COMPARATIVE STUDY OF ENGINE PERFORMANCE AND EXHAUST EMISSION CHARACTERISTICS OF A 4-STROKE COMPRESSION IGNITION ENGINE OPERATED WITH VARIOUS BLENDS OF BIODIESEL EXTRACTED FROM CRUDE RICE BRAN OIL AND RICE BRAN OIL.

Thesis submitted in the partial fulfillment of requirement for award of the degree
of

Master of Engineering
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THERMAL ENGINEERING

Submitted By

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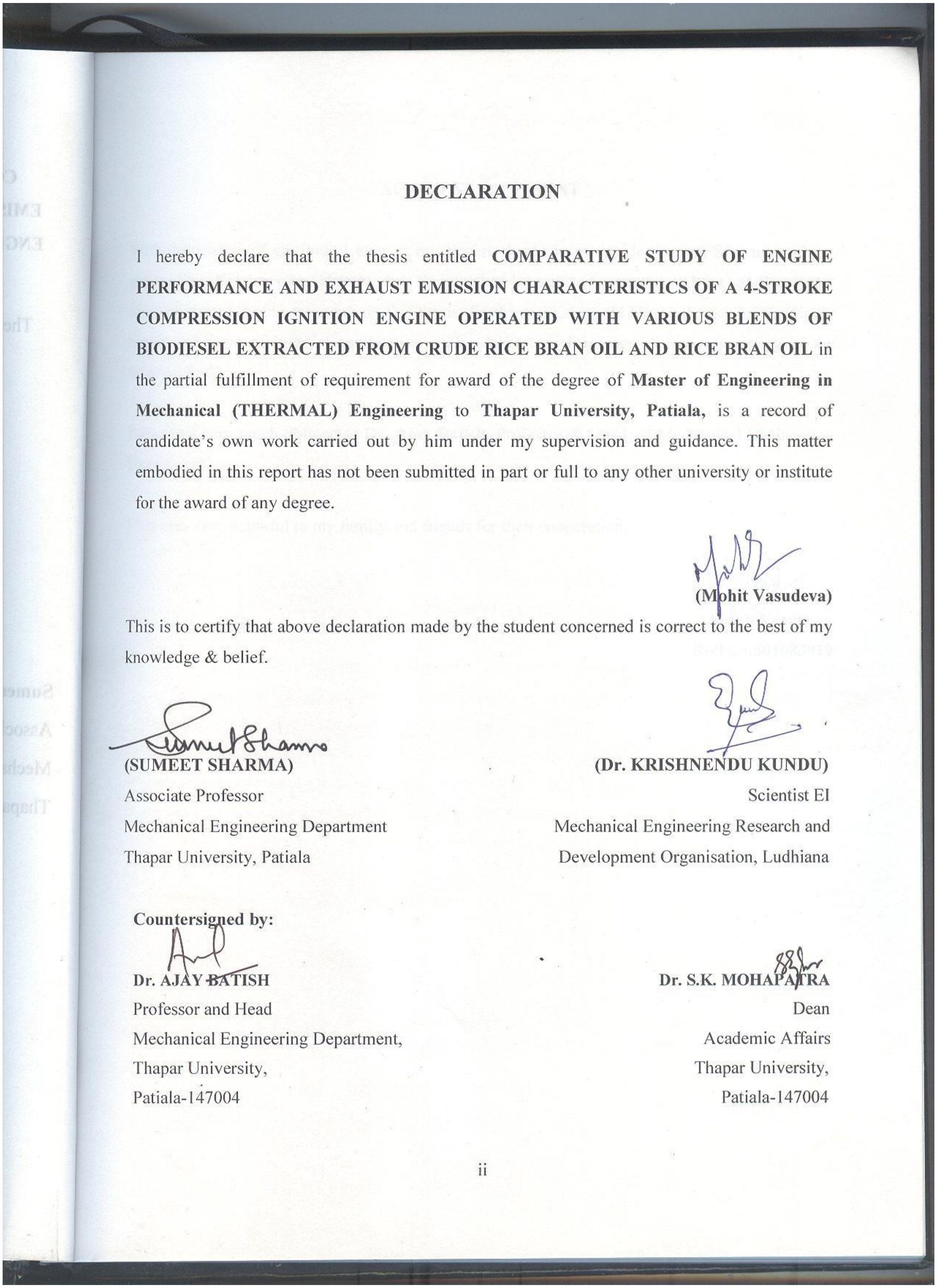

DECLARATION

I hereby declare that the thesis entitled **COMPARATIVE STUDY OF ENGINE PERFORMANCE AND EXHAUST EMISSION CHARACTERISTICS OF A 4-STROKE COMPRESSION IGNITION ENGINE OPERATED WITH VARIOUS BLENDS OF BIODIESEL EXTRACTED FROM CRUDE RICE BRAN OIL AND RICE BRAN OIL** in the partial fulfillment of requirement for award of the degree of **Master of Engineering in Mechanical (THERMAL) Engineering** to **Thapar University, Patiala,** is a record of candidate's own work carried out by him under my supervision and guidance. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

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ABSTRACT

Biodiesel is receiving increased attention as an alternative, non-toxic, biodegradable, and renewable diesel fuel. It is derived from oils and fats by transesterification with alcohols. The main hurdle to the commercialization of biodiesel is the cost of raw materials. Nonedible, inexpensive, low-grade high free fatty acid rice bran oil as raw material, continuous transesterification process and recovery and purification of bioactive compounds from biodiesel by-product are primary options to be considered to lower the cost of biodiesel. An improved engine design can lead to lesser fuel consumption along with better engine performance. This thesis is focused on biodiesel production from crude rice bran oil and rice bran oil, comparative study of engine performance and exhaust emission characteristics between the prepared biodiesel with diesel and optimization of the compression ratio of a compression ignition engine fuelled with blends of biodiesel.

Firstly the methyl esters of crude rice bran oil and rice bran oil were prepared. Crude rice bran methyl ester was produced by an acid catalyzed transesterification followed by base catalyzed transesterification and rice bran methyl ester was produced by base catalyzed transesterification. In the second part experiments were carried out at different compression ratios ranging from 12 to 18 to figure out the optimum compression ratio of a compression ignition engine. A B20 blend of rice bran methyl ester was used as fuel for conducting the experiments. After that comparative analysis based on engine performance and exhaust emission results of B10, B20 and B40 blends of crude rice ban methyl ester with diesel at compression ratio 12 and 14 was investigated. In the last part comparative analysis based on engine performance and exhaust emission results of B10, B20 and B40 blends of crude rice bran methyl ester and rice bran methyl ester at compression ratio 14 was investigated. Based on the experimental investigation the blends of crude rice bran methyl ester can be used as fuel in diesel engine without making any modification to the engine.

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NOMENCLATURE

BP	Brake Power
BMEP	Brake Mean Effective Pressure
BTE	Brake Thermal Efficiency
EGT	Exhaust Gas Temperature
BSFC	Brake Specific Fuel Consumption
NO, NO_2, NO_X	Oxides of Nitrogen
HC	Hydrocarbon
CO_2	Carbon Dioxide
CO	Carbon Monoxide
PM	Particulate Matter
ASTM	American Society of Testing and Petroleum
ISO	International standard organization
EU	European Union
US	United States
H_2SO_4	Sulphuric Acid
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
IC	Internal Combustion
DI	Direct Injection
CI	Compression Ignition
CR	Compression Ratio
FIP	Fuel injection pump
TAG	Triacylglycerols
FA	Fatty Acids
FFA	Free Fatty Acids
DDRBO	Dewaxed Degummed Rice Bran Oil
FAME	Fatty Acid Methyl Ester
CRBO	Crude Rice Bran Oil
RBO	Rice Bran Oil

CRBME	Crude Rice Bran Methyl Ester
CB10	10% Crude Rice Bran Methyl Ester by Volume, 90% Petroleum Diesel
CB20	20% Crude Rice Bran Methyl Ester by Volume, 80% Petroleum Diesel
CB40	40% Crude Rice Bran Methyl Ester by Volume, 60% Petroleum Diesel
RB10	10% Rice Bran Methyl Ester by Volume, 90% Petroleum Diesel
RB20	20% Rice Bran Methyl Ester by Volume, 80% Petroleum Diesel
RB40	40% Rice Bran Methyl Ester by Volume, 60% Petroleum Diesel

Units

Vol	Volume
wt.	weight
ppm	Parts per Million
kcal/kg	Kilo Calorie per Kilogram
mm^2/sec	Square Millimetre per Second
kW	Kilo Watt
g/kWh	Gram per Kilo Watt hour
%	Percentage
°C	Degree Celsius

CHAPTER 1

INTRODUCTION

1.1 ORGANIZATION OF THESIS

Chapter 1 covers brief introduction to biodiesel, different methods for its production, raw material required & its quality.

Chapter 2 presents the extensive literature review of research work which has been done by different researchers in the past.

Chapter 3 covers methodology adopted for the thesis work. It covers the methodology adopted for biodiesel production along with the experimental methodology.

Chapter 4 presents the results and discussion of the experiments conducted.

Chapter 5 discusses the conclusion of the research work and future scope related to it.

1.2 INTRODUCTION

The predicted shortage of fossil fuel has encouraged the search for substitutes for petroleum derivatives. This search has resulted in an alternative fuel called "biodiesel". Bio-diesel is an alternative to petroleum-based fuels derived from vegetable oils, animal fats, and used waste cooking oil including triglycerides. Since the petroleum crises in 1970s, the rapidly increasing prices and uncertainties concerning petroleum availability, a growing concern of the environment and the effect of greenhouse gases during the last decades, has revived more and more interests in the use of biodiesel as a substitute of fossil fuels**[1]**. Bio-diesel production is a very modern and technological area for researchers due to the relevance that it is winning everyday because of the increase in the petroleum prices and the environmental advantages biodiesel offers over diesel. Accordingly, many researchers around the world have dealt with these issues and in many cases devised unique solutions. Countless legislative and regulatory efforts around the world have helped pave the way toward the widespread application of the concept**[2]**.

1.3 BIODIESEL

The major components of vegetable oils and animal fats are triacylglycerols (TAG; often also called triglycerides). Chemically, TAG are esters of fatty acids (FA) with glycerol (1,2,3-propanetriol; glycerol is often also called glycerine). The TAG of vegetable oils and animal fats typically contain several different FA. Thus, different FA can be attached to one glycerol backbone. The different FA that are contained in the TAG comprise the FA profile (or FA composition) of the vegetable oil or animal fat. Because different FA have different physical and chemical properties, the FA profile is probably the most important parameter influencing the corresponding properties of a vegetable oil or animal fat. Biodiesel can be produced from a great variety of feedstocks. These feedstocks include most common vegetable oils (e.g., soybean, cottonseed, palm, peanut, rapeseed/canola, sunflower, safflower, coconut) and animal fats (usually tallow) as well as waste oils (e.g., used frying oils). The choice of feedstock depends largely on geography. Depending on the origin and quality of the feedstock, changes to the production process may be necessary. Biodiesel is miscible with petrodiesel in all ratios. In many countries, this has led to the use of blends of biodiesel with petrodiesel instead of neat biodiesel. It is important to note that these blends with petrodiesel are not biodiesel. Often blends with petrodiesel are denoted by acronyms such as B20, which indicates a blend of 20% biodiesel with petrodiesel **[2]**.

1.4 HISTORY OF BIODIESEL

The use of vegetable oils as alternative fuels has been around for one hundred years when the inventor of the diesel engine Rudolph Diesel first tested peanut oil, in his compression-ignition engine. In the 1930s and 1940s vegetable oils were used as diesel fuels from time to time, but usually only in emergency situations. In 1940 first trials with vegetable oil methyl and ethyl esters were carried out in France and, at the same time, scientists in Belgium were using palm oil ethyl ester as a fuel for buses. Not much was done until the late 1970s and early 1980s, when concerns about high petroleum prices motivated extensive experimentation with fats and oils as alternative fuels. Bio-diesel (mono alkyl esters) started to be widely produced in the early 1990s and since then production has been increasing steadily. In the European Union (EU), bio-diesel began to be promoted in the 1980s as a means to prevent the decline of rural areas while responding to increasing levels of energy demand. However, it only began to be widely developed in the second half of the 1990s **[1]**.

1.5 METHODS

Generally the direct use of vegetable oils in the diesel engine is not preferred due to their high viscosity.

Four methods to reduce the high viscosity of vegetable oils to enable their use in common diesel engines without operational problems such as engine deposits have been investigated:

- Pyrolysis;
- Microemulsification;
- Dilution; and
- Transesterification.

1.5.1 Pyrolysis [3][4]

Pyrolysis is the conversion of one substance into another by means of heat or by heat with the aid of a catalyst. It involves heating in the absence of air or oxygen and cleavage of chemical bonds to yield small molecules The liquid fractions of the thermally decomposed vegetable oil are likely to approach diesel fuels. The pyrolyzates have lower viscosity, flash point, and pour point than diesel fuel and equivalent calorific values. The cetane number of the pyrolyzate is lower. The pyrolysed vegetable oils contain acceptable amounts of sulphur, water and sediment and give acceptable copper corrosion values but unacceptable ash, carbon residue and pour point.

1.5.2 Micro-emulsification [3][4]

The formation of microemulsions (co-solvency) is one of the potential solutions for solving the problem of vegetable oil viscosity. A microemulsion is defined as a colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the 1±150 nm range formed spontaneously from two normally immiscible liquids and one or more ionic or non-ionic amphiphiles. A micro-emulsion can be made of vegetable oils with an ester and dispersant (co-solvent), or of vegetable oils, an alcohol and a surfactant and a cetane improver, with or without diesel fuels. Water (from aqueous ethanol) may also be present in order to use lower-proof ethanol, thus increasing water tolerance of the micro-emulsions.

1.5.3 Dilution [3]

Dilution of vegetable oils can be accomplished with materials as diesel fuels, solvent or ethanol.

1.5.4 Transesterification[2][3][5]

Although blending of oils and other solvents and microemulsions of vegetable oils lowers the viscosity, engine performance problems such as carbon deposit and lubricating oil contamination still exist. Pyrolysis produces more biogasoline than biodiesel fuel. Transesterification is by far the most common method for the production of biodiesel. As the name suggests it is the conversion of one ester into other. When the original ester is reacted with an alcohol, the transesterification process is called alcoholysis. The transesterification is an equilibrium reaction and the transformation occurs essentially by mixing the reactants. However, the presence of a catalyst (typically a strong acid or base) accelerates considerably the adjustment of the equilibrium. In order to achieve a high yield of the ester, the alcohol has to be used in excess. Figure.1.1 describes the basic transesterfication process.

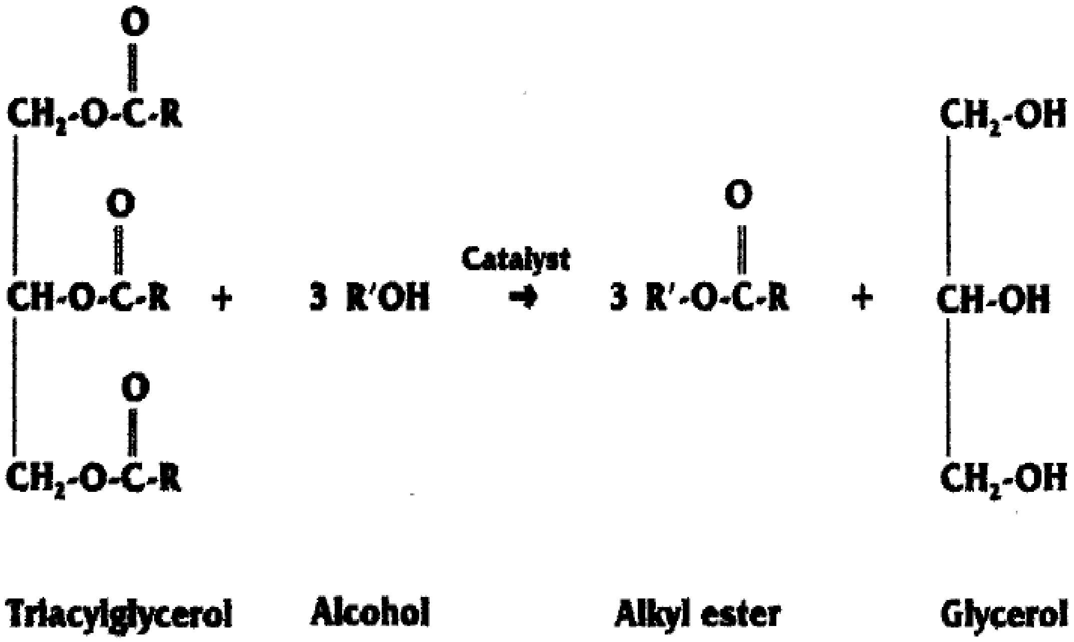


Figure-1.1 The transesterification reaction. R is a mixture of various fatty acid chains. The alcohol used for producing biodiesel is usually methanol (R′ = CH3).**[2]**

Generally, transesterification can proceed by base or acid catalysis. However, in homogeneous catalysis, alkali catalysis (sodium or potassium hydroxide; or the corresponding alkoxides) is a much more rapid process than acid catalysis.

1.5.4.1 Process variables in transesterification

The most important variables that influence transesterification reaction time and conversion are:

- Oil temperature
- Reaction temperature
- Ratio of alcohol to oil
- Catalyst type and concentration
- Mixing intensity
- Purity of reactants.

1.5.4.1.1 Oil Temperature

The temperature to which oil is heated before mixing with catalyst and methanol, affects the reaction. It was observed that increase in oil temperature marginally increases the percentage oil to bio-diesel conversion as well as the bio-diesel recovery. However, the tests were conducted up-to only 60°C as higher temperatures may result in methanol loss in the batch process.

1.5.4.1.2 Reaction temperature

The rate of reaction is strongly influenced by the reaction temperature. Generally, the reaction is conducted close to the boiling point of methanol (60 to 70°C) at atmospheric pressure. The maximum yield of esters occurs at temperatures ranging from 60 to 80°C at a molar ratio (alcohol to oil) of 6:1. Further increase in temperature is reported to have a negative effect on the conversion. Studies have indicated that given enough time, transesterification can proceed satisfactorily at ambient temperatures in the case of the alkaline catalyst.

It was observed that bio-diesel recovery was affected at very low temperatures (just like low ambient temperatures in cold weather) but conversion was almost unaffected.

1.5.4.1.3 Ratio of alcohol to oil

Another important variable affecting the yield of ester is the molar ratio of alcohol to vegetable oil. A molar ratio of 6:1 is normally used in industrial processes to obtain methyl ester yields higher than 98% by weight. Higher molar ratio of alcohol to vegetable oil interferes in the separation of glycerol.

It was observed that lower molar ratios required more reaction time. With higher molar ratios, conversion increased but recovery decreased due to poor separation of glycerol. It was found that optimum molar ratios depend upon type & quality of oil.

1.5.4.1.4 Catalyst type and concentration

Alkali metal alkoxides are the most effective transesterification catalyst compared to the acidic catalyst. Sodium alkoxides are among the most efficient catalysts used for this purpose, although potassium hydroxide and sodium hydroxide can also be used. Transesterification occurs many folds faster in the presence of an alkaline catalyst than those catalysed by the same amount of acidic catalyst. Most commercial transesterifications are conducted with alkaline catalysts. The alkaline catalyst concentration in the range of 0.5 to 1% by weight yields 94 to 99% conversion of vegetable oil into esters. Further, increase in catalyst concentration does not increase the conversion and it adds to extra costs because it is necessary to remove it from the reaction medium at the end.

It was observed that higher amounts of sodium hydroxide catalyst were required for higher FFA oil. Otherwise higher amount of sodium hydroxide resulted in reduced recovery due to more quantity of glycerol being separated from the oil.

1.5.4.1.5 Mixing intensity

The mixing effect is most significant during the slow rate region of the transesterification reaction. As the single phase is established, mixing becomes insignificant. The understanding of the mixing effects on the kinetics of the transesterification process is a valuable tool in the process scale-up and design. It was observed that after adding methanol & catalyst to the oil, 5-10 minutes stirring helps in higher rate of conversion and recovery.

1.5.4.1.6 Purity of reactants

Impurities present in the oil also affect conversion levels. Under the same conditions, 67 to 84% conversion into esters using crude vegetable oils can be obtained, compared with 94 to 97% when using refined oils. The free fatty acids in the original oils interfere with the catalyst. However, under conditions of high temperature and pressure this problem can be overcome.

It was observed that crude oils were equally good compared to refined oils for production of bio-diesel. However, the oils should be properly filtered. Oil quality is very important in this regard. The oil settled at the bottom during storage may give lesser bio-diesel recovery because of accumulation of impurities like wax etc.

1.6 RAW MATERIAL AND ITS QUALITY FOR THE PRODUCTION OF BIODIESEL [3]

1.6.1 Vegetable Oil

The oil must be moisture-free because every molecule of water destroys a molecule of the catalyst thus decreasing its concentration. Any sediment would collect at the bottom of the reaction vessel during glycerol settling and at the liquid interface during washing. This would interfere with the separation of the phases and may tend to promote emulsion formation. The free fatty acid content should be less than 1%.

It was observed that lesser the FFA in oil better is the bio-diesel recovery. Higher FFA oil can also be used but the bio-diesel recovery will depend upon oil type and amount of catalyst used.

1.6.2 Alcohol

Methanol or ethanol, as near to absolute as possible. As with the oil, the water affects the extent of conversion enough to prevent the separation of glycerol from the reaction mixture.

1.6.3 Catalyst

Sodium or potassium hydroxide should be used as a catalyst, preferably the latter. The corresponding alkoxide also can be used, but prohibitively expensive. Best if it has 85% potassium hydroxide. Even best grades of potassium hydroxide have 14-15% water which cannot be removed. It should be low in carbonate, because the carbonate is not an efficient catalyst and may cause cloudiness in the final ester. Sodium hydroxide pellets have given very good results. Because quantity of catalyst used is quite less, good quality catalyst (in-spite of high cost) can be used.

1.6.4 Animal fats

The most prominent animal fat to be studied for potential biodiesel use is tallow. Tallow contains a high amount of saturated fatty acids, and it has therefore a melting point above ambient temperature.

1.6.5 Waste vegetable oils

Every year many millions of tonnes of waste cooking oils are collected and used in a variety of ways throughout the world. This is a virtually inexhaustible source of energy, which might also prove an additional source of power. These oils contain some degradation products of vegetable oils and foreign material. However, analyses of used vegetable oils indicate that the differences between used and unused fats are not very great and in most cases simple heating and removal by filtration of solid particles suffices for subsequent transesterification. The cetane number of a used frying oil methyl ester was given as 49, thus comparing well with other materials.

1.6.6 Esters of vegetable oil

They make good biomass fuels as diesel substitutes, provided the following factors receive special attention:

- The yield of transesterified product should be >90%.
- The fuel should be as neutral as possible (pH 6.5-8.0)
- The fuel should be centrifuged at a temperature below the expected ambient operating temperature. Winterization has been suggested as the ideal solution.
- The neutralizing agent should form fuel in soluble salts, free from carbonate groups.
- Ash content should be 0.01%. The fuel should be free from alcohol as alcohol has an adverse effect on the rubber gaskets and piston rings in the engine.

Table 1.1 US and Indian standards for biodiesel

Source: http://www.svlele.com/biodiesel_std.htm

Standards for Biodiesel	ASTM D-6751	IS 15607 : 2005
Density	Not Mentioned	860 - 900 Kg / m^3
Ester Content	Not Mentioned	96.5 %
Flash point (closed cup)	130°C min. (150°C average)	120°C
Water and sediment	0.050% by vol., max.	500 mg / Kg, max
Kinematic viscosity at 40°C	1.9-6.0 mm^2/s	2.5-6.0 mm^2/s
Oxidation Stability	Not Mentioned	6 hours min, at 110°C
Ramsbottom carbon residue, % mass	0.10	
Sulfated ash	0.020% by mass, max.	
Sulfur	0.05% by mass, max.	50 mg / Kg max
Copper strip corrosion 3 hrs. 50°C	No. 3 max	Class 1
Cetane Number	47 min.	51 min.
Carbon residue	0.050% by mass, max.	
Acid number, mg KOH/g	0.80 max.	0.50 max.
Methanol or Ethanol	Not Mentioned	0.2 % m/m, max
Free glycerin	0.020 % mass	0.020 % mass
Total glycerine (free glycerine and unconverted glycerides combined)	0.24% by mass, max.	0.25% by mass, max.
Group I Metal (Na+K)	5 mg/Kg, max	5 mg/Kg, max
Group II Metal (Ca+Mg)	Not Mentioned	5 mg/Kg, max
Phosphorus content	0.001 max. % mass	10 mg/Kg, max
Distillation	90% @ 360°C	Not Mentioned

1.7 STORABILITY OF BIO-DIESEL

It is generally observed that when the bio-diesels of different oils are stored, their FFA as well as viscosity increases. However, FFA remaines below 1% even after one and a half years of storage. During storage, the bio-diesels also gain some weight due to oxidation.

1.8 RICE BRAN OIL[13][24]

Rice is produced in very large quantities in nine countries of South-east Asia. Considerable amounts are also produced in the USA, Europe and Latin America. China is the largest rice producing country followed by India. Rice bran is a byproduct of rice processing industry and upon extraction yields rice bran oil. The oil content of rice bran varies in each variety, and depends to an even greater extent on the processes and conditions obtained during rice milling. Rice bran, as such, has 15 to 25% of oil associated with it. The total world production of about 4000 million tons of paddy may yield about 6-7 million tons of edible grade oil. Modern techniques of recovery would yield oil and other by-products of better quality than the old technologies, still being used in India, China and other Asian countries. Rice bran oil is comparatively new oil, recently introduced in the consumer market. It is used in the manufacture of vanaspathi and for culinary purposes. Rice bran oil shows great promise for extensive use in India, due to the presence of several factors like γ-oryzanol, which are known to protect from cardiovascular diseases.

There are a number of factors that influence the quality of rice bran oil. Immediate extraction and processing are considered as of prime importance, as delayed extraction can lead to problems, such as color changes and deterioration of organoleptic quality and flavours. Moreover, rice bran quality is also influenced by the presence of an active lipase, which hydrolyses the triglyceride to fatty acids and glycerol. The rate of hydrolysis is so high that the free fatty acid (FFA) content in the oil may rise by 10-20% within a day and up to 70% in a month, imparting a dark colour to the oil. Commonly rice bran oils having an FFA content of 15-40% are produced. Commercial rice bran oil varies in FFA depending on the quality of rice bran from which the oil has been extracted. Rice bran oil is more difficult to refine using methods like alkali or heat treatment, due to the presence of tightly associated wax. Hence, the oil has to be dewaxed and degummed before being neutralized. De-waxing is done by treating with hexane or other solvents and removing the separated wax by filtration or centrifugation. Thereafter, the oil has to be degummed. The total availability of rice bran oil in India is about 6 million tons [**24**]. The present production of rice bran oil is about 400,000 tons of which only 50% is of edible grade, 50% of the total available rice bran oil is left unutilized due to various reasons. Thus the unutilized oil can be used for various purposes. One of the most effective way is to extract biodiesel from it.

1.8.1 RICE BRAN OIL AS BIODIESEL[10]

Biodiesel is a renewable, biodegradable and nontoxic fuel for diesel engines. As alternative fuel biodiesel has attracted considerable attention during the past decades. The main hurdle to the commercialization of biodiesel is the cost of raw materials. The high value of soybean oil or canola oil as a food product makes production of a cost-effective fuel very challenging. Use of edible oils as biodiesel feedstock cost about 60-70% of raw material cost. Nonedible, inexpensive, low-grade oils with value added byproducts is utmost important to make the biodiesel production economical. Rice bran oil ranks first among the non-conventional, inexpensive, low-grade vegetable oils. Furthermore, crude rice bran oil is a rich source of high value-added byproduct. Therefore, use of rice bran oil as raw material for the production of biodiesel not only makes the process economical but also generates value added bio-active compounds. Isolation and purification of these byproducts make the process attractive and remunerative. Thus, if the by-products are derived from crude rice bran oil and the resultant oil is used as feedstock for biodiesel, the resulting biodiesel could be quite economical and affordable.

CHAPTER 2

LITERATURE REVIEW

2.1 REVIEW OF LITERATURE

A substantial amount of work has been done on various aspects of biodiesel. This chapter categorises the literatures into three parts.

First part discusses the literature related to biodiesel and transesterification,

Second part discusses the literature related to the production of biodiesel from rice bran oil.

Third part discusses the literature related to the performance and emission characteristics of diesel engine run on biodiesel.

Mustafa Balat , Havva Balat[1] described that the problems with substituting triglycerides for diesel fuels were mostly associated with their high viscosities, low volatilities and polyunsaturated character. The viscosity of vegetable oils, when used as diesel fuel, can be reduced in at least four different ways: (1) dilution with hydrocarbons (blending), (2) emulsification, (3) pyrolysis (thermal cracking), and (4) transesterification (alcoholysis). Transesterification was the most common method and leads to monoalkyl esters of vegetable oils and fats, now called bio-diesel when used for fuel purposes. The main factors affecting transesterification were molar ratio of glycerides to alcohol, catalyst, reaction temperature and pressure, reaction time and the contents of free fatty acids and water in oils. The commonly accepted molar ratios of alcohol to glycerides are 6:1–30:1. Bio-diesel is a cleaner-burning diesel replacement fuel made from natural, renewable sources such as new and used vegetable oils and animal fats. Just like petroleum diesel, bio-diesel operates in compression-ignition engines or Diesel engines. The bio-diesel was characterized by determining its density, viscosity, high heating value, cetane index, cloud and pour points, characteristics of distillation, and flash and combustion points according to ISO norms. Viscosity is the most important property of bio-diesel since it affects the operation of the fuel injection equipment, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel.

Gerhard Knothe et al.[2] in their book described the technical concept of using vegetable oils or animal fats or even used oils as a renewable diesel fuel. Biodiesel is the form in which these oils and fats are being used as neat diesel fuel or in blends with petroleum-based diesel fuels. The concept itself may appear simple, but that appearance is deceiving since the use of biodiesel is fraught with numerous technical issues. Accordingly, many researchers around the world have dealt with these issues and in many cases devised unique solutions. This book was an attempt to summarize these issues, to explain how they have been dealt with, and to present data and technical information. Countless legislative and regulatory efforts around the world have helped pave the way toward the widespread application of the concept. This book addressed these issues also. To complete the picture, chapters on the history of vegetable oil-based diesel fuels, the basic concept of the diesel engine, and glycerol, a valuable byproduct of biodiesel production, were included.

Report of the committee on development of bio-fuel, Planning Commission India[3] discussed the problems in using petroleum derived high speed diesel, characteristics of biodiesel, rationale, feasibility of producing bio-diesel as petro-diesel substitute, target of bio-diesel production, specifications and quality standards for bio-fuels, R&D issues needing attention(raw material, production technology, utilization as fuel, plants in operation/ under construction, blending of esters & diesel, storage & handling of bio-diesel, engine development & modifications).

While discussing the characteristics it stated that bio-diesel had properties similar to petroleum diesel fuels. Bio diesel is a substitute for diesel. The specifications of bio-diesel are such that it can be mixed with any diesel fuel. Thus, biodiesel can supplement the supply of environment friendly fuels in our country in future. In conventional diesel fuels, the reduction in sulfur content is compensated by adding an additive for lubricity of fuel injection pump (FIP). Biodiesel reported to have superior lubricity. Flash point of bio-diesel is high (> 100º C). Its blending with diesel fuel can be utilized to increase the flash point of diesel particularly in India where flash point is 35º C well below the world average of 55º C. This is important from the safety point of view. The viscosity of biodiesel is higher (1.9 to 6.0 cSt) and is reported to result into gum formation on injector, cylinder liner etc. However, blends of up to 20% should not give any problem. While an engine can be designed for 100% bio-diesel use, the existing engines can use 20% biodiesel blend without any modification and reduction in torque output. It can be stored just like the petroleum diesel fuel and hence does not require separate infrastructure. Bio-diesel has been accepted as clean alternative fuel by US. Due to its favourable properties, biodiesel can be used as fuel for diesel engines (as either, B5-a blend of 5% bio-diesel in petro-diesel fuel, or B20 or B100). USA uses B20 and B100 bio-diesel, France uses B5 as mandatory in all diesel fuel.

Under specifications and quality standards for bio-fuels report described that ASTM(American Society for Testing and Materials**)** had issued bio-diesel standard D 6751 in December 2001, which covers the use of pure bio-diesel (B100) into conventional diesel fuel up to 20% by volume (B20). This replaced the provisional specification PS 121 issued in1999. Austria (ON C 1191), France (JO), Italy (UNI 10635) and Germany (DIN E 51606) had issued bio-diesel standards in 1997, Sweden in 1996 and a common draft standard EN 14214 for the European Union has also been announced. The standards for biodiesel in India were under formulation and were proposed to be based on standards adopted by European Union. It was necessary that the approval of Vehicle, Engine and Fuel Injection manufactures was taken before finalizing standards and implementing fuel change. By getting warranties from OEMs(Original Equipment Manufacturers) and FIE manufacturers, the customer acceptance of bio-fuels will increase and shall go a long way in enhancing the use of bio- fuels.

Different technologies are currently available and used in the industrial production of bio-diesel, which are sold under different trademarks. For example, there are the Italian processes Novamont, and the French IFP. A number of units are manufacturing bio-diesel worldwide. These units are using sunflower oil, soybean oil, rapeseed oil, used-frying oil, Jatropha oil, etc. as a source of triglycerides . Out of 85 plants identified, 44 plants were in Western Europe with Italy as the leading country with 11 plants, 29 plants in Eastern Europe, 8 plants in North America and 4 plants in the rest of the world. Overall capacity grew from 111,000 tons in 1991 to 1,286,000 in 1997. USA is the fastest growing newcomer and a number of companies are emerging there. Additional capacities are expected in Japan and the palm oil producing countries, Indonesia and Malaysia. Actual production grew from 10,000 tons in 1991 to 661,000 tons in 1997. France is the leading producer with 227,000 tons (in 1996).

Fangrui Maa, Milford A. Hannab[4] described the four primary ways to make biodiesel, direct use and blending, microemulsions, thermal cracking (pyrolysis) and transesterification. Of the several methods available for producing biodiesel, transesterification of natural oils and fats was the method of choice. The purpose of the process is to lower the viscosity of the oil or fat. Although blending of oils and other solvents and microemulsions of vegetable oils lowers the viscosity, engine performance problems, such as carbon deposit and lubricating oil contamination, still exist. Pyrolysis produces more biogasoline than biodiesel fuel. Transesterification is basically a sequential reaction. Triglycerides are first reduced to diglycerides. The diglycerides are subsequently reduced to monoglycerides. The monoglycerides are finally reduced to fatty acid esters. The order of the reaction changes with the reaction conditions. The main factors affecting transesterification are molar ratio of glycerides to alcohol, catalysts, reaction temperature and time and the contents of free fatty acids and water in oils and fats. The commonly accepted molar ratio of alcohol to glycerides is 6:1. Base catalysts are more effective than acid catalysts and enzymes. The recommended amount of base used to use is between 0.1 and 1% w/w of oils and fats. Higher reaction temperatures speed up the reaction and shorten the reaction time. The reaction was slow at the beginning for a short time and proceeds quickly and then slowed down again. Base catalyzed transesterifications were basically finished within one hour.

Ulf Schuchardta et al.[5] reviewed the transesterification of vegetable oils with methanol as well as the main uses of the fatty acid methyl esters. The general aspects of this process and the applicability of different types of catalysts (acids, alkaline metal hydroxides, alkoxides and carbonates, enzymes and non-ionic bases, such as amines, amidines, guanidines and triamino(imino)phosphoranes) were described. Special attention was given to guanidines, which can be easily heterogenized on organic polymers. However, the anchored catalysts show leaching problems. New strategies to obtain non-leaching guanidine-containing catalysts are proposed. Finally, several applications of fatty acid esters, obtained by transesterification of vegetable oils, are described.

M.Mathiyazhagan et al.[6] researched on the non-edible oils as feed stocks for biodiesel production to reduce the cost of biodiesel. Normally alkali catalyzed method was followed for biodiesel production process. However the non-edible oils having high FFA content which is not suitable for normal transesterification process. Hence a two-step catalyzed method was used to prepare the biodiesel. High FFA content of non-edible oils were efficiently converted into biodiesel fuel. Figure 2.1 shows the flow diagram of biodiesel production from non-edible oils.

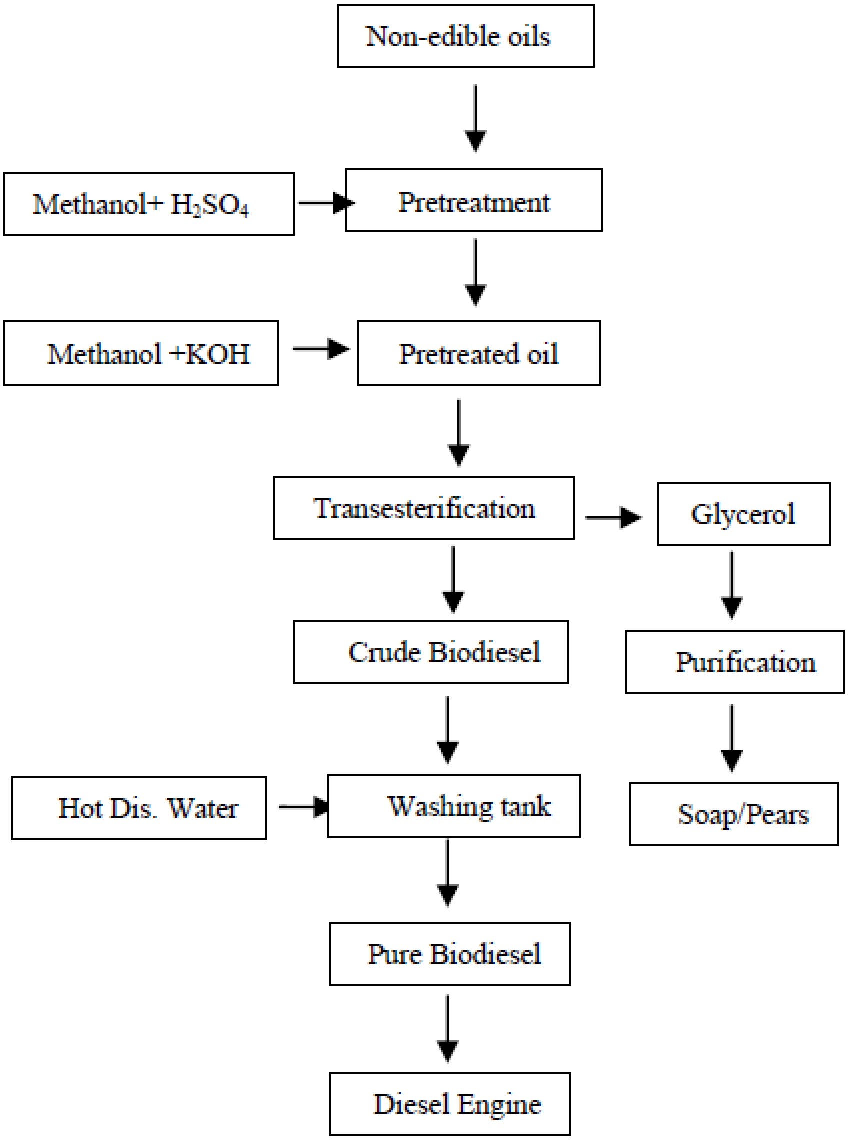


Figure-2.1 Flow chart of Biodiesel production from non-edible oils**[6]**

M. Canakci, J. Van Gerpen[7] investigated the use of low–cost, high FFA feedstocks to produce fuel–quality biodiesel. It was determined that feedstocks with high FFAs could not be transesterified with the traditional alkaline catalysts that have been used with good success for vegetable oils. Alkaline catalysts form soap when they react with the FFAs. Soap removes the catalyst from the reaction and prevents the separation of the glycerin and the ester. A process was developed to use acid catalysts to pretreat the high FFA feedstocks until their FFA level was below 1%, allowing the subsequent use of alkaline catalysts to convert the triglycerides. The effects of the methanol molar ratio, acid catalyst amount, and reaction time on the reduction of FFA level were studied with a simulated high FFA feedstock consisting of 20% palmitic acid in soybean oil. This part of the study showed that the FFA level of the feedstocks could be reduced to less than 1% with a 2–step process of acid–catalyzed pretreatment. Extension of the process to yellow and brown grease showed that higher levels of acid catalyst and methanol were required.

Gerhard Knothe[8] discussed that the fuel properties of biodiesel are strongly influenced by the properties of the individual fatty esters in biodiesel. Both moieties, the fatty acid and alcohol, can have considerable influence on fuel properties such as cetane number with relation to combustion and exhaust emissions, cold flow, oxidative stability, viscosity, and lubricity. Generally, cetane number, heat of combustion, melting point, and viscosity of neat fatty compounds increase with increasing chain length and decrease with increasing unsaturation. It therefore appeared reasonable to enrich (a) certain fatty ester(s) with desirable properties in the fuel in order to improve the properties of the whole fuel. For example, from the available data it appeared that iso-propyl esters had better fuel properties than methyl esters. The major disadvantage was the higher price of iso-propanol in comparison to methanol, besides modifications needed for the transesterification reaction. Similar observations likely hold for the fatty acid moiety.

P.K.Gupta et al.[9] discussed the effect of various parameters on yield and conversion of oil to bio-diesel prepared from rice-bran oil. Percent conversion as well as yield was good at molar ratio of 6:1, reaction time of 4 hour and oil temperature of 60ºC. Yield showed an increasing trend with increase in oil temperature or reaction temperature. Increase in FFA content resulted in decreased yield but conversion remained unaffected. Washing of bio-diesel with warm water prepared from oil of high FFA facilitated better yield. Heating of oil to 100ºC (to remove traces of moisture) helped in better conversion and yield of bio-diesel. Bio-diesel prepared under low ambient temperature should be given washing with warm water in order to obtain good yield.

Orchidea Rachmaniah et al.[10] objective was to conduct a systematic studies of transesterification of low grade high FFA rice bran oil to establish optimal reaction condition. The variables of substrate that affecting ester formation were investigated to determine the best strategy for producing biodiesel. The following conclusions were drawn from the acid-catalyzed biodiesel production study:

1. The amount of free fatty acid in oil can had a significant effect on the transesterification reaction.
2. The rate reaction of fatty acid to methyl ester was faster than rate reaction of triglycerides.
3. Effect of chain length and unsaturation of fatty acid on rate of esterification of fatty acid with methanol were equally reactive irrespective of difference in their chemical structures.
4. Fatty acids from different sources given similar conversions and change in the fatty acids composition had no effect on rate of methanolysis.
5. Acid-catalyzed transesterification was suitable for low grade high FFA oils like rice bran oil than alkaline-catalyzed.

Novy Srihartati Kasim et al.[11] carried out the study of reaction between supercritical methanol and rice bran or DDRBO(dewaxed degummed rice bran oil) with CO_2 as the co-solvent. The production of FAMEs(fatty acid methyl esters) by in situ transesterification of rice bran and supercritical methanol was not a promising way. It was found that the yield of biodiesel was low (51.28%) and rice bran cannot be recovered for reuse. DDRBO was a suitable raw material for biodiesel production by reacting with supercritical methanol. When DDRBO was reacted, the purity and yield were 89.25% and 94.84%, respectively. Trans- FAMEs, which constitute about 16.05% of biodiesel, were discovered which are the products of the isomerization of unsaturated FAMEs. Aliphatic hydrocarbons detected in the product were confirmed to result from the decomposition of TAGs(triacylglycerols). Steroidal hydrocarbons as impurities in FAMEs may have been the results of the dehydration reaction of sterols which is a minor component in DDRBO.

Yi-Hsu Ju, Shaik Ramjan Vali[12] discussed that the main concern with biodiesel fuel is its high price. One of the future aims in biodiesel research is on the selection of inexpensive feedstock with high value-added byproducts. Rice bran is a byproduct of rice milling that contains 15-23% lipids and significant amount of nutraceutical compounds. Due to the presence of active lippase in the bran and lack of economical stabilization methods, most bran is used as livestock feed or boiler fuel and most rice bran oil (RBO) produced is of non edible grade. Thus RBO is relatively an inexpensive raw material for the production of biodiesel. The utilization of the by-product such as defatted rice bran for the production of proteins, carbohydrates, photochemical, and the isolation and purification of value added nutraceutical generated during biodiesel production from RBO are attractive options to lower the cost of biodiesel. Production of biodiesel from RBO can be carried out either via in situ esterification, lipase-catalyzed esterification, acid-catalyzed, base-catalyzed reactions. A single step reaction for the conversion of RBO with high free fatty acid content into biodiesel, via acid-catalyzed, base-catalyzed or lipase-catalyzed, fails to attain high conversion in reasonably short time. Pretreatment of crude RBO such as dewaxing/degumming is a crucial step because of its efficient methanolysis. The fatty acid composition of dewaxed/degummed RBO is similar to that of other vegetable oils, which are used as biodiesel feedstock.

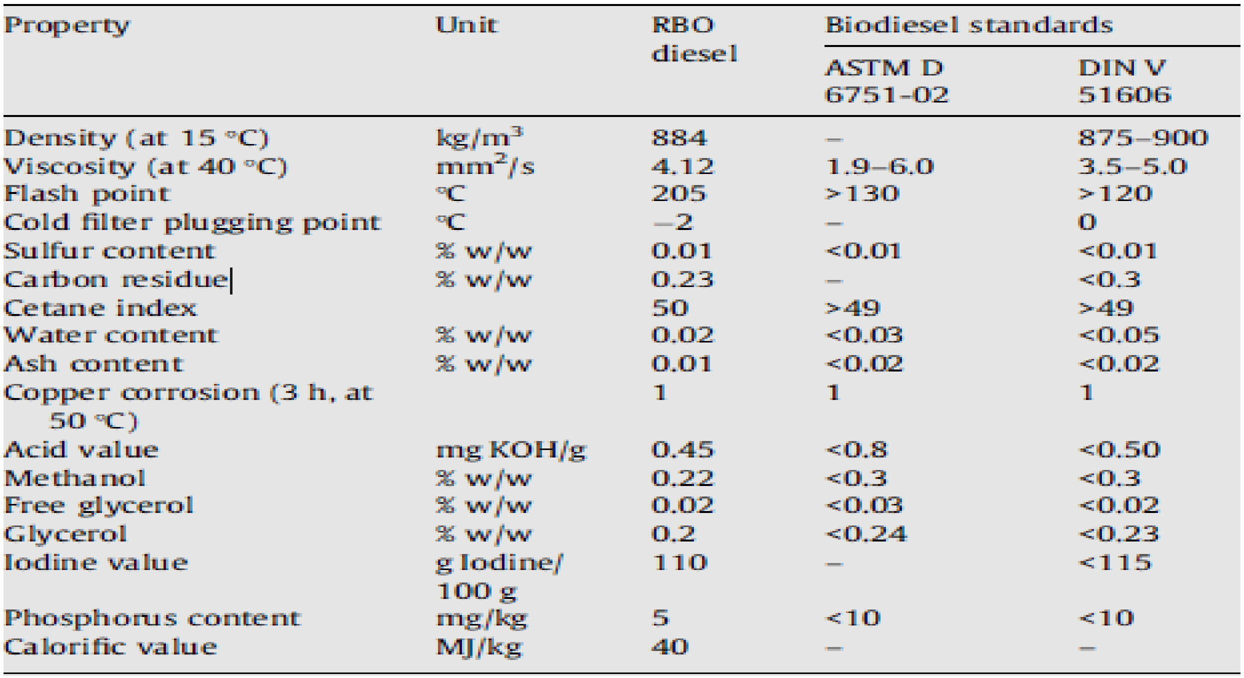
Kusum R. et al.[13] discussed the current status and future prospects of rice bran oil. Several advantages along with the health protecting effects where discussed. Total availability of rice bran oil in India is 6 million tons. India’s production of rice bran oil has been shown about 400,000 tons of which only 50% is of edible grade and 50% of the total available rice bran oil is left unutilized due to various reasons. Necessary steps should be taken to enhance the production of rice bran oil.

Janahiraman Krishnakumar et al.[14] discussed the technical aspects of biodiesel production from vegetable oils. In the first step of their experimental research, edible rice bran oil used as test material and converted into methyl ester and non-edible jatropha vegetable oil was converted into jatropha oil methyl ester, which are known as biodiesel and they were prepared in the presence of homogeneous acid catalyst and optimized their operating parameters like reaction temperature, quantity of alcohol and the catalyst requirement, stirring rate and time of esterification. In the second step, the physical properties such as density, flash point, kinematic viscosity, cloud point, and pour point were found out for the above vegetable oils and their methyl esters. The characteristics like density, viscosity, flash point, cloud and pour point were within the specification of ASTM norms. The same characteristics study was also carried out for the diesel fuel for obtaining the baseline data for analysis. The values obtained from the rice bran oil methyl ester and jatropha oil methyl ester were closely matched with the values of conventional diesel and it can be used in the existing diesel engine without any hardware modification. In the third step the storage characteristics of biodiesel were also studied. Finally it was concluded that based on the field trails and storage, biodiesel from jatropha oil and rice bran oil could be recommended as a fuel, if engine performance tests provide satisfactory results.

Young-Cheol Bak et al.[15] investigated the transesterification of rice bran oil to produce the bio-diesel oil. Experimental condition included molar ratio of rice bran oil to alcohol(1:3, 1:5, 1:7), concentration of catalyst used(0.5,1.0 and 1.5 wt%), types of catalysts(sodium methaoxide, NaOH and KOH), reaction temperatures(30,45 and 60°C) and types of alcohols(methanol, ethanol and butanol). The conversion of rice bran oil increased with alcohol mixing ratio and with the reaction temperature. Sodium methaoxide was the most effective among the catalysts. The conversion was increased with the concentration of catalyst, but slightly increased over 1.0 wt%. the best conversion was obtained using methanol with sodium methaoxide. In the case, 98% conversion was achieved within 1 hr.

Lin Lin et al.[16] research reported on the successful production of biodiesel by transesterification of crude rice bran oil(RBO). The process included three-steps. Firstly, the acid value of RBO was reduced to below 1 mg KOH/g by two-steps pretreatment process in the presence of sulfuric acid catalyst. Secondly, the product prepared from the first process was carried out esterification with an alkaline catalyst. The influence of four variables on conversion efficiency to methyl ester, i.e., methanol/RBO molar ratio, catalyst amount, reaction temperature and reaction time, was studied at this stage. The content of methyl ester was analyzed by chromatographic analysis. Through orthogonal analysis of parameters in a four-factor and three-level test, the optimum reaction conditions for the transesterification were obtained: methanol/ RBO molar ratio 6:1, usage amount of KOH 0.9% w/w, reaction temperature 60 ºC and reaction time 60 min. In the third step, methyl ester prepared from the second processing step was refined to become biodiesel. Fuel properties of RBO biodiesel were studied and compared according to ASTM D6751-02 and DIN V51606 standards for biodiesel. Most fuel properties complied with the limits prescribed in the aforementioned standards. The consequent engine test showed a similar power output compared with regular diesel. Emission tests showed a marked decrease in CO, HC and PM, however, with a slight increase in NOx. The biodiesel obtained by above process was of good quality and it can be used as an alternative fuel in current diesel engines without any expensive modifications. By means of simple chemical methods, a low-quality under-utilized RBO has been used to produce biodiesel. RBO is predicted to be more economical to produce than biodiesel from refined vegetable oil.

Table 2.1 Fuel properties of rice bran oil biodiesel **[13]**



Property	Unit	RBO diesel	Biodiesel standards	
			ASTM D 6751-02	DIN V 51606
Density (at 15 °C)	kg/m^3	884	–	875–900
Viscosity (at 40 °C)	mm^2/s	4.12	1.9–6.0	3.5–5.0
Flash point	°C	205	>130	>120
Cold filter plugging point	°C	−2	–	0
Sulfur content	% w/w	0.01	<0.01	<0.01
Carbon residue	% w/w	0.23	–	<0.3
Cetane index		50	>49	>49
Water content	% w/w	0.02	<0.03	<0.05
Ash content	% w/w	0.01	<0.02	<0.02
Copper corrosion (3 h, at 50 °C)		1	1	1
Acid value	mg KOH/g	0.45	<0.8	<0.50
Methanol	% w/w	0.22	<0.3	<0.3
Free glycerol	% w/w	0.02	<0.03	<0.02
Glycerol	% w/w	0.2	<0.24	<0.23
Iodine value	g Iodine/ 100 g	110	–	<115
Phosphorus content	mg/kg	5	<10	<10
Calorific value	MJ/kg	40	–	–

G. Venkata Subbaiah et al.[17] investigated the performance and emission characteristics of conventional diesel, rice bran oil biodiesel, diesel and biodiesel blend and diesel-biodiesel-ethanol blends on a single cylinder diesel engine. The conclusions of the investigation were the following:

- The maximum brake thermal efficiency of 28.2% was observed with the blend B10E15.The BSFC of the biodiesel and all the other fuel blends was higher than that of the diesel fuel.

- The exhaust gas temperature of the blend B10E15 was slightly lower than that of diesel fuel throughout the range of the load on the engine.
- The CO emissions of the biodiesel and all the other fuel blends were lower than that of the diesel fuel. The minimum CO emissions were observed with the blend B10E15 well below the diesel fuel and the biodiesel.
- The HC emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends, but lower than those of the diesel at higher loads on the engine.
- The NOx emissions of the biodiesel and all the other fuel blends were low at lower loads and high at higher loads compared with the diesel fuel
- The CO_2 emissions of the biodiesel and all the other fuel blends were higher than that of the diesel fuel.

Table 2.2: Properties of diesel, rice bran oil biodiesel **[14]**

Property parameters	**Diesel fuel**	**Rice bran oil biodiesel**
Density at 20 ºC, g/cm³	0.82	0.8742
Viscosity at 40 ºC, mm²/s	3.4	4.63
Flash point, ºC	71	165
Auto-ignition temperature, ºC	225	320
Pour point, ºC	1	3
Cetane number	45	56.2
Iodine number, J2 g/100 g	6	102
Acid value, mg KOH/g	0.07	0.25
Oxygen content, max wt%	0.4	11.25
Net heating value, MJ/kg	43.5	38.725

S. Saravanan et al.[18] made an attempt to test the feasibility of crude rice bran oil methyl ester (CRBME) which was derived from high free fatty acid (FFA) crude rice bran oil (CRBO) by a two-step transesterification process as a fuel for a heavy-duty automotive compression ignition (CI), i.e. diesel engine in blended form. While running with CRBME blend significant reductions in CO, UBHC and particulate emission were observed with a marginal increase in NOx emission than that of diesel. Brake thermal efficiency of the engine reduced marginally for CRBME blend when compared with diesel. In addition to technical feasibility, the economic feasibility of CRBME blend as a CI engine fuel was also analyzed by comparing its hourly fuel cost with CRBO blend and diesel. It was found that the hourly fuel cost of CRBME blend is higher than CRBO blend and diesel. Calculations have shown that the hourly fuel cost of CRBME blend when used in a stationary engine increases by 50% while that in an automotive engine increases by 45% when compared to diesel. Experimental results showed that as a fuel for a heavy-duty diesel engine CRBME blend shows better emission characteristics than diesel with a marginal increase in NOx emission.

Rambabu Kantipudi et al.[19] research focussed on the present trend of reducing the exhaust emissions from engines to suit the norms set by Euro/Bharat Pollution Boards along with the replacement of diesel fuel with renewable alternative fuels in the view of the possible depletion of petroleum reserves. Study made was to utilize biodiesel (Rice bran methyl ester) as a total replacement of Petrol-Diesel. Instead of heated air with carburetion technique, on line heating of the fuel ethanol before its being carburetted at the suction end is tried with the view that the volumetric efficiency of the engine didn’t suffered. Betterment in the engine performance and exhaust emission was observed at retrofit engine.

Ram Prakash et al.[20] investigated the performance analysis of compression ignition engine using alternative fuels as rice bran oil and their ester after esterification for different engine load from 1.8 kg to 6.6 kg and different blending ratios like B0,B25,B50,B75,B100. In different blending ratio and different load condition exhaust emission in terms of CO emission, HC emission, exhaust gas temperature, smoke density and comparative performance analysis were studied. Results obtained were satisfactory.

R. Ragu et al.[21] objective was to investigate the effect of preheated rice bran oil on performance and emission characteristics of a direct injection (DI) engine as a substitute for rice bran biodiesel. Experiments were conducted in a constant speed, stationary, direct injection diesel engine and the performance and emissions were investigated. The engine fueled with diesel, rice bran biodiesel (methyl ester), neat rice bran oil, and preheated rice bran oil with standard injection timing and injection pressures at different load conditions and the performances were compared. With the help of a heat exchanger and using the exhaust gases, the rice bran oil was preheated. It was found that the preheated rice bran oil exhibits a closer performance as compared to rice bran biodiesel.

GVNSR Ratnakara Rao et al.[22] made an attempt to find out the optimum compression ratio of a diesel fuelled C.I engine. Experiments were carried out on a single cylinder four stroke variable compression ratio diesel engine. Tests were carried out at compression ratio of 13.2, 13.9, 14.8, 15.7, 16.9, 18.1 and 20.2. Results showed a significant improved performance and emission characteristics at a compression ratio 14.8. the compression ratio lesser than 14.8 and greater than 14.8 showed a drop in brake thermal efficiency, rise in fuel consumption along with increased smoke densities.

R. Anand et al.[23] investigated the performance and emissions of a variable compression ratio diesel engine fuelled with methyl ester of cottonseed oil. Blends with diesel were prepared in four different compositions varying from 5% to 20% in steps of 5%. Tests were conducted in a single cylinder variable compression ratio diesel engine at a constant speed of 1500 rpm. Highest brake thermal efficiency and lowest specific fuel consumption were observed for 5% biodiesel blend for compression ratio of 15 and 17 and 20% biodiesel blend for compression ratio of 19. The 20% biodiesel blend at a compression ratio of 17 had maximum nitric oxide emission as 205 ppm, while it was 155 ppm for diesel. Substantial reduction in carbon monoxide emissions and smoke in the full range of compression ratio and loads was observed. Improved heat release characteristics were observed for the prepared biodiesels. The results revealed that the biodiesels can be used safely without any modification to the engine.

2.2 GAP IN LITERATURE

A lot of work has been done on transesterification of edible oils. Limited amount of work is done for the extraction of the biodiesel through transesterification from non-edible oils. In India, the high cost of edible oils prevents their use in biodiesel preparation. But non-edible oils are affordable for biodiesel production. Cost associated with biodiesel is reduced due to the low cost of the non edible oils. Awareness of the biodiesel extracted from crude rice bran oil is very less. Limited amount of work has been done on the engine performance and emission analysis fuelled with methyl ester of crude rice bran oil. India is the second largest producer of rice in the world and its present production of rice bran oil is about 400,000 tons of which only 50% is of edible grade, 50% of the total available rice bran oil is left unutilized due to various reasons. Thus due to the unawareness of the benefits of this unutilized oil to extract biodiesel limited amount of research work has been done on its use in diesel engines.

2.3 OBJECTIVE OF PRESENT WORK

1. To extract biodiesel from crude rice bran oil and rice bran oil.
2. To evaluate the performance and emission analysis of compression ignition engine fuelled with different blends of biodiesel extracted from crude rice bran oil and rice bran oil.
3. To optimise the compression ratio of a variable compression ratio compression ignition engine using blend of rice bran methyl ester.
4. To compare crude rice bran methyl ester and rice bran methyl ester based on the performance and emission characteristics.

CHAPTER 3

METHODOLOGY

Here in this chapter the methodology for the preparation of biodiesel along with its various properties are described. Along with this it also describes the experimental methodology adopted to evaluate the performance and exhaust emission characteristics of a variable compression ratio(VCR) compression ignition engine using different blends. Biodiesel preparation was done in the biofuel laboratory at Mechanical Engineering Research And Development Organisation(MERADO) Ludhiana, Punjab(India). Experiments were performed in the Internal Combustion Engine Laboratory, Department of Mechanical Engineering, Thapar University, Patiala, Punjab(India).

3.1 BIODIESEL PREPRATION METHODOLOGY

Here starting from the raw material used for biodiesel production along with its method each step for biodiesel production is explained. Various properties of the prepared biodiesel are also discussed.

3.1.1 Material

Following materials were used:

1. Crude rice bran oil
2. Refined rice bran oil
3. Methanol(Methyl alcohol)
4. Potassium hydroxide(KOH) as base catalyst
5. Sulphuric acid(H_2SO_4) as acid catalyst

Dewaxed and degummed crude rice bran oil was provided by A. P. Refinery Private Limited, Jagron, Punjab(India). Refined rice bran oil popularly known as Ricela was purchased from local general provision store. Methanol, Potassium hydroxide(KOH) and Sulphuric acid(H_2SO_4) were available in the biofuel laboratory at MERADO Ludhiana, Punjab. Transesterification was carried out in a water bath shaker.

3.1.2 Biodiesel preparation

As two different oils were used for the extraction of biodiesel, thus two different processes were employed. Because of the high Free Fatty Acid(FFA) content for crude rice bran oil a 2-stage transesterification process which includes an acid catalyzed transesterification followed by a base catalyzed tranesterification was carried out. Whereas for refined rice bran oil a single stage base catalyzed transesterification was carried out.

3.1.2.1 Crude rice bran oil biodiesel preparation (Two stage transesterification)

First stage(Acid catalyzed transesterification)

1. Some known quantity of crude oil was taken in a conical flask.
2. The oil in the flask was then heated on a heating plate upto a temperature of 60°C.
3. A mixture of known quantity of sulphuric acid (H_2SO_4) as acid catalyst and methanol was then mixed with the preheated crude oil.
4. The preheated oil mixture was then subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker.
5. After 1 hour of constant stirring the mixture was poured into a separating funnel for impurities to settle down.
6. After 4-5 hours the settled down impurities are separated from the remaining oil.

Second Stage(Base catalyzed transesterification)

7. Remaining oil quantity was measured and again heated upto 60°C.
8. A mixture of known quantity of Potassium hydroxide (KOH) as base catalyst and methanol was then mixed with the remaining preheated oil.
9. The preheated oil mixture was then again subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker.
10. After 1 hour of constant stirring the mixture was poured into a separating funnel for glycerol to settle down.
11. After 2-3 hours settled down glycerol is separated and removed.
12. Remaining is methyl ester(biodiesel) of crude rice bran oil(Yield 82%) which is further purified through washing and drying for removal of excess KOH, methanol and water.

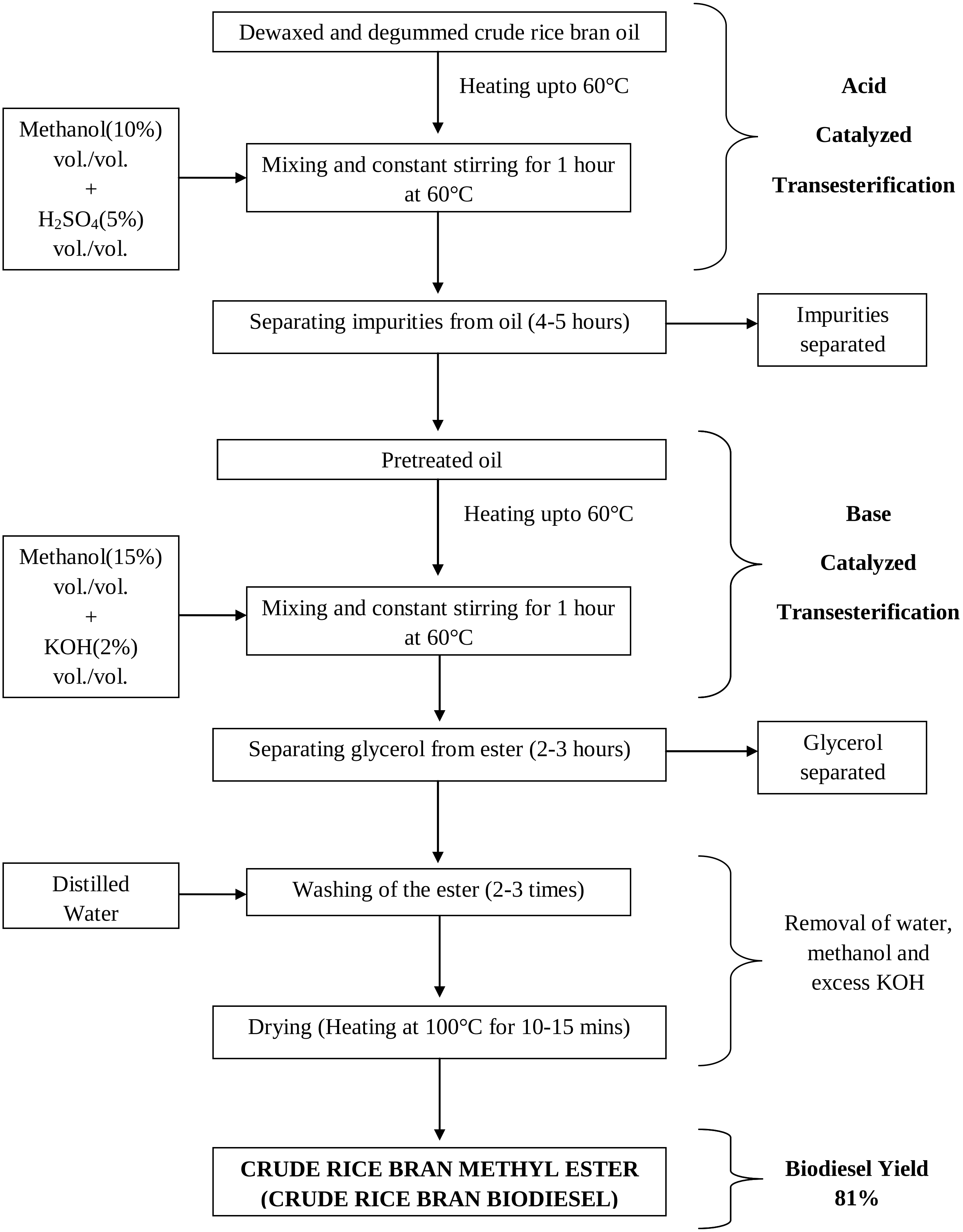


Figure3.1 Schematic diagram of procedure employed for production of Crude rice bran biodiesel

Figure 3.1 shows the schematic diagram of the procedure employed for the production of crude rice bran oil methyl ester (biodiesel).

Various property parameters were evaluated using their respective test methods. Table 3.1 shows the properties evaluated for crude rice bran methyl ester.

Table 3.1 Properties of Crude rice bran methyl ester

Property parameters	**Test method**	**Crude rice bran methyl ester**
Relative Density	Hydrometer, IS: 1448 [P: 32]: 1992	0.877
Viscosity at 40 °C, mm²/sec	Redwood Viscometer, IS : 1448 [P: 25] 1976	3.57
Carbon Residue, % by mass	Carbon Residue Apparatus, ASTM D189-IP 13 of IIP	0.244
Ash Content, % by mass	Electric Muffle Furnace, ASTM D482-IP 4of IIP	0.29
Flash point, °C	Closed cup flash and fire point apparatus, IS: 1448 [P: 32]: 1992	210
Fire point, °C	Closed cup flash and fire point apparatus, IS: 1448 [P: 32]: 1992	215
Calorific value, (kcal/kg)	Bomb Calorimeter, IS:1350 [P: 2]: 1940, reaff. 1994	9812
FFA content (%)	Titration with 0.1N NaOH	0.25
Cloud point, °C	Cloud and Pour point apparatus, IS: 1448 [P: 10]: 1970	0
Pour point, °C	Cloud and Pour point apparatus, IS: 1448 [P: 10]: 1970	-4

3.1.2.2 Refined rice bran oil biodiesel preparation (Single stage transesterification)

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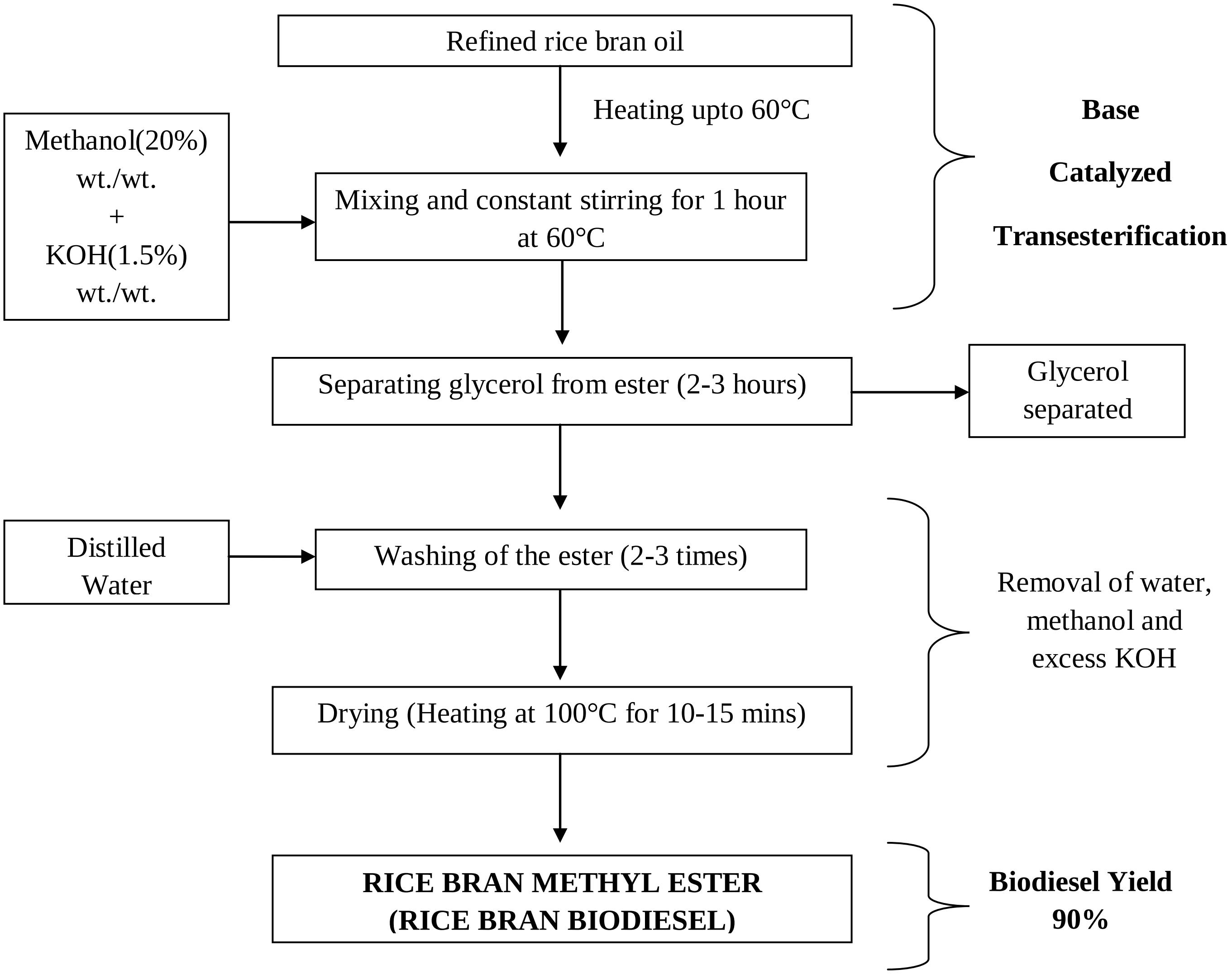


Figure 3.2 Schematic diagram of procedure employed for production of rice bran biodiesel

Single stage (Base catalyzed transesterification)

1. Some known quantity of rice bran oil was taken in a conical flask.
2. The oil in the flask was then heated on a heating plate upto a temperature of 60°C.
3. A mixture of known quantity of Potassium hydroxide (KOH) as base catalyst and methanol was then mixed with the oil.
4. The preheated oil mixture was then subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker.

5. After 1 hour of constant stirring the mixture was poured into a separating funnel for glycerol to settle down.
6. After 2-3 hours settled down glycerol is separated and removed.
7. Remaining is methyl ester (biodiesel) of refined rice bran oil (Yield 90%) which is further purified by washing and drying for removal of excess KOH, methanol and water.

Table 3.2 shows the properties evaluated for rice bran methyl ester.

Table 3.2 Properties of Rice bran methyl ester

Property parameters	**Test method**	**Rice bran methyl ester**
Relative Density	Hydrometer, IS: 1448 [P: 32]: 1992	0.8642
Viscosity at 40 ºC, mm^2/sec	Redwood Viscometer, IS : 1448 [P: 25] 1976	3.21
Carbon Residue, % by mass	Carbon Residue Apparatus, ASTM D189-IP 13 of IIP	0.18
Ash Content, % by mass	Electric Muffle Furnace, ASTM D482-IP 4of IIP	0.24
Flash point, ºC	Closed cup flash and fire point apparatus, IS: 1448 [P: 32]: 1992	158
Fire point, ºC	Closed cup flash and fire point apparatus, IS: 1448 [P: 32]: 1992	163
Calorific value, (kcal/kg)	Bomb Calorimeter, IS:1350 [P: 2]: 1940, reaff. 1994	9918
FFA content (%)	Titration with 0.1N NaOH	0.08
Cloud point, °C	Cloud and Pour point apparatus, IS: 1448 [P: 10]: 1970	2
Pour point, °C	Cloud and Pour point apparatus, IS: 1448 [P: 10]: 1970	-2

Table 3.3 Fatty acid composition of rice bran oil

Fatty Acid Profile	Composition(%)
Myristic Acid (C14)	0.34
Palmitic Acid (C16)	19.5
Stearic Acid (C18)	2.3
Oleic Acid (C18: 1)	43.0
Linolic Acid (C18: 2)	32.0
Linolenic Acid (C18: 3)	1.6
Arechidic Acid (C20)	0.7
Higher Fatty Acids (C22)	0.6

Table 3.3 shows the fatty acid composition of rice bran oil. This composition is same for both crude oil and refined oil.

3.2 EXPERIMENTAL METHODOLOGY

Here a brief description of the apparatus and its method of opertaion is given. Along with it different performance and exhaust emission parameters are also discussed.

3.2.1 Engine Performance Evaluation

Evaluation of the engine performance is described

- Engine description
- Operation
- Parameters evaluated

3.2.1.1 Engine description

Pictorial view of variable compression ratio compression ignition engine setup along with the on line performance evaluation system is shown in figure 3.3.

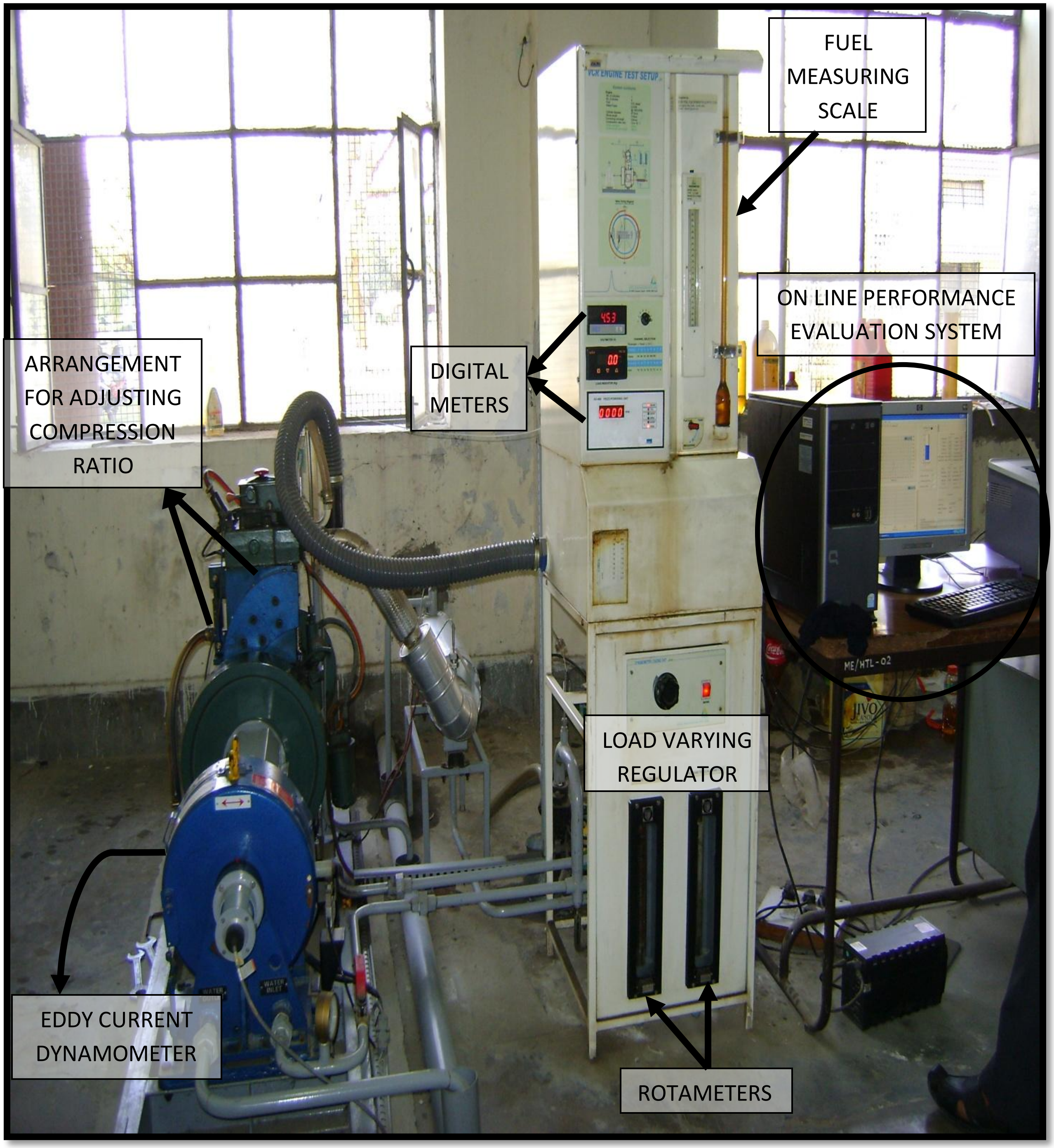


Figure 3.3 Pictorial view of the variable compression ratio compression ignition engine.

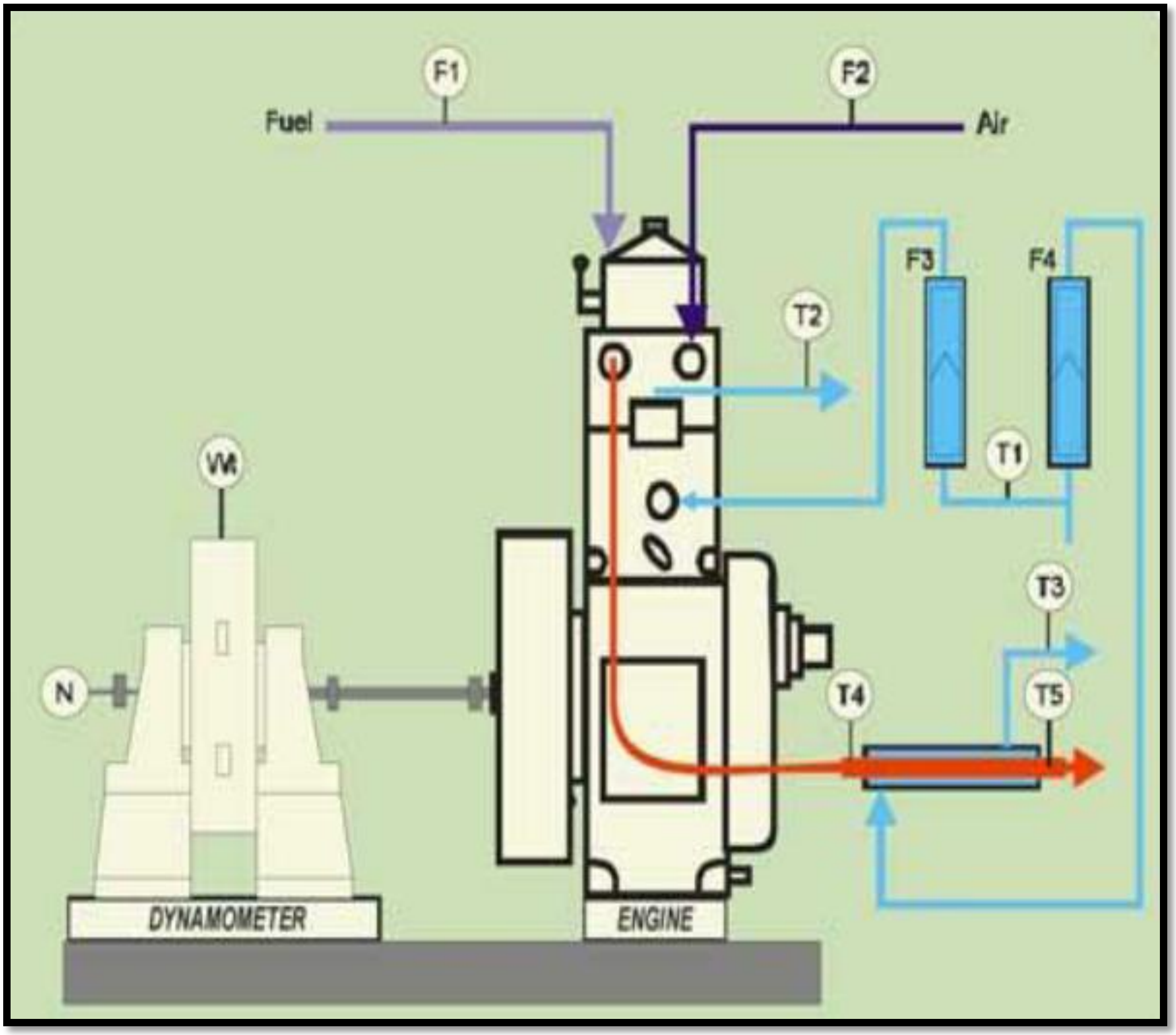


Figure 3.4 Flow line diagram of variable compression ratio compression ignition engine setup.

T1	Inlet temperature of water into engine jacket and calorimeter
T2	Outlet temperature of water from the engine jacket
T3	Outlet temperature of water from the calorimeter
T4	Inlet temperature of exhaust gases into the calorimeter
T5	Outlet temperature of exhaust gases from the calorimeter
N	Non contact type speed sensor(Engine shaft speed)
W	Load sensor(Eddy current dynamometer)
F1	Fuel supply to engine cylinder
F2	Air flow to engine cylinder
F3	Water flow to the engine jacket
F4	Water flow to calorimeter

Make Type: Kirloskar

Engine Type: Single Cylinder 4-Stroke, Water Cooled

Compression ratio: Variable ranging from 12 to 18

Rated power: 3.75 kW@1500 R.P.M

Stroke: 110 mm

Bore: 87.5 mm

Connecting rod length: 234 mm

Loading device: Eddy current dynamometer

Load indicator: Digital, Range 0-50 Kg, Supply 230V AC

Load sensor: Load cell, type strain gauge, range 0-50 Kg

Speed indicator: Digital with non contact type speed sensor

Temperature sensor: Thermocouple, Type K

Rotameter: Engine cooling 40-400 LPH; Calorimeter 25-250 LPH

A tilting cylinder block arrangement is used for varying the compression ratio without stopping the engine. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for P -V diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement.

Labview based Engine Performance Analysis software package "**Enginesoft**" is provided for on line performance evaluation.

3.2.1.2 Operation

3.2.1.2.1 Experimental procedure

For getting the base line data of the engine first the experimentation is performed with diesel and then with blends of crude rice bran methyl ester and rice bran methyl ester (10%, 20% and 40%).

1. Fill the diesel in fuel tank.
2. Initially adjust the compression ratio of the engine to a ratio of 12:1.
3. Start the water supply. Set cooling water flow for engine at 300 LPH and calorimeter flow at 70 LPH.
4. Also ensure adequate water flow rate for dynamometer cooling and piezo sensor cooling.
5. Check for all electrical connections. Start electric-supply to the computer through the UPS.
6. Open the lab view based engine performance analysis software package "**Enginesoft**" for on screen performance evaluation.
7. Supply the diesel to the engine by opening the valve provided at the burette.
8. Set the value of calorific value and specific gravity of the fuel through configure option in the software.
9. Select run option of the software. Start the engine and let it run for few minutes under no load condition.
10. Choose log option of the software. Turn on the fuel supply knob. After 1 minute the display changes to input mode then enter the values of water flows in cooling jacket and calorimeter and then the file name (applicable only for the first reading) in the software. The first reading for the engine gets logged for the no load condition. Turn the fuel knob back to regular position.
11. Repeat the experiment for different load.

12. All the readings will be displayed on the monitor.
13. Save the readings for particular compression ratio.
14. Change the compression ratio by adjusting the screw arrangement.
15. Repeat the whole experiment for different compression ratio.
16. Save the readings for each compression ratio.
17. Similarly change the fuel in the fuel tank and the fuel calorific value and specific gravity in the software.
18. Repeat the experiment for particular fuel at different compression ratio.
19. At the end of the experiment bring the engine to no load condition and turn off the engine and computer so as to stop the experiment.
20. After few minutes also turn off the water supply.

3.2.1.2.2 Precautions and Maintenance Instructions

1. Always check the oil level in the engine before starting and make sure that sufficient oil is present in the engine.
2. Fuel tank and fuel line should cleaned and free from foreign particles.
3. Always ensure that the water supply is turned on before starting the engine.

3.2.1.3 Parameters evaluated

1. Brake power (BP)
2. Brake thermal efficiency(BTE)
3. Brake specific fuel consumption(BSFC)
4. Brake mean effective pressure(BMEP)
5. Cylinder pressure-Crank angle(P-θ) data.

3.2.2 Exhaust Emission Evaluation

3.2.2.1 Equipment and parameters measured

Two emission equipments were used for exhaust gas evaluation. Both the equipment have their individual sensors attached with them. Figure 3.5 and 3.6 shows the Horiba analyzer and Flue gas analyzer.

Figure 3.5 Horiba analyzer

Figure 3.6 Flue gas analyzer

Both the equipment have their individual sensors attached with them.

Table 3.4 shows the exhaust emission parameters and their respective test methods along with its unit.

Table 3.4 Exhaust emission parameters

Parameters	**Test method**
Hydro Carbon as HC (ppm)	Horiba Analyser
Carbon monoxide as CO (ppm)	Flue Gas Analyser(KM19106)
Carbon monoxide as CO_2 (%)	Flue Gas Analyser(KM19106)
Nitrogen oxides as NO (ppm)	Flue Gas Analyser(KM19106)
Nitrogen oxides as NO_2 (ppm)	Flue Gas Analyser(KM19106)
Nitrogen oxides as NO_x (ppm)	Flue Gas Analyser(KM19106)

3.2.2.2 Operation

3.2.2.2.1 Experimental procedure

1. At particular load condition insert the sensors into the provided outlet for exhaust gases to escape into the environment.
2. Exhaust gases passes through these sensors to the respective analyzer attached with it.
3. After entering into the analyzer the readings are displayed on the digital screen.
4. After 2-3 minutes when the values are stabilized 3 readings are noted down.
5. Mean value of the three readings is evaluated.
6. Sensors are removed for the values on the analyzers to settle down again to zero value.
7. Reapeat the above procedure for different fuel and load condition respectively.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Experimental Results

The objective of the experiments can be categorised in the following manner:

1. Optimising Compression Ratio
2. Comparison of the blends of crude rice bran methyl ester and diesel on performance and emission parameters.
3. Comparison of the blends of crude rice bran methyl ester and rice bran methyl ester on performance and emission parameters.

4.1.1 Optimising Compression Ratio

An optimum compression ratio was to be figured out to carry out the performance and emission characteristics of the all the blends mentioned in chapter 3. Experiments were carried out using a B20 blend of rice bran methyl ester at different load conditions. Based on the performance characteristics of the engine the results obtained are as follows:

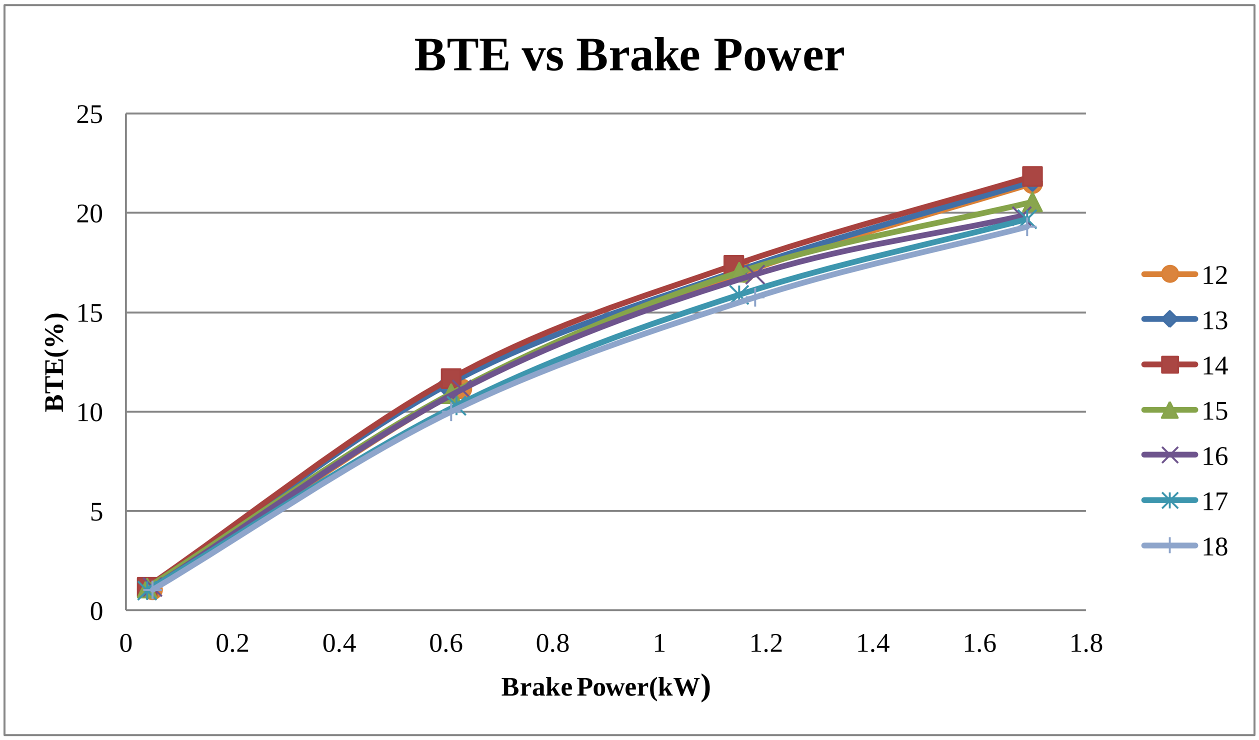


Figure 4.1 Variation of brake thermal efficiency with brake power at various compression ratios

Variation in brake thermal efficiency with brake power is shown in Figure 4.1. Graph shows a similar increasing trend in brake thermal efficiency w.r.t brake power for all compression ratios. Maximum thermal efficiency achieved is about 21.84% at a compression ratio of 14. Minimum thermal efficiency achieved is about 19.31% at a compression ratio of 18. It is noticed that upto a compression ratio of 14 the brake thermal efficiency shows an increasing trend, but reverses its trend and starts decreasing with further increase in the compression ratio. Reason can be due to the better intermixing of fuel and air along with better combustion at compression ratio of 14 maximum thermal efficiency is achieved.

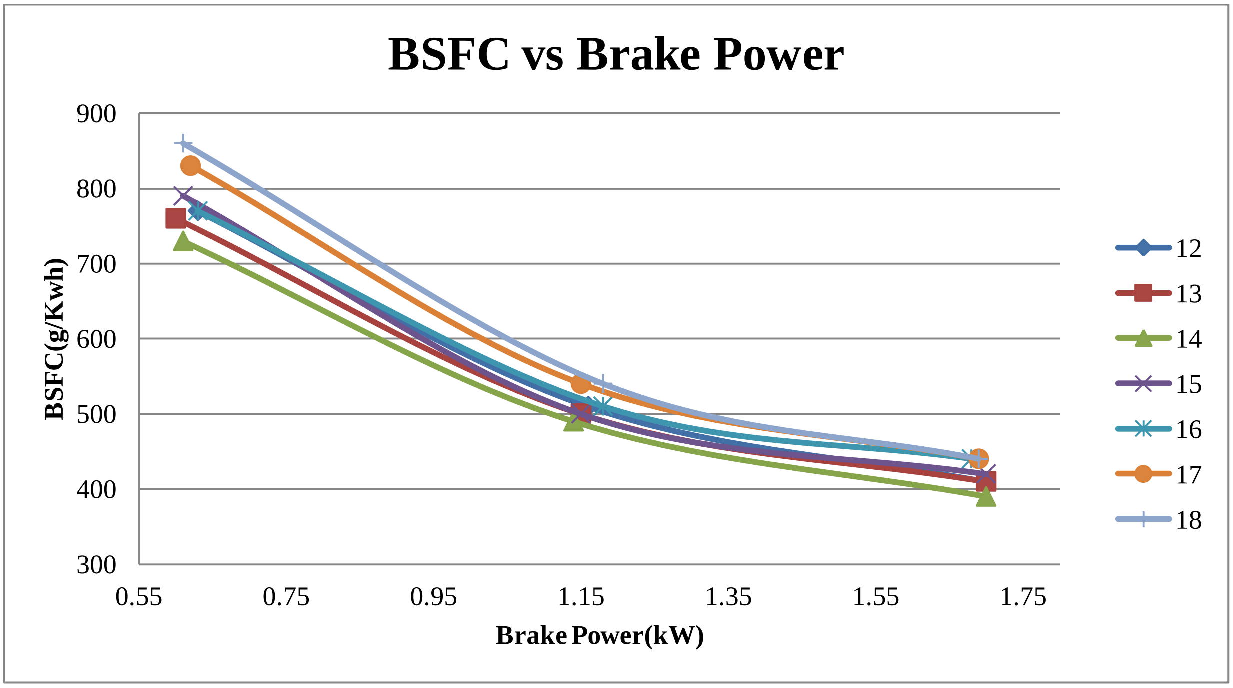


Figure-4.2 Variation of brake specific fuel consumption with brake power at various compression ratios

Figure-4.2 shows brake specific fuel consumption as a function of engine load(brake mean effective pressure). At full load condition the lowest brake specific fuel consumption obtained is about 390 g/Kwh at a compression ratio of 14. Highest obtained is 440 g/Kwh at compression ratios of 16, 17 and 18. This can be contributed to charge dilution. Also brake specific fuel consumption is almost same at compression ratio of 12 and 13 due to incomplete combustion of the fuel at these compression ratios.

Variation in exhaust gas temperature with brake power is shown in Figure-4.3. It is noticed that exhaust gas temperature increases with increase in engine load and compression ratio. Highest exhaust gas temperature obtained is about 240.17°C at a compression ratio of 18 and lowest of about 213.12°C at a compression ratio of 12 under full load condition.

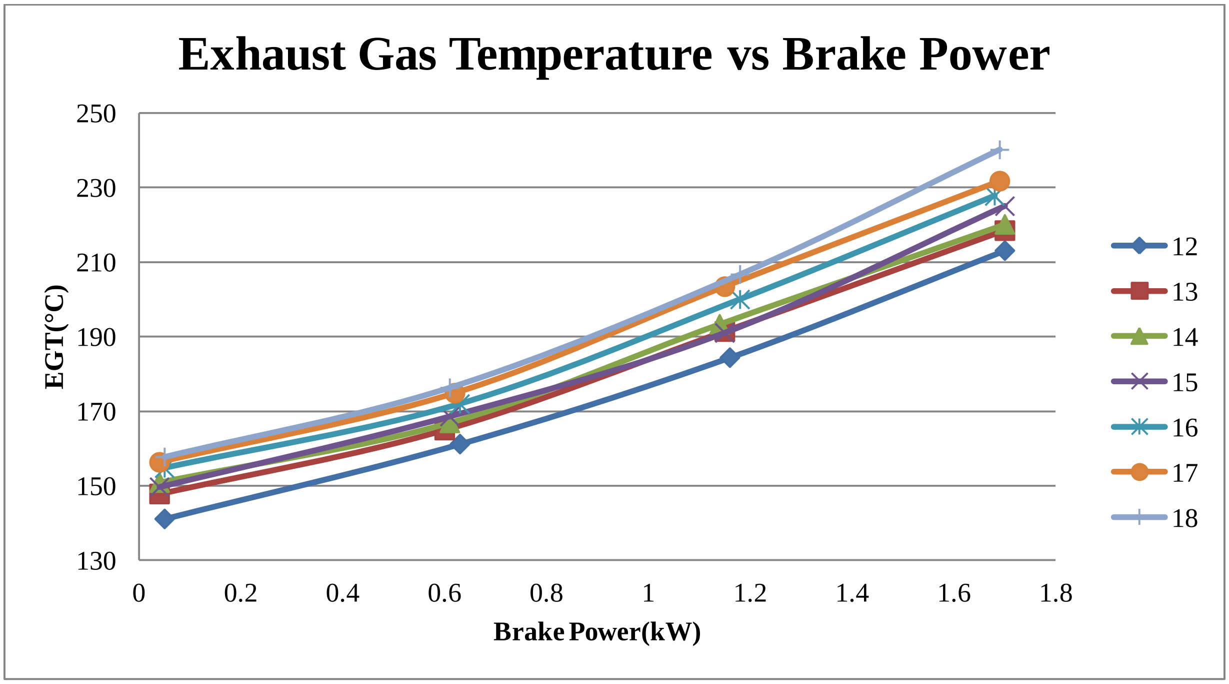


Figure-4.3 Variation of exhaust gas temperature with brake power at various compression ratios

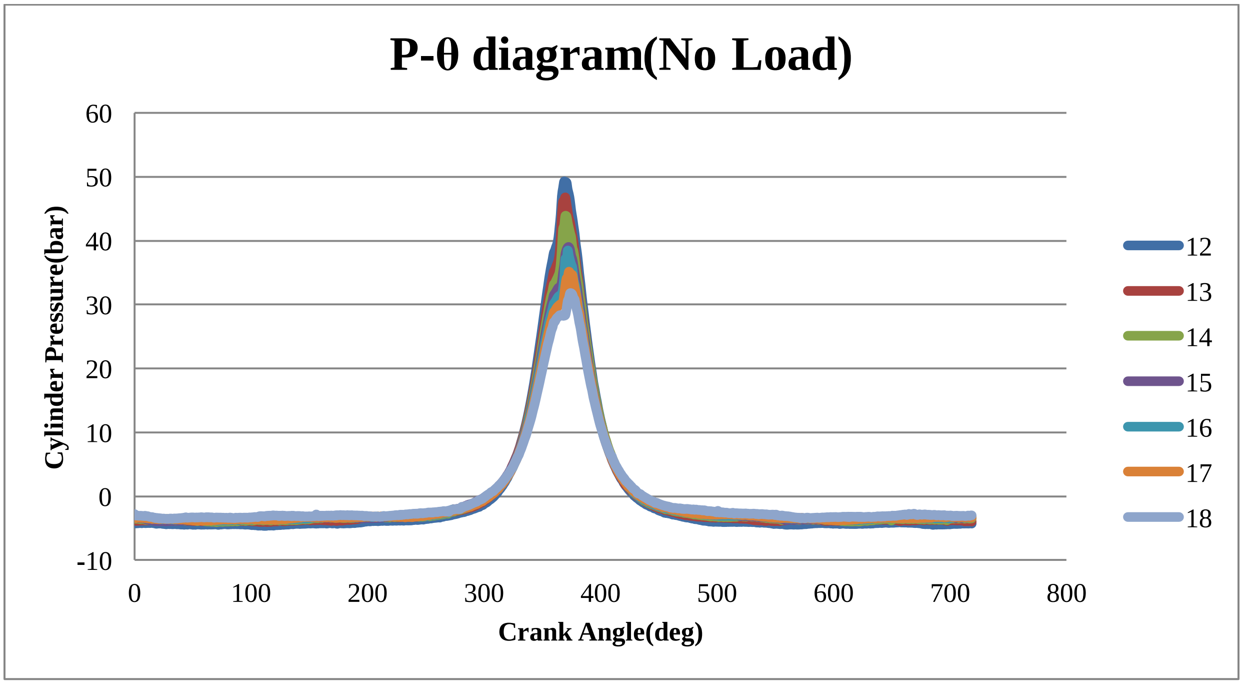


Figure-4.4 Variation of cylinder pressure with crank angle at different compression ratios under no load condition

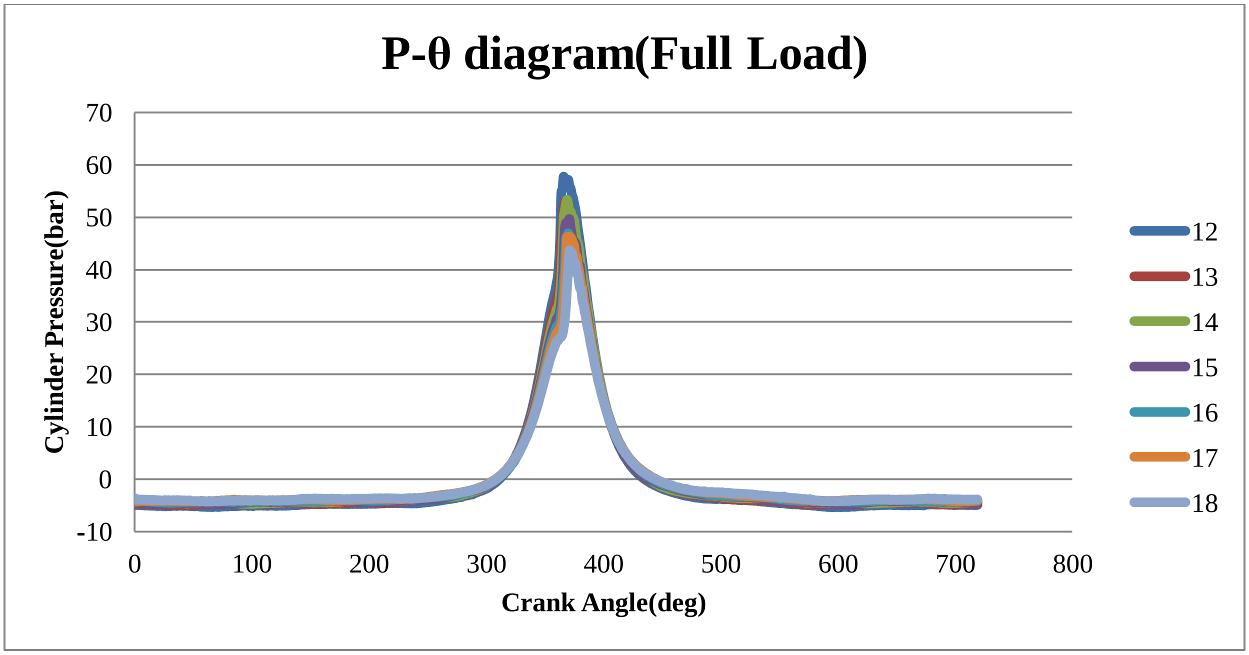


Figure-4.5 Variation of cylinder pressure with crank angle at different compression ratios under no load condition

Figure-4.4 and Figure-4.5 shows the variation of cylinder pressure with crank angle at different compression ratios under no load and full load conditions respectively. In both the load conditions maximum pressure attained is at a compression ratio of 12 and minimum at a compression ratio of 18. It is noticed that while moving from no load to full load condition the change in the cylinder pressure along with the decrease in the ignition delay period is maximum at a compression ratio of 14. It can be attributed to better mixing ability and burning of the fuel with air during the initial stage of combustion at this compression ratio.

4.1.2 Blends of Crude Rice Bran Methyl Ester Vs Diesel

Comparative results of engine performance and exhaust emission characteristics of the different blends of crude rice bran methyl ester with that of diesel at compression ratio of 12 and 14 are discussed.

Blends used are as follows:

1. CB10
2. CB20
3. CB40

4.1.2.1 Compression Ratio 12

Engine performance and emission results obtained at compression ratio 12 are as follows:

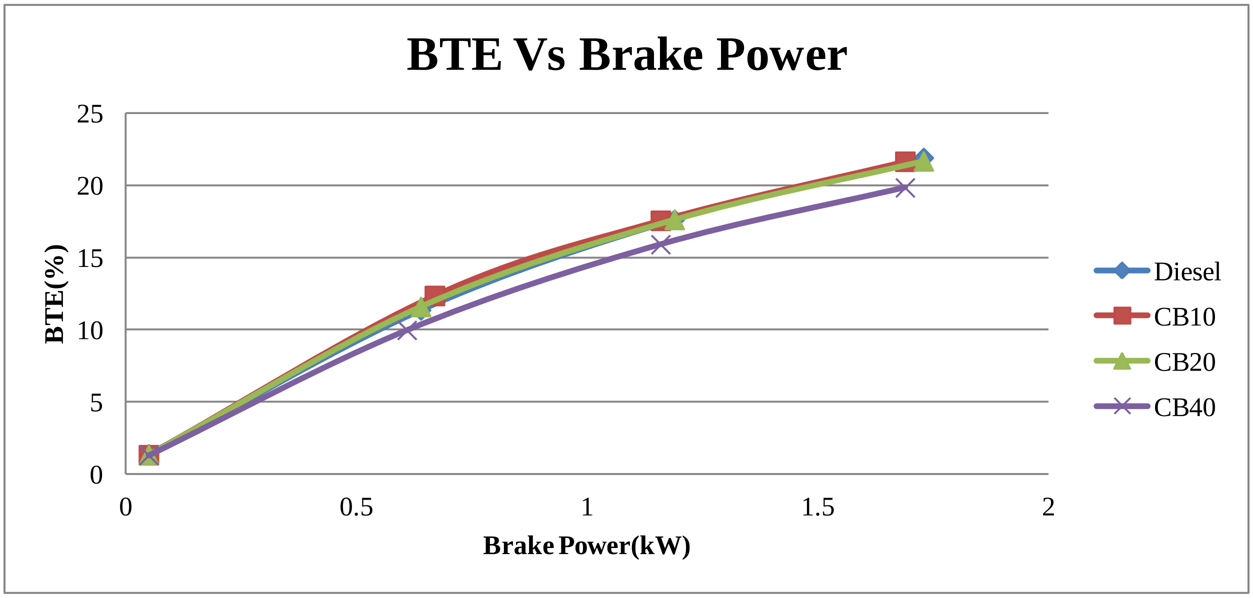


Figure-4.6 Variation of brake thermal efficiency with brake power

Variation in brake thermal efficiency with brake power is shown in Figure-4.6. Results show that CB10 and CB20 have almost similar brake thermal efficiency as that of diesel. Only CB40 showed value on the lower side. Maximum thermal efficiency achieved is about 21.91% for diesel. Minimum thermal efficiency achieved is about 19.84% for CB40.

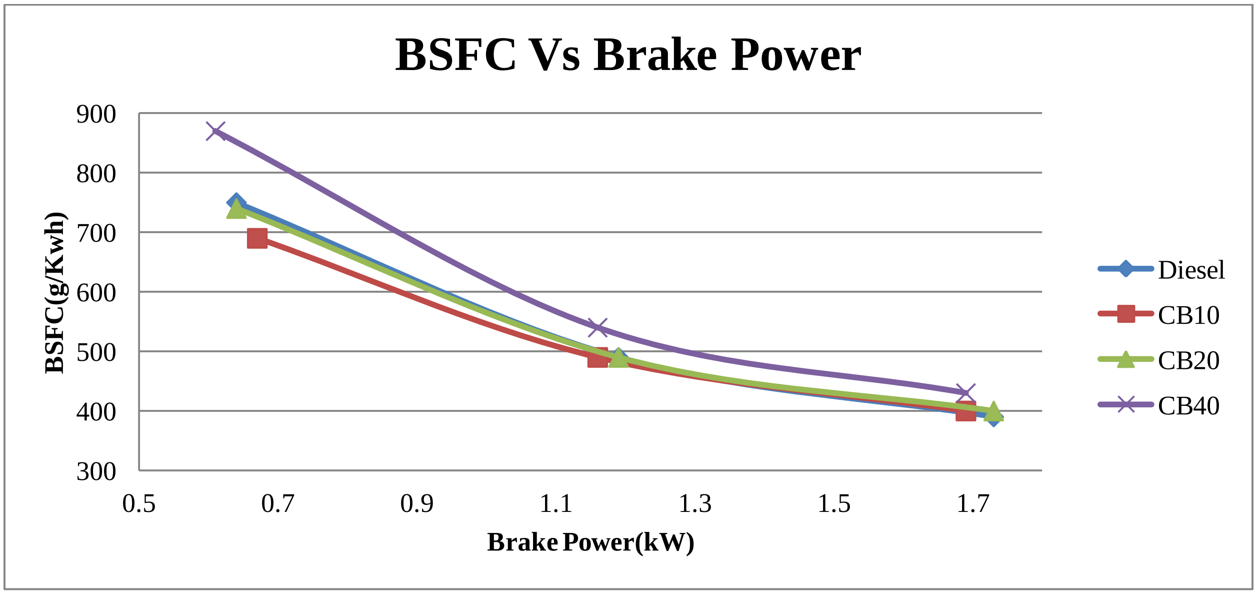


Figure-4.7 Variation of brake specific fuel consumption with brake power

Figure-4.7 shows the variation of brake specific fuel consumption with brake power. At full load condition the lowest brake specific fuel consumption obtained is about 390 g/kWh for diesel and highest obtained is 430 g/kWh for CB40. Also brake specific fuel consumption is same for CB10 and CB20 i.e 400g/kWh.

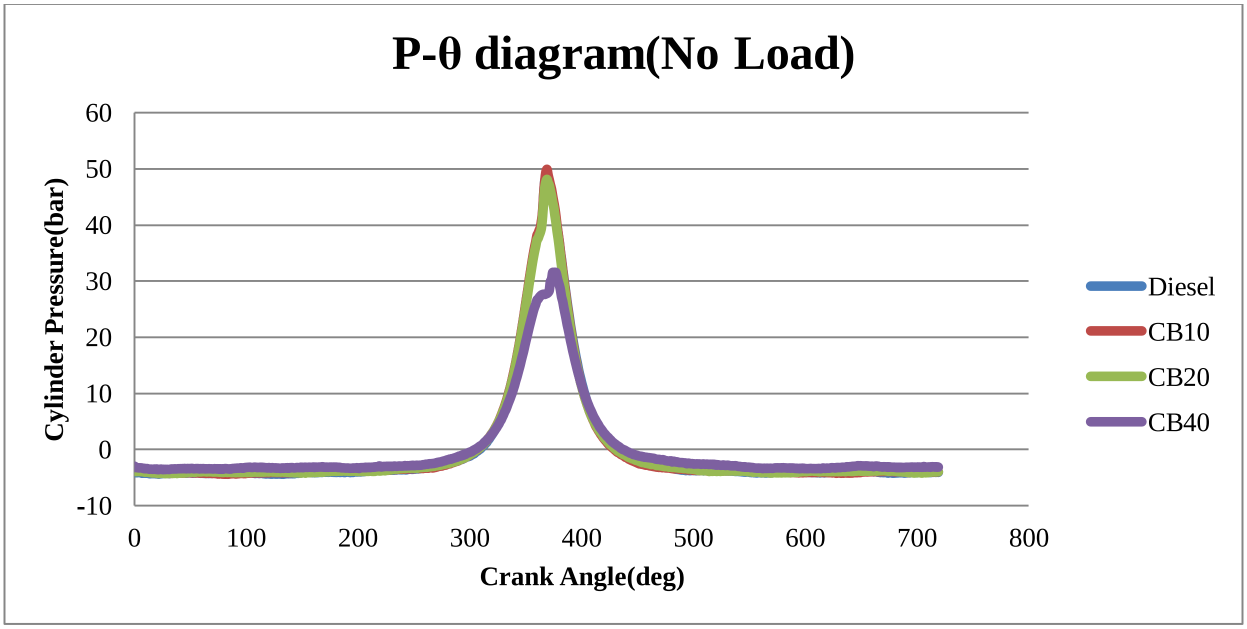


Figure-4.8 Variation of cylinder pressure with crank angle under no load condition

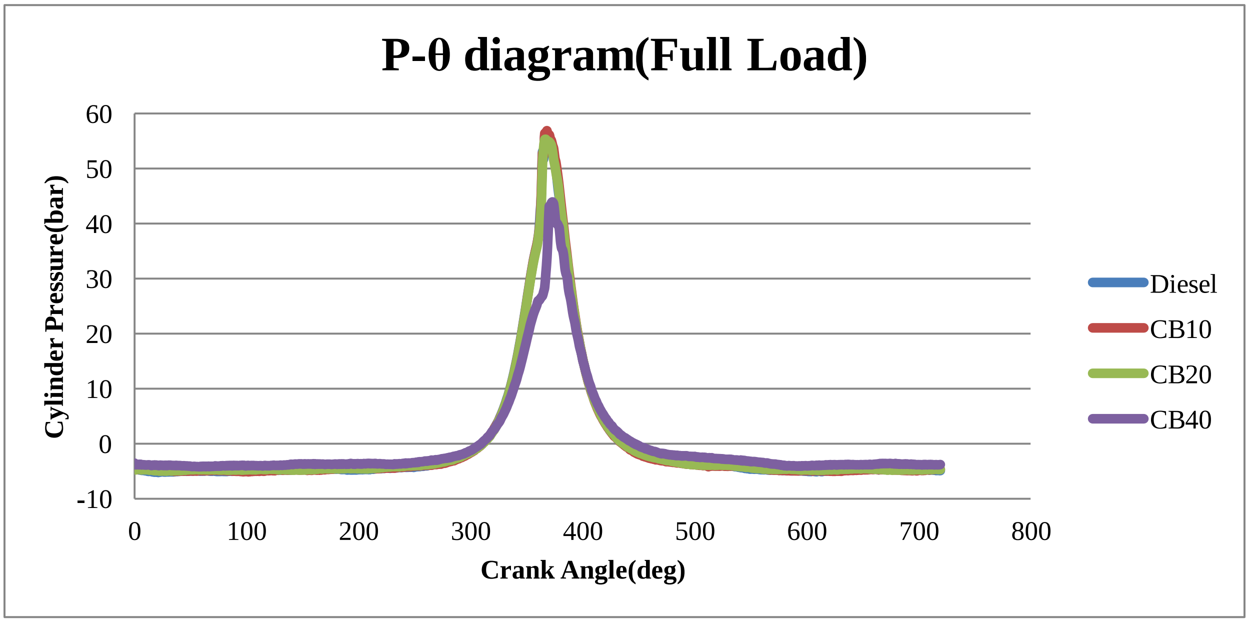


Figure-4.9 Variation of cylinder pressure with crank angle under full load condition

Figure-4.8 and 4.9 shows variation of cylinder pressure with crank angle under no load and full load condition respectively. Maximum cylinder pressure attained was for CB10 at both no load and full load condition. Lowest cylinder pressure attained was for CB40 at both no load and full load condition. Longer ignition delay observed was for CB40 whereas CB10 had the shortest ignition delay.

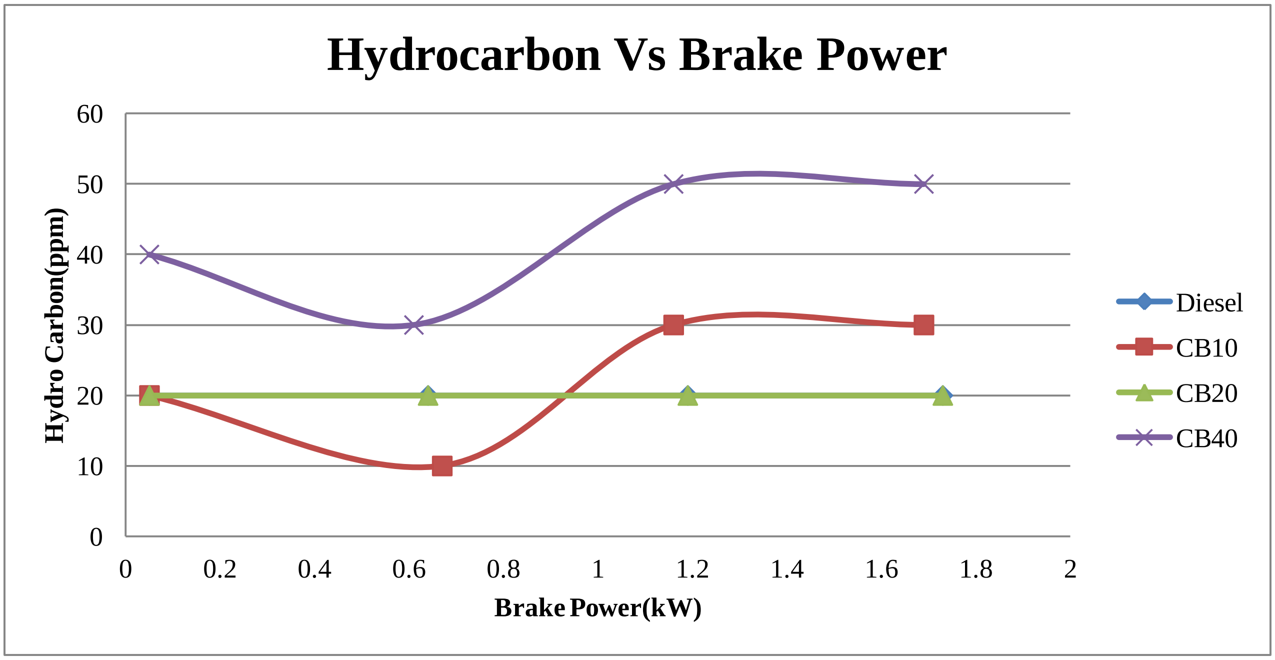


Figure-4.10 Variation of hydro carbon(HC) with brake power

Figure-4.10 shows variation in hydro carbon(HC) with brake power. Diesel and CB20 showed same hydrocarbon emissions from no load to full load condition. This is due to their nearly same brake specific fuel consumption. Lowest hydro carbon emission of about 10 ppm was observed for CB10 at part load condition. Whereas maximum hydro carbon emission of about 50 ppm was observed for CB40 at full load condition. Higher hydrocarbon emission for CB40 is due to its higher brake specific fuel consumption.

Figure-4.11 shows variation in carbon monoxide (CO) with brake power. At full load condition lowest carbon monoxide of about 336 ppm was observed for CB10 followed by CB20(489 ppm), diesel(510 ppm) and highest of about 961 ppm for CB40. This can be attributed to the longer ignition delay observed for CB40. Longer ignition delay along with increased brake specific fuel consumption decreases the air-fuel ratio inside the cylinder leaving less amount of air for complete combustion which in turn gives rise to higher CO emissions.

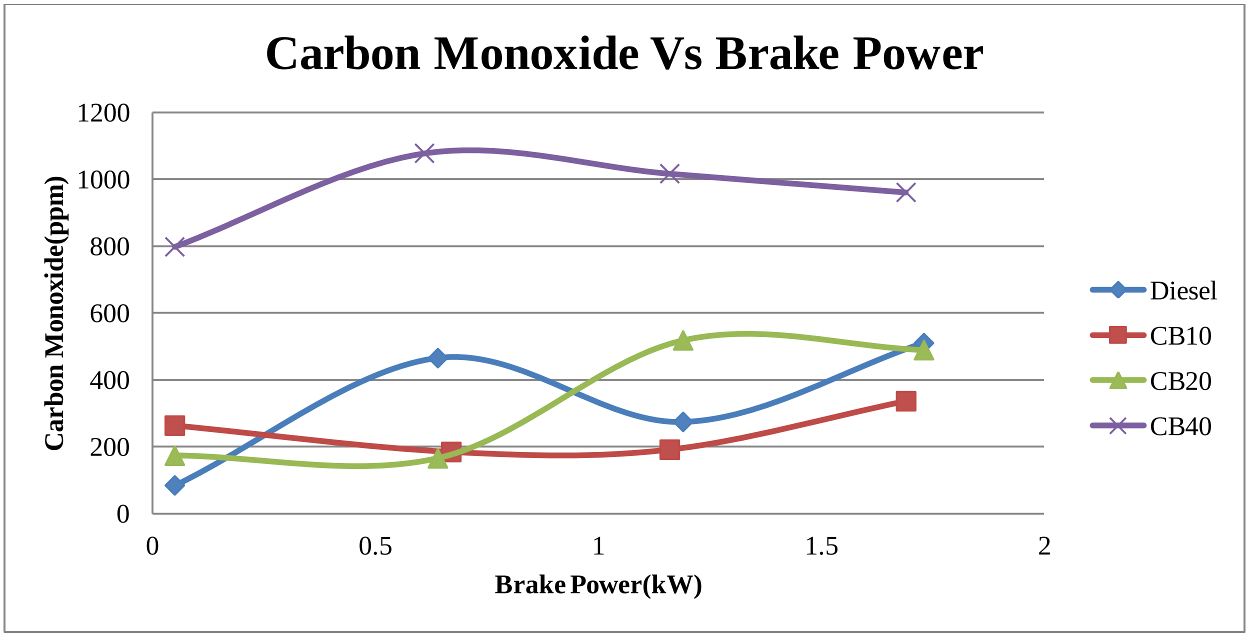


Figure-4.11 Variation of Carbon Monoxide (CO) with brake power

Figure-4.12 shows variation in carbon dioxide (CO_2) with brake power. From no load condition to full load condition graphs show that CB10 has lower value of carbon dioxide. Whereas CB40 showed higher value of carbon dioxide emission at all load condition. At full load condition lowest value obtained is about 25% for CB10 and highest of about 37% for both CB20 and CB40.

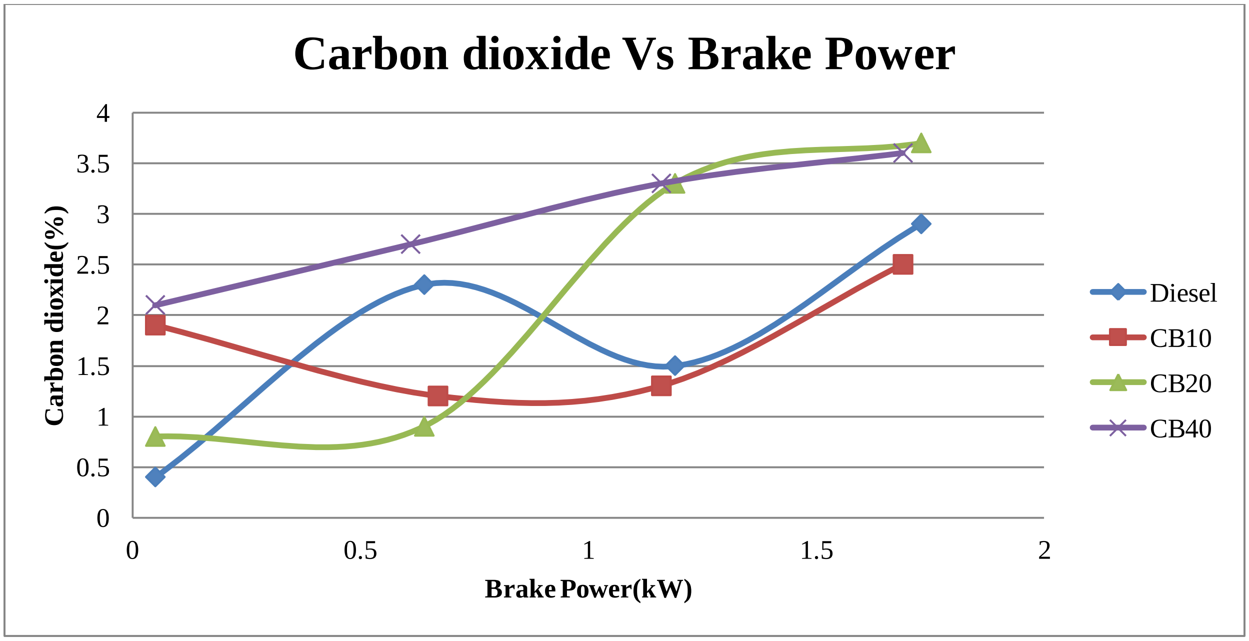


Figure-4.12 Variation of Carbon Dioxide (CO_2) with brake power

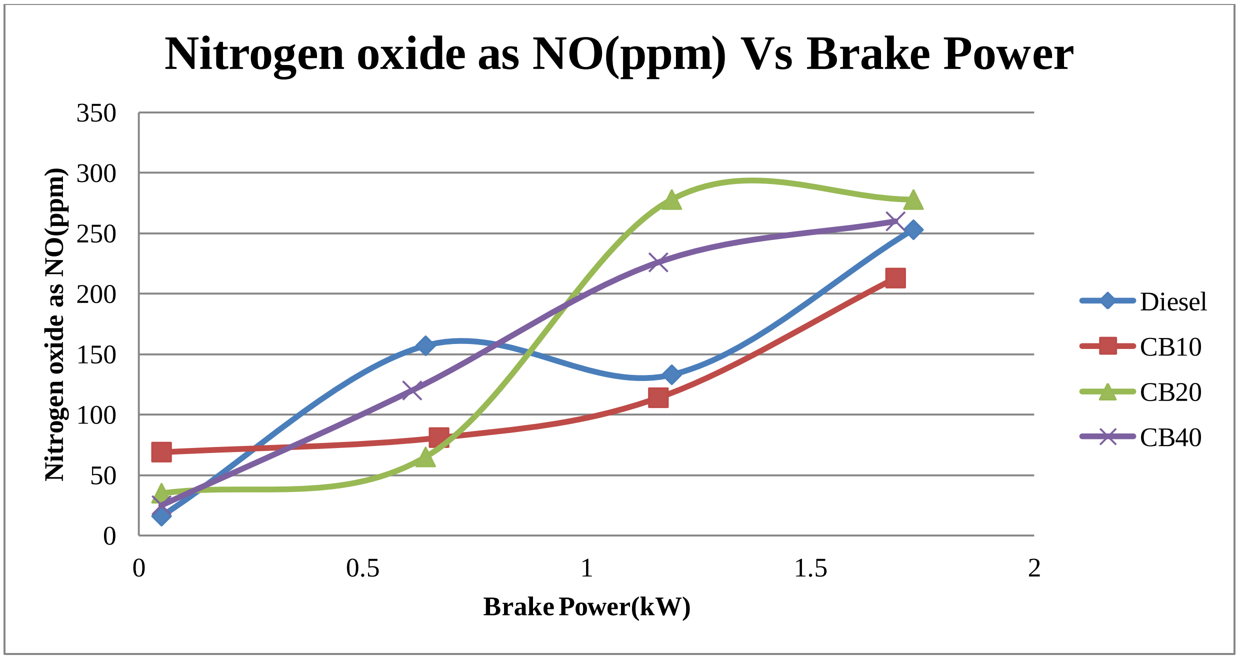


Figure-4.13 Variation of Nitrogen oxide as NO with brake power

Figure-4.13 shows variation in nitrogen oxide as NO with brake power. From no load condition to full load condition graphs show that CB10 has lower value of nitrogen oxide as NO. At full load condition highest value obtained is about 278 ppm for CB20 followed by CB40, diesel and lowest of about 213 ppm for CB10.

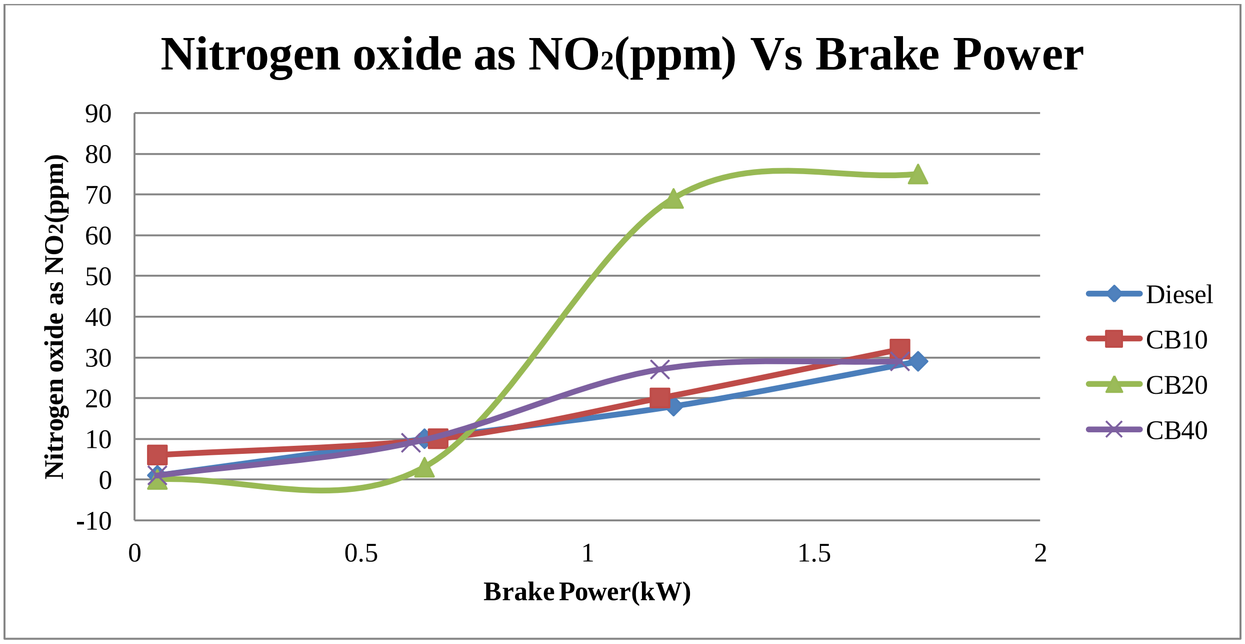


Figure-4.14 Variation of Nitrogen oxide as NO_2 with brake power

Figure-4.14 shows variation in nitrogen oxide as NO_2 with brake power. From no load condition to full load condition graphs show that diesel has lower value of nitrogen oxide as NO_2. CB10 also had values nearly same as that of diesel. At full load condition lowest value obtained is about 29 ppm for both CB40 and diesel. Lowest value of about 75 ppm was obtained for CB20.

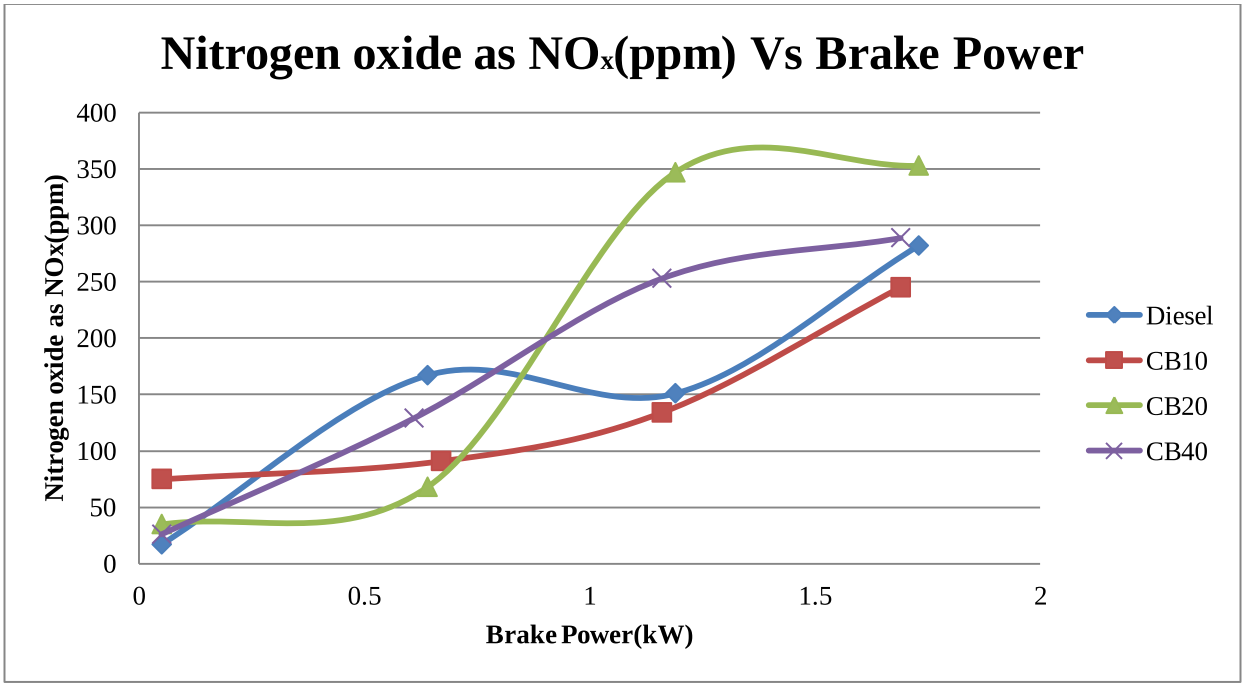


Figure-4.15 Variation of Nitrogen oxide as NOx with brake power

Figure-4.15 shows variation in nitrogen oxide as NOx with brake power. At full load condition highest value obtained is about 353 ppm for CB20 followed by CB40, diesel and lowest of about 245 ppm for CB10.

Both CB20 and CB40 showed higher nitrogen oxide emissions than diesel.

4.1.2.2 Compression Ratio 14

Engine performance and emission characteristics results obtained at compression ratio 14 are as follows:

Variation in brake thermal efficiency with brake power is shown in Figure-4.16. Results show that CB10 has the maximum thermal efficiency whereas CB40 has minimum thermal efficiency at full load conditions.

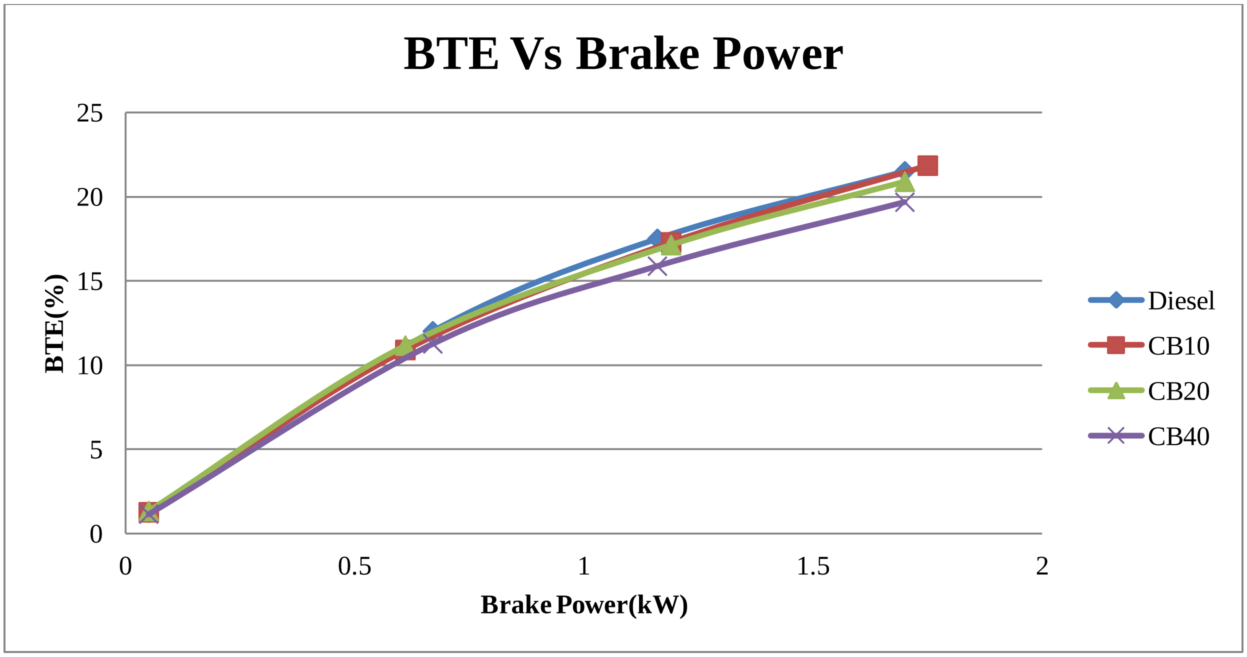


Figure-4.16 Variation of brake thermal efficiency with brake power

Figure-4.17 shows variation in brake specific fuel consumption with brake power. At full load condition the lowest brake specific fuel consumption obtained is about 390 g/kWh for CB10 and highest obtained is 440 g/kWh for CB40. Also brake specific fuel consumption is nearly same for CB10 and diesel.

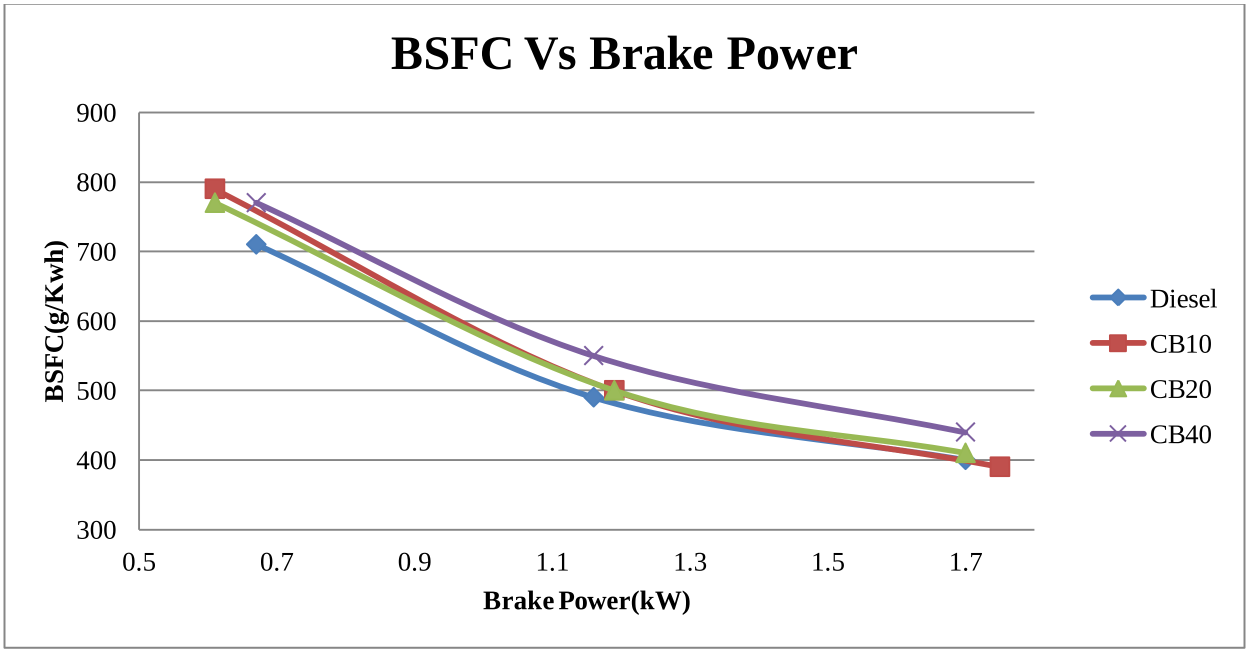


Figure-4.17 Variation of brake specific fuel consumption with brake power

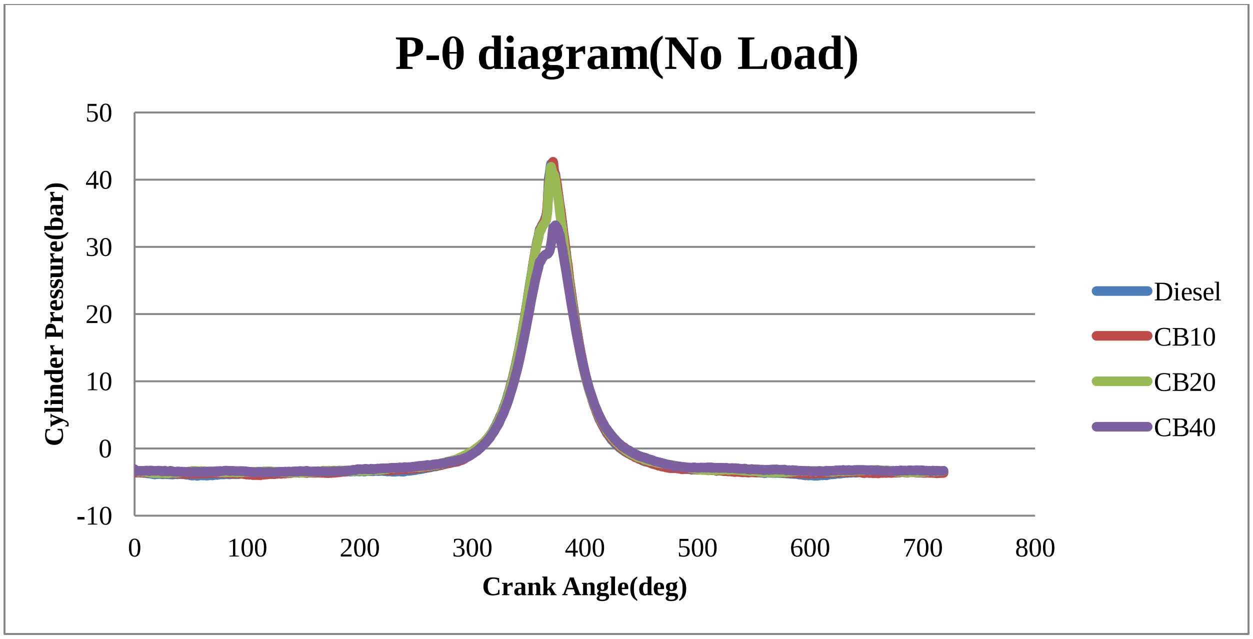


Figure-4.18 Variation of cylinder pressure with crank angle under no load condition

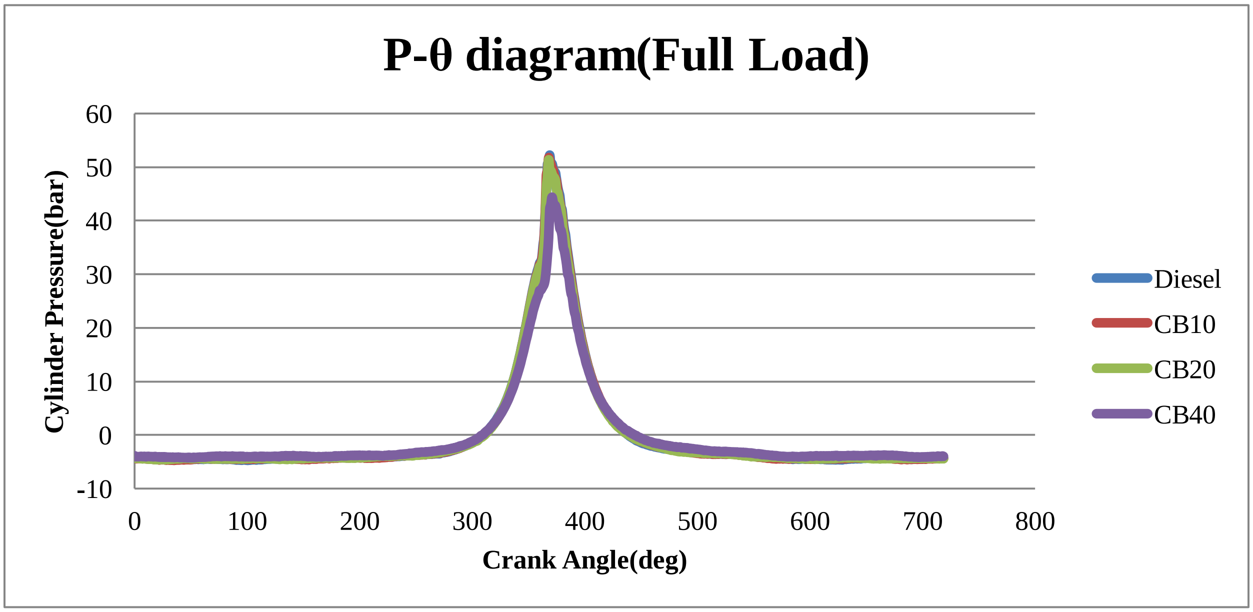


Figure-4.19 Variation of cylinder pressure with crank angle under full load condition

Figure-4.18 and 4.19 shows variation of cylinder pressure with crank angle under no load and full load condition respectively. Maximum cylinder pressure attained was for CB10 at no load condition but with a delay of 2 degree in crank angle as compared to diesel. At full load condition maximum cylinder pressure attained was for diesel followed by CB10,CB20 and lowest for CB40. Shorter ignition delay was observed at this compression ratio as compared to compression ratio 12.

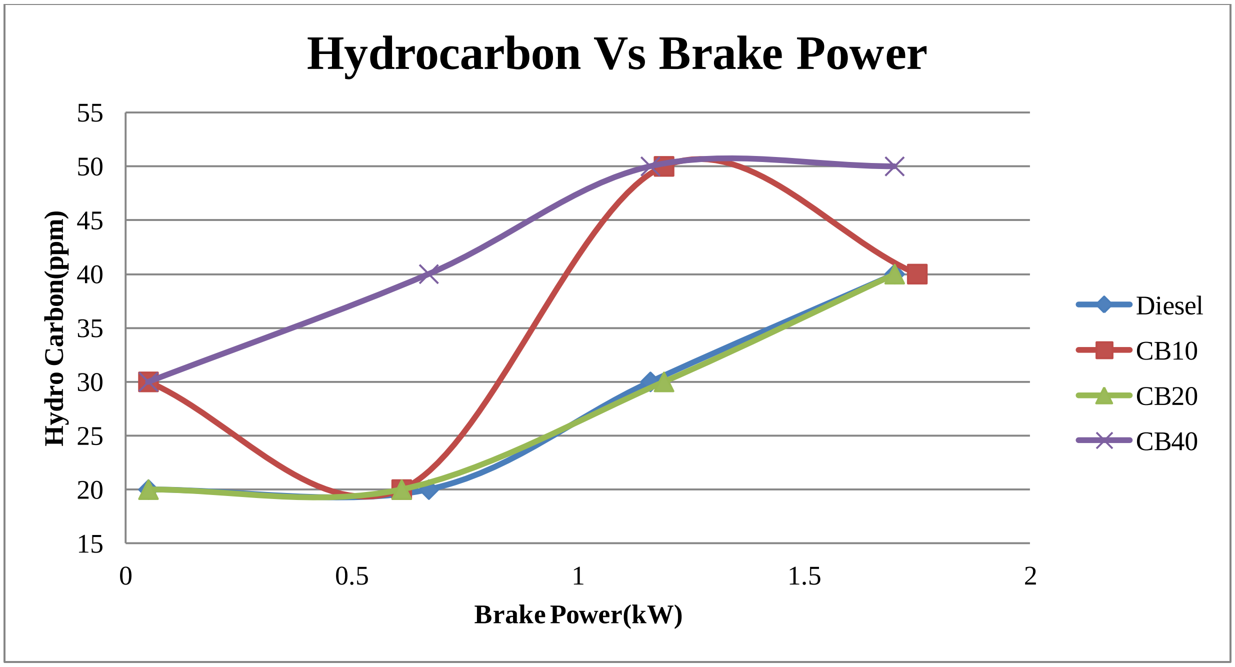


Figure-4.20 Variation of hydro carbon (HC) with brake power

Figure-4.20 shows variation in hydro carbon (HC) with brake power. Diesel and CB20 showed same hydrocarbon emissions from no load to full load condition. Maximum hydro carbon emission of about 50 ppm was observed for CB40 at full load condition.

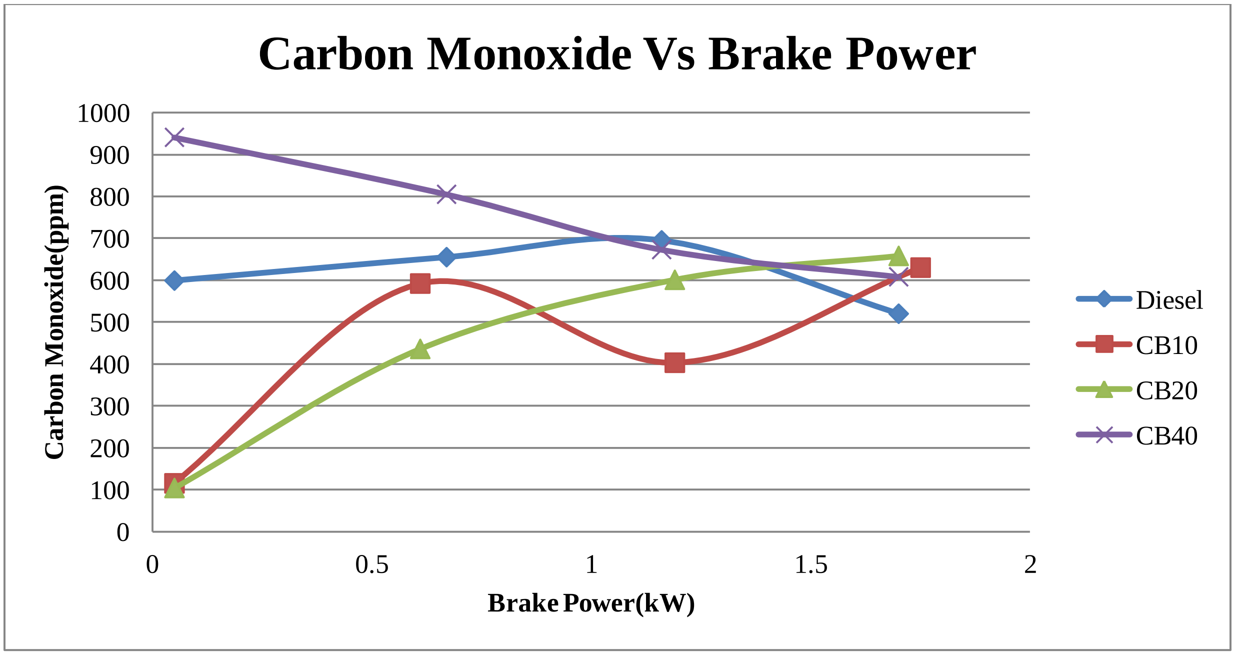


Figure-4.21 Variation of Carbon Monoxide (CO) with brake power

Figure-4.21 shows variation in carbon monoxide (CO) with brake power. CB10 and CB20 had carbon monoxide emission on the lower side whereas diesel and CB40 had emissions on the higher side.

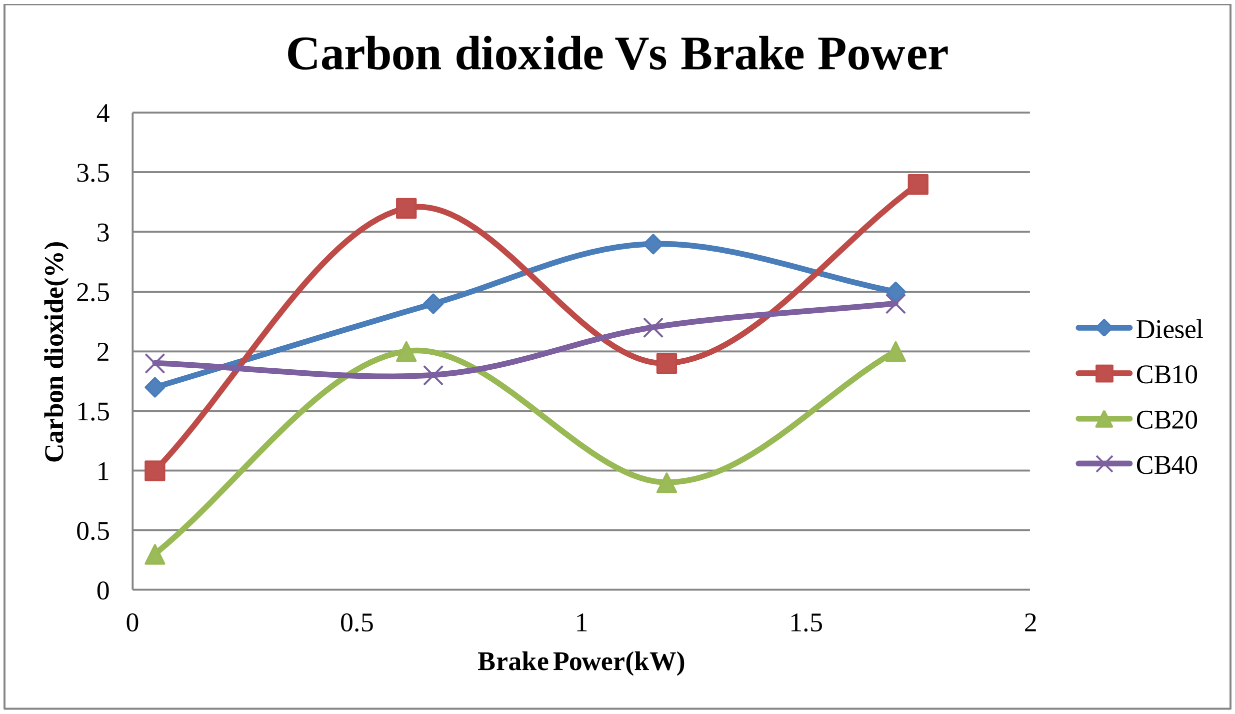


Figure-4.22 Variation of Carbon Dioxide (CO_2) with brake power

Figure-4.22 shows variation in carbon dioxide(CO_2) with brake power. From no load condition to full load condition graphs show that CB10 and CB20 have the same type of variation. Only difference is that carbon dioxide emissions for CB10 were on the higher side of the graph whereas CB20 had on the lower side. Carbon dioxide emissions for diesel were found higher than both CB20 and CB40.

Figure-4.23 shows variation in nitrogen oxide as NO with brake power. From no load condition to full load condition graphs show that CB40 has lower value of nitrogen oxide as NO. At full load condition highest value obtained is about 310 ppm for CB10 followed by CB20, diesel and lowest of about 148 ppm for CB40.

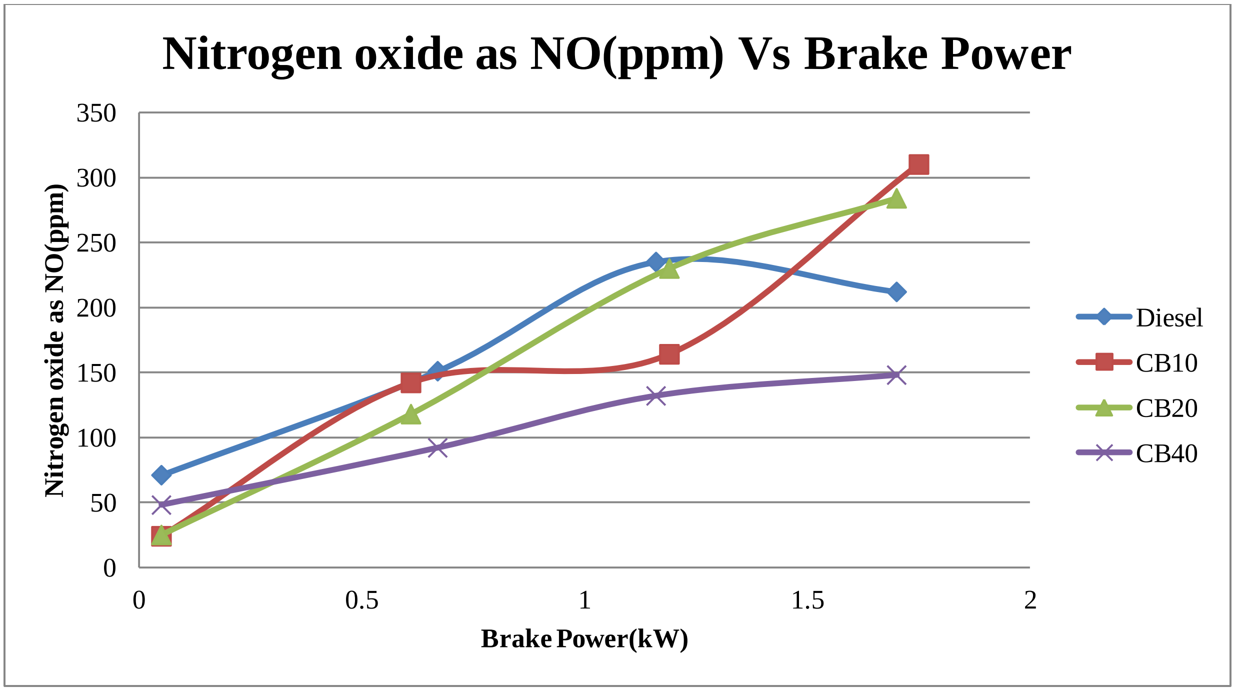


Figure-4.23 Variation of Nitrogen oxide as NO with brake power

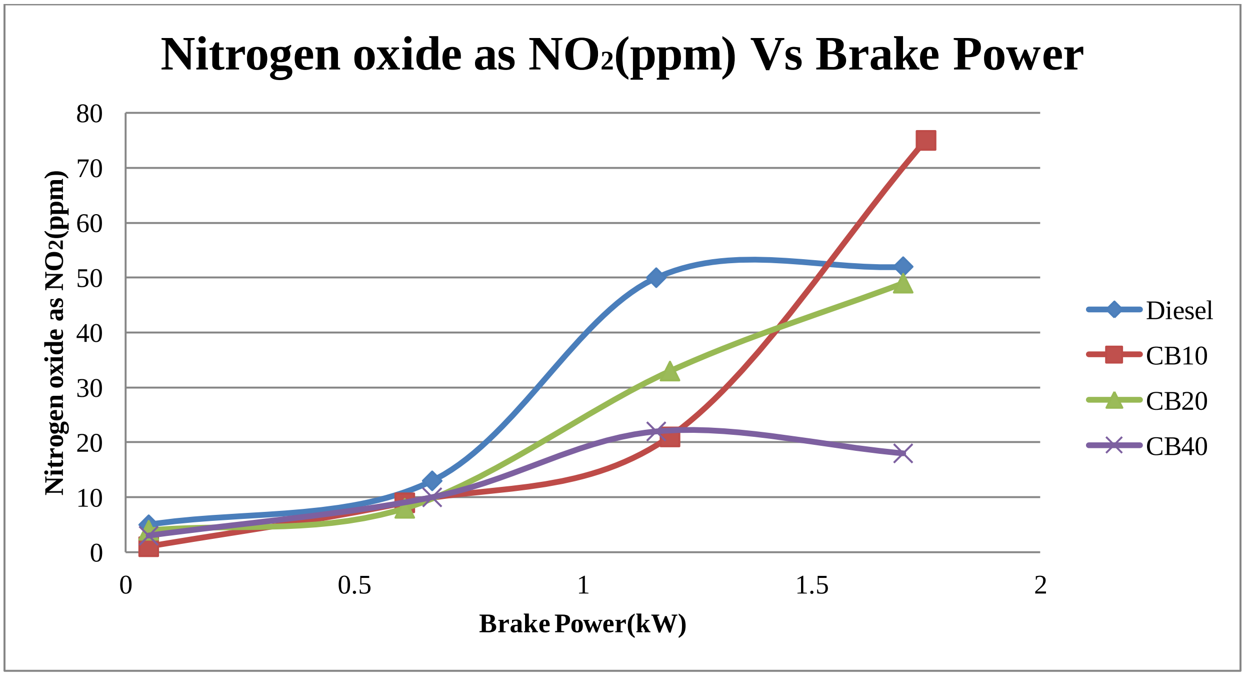


Figure-4.24 Variation of Nitrogen oxide as NO_2 with brake power

Figure-4.24 shows variation in nitrogen oxide as NO_2 with brake power. Higher amount of NO_2 emissions were observed for CB10 and diesel. Whereas lowest value of NO_2 emissions were observed for CB40. CB20 showed intermediate NO_2 emissions.

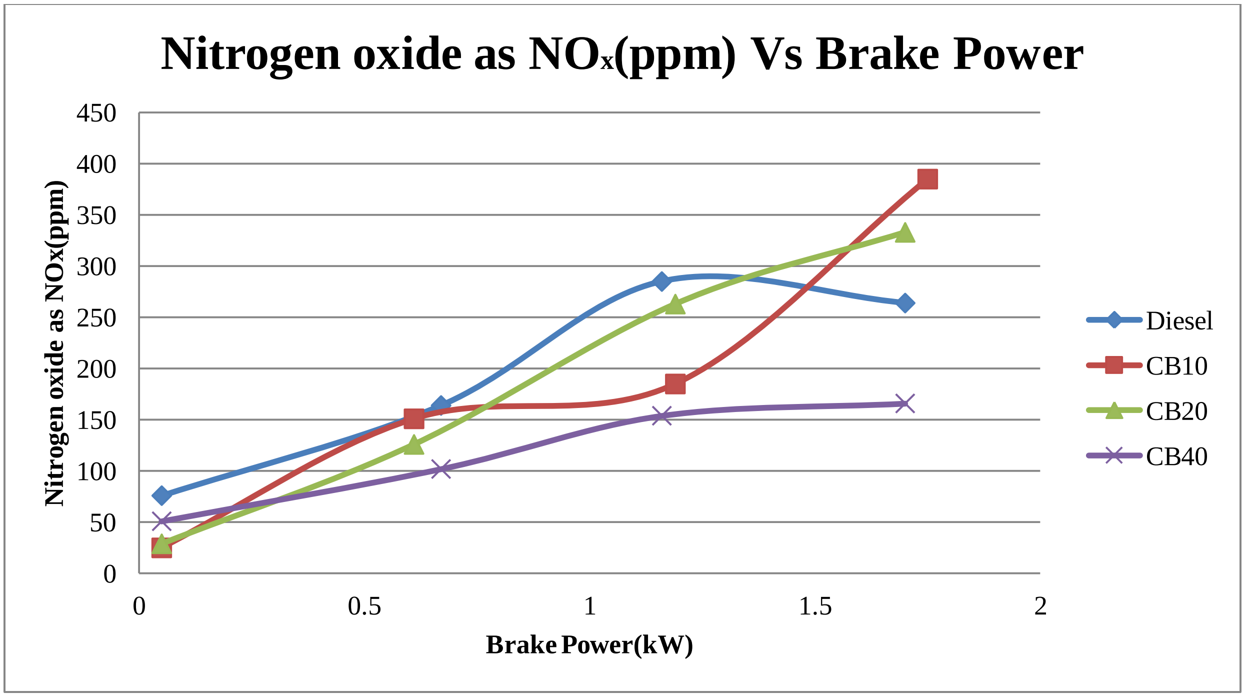


Figure-4.25 Variation of Nitrogen oxide as NOx with brake power

Figure-4.25 shows variation in nitrogen oxide as NOx with brake power. At full load condition highest value obtained is about 385 ppm for CB10 followed by CB20, diesel and lowest of about 166 ppm for CB10.

4.1.3 Blends of Crude Rice Bran Methyl Ester Vs Blends of Rice Bran Methyl Ester

Engine performance and emission characteristics results obtained at compression ratio 14 are shown below. Also comparative results of Crude oil methyl ester and Refined oil methyl ester at full load condition are also shown.

Table 4.1

Brake thermal efficiency(%) at full load condition			
CB10	21.84325	RB10	19.75581
CB20	20.88933	RB20	19.73751
CB40	19.67324	RB40	19.74277

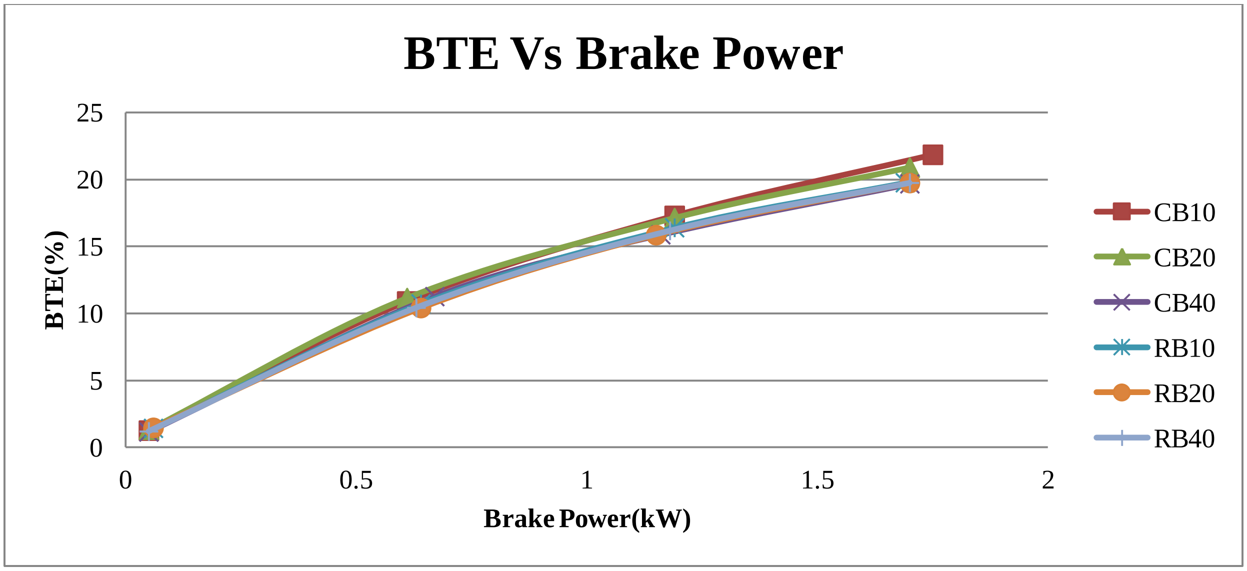


Figure-4.26 Variation of brake thermal efficiency with brake power

Table 4.2

Brake specific fuel consumption(g/kWh) at full load condition			
CB10	390	RB10	430
CB20	410	RB20	440
CB40	440	RB40	440

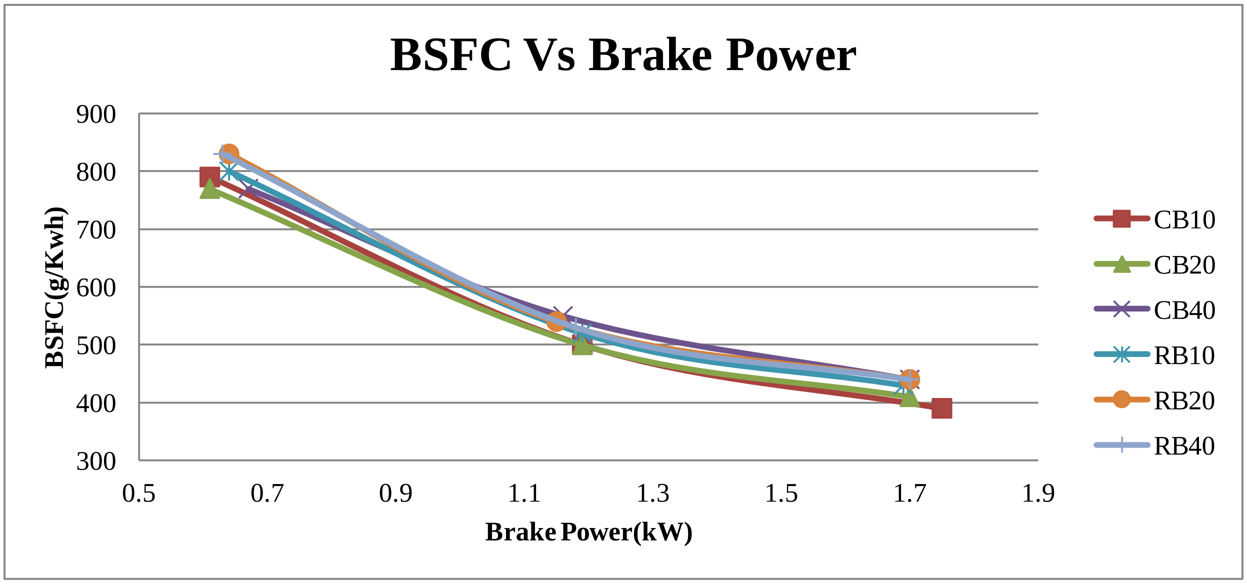


Figure-4.27 Variation of brake specific fuel consumption with brake power

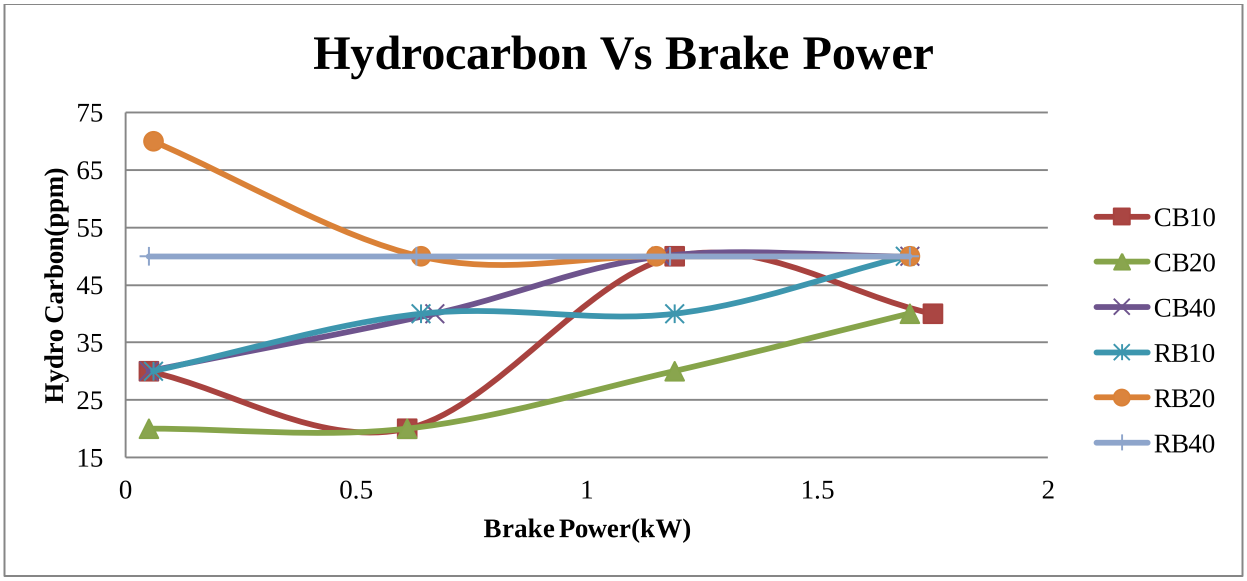


Figure-4.28 Variation of hydro carbon (HC) with brake power

Table 4.3

Hydro carbon(HC)(ppm) at full load condition			
CB10	40	RB10	50
CB20	40	RB20	50
CB40	50	RB40	50

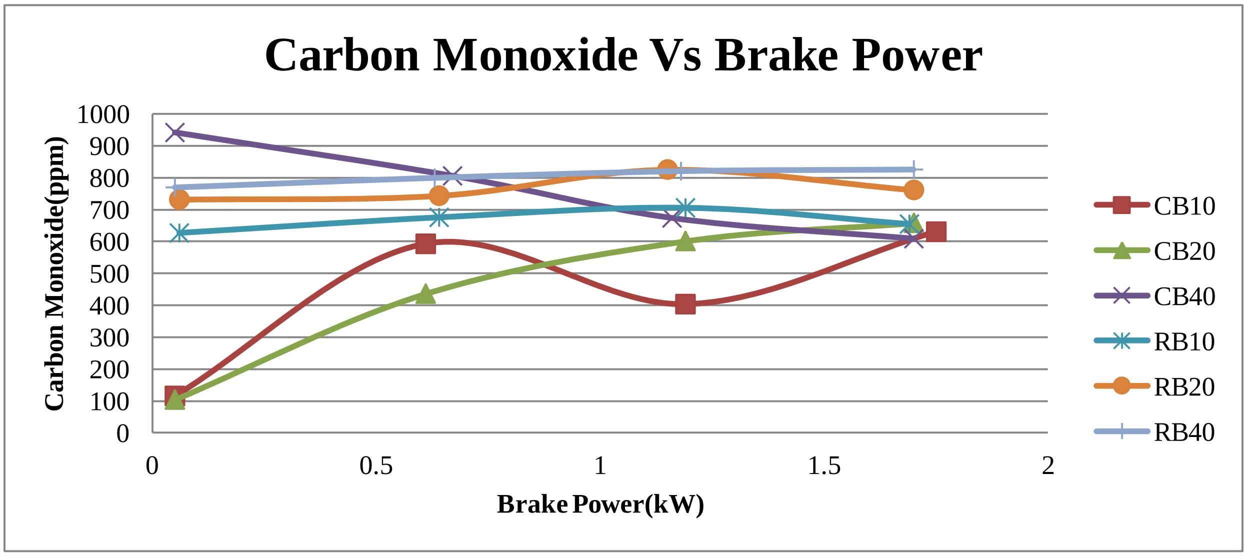


Figure-4.29 Variation of Carbon Monoxide (CO) with brake power

Table 4.4

Carbon Monoxide (CO)(ppm) at full load condition			
CB10	630	RB10	654
CB20	658	RB20	761
CB40	608	RB40	825

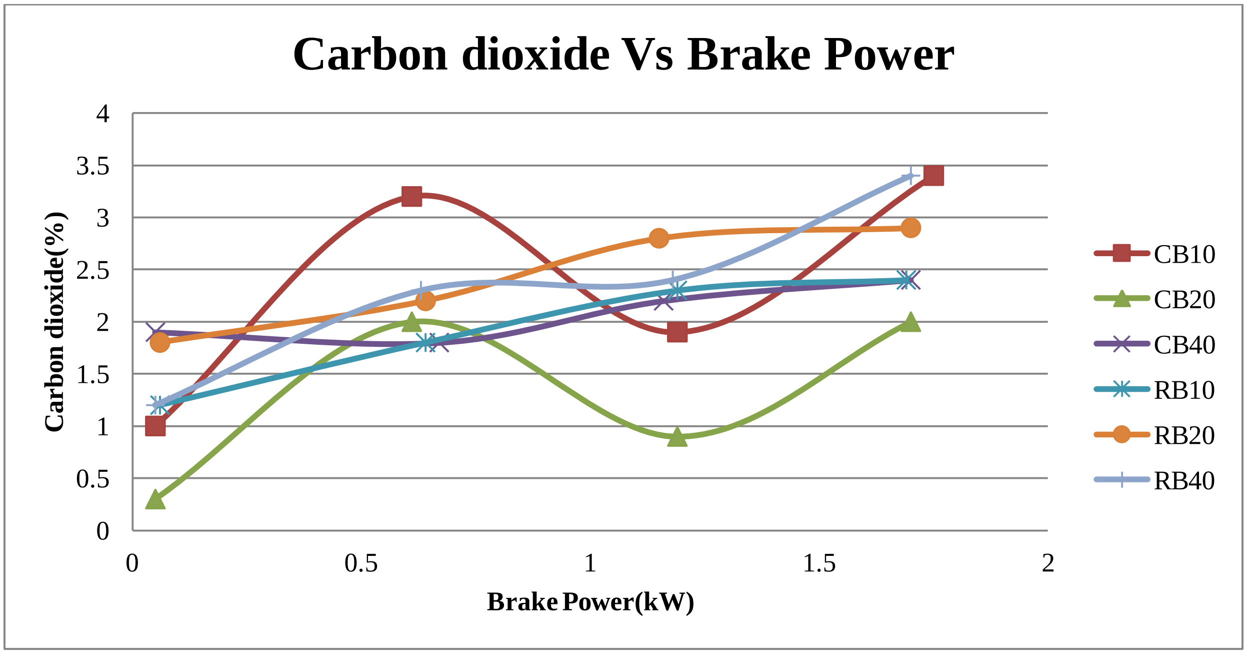


Figure-4.30 Variation of Carbon Dioxide (CO_2) with brake power

Table 4.5

Carbon Dioxide (CO_2)(%) at full load condition			
CB10	3.4	RB10	2.4
CB20	2	RB20	2.9
CB40	2.4	RB40	3.4

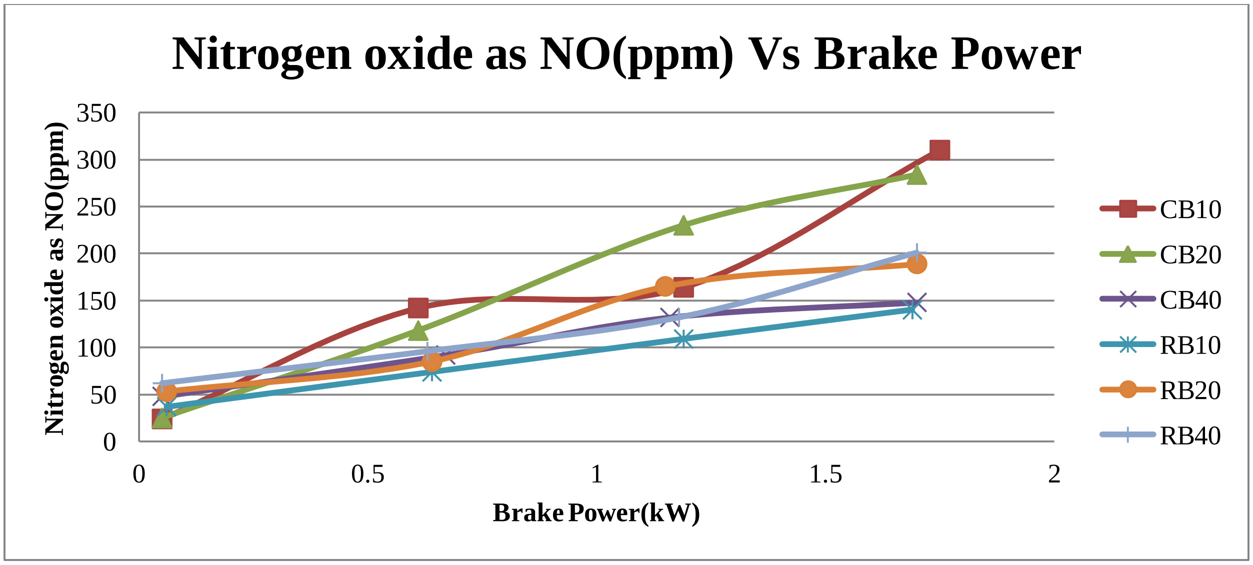


Figure-4.31 Variation of Nitrogen oxide as NO with brake power

Table 4.6

Nitrogen oxide as NO (ppm) at full load condition			
CB10	310	RB10	140
CB20	284	RB20	189
CB40	148	RB40	201

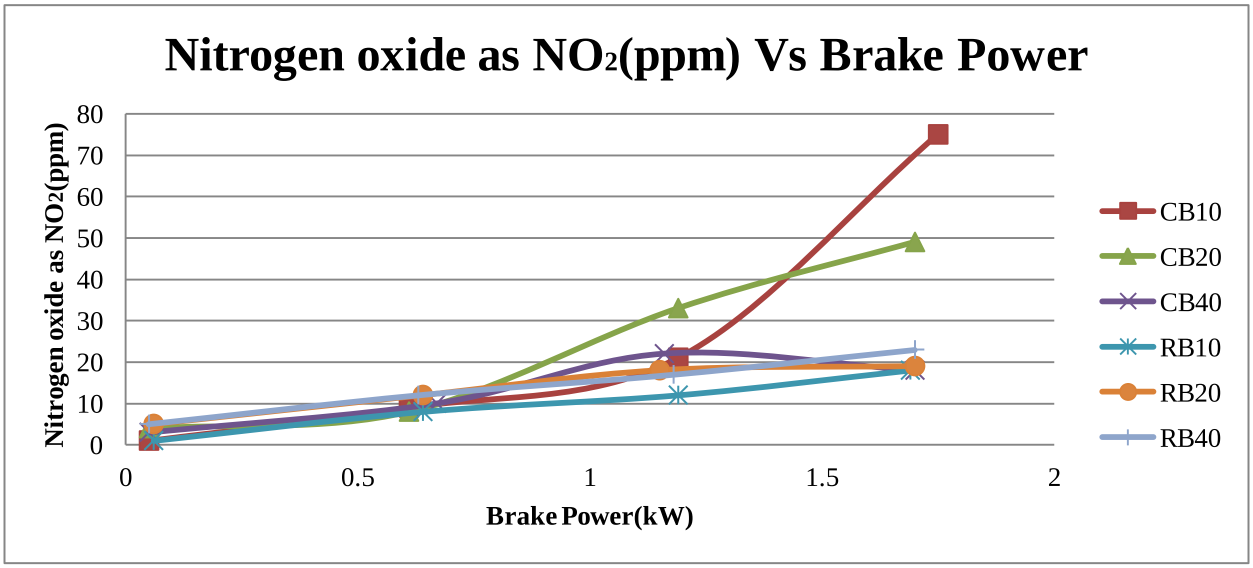


Figure-4.32 Variation of Nitrogen oxide as NO_2 with brake power

Table 4.7

Nitrogen oxide as NO_2 (ppm)at full load condition			
CB10	75	RB10	18
CB20	49	RB20	19
CB40	18	RB40	23

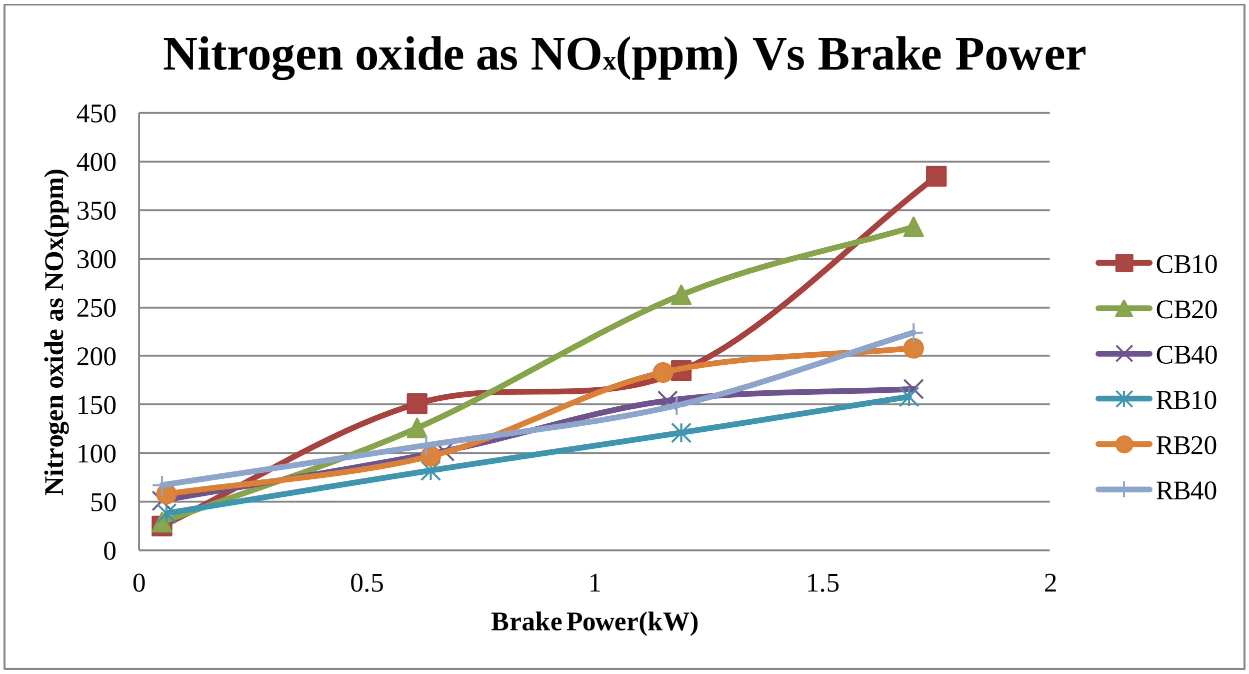
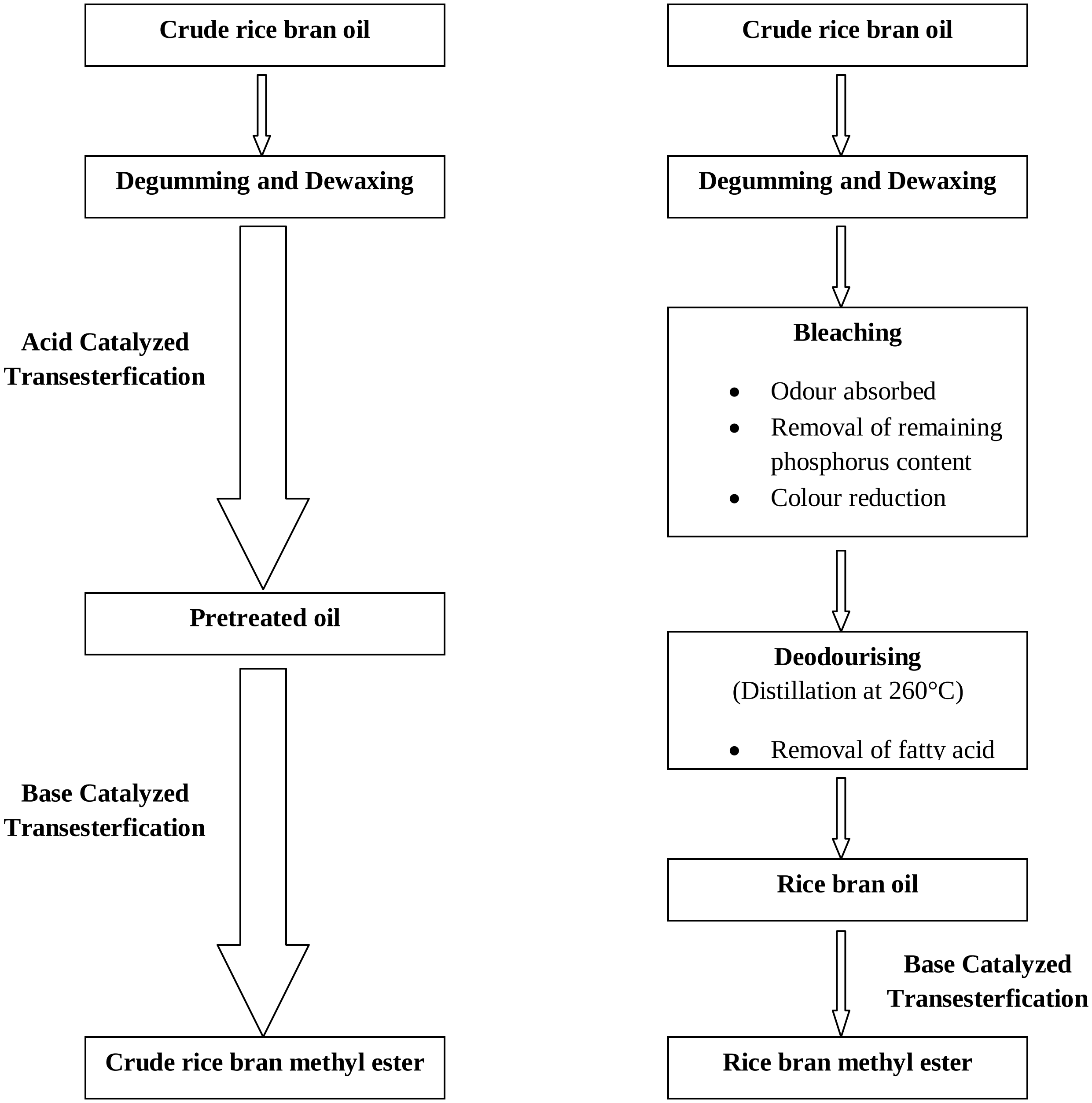


Figure-4.33 Variation of Nitrogen oxide as NOx with brake power

Table 4.8

Nitrogen oxide as NOx (ppm)at full load condition			
CB10	385	RB10	158
CB20	333	RB20	208
CB40	166	RB40	224

It is observed that the engine performance and exhaust emission parameters for blends of crude rice bran methyl ester are better than that of rice bran methyl ester. Only the nitrogen oxide emissions were found to be higher for blends of crude rice bran methyl ester as compared to rice bran methyl ester. This difference in properties can be attributed to the method adopted for the prepration of both the methyl ester.



(a) (b)

Figure-4.34 FFA reduction and biodiesel prepration for (a) Crude rice bran oil (b) Rice bran oil

Figure-4.34 shows the method employed for the reduction of the free fatty acid(FFA) content for the prepration of crude rice bran methyl ester and rice bran methyl ester. The main difference is between the method employed for the prepration of oil before base catalyzed transesterification.

In case of crude rice bran methyl ester the crude oil after degumming and dewaxing undergoes an acid catalysed transesterification for the removal of the unwanted fat to reduce its FFA content below 1%.

Keeping in view the food norms no acidic treatment is employed to reduce its FFA content for making it use for human consumption. The method employed for producing rice bran oil includes the following:

1. Degumming and dewaxing
2. Bleaching which includes
    - Odour absorbed
    - Removal of remaining phosphorus content
    - Colour reduction
3. Deodourising which includes distillation at 260°C for the removal the fatty acid.

Crude rice bran oil consists of oryzanol which acts as an antioxidant in the oil. After acid catalyzed transesterification oryzanol content in the oil remains very less as compared to the oryzanol content present in rice bran oil(edible grade). After base catalyzed transesterification the oryzanol content is higher in rice bran methyl ester compared to crude rice bran methyl ester.

This presence of oryzanol which acts as an antioxidant which resists the proper oxidation/combustion of the blends of rice bran methyl ester inside the combustion chamber. Due to this reason the engine performance and exhaust emission results of blends of rice bran methyl ester when compared with the blends of crude rice bran methyl ester resulted in lower brake thermal efficiency, higher brake specific fuel consumption, higher exhaust emissions(CO, CO_2, HC) except nitrogen oxides emissions which were higher in case crude rice bran methyl ester.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

Present work is done to study the production, engine performance and exhaust emission characteristics of crude rice bran methyl ester and rice bran methyl ester.

Based on the results of the present work, following conclusion are drawn:

1. **Biodiesel Production :** A two stage transesterification process is required for the production of methyl ester from crude rice bran oil(Higher FFA) which includes an acid catalyzed transesterification with sulphuric acid(H_2SO_4) as catalyst followed by a base catalyzed transesterification with potassium hydroxide(KOH) as base catalyst. For rice bran oil a single stage base catalyzed transesterification with potassium hydroxide(KOH) as base catalyst is required.
2. **Optimising Compression Ratio :** Following conclusions were summarized from the experimental investigation:
    - Brake thermal efficiency was found to have maximum value at compression ratio of 14.
    - Fuel consumption and brake specific fuel consumption was found to be lowest at compression ratio of 14.
    - Increase in cylinder pressure along with decrease in the ignition delay was found maximum at compression ratio of 14 with increase in load.

Based upon the performance characteristics 14 is the most optimum compression ratio.

3. **Engine performance and exhaust emission comparison of blends of crude rice bran methyl ester with diesel :**
    - Similar brake thermal efficiency was observed for CB10 and CB20 as that of diesel at compression ratio of 12. At compression ratio 14 maximum brake

thermal efficiency was observed for CB10 higher than that at compression ratio 12.

- Nearly same brake specific fuel consumption was observed for CB10 and CB20 as that of diesel at compression ratio 12. A slight decrease in the specific fuel consumption was observed for CB10 at full load condition for compression ratio 14. Maximum brake specific fuel consumption was observed for CB40 for both the compression ratio.
- Maximum cylinder pressure attained was for CB10 at compression ratio 12 and for diesel at compression ratio 14. Shorter ignition delay was observed with the increase in compression ratio. CB40 attained minimum cylinder pressure with longer ignition delay at both compression ratio.
- Similar hydrocarbon emissions were observed for both CB20 and diesel at both compression ratio. CB40 had highest hydrocarbon emission in both cases.
- CB10 and CB20 showed better carbon monoxide and carbon dioxide emissions than diesel at both compression ratios.
- Higher NOx emissions were observed as compared to diesel.

Similar performance results were observed for CB10 and CB20 as that of diesel. Lower emissions as compared to diesel were observed for CB10 and CB20 expect the NOx emissions which were higher in both case. CB40 showed lowest performance and higher emission results as compared to diesel and other blends. Blends of crude rice bran methyl ester can be used as fuel in diesel engine without any modification.

4. Engine performance and exhaust emission comparison of blends of crude rice bran methyl ester with rice bran methyl ester :

- Comparison of engine performance and exhaust emission results of blends of rice bran methyl ester with the blends of crude rice bran methyl ester resulted in lower brake thermal efficiency, higher brake specific fuel consumption, higher exhaust emissions(CO, CO_2, HC) except nitrogen oxides emissions which were higher in case crude rice bran methyl ester.

5.2 FUTURE SCOPE

Worldwide energy demands are increasing day-by-day. Major part of it is contributed by fossil fuels. Petroleum diesel being cheaper in cost has attracted the minds of people to use it as fuel in diesel engine which has increased the number of diesel fuelled vehicles. For a petroleum importing country like India it is a major concern. Due to this rapidly increasing demand of petroleum diesel biodiesel as an alternative fuel comes into consideration. Selection of inexpensive and available feedstock for biodiesel production within the country is the major concern. Crude rice bran oil is relatively an inexpensive and available raw material for biodiesel production as India is the second largest producer of rice in the world.

- Attempts for making proper use of the unutilized bran extracted from rice for the production of biodiesel should be undertaken by the government.
- Further studies can be carried out for making proper use of the by-products from crude rice bran oil and prepared biodiesel.
- Study on the long term stability of the studied biodiesel blends in cars, tractors, trucks etc. should be done.
- Further investigation can be carried out for the production of ester of crude rice bran oil from different alcoholic groups to conduct various engine tests.
- Experimental investigation on heavy load engines like trucks can be done to figure out an optimum compression ratio for its improved performance along with effects of injection advance and kinetics of emission in C.I engine with biodiesel.

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APPENDIX

A.1.0 PERFORMANCE PARAMETERS

A.1.1 Compression ratio 12 to 18 using B20 blend of rice bran methyl ester

Table A.1.1.1 Brake power (kW) at compression ratios 12 to 18.

Load → C.R ↓	0	2	4	6
12	0.05	0.63	1.16	1.7
13	0.04	0.6	1.15	1.7
14	0.04	0.61	1.14	1.7
15	0.04	0.61	1.15	1.7
16	0.05	0.63	1.18	1.68
17	0.04	0.62	1.15	1.69
18	0.05	0.61	1.18	1.69

Table A.1.1.2 Brake thermal efficiency (%) at compression ratios 12 to 18.

Load → C.R ↓	0	2	4	6
12	1.04	11.15	17.01	21.48
13	1.08	11.31	17.11	21.58
14	1.17	11.67	17.37	21.84
15	1.13	10.91	17.02	20.56
16	1.18	11.12	16.9	19.84
17	1	10.3	15.88	19.69
18	1.03	10	15.76	19.31

Table A.1.1.3 Brake specific fuel consumption (g/kWh) at compression ratios 12 to 18.

Load → C.R ↓	0	2	4	6
12	8220	770	510	410
13	7970	760	500	410
14	7340	730	490	390
15	7570	790	500	420
16	7260	770	510	440
17	8610	830	540	440
18	8320	860	540	440

Table A.1.1.4 Exhaust gas temperature (°C) at compression ratios 12 to 18.

Load → C.R ↓	0	2	4	6
12	141.14	161.22	184.41	213.12
13	147.83	164.98	191.41	218.49
14	150.88	166.91	193.37	220.17
15	149.66	168.59	191.03	225.05
16	154.74	171.95	200.01	227.77
17	156.32	174.87	203.45	231.76
18	157.75	176.32	206.71	240.17

Contd..

A.1.2 Compression ratio 12 for diesel and crude rice bran methyl ester blends.

Table A.1.2.1 Brake power (kW) for diesel and crude rice bran methyl ester blends

Load Fuel	0	2	4	6
Diesel	0.05	0.64	1.19	1.73
CB10	0.05	0.67	1.16	1.69
CB20	0.05	0.64	1.19	1.73
CB40	0.05	0.61	1.16	1.69

Table A.1.2.2 Brake thermal efficiency (%) for diesel and crude rice bran methyl ester blends

Load Fuel	0	2	4	6
Diesel	1.38	11.36	17.63	21.91
CB10	1.325843	12.35587	17.56108	21.6508
CB20	1.337465	11.59421	17.62043	21.67615
CB40	1.307328	9.970094	15.90613	19.84153

Table A.1.2.3 Brake specific fuel consumption (g/kWh) for diesel and crude rice bran methyl ester blends

Load Fuel	0	2	4	6
Diesel	6210	750	490	390
CB10	6460	690	490	400
CB20	6340	740	490	400
CB40	7450	870	540	430

A.1.3 Compression ratio 14 for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Table A.1.3.1 Brake power (kW) for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load Fuel	0	2	4	6
Diesel	0.05	0.67	1.16	1.7
CB10	0.05	0.61	1.19	1.75
CB20	0.05	0.61	1.19	1.7
CB40	0.05	0.67	1.16	1.7
RB10	0.06	0.64	1.19	1.69
RB20	0.06	0.64	1.15	1.7
RB40	0.05	0.63	1.18	1.7

Table A.1.3.2 Brake thermal efficiency (%)for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load Fuel	0	2	4	6
Diesel	1.24	12.01	17.5	21.51
CB10	1.259269	10.89679	17.28366	21.84325
CB20	1.329355	11.15511	17.12538	20.88933
CB40	1.151256	11.25814	15.87549	19.67324
RB10	1.426446	10.71838	16.39768	19.75581
RB20	1.46536	10.40706	15.84937	19.73751
RB40	1.193	10.41969	16.17138	19.74277

Table A.1.3.3 Brake specific fuel consumption (g/kWh) for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load → Fuel ↓	0	2	4	6
Diesel	6900	710	490	400
CB10	6820	790	500	390
CB20	6370	770	500	410
CB40	7320	770	550	440
RB10	6050	800	520	430
RB20	5870	830	540	440
RB40	6990	830	530	440

A.2.0 EXHAUST EMISSION PARAMETERS

A.2.1 Compression ratio 12 for diesel and crude rice bran methyl ester blends.

Table A.2.1.1 Hydro carbon (ppm) for diesel and crude rice bran methyl ester blends

Load → Fuel ↓	0	2	4	6
Diesel	20	20	20	20
CB10	20	10	30	30
CB20	20	20	20	20
CB40	40	30	50	50

Contd..

Table A.2.1.2 Carbon Monoxide (ppm) for diesel and crude rice bran methyl ester blends

Load Fuel	0	2	4	6
Diesel	84	465	274	510
CB10	263	184	191	336
CB20	173	165	518	489
CB40	798	1078	1017	961

Table A.2.1.3 Carbon dioxide (%) for diesel and crude rice bran methyl ester blends

Load Fuel	0	2	4	6
Diesel	0.4	2.3	1.5	2.9
CB10	1.9	1.2	1.3	2.5
CB20	0.8	0.9	3.3	3.7
CB40	2.1	2.7	3.3	3.6

Table A.2.1.4 Nitrogen oxide as NO (ppm) for diesel and crude rice bran methyl ester blends

Load Fuel	0	2	4	6
Diesel	16	157	133	253
CB10	69	81	114	213
CB20	35	65	278	278
CB40	25	120	226	260

Contd..

Table A.2.1.5 Nitrogen oxide as NO_2 (ppm) for diesel and crude rice bran methyl ester blends

Load → Fuel ↓	0	2	4	6
Diesel	1	10	18	29
CB10	6	10	20	32
CB20	0	3	69	75
CB40	1	9	27	29

Table A.2.1.6 Nitrogen oxide as NOx (ppm)for diesel and crude rice bran methyl ester blends

Load → Fuel ↓	0	2	4	6
Diesel	17	167	151	282
CB10	75	91	134	245
CB20	35	68	347	353
CB40	26	129	253	289

Contd..

A.1.3 Compression ratio 14 for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Table A.1.3.1 Hydro carbon (ppm) for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load → Fuel ↓	0	2	4	6
Diesel	20	20	30	40
CB10	30	20	50	40
CB20	20	20	30	40
CB40	30	40	50	50
RB10	30	40	40	50
RB20	70	50	50	50
RB40	50	50	50	50

Table A.1.3.2 Carbon Monoxide (ppm) for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load → Fuel ↓	0	2	4	6
Diesel	599	655	695	520
CB10	115	592	403	630
CB20	104	436	601	658
CB40	941	805	673	608
RB10	626	675	705	654
RB20	731	743	825	761
RB40	769	799	820	825

Table A.1.3.3 Carbon dioxide (%) for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load → / Fuel ↓	0	2	4	6
Diesel	1.7	2.4	2.9	2.5
CB10	1	3.2	1.9	3.4
CB20	0.3	2	0.9	2
CB40	1.9	1.8	2.2	2.4
RB10	1.2	1.8	2.3	2.4
RB20	1.8	2.2	2.8	2.9
RB40	1.2	2.3	2.4	3.4

Table A.1.3.4 Nitrogen oxide as NO (ppm) for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load → / Fuel ↓	0	2	4	6
Diesel	71	151	235	212
CB10	24	142	164	310
CB20	25	118	230	284
CB40	48	92	132	148
RB10	37	74	109	140
RB20	53	85	165	189
RB40	62	96	132	201

Contd..

Table A.1.3.5 Nitrogen oxide as NO_2 (ppm) for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load → Fuel ↓	0	2	4	6
Diesel	5	13	50	52
CB10	1	9	21	75
CB20	4	8	33	49
CB40	3	10	22	18
RB10	1	8	12	18
RB20	5	12	18	19
RB40	5	12	17	23

Table A.1.3.6 Nitrogen oxide as NOx (ppm) for diesel, crude rice bran methyl ester blends and rice bran methyl ester blends

Load → Fuel ↓	0	2	4	6
Diesel	76	164	285	264
CB10	25	151	185	385
CB20	29	126	263	333
CB40	51	102	154	166
RB10	38	82	121	158
RB20	58	97	183	208
RB40	67	108	149	224