Biodiesel Production and optimization of production from waste Palm Oil and Performance Evaluation of Palm Biodiesel-Diesel Blend in Diesel Engine

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CERTIFICATE OF RECOMMENDATION

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DEDICATED TO MY PARENTS

ABBREVIATIONS

B10: 10% Biodiesel and 90% pure diesel

B20: 20% Biodiesel and 80% Pure diesel

B30: 30% Biodiesel and 70% Pure diesel

B40: 40% Biodiesel and 60% Pure diesel

B50: 50% Biodiesel and 50% Pure diesel

SFC =Specific Fuel Consumption

BTE =Brake Thermal Efficiency

HRR=Heat Rejection Ratio

C.I. =Compression Ignition

C.R =Compression Ratio

I.P =Injection Pressure

EGT= Exhaust Gas Temperature

ml/Kwh= milliliters per Kilowatt-hour

cSt= Centistoke

Rpm= Revolution per minute

ml/hr=milliliters per hour

Wpo: waste palm oil

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CHAPTER 1

1. INTRODUCTION

As the fossil fuels are getting depleted day by day, the urge for an alternative fuel to fulfill the energy demands of the world is also increasing. Bio-diesel is one of the best available sources to fulfill the energy demands of the world. Though the petroleum fuels play a very important role in the development of industrial growth , transportation, agricultural sector and to meet many other basic human needs, these fuels are limited and depleting day by day as the consumption is increasing rapidly. Moreover, its usage is alarming and it causes a lot of environmental problems to the society (i.e.) burning of the fossil fuel which releases smog and greenhouse gases that contribute to global warming. Bio-diesel is gaining more importance as an alternative fuel to meet out the energy demands of the society [1]. Rapid growth of a number of automotive industries in the world has resulted in increase of exhaust emissions to the environment. Vehicular emissions such as particulate matter, hydro carbon, carbon dioxides, carbon monoxides and nitrogen oxides are hugely responsible for the air quality deterioration [2]. Two main internal combustion engine types such as petrol engine and diesel engine contribute to degrade the air quality in the urban environment. There are about 22% of global GHG (greenhouse gas) emissions comes only from the transportation sector due the increasing demand of vehicles. The fast emission growth was driven by emissions from road transport sector which increased by 52% since 1990 and accounted for three quarters of transport emission in 2011. The International Energy Agency (IEA) forecasts that the emissions of carbon dioxide (CO2) from transport sector will increase by 92% between 1990 and 2020 and it is estimated that 8.6 billion metric tons of carbon dioxide will be released to the atmosphere from 2020 to 2035. It has been also reported that, an increase in average global temperature by 2o C will result in death of hundreds of millions of people [3]. It is very urgent to find out alternative fuels for transportation sector as this sector is emitting higher GHG emission and contribute to the rapid growth of global oil demand. Recently, attention has been drawn to develop cleaner alternative fuels from renewable sources to reduce the harmful emission to the air and to reduce the dependency on the petro-diesel fuel. The most feasible alternative for vehicles being considered globally are biofuel such as biodiesel and ethanol due to their renewable property and reduction of fossil CO2 discharge which most probably contributes to the global climate changes. Ethanol is produced from a number of crops such as potatoes, sugarcane, grains, corn and sorghum etc [4] whereas, biodiesel can be produced from vegetable oils, recycled waste oil and animal fats.

The name bio-diesel was introduced in the United States during 1992 by the National soy diesel Development Board (presently national bio-diesel board) which has pioneered the commercialization of bio-diesel in the United States [5]. Bio-diesel can be used in any ratio with petroleum diesel as it has very similar characteristics. Usually, coconut, sesame, rapeseed, corn, palm and soybean are the present feedstock for bio-diesel production because they are edible oils. The high value of edible vegetable oils as a food product makes production of bio-diesel fuel very challenging as a cost of raw material accounts for 60– 70% of the total production cost of biodiesel fuel [6].

1.1. Aims and Objective of Present study

This study deals with the production of biodiesel from waste palm oil. Major aim and objectives of this study are

1. To produce biodiesel by the process of transesterification of waste palm oil using inorganic catalyst (potassium hydroxide).
2. To optimization of production process by using TAGUCHI EXPERIMENTAL DESIGN.
3. To measure the properties of the biodiesel.
4. To analyze the combustion performance of biodiesel-diesel blend in the ratio of B-10, B20, B30, B40, B50.
5. To measure the Specific Fuel Consumption of the engine by varying the load applied on the engine and record the resultant fuel consumption while comparing the fuel consumption for the same load when only pure diesel is applied.
6. To analyse the Exhaust gas Temperature of engine for different load at different biodiesel blend.

CHAPTER 2

2. LITERATURE REVIEW

Biodiesel by definition is a compound of methyl ester derived from the esterification/ transesterification process of various types of vegetable oils or animal fats. The quality of biodiesel oscillates in a wide range mainly as a function of the quality of the feedstock, the fatty acid composition of the parent vegetable oil or animal fat, the production process and post-production parameters.

Over the last few years, there has been increasing amounts of research and interest in the different edible feedstocks that can be used to make biodiesel and the effects of the different feedstocks on the quality of the biodiesel. The major difference between various edible oils is the type of fatty acids attached in the triglyceride molecule. Fatty acid composition effects the yield percentage, reaction temperature, and molar ratio of the biodiesel oil [7].

Shailendra Sinha et.al[8] The most detrimental properties of vegetable oils are its high viscosity and low volatility, and these cause several problems during their long duration usage in compression ignition (CI) engines. The most commonly used method to make vegetable oil suitable for use in CI engines is to convert it into biodiesel, i.e. vegetable oil esters using process of transesterification. Results showed that biodiesel obtained under the optimum conditions has comparable properties to substitute mineral Diesel, hence, palm oil, rice bran oil methyl ester biodiesel could be recommended as a mineral Diesel fuel substitute for compression ignition (CI) engines in transportation as well as in the agriculture sector.

Sarin Rakesh *et al.* [9], made appropriate blends of Jatropha and palm bio-diesel to improve oxidation stability and low temperature properties because Jatropha bio-diesel has good low temperature property and palm bio-diesel has good oxidative stability. It was found that antioxidant dosage could be reduced by 80- 90% when palm oil bio-diesel is blended with Jatropha bio-diesel at about 20-40%.

Md. Nurun Nabi et.al [10] Different parameters for the optimization of biodiesel production were investigated in the first phase of this study, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures were carried out. Cottonseed is non-edible oil, thus food versus fuel conflict will not arise if this is used for biodiesel production. The trans-esterification results showed that with the variation of catalyst, methanol or ethanol, variation of biodiesel production was realized. However, the optimum conditions for biodiesel production are suggested in this paper. A maximum of 77% biodiesel was produced with20% methanol in presence of 0.5% sodium hydroxide. The engine experimental results showed that exhaust emissions including carbon monoxide (CO) particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.

Bhaskar Mazumdar et.al [11] In present experimental investigation, wastecooking oil obtained from restaurant was used to produce biodiesel through transesterification process and the chemical kinetics of biodiesel production was studied. Biodiesel was blended with petroleum diesel in different proportions. The blends were evaluated for the engine performance, emissions and combustion characteristics in a four-stroke, four-cylinder, indirect injection transportation engine via baseline data of petroleum diesel. It is observed that mass emission of various regulated pollutant species from biodiesel blends is not significantly different from baseline petroleum diesel. Oxides of nitrogen (NOx)emissions increased with increasing concentration of biodiesel in blends, while carbon monoxide (CO) emissions decreased. Brake thermal efficiency of biodiesel blends was observed to be higher as compared to petroleum diesel for all blends. Brake specific fuel consumption (bsfc) and brake specific energy consumption of all biodiesel blends was found to be lower than petroleum diesel and it was found to be lowest for B20.

M. Anandan et.al [12] conducted the performance and emission tests, which were carried out on a Kirloskar single cylinder direct injection diesel engine. The performance of the engine was almost same for palm oil methyl ester and its blend compared to diesel. It was also inferred that NOx emissions were higher for palm oil methyl ester and its blend when compared to those of diesel. To decrease NOx, EGR was adopted. Again the above tests were performed with varying percentage of EGR and it was found that NOx decreased but at the same time the performance of the engine decreased.

Abdul Monyem et.al [13] used neat Biodiesel in a single cylinder C.I. Engine at speed of 1400 rpm to evaluate the performance and emission characteristics. From this study it was reported that thermal efficiency did not change and fuel consumption increased compared to diesel. The emissions like CO and HC were reduced by 15% and 16% compared to diesel fuel results.

The investigation of different blends of biodiesel (obtained from soybean, rapeseed or sunflower) and diesel oil (i.e. 100%, 80%, 70%, 50%, 30%, 20% and 0% volume of biodiesel, respectively) on six cylinders direct injection diesel engine has been carried out by Carraretto, et. al., (2004). The result showed that the use of biodiesel has slightly reduced the engine performances while notably increased Specific Fuel Consumption (SFC). CO emissions was reduced, but NOx were increased. Performance and emission can be improved by optimizing the injection system.

Deepak Agarwal et.al[14] Fuel crisis because of dramatic increase in vehicular population and environmental concerns have renewed interest of scientific community to look for alternative fuels of bio-origin such as vegetable oils. This study was carried out to investigate the performance and emission characteristics of mahua oil, rice bran oil and linseed oil methyl ester (LOME), in a stationary single cylinder, four-stroke diesel engine and compare it with mineral diesel Economic analysis was also done in this study and it is found that use of vegetable oil and its derivative as diesel fuel substitutes has almost similar cost as that of mineral diesel.

Siva Kumar et.al [15] In this study, different parameters for the optimization of biodiesel production were investigated in the first phase, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures was carried out. The engine experimental results showed that exhaust emissions including carbon monoxide (CO), particulate matter (PM) and Smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.

Fujia Wu et.al [16] In this study, five biodiesels such as cottonseed methyl ester (CME), soybean methyl ester (SME), rapeseed methyl ester (RME), palm oil methyl ester (PME) and waste cooking oil methyl ester (WME) are used in diesel engine. It is used to evaluate the performance and emission characteristics of the engine. All the results are compared to those of diesel. The results reveals that Particulate matters and Dry Soot are reduce from 56% to 69% and 79% to 83% respectively with these oils. All emissions such as CO,HC, Smoke emissions are reduced compared to diesel.

Ahmet Necati Ozsezen et.al [17] In this study, waste palm oil(WPOME) and canola oil methyl esters (COME) are used as fuels in DI diesel engine. It is used to evaluate the performance and combustion characteristics of the engine. The engine performance slightly decreased and combustion characteristics slightly changed when compared to petroleum based diesel fuel (PBDF). The biodiesels caused reductions in carbon monoxide (CO), unburned hydrocarbon (HC) emissions and smoke opacity, but they caused to increases in nitrogen oxides (NOx) emissions.

It is clear that the performance and characteristics of engine is strongly affected by fuel quality. However, the fuel quality varies in a wide range as a function of the process, raw material properties, etc.

CHAPTER 3

3. 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.

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 petrodiesel in any proportions.

3.1. Biodiesel Fuel Feedstocks

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:

1. **Edible vegetable oil**

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

2. **Non-edible vegetable oil**

   Jatropha, Karanja, Pongamia, Neem, Jojoba, Cottonseed, Linseed, Mahua, Deccan hemp, Kusum, Orange, Rubber seed, Sea Mango, Algae and Halophytes.

3. **Waste or recycled oil or used vegetable oil**

   It may be different feed stocks like soybean oil, mastered oil, sunflower etc.

4. **Future feedstock**

   algae, pennycress, jatropha, brown grease, halophytes, low ricin, castor oil, and others.

Jatropha oil is commonly used in India, soyabean oil in USA, rapseed oil in European countries and palm oil in Malaysia.

3.2. Palm oil as Feedstock

Among all plant families, palm is the most popular and extensively cultivated. All tropical areas with hot and humid weather, such as Malaysia and Indonesia, are ideal for palm cultivation [18]. This particular variety can produce 10–35 t/ha of palm fruits. Oil is extracted from both the pulp and the seed. Palm oil trees are commercially cultivated to produce commercial edible oil [19].

Palm oil is the second most traded vegetable oil crop in the world, after soy , and over 90% of the world‘s palm oil exports are produced in Malaysia and Indonesia . Palm oil is still mostly used in the manufacture of food products and is found in one in ten products sold in UK supermarkets.

However, palm oil is now starting to be used as an ingredient in bio-diesel and as a fuel to be burnt in power stations to produce electricity. This is a new market for palm oil which has the potential to dramatically increase global demand for this commodity. The development of the oil palm industry in Indonesia and Malaysia has brought economic benefits to both these countries. However it has also generated considerable environmental and social costs.

The development of oil palm plantations is one of the biggest causes of rainforest clearance. The palm oil industry has already set up 6.5 million hectares of oil palm plantations across Sumatra and Borneo but it is estimated that it is probably responsible for the destruction of 10 million hectares of rainforest.

Palm oil has several advantages as a potential biofuel source, Hisham Hashim said. It has a larger yield than any other source of vegetable oil, for example at 3.93 tonnes per hectare per year, it has nearly three times the yield of rapeseed, its closest competitor. ―It is cheaper than any other vegetable oil used in biodiesel production,‖ he said. ―And it is a perennial crop with a life-cycle of 25 years, so it can be very productive over a significant duration of time.‖ Indeed, one issue in Malaysia is that the overall yield per hectare is declining because so many of the palms are getting close to the end of their productive period and their yield is decreasing, but the plantation owners are putting off replanting because the cash flow is still substantial.

When compared to petroleum-based diesel, biodiesel from palm oil has certain advantages in its physical and chemical characteristics, Hisham Hashim said. For example, its sulfur content is much lower; this is an advantage because the sulfur dioxide release from the use of petroleum-based diesel is a serious atmospheric pollutant which can lead to acid rain and is hazardous to human health. A recently developed variety of palm biodiesel has a very low pour point so that it pours more easily at cold temperatures, making it a possible product for use in colder climates. Palm biodiesel also has an advantage in its cetane number—which is analogous to the octane number for gasoline—when compared with petroleum-based diesel. It also produces far less carbon residues, which means that it will leave less carbon build-up in a diesel engine than petroleum diesel.

Palm biodiesel also has some physical and chemical disadvantages, such as a higher viscosity, a higher flashpoint, and a lower gross heat of combustion.

3.3. Advantages of Biodiesel

- **Produced from Renewable Resources**:

  Biodiesel is a renewable energy source unlike other petroleum products that will vanish in years to come. Since it is made from animal and vegetable fat, it can be produced on demand and also causes less pollution than petroleum diesel.

- **Can be Used in existing Diesel Engines**:

  One of the main advantage of using biodiesel is that can be used in existing diesel engines with little or no modifications at all and can replace fossil fuels to become the most preferred primary transport energy source. Biodiesel can be used in 100% (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 CO_2 by 15%):

  Fossil fuels when burnt release greenhouse gases like carbon dioxide in the atmosphere that raises the temperature and causes global warming. To protect the environment from further heating up, many people have adopted the use of biofuels. Experts believe that using biodiesel instead of petroleum diesel can reduce greenhouse gases up to 78%.

- **Grown, Produced and Distributed Locally**:

  Fossil fuels are limited and may not be able to fulfill our demand for coal, oil and natural gas after a certain period. Biodiesel can work as an alternative form of fuel and can reduce our dependence on foreign suppliers of oil as it is produced from domestic energy crops. It is produced in local refineries which reduce the need to import expensive finished product from other countries.

- **Cleaner Biofuel Refineries**:

  When oil is extracted from underground, it has to be refined to run diesel engines. You can‘t use it straight away in the crude form. When it is refined, it releases many chemical compounds including benzene and butadiene in the environment which are harmful for animals, plants and human life. Biofuelrefineries, which mainly uses vegetable and animal fat into biofuel releases less toxic chemicals, if spilled or released to the environment.

- **Biodegradable and Non-Toxic**:

  When Biofuels are burnt, they produce significantly less carbon output and few pollutants. As compared to petroleum diesel, biodiesel produces less soot (particulate matter), carbon monoxide, unburned hydrocarbons, and sulfur dioxide. Flashpoint for biodiesel is higher than 150°C whereas the same is about 52°C for petroleum diesel, which makes it less combustible. It is therefore safe to handle, store and transport.

- **Positive Economic Impact** :

Biofuels are produced locally and thousands of people are employed in biofuel production plant. Since biodiesel is produced from crops , an increase in demand for biodiesel leads to increase in demand for suitable biofuel crops. Moreover, it creates less emission by reducing the amount of suspended particles in the air. This reduces the cost of healthcare products.

- **Reduced Foreign Oil Dependance**:

With locally produced biofuels, many countries have reduced their dependance on fossil fuels. It may not solve all problems in one blow but a nation can save billions by reducing their usage on foreign oil.

- **More Health Benefits**:

Air pollution cause more deaths and diseases than any other form of pollution. Pollutants from gasoline engines when released in the air, form smog and make thousands of people sick every year. Biodiesel produce less toxic pollutants than other petroleum products.

3.4. Disadvantages of Biodiesel

- **Variation in Quality of Biodiesel**:

Biodiesel is made from variety of biofuel crops. When the oil is extracted and converted to fuel using chemical process, the result can vary in ability to produce power. In short, not all biofuel crops are same as amount of vegetable oil may vary.

- **Not Suitable for use in Low Temperatures**:

Biodiesel gels in cold weather but the temperature that it will gel depends on the oil or fat that was used to make it. The best way to use biodiesel during the colder months is to blend it with winterized diesel fuel.

- **Food Shortage**:

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. For e.g.: the production of biodiesel from corn may raise its demand and it might become more expensive which may deprive poor people from having it.

- **Increased use of Fertilizers**:

As more crops are grown to produce biofuels, more fertilizer is used which can have devastating effect on environment. The excess use of fertilizers can result in soil erosion and can lead to land pollution.

- **Clogging in Engine**:

Biodiesel cleans dirt from the engine. This proves to be an advantage of biofuels but the problem is that this dirt gets collected in fuel filter and clogs it.

- **Regional Suitability**:

Some regions are not suitable for oil producing crops. The most productive crops can‘t be produced anywhere and they need to be transported to the plants which increases the cost and amount of emission associated with the production and transportation.

- **Water Shortage**:

The use of water to produce more crops can put pressure on local water resources. The areas where there is water scarcity, production of crops to be used in making of biofuels is not a wise idea.

- **Monoculture**:

Monoculture refers to the practice of producing same crop over and over again rather than producing different crops. While this results in fetching best price for the farmer but it has some serious environmental drawbacks. When the same crop is grown over large acres, the pest population may grow and it may go beyond control. Without crop rotation, the nutrients of soil are not put back which may result in soil erosion.

- **Use of Petroleum Diesel to Produce Biodiesel**:

It requires much amount of energy to produce biodiesel fuel from soy crops as energy is needed for sowing, fertilizing and harvesting crops.

Apart from that, raw material needs to be transported through trucks which may consume some additional fuel. Some scientists believe that producing one gallon of biofuel needs energy equivalent to several gallons of petroleum fuel.

- **Slight Increase in Nitrogen Oxide Emissions**:

Biodiesel has about 10% higher Nitrogen Oxide(NoX) than other petroleum products. Nitrogen Oxide is one the gas that is used in the formation of smog and Ozone. Once it gets dissolved in atmospheric moisture, can cause acid rain.

3.5. 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, microemulsion, dilution and transesterification.[22]

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.[23]

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, wasteless, pollution free and effective compared with other cracking processes [24].

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.[25]

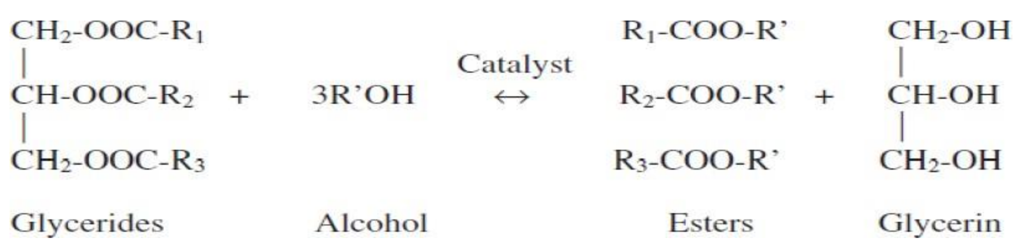
Transesterification: Transesterification is the method of biodiesel production from oils and fats and can be carried out by two ways.

(a) Catalytic Transesterification.

(b) Supercritical Methanol Transesterification

(a) 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 glycerin 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 glycerin. 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.

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.

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 favor 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.

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 unfavorable compared to the alkaline catalyzed reaction systems.

. (b) 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

CHAPTER 4

4.OPTIMIZATION OF BIODIESEL PRODUCTION PROCESS BY USING TAGUCHI EXPERIMENTAL DESIGN

4.1 STEPS IN TAGUCHI METHODOLOGY

- Decide the important input process parameters and their levels (by pilot experimentation and literature survey) and response parameter and its characteristic.
- Select appropriate orthogonal array (OA) and assign the parameters to its various columns.
- Conduct experiments for the levels given in each row RANDOMLY and note down the values of the response parameter. Repeat each experiment THREE times.
- Study factor effects and find out the optimum combination of the input parameters. Calculate the best value of the response characteristic .
- Calculate the range within which the experimental value should lie and conduct conformation experiment to verify the same.
- Perform analysis of variance (ANOVA) to find out the significance of the various factors and their relative contribution.

4.2 INPUT PROCESS PARAMETERS AND THEIR LEVELS

PARAMETER	LEVEL
Methanol to oil molar ratio	12:1, 9:1, 6:1
Amount of KOH(wt% of oil)	.5 ,1 ,1.5
Reaction temperature(°C)	40 , 50 ,60

Reaction time(fixed) 2 hour

RPM(fixed) 600

Reaction time and RPM are fixed by some pilot experiment and literature survey [5] and [6].

All Methanol to oil molar ratio levels are taken form literature survey [3].

All KOH amount levels are taken form literature survey [4].

All reaction temperature levels are taken form literature survey [3] .

4.3 DESIGN OF EXPERIMENT(DOE)

Response name : amount of biodiesel

Response type : higher the better

Based on these three parameters levels input L9 orthogonal array was selected for the experimentation .

L9 orthogonal array(Taghuchi design)

Experiments number	Methanol(ml)	KOH(gm)	Temparature(deg C)
1	53.08	0.463	40
2	53.08	0.926	50
3	53.08	1.38	60
4	39.81	0.463	50
5	39.81	0.926	60
6	39.81	1.38	40
7	26.54	0.463	60
8	26.54	0.926	40
9	26.54	1.38	50

Table-4.1: L9 orthogonal array

To know the optimum combination of the three parameters levels for maximum biodiesel production we have to do total nine (9) experiment and each experiment have to do three times.

4.4 PROPERTIES OF THE WASTE PALM OIL

4.4.1 DENSITY:

_The density of WASTE PALM OIL sample is measured by specific gravity bottle of 10 ml shown in fig……….

Weight of empty beaker = 18.986 gm

Volume of oil taken = 10 ml

Weight of the filled bottle = 28.252 gm

Wight of 10 ml Oil = 28.252-18.986 = 9.266 gm

Hence density of wpo = 9.266/10 = 0.9266 gm/ml.

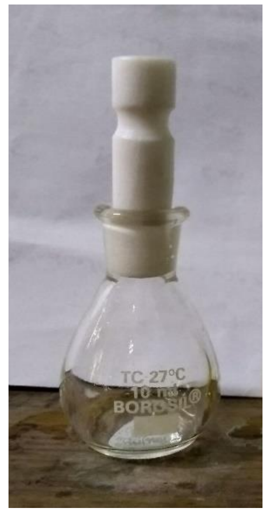


Fig-4.1:Density measurement

4.4.2 FREE FATTY ACID (FFA%)

The molecular weight of waste palm oil = 847.3 g/mol
Density of the oil = 0.9266 g/ml
Molecular weight of potassium hydroxide = 56.1 g/mol

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

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 1 gram KOH dissolved in one litter distilled water. So the normality of the KOH solution = (1/56.1) N. take 1ml of WCO sample (W=1×0.9264 g). 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= 0.9 ml
Average volume required = 0.85 ml

So, Acid value = $\frac{56.1\times0.85\times(\frac{1}{56.1})}{0.9264}$ = 0.9175 mg KOH / gm

Acid value = FFA%×1.99
FFA% = $\frac{\text{Acid value}}{1.99} = \frac{0.9175}{1.99}$ = 0.461%

As the FFA% is less than 2%, acid esterification is not needed, direct transesterification reaction can be done for biodiesel production by the use of alkaline catalyst[8].

4.5 CALCULATION

Calculation of raw materials used for biodiesel production of experiment number 1 methanol:oil=12:1, KOH=.5wt% of oil, reaction temperature= 40 deg c .
Volume of wpo = 100ml
Density of wpo = .9266 gm/ml
Weight of 100 ml wpo = 100 * .9266 =92.66 gm
Wpo molar weight = 847.3 gm / mol
Methanol molar weight = 32.04 gm/mol
Molar ratio, methanol:oil = 12:1
So weight ratio, methanol:oil = 12*32.04 : 1* 847.3
= 384.48 : 847.3
Thus methanol required for 100ml wpo = (384.48 * 92.66)/847.3
= 42.04gm
Density of methanol = .792gm/ml
So volume of methanol required for 100 ml wpo = 42.04/.792

= 53.08 ml

KOH required = .5wt% of wpo

Weight of 100 ml wpo = 92.66gm

So amount of KOH required for 100 ml wpo =(92.66 * .5)/100

= .463 gm

Sameway we have calculated the volume of methanol and amount of KOH required for other 8 experiment in the taghuchi table , each experiment we have taken volume of wpo is 100ml.

4.6 biodiesel production procedure

Step1:

After calculation, measured 0.463 gm of KOH pallet in digital weighing machine and put that in a laboratory flask.

Fig-4.2: measuring KOH

Fig-4.3 : measuring methanol

Step 2:

Measured 53.08 ml methanol in a graduated cylinder and pour that to the same laboratory flask by the help of a funnel.

Step3:

Transesterification has been done by the help of a magnetic stirrer machine. This machine has been used to rotate the mixture 600 rpm and helped to mix the waste palm oil and methanol. In magnetic stirrer machine there is a hot plate on which the laboratory flash has been fixed. Hot plate temperature in this case has been maintained to 40 degree centigrade.

Laboratory flask contained methanol and KOH. A magnetic stirrer put the flask. Then the flask put on the plate of the magnetic stirrer machine. KOH and Methanol solution mixed for 15 minutes at magnetic stirrer machine.

Step 4:

After 15 minutes 100 ml waste palm oil has been poured to the laboratory flask wait for 2 hour for completion of the reaction.

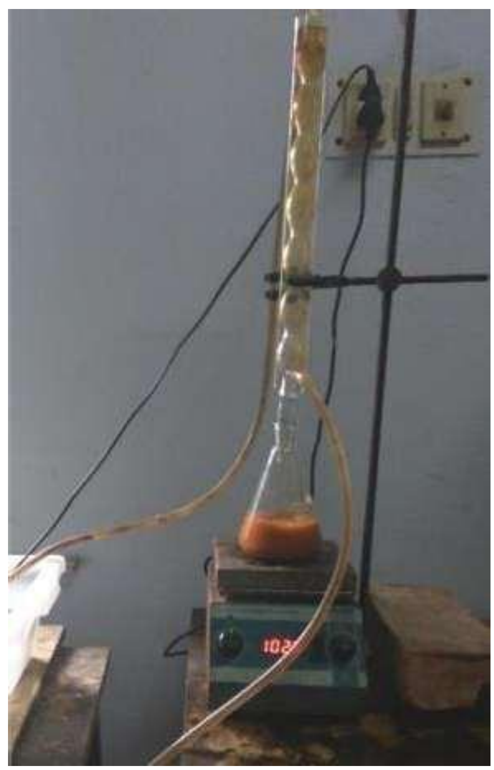


Fig-4.4:biodiesel production

Step 5:

Separation of biodiesel in separating funnel:

The product mixture obtained from the laboratory flask is kept for settling in a separating flask for 10-12 hours i.e. overnight to separate glycerin from accurately. As the glycerin is denser than biodiesel, it settles at the bottom creating a perfect separating layer. The glycerin is then separated carefully by a controlling knob and the glycerin is taken out carefully and is measured by a measuring cylinder. The glycerin is obtained is brownish in color.

After the glycerin separation the crude biodiesel is taken out from the same outlet for further purification.

Fig-4.5 : palm biodiesel separation

Step 6:

Purification of biodiesel:

Transesterification reaction is a reaction that is widely considered and mostly adopted to produce commercial biodiesel. The trans esterified products undergo different purification techniques in order to purify biodiesel from glycerol and other by-products. The main objective of biodiesel washing is to remove free glycerol, soap, excess alcohol, and residual catalyst. Water washing is generally carried out to remove soap, catalyst, methanol and other contaminants from biodiesel, using deionized water.

Fig-4.6 : aquarium pump

Fig-4.7 : biodiesel setup

Water at 60 °C was used for biodiesel washing. An aquarium air pump along with an aquarium stone, a bubble washing setup have been used for purification of biodiesel. The biodiesel is then slowly poured from the top and air is passed by means of the aquarium air pump that creates bubbles inside the water with the help of aquarium stone. 3 sets of washing are done for one batch of crude biodiesel. This amount of washing is sufficient for the removal of excess catalyst, free fatty acids and glycerol molecules inside biodiesel.

Acidity of the waste water is tested by litmus paper and the purification done till the pH of the waste water is around 7.

The biodiesel thus produced is free from catalyst, free fatty acid, and excess methanol and glycerol particles. But the biodiesel may contain moisture as it was subjected to water previously, so a heating or any other form of de-moisturization facility is needed in this regard.

Step 7:

remove moister from biodiesel:

After washing, the moisture present in the biodiesel has to be removed as presence of moisture decreases the flash point and calorific value of the fuel. It also increases the viscosity of the fuel.

So, the biodiesel has been poured in to beaker and placed that inside an air oven. The biodiesel is heated at 100°C in an air oven for 10hours to remove any kind of moister. The biodiesel becomes transparent after heating.

Fig-4.8 : Air oven for remove moisture from biodiesel

After moisture removed we get biodiesel = 91.5 ml for experiment 1.
Sameway we have done all other remaining 8 experiment and their biodiesel amount are given in a table no [2].

AMOUNT OF BIODIESEL PRODUCE IN 9 EXPERIMENT

Methanol(ml)	KOH(gm)	Temparature(deg C)	Biodiesel(ml)
53.08	0.463	40	91.5
53.08	0.926	50	83
53.08	1.38	60	80
39.81	0.463	50	93
39.81	0.926	60	90
39.81	1.38	40	84
26.54	0.463	60	89
26.54	0.926	40	87
26.54	1.38	50	88

Table-4.2: Result of nine experiments

4.7 OPTIMIZATION OF BIODIESEL PRODUCTION

To find the optimum condition of various parameters that are Methanol : wpo value , KOH value , and temperature value such that biodiesel production will be maximum thus we have used taghuchi experimental design method. Taghuchi method give the result is **experiment number 4** has highest production of biodiesel that is **93 ml of biodiesel for 100 ml wpo. Total yield of biodiesel production is 93%.**where optimum condition of various parameters are methanol : wpo = 9: 1 KOH = .5wt% of oil and reaction temperature = 50 deg c . other parameters are RPM = 600 and reaction time = 2 hour are kept constant.

Final Result of taguchi experimental design

Experiments number	**Methanol(ml)**	**KOH(gm)**	**Temparature(deg C)**	**Biodiesel(ml)**	**SNRA1**
1	**53.08**	**0.463**	**40**	**91.5**	**39.2284**
2	**53.08**	**0.926**	**50**	**83**	**38.3816**
3	**53.08**	**1.38**	**60**	**80**	**38.0618**
4	**39.81**	**0.463**	**50**	**93**	**39.3697**
5	**39.81**	**0.926**	**60**	**90**	**39.0849**
6	**39.81**	**1.38**	**40**	**84**	**38.4856**
7	**26.54**	**0.463**	**60**	**89**	**38.9878**
8	**26.54**	**0.926**	**40**	**87**	**38.8402**
9	**26.54**	**1.38**	**50**	**88**	**38.8897**

Table-4.3 : Final result of taguchi method

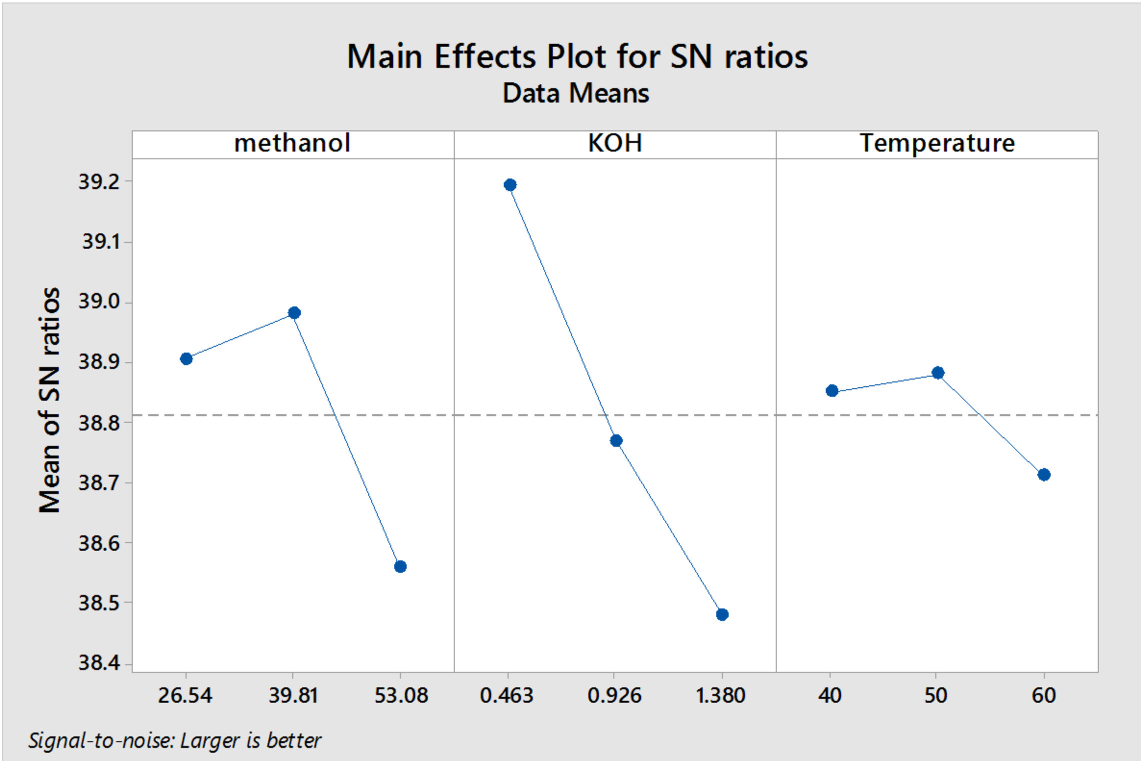


Fig-4.9 : Methanol vs SN ratio, KOH vs SN ratio , Temparature VS SN ratio

4.8 ANOVA METHOD TO FIND PERCENTAGE CONTRIBUTION

To find the significant contribution or percentage contribution of various factor that are methanol , KOH , temperature on the production of biodiesel we have used analysis of varience (ANOVA) method .

Factor	percentage contribution (%)
Methanol	16.58
KOH	58.51
Temparature	2.97

Table-4.4: ANOVA Analysis

CHAPTER 5

5. BIODIESEL PRODUCTION FROM PALM OIL ON A PILOT SCALE

The biodiesel pilot plant in the laboratory of School of Energy Studies department is capable of processing 25 litres of palm oil per batch. It is easy to operate and can be used for mass production. Biodiesel is produced in batch processes.

5.1 The biodiesel production unit consists of the following parts:

a. **Main Transesterifier Reactor** : This is where the reaction takes place. The reaction takes place as a result of circulation and not by stirring.

b. **Auxiliary column:** When the volume of reaction mixture is greater than 10 litres then the reaction also takes place here along with the transesterifier. This ensures better conversion of triglycerides to biodiesel.

c. **Glycerol column:** This is where the separation of reaction mixture takes place.

d. **Wash column:** The biodiesel production unit utilizes ion exchange resins for the purpose of washing of biodiesel. Its advantage being that no emulsions are formed during washing and there is no loss of biodiesel.

e. **Pumps:** There are 4 pumps to facilitate movement of liquid in the system. The first pump is for the transesterifier. The second pump is for the auxiliary unit. The third pump is for transferring the reaction mixture to the glycerol column. Lastly the fourth pump is for transferring the unwashed biodiesel to the wash column.

f. **Control Panel:** It is consists of one main dyanamixer controller, 3 temperature controllers, 2 thermostats to control temperature. The temperature controller at extreme left was out of order. The controller at extreme right is set to control the temperature of the main heater; another one controlled the auxiliary heater. The switch board at extreme right has switches for different valve opening.

Fig-5.1 : control panel

Fig-5.2 : biodiesel production unit

Fig-5.3 : Glycerol column (extreme right), Transesterifier(center), Auxiliary column (extreme left)

5.2 Determination of the amount of raw material

Volume of wpo

oil=3000cc Molar

ratio, Alcohol: oil =9:1

KOH is taken .5% w/w

of oil

Density of wpo=0.9266 gm/ml
Weight of the
oil=0.9266*3000=2779.8gm
Molecular weight of the palm
oil=847.3gm

Density of methanol= 0.792
gm/cc Molecular weight of the
methanol=32 gm

847.3 gm of oil requires 9*32 gm of methanol
2779.8gm of oil requires 9*32*2779.8/847.3=946.04gm of Methanol

Volume of methanol required=946.04/0.792=1194.5 ml

KOH is taken .5% w/w of oil
This implies, 100gm of oil requires .5gm of KOH
So, 2779.8 gm of oil will require2779.8*.5 /100= 13.89 gm of KOH

Amount of oil= 3000ml, Amount of alcohol= 1194.5ml of CH3OH, Amount of KOH= 13.89gm of KOH.

5.3 Transesterification in the Pilot plant

Prior to the transesterification, 1194.5 ml methanol was measured by a measuring cylinder and 13.89 gm KOH was weighed by weighing balance accurately. These two are then mixed in a conical flask and stirred for 20 minutes in a magnetic stirrer. A methoxide solution is thus prepared and fed to the rector by means of a funnel attaching to the top opening of the reactor.

The minimum capacity of the pilot unit is 3 litres per batch. If the volume of feedstock is less than 3 litres then the circulation does not take place. Firstly the feedstock has to be purified completely, devoid of suspended particles and moisture. Then it is added to the transesterifier through a funnel. The feedstock is heated upto the desired set point. The temperature is set on the temperature controller unit and the system is turned on. After the desired temperature has reached then a mixture of commercial grade methanol and KOH is added to the feedstock in the transesterifier.

The system runs for 2 hours, the desired reaction time, and then its switched off. During the reaction, after 1 hour, the transesterifier is paused and a valve at the bottom of the transesterifier is opened. Little bit of the mixture is collected to check if proper conversion has taken place or not.

After completion of reaction the mixture is transferred to the glycerol column for settling. As the mixture cools down the settling happens faster. It is advisable to let it stand for atleast 10 hours. Glycerol is collected from the bottom.

As the liquid transfer takes place by pipes there is a loss of biodiesel of about 300 to 400 ml. But this happens only the first time. The subsequent times that the system runs the 300 ml of biodiesel is recovered. This happens as the new liquid pushes the previously present liquid forward.

Amount of glycerin= 760 ml

Amount of crude biodiesel obtained=

2840 ml **Bubble Washing**

Acidity of the waste water is tested by litmus paper and the purification done till the pH of the waste water is around 7.

First washing: Amount of crude biodiesel=
284**0**ml Amount of wash water= 6000 ml
Time taken for bubble
washing= 2 min. Settling
time= 20 min.
Amount of biodiesel after first washing= 2820 ml

Second washing :Amount of crude biodiesel=
2820 ml Amount of wash water= 6000 ml
Time taken for bubble
washing= 2 min. Settling
time= 20 min.
Amount of biodiesel after second washing= 2810 ml

Third washing: Amount of crude biodiesel=
2810 ml Amount of wash water= 6000 ml
Time taken for bubble
washing= 2 min. Settling
time= 20 min.
Amount of biodiesel after third washing= 2805 ml

Total yield of biodiesel = 2805/3000 = 93.5%

The biodiesel thus produced is free from catalyst, free fatty acid, and excess methanol and glycerol particles. But the biodiesel may contain moisture as it was subjected to water previously. So a heating or any other form of demoisturization facility is needed in this regard.

Heating of biodiesel

Moisture is removed from the biodiesel by heating the biodiesel in the air oven at a temperature of 105°C for 8 hours. Now the biodiesel is ready for used.

CHAPTER- 6

PROPERTIES OF THE BIODIESEL

6.1Density: values depend on their fatty acid composition as well as on their purity. Density increases with decreasing chain length and increasing number of double bonds, or can be decreased by the presence of low density contaminants such as methanol. 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.

Density measurement of biodiesel:

Weight of empty beaker = 18.983 gm

Volume of oil taken = 100ml

Weight of the oil filled beaker= 27.800 gm

Wight of biodiesel = 27.800- 18.983 = 8.8174 gm

Density =0.88174 gm/ ml

6.2Kinematic viscosity:

Reducing viscosity is the major reason why vegetable oils or fats are transesterified to biodiesel because the high viscosity of neat vegetable oils or fats ultimately leads to operational problems such as engine deposits. Viscosity is defined as the internal friction or resistance of a liquid to flow. viscosity depends on temperature. 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. Due to the increased droplet size of the injected biodiesel, the shoot emission may increase. 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 Figure. The viscometer with the sample is immersed in a water bath so that it attains the desired temperature. Suction is applied so that liquid is drawn up to mark ‗A' through bulb D. The efflux time of the liquid between marks A and B is noted after releasing the vacuum.

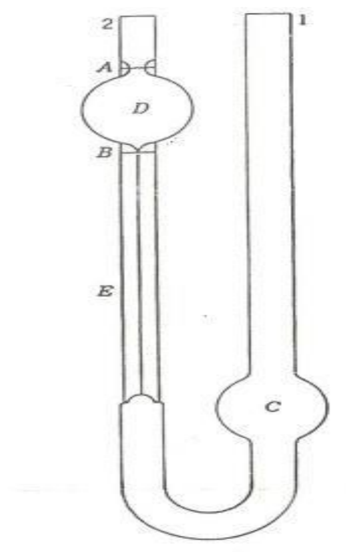


Fig-6.1: Ostwald viscometer

The coefficient of viscosity (η) of a liquid is defined as the tangential force per unit area required maintaining unit velocity gradient between two successive layers of a liquid, which are unit distance apart from each other .The unit of coefficient of viscosity is dyne-sec\cm 2 (poise). 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. As this method requires the comparison with another liquid, it is a relative method.

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. The apparatus has to be dried before pouring biodiesel into it. Then biodiesel produced from palm 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.

$$\boldsymbol{\eta 1 = \eta 2 \cdot \rho 1 t 1 / \rho 2 t 2}$$

where η1 and η2 are viscosity coefficients of the liquid and water, and ρ1 and ρ2 are the densities of liquid and water, respectively.

In the present study we are measuring the relative viscosity in comparison of viscosity of water. So as η2 the viscosity of water and it's density (ρ2) is known (from the chart)[23], then by measuring t2 it's time of flow and ρ1, t1 the density and time of flow of other liquids, viscosity can be calculated. Times of flow of the liquids are determined using Oswald's viscometer and stopwatch.

Fig-6.2 : Measurement of viscosity in laboratory

Calculation:

Time taken by water at 35 degree C to fall from the upper to the lower mark are

First time =51.70 Sec

Second time =51.50 sec

Third time =51.32 sec

So average time taken = 51.5066 sec

Time taken for palm oil biodiesel at 35 degree C to fall from upper to lower mark are

First time =528 sec

Second time =530 sec

Third time =529 sec

So average time taken = 529 sec

Density of the biodiesel =0.897872 gm/ cc

Density of water = 1 gm/ cc

So Kinematic viscosity of biodiesel = (0.7241×0.897872×529)÷ (1×51.566)

= 6.669683entistokes

6.3 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 flash point of a volatile material is the lowest temperature at which vapours of the material will ignite, when given an ignition source.

The flash point may sometimes be confused with the autoignition temperature, which is the temperature at which the vapor ignites spontaneously without an ignition source. The fire point is the lowest temperature at which vapors 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 vapor may not be produced rapidly enough to sustain combustion.

At flash point(defined as the minimum temperature), some part of the fuel is in vapor state and some in liquid. Now you ignite the mixture by some external spark(whose temperature is much higher as compared to the surrounding temperature), the mixture will ignite but after some time this ignition will stop and your fuel will not be consumed fully(some liquid fuel will be left). For continuous burning and full consumption of the fuel, more vapor is required and that can be generated by increasing the surrounding temperature. So the temperature at which we get a sustained and continuous burning is known as fire point.

If flash point is low for a fuel, greater fire hazard. It is also difficult to transport fuels with lower flash point. There are numerous methods to determine the flash point. Different method gives different values. Among which two are most commonly used methods, namely closed cup and open cup, depending upon their physical configuration. Open cup flash point is somewhat higher than a closed cup flash point.

Flash point and Fire point testing in the laboratory:

Flash point and Fire point were tested in the laboratory by means of a Flash point testing apparatus, shown in 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. The cup is filled with biodiesel up to a certain mark, As the motor is stirred continuously it causes development of heat inside the biodiesel. There is a provision to introduce fire in the biodiesel. When the thermometer reading crosses 100C, fire is introduced at certain intervalof temperature rise and condition of the introduced fire is observed. If the fire gets engulfed in the biodiesel, it denotes the flash point of the biodiesel. The point where the fire continues to burn denotes the fire point of the biodiesel. 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.

Flash point of the palm oil biodiesel: 162 °C

Fire point of the palm oil biodiesel :175 °C

Fig-6.3 : Flash point testing apparatus

6.4 Calorific Value:

The calorific value (heat of combustion) of a sample is defined as the number of heat units liberated by a unit mass of a sample when burned with oxygen in an enclosure of constant volume.

Ramirez-Verduzco et al. revealed that the calorific value increased due to the increase in molecular weight decreased due to the number of double bonds increases [21]. In general, a high calorific value is desirable since it is indicative of the energy content of the fuel. Calorific value is tested in the laboratory with the help of a bomb calorimeter. Heats of combustion as determined in an oxygen bomb calorimeter are measured by a substitution procedure in which the heat obtained from the sample is compared with the heat obtained from combustion of a similar amount of benzoic acid or other standardizing material whose calorific value is known. These measurements are obtained by burning a representative sample in a high-pressure oxygen atmosphere within a metal pressure vessel or bomb.

The energy released by this combustion is absorbed within the calorimeter and the resulting temperature change within the absorbing medium is noted. The heat of combustion of the sample is then calculated by multiplying the temperature rise in the calorimeter by a previously determined energy equivalent or heat capacity determined from previous tests with benzoic acid.

Four essential parts are required in any bomb calorimeter:

1. Bomb or vessel in which the combustible charges can be burned.
2. Bucket or container for holding the bomb in a measured quantity of water, together with a stirring mechanism.
3. An insulating jacket to protect the bucket from transient thermal stresses during the combustion process.
4. Thermocouple for measuring temperature changes within the bucket.

Fig-6.4 : Bomb

Fig-6.5: Bomb Calorimeter

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. The amount of heat introduced by the reference sample is determined by multiplying the heat of combustion of the standard material by the weight of the sample burned. Then, by dividing this value by the temperature rise produce in the test, we obtain a resultant energy equivalent for this particular calorimeter.

Mass of benzoic acid = 0.738 gm
Standard heat of combustion of benzoic acid = 6318 Cal/ gm at 27°C Temperature rise due to the combustion of benzoic acid = 2.08 °C
energy equivalent of the calorimeter = (6318x0.738)/2.08 = 2241.675 Cal/°C

As the energy equivalent of the calorimeter is known, now it is easy for us to determine calorific value of any fuel o known mass. The fuel sample taken in a container is burnt inside the bomb and the resultant temperature change is recorded. The calorific value of the sample of unit weight for the particular temperature rise is calculated by multiplying the temperature rise with the energy equivalent of the calorimeter and dividing it by the mass of the sample. A small mass correction is made as some amount of unburnt carbon is left in the container.

WCO biodiesel:

Mass of biodiesel = 2.163 gm
Mass of unburnt carbon left in the container = 0.3 gm
Temperature rise due to combustion = 5.23 °C
Energy equivalent of the calorimeter = 2241.675 cal/°C

Calorific value of biodiesel from WCO = $\frac{2241.675 \times 5.23}{(2.163 - .3)}$ = 6293.05 cal/gm

= 6293.05×4.2 = 26430.82 KJ/ kg

CHAPTER 7

7DIESEL ENGINE

Fig-7.1 :Diesel generator connected with load

The diesel engine (also known as a compression-ignition or CI engine), named after Rudolf Diesel, is an internal combustion engine in which ignition of the fuel which is injected into the combustion chamber is caused by the elevated temperature of the air in the cylinder due to mechanical compression (adiabatic compression). Diesel engines work by compressing only the air. This increases the air temperature inside the cylinder to such a high degree that atomised diesel fuel that is injected into the combustion chamber ignites spontaneously. This contrasts with spark-ignition engines such as a petrol engine (gasoline engine) or gas engine (using a gaseous fuel as opposed to petrol), which use a spark plug to ignite an air-fuel mixture. The original diesel engine operates on the "constant pressure" cycle of gradual combustion and produces no audible knock. In diesel engines, glow plugs (combustion chamber pre-warmers) may be used to aid starting in cold weather, or when the engine uses a lower compression-ratio, or both.

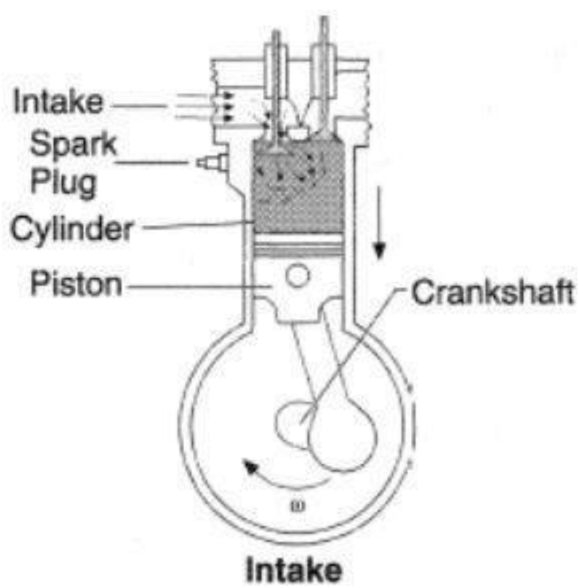
The diesel engine has the highest thermal efficiency (engine efficiency) of any practical internal or external combustion engine due to its very high expansion ratio and inherent lean burn which enables heat dissipation by the excess air. A small efficiency loss is also avoided compared to two-stroke non-direct-injection gasoline engines since unburned fuel is not present at valve overlap and therefore no fuel goes directly from the intake/injection to the exhaust. Low-speed diesel engines (as used in ships and other applications where overall engine weight is relatively unimportant) can have a thermal efficiency that exceeds 50%.[25]

7.1Working of Four Stroke Diesel Engine

A **four-stroke engine** (also known as **four-cycle**) is an internal combustion engine in which the piston completes four separate strokes which constitute a single thermodynamic cycle. A stroke refers to the full travel of the piston along the cylinder, in either direction. Power generation in four stroke is divided into four parts namely suction stroke, compression stroke, expansion stroke (power stroke) and exhaust stroke.

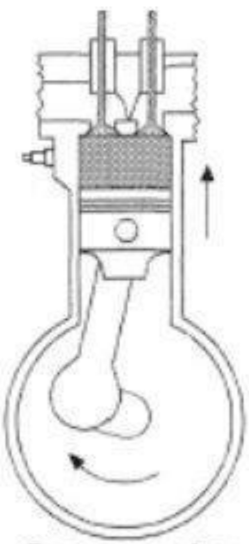
Suction stroke:

In the suction stroke of diesel engine the piston start moves from Top Dead Centre (TDC) of the cylinder to Bottom Dead Centre (BDC) of the cylinder and simultaneously inlet valve opens. At this time air at atmospheric pressure drawn inside the cylinder through the inlet valve due to the suction created. The inlet valve remains open until the piston reaches the BDC of cylinder (not practically but theoretically.).



Compression stroke:

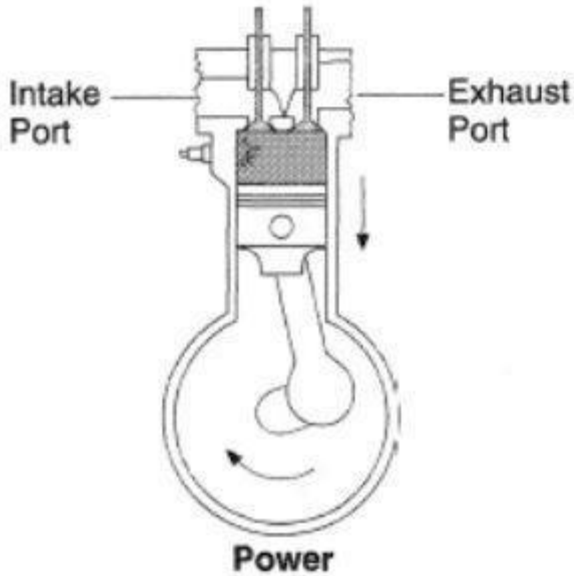
After the piston passes BDC of the cylinder, it starts moving up. Both valves are closed and hence the cylinder is sealed. The piston moves upward. This movement of piston compresses the air into a small space between the piston and TDC of cylinder . The air is compressed into 1/22 (compression ratio: 22, varies from engine to engine) or less of its original volume. Due to this compression a high pressure and temperature is generated inside the cylinder. Both the inlet and exhaust valves do not open during any part of this stroke. At the end of compression stroke the piston is at TDC the cylinder.



Compression

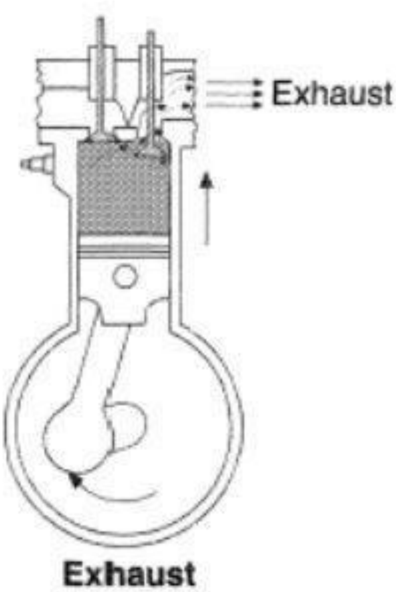
Power stroke:

At the end of the compression stroke when the piston is at TDC a pre metered quantity of diesel is injected into the cylinder by the injector. The temperature inside the cylinder is very high which is sufficient to ignite the fuel injected and this generates tremendous energy which is in the form of high pressure which pushes down the piston. The connection rod carries this force to the crankshaft which turns to move the vehicle. At the end of power stroke the piston reaches the BDC.



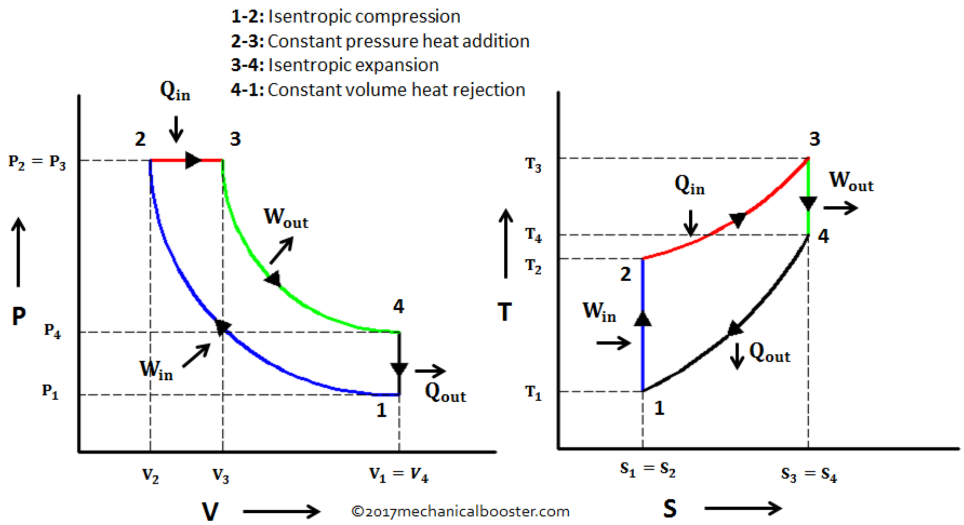
Exhaust stroke:

When the piston reaches the BDC after the power stroke, the exhaust valve opens. The pressure of the burnt gases is higher than atmospheric pressure. This pressure difference allows burnt gases to escape through the exhaust port and the piston move through the TDC. At the end of exhaust all burn gases escape (theoretically) and exhaust valve is closed.



The cycle repeats…

7.1P-V and T-s Diagrams of Diesel Cycle:



P-V and T-S Diagram of Diesel Cycle

7.2Diesel Engine Applications:

1. Cars and light commercial vehicles
2. Heavy goods vehicles
3. Construction and agricultural machinery
4. Railway locomotives
5. Ships etc

7.3Engine speeds

Within the diesel engine industry, engines are often categorized by their rotational speeds into three unofficial groups:

- High-speed engines (> 1,000 rpm),
- Medium-speed engines (300–1,000 rpm), and
- Slow-speed engines (< 300 rpm).

CHAPTER 8

8 . TESTING OF BIODIESEL IN A COMPRESSION IGNITION ENGINE

The biodiesel prepared in pilot scale was fed into the specified diesel engine with varying biodiesel concentrations; viz. B5, B10, B20 and B30. The performances were compared with the results of CI engine run by normal Petro Diesel.

Table 8.1 : Test engine Specification

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

8.1 EXPERIMENTAL PROCEDURE

Different loads have been applied in the form of tungsten filament lamps of 500W and 200W. Rpm reduced as the load increases.Fuel consumption and EGT were measured for 500,1000,1500 and 2000 W Load. For 500W load, only one lamp of 500W was switched ON and keeping the other lamps off. For 1000W load, two lamps of 500W each are kept ON. For 1500W load, three lamps of 500W are kept ON. Again for 2000W load, four lamps of 500W were switched ON. Before starting a new test, the engine was allowed to run for a sufficient time to consume the remaining fuel from the previous experiment.

8.1 LOAD (watt) V/S FUEL CONSUMPTION (ml/hr):

8.1.1 For pure diesel oil , Load(watt) v/s fuel consumption(ml/hr):

Load(watt)	fuel consumption(ml/hr)
500	300
1000	360
1500	390
2000	468

Table-8.2 : For pure diesel, the Load (Watt) v/s Fuel Consumption (ml/hr).

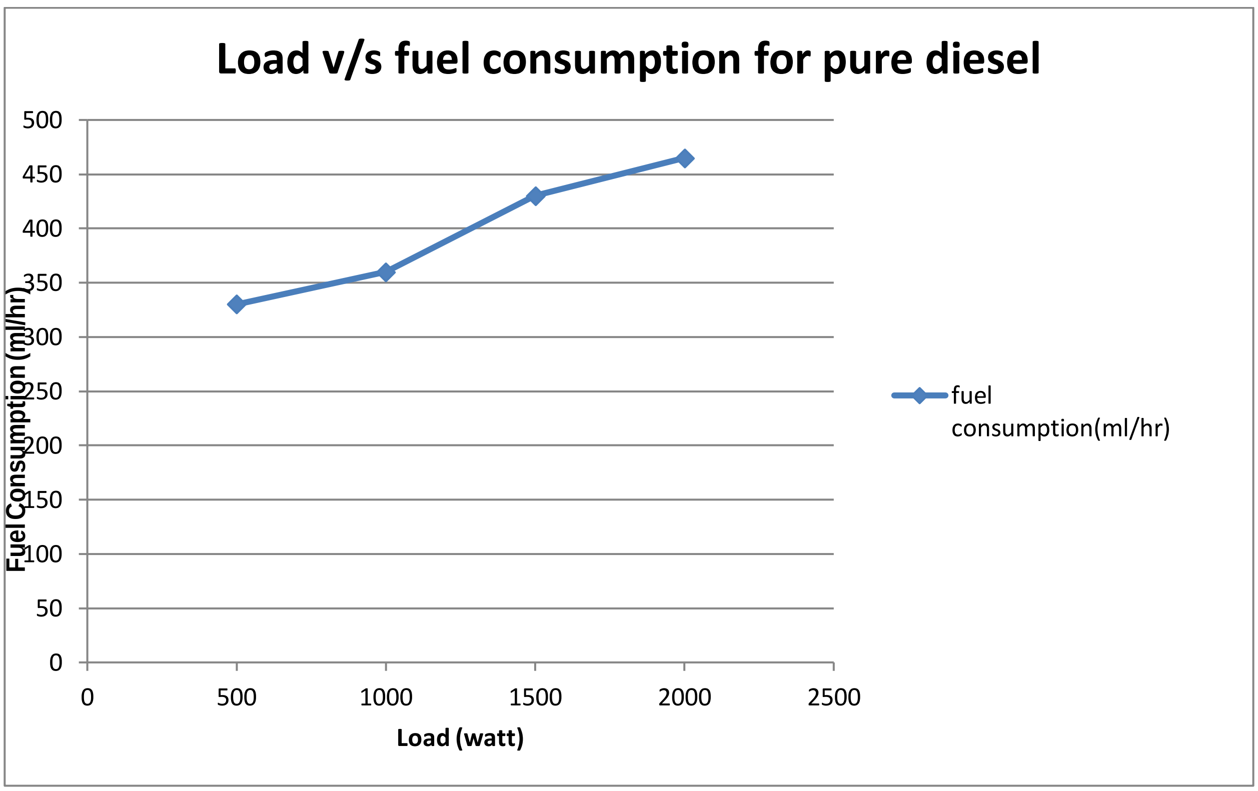


Fig-8.1: load vs fuel consumption for pure diesel

8.1.2 For B10 palm oil biodiesel, the Load (Watt) v/s Fuel Consumption (ml/hr):

Load(watt)	fuel consumption(ml/hr)
500	330
1000	360
1500	430
2000	465

Table-8.3: For B10 palm oil biodiesel, the Load (Watt) v/s Fuel Consumption (ml/hr)

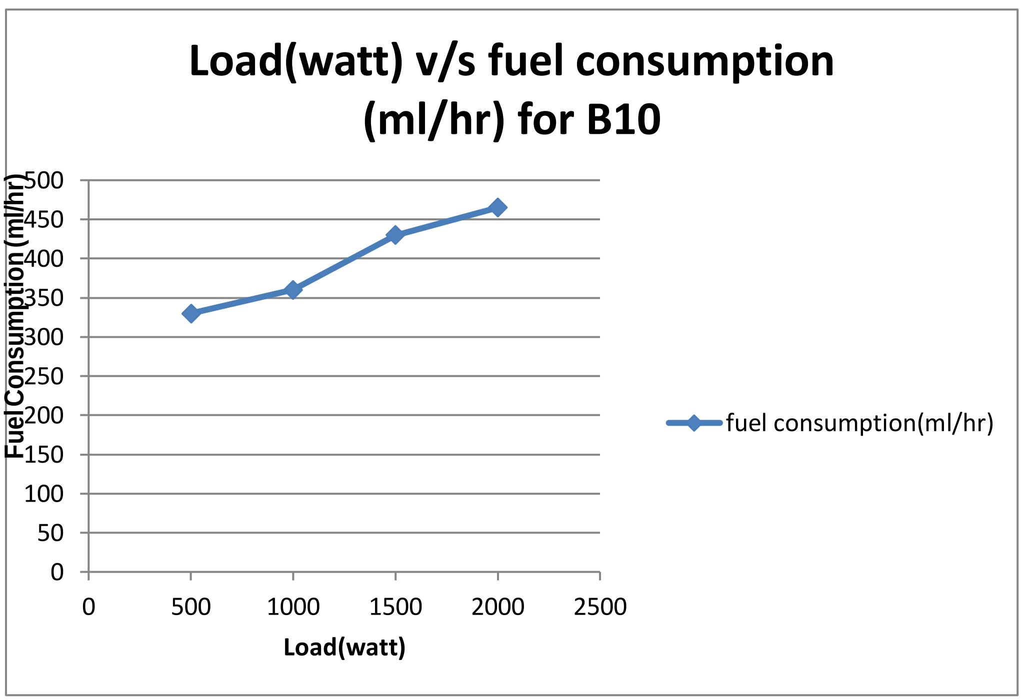


Fig-8.2 : load vs fuel consumption for B10

8.1.3 For B20 palm oil biodiesel, the Load (Watt) v/s Fuel Consumption (ml/hr):

Load(Watt)	Fuel consumption (ml/hr)
500	300
1000	360
1500	440
2000	480
2200	490

Table-8.4 : For B20 palm oil biodiesel, the Load (Watt) v/s Fuel Consumption (ml/hr)

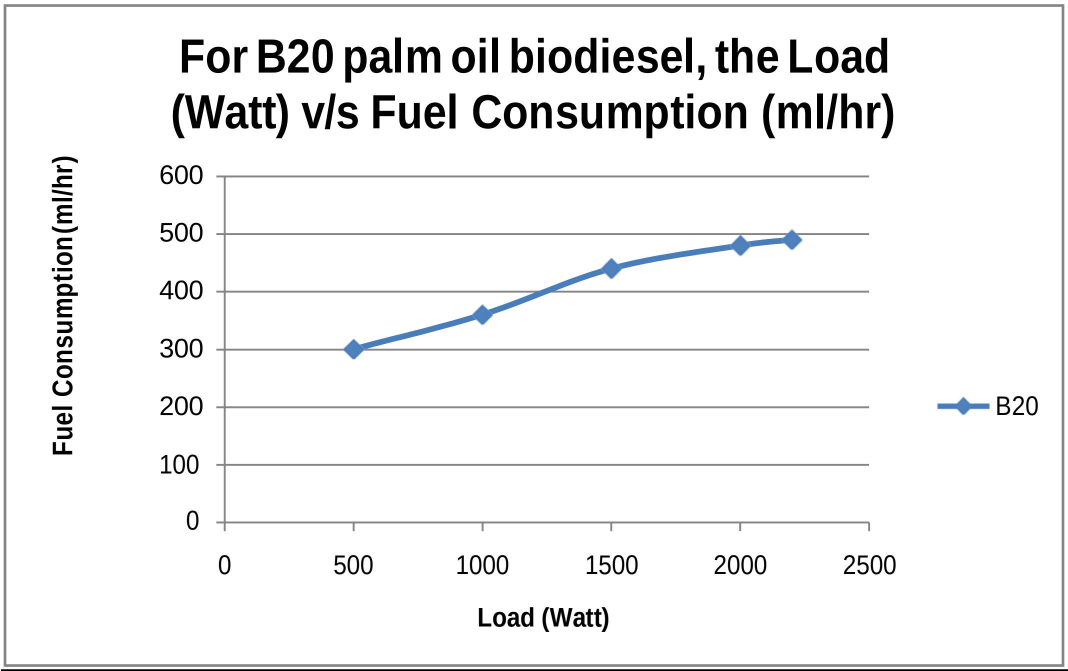


Fig-8.3 : load vs fuel consumption for B20

8.1.4 Load vs fuel consumption for B30

Load(watt)	fuel consumption for B30(ml/hr)
500	390
1000	420
1500	456
2000	504

Table-8.5 : For B30 palm oil biodiesel, the Load (Watt) v/s Fuel Consumption (ml/hr)

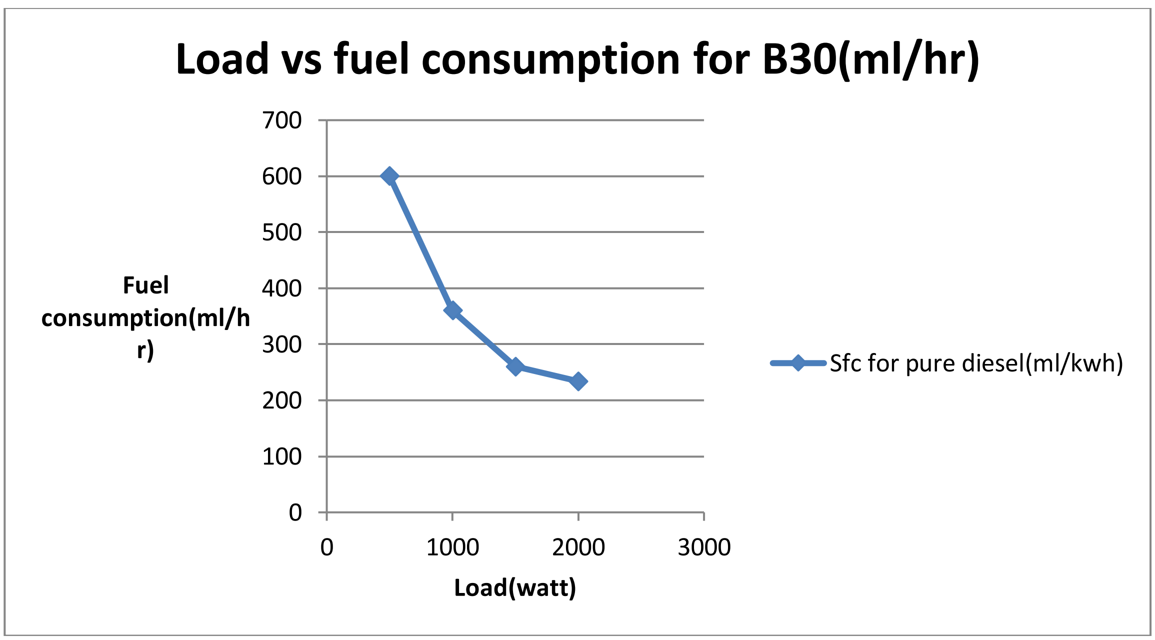


Fig-8.4 : load vs fuel consumption for B30

8.1.5 Load vs fuel consumption for B40

Load(watt)	fuel consumption for B40(ml/hr)
500	360
1000	405
1500	450
2000	525

Table-8.6 : For B40 palm oil biodiesel, the Load (Watt) v/s Fuel Consumption (ml/hr)

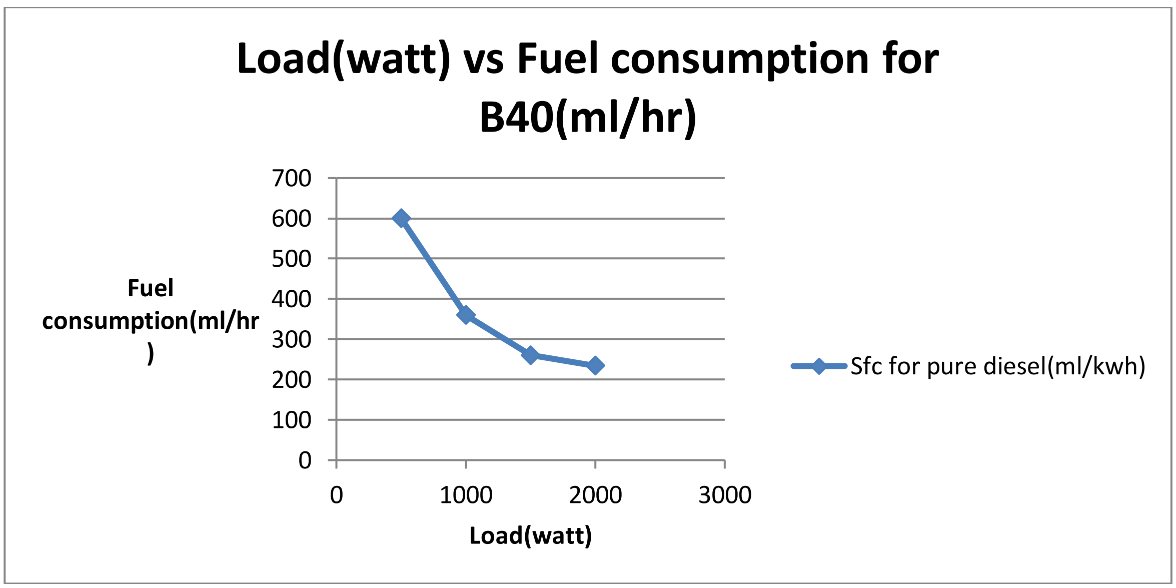


Fig-8.5 : load vs fuel consumption for B40

8.1.6 Load vs fuel consumption for B50

Load(watt)	fuel consumption for B50(ml/hr)
500	342
1000	390
1500	450
2000	540

Table-8.7 : For B50 palm oil biodiesel, the Load (Watt) v/s Fuel Consumption (ml/hr)

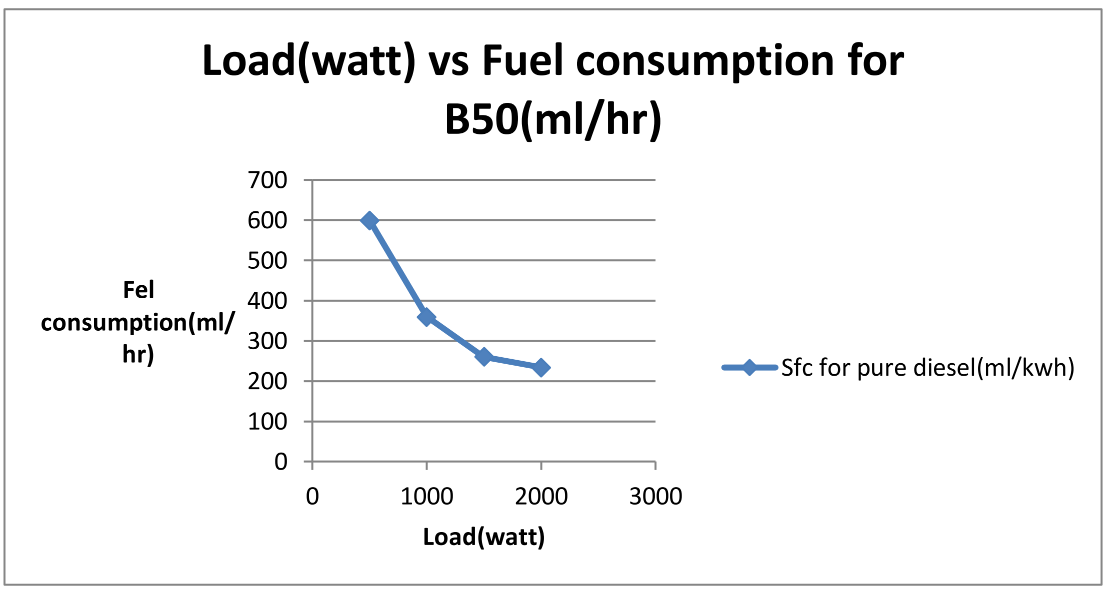


Fig-8.6: load vs fuel consumption for B50

8.1.7 Load(watt) vs Fuel consumption(ml/hr) in one chart

Load(watt)	Fuel consumption for pure diesel(ml/hr)	Fuel consumption for B10(ml/hr)	Fuel consumption for B20(ml/hr)	Fuel consumption for B30(ml/hr)	Fuel consumption for B40(ml/hr)	Fuel consumption for B50(ml/hr)
500	300	330	320	390	360	342
1000	360	360	360	420	405	390
1500	390	430	440	456	450	450
2000	468	465	480	504	525	540

Table -8.8 : Load(watt) vs Fuel consumption(ml/hr) of different load

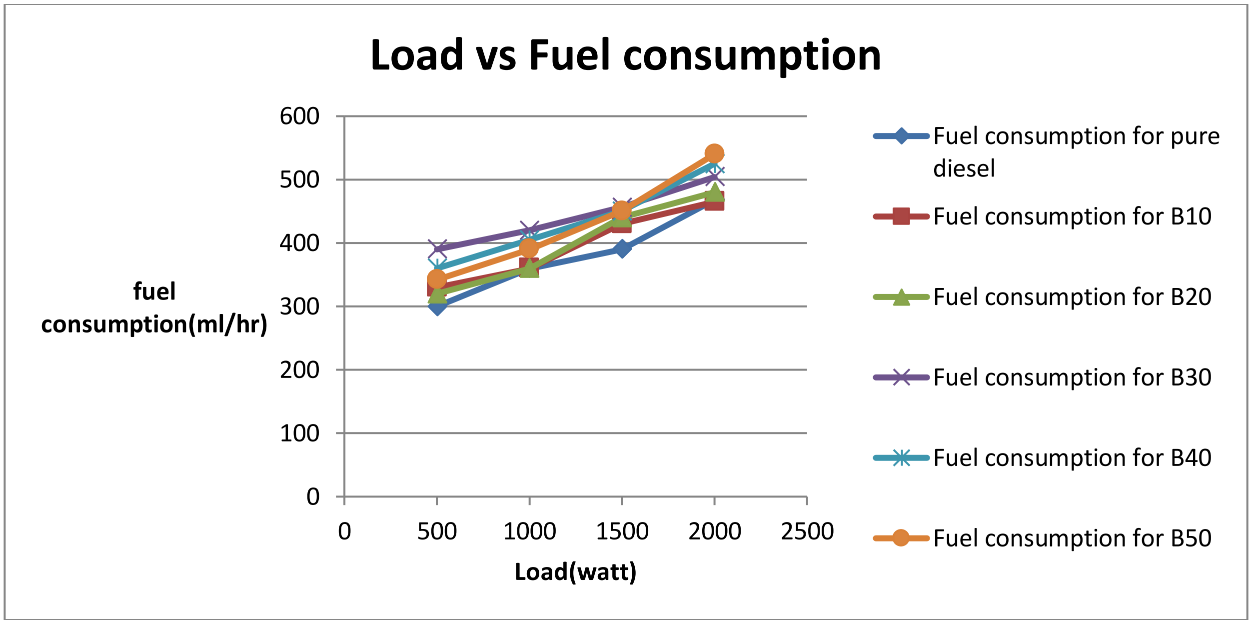


Fig-8.7: Load vs Fuel consumption

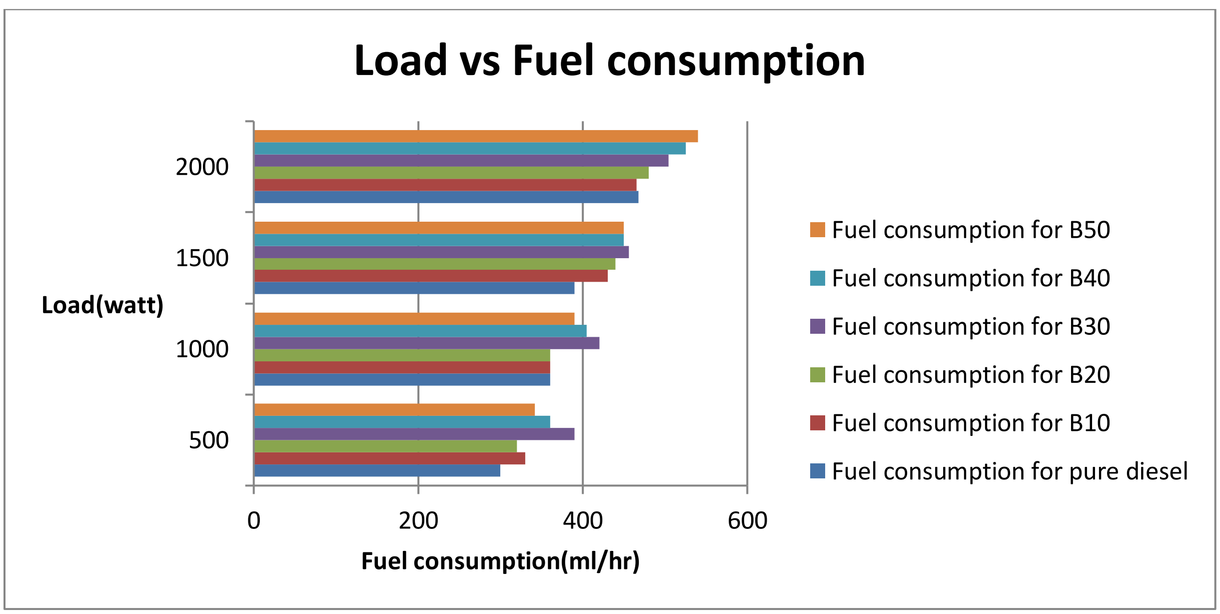


Fig-8.8 : Load vs fuel consumption in bar graph

8.2 LOAD(watt) vs SPECIFIC FUEL CONSUMPTION(ml/kwh)

8.2.1 Load vs Specific Fuel Consumption for pure diesel

Load(watt)	Sfc for pure diesel(ml/kwh)
500	600
1000	360
1500	260
2000	234

Table-8.9: Load vs Specific Fuel Consumption for pure diesel

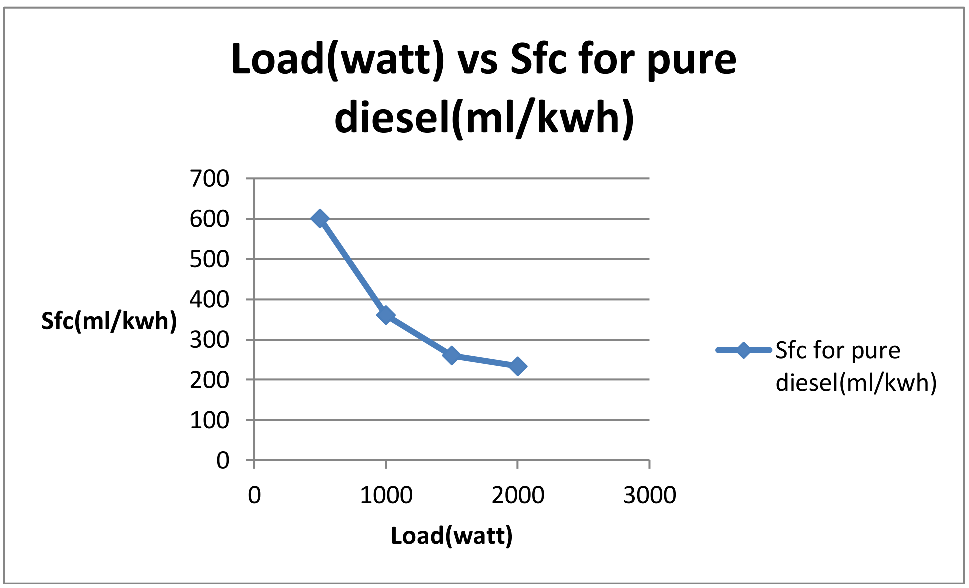


Fig-8.9 : Load vs Specific Fuel Consumption for pure diesel

8.2.2 Load vs Specific Fuel Consumption for B10

Load(watt)	Sfc for B10 (ml/kwh)
500	660
1000	360
1500	285
2000	230

Table-8.10 : Load vs Specific Fuel Consumption for B10

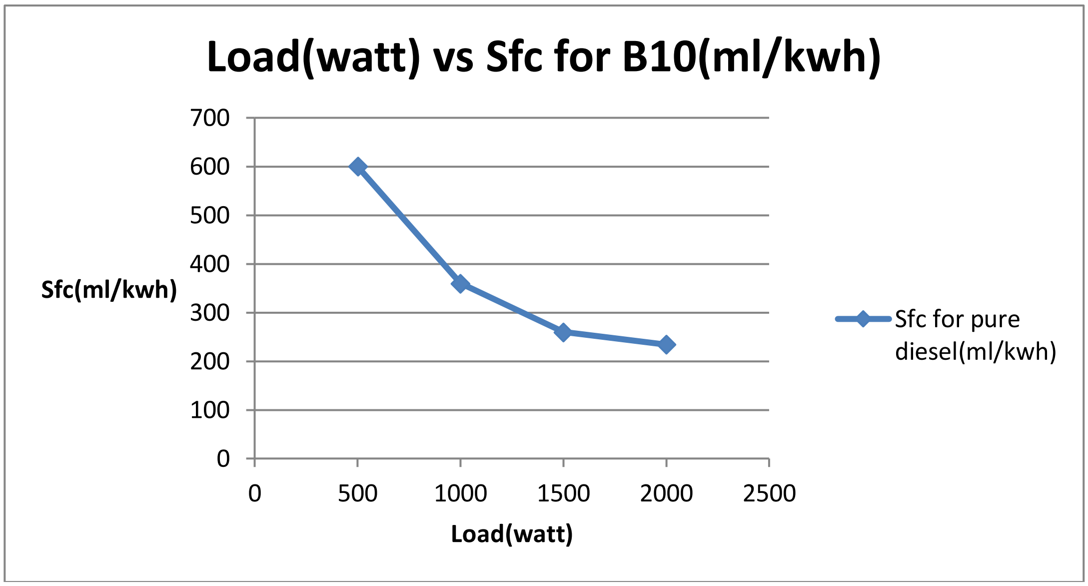


Fig-8.10 : Load vs Specific Fuel Consumption for B10

8.2.3 Load vs Specific Fuel Consumption for B20

Load(watt)	Sfc for B20 (ml/kwh)
500	640
1000	360
1500	293
2000	240

Table-8.11 : Load vs Specific Fuel Consumption for B20

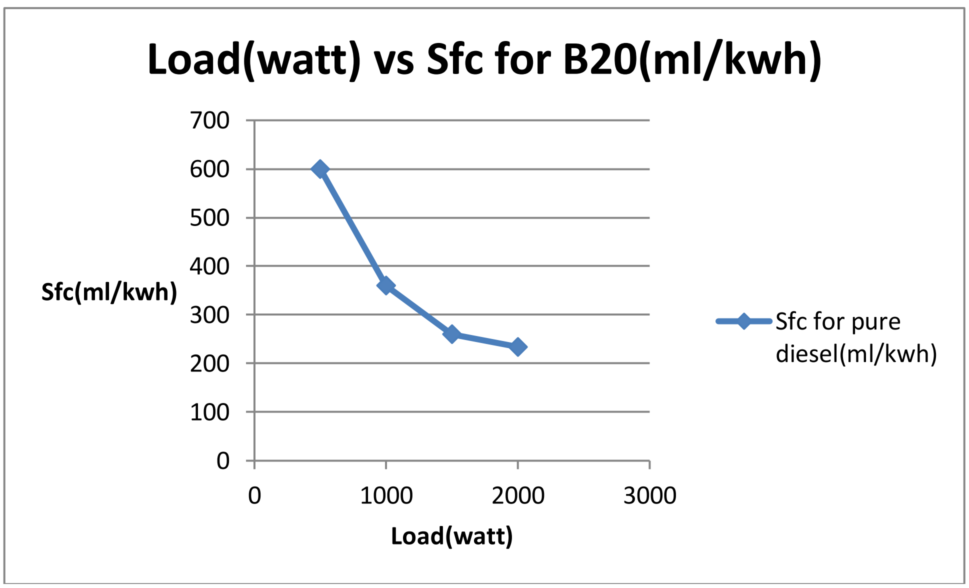


Fig-8.11 : Load vs Specific Fuel Consumption for B20

8.2.4 Load vs Specific Fuel Consumption for B30

Load(watt)	Sfc for B30 (ml/kwh)
500	780
1000	420
1500	304
2000	252

Table-8.12 : Load vs Specific Fuel Consumption for B30

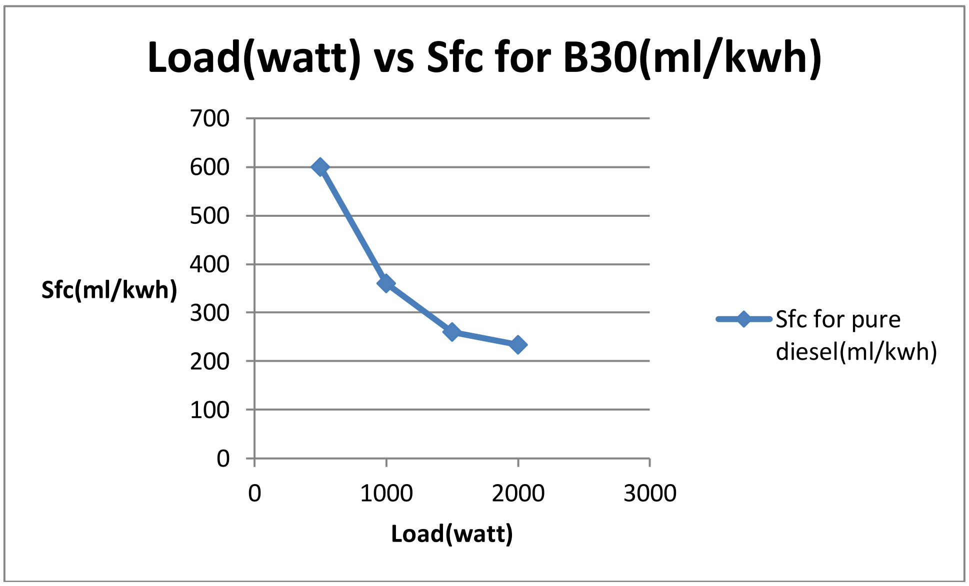


Fig-8.12 : Load vs Specific Fuel Consumption for B30

8.2.5 Load vs Specific Fuel Consumption for B40

Load(watt)	Sfc for B40 (ml/kwh)
500	720
1000	405
1500	300
2000	262

Table-8.13 : Load vs Specific Fuel Consumption for B40

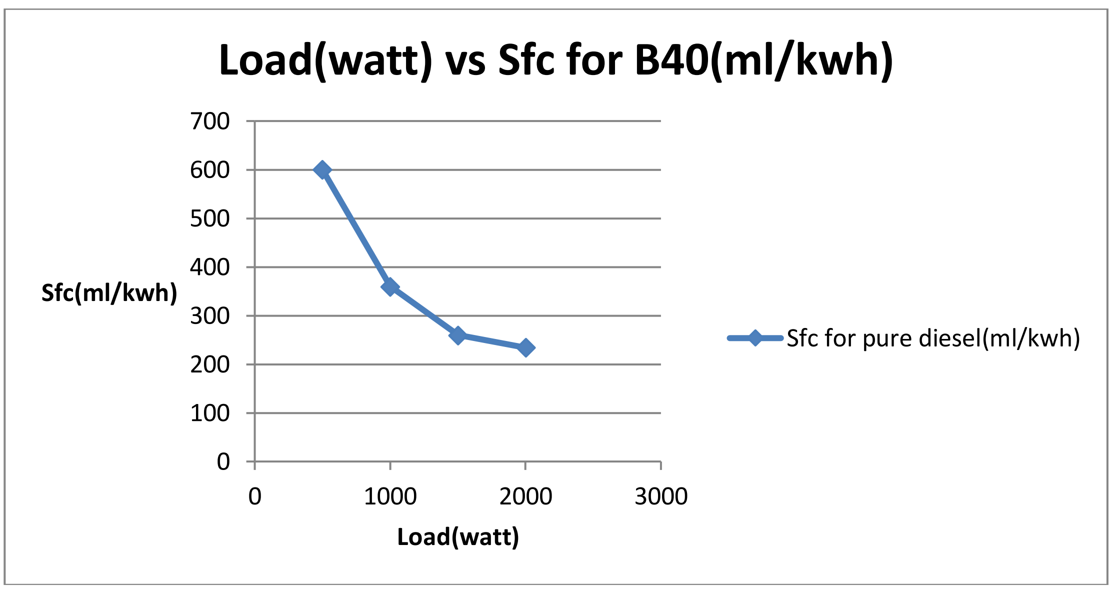


Fig-8.13 : Load vs Specific Fuel Consumption for B40

8.2.6 Load vs Specific Fuel Consumption for B50

Load(watt)	Sfc for B50 (ml/kwh)
500	684
1000	390
1500	300
2000	270

Table-8.14 : Load vs Specific Fuel Consumption for B50

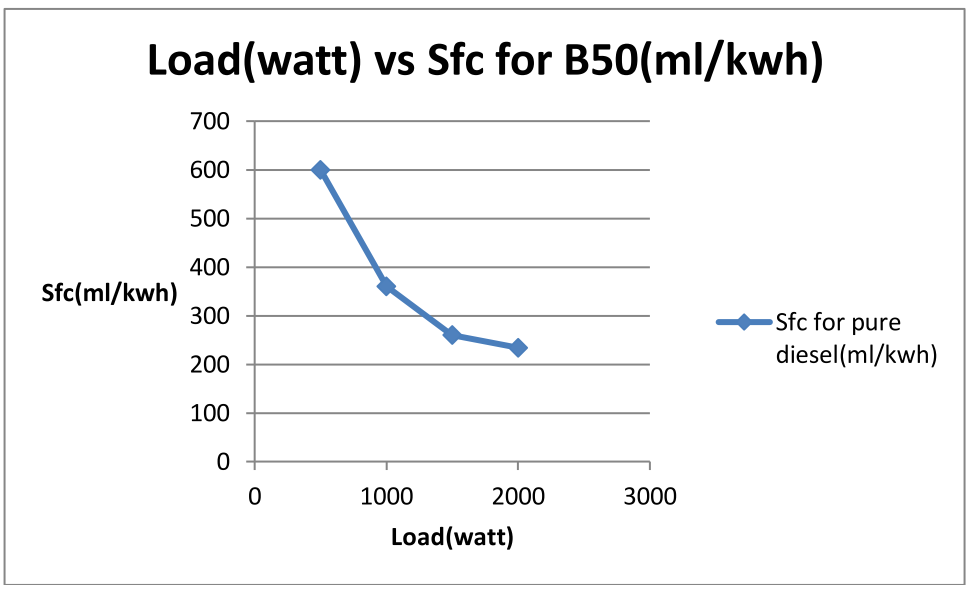


Fig-8.14 : Load vs Specific Fuel Consumption for B50

8.2.7 Load vs Specific Fuel Consumption in one chart

Load(watt)	Sfc for pure diesel(ml/kwh)	Sfc for B10(ml/kwh)	Sfc for B20(ml/kwh)	Sfc for B30(ml/kwh)	Sfc for B40(ml/kwh)	Sfc for B50(ml/kwh)
500	600	660	640	780	720	684
1000	360	360	360	420	405	390
1500	260	285	293	304	300	300
2000	234	230	240	252	262	270

Table-8.15: Load vs Specific Fuel Consumption

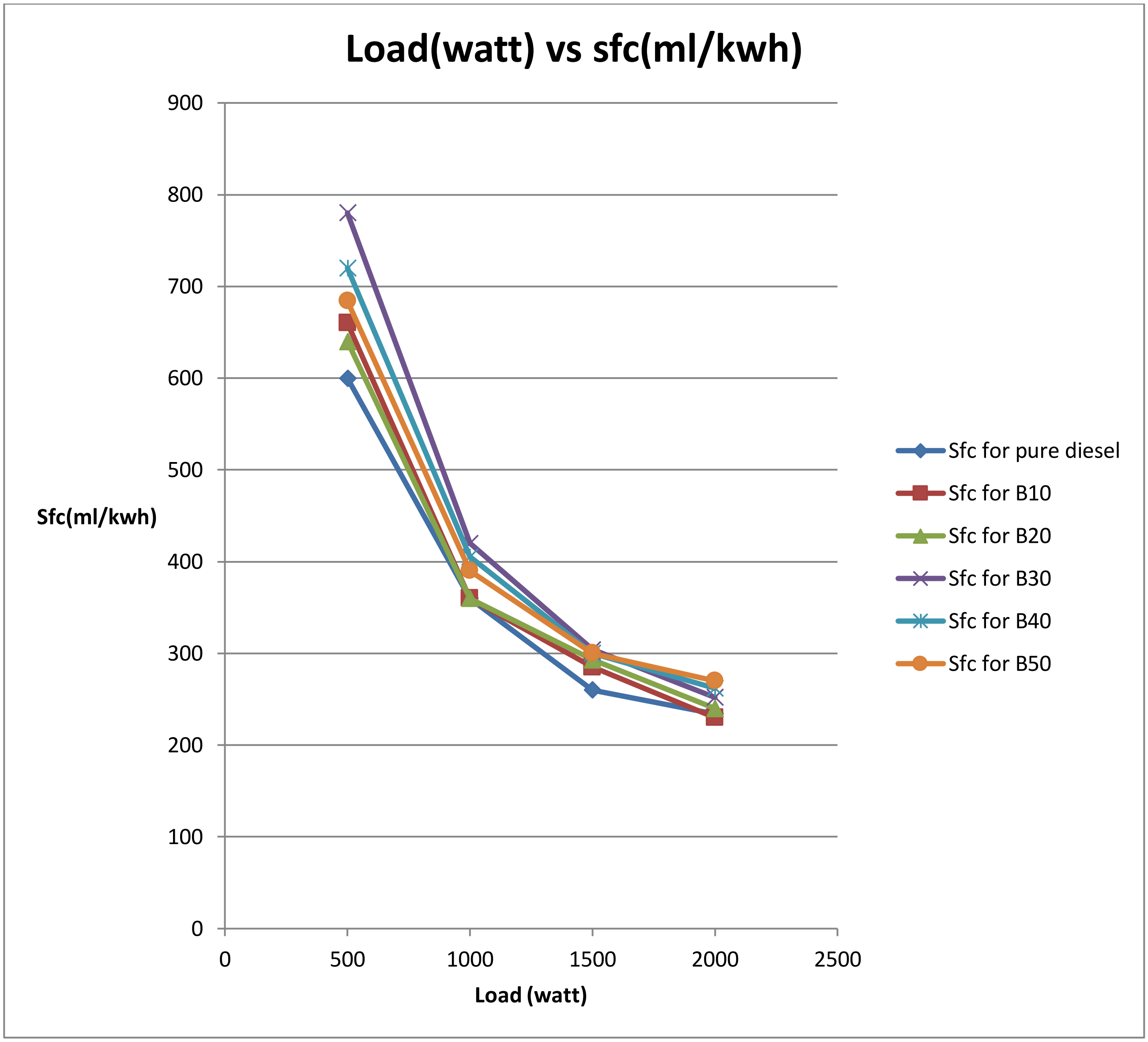


Fig-8.15 : Load vs specific fuel consumption

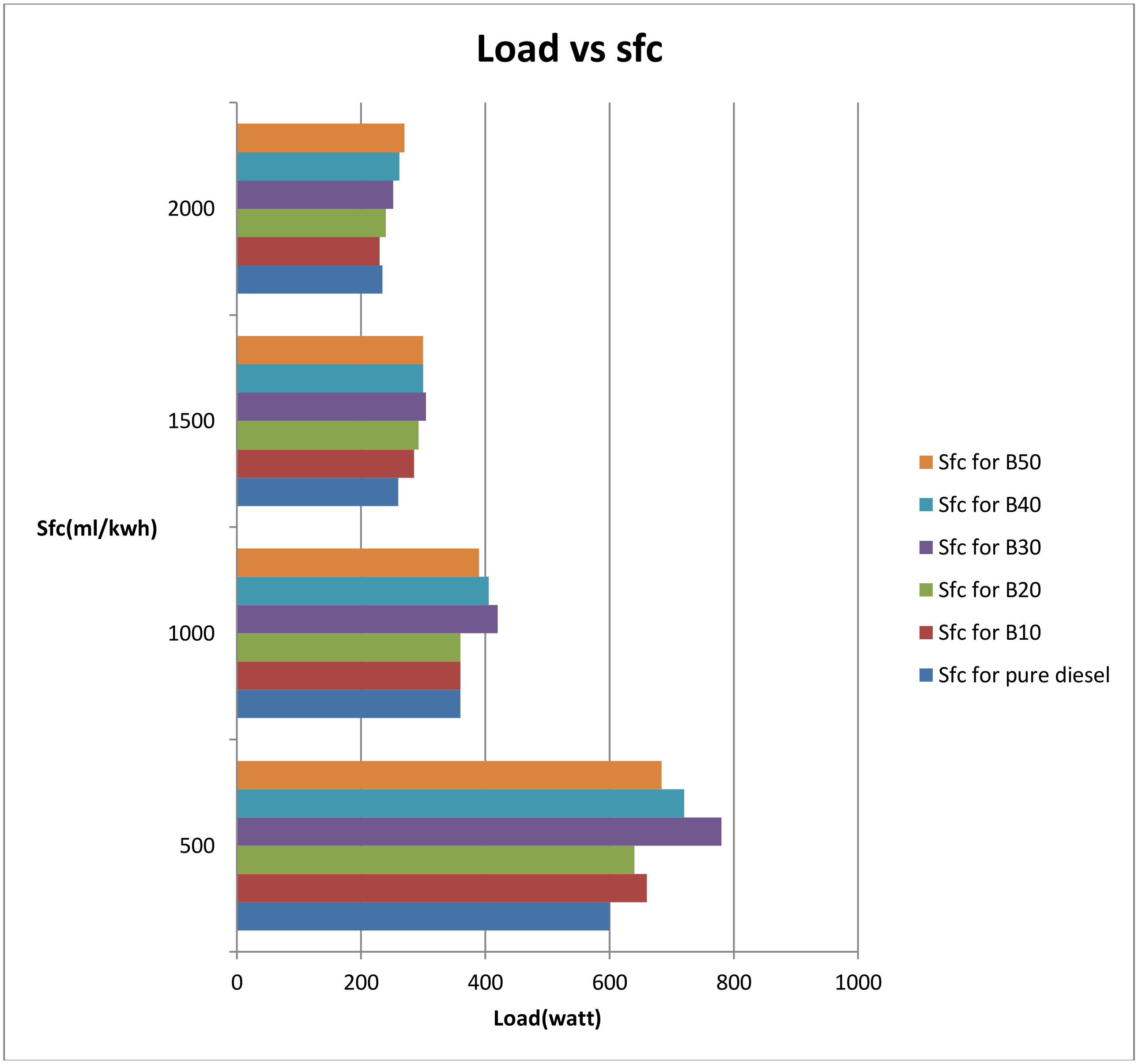


Fig-8.16 : Load vs specific fuel consumption in bar graph

8.3. Load vs Exhaust Temperature

Load(watt)	**Pure diesel(deg C)**	**B10(deg C)**	**B20(deg C)**	**B30(deg C)**	**B40(deg C)**	**B50(deg C)**
500	**173**	**171**	**174**	**186**	**180**	**176**
1000	**200**	**220**	**190**	**200**	**205**	**204**
1500	**218**	**260**	**228**	**214**	**220**	**230**
2000	**272**	**295**	**270**	**222**	**239**	**287**

Table-8.16: Load vs Exhaust Temperature

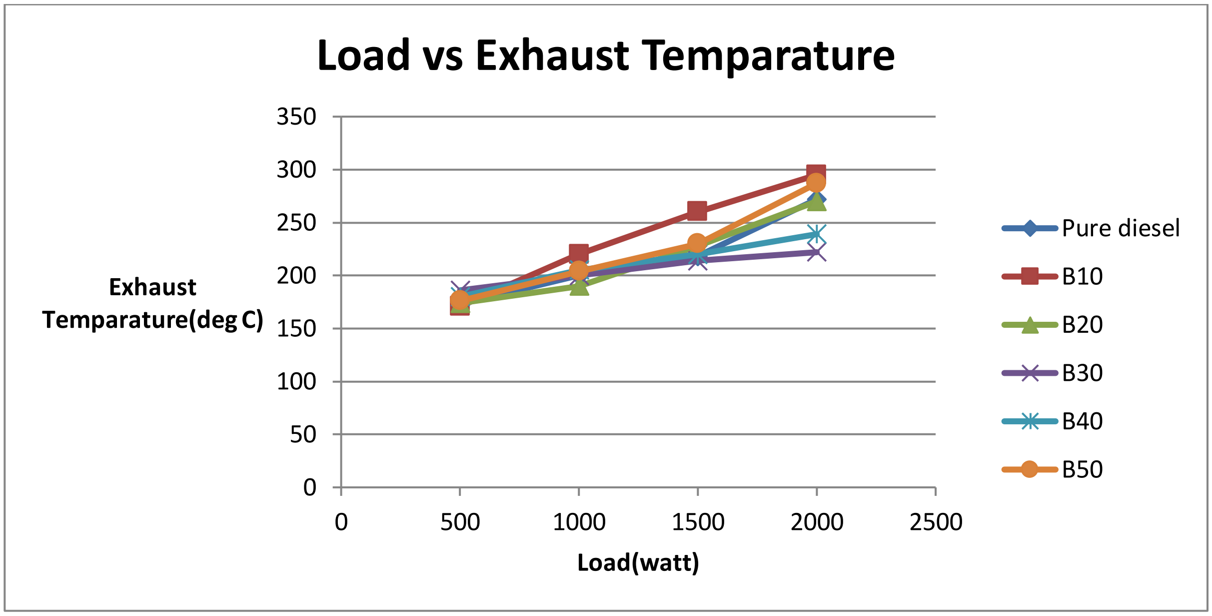


Fig-8.17 : Load vs Exhaust Temperature

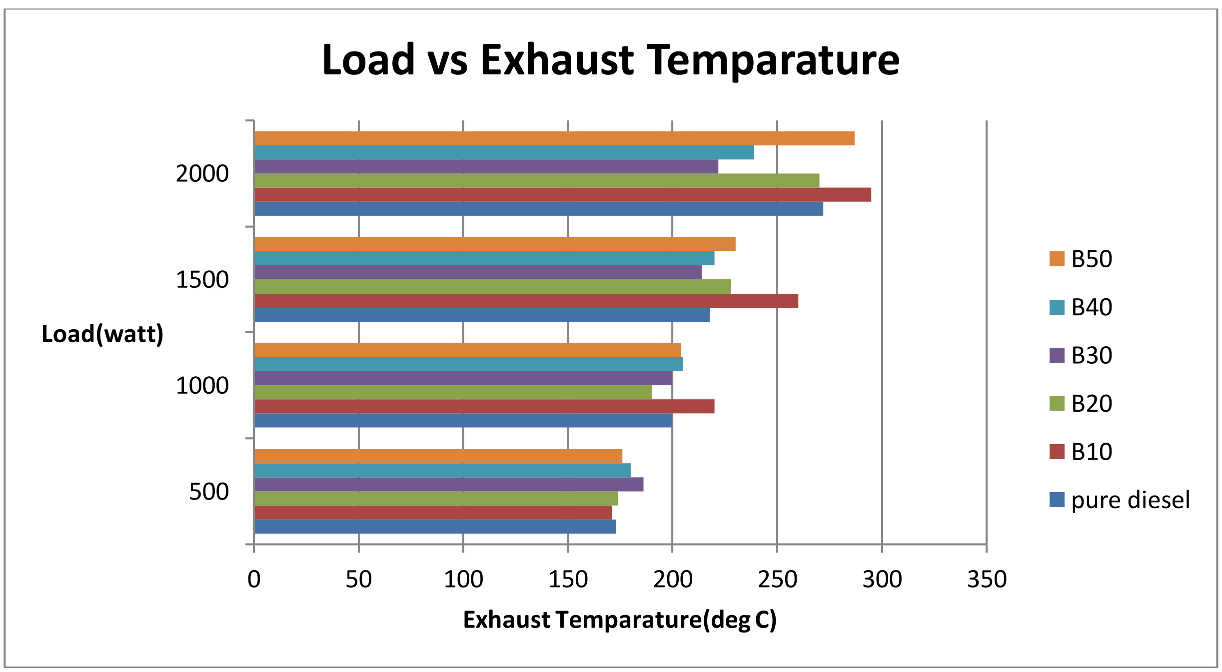


Fig-8.18: Load vs Exhaust Temperature of different load in bar graph

CHAPTER 9

CONCLUSION

This study was conducted in three phases. In the first phase, optimum condition of biodiesel production was obtained.In the second phase biodiesel production in pilot scale. In the 3rd phase, engine performance fueled with waste palm oil biodiesel – diesel blend were investigated. Biodiesels were produced by chemical transesterification in pilot scale and different properties of biodiesel were determined. Performance and combustion characteristics of the engine fueled with biodiesel and diesel were compared. Based on the experimental results, the following conclusions can be drawn.

- The maximum yield obtained was 93% and condition was Methanol : wpo= 9:1, KOH= 0.5wt% of oil , Reaction Temparature= 50 deg C and RPM=600 , Reaction time= 2 hr.
- Properties of the biodiesel from wpo are comparable to that of petroleum diesel.
- Density, viscosity, flash point and calorific value are comparable to petroleum diesel.
- Although they have different fuel values they can be used in the diesel engine by mixing it in various blend ratio. Biodiesels in different blend exhibit different combustion characteristics at different load.
- Fuel consumption and Sfc values of test fuel in the engine under various conditions are presented. 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.
- Sfc of all blends of biodiesel-diesel are higher in comparision to Diesel. Because lower heating value of biodiesel leads to higher amount of fuel consumption to generate the same power.
- The various EGT with respect to engine loading are presented. In general the EGT increased with increase in engine loading for all the fuel tested. This increase in exhaust gas temperature with load is obvious from the simple fact that more amount of fuel was required in the engine to generate that extra power needed to take up the additional loading.

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