BIODIESEL PRODUCTION FROM CRUDE AND WASTE SOYABEAN OIL WITH ITS COMBUSTION ANALYSIS IN A VCR DIESEL ENGINE: A COMPARATIVE STUDY

A Thesis Submitted in Partial Fulfilment of The Requirements for Awarding the Degree Of

Master Of Automobile Engineering
Faculty Of Engineering and Technology

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ABSTRACT

Biodiesel can be prepared from edible and non-edible oils by the process of transesterification process and also used as an alternative fuel for diesel engine with or without modifications. This thesis provides a summary of the research being done to produce biodiesel from crude soybean oil and waste soyabean oil with the transesterification method using KOH as a catalyst and methanol as alcohol. Combustion analysis on a four stroke VCR Diesel engine using both biodiesel blends are compared at zero and full loading condition for compression ratio (CR) 18. Prepared biodiesel can be used as fuel for diesel engine because diesel poses a serious threat to running out, which would have a negative impact on life as we know it. This study also focuses the comparison of biodiesel production parameters and its properties like viscosity, density, flash point, fire point, higher heating value and cetane index and later on combustion analysis in a VCR diesel engine. Density and viscosity of waste soyabean oil biodiesel (WSOBD) is obtained as 0.8872 gm/cc and 2.83 mm^2/s which satisfied the standard value. Density and viscosity of crude soyabean oil biodiesel (CSOBD) obtained is more than (WSOBD) but within the range. Flash point and Fire point of WSOBD is found 159^oC and 185^oC respectively which is better than CSOBD obtained.

Both biodiesel blending of 5,10,15 and 20% is done with the diesel fuel to analyse the combustion characteristics of the engine. The obtained peak pressure of WSOBD15 perform slightly better than peak pressure of CSOBD blend at zero load and peak pressure of WSOBD20 shows slightly better result than CSOBD blend at full load condition. Variation in NHR is slight between the Crude and waste biodiesel. CSOBD15 with 32.05 J/deg and WSOBD15 with 31.80 J/deg exhibit highest NHR_{max} among biodiesel blend at zero and full load condition. Combustion duration has slight variation among biodiesel blends. WSOBD is found better close to use as fuel as compared to CSOBD.

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Chapter 1

INTRODUCTION

1.1 General Description

The consumption of energy resources is increasing day by day. Fossil fuel and other unsustainable minerals have been reduced in amount, which triggered the related research in the area of non-petroleum fuel type products, which should be non-renewable and non-polluting. Nowadays, oil is the primary supply of strength with a call for about **12 million** lots per day and an estimation of sixteen million lots by **2030**. Products made from petroleum are essential to modern living. The prices of these goods are influenced by global markets, and there is only about 30 years' worth of petroleum reserves. Due to the country's requirement to import nearly 70% of its petroleum, India's economy has frequently been unstable due to the highly erratic and variable global oil market demand (India, 2004) **[1]**. The depletion of oil reserves, their excessive prices, and the emission of polluting gases produced via combustion make renewable energy sources more attractive. In a developing country like India, modernization, urbanization, globalization, and population growth are all contributing to worrisome daily increases in energy needs. Road transportation uses 75% of the diesel produced, making it the main source of exhaust emissions. In the future, this percentage might rise, and when fossil fuels run out, a crisis might develop. Alternative fuels are crucial in these conditions for energy security, environmental concerns, and socio-economic reasons **[2]**. Diesel engines are the primary sources of energy generation, marine use, etc. While they've got a tremendously better gas performance than their spurt, the pollutants and noise degree are remarkably better. This is the reason why diesel is extensively used, but a direct want for suitable opportunity fuels to apply CI because of the sluggish depletion of fossil gas resources and the environmental consequences of growing exhaust emissions **[3].** One of the best options to lessen dependence on petroleum derivatives is the improvement of biofuels, which includes biodiesel because of its low sulphur content and the presence of mono-alkyl esters of unsaturated fats derived from vegetable oils or animal fats.

Each year in India, a large amount of waste oils is produced which may be suitable sources for biodiesel production. Biodiesel made out of different vegetable oils (like rapeseed, soybean, sunflower, jatropha, etc) has been utilized in I.C engines with mild reduced performance. They are renewable and biodegradable, and their properties are analogous to those of conventional diesel. It is stated experimentally that they have a comparable power output with barely less thermal efficiency because of their lower energy content in comparison to diesel. In India, it is customary to frequently fry food in used cooking oil for both domestic and commercial purposes. This used cooking oil might cause cancer. Repeated use of used frying oil is a health risk since it releases harmful aldehydes and allylbenzene (1,2) that have been connected to major diseases like cancer, dementia, and heart issues. Due to India's large population, the disposal of used cooking oil could cause serious ecological problems. Also, it is bad for farm animal feed. Hence, an exceptionally feasible manner to apply waste cooking oil is that it has to be transformed into biodiesel with the aid of using the method of trans-esterification. Considering waste cooking oil as low-cost feedstock, biodiesel can be a good source than diesel fuel. This opens an opportunity for the use of waste cooking oil (WCO) as a production feedstock **[4-5]**.

Biodiesel comes up as an essential opportunity that may be used as renewable possible fuel and as an additive to mineral fuels. A lot of studies have been done using vegetable oil each in its crude form and modified form. Studies have proven that using vegetable oils in crude form is viable however now no longer preferable because of the excessive viscosity of vegetable oils and the low volatility that impact the atomization, leading to incomplete combustion and severe carbon deposits, injector choking, and piston ring sticking **[6-7].** Methods inclusive of mixing with diesel, emulsification, pyrolysis, and transesterification are used to lessen the viscosity of vegetable oils. Adding additives to biodiesel blends improves combustion by inhibiting oxidation and thermal degradation, further increasing fuel economy and lowering polluting gas emissions.

1.2 Biodiesel as Engine Fuel:

Because biodiesel is made from sustainable raw resources, it is a more environmentally friendly substitute for fossil fuels. Vegetables were used as fuel in 1895 when Dr. Rudolf Diesel built the first engine and ran it on peanut oil. Scientists discovered in 1970 that the possibility that vegetable oils would function in a diesel engine could cause a basic chemical reaction that would lessen their viscosity. The use of biodiesel reduces a nation's reliance on imported fuels. With the advancement of technology, a significant amount of research has been conducted on the topic of using biodiesel in compression ignition engines in unique mixtures with petroleum diesel. Raw vegetable oil cannot be utilized in an unmodified diesel engine because of its high viscosity, flash point, density, and poor heating value**. Kawaguchi et al. (2004)** created a combustion burner for highly viscous waste oil for optimum oil atomization and emission control **[8].** Worldwide biodiesel production is shown in **Fig. 1.1**. It shows leading biodiesel producers. Though India is a tropical country but production of biodiesel is far behind many countries.

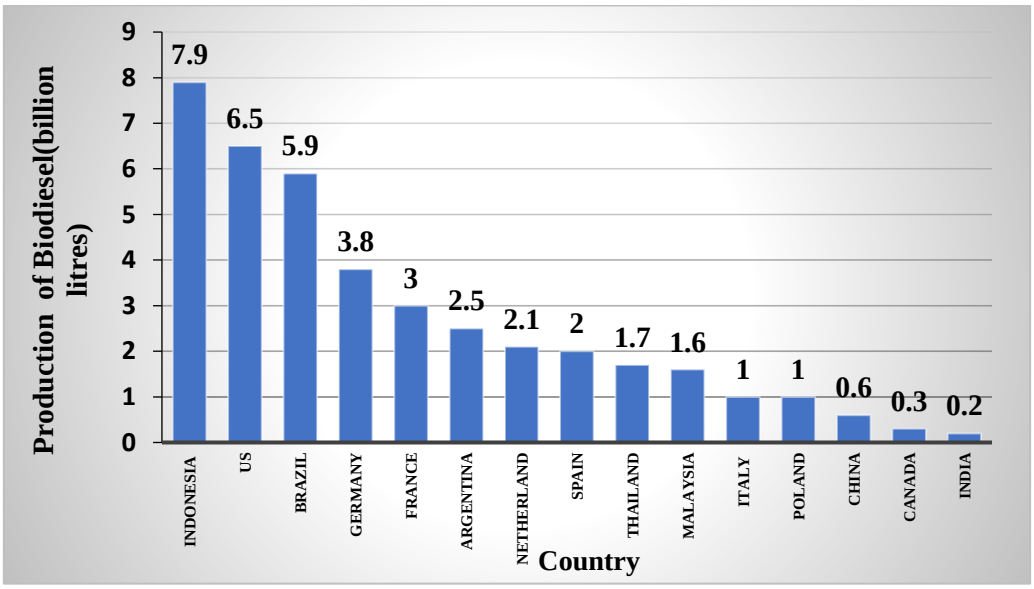

Fig 1.1: Worldwide production of biodiesel in 2019[1]

[1]source**:** Leading biodiesel producers worldwide in 2019, by country (http://www.statitca.com/)

Combining biodiesel with diesel at a certain ratio may increase engine mechanical efficiency and lower sulphate emissions. Operation safety is increased by biodiesel having a high flash point **[9-10]**. Many automakers have embraced the concept of using

biodiesel as a fuel for their diesel vehicles because it is compatible with them. As long as the esterified product maintains acceptable fuel properties, the neem and waste cooking oil biodiesel from inedible sources can be used commercially as a diesel fuel substitute, according to the American Society for Testing and Materials (ASTM), European Committee for Standardization (EN), and Bureau of Indian Standards (BIS) **[11].**

In India according to railway officials, the railways ran the Bandra-Bhuj train on bio-diesel engines from Ahmedabad to Bhuj. From 1.1 crore litres in 2015–16 to 10.56 crore litres in 2019–20, OMCs boosted their biodiesel purchases. There is a vast potential for the production of biodiesel from Jatropha in India. In the West, biodiesel is produced mostly from field crops like rapeseed and sunflower in Europe and soybean in the US. While Malaysia utilizes palm oil while Nicaragua uses Jatropha for biodiesel production. In 2018, the United States and Brazil dominated the biofuels market, accounting for nearly 87 percent of global production. In the last ten years, biodiesel intake grew by 4 % annually; in 2019 an increase of 1% is predicted. The amount of biodiesel procured for mixing with traditional diesel for on-street use could be marginally above last year's level and persisted in accounting for much less than the expected marketplace for biodiesel. Buyers of such blended diesel are confined to a few shops of oil advertising companies, the Indian railways, State Road Transport Corporation of various states, fleet proprietors of street shipping companies, and port authorities.

Some reasons for using biodiesel as an alternative fuel-

- Biodiesel can be used in existing engines without any modifications.
- Biodiesel is made completely from vegetable sources; it does now no longer comprise any sulphur, aromatic hydrocarbons, metals or crude oil residues.
- The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel.
- Biodiesel is produced from renewable vegetable oils/animal fat and consequently improves fuel or energy safety and economic system independence.
- Biodiesel is an oxygenated fuel hence emission of CO and soot is low in comparison to conventional diesel fuel.

However, some drawbacks are also observed with biodiesel, like cold flow properties and inferior storage stability, as well as unsatisfactory spray characteristics with low

heating value **[12]**. However, these drawbacks can be improved with suitable improvisation and biodiesel feedstock.

1.3 Biodiesel Feedstock

The raw material used for biodiesel production is known as a feedstock. Biodiesel is one of the maxima that examines opportunity fuels within the marketplace today. Palm, jatropha, soybean, sunflower, rapeseed, safflower, and peanut oils are taken into consideration as long-lasting. Feedstocks for industrial manufacturing shown in **Table 1.1**.

Some common feedstocks are-

⇒ **Animal fats:** This includes chicken fat, lard, tallow, and the by-product of the production of Omega-3 fatty acids from fish oil.

⇒ **Vegetable oils:** Different edible and non-edible oils are utilized as feedstocks for biodiesel production by different countries and also depend on availability.

⇒ **Waste or recycled oil:** It may be obtained from mastered oil, sunflower oil, and soybean oil, which is fried or used for cooking.

⇒ **Other feedstock:** algae**,** halophytes such as Salicornia bigelovii, sewage sludge, low ricin, etc.

Table 1.1: Biodiesel feedstock

Edible oil	Nonedible oil	Animal fats	Other sources
Palm	Neem	Fish oil	Algae
Soybeans	Mahua	Poultry fat	bacteria
Rice bran oil	Jatropha (Jatropha curcas)	mutton tallow from sheep	fungi
Rapeseed	Pongamia	chicken fat	
Safflower	Castor		

Feedstock composition of global biodiesel is shown in **Fig. 1.2**. It shows that palm, soyabean and rapeseed oils are mostly used feedstocks. Availability of feedstock for some countries are tabulated in **Table 1.2**.

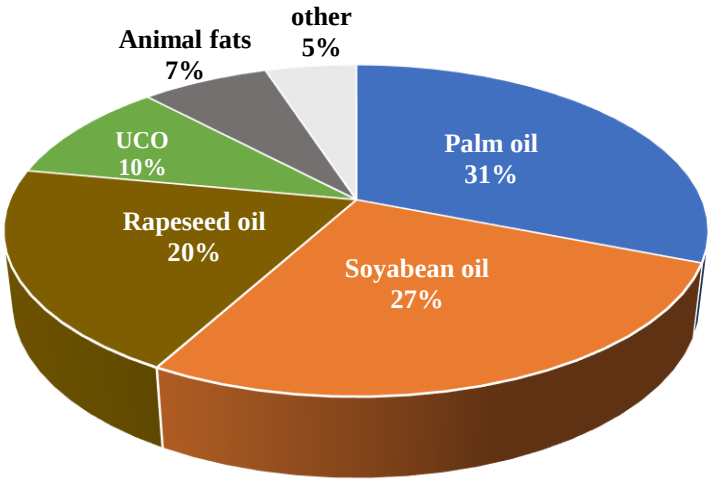

Fig 1.2: Feedstock composition of global biodiesel in 2017[2]

[2]Source: oil world

Table 1.2: Potential Sources of biodiesel for different countries

COUNTRY	FEEDSTOCK
AUSTRALIA	Tallow, used cooking oil
NEW ZEALAND	Used cooking oil, tallow
KOREA	Soybean oil, used cooking oil, palm oil
PHILIPPINES	Coconut oil, jatropha oil
SINGAPORE	Palm oil
US	Soybean oil, sunflower oil, tallow and yellow grease
THAILAND	Palm oil, used cooking oil, jatropha oil
MALAYSIA	Palm oil
INDONESIA	Palm oil, jatropha oil
INDIA	Jatropha oil, rapeseed oil
JAPAN	Used cooking oil
CANADA	Yellow grease and tallow, canola, mustard, flax, soybean oil
CHINA	Rapeseed oil, used cooking oil, jatropha oil

1.4 Waste Cooking oil as a Feedstock

There is a significant amount of waste cooking oil available in hotels, restaurants, and other establishments around the world. After cooking, this waste oil is useless. Therefore, in some places it is dumped into the ground, polluting both the environment and the soil; in other places, it is put into the water, which is extremely hazardous to the area **[13]**. The Energy Information Administration in the US estimated that over 100 million gallons of used cooking oil are created every day, with the average amount of used cooking oil per person being recommended to be nine pounds. About 135,000 tonnes of used cooking oil are produced in Canada each year. 700,000–1,000,000 tonnes of used cooking oil are produced annually in EU member states. Over 200,000 tonnes of used cooking oil are generated annually in the UK **[14]**. Non-edible oils derived from plant species such as Jatropha curcas, Pongamia pinnata (Karanj), Calophyllum inophyllum (Nagchampa), Hevca brasiliensis (Rubber), etc. are the primary raw material sources for biodiesel in India **[15]**.

In India, the Ministry of Health and Family Welfare's Food Safety and Standards Authority of India (FSSAI) has recommended an EEE Strategy - Education Enforcement Ecosystem to remove UCO from the food value chain and help stop the country's ongoing illegal practices of reusing UCO in cooking. An organization called Repurposed Used Cooking Oil (RUCO) will make it possible to collect UCO and turn it into biodiesel. According to the FSSAI administration, the nation may manufacture up to 26 billion litres of UCO.

Because it aids in the management of waste and the reduction of environmental damage, biodiesel made from used cooking oil is a viable alternative for engines. Since the majority of the carbon in fuel obtained from biomass is biogenic and renewable, using used cooking oil as biodiesel aids in the reduction of CO2, particulate matter, and other greenhouse gases. WCO is an inexpensive feedstock since just collection and transportation are required. Suppliers occasionally offer the WCO for no charge. The cost of the feedstock and the use of used cooking oil in the manufacturing of biodiesel increases the viability of biodiesel supply and production from an economic standpoint. Therefore, one of the most cost-effective options for the manufacturing of biodiesel is the readily available waste cooking oil that would otherwise be wasted. Used cooking oil as feedstock for biodiesel production in India from 2011 -2020 is represented in **Fig. 1.3**.

It shows that production of biodiesel is not significant as compared to available waste cooking oils generated in India.

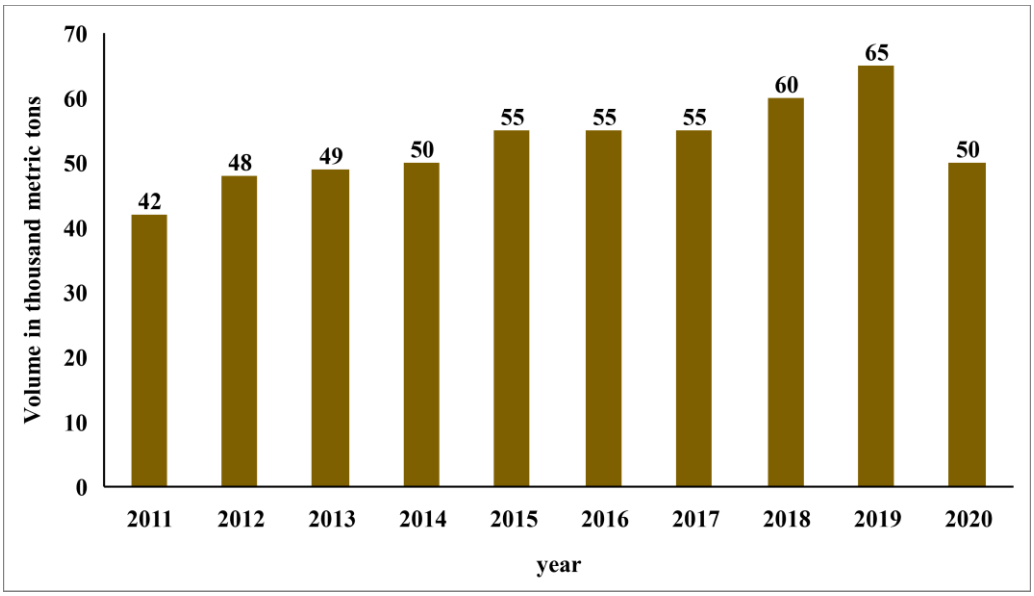

Fig 1.3: Biodiesel production from used cooking oil in India (2011 -2020)[3]

[3]Source: Used cooking oil as feedstock for biodiesel production in India from 2011 - 2020

1.5 Availability of Biodiesel in India

India now has the capacity to meet about 25% of the net demand for fossil fuels. However, in order to close the gap, resources must be imported, which uses up a significant amount of the nation's foreign currency. Therefore, by advancing practical technology, renewable energy may be used to address the current ecological and energy challenges.

Indian farmers reportedly looked for a few oleic seed-bearing trees in the forest that had developed on parched terrain, according to **Biswas and Pohit (2013) [16].** Of those, Jatropha and, to a lesser extent, Pongamia, were picked to produce biodiesel. The main objective of this mission was to blend 20 percent biofuel by 2012. About 400 edible crops that produce oil have been found in India.

Jatropha oil is the typical source of biodiesel in India. However, other feedstock oils need to be thoroughly studied. India is said to have combined reality, curiosity, and the strong amount of aspiration that exists within them when it comes to the biofuel

program. It is a narrative because the generation of ethanol or biodiesel does not depend on extending or diversifying traditional agriculture. The USA, Brazil, and Germany, on the other hand, use a variety of food grains, including rapeseed, sugarcane, soybeans, etc. **[17].** The growing interest in biofuels in India is encouraging several institutions, like the Indian Institute of Science, Tamil Nadu Agriculture University Coimbatore, and Kumara Guru College of Technology, to produce trans-esterified non-edible oil and use it in biodiesel. Indian Oil Corporation has started doing research and development to figure out the specifications for making biodiesel in Faridabad from vegetable oil from the jatropha plant. India is currently home to 26 biodiesel plants, showing that the country is also increasing its production of biofuels.

Figure 1.4 below shows that India's biodiesel production is rising year after year. As a result, India could start using biodiesel as fuel in a wide range in the upcoming year.

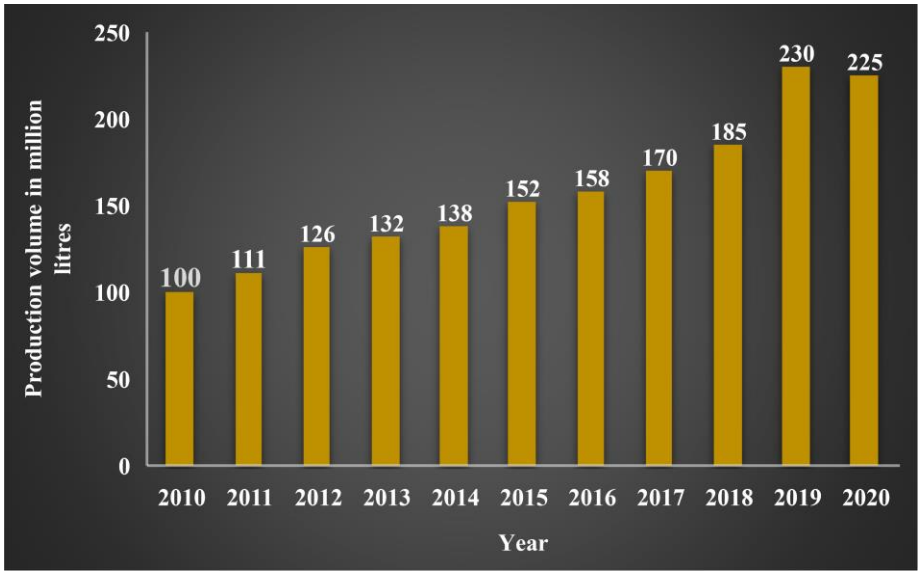

Fig 1.4: Biodiesel production in India from 2010-2020
[4]source**:** production volume of biodiesel in India from 2010 to 2020(http://www.statitca.com/)

An excellent source of biodiesel is used cooking oil. Numerous studies have been conducted on WCO biodiesel production and application in the transportation industry. It turned out to be a shrewd preference to extend the choice of plant and waste cooking oil as a feedstock. Despite the fact that the country hasn't produced any particularly noteworthy work in the creation of biodiesel over the past 20 years of research, it has

produced several significant outputs that could influence how things develop in the future.

1.6 Benefits of Biodiesel

- **Related to Engines**

  - One of the main advantages of using biodiesel is that it can be used in current diesel engines with few or no modifications and might eventually replace fossil fuels as the preferred source of energy.
  - Having high cetane no which refers to a shorter delay between injection and actual burning of fuel ultimately provides better and smoother engine operation in comparison to diesel.
  - With a higher flash point than diesel it ensures less volatility, which is safe to handle, store and transport.
  - The engine operation of a vehicle is improved with biodiesel. The engine runs more smoothly and effectively as a result of the increased fuel lubricity.
  - When utilizing biodiesel, engine wear is measured to be lower than when using petroleum diesel.

- **Social and Environmental**

  - Unlike other petroleum products, which will run out in the future, biodiesel is a renewable source of energy. It can be manufactured on demand and emits less pollution than petroleum diesel because it is made from animal and vegetable fat.
  - When fossil fuels are used, they emit greenhouse gases such as carbon dioxide into the atmosphere, raising the temperature and contributing to global warming. The use of biodiesel instead of petroleum fuel can reduce greenhouse gas emissions by up to 78%. Because it no longer contains sulphur, the exhaust emission of sulphur oxides and sulphates is eliminated after combustion.

- Because fossil fuels are limited, we may not be able to meet our demand for coal, oil, and natural gas beyond a certain period of time. Our dependence on foreign oil supplies can be reduced by using biodiesel as an alternative fuel.
- When biofuels are burned, they emit far less carbon dioxide and fewer pollutants. Biodiesel emits far less soot (particulate matter), carbon monoxide, unburned hydrocarbons, and sulphur dioxide than petroleum diesel.
- According to National Laboratory data, switching from petroleum to biodiesel reduces carbon dioxide emissions by a whopping 74%.

1.7 Issues and Challenges

- With higher viscosity, it causes problems in atomization due to which complete combustion does not occur and ultimately affects the performance of the engine.
- A little increase in NOx emissions. One of the gases involved in the creation of smog and ozone is nitrogen oxide. It can generate acid rain when it dissolves in the environment.
- Calorific value of biodiesel is less in comparison to diesel fuel, as an end result specific fuel consumption is more.
- Having low stability than diesel, it is not suitable to store for the longer term.
- Some areas are not appropriate for crops that produce oil. The cost and volume of emissions involved with producing and transporting the most productive crops rise because they cannot be grown elsewhere and must be carried to the plants.
- Low quality biodiesel fuel clogs the fuel filter.
- Due to its long-chain, saturated fatty acid composition, biodiesel is prone to the issue of poor low-temperature operability. In terms of cold flow characteristics, biodiesel's cloud point (CP), pour point (PP), and cold filter plugging point (CFPP) are less desired than those of petroleum diesel. It cannot be used because it solidifies at low temperatures. Therefore, before starting the engine, it must be re-heated. Biodiesel loses some flowability as a result of its high pour point.

1.8 Problem Statement

The amount of energy being consumed is rising daily. Since there are now fewer fossil fuels and other unsustainable resources, research is needed on non-petroleum fuel items that should be non-renewable and non-polluting. Road transportation consumes a vast amount of diesel fuel, making it the primary contributor to exhaust emissions.

A suitable renewable alternative to petroleum-based fuel is biodiesel. Although the biodiesel industry has seen some success, there are still significant challenges to overcome because the cost of producing biodiesel is still quite high compared to petroleum-based diesel fuel; the cost of raw materials and the cost of processing are the two main factors affecting the price of biodiesel **[18].** Exhaust emission of diesel is a major concern. So, Biodiesel could be the answer to the pollution issue we are now facing. Compared to petroleum-based diesel, biodiesel has different fuel characteristics. Blending biodiesel with various amounts of diesel evolve various fuel characteristics. Biodiesel has also some issues regarding utilization like viscosity, NOx emission, low temperature operability. So, before utilisation in a diesel engine, its qualities or properties have to be established. Many researchers found that by preventing oxidation and thermal deterioration, adding additives to biodiesel blends enhances combustion. This results in higher fuel efficiency and reduced harmful gas emissions. So, by considering all these problems there is need for biodiesel as alternative fuel to cope with the future issues. In this work, a comparative evaluation of crude and waste soyabean oil biodiesel production and its effect on combustion in a diesel engine will be studied. Biodiesel will be prepared from raw soyabean oil. Waste cooking oil generated from same soyabean oil will be utilized for biodiesel production. Testing of both biodiesels will be done whether there are any change its characteristics after cooking. Both biodiesels will be used to run VCR engine to check it combustion characteristics.

1.9 Objective of the Present Study

- To study biodiesel as alternative fuel for diesel engine and waste cooking oil is one of the abundant feedstocks for biodiesel production.
- To prepare biodiesel in the laboratory from waste soyabean oil (WSO) and crude soyabean oil (CSO).
- To determine optimal parameters of catalyst concentration and molar ratio of methanol and oil, reaction time and temperature for high yield production of biodiesel.
- To determine various properties of optimised WSO and CSO biodiesel for comparison.
- To carry out experimental analysis using waste and crude soyabean oil biodiesel blends in a VCR diesel engine for combustion characteristics.

1.10 Organization of the thesis

This dissertation is comprised of seven chapters. The organization of the chapters is listed below:

Chapter 1:	General introduction of the thesis, biodiesel as a fuel, feedstocks available for biodiesel, availability of biodiesel in India, waste cooking oil as a feedstock, advantages and issues related to biodiesel, problem statement, objectives of the present work
Chapter 2:	Literature review of the proposed work, scope of the present study
Chapter 3:	Methodology of the biodiesel production from crude and waste soyabean oil and optimization of yielding of biodiesel by experimentation with different parameters
Chapter 4:	Testing and comparison of crude and waste soyabean oil Biodiesel properties
Chapter 5:	Experimental setup of the VCR diesel engine and combustion analysis
Chapter 6:	Comparison and discussion of combustion characteristics from the results obtained for both biodiesel
Chapter 7:	General conclusion of the thesis and scope of future work

Chapter 2

LITERATURE REVIEW

2.1 Literature survey

In terms of biodiesel production and use, several studies and analyses have been conducted in recent years on biodiesel production and its use in diesel engines. Various articles present various sorts of study in the realm of biodiesel derived from vegetable oils, waste cooking oil, and animal fats. Several studies on biodiesel production from waste cooking oil and crude oil have been published. The quality of biodiesel is determined by the feedstock's quality and the fatty acid composition of vegetable oils/animal fats. Utilization of biodiesel as a fuel has some issues and challenges. Some of the researcher's work is discussed here-

Abed *et al.* (2018) [19] studied the effect of waste cooking oil biodiesel on a diesel engine. Blends of waste cooking-oil biodiesel and diesel oil were prepared in volume percentages of 10, 20, and 30% as B10, B20, and B30. Then, experimental results were observed on diesel engines at different engine loads, from zero to full load. It was observed that biodiesel blend efficiency was lower and specific fuel consumption was higher than diesel fuel. CO2 emissions for biodiesel blends were higher than for diesel oil. CO, smoke opacity, and HC emissions for biodiesel blends were lower than for diesel fuel. But NOx emissions were higher for biodiesel blends in comparison to diesel fuel.

Vijay Kumar *et al.* (2018) [20] did comparative analysis to determine the effects of biodiesel fuel additives and initiatives to improve combustion and performance and reduce emissions. The quality of the biodiesel is improved by the use of metal-based additions, cetane number additives, antioxidant additives, and oxygenated additives. Their study concluded that the best methods for enhancing combustion efficiency and reducing emissions were additives added to second-generation biodiesel.

Saiful Islam *et al.* (2014) [21] in their paper investigated the emission and performance of diesel engines with the help of crude castor biodiesel and its blend with diesel from

0% to 40% by volume. The least smoke emission for B40 was observed compared to diesel. Increment in the specific consumption was observed for B10, B20, B30, and B40 relative to B0 is 3.59%, 3.96%, 4.68%, and 6.23%, respectively. NOx emission increased but CO, PM, and HC decreased with increasing biodiesel blending. They found B20 as a suitable alternative fuel.

Abu-Hamdeh *et al.* (2015) [22] studied the effects of almond biodiesel blending at 10, 30, and 50% (B10.B30, B50) on diesel engine under various load conditions. Their studies have shown a slight increase in exhaust gas temperature, specific fuel consumption, and a slight increase in brake thermal efficiency. It was found that increasing blending ratios of almond biodiesel decreased the particulate matter, unburned fuel emissions, and CO content in the exhaust gas. The higher blending of biodiesel delivered higher NOx emissions. B10 showed the minimum specific fuel consumption and the maximum brake thermal efficiency.

Kumar *et al.* (2020) [23] studied the effects of using different blends of solketal in soybean biodiesel with 9%, 10%, 12%, and 15% of solketal on the performance parameters, emission, and brake specific fuel consumption (BSFC) of a four-stroke CI engine. By experimenting on a single-cylinder water-cooled diesel engine at different speeds and 50% load conditions, it was observed that soybean biodiesel and its blends with solketal resulted in higher BSFC. Oxides of nitrogen (NOx) and carbon dioxide (CO2) emissions were slightly higher in biodiesel blending, but THC and CO were found to be lower with engine speed and percentage of solketal.

Rao *et al.* (2016) [24] analysed diesel engines by testing to replace convectional fuels with the additive Diethyl Ether (DEE) and Mahua biodiesel. Emissions were significantly reduced by biodiesel use, except for NOx. DEE was blended with Mahua methyl ester (MME) at various ratios, including 3%, 5%, and 10%, and tested under various loads on a diesel engine with MME at full load and a 15% DEE blend. Emissions were significantly reduced. In the case of a 15 percent additive blend, the thermal efficiency increased and the SFC improved.

Suresh *et al.* (2018) [25] prepared biodiesel from various oil feedstock such as waste fried oil, pyrolysis oil, preheated palm oil, waste cooking oil, jatropha oil, karanja oil etc. and measured the combustion, performance, and emission characteristics of a diesel

engine with a variable compression ratio (VCR) by blending with diesel. Better efficiency was observed and reduction of 30 % in fuel consumption is observed.

Tirkey *et al.* (2015) [26] studied using waste cooking oil (WCO) to make biodiesel, mixed with diesel fuel (B10, B20, B30, B40, and B50). To assess the performance and emission characteristics, these blends were tested in a single-cylinder, 4-stroke, water-cooled CI engine at various loads with a constant engine speed of 1500 rpm. During testing, it was discovered that an increase in load causes a drop in the specific fuel consumption and an increase in the thermal efficiency of the brakes. While the CO emissions for B10 and B20 reduced as blending increased, the NOx emissions showed increment as load increased. CO follows a similar pattern to diesel but CO2 emissions increased under partial and moderate loading conditions.

Ozener *et al.* (2014) [27] used biodiesel made from soybean oil and its blends (B10, B20, and B50) and compared it to conventional diesel fuel in terms of combustion, performance, and emission characteristics. The tests were conducted in a single-cylinder direct injection diesel engine in steady-state circumstances over the whole rpm range (1200-3000rpm). Biodiesel produced a 1-4% lower torque and a 2-9% higher brake-specific fuel consumption (BSFC) when compared to diesel. However, nitric oxides (NOx) (6.95-17.62%) and carbon dioxide (CO2) emissions increased while biodiesel dramatically decreased carbon monoxide (CO) (28-46%) and unburned total hydrocarbons (THCs).

Muralidharan *et al.* (2011) [28] investigated and compared the performance, emission, and combustion characteristics of a single-cylinder, four-stroke variable compression ratio multi-fuel engine with those of standard diesel using waste cooking oil methyl ester and its 20%, 40%, 60%, and 80% blends as fuel with diesel. At a fixed engine speed of 1500 rpm, 50% load, and compression ratios of 18:1, 19:1, 20:1, 21:1, and 22:1, the experiment was run. When compared to diesel, the results showed that waste cooking oil methyl ester burnt with a higher mass fraction at higher compression ratios and with longer ignition delays, maximum rates of pressure rise, and heat release rates. The blend B40 was found to produce the maximum thermal efficiency when comparing waste cooking oil methyl ester blends and diesel brake thermal efficiency at 50% load.

Chaurasiya *et al.* (2019) [29] analysed raw oil (jatropha, soybean, and waste cooking fuel) to prove its suitability as an alternative fuel in compression ignition (CI) engines Performance and emission test were conducted for each fuel blend. The investigation was done for pure diesel and various blends (between 20 and 50%) of waste cooking oil-diesel, Jatropha-diesel, and soybean-diesel at a compression ratio (CR) of 16.5. The result showed that B20 blends of all biodiesel have shown very close values of brake thermal efficiency (BTE) at all load.

Shah *et al.* (2017) [30] worked on biodiesel derived from waste oil of the refined soybean oil. On a volume basis, various blends were created, and in one of the combinations, a separate mix was created employing anti-gel ingredients at a 2% concentration. Tests were carried out using diesel and blends for single-cylinder, four-stroke, multi-fuel, and water engines a cooled engine operating at a 17.5:1 compression ratio under various loading circumstances. Combustion parameters like HC and CO were reduced and an increase in NOx, CO, and CO2 was shown when similar mixtures of biodiesel were used. Additionally, the same engine was run with 2% anti-gel additives added to one of the blends BD20, which gave a notable decrease in BSFC, exhaust gas temperature, NOx percentage, and integrated heat release rate.

Baweja *et al.* (2021) [31] discussed mustard oil biodiesel's effect on the performance, emission, and combustion characteristics of a diesel engine. By mixing diesel fuel with 10%, 20%, 30%, and 40% of mustard oil biodiesel, four test fuels—designated B10, B20, B30, and B40 were used for engine testing. Under various load circumstances, the various combustion properties of the above-mentioned blends were assessed and compared with those of diesel fuel. At higher load, diesel fuel and all mixes showed nearly the same value of cylinder peak pressure. When the load was at 75% and 100%, the blend B10 resulted in the cumulative heat release rate being the lowest of all the blends and diesel fuel. B10 blend showed better brake thermal efficiency among all blends of diesel fuel up to about 80% load. The B20 blend showed better results by reducing NO emissions under loading circumstances of 0%, 25%, 50%, and 75%.

Qi *et al.* (2009) [32] did the comparative performance, combustion, and emission analysis of a diesel engine by using biodiesel produced from soybean crude oil with respect to diesel. The result showed that peak cylinder pressure, peak rate of pressure

rise, and peak rate of heat release during the premixed combustion phase were higher for biodiesel than for diesel at lower engine loads. The peak cylinder pressure of biodiesel was almost identical to that of diesel at greater engine loads, but for biodiesel, the peak rate of pressure rises and the peak rate of heat release was lower. The brake specific fuel consumption was higher. Biodiesel significantly reduced CO, HC, NOx, and smoke when used at full engine load and speed.

Sakthivel *et al.* (2014) [33] prepared biodiesel from fish oil and investigated various properties such as density, flash point, cetane value, calorific value and viscosity of biodiesel and biodiesel–diesel blends of different proportions. Then, using biodiesel blends, experiments were conducted to assess the performance, emissions, and combustion characteristics of a single cylinder, constant speed, direct injection diesel engine under varying load situations. With the increase in the proportion of biodiesel in the fuel, it was discovered that there was a decrease in NOx, HC, and CO emissions as well as a slight increase in CO2 and smoke emissions. For the entire load, it was discovered that the brake thermal efficiency was higher than diesel. When compared to diesel, biodiesel blends had shorter ignition delays, higher maximum heat release rates, and shorter combustion times.

Geng *et al.* (2018) [34] tested the biodiesel blended with 10% and 20% n-butanol to evaluate the combustion and emission characteristics in a turbocharged, 6-cylinder, common rail diesel engine at a constant speed of 1400 rpm under seven loads. Due to higher oxygen content and lower cetane no of butanol biodiesel blends, the blends showed faster combustion than diesel. They found that addition of butanol is effective in concentrating heat release and minimizing combustion time. Increased butanol content reduces the soot emissions of butanol and biodiesel fuel blends, as well as the number concentration and volume concentration of ultrafine particles (UFPs).

Abu-Jrai *et al.* (2011) [35] prepared biodiesel from waste cooking oil and tested it by preparing biodiesel-diesel blend (50/50 by vol) in a four-cylinder Tempest Engine coupled with dynamometer. The blend resulted in a considerable reduction in unburnt hydrocarbon and smoke opacity along with an increase in CO2 and NOx emissions. Compared to diesel, the results showed a decrease in engine thermal efficiency and an increase in brake-specific fuel consumption.

Rao *et al.* (2008) [36] studied the combustion, performance and emission characteristics of direct injection C.I. engine by using Used Cooking oil Methyl Ester (UCME) and its blends with diesel oil. When compared to diesel, there was a slight drop in thermal efficiency but a large improvement in the reduction of particles, carbon monoxide, and unburned hydrocarbons. They suggested that Used cooking oil that has been trans esterified and its blends will significantly lessen environmental pollution and reduce dependence on fossil fuels.

Yu *et al.* (2002) [37] carried out combustion and performance tests from WCO and diesel as fuel The premixed combustion phase of WCO was found to be less intense than that of diesel due to the shorter ignition delay. But because the combustion volume was less, the peak pressures were generally 1.5 bar higher and occurred 1.1°–3.8° earlier than for diesel. The level of WCO emissions was higher than diesel for CO, NO, and SO2 emissions.

Aransiola *et al.* (2012) [38] used crude neem oil as a feedstock for biodiesel production by two step acid base transesterification process considering NaOH as a catalyst Neem biodiesel has higher NO_x than petrol diesel, but lower CO and NO emissions of different blends. The result obtained in their research would be applicable to expansion of neem oil-based biodiesel production, especially in nations where this feedstock is widely available.

Shah *et al.* (2016) [39] compared the effect of edible and non-edible crude vegetable oil on the DI diesel engine characteristics at constant speed by varying brake load. Sunflower oil (SF) as edible oil and Karanj oil (KO) as non-edible oil was selected for test. The experimentally determined results showed that both edible oil (SF) and non-edible oil (KO) had longer ignition delays, which ultimately affect to increase cylinder pressure, HRR, higher NOx emissions and it showed lower BSEC and smoke opacity as compared to diesel fuel. While maintaining a slight difference in thermal efficiency from SF, the KO oil showed decreased NOx and CO emissions. The test results revealed that while both additions increased NOx and CO emissions with SF, they decreased ignition delay, HRR, and NOx production with KO.

2.2 Scope of the Present Study

This thesis will help us to find out how biodiesel can be an alternative fuel for diesel. This study is needed because petroleum derivatives is eventually running out that demonstrate the necessity and importance of using environmentally friendly and sustainable power resources.

There are numerous feedstocks that can be used to produce biodiesel. Palm oil is for biodiesel in Asian countries favoured and rapeseed oil is generally used for biodiesel production in Europe. Developing countries like India, are attempting for jatropha plant. Waste cooking oil is easily available so it can be a great approach for biodiesel production which helps in reduction of fuel cost also. Also waste cooking oil biodiesel can be compared with crude cooking oil biodiesel for better understanding of fuel selection. So, this study involves the production of crude and waste soyabean oil biodiesel and later on combustion characteristics analysis in a VCR diesel engine. Various research papers have been published related to this topic on combustion, performance and emission characteristics of diesel engine using crude and waste cooking oil. Biodiesel will be prepared by optimizing the yield and various properties of both biodiesels will be tested and compared for the suitable use as alternative fuel in diesel engine. Comparison of various combustion parameters like peak pressure, combustion duration, Net heat release, mean gas temperature for both biodiesel blends with diesel could be useful for approval of biodiesel as a fuel for diesel engine. This is necessary to be done so that conclusion would be drawn between crude and waste soyabean oil for the better utilisation as fuel in engine.

Chapter 3

CRUDE AND WASTE SOYABEAN OIL BIODIESEL PRODUCTION

3.1. Introduction

General Methods of preparation of biodiesel are Electrolysis method, Pilot scale reactor method, Bubble column reactor method, Microwave Technique and Lab scale batch reactor method. In this present study Biodiesel is prepared from waste soyabean oil (WSO) and crude soyabean oil (CSO) by the Lab scale batch reactor method by taking methanol as fuel additives and KOH as a catalyst. Fig 3.1: Schematic diagram of biodiesel production is shown in **Fig. 3.1.** Waste soyabean oil and crude soyabean oil is taken of the same refined soyabean oil for comparative analysis of production of biodiesel and its effect in diesel engine. Optimisation of biodiesel has been done by experimentation for the best result. In this chapter, a comparative evaluation of production of biodiesel from crude and waste soyabean oil will be presented with its different process parameters.

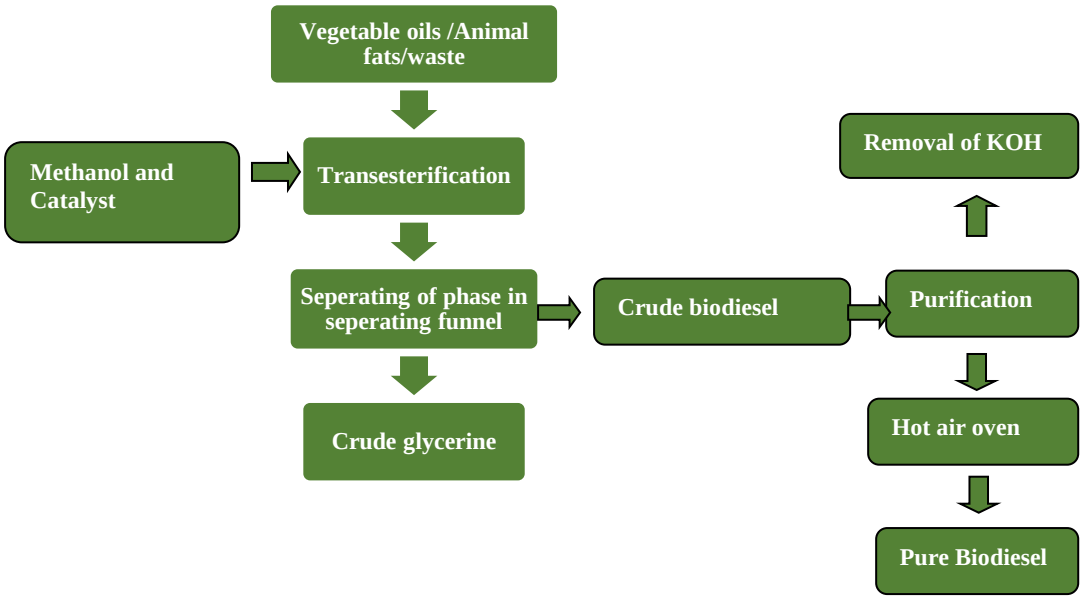

Fig 3.1: Schematic diagram of biodiesel production

3.2. Materials and apparatus

- **Apparatus**

  Filter paper, Filter Funnel, Beaker, weighing machine, Hot plate Magnetic stirrer, Magnetic needle, Digital temperature controller, Helical condenser, Rubber tube for water supply, circulating pump, water bath, Separator with Separating stand, Aquarium pump, P^H measuring indicator, Drier.

- **Materials**

  Waste soyabean oil (WSO), Crude soyabean oil (CSO), Catalyst (KOH), Methanol, Distilled water

3.3 Methodology for production of biodiesel from WSO and CSO

Waste soyabean oil (WSO) is collected from a chips restaurant which is used to fry potato chips and Crude soyabean oil (CSO) is purchased from grocery shop.

3.3.1 Pre-Treatment of raw material (WSO and CSO) for the production of biodiesel

At the beginning collected WSO/CSO undergoes filtration process by using filter paper. That filtered WSO/CSO is kept on a hot plate up to 65ºC for 3-4 min to remove some impurities and moisture. Some properties of WSO/CSO like density, acid value, Free fatty acid, saponification value and molecular weight is obtained.

- **Density**

It is defined as mass per unit volume. Density of diesel is approx. 15-20% higher than gasoline. And biodiesel is denser than diesel fuel.

Specific gravity bottle and digital weighing machine shown in **Fig. 3.2** is required for measuring density.

Volume of oil which is taken in the specific gravity bottle (V) =25cc

Mass of WSO sample = 23.37 gm

Mass of CSO sample = 23.11 gm

Density of WSO = mass/volume

= 23.37/25

=0.935 gm/cc

Density of WSO sample= 0.935gm/cc

Density of CSO = mass/volume

= 23.11 /25

=0.924 gm/c

Density of CSO sample= 0.924 gm/cc

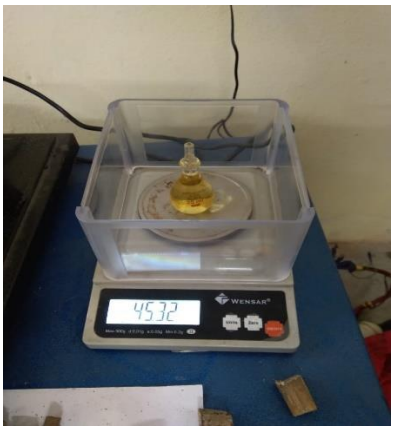

Fig 3.2: Digital weighing machine with Specific gravity bottle

❖ Acid value (A.V)

The amount of potassium hydroxide (KOH) in mg required to neutralise the organic acids present in 1 gm of sample of waste cooking oil.

It measures the breakdown of triacylglycerol into free fatty acid. Higher Acid value means lower the ester yields and increase base consumption for neutralization. High value also indicates oxidation of oil which may lead to gum and sludge formation besides corrosion.

Conical flask and Burette with burette stand are required. Reagents used for obtaining acid value are 2-Propanol and phenolphthalein.

20 gm WCO/CCO is mixed with 50 ml of 2-propanol and 2 to 3 droplets of Phenolphthalein into the flask. Then solution was titrated with 0.1(N) of KOH. The titration process is stopped when the solution turns into pink colour.

Volume of KOH used for titration of WSO (V_{KOH}) = 2.3 ml

Volume of KOH used for titration of CSO (V_{KOH}) = 2.1 ml

Molar mass of KOH= 56.1 gm/mol

Normality of KOH =0.1N

Calculation -

$$\text{A. V of WSO} = \frac{\text{molar mass of KOH} \times \text{volume of KOH used} \times \text{normality of KOH}}{\text{masss of WSO sample}}$$

$$= \frac{56.1 \times 2.3 \times 0.1}{20}$$

$$= 0.6452 \text{ mg KOH/gm of oil}$$

Acid value of WSO=0.6452 mg KOH/gm of oil

$$\text{A. V of CSO} = \frac{\text{molar mass of KOH} \times \text{volume of KOH used} \times \text{normality of KOH}}{\text{masss of CSO sample}}$$

$$= \frac{56.1 \times 2.1 \times 0.1}{20}$$

$$=0.589 \text{ mg KOH/gm of oil}$$

Acid value of CSO=0.589 mg KOH/gm of oil

Free fatty acid (FFA) of WSO = A.V/1.99

= 0.6452/1.99

= 0.3242

Free fatty acid (FFA) of CSO = A.V/1.99

= 0.589/1.99

= 0.2959

The obtained Acid Value for WSO is 0.6452 mg KOH/gm and for CSO is 0.589 mg KOH/gm. The free fatty acid concentration in the WSO is 0.3242% and in CSO is 0.2959%.

❖ **Saponification value (S.V)**

It is defined as the amount of potassium hydroxide (KOH) in mg required to neutralize the fatty acids resulting from complete hydrolysis of 1 gm of Sample of waste cooking oil.

The higher the saponification value, the lower the fatty acids average length, the lighter the mean molecular weight of triglycerides and vice-versa. It is a measure of the average molecular weight (or chain length) of all the fatty acids present in the sample.

- Conical flasks, burette, heater with temperature sensor is required.
- Reagents used for S.V are 0.5(N) ethanolic KOH, 0.5(N) HCL and phenolphthalein.

Procedure-

2 gm sample of WSO/CSO is taken into 200 ml of conical flask and reflux condenser is fitted with the flask. Then 25 ml 0.5(N) ethanolic KOH is added and heated under reflux (60-70^0 C) on water bath for 1hour. Add 1 ml Phenolphthalein solution and titrate with 0.5(N) HCL. The titration process is stopped when the solution is turned into pink colour. Also carry out a blank titration without the sample and follows the same procedure.

Titration volume of WSO sample $(V_s)_{wso}$ = 9ml
Titration volume of CSO sample $(V_s)_{cso}$ = 8.8ml
Titration volume of blank (V_b) = 23.3 ml
Normality of HCL= 0.5N Molar mass of KOH= 56.1 gm/mol

Saponification value is calculated by –

$$\text{S.V of WSO} = \frac{\text{normality of HCL} \times \text{molar mass of KOH} \times (\text{Volume of blank} - \text{volume of WSO sample})}{\text{WSO sample weight}}$$

$$= \frac{0.5 \times 56.1 \times (23.3 - 9)}{2}$$

= 200.557 mg KOH/ gm of oil

S.V of WSO = 200.557 mg KOH/ gm of oil

$$\text{S. V of CSO}$$

$$= \frac{\text{normality of HCL} \times \text{molar mass of KOH} \times (\text{Volume of blank} - \text{volume of CSO sample})}{\text{CSO sample weight}}$$

$$= \frac{0.5 \times 56.1 \times (23.3 - 8.8)}{2}$$

= 203.36 mg KOH/ gm of oil

S.V of CSO = 203.36 mg KOH/ gm of oil

❖ **Molecular Weight**

Molecular weight is a measure of the sum of the atomic weight values of the atoms in a molecule.

Acid value of WSO=0.6452 mg KOH/gm of oil

S.V of WSO = 200.557 mg KOH/ gm of oil

Molar mass of KOH= 56.1 gm/mol

Molecular weight of WSO sample-

$$\text{MW of WSO} = \frac{\text{molar mass of KOH} \times 3 \times 1000}{(\text{SV of WSO} - \text{AV of WSO})}$$

$$= \frac{56.1 \times 1000 \times 3}{(200.557 - 0.6452)}$$

= 841.87 gm/mol

S.V of CSO = 203.36 mg KOH/ gm of oil

Acid value of CSO=0.589 mg KOH/gm of oil

Molecular weight of CSO sample-

$$\text{MW of CSO} = \frac{\text{molar mass of KOH} \times 3 \times 1000}{(\text{SV of CSO} - \text{AV of CSO})}$$

$$= \frac{56.1 \times 1000 \times 3}{(203.36 - 0.589)}$$ = 830 gm/mol

Obtained properties of WSO and CSO are given below in **Table 3.1**.

Table 3.1: Properties of WSO and CSO

Property	Experimentally determined value of WSO	Experimentally determined value of CSO
Density	0.935 gm/cc	0.924 gm/cc
Acid value	0.6452 mg KOH/gm	0.589 mg KOH/gm
Free fatty acid (%)	0.3242 %	0.2959 %
Saponification value	200.557 mg KOH/gm	203.36 mg KOH/gm
Molecular weight	841.87gm/mol	830 gm/mol

3.3.2 Experimental setup and procedure

WSO/CSO is kept on a hot plate in a flask as shown in **Fig. 3.3** up to 65ºC for 3-4 min to remove some impurities and moisture.

Fig 3.3: Heating of WSO/CSO

Step1: Alcohol-Catalyst mixing

Proper amount of potassium hydroxide (KOH) is dissolved with required amount of methanol in a beaker and stirred continuously until the pellets of KOH are dissolved which results in the potassium methoxide solution.

Proper amount of potassium hydroxide (KOH) is dissolved with required amount of methanol in a beaker and stirred continuously as shown in the **Fig. 3.4** until the pellets of KOH are dissolved which results in the potassium methoxide solution.

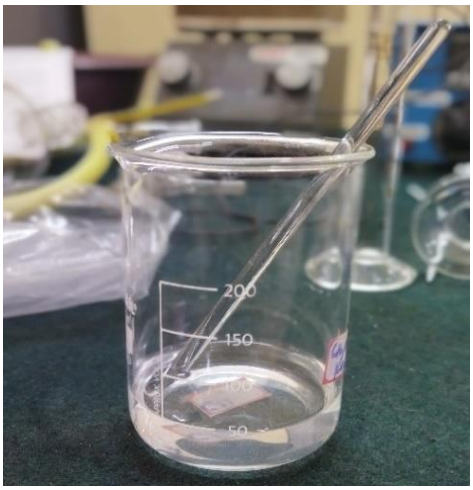

Fig 3.4: Alcohol catalyst mixing

Step2: Chemical Reaction

The potassium methoxide solution is then poured slowly into the conical flask having WSO/CSO to mix by stirring with the help of magnetic stirrer bar. That conical flask is kept on the hot magnetic stirrer. The helical condenser is fitted with the conical flask to prevent the vaporization of methanol. Temperature is controlled with the help of Digital temperature controller by inserting temperature sensor that passes through helical condenser and touches the WSO/CSO solution. Solution is then heated for various hours required with different Speed. Hence Transesterification process is carried out by the reaction between the Waste cooking oil, alcohol and the catalyst as shown in the **Fig. 3.5**.

Fig 3.5: Setup of Transesterification process of WSO/CSO

Step 3- Separation of the Reaction Product (glycerol and crude biodiesel)

After completion of transesterification process solution is kept into the separating funnel for 8-12 hrs in order to separate the glycerol from waste cooking oil methyl ester. Glycerine is denser than crude biodiesel so it is at the bottom of the separating funnel as shown in the **Fig. 3.6**. Glycerine and above part that is methyl ester is collected in a two separate beaker. Measure the volume of crude oil obtained. Crude biodiesel methyl ester is then carried out for purification.

Fig 3.6: Separation of crude biodiesel and glycerol

Step 4- Purification and Separation of crude biodiesel

Purification is done to remove glycerol, excess alcohol and remaining catalyst. Water washing is required to remove catalyst, soap, un reacted methanol and other contaminants from crude biodiesel. An aquarium air pump along with an aquarium stone, a bubble washing setup is used for purification of biodiesels shown in the **Fig. 3.7**. Amount of distilled water required is double the volume of crude oil obtained. Crude biodiesel is kept in a beaker and hot distilled water (approx. 80ºC) is then poured into the beaker or vice-versa. Air is passed by the help of the aquarium air pump and bubbles are formed in the mixture with the help of aquarium stone. This process is carried out for some time more or less three times. Then the mixture is kept in a separating funnel for approx. half an hour. At the end biodiesel comes to upper part and water to the lower part of the funnel as shown in the **Fig 3.8**. Now PH value of water is checked by PH strip and this whole process is carried out until the PH strip indicates green i.e., PH value approx. 7 neutral) which means complete removal of catalyst, methanol and glycerol is done. After this remove water from separating funnel from lower part. There is chance of moisture in the biodiesel so further removal of moisture is done

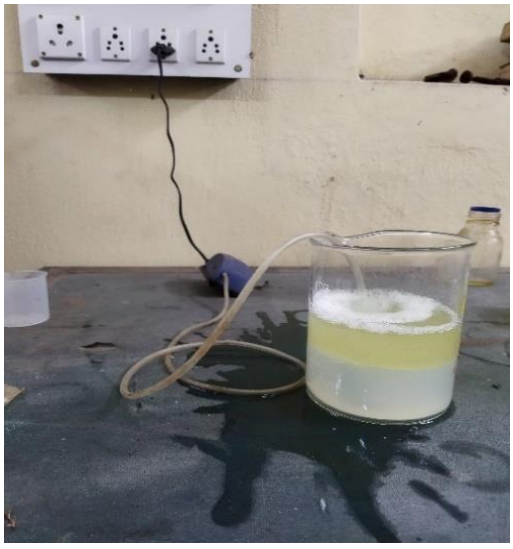

Fig 3.7: Purification of crude biodiesel

Fig 3.8: Separation of biodiesel and water after purification

Step 5- Removal of moisture

Flash point and calorific value of biodiesel can be reduced by the presence of moisture which increases the fuel consumption and knocking. The biodiesel is poured into the beaker and placed inside the air oven for heating as shown in the **Fig. 3.9**. Temperature inside the oven is kept at 100^{o}c at normal atmosphere for removing moisture. By doing this fuel becomes clearer. This is the final biodiesel obtained.

Fig 3.9: Remaining Moisture removal

3.4 Calculation

3.4.1 Sample calculation for WSO

Catalyst concentration = 1% w/w of oil

Molar ratio of WSO to methanol = 1:6

Volume of WSO= 100ml

Molecular weight of WSO= 841.87gm/mol

Molecular weight of methanol=32gm/mol

Density of methanol (25℃) = 0.792gm/cc

Density of WSO= 0.935 gm/cc

Mass of WSO= density×volume

= 0.935×100

= 93.5 gm

Case: 1

For 1 mole of WSO, requirement of CH_3OH is 6 moles

Now for (1×841.87) gm of WSO, CH_3OH required is - (6×32) gm

Then for 93.5 gm (Or 100ml) WSO, required CH_3OH is $=\frac{6\times32\times93.5}{841.87}$

= 21.32gm

Therefore, Volume of 21.32gm CH_3OH = mass/density

= 21.32/.792

= 26.92 or 27 ml

Case: 2

For 100 gm of WSO required KOH = 1gm

Then for 93.5gm (Or 100 ml) of WSO required KOH $=\frac{1\times93.5}{100}$

= 0.935gm or 0.94 gm

Therefore, When the quantity of WSO= 100ml

Requirement of CH_3OH = 27 ml And KOH = 0.94 gm.

3.4.2 Sample calculation for CSO

Catalyst concentration = 1% w/w of oil

Molar ratio of CSO to methanol = 1:6

Volume of CSO= 100ml

Molecular weight of CSO= 830 gm/mol

Molecular weight of methanol=32gm/mol

Density of methanol (25℃) = 0.792gm/cc

Density of CSO= 0.924 gm/cc

Mass of CSO= density ×volume

= 0.924×100

= 92.4 gm

Case: 1

For 1 mole of CSO, requirement of CH_3OH is 6 moles

Now for (1×830) gm of CSO, CH_3OH required is - (6×32) gm

Then for 92.4 gm (Or 100ml) CSO, required CH_3OH is $=\frac{6\times32\times92.4}{830}$

= 21.374gm

Therefore, Volume of 21.374gm CH_3OH = mass/density

= 21.374/.792

= 26.98 or 27 ml

Case: 2

For 100 gm of CSO required KOH = 1gm

Then for 92.4gm (Or 100 ml) of CSO required KOH $=\frac{1\times92.4}{100}$

= 0.924gm or 0.92 gm

Therefore, When the quantity of CSO= 100ml

Requirement of CH_3OH = 27 ml

And KOH = 0.92 gm

3.5 Observations and Graph

In this study to obtain biodiesel of best yield various experiments are performed with different catalyst concentration, molar ratio of WSO/CSO to methanol, and process time.

Yield of biodiesel is evaluated by-

$$yield\ of\ biodiesel = \frac{weight\ of\ biodiesel}{weight\ of\ oil}$$

3.5.1 Experimental observation of biodiesel yield

In the first series of **Table 3.2**, we have –

Reaction temp. = **45°C**

Reaction time = **1 hr**

Molar ratio = **1:6**

Catalyst conc. = **0.5,0.75,1** and **1.5 %**

Speed = **1000 rpm**

Table 3.2: Experimental parameters with yield of biodiesel

Parameters	**WSO**				**CSO**			
Reaction Temperature (°C)	45				45			
Catalyst conc. (%)	0.5	0.75	1	1.5	0.5	0.75	1	1.5
Molar ratio	1:6				1:6			
Speed (rpm)	1000				1000			
Reaction time (hr)	1				1			
Yield of biodiesel (%)	91.50	93.88	86.50	83.10	95.00	96.70	97.60	94.50

Catalyst conc. of 0.75% for WSO yield 93.88% and 1% for CSO yield 97.6% has given better result among the above four conc. as seen from **Table 3.2**.

Table 3.3: Experimental parameters with yield of biodiesel

Parameters	**WSO**			**CSO**		
Reaction Temperature (ºC)	50	55	60	50	55	60
Catalyst conc. (%)	0.75			1		
Molar ratio	1:6			1:6		
Speed (rpm)	1000			1000		
Reaction time (hr)	1			1		
Yield of biodiesel (%)	95.55	96.00	95.00	97.00	95.30	92.50

Now for second series of **Table 3.3** we have-

Catalyst conc. for WSO = **0.75 %** Catalyst conc. for CSO = **1 %**

Reaction temp. = **50,55 and 60^{o}C**

Reaction time = **1 hr**

Molar ratio (WSO/CSO: methanol) = **1:6**

Speed = **1000 rpm**

It has been observed from **Table 3.2** and **Table 3.3**, yield of WSO biodiesel is better at temperature of 55ºC and conc. of 0.75% and for yield of CSO biodiesel is better at temperature of 45ºC and conc. of 1%.

For the third series of table 3.4, we have-

Catalyst conc. for WSO = **0.75 %** Catalyst conc. for CSO = **1%**

Reaction temp. for WSO = **55^{o}C** Reaction temp. for CSO = **45ºC**

Reaction time = **1 hr**

Molar ratio = **1:4, 1:8 and 1:10**

Speed = **1000 rpm**

Table: 3.4: Experimental parameters with yield of biodiesel

Parameters	**WSO**			**CSO**		
Molar ratio	1:4	1:8	1:10	1:4	1:8	-
Reaction Temp. (ºC)	55			45		
Catalyst conc. (%)	0.75			1		
Speed (rpm)	1000			1000		
Reaction time (hr)	1			1		
Yield of biodiesel (%)	93.33	94.67	80.00	94.80	91.50	-

From **Table 3.2, 3.3 and 3.4**, it shows that temp. of 55ºC with 1:6 molar ratio is better for WSO and for CSO yield of biodiesel with temp of 45ºC and 1:6 molar ratio is better.

For the fourth **Table 3.5** series, we have-

Catalyst conc. for WCO = **0.75 %** Catalyst conc. for CCO = **1 %**

Reaction temp. for WCO = **55ºC** Reaction temp. for CCO = **45ºC**

Reaction time = **1.5 and 2 hr**

Molar ratio = **1:6**

Speed = **1000 rpm**

Table 3.5: Experimental parameters with yield of biodiesel

Parameters	**WSO**		**CSO**	
Reaction time(hr)	1.5	2.0	1.5	2.0
Catalyst conc. (%)	0.75		1	
Molar ratio	1:6		1:6	
Reaction Temp.(ºC)	55		45	
Speed (rpm)	1000		1000	
Yield of biodiesel (%)	98.10	96.50	96.4	95.00

3.5.1 Variation of biodiesel yield with different parameters

From the observation of **Fig. 3.10** we can see variation of yield with respect to catalyst conc. at temperature of 45°C. CSO yield is increased up to 1% and then decreased for 1.5% catalyst conc. And for WSO, yield is increased up to 0.75% and then decreased for 1 and 1.5% catalyst conc. WSO shows maximum yield of 93.88% at catalyst conc. of 0.75% and minimum yield of 83.1% at 1.5% catalyst conc. And for CSO maximum yield of 97.6% at catalyst conc. of 1% and minimum yield of 94.5% at 1.5% catalyst conc. is obtained.

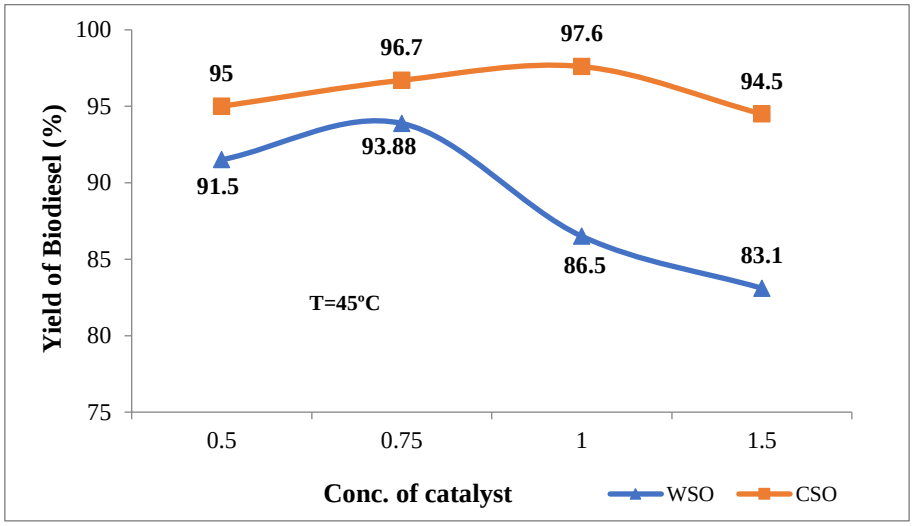

Fig: 3.10: Variation of biodiesel yield with Catalyst conc.

Variation of yield with respect to temperature is plotted in the **Fig. 3.11** by considering catalyst conc. of 0.75% for WSO and 1% for CSO. It is observed from the graph that yield of biodiesel for WSO is increased as temperature increases but slightly decrease for 60°C. While yield of biodiesel for CSO shows decrement as temperature rises. Maximum and minimum yield of WSO biodiesel is 96% at 55°C and 93.88% at 45°C respectively. CSO shows maximum and minimum yield of 97.6% at 45°C and 92.5% at 60°C respectively.

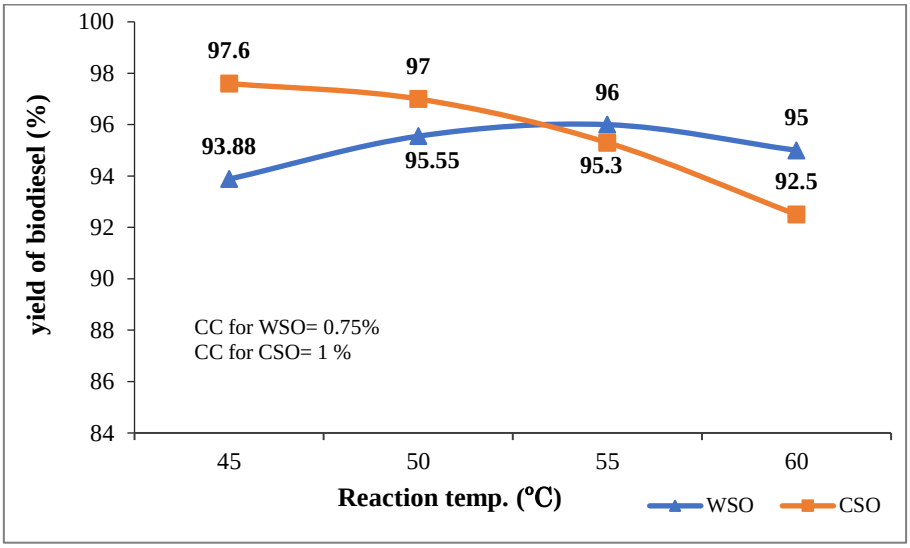

Fig 3.11: Variation of biodiesel yield with reaction temperature

From the **Fig. 3.12**, we can see the variation of molar conc. on yield. Above Graph is shown by Considering the catalyst conc. of 0.75% for WSO and 1% for CSO. Temperature of 45°C for CSO and 55°C for WSO is considered in the **Fig. 3.11**. Biodiesel yield for WSO shows minimum of 80% at molar ratio of 1:10 and maximum of 96% at molar ratio of 1:6. For CSO yield is maximum of 97.6% at 1:6 and minimum of 91.5% at 1:8.

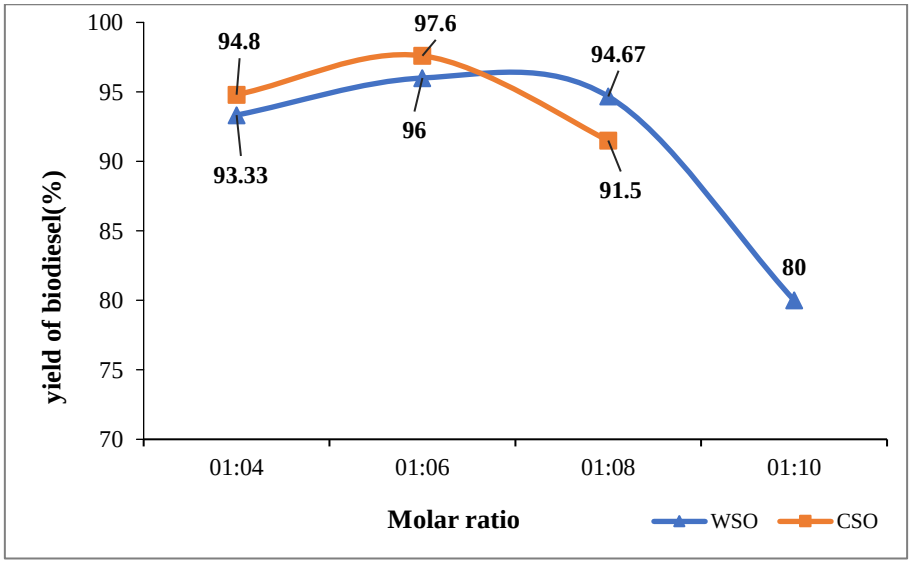

Fig 3.12: Variation of biodiesel yield with molar ratio

In the **Fig. 3.13**, variation of yield with respect to time is shown with molar ratio of 1:6 for both WSO and CSO, catalyst conc. of 0.75% for WSO and 1% for CSO, temperature of 55^{o}C for WSO and 45^{o}C for CSO. CSO yield shows decrement as time is increased. We can see from above graph yield for WSO and CSO is maximum of 98.1% at 1.5hr and 97.6% at 1 hr respectively.

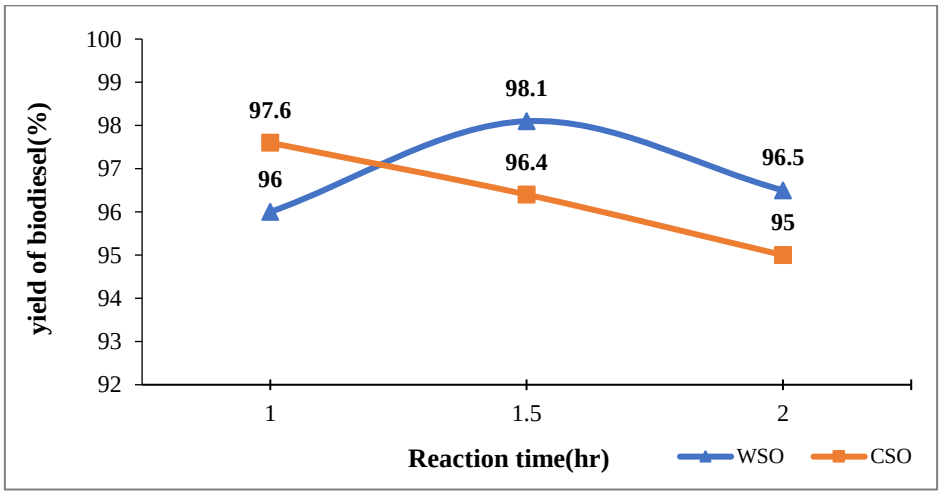

Fig 3.13: Variation of biodiesel yield with reaction time

From the above all observations optimum reaction parameters for biodiesel production from waste soyabean oil (WSO) and crude soyabean oil (CSO) on a batch scale reaction method is given below in **Table 3.6**

Table 3.6: Optimum Parameters for WSO and CSO biodiesel yield

Parameters	**WSO**	**CSO**
Reaction temp. (^{o}C)	55	45
Reaction Time (hr)	1.5	1
Stirring rate (rpm)	1000	1000
Catalyst concentration (%)	0.75	1
Molar ratio of WSO/CSO to methanol	1:6	1:6
Yield of biodiesel (%)	98.10	97.60

Chapter 4

TESTING OF BIODIESEL PROPERTIES

Testing of biodiesel obtained from WSO and CSO is a major part to use in engine applications. Fuel is characterised by testing the properties. In this chapter we will determine different properties like density, viscosity, Acid value, Flash point, Fire point, Calorific value, iodine value and Cetane number in different laboratory with various apparatus. The properties of produced biodiesel are analysed according to the ASTM D6751 and EU biodiesel Standard. Detailed testing procedures are discussed below.

4.1 Properties of waste soyabean oil biodiesel (WSOBD) and Crude soyabean oil Biodiesel (CSOBD)

4.1.1 Acid value

The amount of potassium hydroxide (KOH) in mg required to neutralise the organic acids present in 1 gm of sample of oil. It measures the breakdown of triacylglycerol into free fatty acid. Higher Acid value means lower the ester yields and increase base consumption for neutralization. High value also indicates oxidation of oil which may lead to gum and sludge formation besides corrosion.

In this study acid value of biodiesel is illustrated using EN 14104/ASTM D 974 method. The determined acid value of WSOBD is 0.449 mg KOH/g and for CSOBD is 0.561 mg KOH/g. This value complies with the requirements of ASTM D 6751 and EN 14214, which both stipulate a maximum acid number of 0.5 mg KOH/g.

4.1.2 Density

Density of biodiesel is measured by measuring the volume and mass of the biodiesel. Density is measured as: Density = mass / volume

Density calculated at 34^{o}C for WSOBD is 0.8872 gm/cc and CSOBD is 0.8896 gm/cc.

4.1.3 Viscosity

Viscosity plays an important role in engine applications. It affects the atomization of the fuel which ultimately influence the thermal efficiency. High viscous fuel is not preferable to use as slug development in the delivery valve might cause issues in the engine. On the other hand, low viscous fuels may not provide sufficient lubrication in the injector plungers resulting in leakage or increased wear. The schematic view is shown in **Fig. 4.1**. In this study viscometer is used for measuring viscosity. The viscometer shown below in **Fig. 4.2** is first washed and completely dried

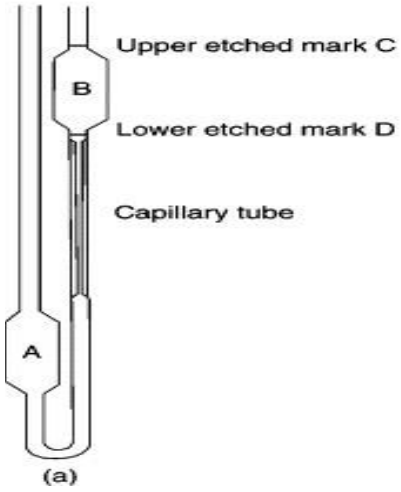

Fig 4.1: Schematic view of viscometer

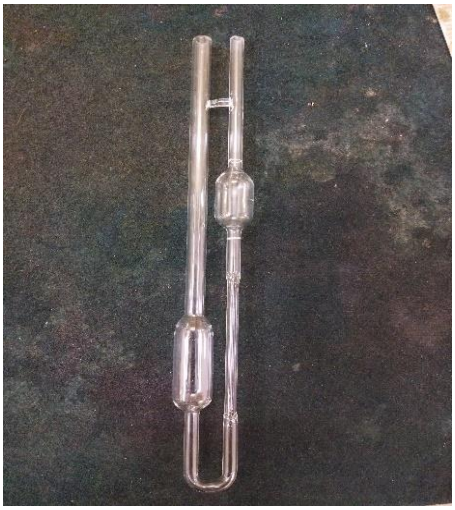

Fig 4.2: Actual view of viscometer

Distilled water density and viscosity is taken as standard value. Biodiesel is passed through the tube and filled up to mark A. Then the biodiesel is sucked up to slightly above upper etched mark C. After thar suction is removed biodiesel falls and the time is measured by stopwatch for falling from upper mark C to lower mark D.

Then the viscosity is measured by-

$$\mu_2 = \frac{\mu_1 \times \rho_2 \times t_2}{\rho_1 \times t_1}$$

Where μ_2 and μ_1 = viscosity of biodiesel and water respectively

ρ_2 and ρ_1 = density of biodiesel and water respectively

t_2 *and* t_1 = time taken for falling of biodiesel and water respectively

Kinematic Viscosity of WSOBD at 40°C obtained is η_{WSOBD} = 2.83 mm^2/s

Kinematic Viscosity of WSOBD at 40°C obtained is η_{CSOBD} = 3.87 mm^2/s

4.1.4 Flash point and Fire point

Flash point- Flash point describes the lowest temperature at which the ignition of a substance initiates.

Fire point - Fire point describes the lowest temperature at which the fuel continues to burn for a short time period after the initiation of the ignition.

Pensky Martens apparatus is used to find flash and fire point of the biodiesel as shown in **Fig. 4.3**.

Fig 4.3: Pensky Martens apparatus setup

It consists of an oil cup with a filling mark and is provided with heat control system and thermometer for measuring temperature.

Procedure -

- All parts of the cup and accessories should be clean before the test is run
- Oil to be tested is filled in the cup up to filling ark.
- Start heating of the oil and stirrer is rotated at the rate of 1 to 2 rev/s
- Test the oil flame at the interval of 1^oC up to 100^oC and 2^oC above 100^oC

In this study flash point of the WSOBD and CSOBD is 159^oC and 148^oC respectively. On the other hand, Fire point of WSOBD and CSOBD is 185^oC and 167^oC respectively.

4.1.5 Higher Heating Value

The amount of energy produced by the complete combustion of a material or fuel. Calorific value of biodiesel is lower as compared to petrol or diesel.
HHV is estimated through the empirical equation suggested by **Ayhan Demirbas [40]**

$$HHV = 49.43 - [0.041(SV) + 0.015(IV)]$$

Where, SV= saponification value

IV= iodine value

Higher heating value for WSOBD is 38.67 KJ/g and for CSOBD is 38.5 KJ/g

4.1.6 Iodine Value

It is defined as the amount of iodine in gm absorbed by 100 gm of given oil sample.

Procedure-

- Prepare 1% starch solution and 0.1N sodium thiosulphate solution ($Na_2S_2O_3$)
- Take 0.25 g of biodiesel in a flask and add 25ml of carbon tetrachloride (CCl_4)
- Then add 25ml of Wiji's solution into the sample flask and close the flask with flask cover immediately.
- Shake well for proper mixing of the solutions and keep it for 30 min in dark place.

- After that add 10 ml of KI solution and 100ml of distilled water into the previous solution and do the proper mixing by shaking the flask. Colour becomes dark red brown after mixing.
- Now start titration with the help of burette having 0.1N $Na_2S_2O_3$
- Add 1ml starch solution to the flask when colour changes to pale yellow/ straw and titrate until colour becomes colourless.
- Now do all the procedure without sample.

Iodine value is calculated using Wijs / Hanus method-

$$IV = \frac{12.69 \times (Vb - Vs) \times N}{weight\ of\ sample}$$

where 12.69= conversion factor from mEq sodium thiosulphate to grams of iodine (MW of iodine is 126.9 g/mol)

V_b = Volume of sodium thiosulphate required for blank titration

V_s= Volume of sodium thiosulphate required for sample titration

N= normality of sodium thiosulfate solution in Eq/ L

Iodine value for WSOBD obtained is 107.6 gm I_2/100gm oil and for CSOBD is 126.29 gm I_2/100gm oil.

4.1.7 Cetane Index

Cetane number is a measurement of the quality or performance of diesel fuel. The higher the number, the better the fuel burns within the engine of a vehicle. The cetane number is similar to the octane rating in that it is a rating assigned to a fuel to rate the quality of its combustion.

Kanit krishnaga [41] proposed the estimation of cetane index for vegetable oil methyl esters based on the iodine value and saponification value.

$$CI = 46.3 + \frac{5458}{SV} - 0.225\ IV$$

Where SV= saponification value

IV= iodine value

Cetane index obtained for WSOBD is 46.565 for CSOBD is 42.67

4.1.8 Saponification Value

Saponification value for WSOBD and CSOBD obtained is 223 mg KOH/gm and 220.2 mg KOH/gm respectively.

Instruments used and method of tests for properties of biodiesel are listed below in **Table 4.1.**

Table 4.1 Instruments and method of test for measuring biodiesel properties

Properties	Instrument	Method of test
Density	Specific gravity bottle	ISO 3675/ ISO 12185
Acid value	Titration	EN14104/ ASTMD664
Saponification value	Titration	ASTM D5558-95 / ISO3657
Viscosity	Oswald viscometer	ASTM D 445
Iodine value	Titration	ISO3961/ EN14111
Higher Heating value	Empirical formula	
Flash and Fire point	Pensky Marten Apparatus	ASTM D 93/ ISO 2719
Cetane index	Empirical formula	ASTM D613

4.2 Experimental values of the biodiesel properties

Experimental determined values of properties of produced biodiesel from WSO and CSO are listed in **Table 4.2**.

Table 4.2: Comparison of Experimental values of WSOBD/CSOBD with Diesel and standard biodiesel values

Fuel Properties	**Diesel**		**Biodiesel from WSO (WSOBD)**	**Biodiesel from CSO (CSOBD)**	**Requirement For Biodiesel ASTM D6751/EN14214**	
	Min	**Max**			**Min**	**Max**
Density at 34^{o}C (gm/cc)	0.820	0.845	0.8872	0.8896	0.860	0.900
Kinematic Viscosity at 40^{o}C (mm^2/s)	2.15	4.6	2.83	3.87	1.9	6
Acid Value (mg KOH/gm)	_	_	0.449	0.561	0.5(max)	
Saponification Value (mg KOH/gm)	_	_	223	220.2	370(MAX)	
Iodine Value (Gm I_2/100gm oil)	_	_	107.6	126.29	120(max)	
Flash Point (^{0}C)	66	85	159	148	130(min)	
Fire point(^{0}C)			185	167	-	
Higher Heating Value (MJ/kg)	42.6	45.6	38.67	38.50		
Cetane Index	51.4		46.56	42.67	47 (min)	

Chapter 5

EXPERIMENTAL SETUP AND METHODOLOGY

In this chapter, comparative analysis on performance and combustion by WSOBD and CSOBD blending has been done on VCR diesel engine. Biodiesel blending is prepared by taking 5,10,15 and 20 % of biodiesel with diesel fuel designated as CSOBD 5, CSOBD 10, CSOBD 15, and CSOBD 20 for crude soyabean oil biodiesel and WSOBD 5, WSOBD 10, WSOBD 15 and WSOBD 20 for waste soyabean oil biodiesel. Combustion characteristics of engine is observed at zero load and full load for CR 18 having speed of 1500 rpm.

5.1 Description of the experimental setup

A single-cylinder, four-stroke VCR (variable compression ratio) diesel engine is coupled to an eddy current-type dynamometer for loading in the configuration. By using a specifically created tilting cylinder block arrangement, the compression ratio may be adjusted without the engine being stopped or the geometry of the combustion chamber being modified. Measurements of combustion pressure and crank-angle setup is offered with the required equipment. Engine indicators for Pθ-PV diagrams are used to connect these signals with the computer. Provisions is likewise available for interfacing temperature, load monitoring, fuel flow, and airflow measurement. A fuel delivery system for both diesel and biodiesel, a water-cooling system, and a lubrication system are all parts of the experimental test setup. Two fuel tanks are used for the blend test, and the configuration includes a standalone panel box with an air box, manometers. fuel metering device, process indicator, engine indicator, fuel and air flow transmitters. Water flow measurement rotameters for calorimeters are available. The configuration allows for the analysis of braking power, indicated power, frictional power, BMEP, IMEP, indicated thermal efficiency, mechanical efficiency, brake thermal efficiency, heat balance, A/F ratio, volumetric efficiency, and specific fuel consumption for VCR engines with EGR. “Enginesoft” a software programme for Engine Performance Analysis based on Lab View, is available for online performance assessment. Through the laptop that is directly connected to the electronic data acquisition system of the test

engine setup, all performance and combustion-related data is gathered. The full test result is being produced by the laptop. The immediate experimental results were gathered throughout a number of cycles. The experiment is run at 1500 rpm, which is the rated speed. Both the injection pressure and timing are maintained constant at 23 TDC and 210 bar, respectively. The six allen bolts that are provided for securing the tilting block are initially slightly loosened to allow for variable compression ratio during engine operation. The adjuster's lock nut is then unfastened, and the adjuster is turned to adjust the compression ratio to the appropriate value by referring to the marking on the CR indicator. The lock nut and each of the six allen bolts are tightened when the desired compression ratio has been determined. The Schematic Diagram and VCR engine set up is shown in **Fig. 5.1** and **Fig. 5.2** respectively and Engine specification is listed in **Table 5.1**.

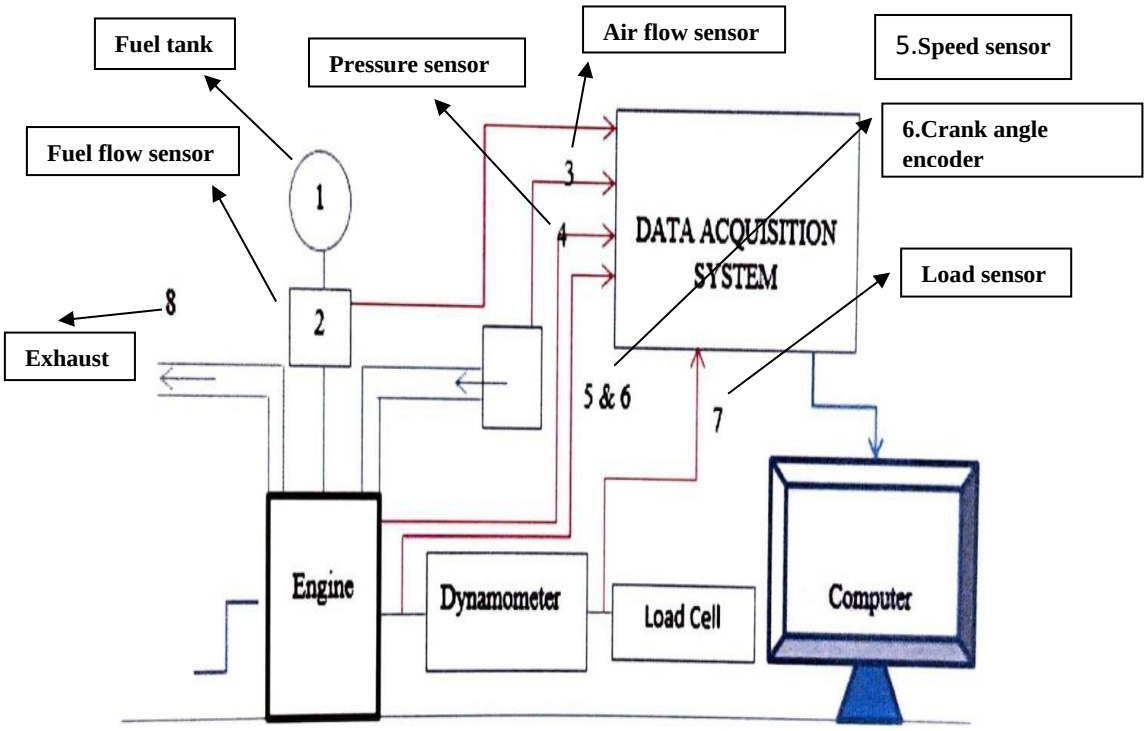

Fig 5.1 Schematic diagram of experimental engine setup

Fig 5.2: VCR Engine Set up

Table 5.1 Experimental engine setup specification

Parameters	Specification
Make and model	Make Kirloskar, Model TV1, single cylinder, 4 stroke Diesel
Rated power	3.5 kw @1500 rpm
Compression ratio	12 to 18
Injection type and timing	Direct injection @ 23ºBTDC
Bore	87.50 mm
Stroke	110 mm
Injection pressure	210 bars
Dynamometer	Eddy current, water cooled with loading unit
Method of cooling	Water cooled
Connecting rod length	234 mm
Load sensor	Strain gauge load cell

5.2 Measurement systems

The load measurement system, fuel injection pressure measurement system, cylinder pressure measurement system, air flow measurement system, and data acquisition system are some of the measurement systems utilised to record the experimental data used in the test. Below is a discussion about them.

5.2.1 Dynamometer load measurement system

This experimental test rig's load measurement equipment is made up of an eddy current type dynamometer, a strain gauge type load cell, and a loading unit. By utilising a loading unit to deliver current to the dynamometer, the load is applied. A load cell measures the load placed on the engine. The next paragraphs cover the dynamometer, load cell, and loading unit. A dynamometer is a tool used to gauge the force, torque, or power an engine produces. Additionally, it can be utilised to load or torque the engine.

This study's dynamometer is an eddy current model with a water-cooling system. The benefit of a quicker rate of load change for quick load setting is offered by eddy current dynamometers. With the help of a loading device, the VCR diesel engine is directly connected to the eddy current dynamometer and may be subjected to weights of up to 10 kg. A strain gauge load cell is used to measure the load, and a shaft fixed on a crank angle sensor is used to detect the speed. The main components of an eddy current dynamometer are a rotor, shaft, bearings, casing, and bed plate. The shaft on which the rotor is mounted runs in bearings. Two field coils are linked in sequence within the casing. A magnetic field is produced in the casing across the air gap on each side of the rotor when a direct current is applied to these coils through a loading device. The actual photograph is given in **Fig. 5.3**.

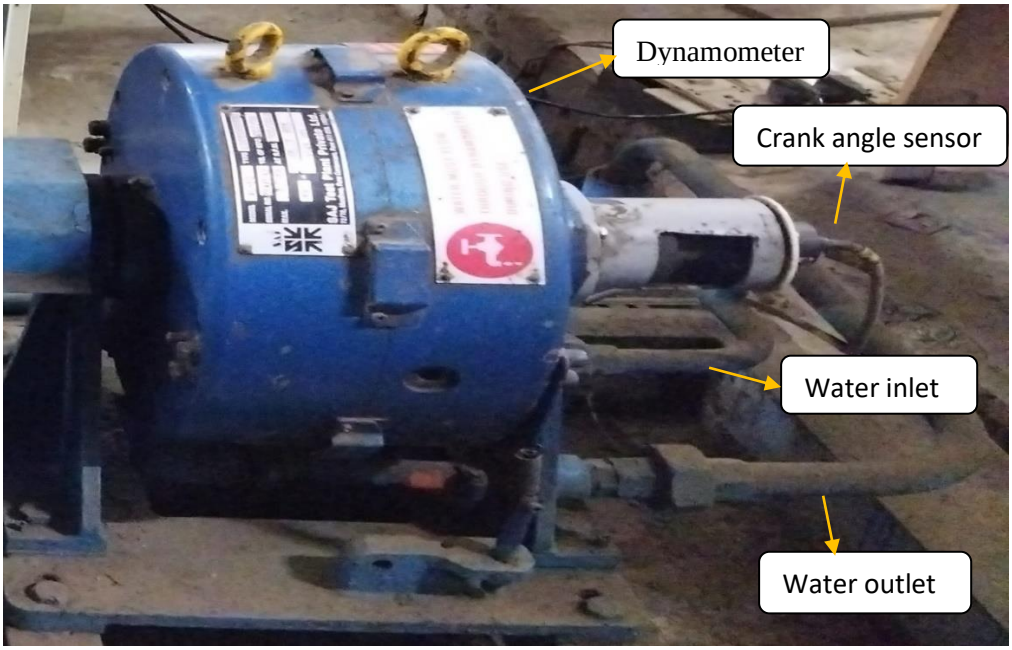

Fig 5.3 Dynamometer

5.2.2 Fuel injection pressure measurement system

An internal combustion engine's fuel is introduced via a fuel injection system. The pressure at which fuel is injected into the engine cylinder is referred to as the fuel injection pressure (also known as fuel inline pressure). The fuel injection pressure is recorded in the current experimental investigation using a Piezo Sensor, Make PCB Piezotronics, Model $111A22, Range 5000 psi (345 bar). The diaphragm of the sensor is composed of stainless steel and is hermetically sealed. In a specifically designed high pressure pipe line, the sensor is mounted. Adjusting the fuel injector spring tension, which is carried out by the fuel injector, changes the injection pressure in order to achieve larger or lower injection pressures, respectively, by tightening or loosening the nut. The nut is turned clockwise to tighten it and counter clockwise to loosen it.

5.2.3 Cylinder pressure measurement system

A Piezo sensor Make PCB Piezotronics, Model $111A22 with a range of 5000 psi (345 bar), a diaphragm made of stainless steel, and a hermetically sealed design is mounted on the cylinder head to monitor the cylinder pressure. On the engine head, the piezo sensor

is installed. The charge output from the piezoelectric transducer is proportional to the pressure within the cylinder. The quartz crystal that makes up the piezo sensor. Through the diaphragm, one end of the sensor is exposed to the cylinder pressure. The crystal is squeezed as the pressure within the cylinder rises. The sensor produces an electric charge proportionate to the pressure because piezoelectric crystals have a propensity to do so when they are distorted. The produced charge is smaller in magnitude and difficult to measure. Thus, the sensor has a charge amplifier to provide an output voltage proportionate to the charge. The piezoelectric sensor is displayed in **Fig. 5.4.**

Fig 5.4 Piezoelectric sensor

5.2.4 Air flow measurement System

An air surge tank equipped with an orifice metre, a manometer, and a pressure transducer (Model: SL-1-A-MQA-ND-ZA4Z-ZZZ) is used to route the inducted air through in order to measure the flow rates and the associated pressure drop required for computing the volumetric efficiency of the engine under various operating conditions. The air box is used to dampen the airflow's pulsations. The orifice meter's coefficient of discharge is assumed to be 0.65. The pressure transducer and manometer for measuring airflow are shown in **Fig. 5.5**.

Fig 5.5 Pressure transducer

5.2.5 Data acquisition panel system

A high-speed data collecting system is needed to capture in-cylinder pressure variations in relation to the crank angle. This is used to analyse the data from the measured injection pressure and cylinder pressure. During testing, the charge amplifier setting and transducer sensitivity are taken into account while converting the pressure signals from the pressure sensors into digital form. Relative pressures are typically provided using transducers. Therefore, it is essential to have tools for figuring out the absolute pressure at a particular cycle point that will be used as a standard. The reference pressure is the pressure at the input manifold. When the piston is at bottom dead centre, the mean intake manifold pressure is typically an accurate predictor of the cylinder pressure (BDC). A data acquisition system records the change in cylinder pressure in relation to piston displacement in terms of pressure and crank angle in the computer. The data must also be examined in order to obtain the relevant information obtained from the experiment after ensuring that the data was accurately recorded. Consequently, data processing is a crucial phase in the experimental inquiry. Due to the high cycle-to-cycle changes in cylinder pressure and injection pressure with respect to crank angle, one cycle's data cannot be utilised to accurately reflect a given operating situation. For quantitative examination, an average of 100 cycles of pressure vs. crank angle data are often utilised. The repeatability of the pressure data determines the number of cycles that should be averaged. For the conversion of the pressure signals in voltages to the conventional unit, an appropriate calibration factor is calculated. The average cycle is now subjected to the

calibration factor, and the relative pressures are computed. There are these relative pressures. The absolute pressure values for the average cycle are then determined by calibrating these relative pressures once more using the reference pressure, which is set to be equal to the pressure in the intake manifold with the piston at bottom dead centre. Now that the average cycle has absolute pressure values, pressure volume phasing may be completed with ease. Actual view of DAQ card is shown in **Fig. 5.6.**

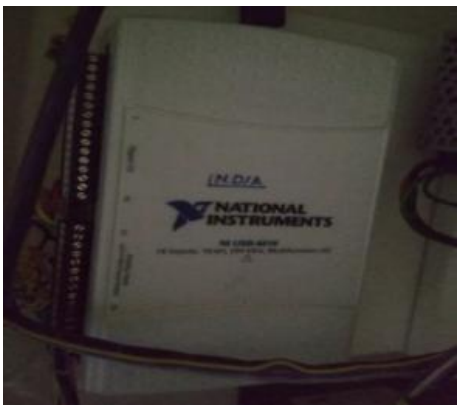

Fig 5.6 DAQ card

Chapter 6

ANALYSIS OF ENGINE COMBUSTION

6.1 Results and Discussion

In this chapter we are going to do comparative analysis and discuss about the results obtained for combustion characteristics of VCR Diesel engine using crude soyabean oil biodiesel (CSOBD) and waste soyabean oil biodiesel (WSOBD) with different blending and a compression ratio of 18 at zero load (0%) and full load (100%) for diesel and biodiesel blending.

6.1.1 Combustion Characteristics at Zero load and Full load for CR 18

6.1.1.1 Variation of Cylinder pressure with crank angle at Zero load (0%) and Full load (100%) for CR 18

The pressure variation with crank angle at zero load and full load for CR 18 for the diesel and fuel blending is shown in **Figure 6.1** and **6.2** respectively. Combustion chamber pressure (CP) mainly depends upon fuel accumulated during the ignition delay period and rate of combustion during premixed burning phase. No significant change is seen in the graph of all blends at both load condition. No significant change occurs in CP for blends as compared to diesel at full load.

Peak pressure obtained for diesel at zero load and full load 60.32 and 73.16 bar respectively lower than blend. All the CSOBD and WSOBD blending shows generally lower chamber pressure than diesel during the ignition period at zero and full engine load. CSOBD10 and WSOBD20 shows better result with lower CP_{max} of 55.47 and 56.32 bar respectively while CSOBD15 and WSOBD15 exhibit higher CP_{max} of 57.02 and 56.91 bar respectively at zero load condition. AT full load condition CP_{max} shows generally slight increment as increase in biodiesel concentration for both fuel blending. CSOBD5 and WSOBD5 shows better result with lower CP_{max} of 72.29 and 71.60 bar respectively while CSOBD15 and WSOBD20 shows higher CP_{max} of 72.92 and 72.32 bar respectively.

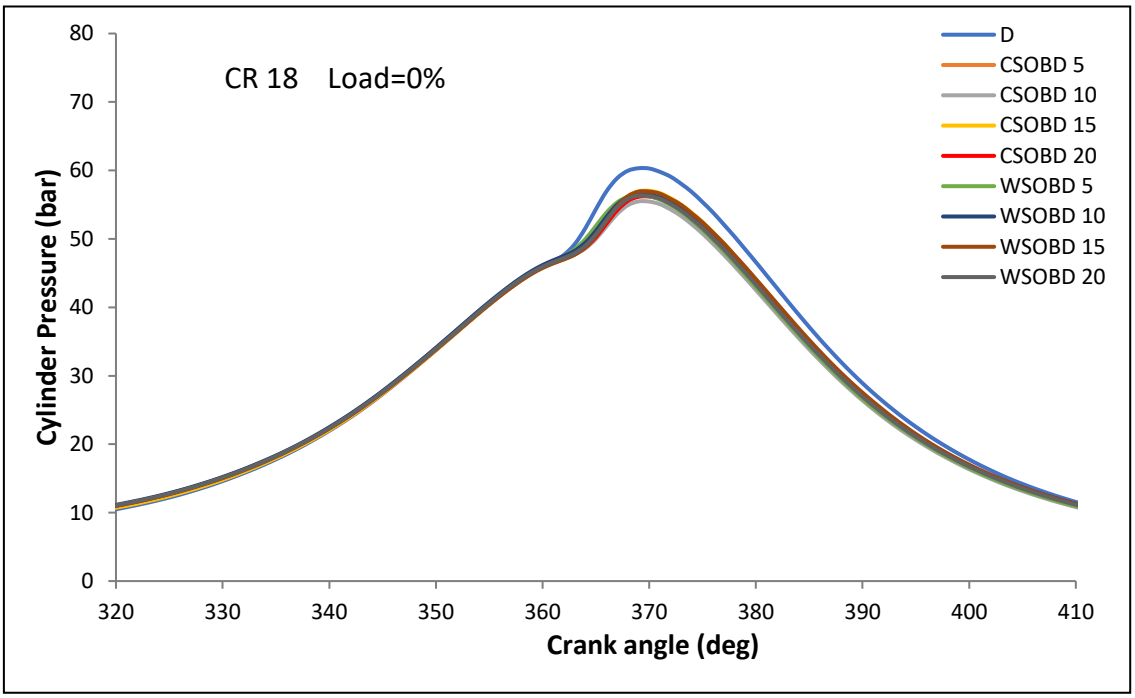

Fig 6.1: Variation of Cylinder Pressure with CA of Diesel (D), CSOBD and WSOBD blending for CR 18 at zero load (0%)

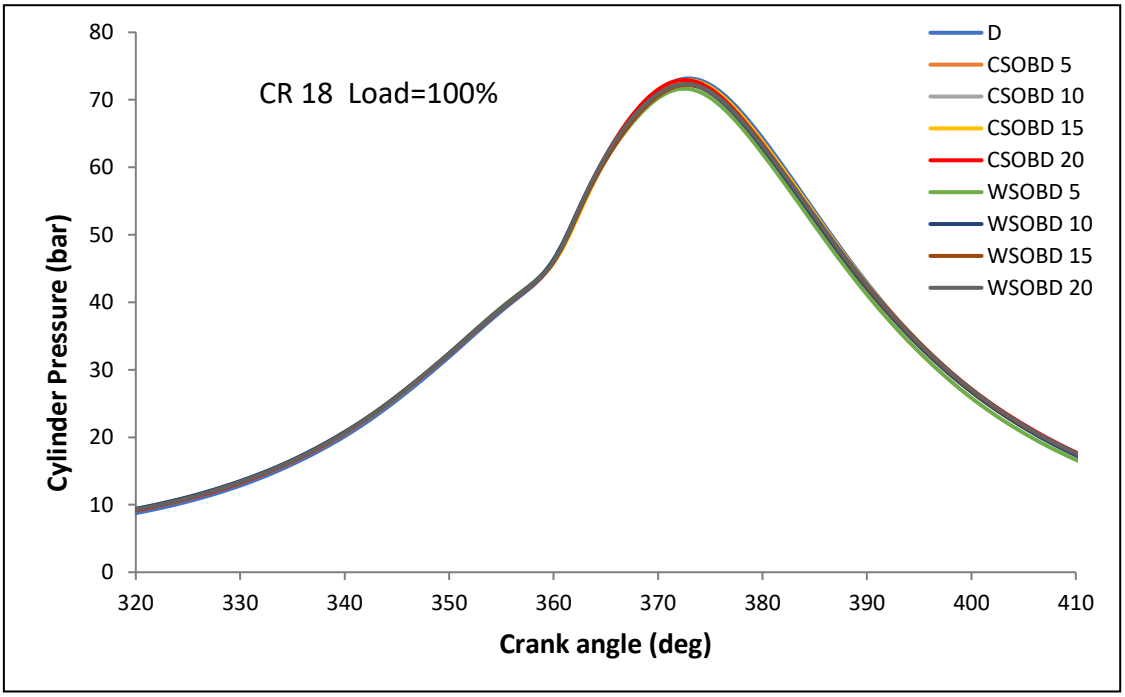

Fig 6.2: Variation of Cylinder Pressure with CA of Diesel(D), CSOBD and WSOBD blending for CR 18 at full load (100%)

6.1.1.2 Variation of Net Heat Release (NHR) with Crank angle at zero load (0%) and full load (100%) for CR 18

The variation of net heat release with respect to crank angle for Diesel, CSOBD and WSOBD blending at CR 18 for zero load and full loading condition is given in **Fig. 6.3** and **6.4** respectively. The NHR depends upon SOC, ignition delay and fuel mass burnt in premixed phase. It can be concluded from the graph that CSOBD and WSOBD blending exhibit lower NHR than diesel fuel at zero load. on the other hand, it can be seen that for full load condition also CSOBD and WSOBD blending generally exhibit lower NHR than diesel fuel. Diesel shows slightly higher NHR_{max} of 35.432 KJ/deg and 38.6 J/deg at zero and full load condition respectively respect to all blending of CSOBD and WSOBD. Due to its higher volatility and improved mixing with air, diesel fuel has a slightly higher peak heat release rate than biodiesel blend. Another reason could be increased fuel accumulation during the premixed phase, relatively longer ignition delay period. Same variation was obtained by **Raghvendra Gautam *et al.* (2020) [42]**. Slight variation in NHR can be observed between the Crude and Waste biodiesel.

For zero load condition, it is observed from the fig 6.3 that NHR_{max} for CSOBD5, CSOBD10, CSOBD15 and CSOBD20 are 30.38 J/deg, 28.54 J/deg, 32.05 J/deg and 30 J/deg respectively while NHR_{max} for WSOBD5, WSOBD10, WSOBD15, WSOBD20 are 27.49 J/deg, 29.06 J/deg, 31.80 J/deg and 30.06 J/deg respectively. CSOBD15 and WSOBD15 exhibit highest NHR_{max}.

For full load condition. It is observed from the fig 6.4 that NHR_{max} for CSOBD5, CSOBD10, CSOBD15 and CSOBD20 are 36.29 J/deg, 36.26 J/deg, 37.33 J/deg and 36.76 J/deg respectively and NHR_{max} for WSOBD5, WSOBD10, WSOBD15, WSOBD20 are 36.07 J/deg, 35.51 J/deg, 36.59 J/deg and 35.90 J/deg respectively. CSOBD15 and WSOBD15 exhibit also highest NHR_{max} for full load condition as seen in zero load. Biodiesel addition result in NHR decrement.

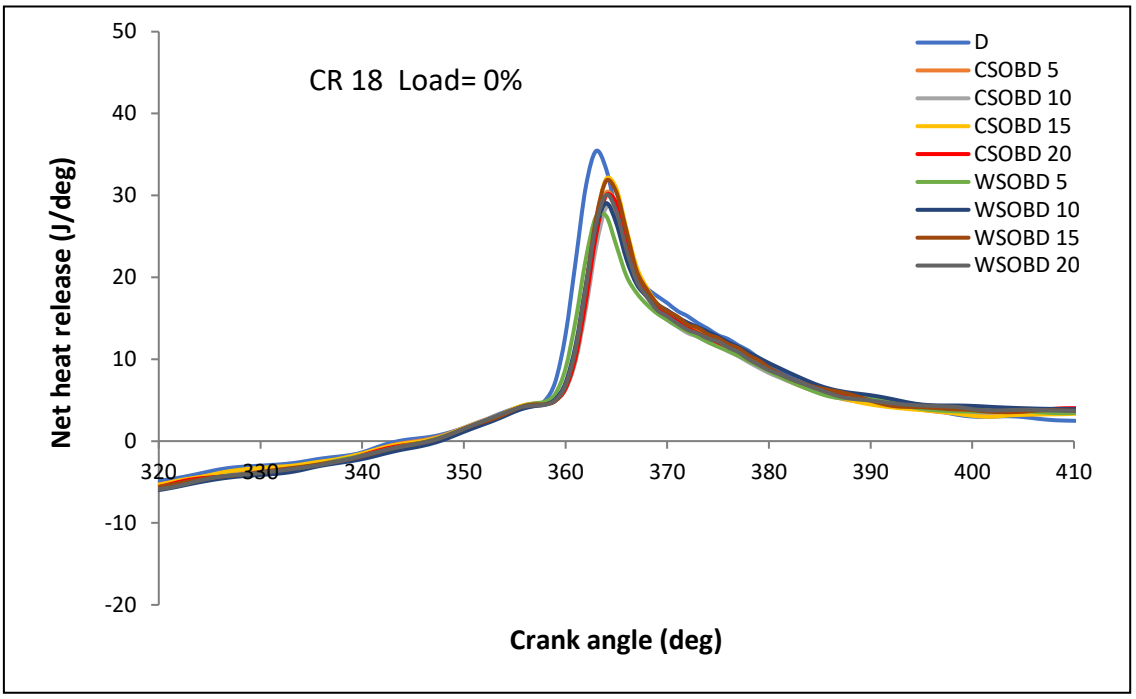

Fig 6.3: Variation of net heat release with CA of Diesel(D), CSOBD and WSOBD blending for CR 18 at zero load (0%)

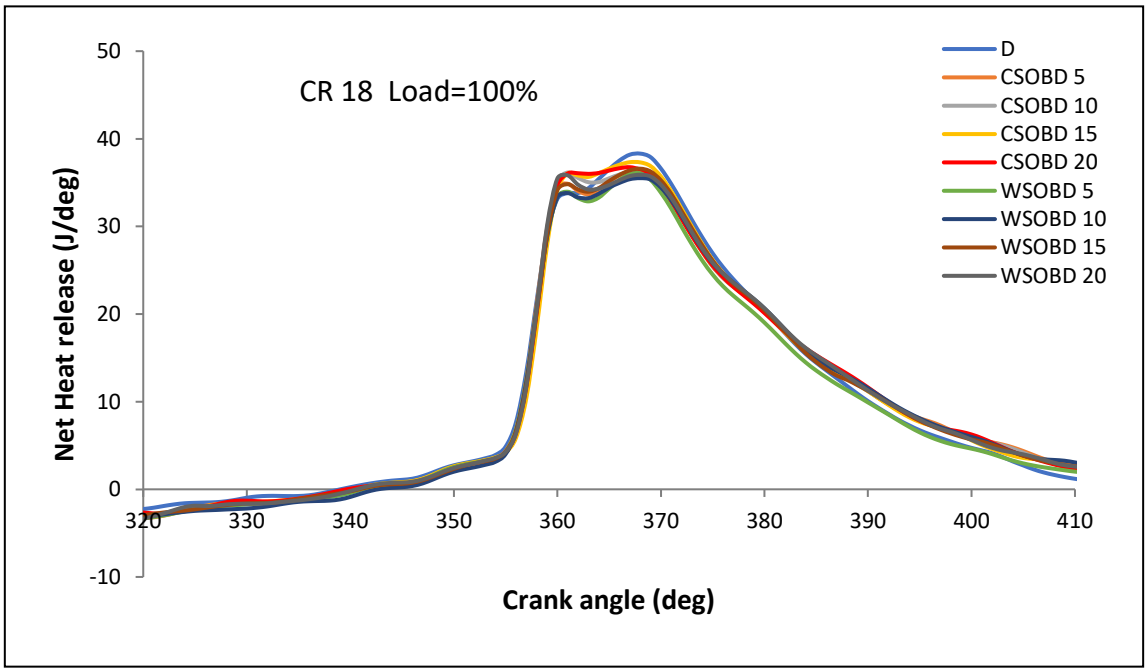

Fig 6.4: Variation of net heat release with CA of Diesel(D), CSOBD and WSOBD blending for CR 18 at full load (100%)

6.1.3 Variation of Combustion duration with load condition for CR 18

The combustion duration variation with load condition can be seen in **Fig. 6.5** and **6.6**. combustion duration is time between start of combustion (SOC) and end of combustion (EOC). The graph shows increment in combustion duration as the engine load increases for diesel and both biodiesel blends. The occurs due to more fuel injection in combustion chamber. Slightly variation in combustion duration can be seen with increase in biodiesel percentage for both biodiesel blends. This can be due to Diesel has a longer ignition delay period than biodiesel, which causes more fuel to accumulate in the cylinder before atomization and proper mixing, which results in a shorter combustion duration compared to biodiesel blends. Biodiesel has a higher latent heat of vaporisation than diesel, it takes longer to vaporise, which results in a longer combustion duration than diesel.

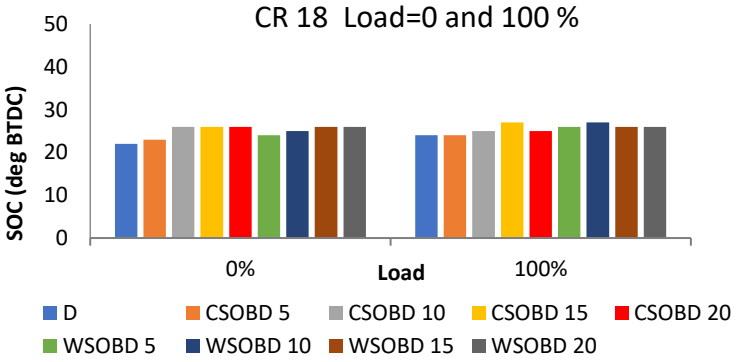

Fig 6.5: SOC at zero and full load condition

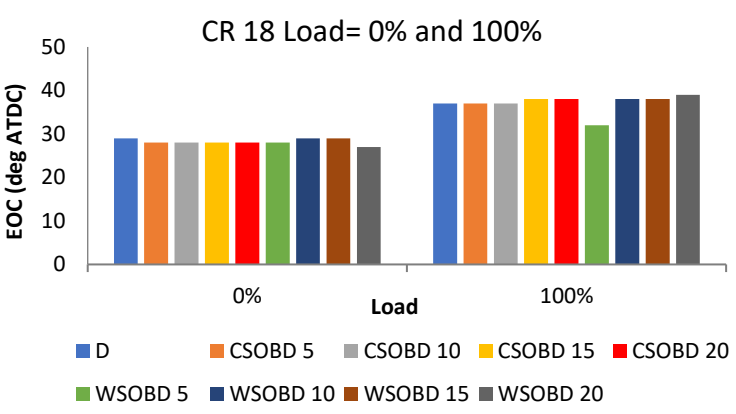

Fig 6.6: EOC at zero and full load condition

6.1.4 Variation of Mass fraction burned (MFB) at zero load (0%) and full load (100%) for CR 18

The variation of mass fraction burnt with the crank angle at both load condition is given in **Fig 6.7** and **6.8**. It is observed that 5% and 10% MFB for CSOBD blend at zero load condition is earlier than WSOBD blend but MFB for only WSOBD5 occurs after CSOBD5. It is observed that 5% MFB for CSOBD blend is earlier than WSOBD blend at full load condition. CSOBD5 and CSOBD15 shows earliest and latest 10% MFB respectively among all blends at full load condition. WSOBD5 and WSOBD10 shows 50% MFB earliest and latest respectively among all fuel blends at zero condition. CSOBD20 and WSOBD15 exhibit earliest and latest 50% MFB respectively at full load. It is observed that 90% MFB for CSOBD blend at zero load occurs earlier but for only CSOBD20, it occurs after WSOBD5. WSOBD 5 and CSOBD5 shows earliest and latest 90% MFB respectively at full load.

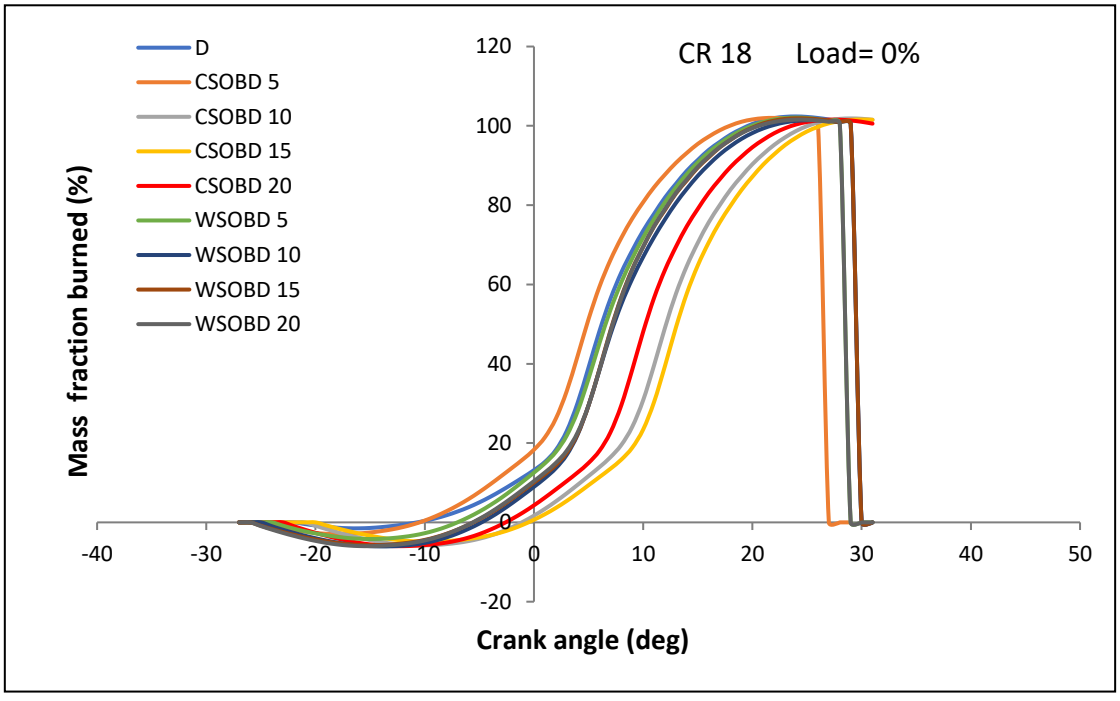

Fig 6.7: Variation of MFB with CA of Diesel(D), CSOBD and WSOBD blending for CR 18 at zero load (0%)

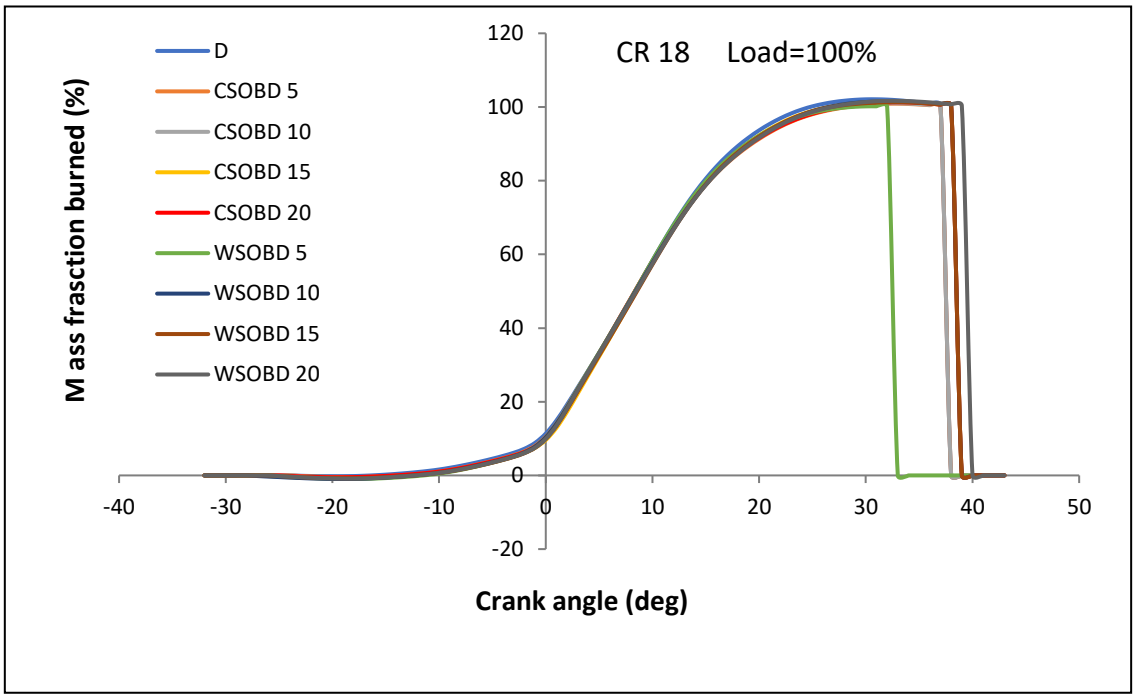

Fig 6.8: Variation of MFB with CA of Diesel(D), CSOBD and WSOBD blending for CR 18 at full load (100%)

6.1.5 Variation of Cylinder pressure with Cylinder volume at zero load (0%) and full load (100%) for CR 18

The variation of PV curve for diesel and all blend fuel can be seen in the **fig 6.9** and **6.10** at both load condition. No significant change occurs in PV curve for Biodiesel blend as compared to diesel. Peak pressure at zero load of diesel is slightly more than blend but similar graph is obtained for diesel and blend at full load.

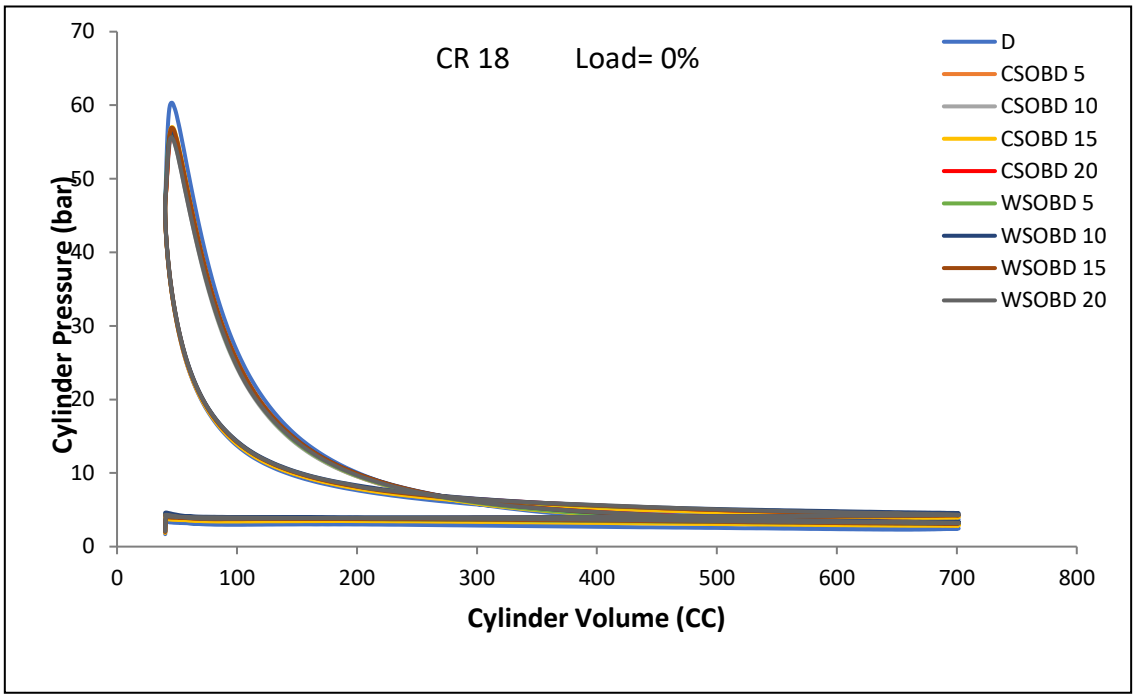

Fig 6.9: Variation of cylinder pressure with cylinder volume of Diesel(D), CSOBD and WSOBD blending for CR 18 at zero load (0%)

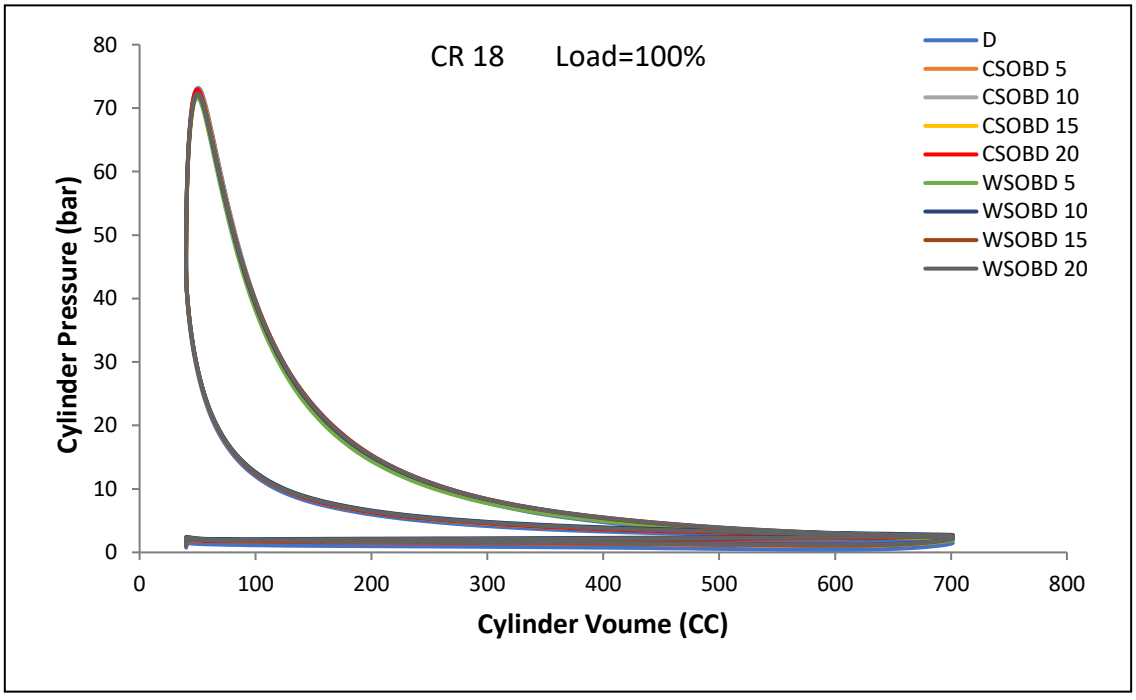

Fig 6.10: Variation of cylinder pressure with cylinder volume of Diesel(D), CSOBD and WSOBD blending for CR 18 at full load (100%)

6.1.6 Variation of Mean gas temperature (MGT) at zero load (0%) and full load (100%) for CR 18

Variation of mean gas temperature with the crank angle for diesel and different blend at both load conditions can be seen in the fig 6.11 and fig 6.12 given below. Significant changes can be seen between zero and full condition from the graph. Diesel shows lower MGT before its peak than all biodiesel blend and higher for some crank angle around its peak MGT then graph goes towards lower MGT than all blend at zero load. Lower MGT is generally observed for diesel except slightly higher at its peak than all blend at full load. Peak MGT of diesel for zero and full load is observed as 1234.24^{o}C and 1711.85^{o}C respectively. MGT graph for WSOBD is slightly higher with 5,10 and 15% blending as compared to CSOBD with WSOBD10 having higher peak MGT of 1306.21^{o}C than CSOBD20 having peak MGT of 1239.43^{o}C at zero load condition. Peak MGT of CSOBD and WSOBD increases with increase in biodiesel percentage and CSOBD15 and WSOBD20 shows their peak MGT of 1698.94^{o}C and 1686.09^{o}C respectively at full load condition. This can due to the viscosity of biodiesel is more than diesel fuel.

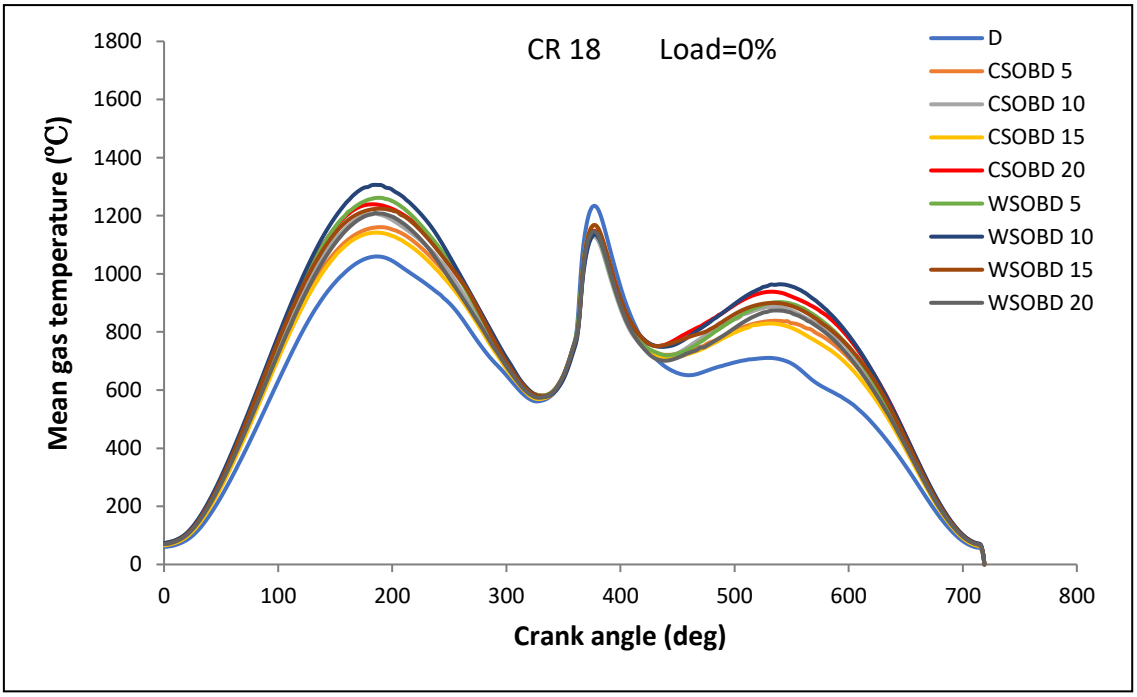

Fig 6.11: Variation of MGT with CA of Diesel(D), CSOBD and WSOBD blending for CR 18 at zero load (0%)

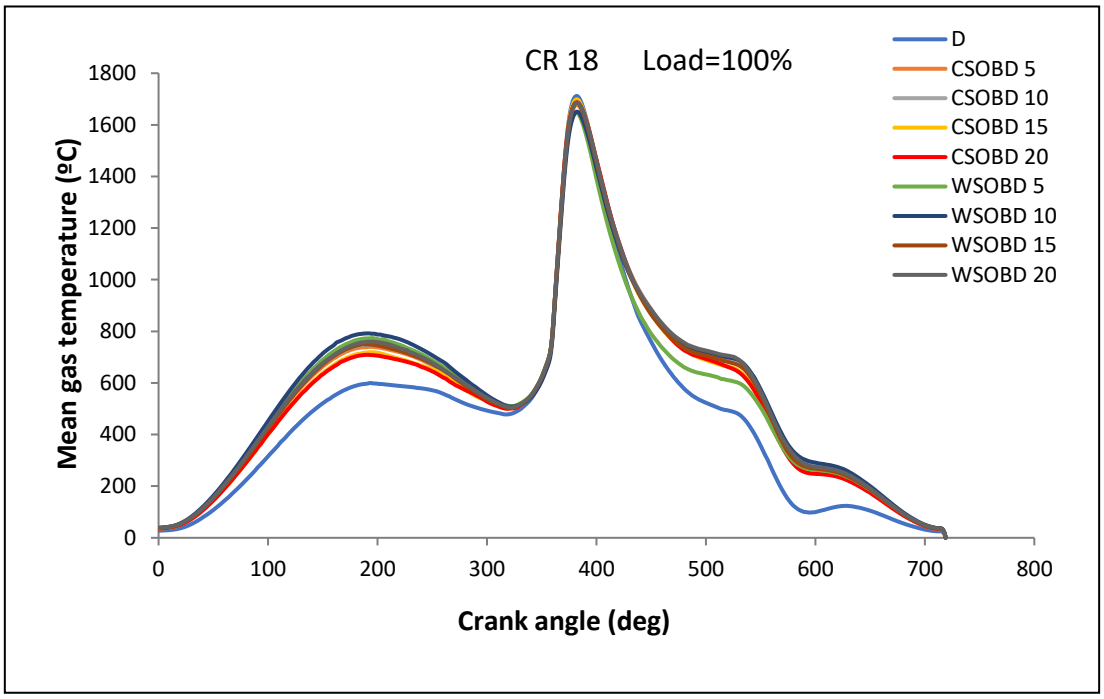

Fig 6.12: Variation of MGT with CA of Diesel(D), CSOBD and WSOBD blending for CR 18 at full load (100%)

Chapter 7

CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

Waste cooking oil is a valuable source for the production of biodiesel due to organic components present that does not harm the environment and may be easily found in hotels and restaurants. As far as crude cooking oil is concerned it differs in costing and viscosity from waste oil that is a major concern part. This study provides the comparison of biodiesel production and properties and combustion characteristics of a diesel engine from crude and waste soyabean oil. CSOBD and WSOBD blends are made at 5,10,15 and 20 % biodiesel blend with diesel fuel and tested for combustion characteristics in a VCR Diesel engine.

The following significant results can be concluded based on biodiesel production and testing in a diesel engine with blend proportion.

- Various experiments are done by taking different parameters for optimum yielding parameters for CSO and WSO biodiesel preparation which is somewhere different. Optimum yield for CSO and WSO biodiesel is 97.6% and 98.1% respectively.
- The tested biodiesel properties obtained for WSO biodiesel is found better close to ASTM and EN standards than CSO biodiesel.
- Viscosity for WSOBD is observed lesser than CSOBD and flash point of WSOBD is found better within standard value.
- Measured HHV based on SV and IV and measured cetane index for WSOBD is 38.67 Mj/Kg and 46.56 which is closer to standard value.
- The measured peak pressure of biodiesel blend is lower than diesel fuel at both load condition. CSOBD10 and WSOBD20 shows better result with lower CP_{max} of 55.47 and 56.32 bar respectively at zero load but CSOBD5 and WSOBD5 shows better result with lower CP_{max} of 72.29 and 71.60 bar respectively at full load.

- Slight variation in NHR is seen between the Crude and waste biodiesel. CSOBD15 with 32.05 J/deg and WSOBD15 with 31.80 J/deg exhibit highest NHR_{max} among biodiesel blend at zero and full load condition.
- Slightly variation in combustion duration can be seen with increase in biodiesel percentage for both biodiesel blends.
- WSOBD10 have higher peak MGT of 1306.21^{o}C than CSOBD20 having peak MGT of 1239.43^{o}C at zero load condition. Peak MGT of CSOBD and WSOBD increases with increase in biodiesel percentage and CSOBD15 and WSOBD20 shows their peak MGT of 1698.94^{o}C and 1686.09^{o}C respectively at full load condition.

7.2 Scope of Future Work

The current study compares the synthesis of biodiesel from crude and used soyabean oil and examines how different biodiesel/diesel blend ratios affect the combustion characteristics of a diesel engine. Further research on this subject is possible.

- Investigation using different catalyst and fuel additives for biodiesel production and its effect in Diesel engine at different blending.
- Comparative evaluation of performance and emission characteristics of a Diesel engine by taking different edible and non-edible oils in crude and waste form.
- Production of biodiesel from different oils by with catalyst such as NaOH and different fuel additives like methanol, ethanol and its effect on performance, combustion and emission in Diesel engine.
- Evaluation using different blending ratio of biodiesel and diesel on the performance, combustion and emission at different compression ratio and load.
- Performance and emission analysis using biodiesel from different cooking oil like fish oil, vegetable oil, non-edible oil etc.
- Evaluation of performance, combustion and emission of diesel engine by mixing crude and waste oil biodiesel.

Reference

[1] D. Ramesh and A. Sampanthan, "Investigations on Performance and Emission Characteristics of Diesel Engine with Jatropha Biodiesel and Its Blends", Agricultural Engineering International: the CIGRE-journal. Manuscript EE 07 013. Vol. X. March, 2008

[2] Recep Altona, SelimCBetinkaya, Useyinserdar & Ucesu, "The potential of using vegetable oil fuels as fuel for diesel engines," Energy Conversion and Management, vol. 42, pp. 529-538 (2001).

[3] Surakasi Ravitejaa, CH Polayyab, D Appannac, VV Prasanna Kumard, B Ranjan Kumar, "Combustion Characteristics of Waste Cooking Oil Bio Diesel on Four Stroke Diesel Engine Using Additives", *Turkish Journal of Computer and Mathematics Education Vol.12 No.13 (2021), 1795-1808.*

[4] Shiv Kumar Sharma, D.D. Shukla, Kamal Kishor Khatri & Nitesh Singh Rajput, "Performance Evaluation of diesel Engine using Biodiesel fuel derived from waste cooking refined soyabean oil", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 7, Issue 5, Oct 2017, 103-110.

[5] Jeewan VachanTirkey, Amar Kumar Singh, S. K. Shukla, "Performance and Emission Characteristics of CI Engine Operated with Waste Cooking oil Methyl-Ester and Diesel Blends", International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-5 Issue-1, October 2015.

[6]. Rupesh Gupta, Param Gupta1, Jatin Bhalla and Shubham Mourya, "Performance Analysis of a Diesel Engine using the Soybean Oil based Biodiesel", Indian Journal of Science and Technology, *Vol 9(36), DOI: 10.17485/ijst/2016/v9i36/102153, September 2016.*

[7] N.L. Panwar, Hemant Y. Shrirame, N.S. Rathore, Sudhakar Jindal, A.K. Kurchania / Applied Thermal Engineering 30 (2010) 245–249, "Performance evaluation of a diesel engine fuelled with methyl ester of castor seed oil"

[8] Kawaguchi, Y., Tamaki, N., Shimizu, M. and Hiroyasu, H., "Experimental investigation on the waste oil combustion burner for energy saving and low-pollution", *International Journal of Energy for a Clean Environment*, vol. 5, Issue 3, 2004.

[9] Kumar, A.A., Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Prog Energy Combust Sci*., vol. 33, pp. 233–271, 2007.

[10]. Singh, J. and Gu S., Commercialization potential of microalgae for biofuels production, *Renew Sustain Energy Rev*, vol. 14, pp. 2596–2610, 2010.

[11] Singh, D., Sharma, D., Soni, S.L., Sharma, S. and Kumari, D., Chemical compositions, properties, and standards for different generation biodiesels: A review, *Fuel,* vol. 253, pp. 60–71, 2019.

[12] Misra, R.D. and Murthy, M.S., Blending of additives with biodiesels to improve the cold flow properties, combustion and emission performance in a compression ignition engine—A review. *Renew Sustain Energy Rev*, vol. 15, pp. 2413-2422, 2011.

[13] Nur Atiqah Ramlan, Mohd Herzwan Hamzah, Nur Fauziah Jaharudin, Abdul Adam Abdullah, Rizalman Mamat "Analysis of Diesel Engine Performance Fuelled with Waste Cooking Oil" *Applied Mechanics and Materials Vols. 465-466 (2014) pp 418-422, © (2014) Trans Tech Publications, Switzerland*

[14] Arjun B. Chhetri, K. Chris Watts and M. Rafiqul Islam, "Waste Cooking Oil as an Alternate Feedstock for Biodiesel Production", *Energies* 2008, *1*, 3-18; DOI: 10.3390/en1010003

[15] C.V. Sudhir, N.Y. Sharma and P. Mohanan, "Potential of Waste Cooking pois as Feedstock", *Emirates Journal for Engineering Research, 12 (3), 69-75 (2007).*

[16] Biswas, P.K. and Pohit, S., What ailsIndia'sbiodieselprogramme? *Energy Policy*, vol. 52, pp. 789–796, 2013.

[17] Biswas, P.K., Pohit, S. and Kumar, R., Biodiesel from jatropha: can India meet the 20% Bl22ending target? *Energy Policy*, vol. 38, pp. 1477–1484, 2010.

[18] Demirbas, A. 2009: A progress and recent trends in biodiesel fuels. *Energy conservation and Management* 50: 14 – 34.

[19] K.A. Abed, A.K. El Morsi, M.M. Sayed, A.A. El Shaib, M.S. Gad, "Effect of waste cooking-oil biodiesel on performance and exhaust emissions of a diesel engine", Egyptian Journal of Petroleum 27 (2018) 985–989

[20] M. Vijay Kumar, A. Veeresh Babu, P. Ravi Kumar, "The impacts on combustion, performance and emissions of biodiesel by using additives in direct injection diesel engine", Alexandria Engineering Journal (2018) 57, 509–516

[21] Md. Saiful Islam, Abu Saleh Ahmed, Aminul Islam, Sidek Abdul Aziz, Low Chyi Xian, and Moniruzzaman Mridha, "Study on Emission and Performance of Diesel Engine Using Castor Biodiesel", Hindawi Publishing Corporation Journal of Chemistry Volume 2014

[22] Nidal H. Abu-Hamdeh and Khaled A. Alnefaie, "A Comparative Study of Almond Biodiesel-Diesel Blends for Diesel Engine in Terms of Performance and Emissions, Hindawi Publishing Corporation BioMed Research International Volume 2015, Article ID 529808, 8 pages, http://dx.doi.org/10.1155/2015/529808

[23] Pardeep Kumar· Shailendra Kumar · Saumya Shah · Sandeep Kumar, "Study of performance parameters and emissions of four stroke CI engine using solketal-biodiesel blends", SN Applied Sciences (2021) 3:59 | https://doi.org/10.1007/s42452-020-04073-3

[24] K. Prasada Rao and Vara Lakshmi Reddi, "performance evaluation of diesel engine with biodiesel along with additives for replacing diesel fuel", *Int. J. Chem. Sci.: 14(4), 2016, 2379-2388 ISSN 0972-768X,www.sadgurupublications.com*

[25] M. Suresh, C.P. Jawahar, Arun Richard, "A review on biodiesel production, combustion, performance, and emission characteristics of non-edible oils in variable compression ratio diesel engine using biodiesel and its blends", Renewable and Sustainable Energy Reviews 92 (2018) 38–49

[26] Jeewan VachanTirkey, Amar Kumar Singh, S. K. Shukla, "Performance and Emission Characteristics of CI Engine Operated with Waste Cooking oil Methyl-Ester and Diesel Blends, International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-5 Issue-1, October 2015.

[27] Orkun Ozener, Levent Yuksek, Alp Tekin Ergenc, Muammer Ozkan , "Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics", Fuel 115 (2014) 875–883, journal homepage: www.elsevier.com/locate/fuel

[28] K. Muralidharan, D. Vasudevan, "Performance, emission and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends, Applied Energy 88 (2011) 3959–3968, journal homepage: www.elsevier.com/locate/apenergy.

[29] Prem Kumar Chaurasiya, Sanjay Kumar Singh, Rashmi Dwivedi, Ravishanker V.Choudri, "Combustion and emission characteristics of diesel fuel blended with raw jatropha and waste cooking oils", https://doi.org/10.1016/j.heliyon.2019.e01564

[30] Abhijeet P. Shah and Sharad D. Patil, “Performance, Emission and Combustion Analysis of Biodiesel Extracted from Acidic oil: A By-product of Soybean Oil Refining Process, AMSE JOURNALS-AMSE IIETA publication-2017-Series: Modelling C; Vol. 78; N°3; pp 337-350, https://doi.org/10.18280/mmc_c.780306

[31] Sarthak Baweja, Ajay Trehan and Rajan Kumar, “Combustion, performance, and emission analysis of a CI engine fueled with mustard oil biodiesel blended in diesel fuel”, https://doi.org/10.1016/j.fuel.2021.120346

[32] D.H. Qi, L.M. Geng, H. Chen, Y.ZH. Bian, J. Liu, X.CH. Ren, “Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil”, Renewable Energy 34 (2009) 2706–2713, www.elsevier.com/locate/renene

[33] G. Sakthivel, G. Nagarajan, M. Ilangkumaran, Aditya Bajirao Gaikwad, “Comparative analysis of performance, emission and combustion parameters of diesel engine fuelled with ethyl ester of fish oil and its diesel blends”, Fuel 132 (2014) 116–124

[34] Limin Geng, Yang Chen, Xubo Chen, Chia-fon F. Lee, “Study on combustion characteristics and particulate emissions of a common-rail diesel engine fueled with n-butanol and waste cooking oil blends”, Journal of the Energy Institute 92 (2019) 438e449

[35] A. Abu-Jraia, Jehad A. Yamin, Ala’a H. Al-Muhtaseb, Muhanned A. Hararah, “Combustion characteristics and engine emissions of a diesel engine fueled with diesel and treated waste cooking oil blends”, Chemical Engineering Journal 172 (2011) 129–136

[36] G Lakshmi Narayana Rao, S Sampath, K Rajagopal, “Experimental Studies on the Combustion and Emission Characteristics of a Diesel Engine Fuelled with Used Cooking Oil Methyl Ester and its Diesel Blends “, World Academy of Science, Engineering and Technology 13 2008

[37] C W Yu, S Bari and A Ameen, “A comparison of combustion characteristics of waste cooking oil with diesel as fuel in a direct injection diesel engine”, http://pid.sagepub.com/content/216/3/237

[38] Aransiola, Betiku, Ikhuomoregbe and Ojumu, “Production of biodiesel from crude neem oil feedstock and its emissions from internal combustion engines”, African Journal of Biotechnology Vol. 11(22), pp. 6178-6186, 15 March, 2012

[39] Pinkesh R. Shah and Prof. Anuradda Ganesh, “A Comparative Study on Influence of Fuel Additives with Edible and Non-Edible Vegetable Oil Based on Fuel Characterization and Engine Characteristics of Diesel Engine”, 2016,

http://dx.doi.org/10.1016/j.applthermaleng.2016.03.128

[40] Ayhan Demirbas, “Fuel properties and calculation of higher heating values of vegetable oils”, *Fuel* Vol. 77, No. 9/10, pp. 1117-1120, 1998

[41] Kanit krishnaga, “A simple method of estimation of cetane index of vegetable oil methyl esters,” JAOCS, vol 63, no 4, 1986

[42] Raghvendra Gautam, Saket Kumar, “Performance and combustion analysis of diesel and tallow biodiesel in CI engine”, Energy Reports 6 (2020) 2785–2793