Optimization of Biodiesel Production by Taguchi Method from Used Rice Bran Oil and Performance Evaluation of Biodiesel-Diesel Blend in Diesel Engine

A thesis submitted in partial fulfilment of the requirement for the award of degree of

Master of Technology in
Energy Science and Technology

Submitted by

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Certificate of Recommendation

This is to certify that the thesis entitled ***"Optimization of biodiesel production from Used Rice Bran Oil and Performance Evaluation of Biodiesel-Diesel Blend in Diesel Engine"*** submitted by Mr. Parthajit Mondal in partial fulfilment of the requirements for the award of the degree of Master of Technology in Energy Science and Technology at Jadavpur University, Kolkata is an authentic work carried out by him under our supervision and guidance.

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The foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner of satisfactory to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn there in but approve the thesis only for the purpose for which it has been submitted.

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I, hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his Master of Technology in Energy science &Technology studies during academic session 2018-2019. All information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

TITLE: **Optimization of Biodiesel Production by Taguchi Method from Used Rice Bran Oil and Performance Evaluation of Palm Biodiesel-Diesel Blend in Diesel Engine**

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Parthajit Mondal

Place: Jadavpur

DEDICATED TO MY PARENTS

ABBREVIATIONS

RBO : Rice Bran Oil
URBO : Used Rice Bran Oil FFA
:Free Fatty Acid
ml/Kwh : millilitres per Kilowatt-hour
cSt :Centistoke
Rpm : Revolution per minute
ml/hr : millilitres per hour
CBD : Crude biodiesel
B50 : 50% biodiesel and 50% Petro-diesel
B40 : 40% Biodiesel and 60% Petro-diesel
B30 : 30% Biodiesel and 70% Petro-diesel
SFC : Specific Fuel Consumption
BTE : Brake Thermal Efficiency
HRR : Heat Rejection Ratio
C.I. : Compression Ignition

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ABSTRACT

The rapid depletion of petroleum fuels and their ever increasing costs and concern for vehicular emissions have led to an intensive search for alternative fuels. At present, biodiesel is commercially produced from the refined edible vegetable oils such as sunflower oil, palm oil and soybean oil, etc. esterification process. The various parameters that have been considered for the Research in this direction with edible oil has yielded encouraging results with rice bran oil which is edible has been considered as an alternative fuel. It also observed that with bio-diesel, the engine is capable of running without difficulty but with a deviation from its optimum performance.

This process is not suitable for production of biodiesel from many Used non-edible vegetable oils because of their high acid value. Used rice bran oil (URBO) with high free fatty acids (FFA) is used as a source for the production of Used rice bran oil methyl ester (URBOME). Two-stage transesterification process is successfully used. Initially, the FFA of URBO is reduced below 1% (0.8%) by using esterification process with methanol in the presence of acid (H_2SO_4) as a catalyst. Finally, biodiesel has produced by alkaline (KOH) catalyzed transesterification process which has designed and optimized by using Taguchi Method. Optimum yield value of the crude biodiesel comes 93% in presence of CH3OH (10% v/v of oil), KOH (0.5% w/v of oil) and reaction time (90 minutes) and reaction temperature (55˚C to 60˚C).The lower blends of biodiesel increase the brake thermal efficiency and reduce the fuel consumption. The exhaust gas emissions are reduced with increase in biodiesel concentration. The experimental results proved that rice bran oil can be substituted for diesel without any engine modification as a fuel. In this research work 40to 60% of the RBO is effective combination to give the better results. Finally Pure rice bran oil, diesel and biodiesel are used as fuels in the compression ignition engine and the performance and emission characteristics of the engine are analyzed

C

CHAPTER 1

1. INTRODUCTION

1.1 BACKGROUND OF BIODIESEL PRODUCTION FROM RBO

Due to clean emission profile, ease of use and other benefits biodiesel quickly become one of the fastest growing alternative fuels in the world. The future of biodiesel lies in the world's ability to produce renewable feedstock such as vegetable and animal oils, to keep the cost of biodiesel competitive with petroleum. The rice bran oil is extracted from the rice bran, which is a by-product obtained during the grinding of paddy. Since rice is the staple food in a large part of south Asia, there is a huge potential to produce and utilize rice bran oil.

India is the second largest producer of paddy. Hardly 50% of the bran is utilized for producing rice bran oil and 19% of edible grade rice bran oil is consumed for cooking, hence Rice bran oil is commercially feasible for biodiesel production. Rice bran oil is a by-product obtained from outer layers of brown rice kernel during milling operation to produce polished rice. Rice bran has 16 wt% to 32 wt% [1] oil (lipids) and nutraceutical compounds are depending on the rice variety and degree of milling.

Few researchers [2]-[4] investigated biodiesel production from crude RBO by alkaline catalyzed transesterification process. However, possibility of soap formation increases with the use of this method as its FFA level found to be more than 1% and finally it affects the quality and quantity of biodiesel. Many researchers [5] [6] used acid catalyzed transesterification process for biodiesel production from RBO and conducted a series of experiments at 1:10 molar ratio of oil/methanol, 2 wt% H2SO4, and reaction temperature of 60˚C for a wide range of FFA. Researchers found that biodiesel yield decreased with an increase in FFA level.

Considerable research has also been done on biodiesel production from RBO by using two-stage transesterification and lipase catalyzed transesterification process. Alcoholysis of crude RBO can be achieved under mild reaction conditions and in short reaction times in the presence of lipases. Lipase catalyzed transesterification allows easy recovery of glycerol with any purification method.

1.2 OBJECTIVE OF THE PRESENT PROJECT WORK

In the present investigation, the Optimization of the reaction for biodiesel production and effect of different blend in CI engine is our main area of interest.

1. Determination of FFA value of the Used rice bran oil
2. Use two-stage transesterification processes to get biodiesel
3. Use Taguchi method to optimize the reaction yield.

4. Various property test and compare with biodiesel stander specification
5. Study the engine performance with different blend

The below figure (Fig 1) represent the two-stage transesterification process for the Used rice bran oil

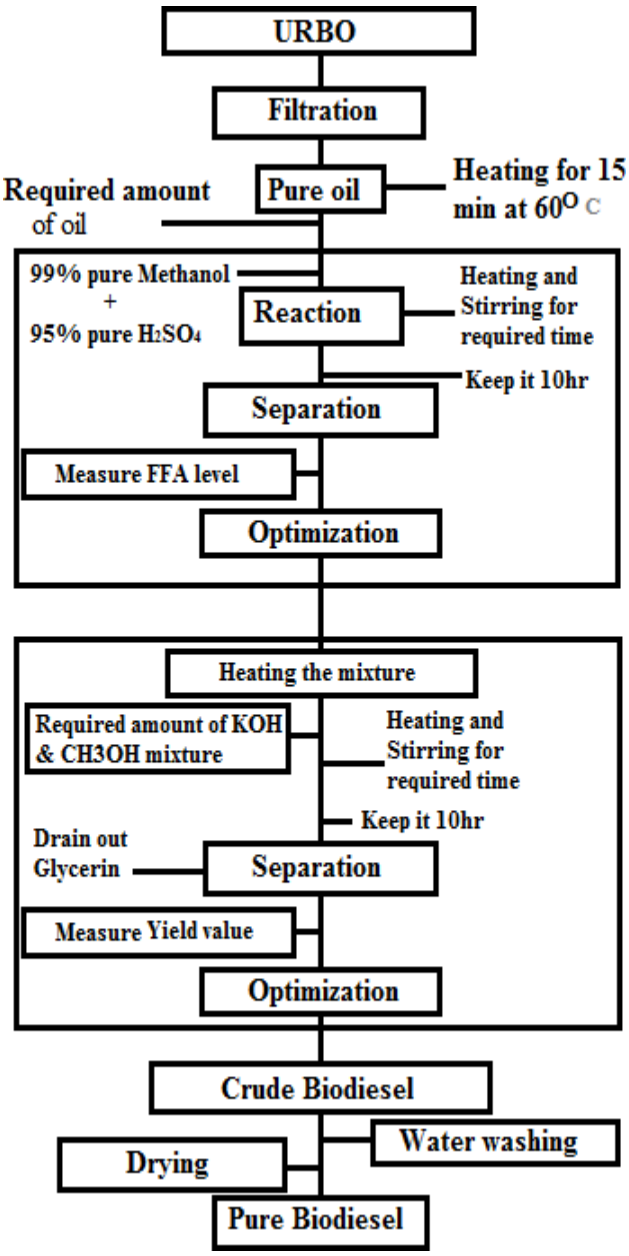

Fig1.1: Layout of Experiment

CHAPTER 2

2. Literature Review

2.1. BIODIESEL

Biodiesel refers to a vegetable oil- or animal fat-based diesel fuel consisting of long chain alkyl (methyl, ethyl, or propyl) esters. Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, soybean oil, animal fat with an alcohol producing fatty acid esters. [7]

Biodiesel is meant to be used in standard diesel engines and is thus distinct from the vegetable and waste oils used to fuel converted diesel engines. Biodiesel can be used alone, or blended with petro diesel in any proportions.

2.1.1. Biodiesel Fuel Feedstock

Biodiesel fuel is one of the easiest alternative fuels to use. The raw material used for biodiesel production is called feedstock. A variety of oils as biodiesel fuel feedstocks are used to produce the fuel. There are more than 300 types of feedstock from which biodiesel can be produced. Common biodiesel feedstock are:

A. Edible vegetable oil Rice Bran ,Sunflower, Rapeseed, Rice bran, Soybean, Coconut, Corn, Palm, Olive, Palestine, Sesame seed, Peanut, Opium Poppy, Safflower oil.

B. Non-edible vegetable oil Jatropha, Karanja, Pongamia, Neem, Jojoba, Cottonseed, Linseed, Mahua, Deccan hemp, Kusum, Orange, Rubber seed, Sea Mango, Algae and Halophytes.

C. Waste or recycled oil or used vegetable oil It may be different feed stocks like Rice bran oil,soybean oil, mastered oil, sunflower etc.

2.1.2. Rice Bran oil as Feedstock

RBO is a uncommon source of edible oil which is produced from rice bran and rice contains approximately 7-8% (wt. basis) rice bran oil [8]. The estimated potential yield of crude RBO is about 8 million metric tons if all rice bran produced in the world were to be harnessed for oil extraction [9].

2.1.3. Advantages of Biodiesel

Advantages of biodiesel are described below [10]

- Produced from Renewable Resources unlike other petroleum products that will vanish in years to come
- Can be used in existing Diesel Engines in B100 or in blends with petroleum diesel. For e.g.: B20 is called as 20% blend of biodiesel with 80% diesel fuel. It improves engine lubrication and increases engine life since it is virtually sulphur free.
- Less Greenhouse Gas Emissions (e.g., B20 reduces CO2 by 15%)

- Grown, Produced and Distributed Locally from domestic energy crops
- Cleaner Biofuel Refineries releases less toxic chemicals
- Biodegradable and Non-Toxic
- Positive Economic Impact
- Reduced Foreign Oil Dependence
- More Health Benefits as it pollute the air less

2.1.4. Disadvantages of Biodiesel

Disadvantages of biodiesel are described below [10]

- Variation in Quality of Biodiesel as it made of variety of crops or animal fat;
- Not Suitable for use in Low Temperatures
- Since biofuels are made from animal and vegetable fat, more demand for these products may raise prices for these products and create food crisis in some countries
- Increased use of Fertilizers and excess use of fertilizers can result in soil erosion and can lead to land pollution.

- Clogging in Engine as the engine dirt gets collected in fuel filter by biodiesel
- All regions are not suitable for oil producing crops and they need to be transported to the plants which increases the cost and amount of emission.
- Use of Petroleum Diesel to Produce Biodiesel:
- Slight Increase in Nitrogen Oxide Emissions (10% higher Nitrogen Oxide)

2.2. Different Production processes of Biodiesel

Considerable efforts have been made to develop vegetable oil derivatives that approximate the properties and performance of hydrocarbons-based diesel fuels. The problem with substituting triglycerides for diesel fuel is mostly associated with high viscosity, low volatility and polyunsaturated characters. These can be changed in at least four ways: pyrolysis, micro emulsion, dilution and transesterification.[11]

2.2.1. Dilution : The vegetable oil is diluted with petroleum diesel to run the engine. Caterpillar Brazil, in 1980, used pre-combustion chamber engines with the mixture of 10% vegetable oil to maintain total power without any alteration or adjustment to the engine. At that point it was not practical to substitute 100% vegetable oil for diesel fuel, but a blend of 20% vegetable oil and 80% diesel fuel was successful. Some short-term experiments used up to a 50/50 ratio.[12]

2.2.2. Thermal cracking (Pyrolysis) : Pyrolysis is a method of conversion of one substance into another by mean of heat or by heat with the aid of the catalyst in the absence of air or oxygen. The process is simple, waste less, pollution free and effective compared with other cracking processes [13].

2.2.3. Micro-emulsion: The formation of micro emulsion is one of the potential solutions for solving the problem of vegetable oil viscosity. Micro-emulsions are defined as transparent, thermodynamically stable colloidal dispersion. The droplet diameters in micro-emulsions range from 100 to 1000 Å. Microemulsion can be made of vegetable oils with an ester and dispersant (co solvent), or of vegetable oils, and alcohol and a surfactant and a cetane improver, with or without diesel fuels. All micro-emulsions with butanol, hexanol and octanol met the maximum viscosity requirement for diesel fuel.[14]

2.2.4. **Transesterification:** Transesterification is the method of biodiesel production from oils and fats and can be carried out by two ways.

I. Catalytic Transesterification. The Catalytic Transesterification‖ process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of some catalyst to form esters and glycerol. A triglyceride has a glycerine molecule as its base with three long chain fatty acids attached. The characteristics of the oil/fat are determined by the nature of the fatty acids attached to the glycerine. The nature of the fatty acids can in turn affect the characteristics of the biodiesel.

A successful transesterification reaction is signified by the separations of the ester and glycerol layer after the reaction time. The heavier, co-product, glycerol settles out and may be sold as it is or it may be purified for use in other industries, e.g. the pharmaceutical, cosmetics etc.

A. Acid Catalyzed Transesterification The acid catalyzed process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of acid catalyst, preferably sulphonic and sulphuric acids to form esters (biodiesel) and glycerol. These catalysts give very high yields in alkyl esters, but the reactions are slow, requiring, typically, temperatures above 100°C. The acid-catalyzed transesterification should be carried out in the absence of water, in order to avoid the competitive formation of carboxylic acids which reduce the yields of alkyl esters.

B. Alkaline Catalyzed Transesterification The alkaline catalyzed transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of an alkaline catalyst such as alkaline metal alkoxides and hydroxides as well as sodium or potassium carbonates to form esters (biodiesel) and glycerol. The alkaline catalyzed transesterification of vegetable oil proceeds faster than the acid catalyzed reaction. Due to this reason, together with the fact that the alkaline catalysts are less corrosive than acidic compounds, industrial processes usually favour alkaline catalysts, such as alkaline metal alkoxides and hydroxides as well as sodium or potassium carbonates. But the presence of water and high amount of free acid gives rise to saponification of oil and therefore, incomplete reaction during the alkaline transesterification process with subsequent formation of emulsion and difficulty in separations of glycerol.

C. Lipase Catalyzed Transesterification The lipase catalyzed transesterification process is the reaction of a triglyceride (fat/oil) with an alcohol in the presence of lipase enzyme as a catalyst to form esters (biodiesel) and glycerol. In lipase catalyzed process no complex operations are needed not only for the recovery of glycerol but also in the elimination of catalyst and soap. This is an environmentally more attractive option to the conventional process. However, the reaction yields as well as the reaction times are still unfavourable compared to the alkaline catalyzed reaction systems.

II. **Supercritical Methanol Transesterification** The simple transesterification processes discussed above are confronted with two problems, i.e. the processes are relatively time consuming and needs separations of the catalyst and saponified impurities from the biodiesel. The first problem is due to the phase separations of the vegetable oil/ alcohol mixture, which may be dealt with by vigorous stirring. These problems are not faced in the supercritical method of transesterification. This is perhaps due to the fact that the tendency of two phase formation of vegetable oil/alcohol mixture is not encountered and a single phase is found due to decrease in the dielectric constant of alcohol in the supercritical state (at 340°C and 43 MPa). As a result, the reaction was found to be complete in a very short time within 2-4 mins. Further, since no catalyst is used, the purification of biodiesel is much easier, trouble free and environment friendly.

2.3. APPROACH TO PROCESS DEVELOPMENT

The Design of Experiments is considered as one of the most comprehensive approach in product/process developments. It is a statistical approach that attempts to provide a predictive knowledge of a complex, multi-variable process with few trials. Following are the major approaches to DOE:

2.3.1. Full Factorial Design

A full factorial experiment is an experiment whose design consists of two or more factors, each with a discrete possible level and whose experimental units take all possible combinations of all those levels across all such factors. Such an experiment allows studying the effect of each factor on the response variable, as well as on the effects of interactions between factors on the response variable. A common experimental design is the one with all input factors set at two levels each. If there are k factors each at 2 levels; a full factorial design has 2k runs. Thus for 6 factors at two levels it would take 64 trial runs [15].

2.3.2. Taguchi Method

The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyse the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the-better. [15]

The use of Taguchi's parameter design involves the following steps

a) Identify the main function and its side effects.
b) Identify the noise factors, testing condition and quality characteristics.
c) Identify the objective function to be optimized.
d) Identify the control factors and their levels.
e) Select a suitable Orthogonal Array and construct the Matrix
f) Conduct the Matrix experiment.
g) Examine the data; predict the optimum control factor levels and its performance.
h) Conduct the verification experiment.

1.4. PROPERTIES TEST

1.4.1. Density: Density values depend on their fatty acid composition as well as on their purity. The densities of biodiesels are generally higher than those of fossil diesel fuel.

Density is an important fuel property, because injection systems, pumps, and injectors must deliver an amount of fuel precisely adjusted to provide proper combustion.

A slight change in density can affect engine output power.

Pycnometer was used to measuring density of the oil.

Fig.2.1 : Pycnometer

Density measurement steps are given below:

I. Measure the Weight of empty beaker (w_1) and Volume(v) of oil taken
II. Also measure the Weight of the oil filled beaker(w_2)

Hence **density = $((w_2 - w_1)/v)$**

1.4.2. Kinematic viscosity: Viscosity is defined as the internal friction or resistance of a liquid to flow. Increase in temperature decreases the viscosity of biodiesel. In most cases, the viscosity of biodiesel is higher than that of diesel.

Due to higher viscosity, the atomization property is reduced, so this may increase the fuel droplet size when compared to diesel. On the other hand, the higher viscosity of biodiesel acts as a good lubricating agent, and so mechanical efficiency is improved. The Kinematic viscosities were measured at the desired temperature using **Ostwald viscometer** as shown in **Fig.3**.

I. The viscometer with the sample is immersed in a water bath so that it attains the desired temperature.

II. Suction is applied so that liquid is drawn up to mark A. The efflux time of the liquid between marks A and B is noted after releasing the vacuum.

The co-efficient of viscosity of liquid can be determined by comparing its coefficient of viscosity with the known coefficient of viscosity of a liquid. Generally water is taken as the known liquid for comparison..

a. Water is passed through the capillary and three readings are taken of the time water takes to fall from the upper mark to the lower mark.
b. The apparatus has to be dried before pouring oil into it.

Fig2:Ostwald viscometer

c. Then oil is passed through the viscometer's capillary. Again three readings are taken of the time biodiesel takes to fall from the upper mark to the lower mark.

The kinematic viscosity was obtained from below mentioned formula.

$$\eta_1 = \eta_2 \cdot (\rho_1 t_1 / \rho_2 t_2)$$

where η_1, η_2= viscosity coefficients of the liquid and water,

ρ_1,ρ_2 = the densities of liquid and water,

t_1, t_2 = The efflux time of the liquid between marks A and B

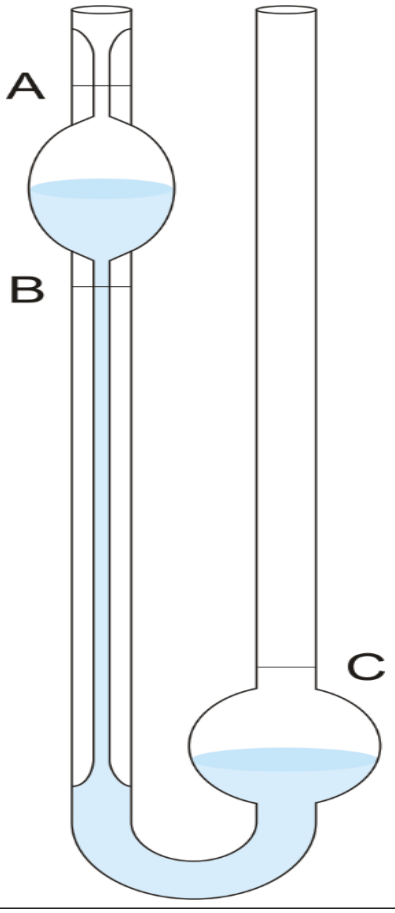

Fig.2.2:Ostwald viscometer

2.4.3. Flash Point and Fire point

Flash Point can be defined as the minimum temperature of liquid to give enough vapours to form combustible mixture with air. To maintain combustion adequately we required to burn the vapours continuously at the flash point. The fire point is the lowest temperature at which vapour of the material will keep burning after being ignited and the ignition source removed. The fire point is higher than the flash point, because at the flash point more vapour may not be produced rapidly enough to sustain combustion.

Fig.2.3 Flash point measurement set up

The apparatus consists of a motor, a cup to hold biodiesel, an internal heater and a thermometer of range 300C to register the temperature rise.

Following steps were followed for measuring the flash point and fire point of the oil:

a. The cup is filled with biodiesel up to a certain mark
b. When the thermometer reading crosses 100C, fire is introduced at certain interval of temperature rise and condition of the introduced fire is observed.
c. If the fire gets engulfed in the biodiesel, it denotes the flash point of the biodiesel.
d. The point where the fire continues to burn denotes the fire point of the biodiesel.
e. If the flash point misses out and fire point is reached then the experiment has to be performed again within those degrees of rise in temperature.

2.4.4. ACID VALUE

Acid value indicates the proportion of free fatty acid present in an oil or fat and may be defined as the number of milligrams of caustic potash required to neutralize the acid in 1 gm of the sample. The normal acid value for most samples lies within 0.5. If any titrable acid other than a fatty acid is present in the sample, it will be an error. A high acid value indicates a stale oil or fat stored under improper conditions [16].

Acid value measurement involves following steps:

a. Weight 5 gm of oil and transfer it into 250 ml conical flask.
b. Add 50 ml of neutralized alcohol solution to the oil solution.
c. Heat this mixture for 10 minutes by using the heater.
d. Take the solution after 10 minutes and add 1 or 2 drops of phenolphthalein indicator.
e. Titrate this against the KOH solution from the burette.
f. The appearance of pink colour indicates the end point

After getting the all measured value, acid value calculated by following below formula

Acid value = (Volume of KOH x Normality of KOH x Eq. wt x 1000) / Weight of Oil sample

2.4.5. CALORIFIC VALUE

The calorific value is the total energy released as heat when a substance undergoes complete combustion with oxygen under standard conditions. The chemical reaction is typically a hydrocarbon or other organic molecule reacting with oxygen to form carbon dioxide and water and release heat[17].

For calculating the calorific value we used Bomb Calorimeter by following the steps given below

I. Take required amount of sample oil
II. Fine wire connected to electrical lead for ignition

III. Place the sample cup in Bomb and fill the bomb with oxygen.

IV. Take required amount of water in a container

V. Place the bomb inside the container

VI. After sealing the container reaction start to take the temperature difference

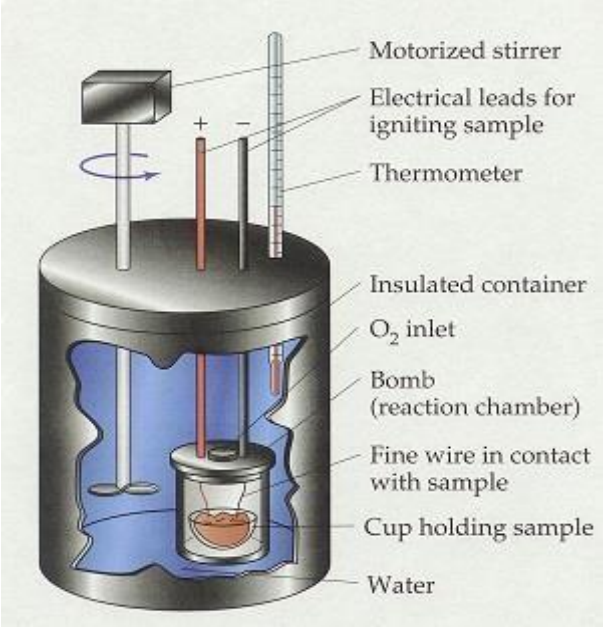

Fig.2.4 Bomb Calorimeter

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CHAPTER 3

3. EXPERIMENTAL

3.1. PRE-PROCESSING OF RBO FEEDSTOCK

3.1.1. FILTRATION OF RBO

Collected URBO was containing solid particles and dust contaminated in it. The main drawback of using URBO as a feedstock in biodiesel production is the presence of unwanted contents, such as FFA, water and other solid impurities.

Steps to remove unwanted particles and water are mentioned below.

i. URBO sample is heated to above 100°c in air oven for 30 minutes to eliminate water content.
ii. Then URBO is passed through waste cotton to filter the larger food particles.
iii. After this process only the black carbon particles are left. This was removed through vacuum filtration technique.

Fig.3.1 VACUUM FILTRATION

3.1.2. PHYSICAL PROPERTIES OF URBO

A. DENSITY MEASUREMENT OF URBO:

The density of URBO sample is measured by **Pycnometer** of 10 ml .

Weight of empty Pycnometer = 18.962 gm

Volume of oil taken = 10 ml

Weight of the filled Pycnometer = 28.205 gm

So, Wight of 10 ml Oil = (28.205-18.962) = 9.243 gm

Hence density = 9.243/10 = 0.9243 gm/ml

B. Measurement of free fatty acid (FFA%):

$$\text{Acid value} = \frac{56.1 \times V \times N}{W}$$

Where, V = Volume in mL of standard potassium hydroxide solution.

N = Normality of the potassium hydroxide solution

W = Weight in gm. of the sample

Prepare KOH solution so that the normality of the KOH solution = 0.1 N.

Take 1ml of URBO sample (W=1×0.9243 gm). Mix the oil with 10 ml isopropyl alcohol properly, add four drops of phenolphthalein used as colour indicator.

Now add the KOH solution drop by drop by the use of a burette. Note down the amount of KOH volume (V) required to neutralize the oil sample by observe the change in colour.

Volume of KOH solution required in experiment (i) V= 0.8 ml

(ii) V= 0.7 ml

So, Average volume required = 0.75 ml

$$\text{So, Acid value} = \frac{56.1 \times 0.75 \times (.1)}{0.9264} = 4.56 \text{ mg KOH / gm}$$

$$\text{Acid value} = \text{FFA\%} \times 1.99$$

$$\text{FFA\%} = \frac{\text{Acid value}}{1.99} = \frac{4.56}{1.99} = 2.287\%$$

URBO has a higher amount of FFA (2.287%) which is above the accepted limit (i.e., 1%) for alkaline catalyst transesterification process. Therefore, in this work pre-treatment stages have used to convert FFA into esters by treating URBO with methanol in the presence of an acidic catalyst (H_2SO4, 0.5% v/v) to bring the FFA amount to less than 1%. Finally, transesterification process is completed by using an alkaline catalyst.

Sl. No	Properties	Unit	RBO
1	Viscosity at 40˚C	cSt	12.3
2	Density	gm/ml	0.9243
3	Flash point	˚C	260
4	Calorific value	MJ/kg	36.16
5	FFA	%	2.287

Table.3.1 Physical properties of URBO

3.2. MATERIAL

Required quantity of URBO is collected from collage canteen at Jadavpur, Kolkata, West Bengal ,India. All chemicals such as methanol (99.5% purity), H_2SO4 (99% purity), KOH are used as required for making biodiesel.

3.3. EXPERIMENTAL PROCEDURE

In this work the whole experiment is done in two stage. "Stage 1" and "Stage 2" are described in detail below.

3.3.1. "STAGE 1" ACID CATALYZED ESTERIFICATION PROCESS

In this stage, experiments have designed by using "Full fractional method" and nine experiments were conducted by varying methanol quantity (10%, 12%, and 15% v/v of oil) and reaction time (1:30 hr, 2 hr, and 2:30 hr) and keeping acid catalyst concentration (H_2SO4, 0.5% v/v) and reaction temperature (55˚C to 60˚C) constant.

URBO (100 ml) has taken into the reactor. Reaction temperature is maintained at 55˚C to 60˚C. Required amount of CH_3OH added to the concentrated H_2SO4 (0.5% v/v of oil). The mixture slowly added to the heated oil. Stirring at low RPM and heating (55˚C to 60˚C) is continued for different reaction times. Similar methods were used for all nine experiments which were conducted according to the experimental matrix shown in Table.3.2. On completion of reaction, the mixtures were allowed to fall into two layers. The excess methanol, H_2SO4, and impurities were separated. The acid value of the product separated at the bottom is measured. Table.3.2 shows the FFA level for different combination of CH_3OH and reaction time for URBO for "Stage-1" acid catalyzed transesterification process

SAMPLE	CH_3OH (v/v %)	TIME(hr)	KOH(ml)	Acid Value
S1	10	01:30	0.31	1.9
S2	10	2	0.27	1.6
S3	10	02:30	0.25	1.5
S4	12	01:30	0.23	1.4
S5	12	2	0.15	0.9
S6	12	02:30	0.23	1.4
S7	15	01:30	0.24	1.5
S8	15	2	0.1	0.6
S9	15	02:30	0.18	1.1

Table.3.2 Layout of experimental design and results for "Stage-1" acid catalyzed transesterification process

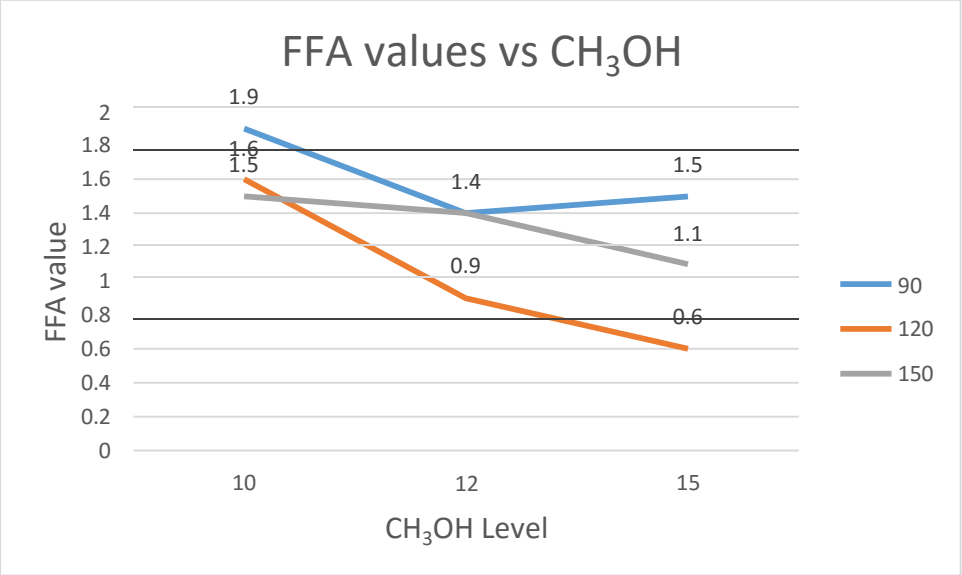

Fig.3.2. Influence of quantity of methanol and reaction time on FFA level

3.3.2. "Stage 2" Alkaline Catalyzed Transesterification Process

Sample (S8) has selected as a source for alkaline catalyzed transesterification process as its Acid value is less than 1% (i.e., 0.6%).Now the alkaline catalyzed transesterification process is optimised by using "Taguchi Optimization Method".

Before proceeding on to further steps, it is necessary to list down all the factors that are going to affect or influence the alkaline catalyzed transesterification process and from those factors, identify the control and noise factors. All the factors listed down in Table.3.3

Control factors	Noise Factors
CH3OH	Coolant
KOH	Operator Skill
Reaction time	Machine Condition
Temperature	Outer Temperature
Stirring RPM	material variation

Table.3.3List of Control factors and Noise factors

Among the factors listed in Table.3.3 CH_3OH, KOH and reaction time are selected as Control Factors and other all factors are considered as Noise Factor. The factors and their levels were decided for conducting the experiment as given below in the **Table**.3.4

Control Factors	Unit	Symbol	Level		
			1	2	3
CH3OH	ml	A	10	15	20
KOH	gm	B	0.5	1	1.5
Reaction Time	hr	C	01:30	2	02:30

Table.3.4: variables of the reaction and their chosen quantity

The most suitable orthogonal array for experimentation is L9 array as shown in Table 6. Therefore, a total nine experiments are to be carried out. All nine experiments have conducted by varying methanol quantity (10%, 15%, and 20% v/v of oil) ,KOH quantity (0.5%, 1% and 1.5% w/v of oil) and reaction time (1:30 hr, 2 hr, and 2:30 hr) and the yield value of every experiment are shown in Table 3.5

Sample	A	B	C	Yield	
				Set 1	Set 2
S81	1	1	1	94	93
S82	1	2	2	85	88
S83	1	3	3	78	75
S84	2	1	2	83	80
S85	2	2	3	84	81
S86	2	3	1	79	82
S87	3	1	3	88	85
S88	3	2	1	82	83
S89	3	3	2	68	70

Table.3.5 : Layout of experimental design and Yield Values of different sample

Sample (S8) (Table 3) has taken into the reactor. Reaction temperature is maintained at 55˚C to 60˚C . KOH solution is prepared by dissolving required amount of KOH in desired amount of CH_3OH as mentioned in Table 6. Half of the prepared KOH and CH_3OH solution slowly added to the heated oil. Stirring and heating continued for 10 to 15 minutes. Then, remaining half of the prepared KOH and CH_3OH solution slowly added to the heated mixture. Stirring at low RPM (500 rpm) and heating (55˚C to 60˚C) is continued for required time mentioned in Table.3.5. Similar method has used for all 18 experiments which have conducted according to the experimental matrix shown in Table.3.5. On completion of reaction, the mixtures allowed to fall into

two layers with the CBD on the top and glycerol on the bottom. The raw CBD collected, and water washed as many times to bring the pH of CBD to 7.

CBD collected in a container and warm water (approximately double amount of CBD) was poured into that container. CBD was washed by air blower and keep them for 10 min for separation. All the impurities with warm water drain out and measure the pH value of the water. This process was continued three or four times until the pH value of the water become 7.

Since the objective function (Reaction Yield) is larger-the-better type of control function, was used in calculating the S/N ratio. The S/N ratios of all the experiments were calculated and tabulated as shown in

Sample	A	B	C	Yield		S/N Ratio
				Set 1	Set 2	
S81	1	1	1	94	93	39.416
S82	1	2	2	85	88	38.736
S83	1	3	3	78	75	37.668
S84	2	1	2	83	80	38.219
S85	2	2	3	84	81	38.325
S86	2	3	1	79	82	38.111
S87	3	1	3	88	85	38.736
S88	3	2	1	82	83	38.329
S89	3	3	2	68	70	36.774

Table.3.6: S/N ratio of every experiment

The S/N ratio for the individual control factors are calculated (calculation done by using MINI TAB) and also their rank was analysed in Table 8.The S/N ratio of individual control factors are plotted in Graph 1 by using Mini Tab.

The S/N ratio for the individual control factors are calculated as given below:

1) Summation of the S/N ratio of every individual control factors at different levels. As an example
$S1_{CH3OH}$ = [S/N value of (S_{81} + S_{82} + S_{83})]
Means all the S/N values of CH_3OH at level of 10ml are added. Similarly summation of S/N values of CH_3OH,KOH and Reaction time at every level were calculated.

2) Average S/N ratio corresponding to the individual control factors at every levels were calculated

3) All the average S/N ratio and different levels of every individual control factors were plotted in the fig.

4) Determine the Rank (which control factor more effective) by the help of the difference between maximum and minimum value of Average S/N ratio of every individual control factors.

Level	A	B	C
1	38.61	38.79	38.62
2	38.22	38.46	37.91
3	37.95	37.52	38.24
Delta	0.66	1.27	0.71
Rank	3	1	2

Table.3.7: Avg. S/N ratio for individual control factors and their rank

According to the above table KOH plays the major role in the reaction and CH3OH plays the minor effect in the reaction among all the Control Factors.

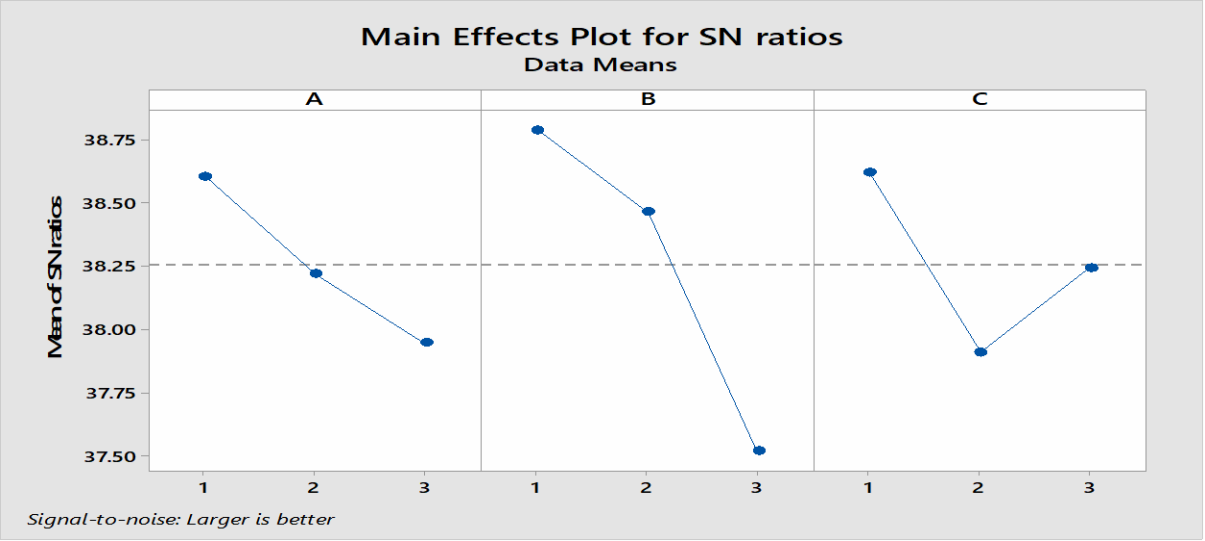

Fig.3.3 : S/N ratio of control factors vs different level of control factors.

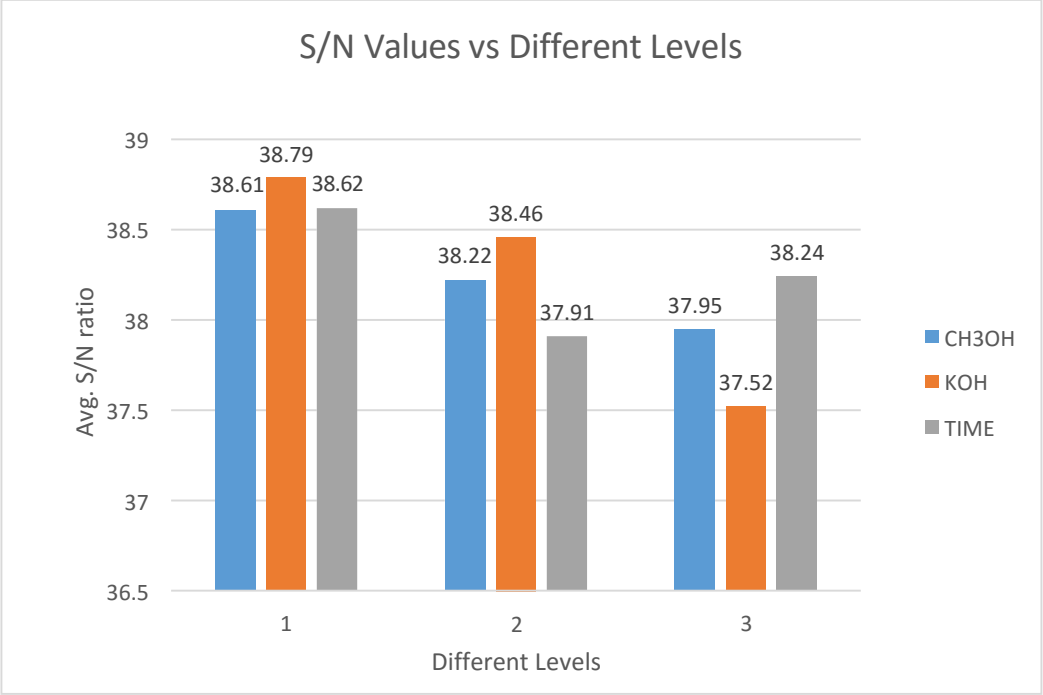

Fig.3.4 : S/N ratio of control factors vs different level of control factors in bar graph

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition. From these linear graphs it is clear that the optimum values of the factors and their levels are as given in Table.3.8.

Parameter	Optimum Level
CH3OH	10% (v/v)
KOH	0.5% (w/v)
Reaction time	1:30 hr

Table.3.8 : Optimized value of control factor

CHAPTER 4

4 RESULTS AND DISCUSSIONS

4.1. PROPERTIES OF THE BIODIESEL

Various properties of the produced crude biodiesel from rice bran oil were measured to compare with the standard properties of biodiesel.

4.1.1. DENSITY TEST RESULT

Density of the biodiesel was measured by using **Pycnometer.** Measured all the parameters and their values are provided below in Table.4.1

Sample no.	Weight of empty pycnometer	Volume of pycnometer	Weight of oil filled pycnometer	Weight of biodiesel	Density	Avg. Density
UNIT	**gm.**	**ml**	**gm.**	**gm.**	**gm./ml**	**gm./ml**
T1	18.983	10	27.882	8.899	0.8899	0.8885
T2	18.929		27.785	8.859	0.8859	
T3	18.962		27.852	8.89	0.889	

Table.4.1 Measured values of the biodiesel for density calculation

4.1.2. KINEMATIC VISCOSITY TEST RESULT:

Kinematic Viscosity measured by process described in Chapter 2 at section 2.4.2 and all the measured values given below in Table.4.2 at 40ºC and the density and kinematic viscosity of water at 40ºC are collected. All the experiments are done three times respectively.

Sample No.	WATER			BIODIESEL			
	Time Taken	Density	Kinematic Viscosity	Time Taken	density	Kinematic Viscosity	Avg. Kinematic Viscosity
Unit	**Sec.**	**Sec.**		**Sec.**	**Sec.**		
T1	52	1	0.6579	380	0.8885	4.271	4.104
T2	56			398		4.154	
T3	54			359		3.886	

Table.4.2 Measured values for Kinematic Viscosity measurement

4.1.3. FLASH POINT AND FIRE POINT TEST RESULT:

Flash point and fire point measured by following the steps described in Chapter 2 at section 2.4.3 and for better result whole process were repeated three times and flash point and fire point of the biodiesel are considered as the average of those three results

Sample No.	Flash Point	Fire Point
T1	172	188
T2	173	190
T3	165	186

Table.4.3 Measured values of biodiesel

So from the above results we can say that the fire point of the biodiesel is approximately 171ºC and fire point is approximately 189 ºC

4.1.4. CALORIFIC VALUE TEST RESULT

Before a material with an unknown heat of combustion can be tested in a bomb calorimeter, the energy equivalent or heat capacity of the calorimeter must first be determined. This value represents the sum of the heat capacities of the components in the calorimeter, notably the metal bomb, the bucket and the water in the bucket.

ENERGY EQUIVALENT CALCULATION

Mass of benzoic acid = 2.215 gm

Standard heat of combustion of benzoic acid = 26.454 MJ/ kg = 26454 J/g

Temperature rise due to the combustion of benzoic acid = 2.08 °C

Energy equivalent of the calorimeter = $\frac{26454 \times 2.215}{6.22}$ = 9420.516 J/°C

Calorific value of oil measured in Bomb Calorimeter where 2 lit of water is taken for heat absorption and remaining values are measured as given below and calculated the calorific values of biodiesel in Table.4.4

Wt. container	**wt. of oil with container**	**wt. of biodiesel**	**Temp. Diff**	**energy increase**	**Avg. Calorific Value**
gm	**gm**	**gm**		**KJ**	**MJ/kg**
2.94	5	2	6.58	61.9836	30.08913
2.93	5.1	2.1	6.98	65.7516	30.30028
2.94	5.3	2.3	7.15	67.353	28.53941

Table.4.4 measured data and calculated calorific value of biodiesel

So the average calorific of biodiesel is approximately 29.645 MJ/kg from the above table values

4.2. ENGINE TEST

Biodiesel and its various blend with diesel is tested in CI engine with the specification given below in Table.4.5

Model	Z170f
Type	Single cylinder,horizontal,4-stroke
Combustion system	Swirl combustion chamber
Bore*stroke(mm)	70*70
Rated power	2.94kw/4hp
Rated speed(r/min)	2600
Max power	3.23kw/4hp
Cooling method	Air-cooled
Lubrication method	Centrifugal splashing
Starting method	Hand-cranking
Net weight(kg)	44

Table.4.5 Specification of the used CI engine

Four different blend of B50,B40,B30 and B20 are tested in different load and also the exhaust gas temperature.

4.2.1. B50 FUEL BLEND TEST

Tested values of fuel consumption at different load and exhaust temperature are given Table.4.6

Load	Duration	oil consumption			Speed	Exhaust Temp.	Spc. Fuel consumption
		start	stop	consumption			
Watt	min	ml			rpm	ºC	ml/Kw-hr
200	10	395	348	47	2080	159	1410
500	10	348	298	50	2130	171	600
700	10	298	225	73	2050	185	625.71
1000	10	225	149	76	2030	201	456
1200	10	258	188	70	1756	203	350
1500	10	175	99	76	2120	245	304

Table.4.6 fuel consumption and other tested values in engine test

A. LOAD VS FUEL CONSUMPTION CURVE FOR B50

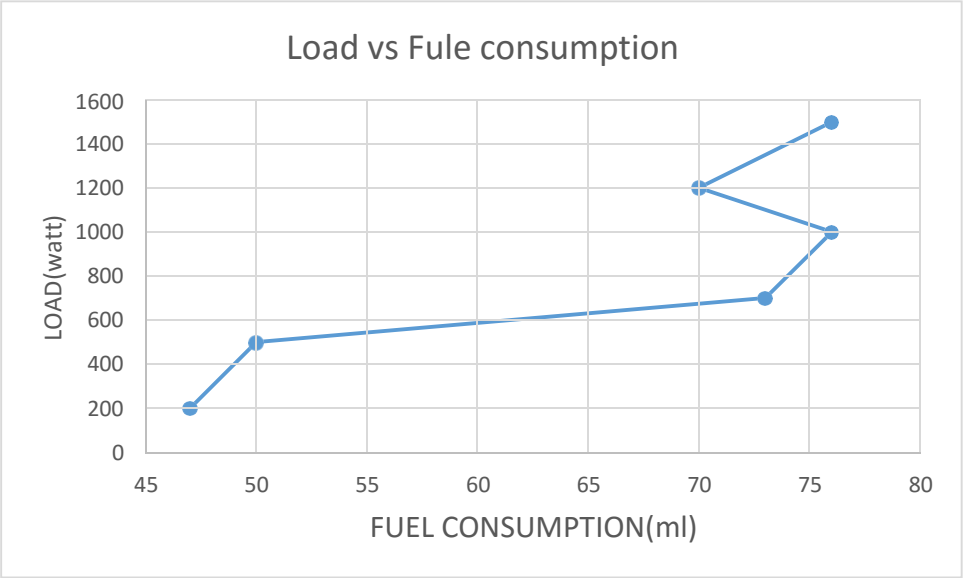

Fig.4.1 load vs fuel consumption curve

B. LOAD VS EXHAUST TEMPERATURE CURVE FOR B50

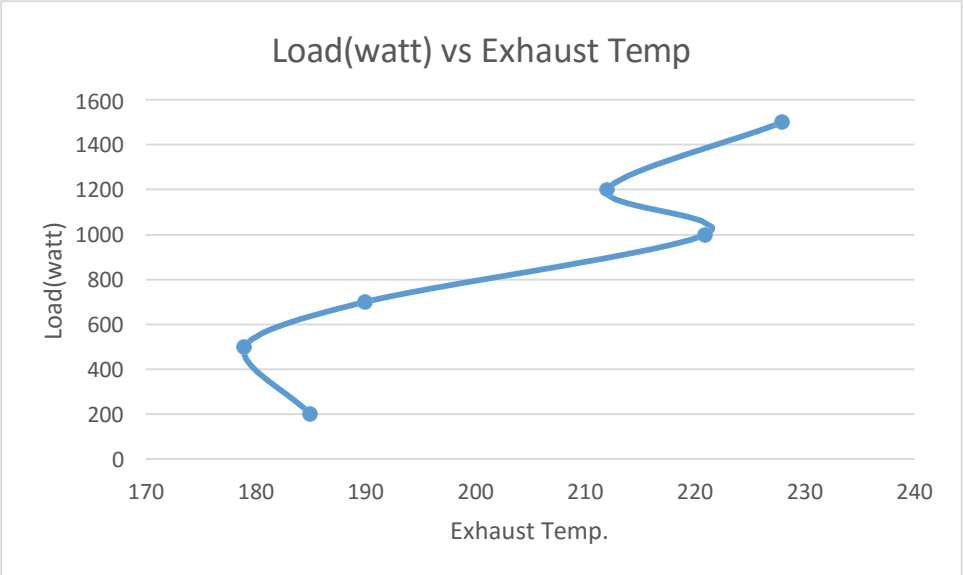

Fig.4.2 load vs Exhaust Temp. curve

C. LOAD VS RPM CURVE FOR B50

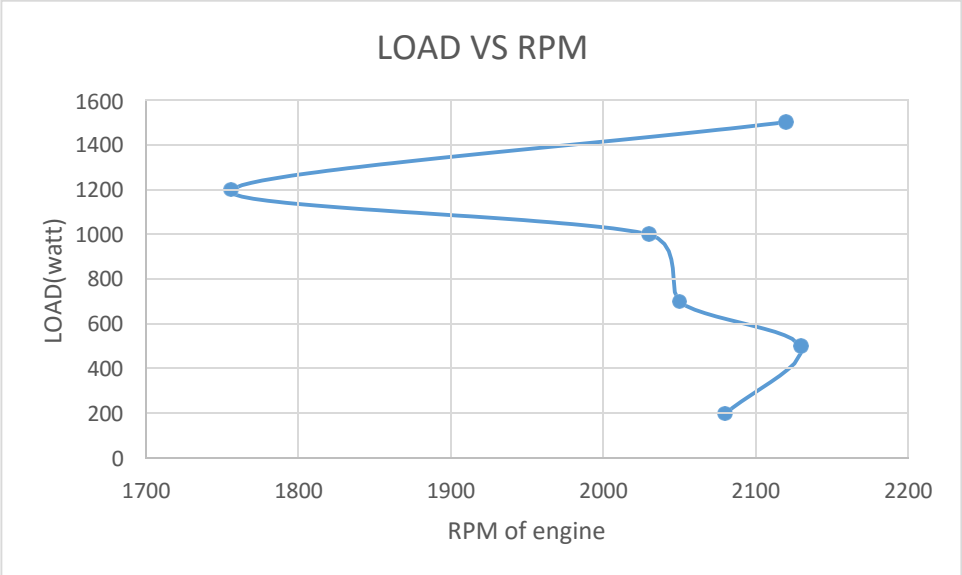

Fig.4.3 load vs. RPM curve

D. LOAD VS SPECIFIC FUEL CONSUMPTION CURVE B50

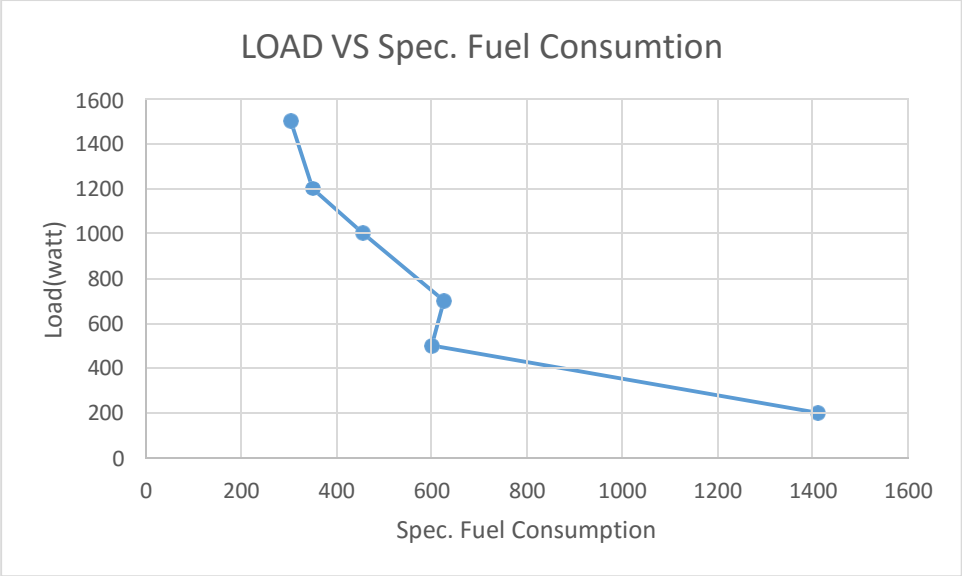

Fig.4.4 load vs. Specific Fuel Consumption curve

4.2.2. B40 FUEL BLEND TEST

Tested values of fuel consumption at different load and exhaust temperature are given Table.4.7

Load	Duration	oil consumption			Speed	Exhaust Temp.	Spc. Fuel consumption
		start	stop	consumption			
Watt	min	ml			rpm		ml/Kw-hr
200	10	405	360	45	1998	162	1350
500	10	358	310	48	2010	175	576
700	10	300	230	70	2058	190	600.00
1000	10	228	155	73	2061	212	438
1200	10	300	226	74	2108	201	370
1500	10	225	149	76	2110	248	304

Table.4.7 fuel consumption and other tested values in engine test

A. LOAD VS FUEL CONSUMPTION CURVE FOR B40

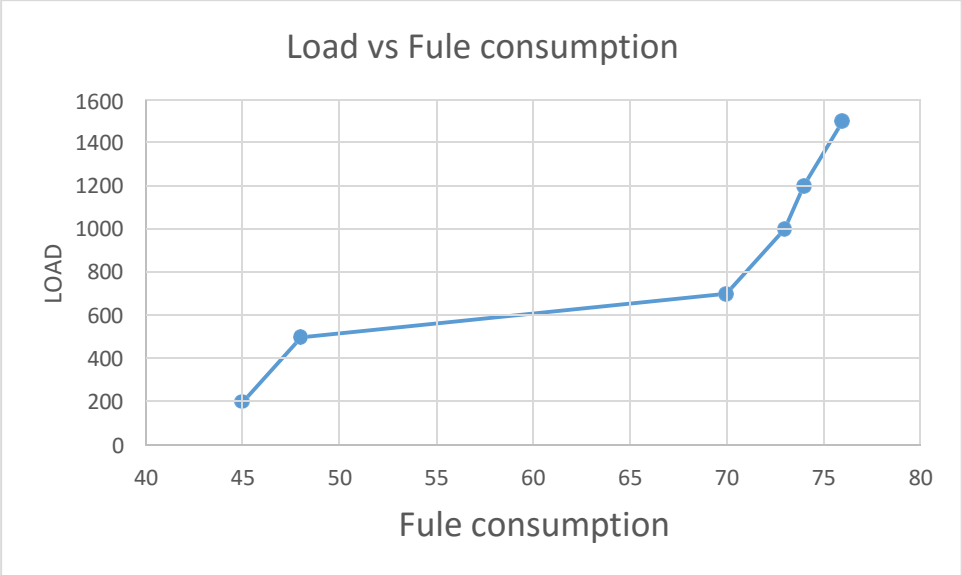

Fig.4.5 load vs fuel consumption curve

B. LOAD VS EXHAUST TEMPERATURE CURVE FOR B40

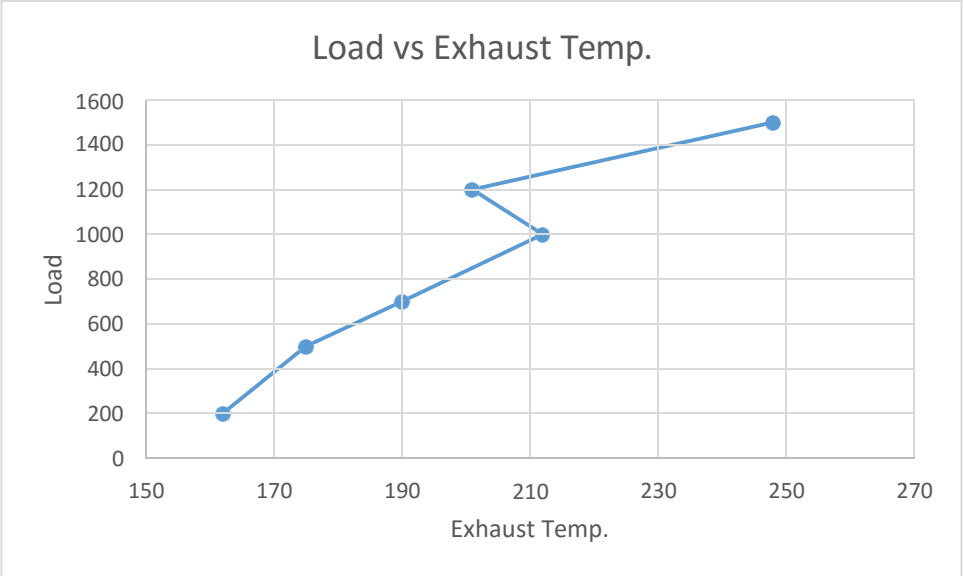

Fig.4.6 load vs Exhaust Temp. curve

C. LOAD VS RPM CURVE FOR B40

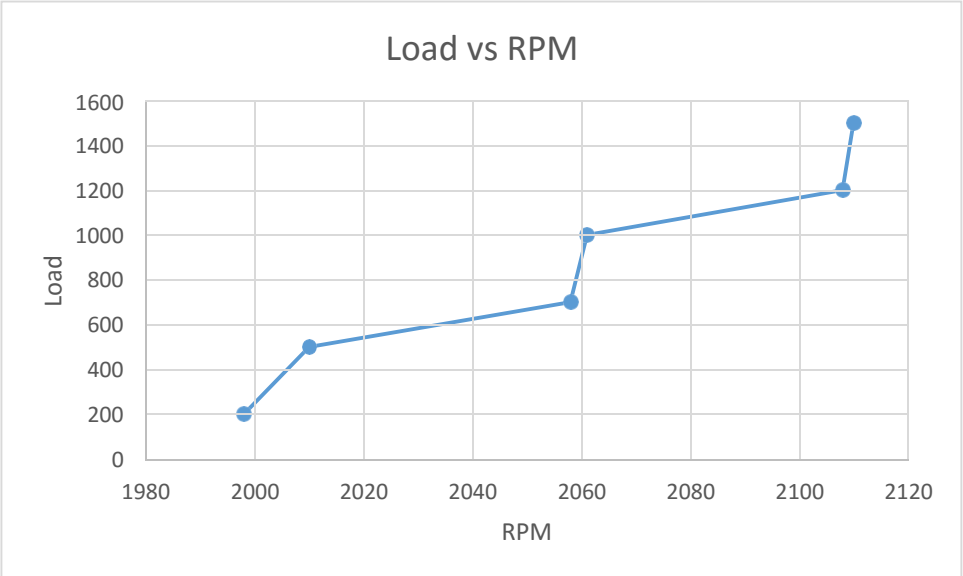

Fig.4.7 load vs. RPM curve

D. LOAD VS SPECIFIC FUEL CONSUMPTION CURVE B40

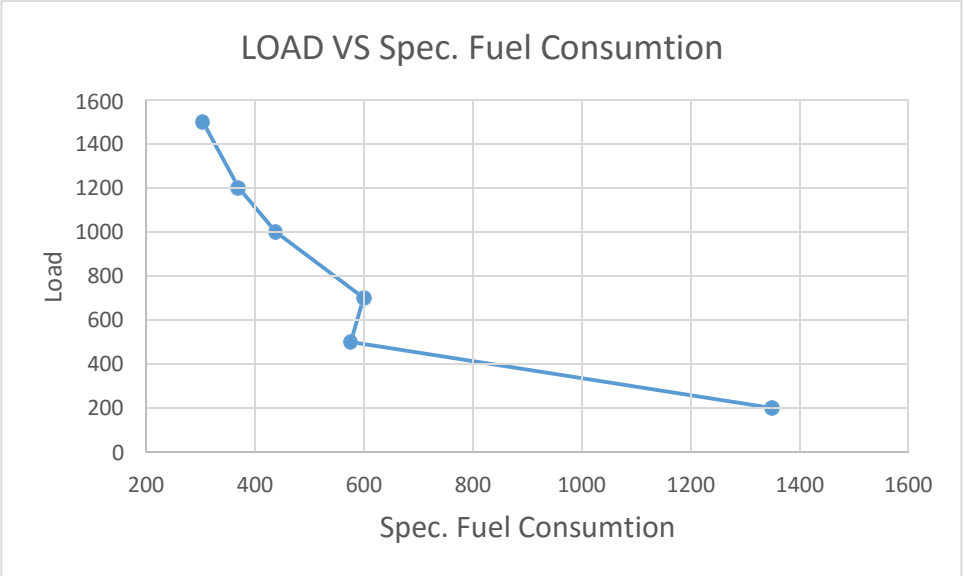

Fig.4.8 load vs. Specific Fuel Consumption curve for B40

4.2.3. B30 FUEL BLEND TEST

Tested values of fuel consumption at different load and exhaust temperature are given Table.4.8

Load	Duration	oil consumption			Speed	Exhaust Temp.	Spc. Fuel consumption
		start	stop	consumption			
Watt	min	ml			rpm		ml/Kw-hr
200	10	450	408	42	2015	185	1260
500	10	400	356	44	1985	179	528
700	10	350	282	68	1996	190	582.86
1000	10	300	221	79	2100	221	474
1200	10	220	149	71	1998	212	355
1500	10	200	125	75	2090	228	300

Table.4.8 fuel consumption and other tested values in engine test

A. LOAD VS FUEL CONSUMPTION CURVE FOR B30

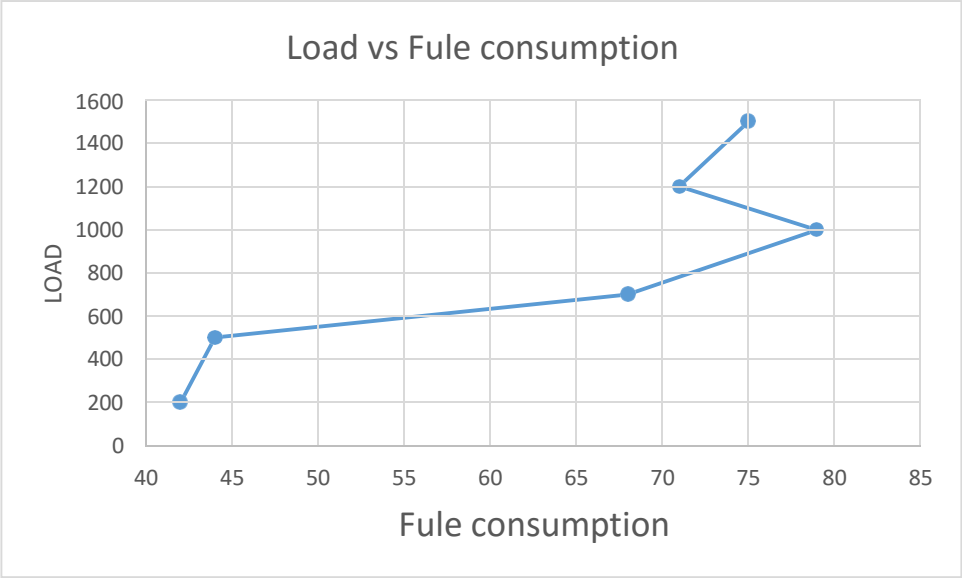

Fig.4.9 load vs fuel consumption curve for B30

B. LOAD VS EXHAUST TEMPERATURE CURVE FOR B30

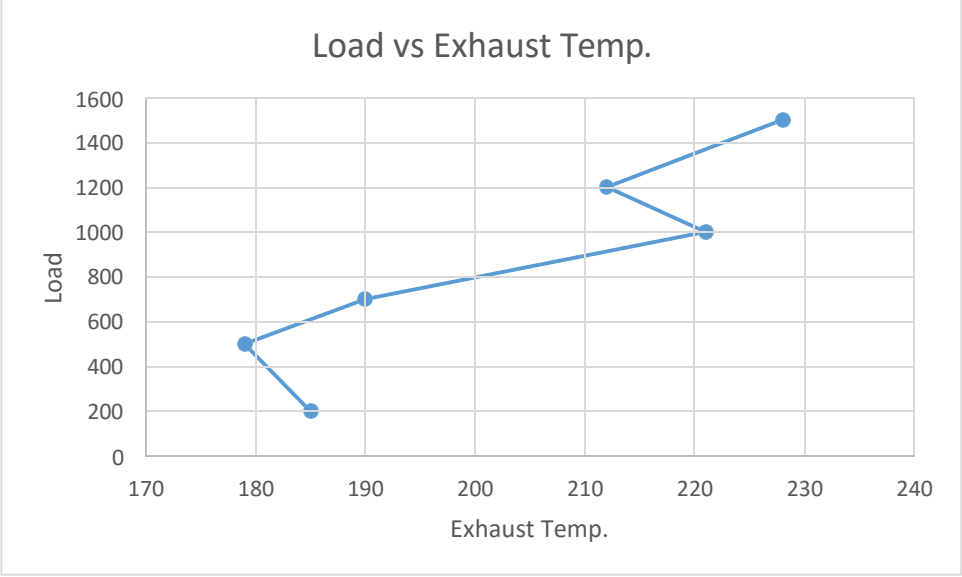

Fig.4.10 load vs Exhaust Temp. curve for B30

C. LOAD VS RPM CURVE FOR B30

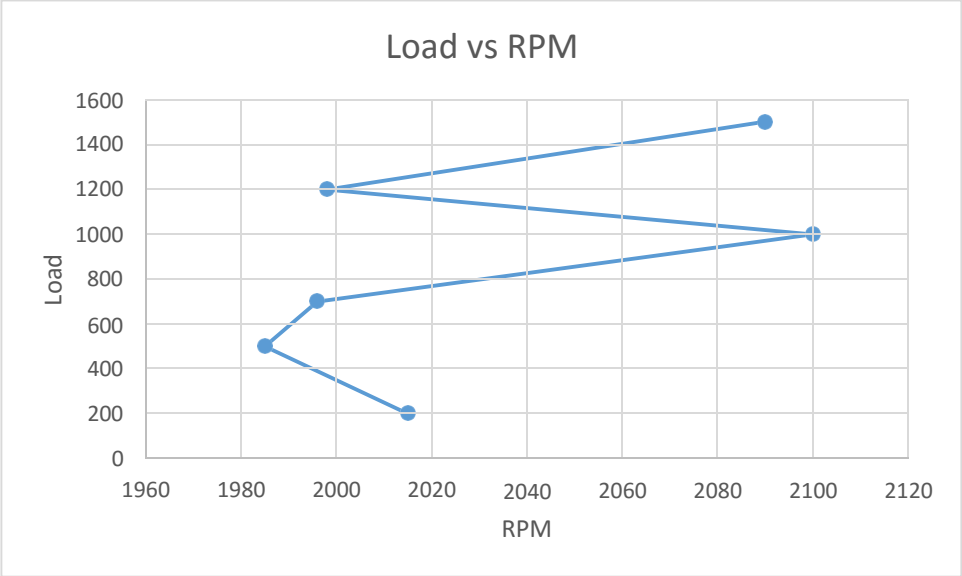

Fig.4.11 load vs. RPM curve for B30

D. LOAD VS SPECIFIC FUEL CONSUMPTION CURVE B30

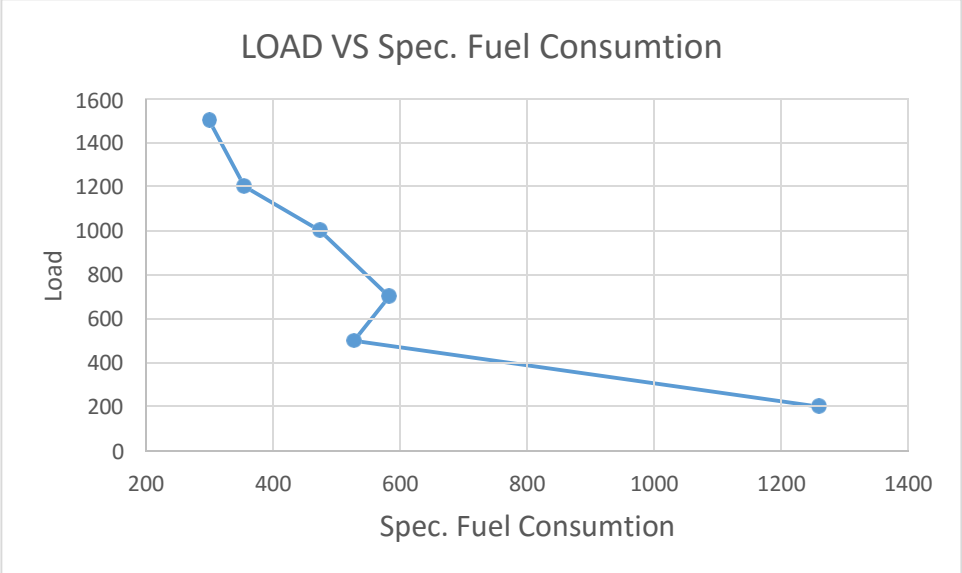

Fig.4.12 load vs. Specific Fuel Consumption curve

4.2.4. PETRO DIESEL FUEL BLEND TEST

Tested values of fuel consumption at different load and exhaust temperature are given Table.4.8

Load	Duration	oil consumption			Speed	Exhaust Temp.	Spc. Fuel consumption
		start	stop	consumption			
Watt	Min	ml			rpm		ml/Kw-hr
200	10	450	402	48	2052	162	1440
500	10	400	351	49	1985	174	588
700	10	350	300	50	1980	250	428.57
1000	10	450	388	62	1850	230	372
1200	10	385	325	60	1865	260	300
1500	10	300	238	62	1845	265	248

Table.4.9 fuel consumption and other tested values in engine test

4.3. COMPARISION BETWEEN DIESEL AND OTHER BIODIESEL BLEND

General fuel consumption, Specific fuel consumption, rpm and exhaust temperature of B50,B40,B30 and Diesel are compared through four different graph

4.3.1. FUEL CONSUMPTION

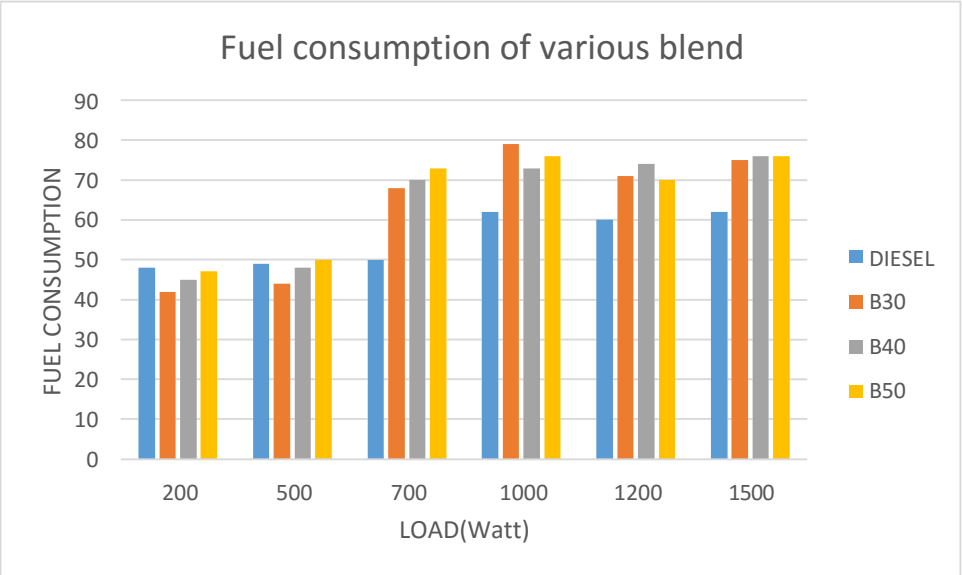

Fig.4.13 load vs. Fuel Consumption for all blend and diesel

4.3.2. SPEED (RPM)

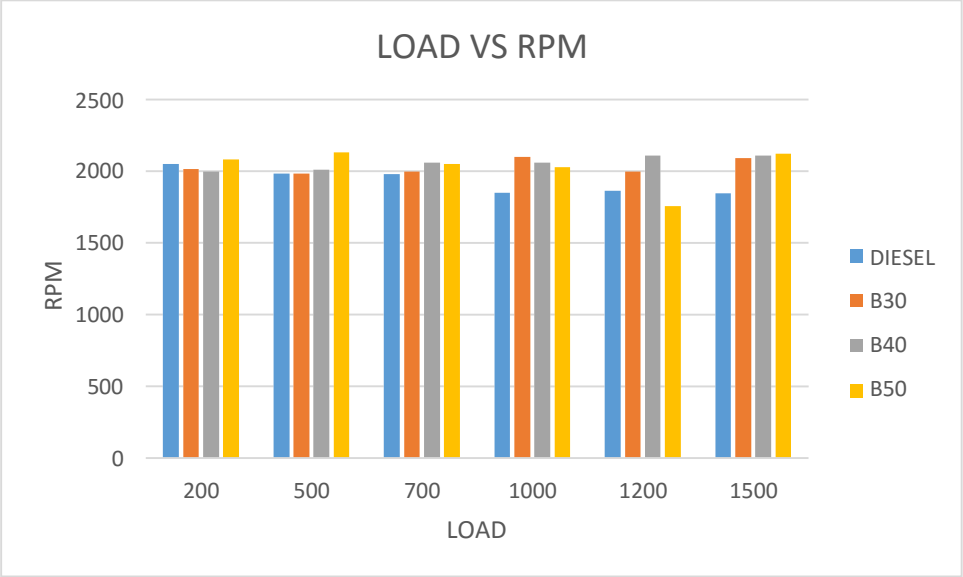

Fig.4.14 load vs. rpm

4.3.3. EXHAUST TEMPERATURE

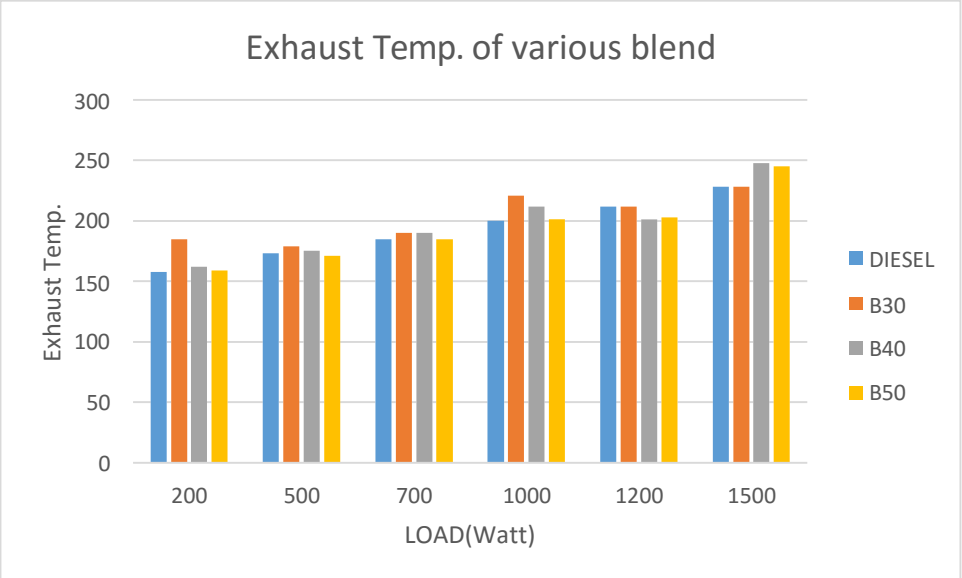

Fig.4.15 load vs Exhaust Temp.

4.3.4. SPECIFIC FUEL CONSUMPTION

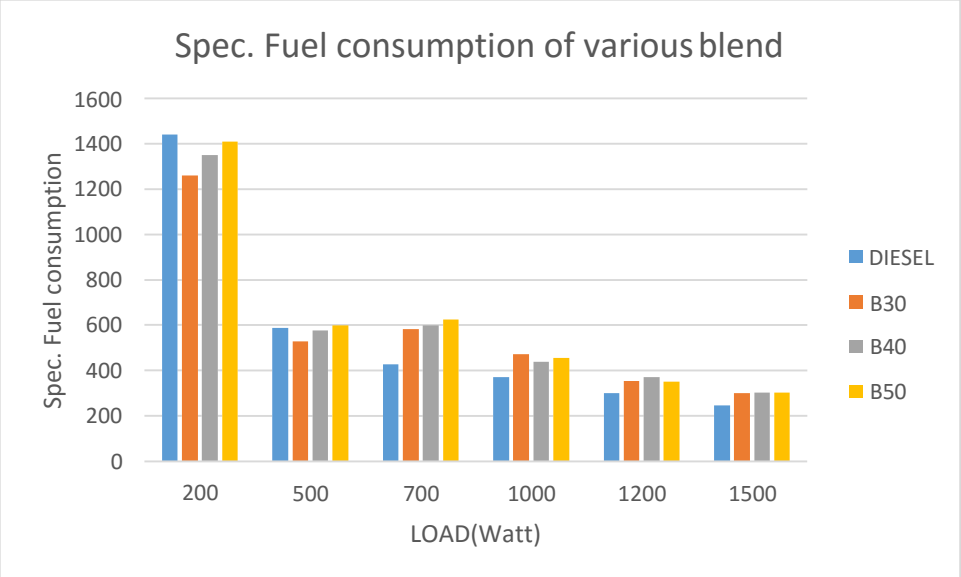

Fig.4.16 load vs. Specific Fuel Consumption

CHAPTER 5

5. CONCLUSION

Whole study were divided into two part. In the first part, optimization of the biodiesel was done by following Full fractional method and Taguchi Method. Optimized yield value of reaction was 94% i.e. 94 ml of biodiesel can be produced from 100 ml of rice bran oil.

In the second part, engine performance fuelled with rice bran oil biodiesel – diesel blend were investigated. Mainly performance and combustion characteristics of the engine fuelled with biodiesel and diesel were compared. Based on the experimental results, the following conclusions are

Density, Kinematic Viscosity and flash point of the crude biodiesel producer from rice bran oil are slightly higher comparable to that of petroleum diesel. As this properties are not same as the petro diesel, engine can be affected. Thus mixing it with the petro diesel in various blend ratio (B50,B40 and B30) and different blend exhibit different combustion characteristics at different load.

As expected, when the load was increased the mass fuel consumption values were increased, while the values of SFC were decreased with the load increase. With increasing of applied load the SFC values were sharply decreased for all the test fuel.

There are huge scopes for future work in this particular area involving the biodiesel pilot plant.

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