four blends (B10, B20, B30 and B40) was used to compare performance and emission characteristics with the characteristics of pure diesel.

Chapter 5

Results and Discussion

5.1 Introductory comment

In this chapter results have shown with the help of graphs and along with possible reasoning behind the results. The experiments were conducted on the variable compression ignition engine to evaluate its performance and emission characteristics using pure diesel and different blends of diesel with hydrotreated rapeseed biodiesel. These are as follows:

5.2 Performance characteristics

5.2.1 Brake specific fuel consumption

5.2.1.1 Effect of blends and load on brake specific fuel consumption

The comparison of brake specific fuel consumption with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.1. It is found during the investigations that at all the loads (0, 3, 9 and 15 kg), with increase in blending of pure diesel with hydrotreated rapeseed biodiesel (HRD) up to 40 % brake specific fuel consumption (BSFC) of the compression ignition (CI) engine decreases compared to the pure diesel. This could be due to complete combustion of blended fuel due to appropriate carbon oxygen and hydrogen oxygen ratio. Due to complete combustion of hydrotreated rapeseed biodiesel the energy available in the fuel is utilised completely which results in lower fuel consumption as compared to pure diesel for the same power output. The lowest brake specific fuel consumption (BSFC) is observed for B40 at full load which is 0.29 kg/kW-hr where as for B10 and neat diesel are 0.31 kg/kW-hr and 0.32 kg/kW-hr respectively.

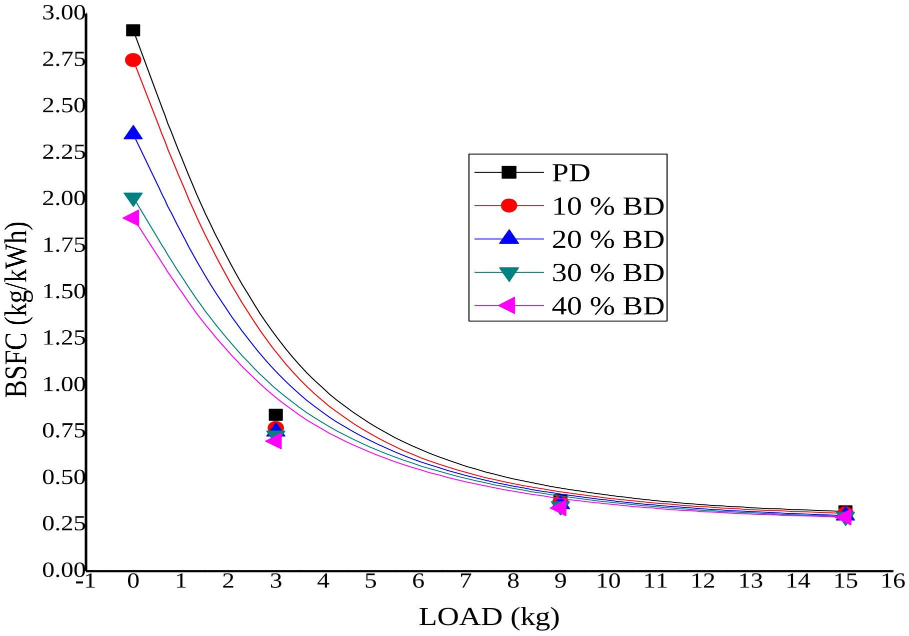

Figure 5.1: A comparison of Brake specific fuel consumption with varying load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

5.2.2 Fuel consumption per hour

5.2.2.1 Effect of blends and load on fuel consumption per hour

The comparison of fuel consumption per hour with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.2. It is found during the investigation that at all the loads (0, 3, 9 and 15 Kg) fuel consumption per hour decreases with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 30 %. This might be due to low density (0.835 g/cm^3) and results of complete combustion due to appropriate carbon oxygen and hydrogen oxygen ratio of the hydrotreated rapeseed biodiesel (HRD) as compared to pure diesel (PD) having density (0.845 g/cm^3). As the injection system of engine is designed to spray pre determined volume of fuel during the injection period and we calculate fuel consumption per hour according to mass of the fuel consumed by the engine per hour. Mass of blended fuel is less in unit volume as compared to the pure diesel. Marginal increase in fuel consumption was found in case of 40 % blend as compared to 30% blend. This might be due to low calorific value (43296.032 KJ/Kg) of the hydrogenated rapeseed biodiesel (HRD) as compared to pure diesel (46500 KJ/Kg). The minimum fuel consumption is observed for B30 at full load which is 1.20 Kg/hr where as for the diesel and B20 these are 1.29 Kg/hr and 1.25 Kg/hr respectively.

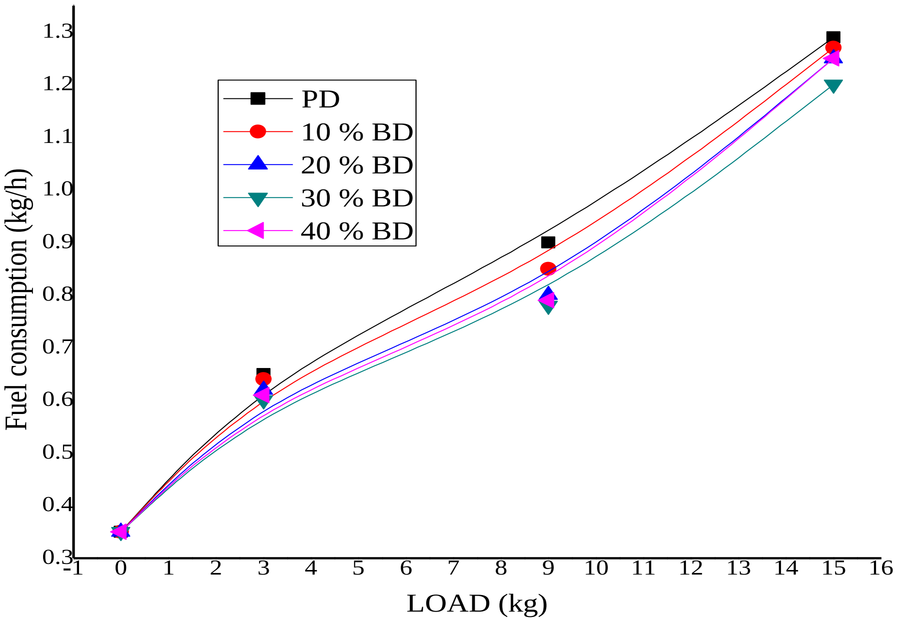

Figure 5.2: A comparison of fuel consumption per hour with varying load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

5.2.3 Brake thermal efficiency

5.2.3.1 Effect of blends and load on brake thermal efficiency

The comparison of brake thermal efficiency with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.3. It is found during the investigations that at all the loads (0, 3, 9 and 15 kg) with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % brake thermal efficiency increases. This might be due to complete combustion and high Cetane Number in case of fuel blended with hydrotreated rapeseed biodiesel (HRD). Due to high Cetane Number of blended fuel ignition delay is less as compared to the engine using pure diesel fuel, hence more time for combustion is available which results in efficient combustion. Reduction in waste heat from the engine might be the reason for high brake thermal efficiency. Exhaust gas temperature tables clearly shows that temperatures of the exhausts decreases with the increase of blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % which shows in case of blends heat produced during combustion is more efficiently utilised in producing power as compared to pure diesel (PD). The BTE of B40 at full load is found to be 5.82% and 3.83% higher than base fuel diesel and B10.

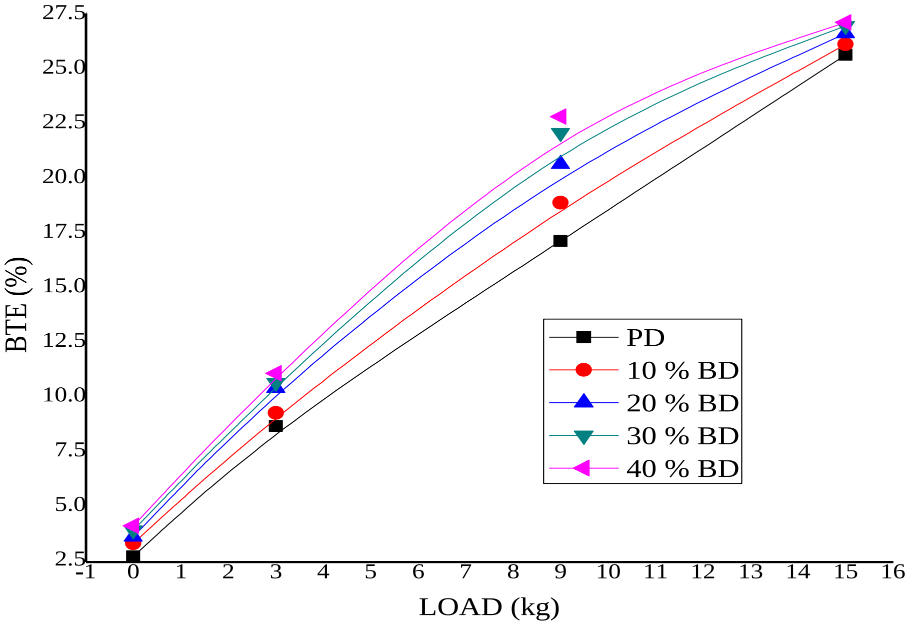

Figure 5.3: A comparison of brake thermal efficiency with varying load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

5.2.4 Brake power

5.2.4.1 Effect of blends and load on brake power

The comparison of brake power with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.4. It is found during the investigation that at no load (0 kg) brake power (BP) increases with the increase of blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 %. With the further increase in load (up to 15 kg) there is marginal decrease in brake power (BP) with the increase in blending (up to 40%) of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) compared to pure diesel (PD). In brake power (BP) two factors play important role, one is combustion efficiency and other is heating value of fuel. Combustion efficiency of hydrotreated rapeseed biodiesel (HRD) is better but heating value of hydrotreated rapeseed biodiesel (HRD) is low as compared to pure diesel (PD). At no load condition (0 kg) increase in brake power (BP) with increase in blending (up to 40%) might be due to better combustion efficiency of the fuel. The reason behind marginal decrease in brake power (BP) of blended fuel as compared to diesel with further increase in loading (up to 15 kg) is lower heating value of the blended fuel (43296.032 KJ/kg) as compared to diesel fuel (46500 KJ/kg). Brake power (BP) of diesel is observed to be maximum among the all fuels that is 4.28 kW. This is 0.23% and 1.86% more than that of B10 and B40 respectively at full load.

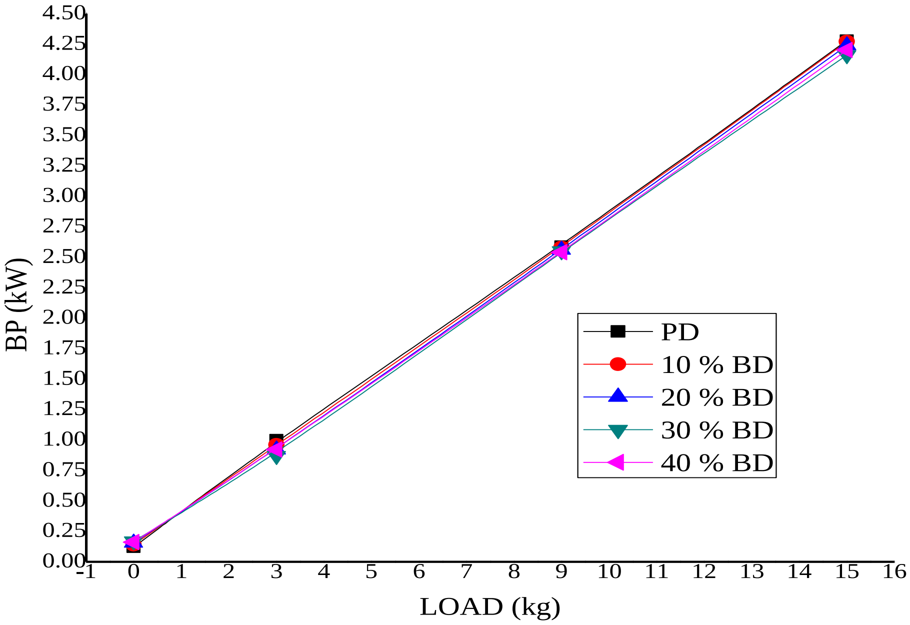

Figure 5.4: A comparison of Brake Power with Varying Load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

5.2.5 Mechanical efficiency

5.2.5.1 Effect of blends and load on mechanical efficiency

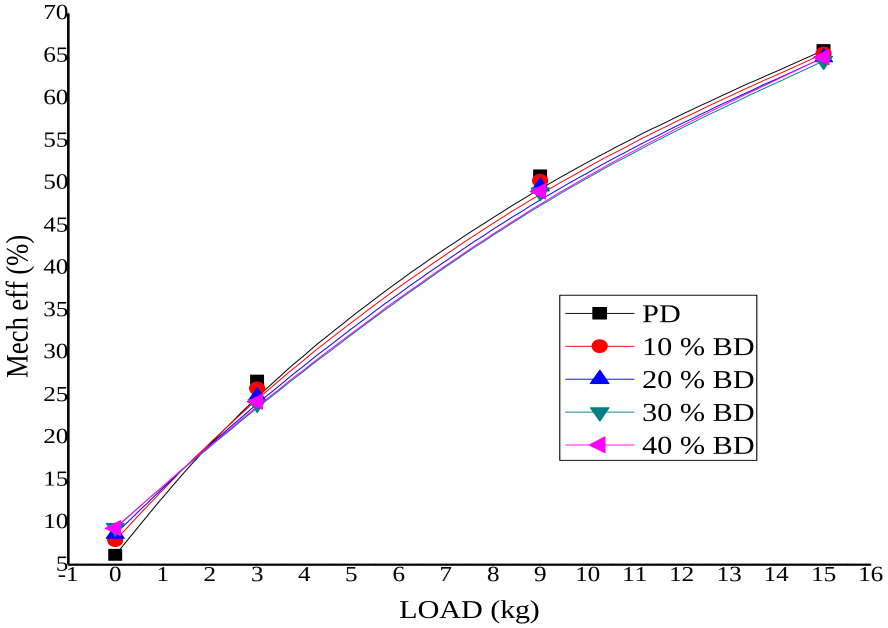

Figure 5.5: A comparison of mechanical efficiency with varying load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

The comparison of mechanical efficiency with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.5. Mechanical efficiency depends upon brake power and frictional power and in our investigation it is clearly seen that trend of increasing and decreasing of mechanical efficiency with the increase of blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % is very similar to the trend shown by brake power. It indicates that frictional power of engine remains almost same with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD). This shows that lubrication capacity of hydrotreated rapeseed biodiesel (HRD) is almost similar to pure diesel (PD). So there is no need of the addition of lubricating agents in hydrotreated rapeseed biodiesel (HRD) to be used in the CI engines. Mechanical efficiency of diesel is observed to be maximum (65.67 %) among the all fuels. This is 0.63 % and 1.29 % more than that of B10 and B40 respectively at full load.

5.3 Emission parameters

Table 5.1: Exhaust emission parameters

Parameter	Accuracy	Range
Carbon Monoxide (CO)	+/- 0.01 %	0 – 10 %
Carbon Dioxide (CO_2)	+/- 0.5 %	0 – 20 %
Hydro Carbon (HC)	+/- 10 PPM if < 200 PPM +/- 5 % if > 200 PPM	0 – 20000 PPM
Nitrogen Oxides (NO_x)	+/- 50 PPM if < 500 PPM +/- 10 % if > 500 PPM	0 – 5000 PPM
Oxygen (O_2)	+/- 0.01 %	0 – 22 %

5.3.1 Nitrogen Oxides

5.3.1.1 Effect of blends and load on nitrogen oxides emission

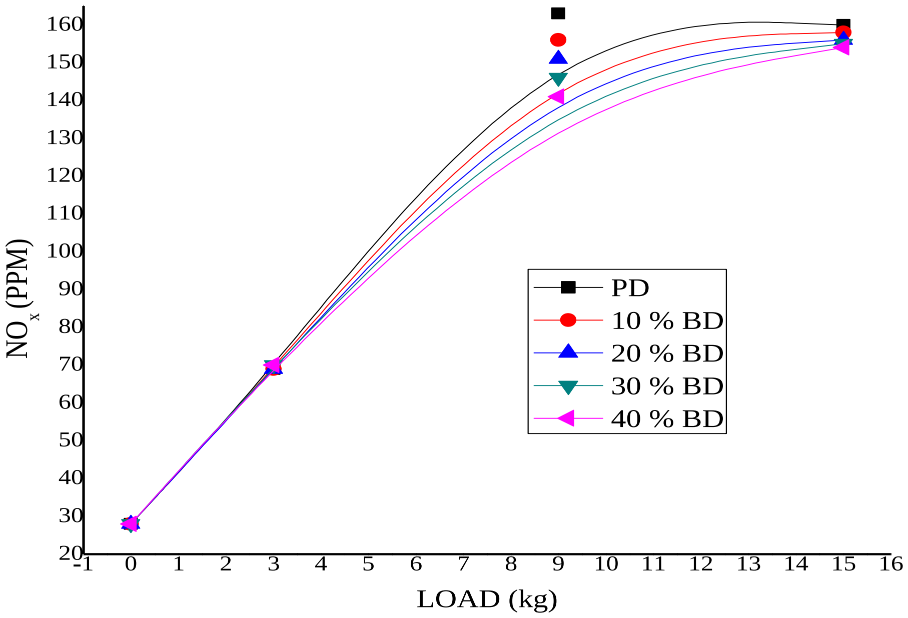

Figure 5.6: A comparison of nitrogen oxide emission with varying load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

The comparison of nitrogen oxide emission with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.6. During the investigation it is found that at higher load conditions (9 and 15 kg) nitrogen oxides (NO_x) shows decreasing trend with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 %. This might be due to competition of reaction between carbon and nitrogen at higher loads with the thermal oxygen generated inside the combustion chamber. CO_2 forms predominantly as compared to NO_x because nitrogen is more inert as compared to carbon that results lower emission of NO_x. Decrease in local flame temperature at higher loads might be the reason of this decrease. As NO_x depends on temperature, higher the local temperature higher is the NOx formation. NO_x emissions decreased up to 3.89 % for B40 as compared to diesel at full load.

5.3.2 Hydrocarbon

5.3.2.1 Effect of blends and load on hydrocarbon emission

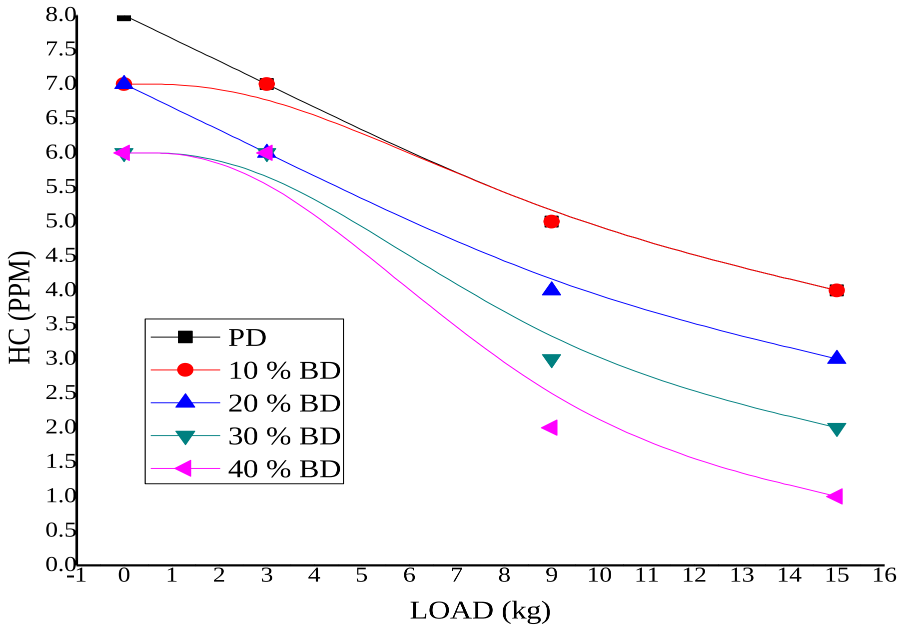

Figure 5.7: A comparison of hydrocarbon emission with varying load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

The comparison of hydro carbon emission with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.7. During the investigation it is found that hydrocarbon (HC) decreases with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % at all the loads (0-15 kg). This decrease in HC is due the complete combustion of the blended fuel due to presence of excess oxygen and hydrogen content as compared to pure diesel (PD). Minimum HC emission magnitude is found for B40 which is 1 PPM. The magnitude of HC emissions for pure diesel and B30 are observed to be 4 PPM and 2 PPM respectively at full load.

5.3.3 Carbon dioxide

5.3.3.1 Effect of blends and load on carbon dioxide emission

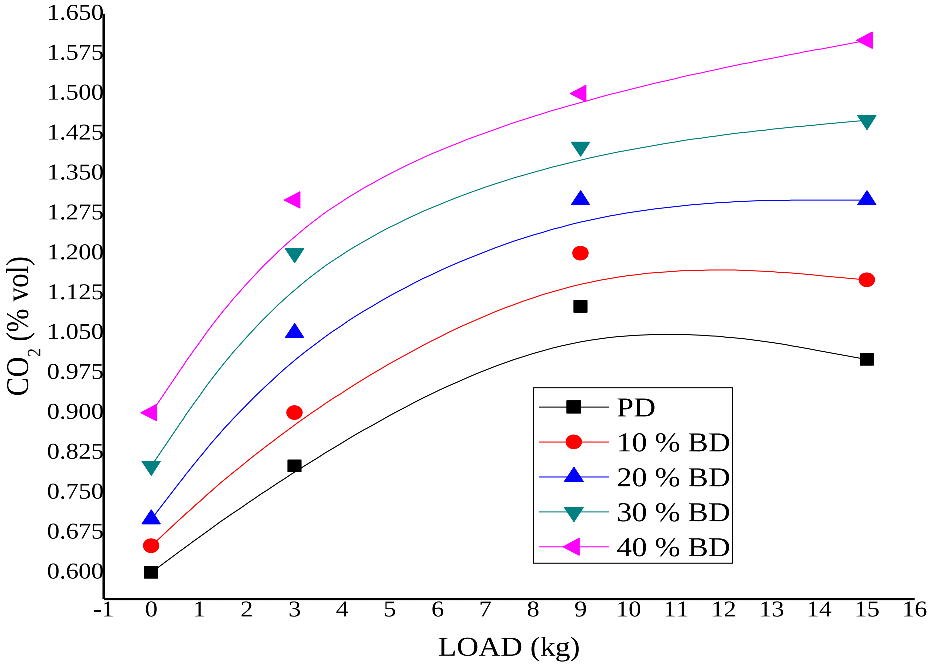

Figure 5.8**:** A comparison of carbon dioxide (CO_2) with varying load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

The comparison of carbon dioxide with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.8. It is found during the investigations that with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % carbon dioxide (CO_2) increases at all loads (0-15 kg). This increase is due to complete combustion of fuel. Higher Cetane Number and oxygen content in the hydrotreated rapeseed biodiesel (HRD) leads to complete combustion of the fuel. Due to high Cetane Number of the blended fuel time of combustion increases and excess oxygen reacts with carbon and carbon monoxide (CO) to form carbon dioxide (CO_2). With the increase in blending of pure diesel (PD) oxygen content in the fuel goes on increasing and ignition delay of the fuel goes on decreasing which results in increase of carbon dioxide (CO_2) in exhausts. The CO_2 is increased by up to 37.50 % and 31.03 % respectively, in B40 and B30 compared to neat diesel at full load.

5.3.4 Carbon monoxide

5.3.4.1 Effect of blends and load on carbon monoxide emission

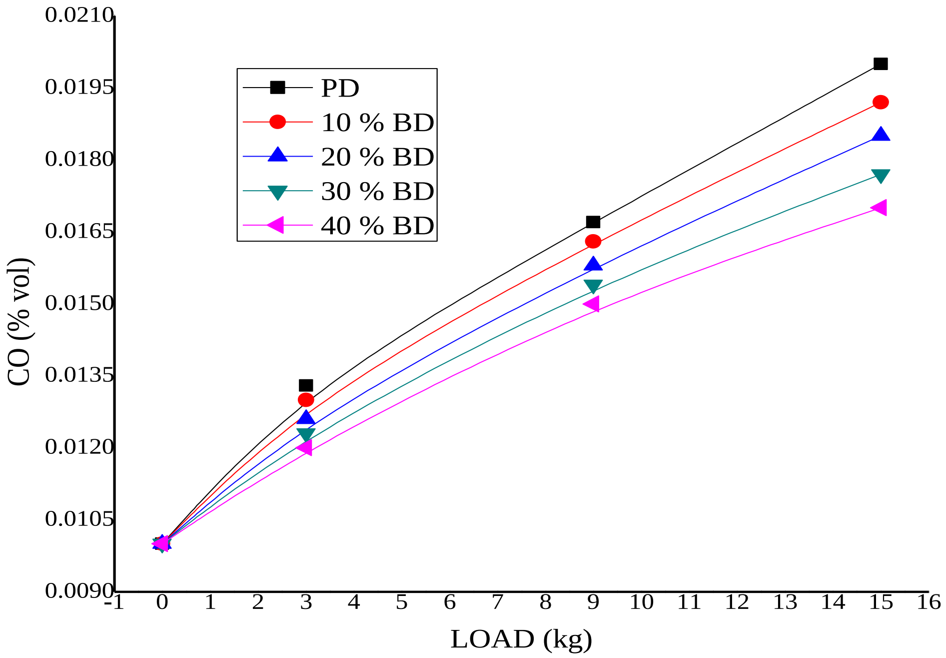

Figure 5.9: A comparison of carbon monoxide (CO) with varying load for pure diesel along with varying percentage of hydrogenated rapeseed biodiesel.

The comparison of carbon monoxide with varying load for pure diesel and various blends of hydrotreated rapeseed biodiesel (HRD) with pure diesel (PD) have been shown in Figure 5.9. It is found during the investigations that with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % carbon monoxide (CO) decreases at all loads (0-15 kg). This decrease is due to complete combustion of fuel and conversion of CO into CO_2. Higher Cetane Number and oxygen content in the hydrotreated rapeseed biodiesel (HRD) leads to complete combustion of the fuel. Due to high Cetane Number of the blended fuel time of combustion increases and excess oxygen reacts with carbon and carbon monoxide (CO) to form carbon dioxide (CO_2). With the increase in blending of pure diesel (PD) oxygen content in the fuel goes on increasing and ignition delay of the fuel goes on decreasing which results in decrease of carbon monoxide (CO) in exhausts. The CO is decreased by up to 17.64 % and 12.99 % respectively, in B40 and B30 compared to neat diesel at full load.

Chapter 6

Conclusions and future scope

6.1 Conclusion

The objective of present study was to evaluate the performance and emission characteristics of variable compression ratio engine using various blends of hydrogenated rapeseed biodiesel with pure diesel as fuel. These results are then compared with the base fuel (diesel). In this study overall investigation is based on the production of biodiesel and hydrogenated biodiesel, evaluation of properties of both fuels, evaluation of performance and emission characteristics of different blends of diesel-biodiesel. The conclusions of the present work are described below:

6.1.1 Fuel properties comparison

1. It is seen that flash point is increased for of both hydrogenated biodiesel (195ºC) and normal biodiesel (207 ºC) as compared to base fuel (35ºC) but density of hydrogenated biodiesel (0.835 g/cm^3) is found to be lower as compared to base fuel (0.845 g/cm^3).
2. Hydrogen is energetic material. Gross calorific value of hydrogenated biodiesel (43296.032 KJ/Kg) is found to be very close to neat diesel (46500 KJ/Kg).

6.1.2 Performance and emission characteristics comparison for optimum blend:

At constant compression ratio of 17.5 and full load:

1. It is found that with increase in blending of pure diesel with hydrotreated rapeseed biodiesel (HRD) up to 40 %, brake specific fuel consumption (BSFC) of the compression ignition (CI) engine decreases compared to the pure diesel. The lowest brake specific fuel consumption (BSFC) is observed for B40 at full load which is 0.29 kg/kW-hr where as for B10 and neat diesel are 0.31 kg/kW-hr and 0.32 kg/kW-hr respectively.

2. It is found that fuel consumption per hour decreases with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 30 % but marginal increase in fuel consumption was found in case of 40 % blend as compared to 30% blend. The minimum fuel consumption is observed for B30 which is 1.20 Kg/hr where for diesel and B20 are 1.29 Kg/hr and 1.25 Kg/hr respectively.
3. It is also observed that with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % brake thermal efficiency increases. The BTE of B40 is found to be 5.82% and 3.83% higher than base fuel diesel and B10.
4. The marginal decrease in brake power (BP) with the increase in blending (up to 40%) of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) compared to pure diesel (PD) is found. Brake power (BP) of diesel is observed to be maximum among the all fuels that is 4.28 kW. This is 0.23% and 1.86% more than that of B10 and B40 respectively.
5. It is found that mechanical efficiency decreases marginally with the increase of blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 %. This decrease is very similar to the trend shown by brake power. Mechanical efficiency of diesel is observed to be maximum (65.67 %) among the all fuels. This is 0.63 % and 1.29 % more than that of B10 and B40 respectively.
6. It is found that nitrogen oxide (NO_x) shows decreasing trend with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 %. Minimum NO_x emission magnitude is found for B40 which is 154 PPM. The magnitude of NO_x emissions for pure diesel, B10, B20 and B30 are observed to be 160 PPM, 158 PPM, 156 PPM and 155 PPM respectively. NO_x emissions decreased up to 3.89 % for B40 as compared to diesel.
7. The hydro carbon (HC) decreases with the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 %. Minimum HC emission magnitude is found for B40 which is 1 PPM. The magnitude of HC emissions for pure diesel and B30 are observed to be 4 PPM and 2 PPM respectively.

8. With the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % carbon dioxide (CO_2) increases. The CO_2 is increased by up to 37.50 % and 31.03 % respectively, in B40 and B30 compared to neat diesel.

9. With the increase in blending of pure diesel (PD) with hydrotreated rapeseed biodiesel (HRD) up to 40 % carbon monoxide (CO) decreases. The CO is decreased by up to 17.64 % and 12.99 % respectively, in B40 and B30 compared to neat diesel.

Based on above conclusions B40 is found to be optimum blend. It is concluded from the results that B40 performed best for all performance and emission parameters except per hour fuel consumption.

6.2 Future scope

On the account of automotive fuel hydrogenation of biodiesel can play a vital role in order to its improved performance and emission characteristics as compared to base fuel (Diesel). Before introducing hydrogenated biodiesel fuel in India following points may be considered:

There is a scope to study the performance and emission characteristics of the engine using hydrogenated biodiesel as fuel which is produced at temperature above 360 ºC and at different pressure.

1. The performance and emission characteristics of engine using hydrogenated biodiesel as fuel can be studied at different loads and compression ratios.

2. Experiments on compression ignition engines can be performed by changing the other parameters like injection timing, ignition delay and nozzle.

3. Blends of hydrogenated rapeseed biodiesel with diesel above 40 % can be produced to study the performance and emission parameters of the engine.

4. Other edible or non edible oils can be used for the biodiesel production and further hydrogenation to study its effects on performance and emission parameters.

5. The effect of hydrogenated biodiesel on sound produced by the engine while running was not studied. There is a scope to study it.

6. It should be subsidized due to higher initial cost of transesterification and hydrogenation of fuel.

7. Complete environmental analysis of effects of hydrogenated biodiesel should be done.

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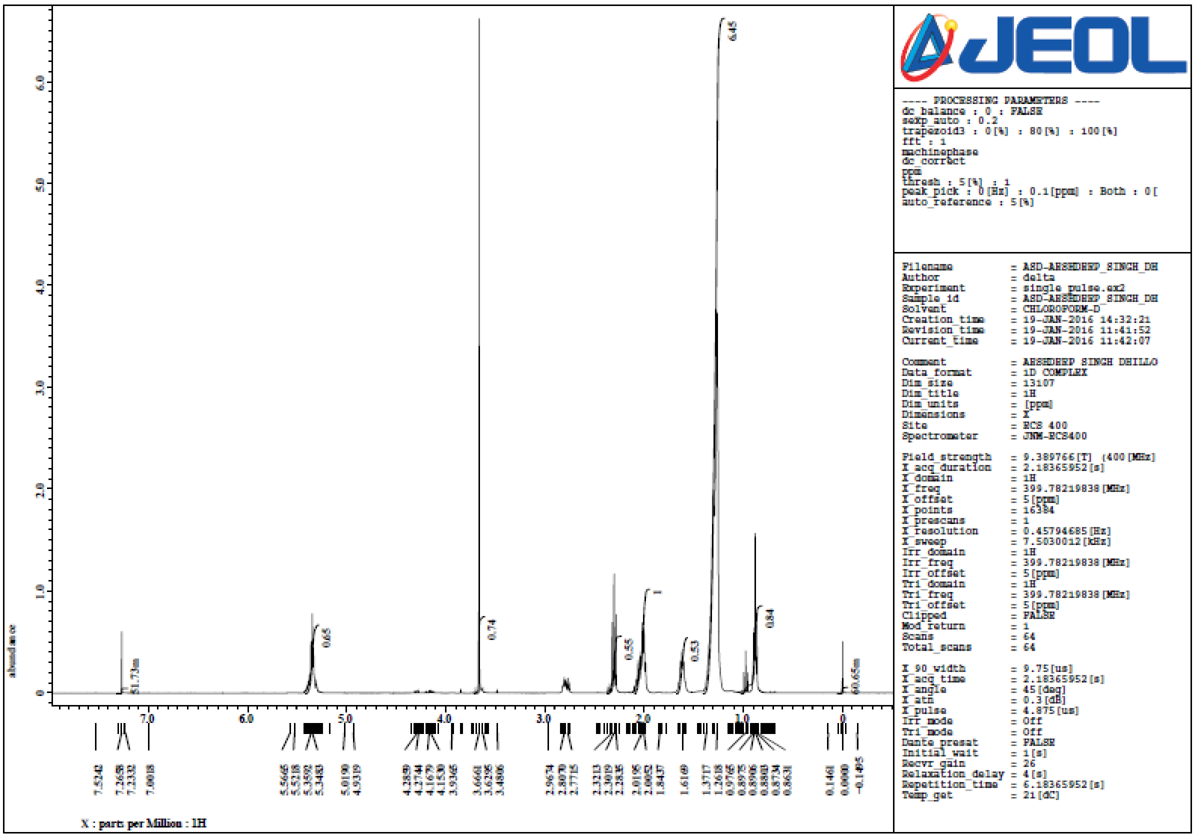
Specifications for blends B5 – B20, www.astm.org

APPENDIX

A. Percentage conversion to biodiesel



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sexp_auto : 0.2
trapezoid3 : 0[%] : 80[%] : 100[%]
fft : 1
machinephase
dc_correct
ppm
thresh : 5[%] : 1
peak_pick : 0[Hz] : 0.1[ppm] : Both : 0[
auto_reference : 5[%]

Filename          = ASD-AHSHDEEP_SINGH_DH
Author            = delta
Experiment        = single_pulse.ex2
Sample_id         = ASD-AHSHDEEP_SINGH_DH
Solvent           = CHLOROFORM-D
Creation_time     = 19-JAN-2016 14:32:21
Revision_time     = 19-JAN-2016 11:41:52
Current_time      = 19-JAN-2016 11:42:07

Comment           = AHSHDEEP SINGH DHILLO
Data_format       = 1D COMPLEX
Dim_size          = 13107
Dim_title         = 1H
Dim_units         = [ppm]
Dimensions        = X
Site              = ECS 400
Spectrometer      = JNM-ECS400

Field_strength    = 9.389766[T] (400[MHz]
X_acq_duration    = 2.18365952[s]
X_domain          = 1H
X_freq            = 399.78219838[MHz]
X_offset          = 5[ppm]
X_points          = 16384
X_prescans        = 1
X_resolution      = 0.45794685[Hz]
X_sweep           = 7.5030012[kHz]
Irr_domain        = 1H
Irr_freq          = 399.78219838[MHz]
Irr_offset        = 5[ppm]
Tri_domain        = 1H
Tri_freq          = 399.78219838[MHz]
Tri_offset        = 5[ppm]
Clipped           = FALSE
Mod_return        = 1
Scans             = 64
Total_scans       = 64

X_90_width        = 9.75[us]
X_acq_time        = 2.18365952[s]
X_angle           = 45[deg]
X_atn             = 0.3[dB]
X_pulse           = 4.875[us]
Irr_mode          = Off
Tri_mode          = Off
Dante_presat      = FALSE
Initial_wait      = 1[s]
Recvr_gain        = 26
Relaxation_delay  = 4[s]
Repetition_time   = 6.18365952[s]
Temp_get          = 21[dC]
```

Figure A.1: XRD image of converted biodiesel

B. Fuel Properties

Table B.1: Fuel properties of biodiesel, hydrogenated biodiesel and neat diesel

S. No	**Properties**	**Biodiesel**	**Hydrogenated Biodiesel**	**Diesel [1]**
1	GCV, KJ/kg	34693.587	43296.032	46500
2	Density @ 40 °C g/cm^3	0.868	0.835	0.845
3	Flash Point, °C	207	195	35
4	Carbon Residue, %	1.006	0.1855	10
5	Kinematic viscosity @ 40 °C, cst	5.78	4.34	2-4.5
6	Freezing Point, °C	+3	+0	-40

C. Experimental data of engine performance

Table C.1: Results of BSFC (kg/kWh) for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	2.91	2.75	2.35	2.01	1.90
3	0.84	0.77	0.75	0.73	0.70
9	0.38	0.37	0.36	0.35	0.34
15	0.32	0.31	0.298	0.294	0.29

Table C.2: Results of fuel consumption per hour (kg/h) for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	0.35	0.35	0.35	0.35	0.35
3	0.65	0.64	0.62	0.60	0.61
9	0.90	0.85	0.80	0.78	0.79
15	1.29	1.27	1.25	1.20	1.25

Table C.3: Results of BTE (%) for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	2.66	3.25	3.55	3.85	4.06
3	8.62	9.22	10.36	10.61	11.04
9	17.08	18.84	20.61	22.04	22.78
15	25.6	26.09	26.58	26.93	27.09

Table C.4: Results of BP (kW) for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	0.12	0.14	0.155	0.17	0.16
3	1	0.96	0.92	0.87	0.92
9	2.59	2.58	2.56	2.55	2.54
15	4.28	4.27	4.24	4.16	4.20

Table C.5: Results of Mechanical Efficiency (%) for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	6.13	7.9	8.62	9.37	9.27
3	26.7	25.78	24.86	23.95	24.21
9	50.91	50.25	49.6	48.95	49.02
15	65.67	65.252	64.836	64.42	64.82

Table C.6: Results of NO_x (PPM) for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	28	28	28	28	28
3	69	69	69	70	70
9	163	156	151	146	141
15	160	158	156	155	154

Table C.7: Results of HC (PPM) for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	8	7	7	6	6
3	7	7	6	6	6
9	5	5	4	3	2
15	4	4	3	2	1

Table C.8: Results of CO_2 (% vol) for all fuels at different loads (kg)

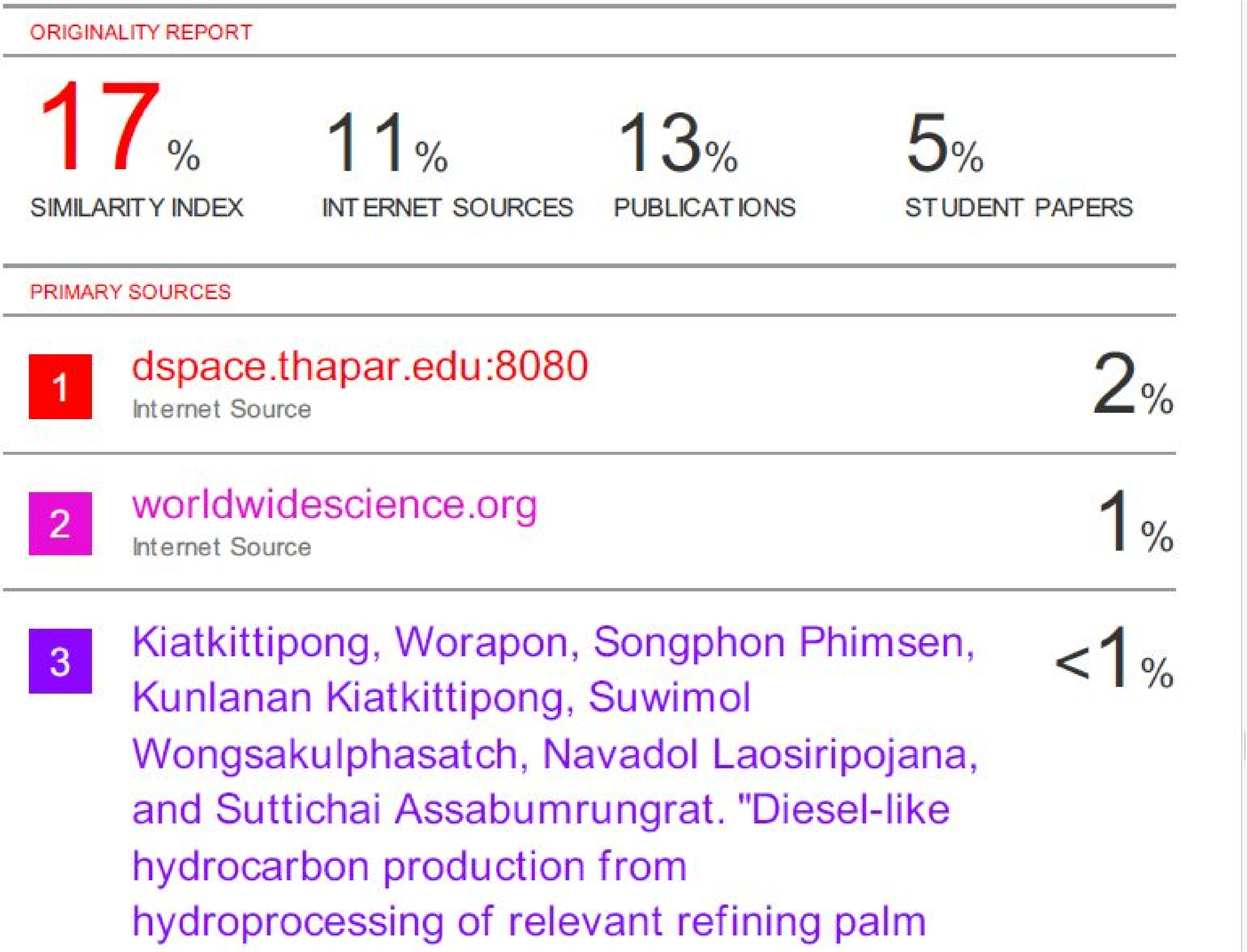
Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	0.6	0.65	0.7	0.8	0.9
3	0.8	0.9	1.05	1.2	1.3
9	1.1	1.2	1.3	1.4	1.5
15	1	1.15	1.3	1.45	1.6

Table C.9: Results of CO (% vol) for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	0.01	0.01	0.01	0.01	0.01
3	0.0133	0.013	0.0126	0.0123	0.012
9	0.0167	0.0163	0.0158	0.0154	0.015
15	0.02	0.0192	0.0185	0.0177	0.017

Table C.10: Results of temperature (ºC) of exhaust gases leaving the engine for all fuels at different loads (kg)

Load	**Diesel**	**B10**	**B20**	**B30**	**B40**
0	209.08	191.04	173.95	142.19	124.75
3	224.72	216.17	208.26	188.51	180.40
9	276.92	272.55	262.42	252.85	248.92
15	386.93	377.34	361.32	352.46	338.87



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