

**Production, characterization and performance of
biodiesel blends of Sesame oil and Bitter almond oil
as an alternative fuel in CI engine**

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Master of Engineering
in
Thermal Engineering

by
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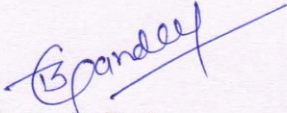
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CERTIFICATE

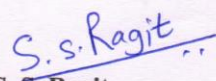
I hereby declare that the thesis entitled, "**Production, characterization and performance of biodiesel blends of Sesame oil and Bitter almond oil as an alternative fuel in CI engine**" is an authentic record of my work carried out as per requirements for the award of degree of **Master of Engineering in Thermal Engineering at Thapar University, Patiala** under the supervision of **Dr. Satish Kumar and Dr. S. S. Ragit**, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala during July 2015 to July 2017. No part of the matter embodied in this report has been submitted to any other university or institute for the award of any other degree.

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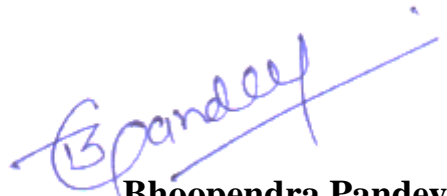

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Dedicated
To
My Beloved Parents
And
My Friends

Bhoopendra

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Abstract

Biodiesel is an eco-friendly, alternative renewable fuel prepared from the vegetable oils and animal fats. As global demand of energy rises and limited source of fossil fuel, research activity is directed towards development of alternative of diesel fuels more and more. There are various advantages to utilize the biodiesel as renewable energy sources. The most benefits of alternative fuel are its biodegradability, renewability and potential to reduce exhaust emissions. The experimental work presented in this thesis is mainly divided into two main parts. In the first part, transesterification process had been utilized for methyl esters production and testing the fuel properties of selected oils and their methyl esters. The present work discusses the feasibility of transesterification of bitter almond oil and sesame oil. The influence of process variables on product yield of the transesterification process has also been studied. A lot of research has already been carried out on karanja and jatropha oil but not on bitter almond oil and sesame oil. In the second part, the performance and exhaust emissions of a 3.5 kW constant speed VCR diesel engine were studied by running the engine with diesel and biodiesel- diesel blends at different engine loadings. Distinctive fuel blends containing 10%, 25% and 40% biodiesel in biodiesel-diesel blended fuel on a volume basis was prepared and used to run VCR engine. Bitter almond biodiesel and sesame biodiesel were used separately to prepare the biodiesel-diesel blends. The VCR engine performances in term of brake thermal efficiency (BTE), specific fuel consumption (SFC) and exhaust gas temperature (EGT) whereas engine exhaust emissions in term of oxides of nitrogen (NO_x), unburned hydrocarbon (HC) and carbon monoxide (CO) were evaluated. The experimental results of each blend were compared with pure diesel. Notable improvements have been seen in term of performance parameters as well as exhaust emissions of VCR diesel engine. The results show significant reduction in NO_x , HC, and CO emission but brake thermal efficiency increased marginally for both biodiesel blends at specific conditions. It concludes that biodiesel blend BAME-25 and SOME-25 biodiesel act as best alternative fuel among all tested fuel at full load condition. The present work carried out to establish the feasibility of biodiesel-fuelled CI engine utility system for agricultural and field applications. Therefore various blends of BAME and SOME can be readily adopted as a substitute fuel to the existing compression ignition engine.

Keywords: Bitter almond oil, Sesame oil, Bitter almond methyl ester, Sesame oil methyl ester Fuel properties, Engine characteristics.

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Nomenclature

BAO	Bitter almond oil
SO	Sesame oil
BAME	Bitter almond methyl ester
SOME	Sesame oil methyl ester
KOH	Potassium hydroxide
NaOH	Sodium hydroxide
FFA	Free fatty acid
DI	Direct injection
CI	Compression ignition
CR	Compression ratio
BP	Brake power
IP	Indicated power
BMEP	Brake mean effective pressure
BTE	Brake thermal efficiency
SFC	Specific fuel consumption
BSFC	Brake Specific fuel consumption
EGT	Exhaust gas temperature
CO	Carbon monoxide
HC	Hydrocarbon
NO _x	Oxide of Nitrogen
CO ₂	Carbon dioxide
ASTM	American Standards for Testing and Materials
Vol	Volume
Wt.	Weight
ppm	Parts per million
Kcal/kg	Kilocalorie/kilogram
kW	Kilowatt

Chapter 1

Introduction and Objectives

1.1 Need for Alternative Fuel

Energy is inevitable for each part of the living world including human being, animals, plants, mechanical devices and vehicles. With growing demand and use of private vehicles in the developing society and widely usage of non-renewable energy source, it becomes very necessary to promote and think about new renewable sources of energy and its proper utilization. At the same time, environmental pollution becomes a real threat for the ecosystem equilibrium due to increases energy demand. The petroleum fuel causes severe environmental pollution due to combustion in vehicular engines. The fossil fuel mainly constitutes of carbon (C) and hydrogen (H). In addition to carbon and hydrogen, they also contain nitrogen and sulphur element. Although sulfur and nitrogen are generally a relatively unnecessary contributor to the energy. It produces various gases, like CO, HC, NO_x, soot, lead compounds and other organic compounds during combustion process which is emitted into the atmosphere causing degradation of air quality [1, 2]. A light vehicular engine discharges 1 to 2 kg of pollutants during a day and heavy automobile discharges 660 kg of CO during a year [3]. The carbon monoxide is highly toxic and the exposure for a couple of hours can cause impairments to physiological functions [4]. Oxides of nitrogen and unburned hydrocarbons from the exhaust of diesel engine can cause environmental fouling by forming photochemical smog [5]. By using renewable energy, pollution can be controlled and also fulfill energy demand. Nowadays every single energy source is required to fulfill the energy demand. So biodiesel is an alternative fuel which has similar properties like conventional fuel and also a renewable source [1].

1.2 Biodiesel: A Potential diesel engine fuel

It is a mono-alkyl (mainly methyl) ester of large chain of fatty acids [2]. It is extracted from renewable bio-lipids, which meet the ASTM D6751 specification for use as a fuel in diesel engine. ASTM (originally known as the American Society for Testing and Materials) states that biodiesel is a mixture of large chain monoalkylic ester derived from fatty acids which are gained from renewable sources to be utilized as an engine fuel [2]. Biodiesel is generally formed from several domestic renewable energy resources like recycled cooking oil, vegetable

oils, or animal fats. There are various type of biodiesel production methods in which transesterification is mostly used for biodiesel production [6]. Biodiesel blends with diesel fuel referred as “BXX”, where XX referred as the amount of biodiesel percentage in the blend by volume [7]. For illustration, “B10” referred a blend with 10% biodiesel and 90% diesel fuel by volume. B100 referred as the pure biodiesel. Biodiesel is the name of an eco-friendly, clean burning, biodegradable and alternative of fossil fuel.

Biodiesel is recommended to be used as a substitute of conventional petroleum diesel fuel [8]. Because of its domestic renewability, readily biodegradable and have an environmental friendly emission profile. Biodiesel reduces the engine exhaust gas emission for example hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO₂), and particulate matter (PM) in comparison to petroleum diesel fuels [9]. However, most of the time exhaust gas emissions of nitrogen oxides (NO_x) are raised. Generally, biodiesel fuel has a higher cetane number compare with conventional petroleum diesel fuel [10]. The high fuel cetane rating suggests low idle noise and very easy cold starting [3]. Biodiesel application can extend the life of an engine's fuel injection system as a result of it being additional lubricating [2]. Power output is not significantly affected by biodiesel.

1.3 Sources of biodiesel

Due to limited source of fossil fuel and concern about global warming, there is an increasing demand to develop renewable resource. Biodiesel is a renewable promising substitute of conventional petroleum-based fossil fuel diesel fuel. Biodiesel fuels produced from regenerative natural resources such as animal fats or vegetable oils. The most popular used oils to produce biodiesel are sunflower [11], soybean [2], canola [4], cotton seed [8], rapeseed [7], palm[12], and Jatropha [8]. As the cost of edible vegetable oils is dearer than conventional petroleum diesel fuel, therefore non-edible oil and waste vegetable oils are picked out due to their low price. The resource of biodiesel production in the form of animal fat, vegetable oils (both edible & non-edible), and various other biomass are recorded in Table 1.1.

An appropriate resource to make biodiesel should not equipped with other utilizations. For instance, pharmacological raw materials but the interest for pharmaceutical raw material is extremely lesser than for fuel sources. Two basic necessities which should be fulfilled to be a source of biodiesel feedstocks are high yield productivity and less production price. Refined oils have less scale of production and high production price. Whereas, non-edible seeds for examples algae and sewerage have less production price and have large availability than refined

or recycled oils. The percentage yield per hectare of oil is significant parameter to be considered as a biodiesel production source. The percentage production of non-edible oil seeds are shown in Table 1.2.

Table 1.1 Source of oil [2]

Vegetable oils	Non-edible oils	Animal Fats	Other Sources
Soybeans	Bitter almond	Lard	Bacteria
Rapeseed	Abutilon muticum	Tallow	Algae
Canola	Andiroba	Poultry Fat	Fungi
Safflower	Babassu	Fishoil	Micro algae
Barley	Brassica carinata		Tarpenes
Coconut	B. napus		Latexes
Copra	Camelina		Cooking Oil (Yellow Grease)
Cotton seed	Cumaru		Microalgae (Chlorellavulgaris)
Groundnut	Cynara cardunculus		
Oat	Jatropha curcas		
Rice	Jatropha nana		
Sorghum	Jajoba oil		
Wheat	Pongamiaglabra		
Winter rapeseed oil	Laurel		
	Lesquerellafendleri		
	Mahua		
	Piqui		
	Palm		
	Karang		
	Tobacco seed		
	Rubber plant		
	Rice bran		
	Sesame		
	Salmon oil		

Table 1.2: Production of non-edible oil seeds and bio-residues in India [2]

Species	Oil fraction (%)	Seed estimate (10 ⁶ tones/yr)	Oil (tons/ha/y)
Castor	45–50	0.25	0.5–1.0
Jatropha	50–60	0.20	2.0–3.0
Mahua	35–40	0.20	1.0–4.0
Sal	10–12	0.20	1.0–2.0
Linseed	35–45	0.15	0.5–1.0
Neem	20–30	0.10	2.0–3.0
Karanja)	30–40	0.06	2.0–4.0
Others	10–50	0.50	0.5–2.0
Others	10–50	0.50	0.5–2.0

1.3.1 Advantages of biodiesel

Some of the important advantages of biodiesel are as follows

- 1) Biodiesel fuel is a renewable alternative source unlike petroleum-based diesel.
- 2) It has significant source of energy.
- 3) It provides alternative of petroleum-derived diesel fuel.
- 4) It can be utilized as efficient fuel in most diesel-powered engine with negligible change in engine geometry.
- 5) It can help much in reducing global warming gas emission.
- 6) It is recyclable and suitable for subtle environment.
- 7) It is produced either from recycled or agricultural resources.

1.3.2 Disadvantages of biodiesel

The disadvantages of biodiesel are as follows

- 1) It has higher viscosity and low energy content.
- 2) It has greater cloud and pour point as compared to diesel fuel.
- 3) Generally, it has higher NO_x emissions unlikely diesel fuel.
- 4) It has lower engine speed and power.
- 5) Some of the problems with biodiesel are injector coking, engine compatibility,
- 6) High price and high engine wear.

1.4 Bitter almond oil

Prunus communis, *P. americana*, and *P. amygdalus*– commonly known as almond, amandier, mandelbaum, almendro, and mandorlo (see Figure 1.1)– belong to the family Rosaceae and grow in temperate Mediterranean areas grows to a height of 3–8 m. It is available in most of producing nations like Italy, Spain, Morocco, France, Greece, and Iran. Numerous types of almonds are grown, however they can be comprehensively separated into two categories: bitter and sweet. Bitter almond consists of amygdalin and an enzyme that causes its hydrolysis to glucose, benzaldehyde, and hydrocyanic acid, making the fruit nonedible. The bitter almond oil yield is around 40–45%, and sometimes as low as 20%. Major composition of fatty acid includes palmitic acid (7.5%), stearic acid (1.8%), oleic acid (66.4%), and linoleic acid (23.5%) [3]. Main uses Bitter almond press cake cannot be used for feed due to its toxic components. They are compressed at low temperatures, normally around 30°C, to stop damage of the hydrolytic enzyme. The meal or press cake from oil extraction from bitter almond is used.5



Figure 1.1: *Prunus communis* tree [3]

1.5 Sesame oil

Sesame (*Sesamum indicum*) is herbaceous annual plant of the Pedaliaceae family. The monetarily essential crop is generally developed in many parts of the world, for the most part in (sub) tropical zones (principally maker: China, Myanmar, India) has been avowed to semiarid regions. Sesame is presently being grown in a main oilseed crop in Turkey (southeastern Anatolia Project). Worldwide sesame production amount 3.3 Mt/yr. Sesame is broadly utilized as a part of sustenance, and for nutraceutical and pharmaceutical reason in view of its high substance of oil (37-63%), protein (18-25%) and cell reinforcements (sesamin and sesaminol lignans). is a broadleaf herb that developed around 4 to 6 feet high. The height depends on the diversity and developing conditions [3].



Figure 1.2: Sesame seeds [3]

1.6 Biodiesel production methods

There are several standardized techniques for the production of biodiesel [5]. The commonly used methods for preparation of biodiesel described on below

1.6.1 Blending

In this technique, vegetable oil is specifically blended with petroleum diesel fuel in a certain proportion [8]. In this method, no chemical reaction is involved. The direct usage of vegetable oils (edible or non-edible oil) in CI engine is unfavorable and problematic because it has numerous inherent failings. Despite the fact that the vegetable oils have recognizable properties as biodiesel fuel.

1.6.2 Transesterification

Transesterification (also called alcoholysis) is a most generalized method for methyl ester production. Transesterification is a biochemical reaction of triglyceride oils containing

vegetable oils, animal fats or recycled greases with a methanol in the existence of a catalyst to form mono-alkyl esters and glycerol [2, 8]. The reaction process needs a high temperature (approximate 60°C) and a solid base alkali catalysts such as KOH and NaOH. Catalyst increases the reaction frequency and production yield. Alcohol converts the triglycerides into ester.

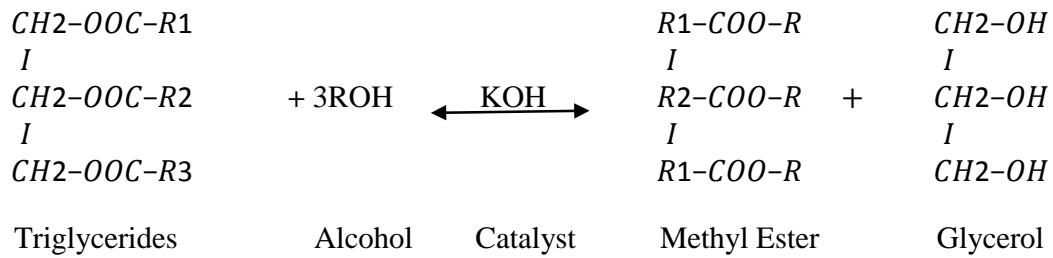


Figure 1.3: Transesterification reaction takes place during biodiesel production [1]

The alcohol which is mainly used in this process is methanol, ethanol, butanol, propanol and amyl alcohol. Amongst these, methanol and ethanol is usually utilized especially methanol. The reaction is catalyzed by any one of the acidic, alkalis or enzyme catalyst. In alkali catalysts, KOH and NAOH are mostly used.

1.6.3 Pyrolysis

Pyrolysis is described as the change of one substance into another by the application of thermal energy in the presence of catalyst [1, 8]. In the thermal cracking process animal fats, vegetable oils, natural fatty acids are heated in the deficiency of air or nitrogen in the temperature higher to 450°C and break the molecules by heating [2]. After heating, we get a mixture of chemical compounds with similar properties like petrodiesel.

1.6.4 Micro-Emulsification

The formulation of hybrid diesel fuel by solubilisation of vegetable oil/alcohol mixtures through the addition of amphiphiles was initially known as microemulsion [1]. Micro-emulsion involves the blending of vegetable oils with appropriate emulsifying agents to form emulsions. The main disadvantage associated with the utilization of micro-emulsion engine is the huge stores carbon in the engine because of incomplete combustion [2]. A micro-emulsion is referred as a clear transparent, isotropic liquid mixer, thermodynamically stable colloidal scattering of microstructure with diameter ranges from 100Å to 1000Å [13].

1.7 Factors affecting production of biodiesel

- 1) Increase in the molar to ratio increases the yield of methyl ester from vegetable oil up to a particular limit. After a higher molar ratio than a particular limit, the glycerol becomes difficult to separate.
- 2) Amount and type of catalyst also affect the conversion rate from vegetable oil to methyl ester. For oils having less fatty acid content alkaline transesterification is used and for oils having higher fatty acid content acid transesterification is used.
- 3) Stirring helps in higher conversion rate of methyl ester from vegetable oil.
- 4) Impurities present in vegetable decreases the conversion rate into methyl ester.

1.8 Properties of biodiesel

Biodiesel characteristics depend on several parameters such as feedstock plants, climate condition, soil type, rainfall and plants health and plants maturity upon harvest. The properties of biodiesel are affected by these parameters. Hence biodiesel fuels are characterized by a number of physiochemical properties. Some of these are density, FFA, heating value, kinematic viscosity, fire point, flash point, pour point, cetane no, copper strip corrosion, carbon residue, iodine value, saponification number and moisture content. Although most of the biodiesel properties are similar to those of diesel, there are considerable differences in some of the basic fuel properties such as calorific values, density and viscosity. Biodiesel properties should meet the IS 15607, ASTM D-6751 and EN 14214 specifications. The details of methodology and equipment used for measuring individual fuel properties are described in Sec. 3.6.

1.8.1 Specific gravity

Specific gravity (SG) of biodiesel is more than the specific gravity of petroleum diesel fuel. This permits to utilize the splash blending by mixing biodiesel on the top of fuel to form biodiesel-diesel blends. If biodiesel fuel is first placed at the base of the tank and after that diesel fuel is poured, it won't combine properly. Density regulator is defined in European specifications however not in ASTM requirement.

1.8.2 Kinematic viscosity

Viscosity plays an essential role in uniform combustion. The performance of fuel in IC engine also greatly depends upon their kinematic viscosity. It is important physical properties of the

fluid. It is a measure internal resistance of fluid to flow. This occurs due to the phenomena of the cohesive force and molecular momentum among the fluid molecules in liquid. In diesel engine, increasing fuel viscosity decreases the injector spray cone angle, fuel penetration and distribution, besides increasing droplet size thus influencing fuel injection. The viscosity of fuel is the function of temperature. Diesel engine fuels with significantly high viscosities can bring out extreme heat generation in the injection equipment because of viscous shear in the clearance amongst cylinder and pump plunger. On the contrary, too low viscosity would lead to leakage through that clearance.

1.8.3 Flash and Fire point

The minimum temperature at which flammable mixture above the liquid fuel may be formed is called flash point. It is the only characteristics of the liquid, which must be considered for the flammability threat of a material. It is distinguished as the possibility of having highly volatile and inflammable substance relative to non-volatile or non-flammable material. The flash point is considered as hazardous when the temperature of the material reaches 90°C or above, as determined by the test. A Pensky Martens closed cup type test setup was used to determine the flash point. Biodiesel fuel has a relatively higher flash point than diesel fuel. Therefore storage point of view, biodiesel and its mixture are not much dangerous compare than petroleum diesel fuel. However, flash point reduces significantly for a mixture of biodiesel fuel. The alcohol used for the formation of biodiesel is not removed properly. It also causes of diminishes fuel combustion quality.

1.8.4 Pour and Cloud point

Cloud point (CP) is characterized by the temperature below which a wax crystal form in the liquid at bottom test jar when the liquid goes through the cooling process under a specified manner. Pour point (PP) is also defined the minimum temperature at which movement of fuel ceases to flow when liquid undergoes in the cooling process. Biodiesel fuel has normally higher cloud and pour point than petroleum diesel fuel.

1.8.5 Calorific value

Calorific value fuel is significant fuel property and it is characterized by the quantity of heat liberated during the burning of a unit weight of fuel. It is also defined as the quantity of heat liberated when the fuel is burnt completely and has given all of its energy.

1.8.6 Ash content

It is characterized as the quantity of inorganic waste product like catalyst residues, abrasive solids and also some soluble metal soaps concentration in a fuel sample. These compounds are oxidized during the burning process to produce ash which is stored with engine deposits. The higher the ash content the higher is the risk of engine damage.

1.8.7 Carbon residual content

Carbon residue is the non-volatile residue left when fuel is warmed to a high temperature in the deficiency of air. It is related with several amounts of glycerides, soaps, catalyst residue and free fatty acids. It gives an indication of the coke forming tendencies (e.g. coke deposits inside the combustion chamber and on injector tips) of the fuel at higher temperature. Fuels having less carbon residue are good for engine operation.

1.8.8 Cetane number

Cetane Number refers the readiness of the substance to self-ignite when the substance is exposed to the high temperatures and pressure in the combustion chamber of diesel engine. Higher Cetane number fuel has better ignition properties or have shorter ignition delay periods. It affects engine performance parameter like fuel combustion, smoke, noise, stability and emission of carbon monoxide (CO) and hydrocarbons (HC).

1.9 Specification of quality standards of biodiesel

Standards play an important role for the producers, suppliers and consumers of biofuels. Traditionally codes for items have been built up, for the most part by analyzing present norms and codes in various nations. A worldwide overview of biodiesel determination was done and an exertion was made to comprehend the goal behind them before exhorting a standard for India. The key constituents, which represent the superiority of biodiesel, are monoalkyl esters, dialkyl esters, residual vegetable oil, free glycerin, reactant alcohol, free fatty acids and the residual catalyst. This specification states that the only form of biodiesel that can be legally resold for the commercial operation must meet ASTM specification which is written in tabular form as in Table 1.3.

Table 1.3: ASTM Specifications (D6751) For B100 [5]

Properties	ASTM Method	Limits	Units
Flash Point	D93	130 min	°C
Water & Sediment	D2709	0.05 max	% vol.
Kinematic Viscosity (40°C)	D445	1.9–6.0	mm ² /s
Sulfated Ash	D874	0.02 max.	% mass
Sulfur	D5453.	0.05 max	% mass
Copper Strip Corrosion	D130	No. 3 max.	-
Cetane	D613	47 min	-
Cloud Point	D2500	Report	°C
Carbon Residue (100% Sample)	D4530 ^a	0.05 max	% mass
Acid Number	D664	0.8 max	Mg KOH/g
Free Glycerin	D6584	0.02 max	% mass
Total Glycerin	D6584	0.24 max	% mass
Phosphorous Content	D4951	0.001 max	% mass
Distillation Temperature, Atmospheric Equivalent Temperature (90% Recovered)	D1160	360 max	°C

1.10 Importance of the present study

The following points have been carefully analyzed for the importance of the study.

- The increasing cost of fuels, widening demand and supply gap, rapid depletion of world fossil fuel reserves.
- Drastic changes in the environment due to combustion of fossil fuels.
- There exists a great potential for transport sector.

Depending on the abundant availability of feedstock in local region, the different feedstocks are the focus of biodiesel production. In South East Asia regions, bitter almond oil and sesame oil are expected to be the major sources for biodiesel productions.

1.11 Objectives of the study

The main objectives of the study can be stated as the following

- 1) Preparation of bitter almond methyl ester and sesame oil methyl ester using alkyl transesterification process by optimizing the production parameters.
- 2) Determination of fuel properties of the bitter almond biodiesel, Sesame biodiesel and diesel.
- 3) Evaluation and Comparison of various performance parameters of methyl ester blend fuels such as brake thermal efficiency, specific fuel consumption, Exhaust gas temperature with diesel fuel on VCR engine.
- 4) Evaluation and Comparison of various emission parameters of methyl ester blend fuels such as hydrocarbon emissions, carbon monoxide emissions and nitrogen oxide emissions with diesel fuel on VCR engine.

Chapter 2

Review of Literature

This chapter reviews the background study on biodiesel production and engine testing. It describes, summarizes, evaluates and clarifies the literature of the problem. It helps us to get a theoretical base for the research and determine the nature of the research.

Pugazhivadivu et al. [14] examined the engine performance and exhaust emission on a single cylinder diesel engine driven by preheated waste frying oil as engine fuel. High viscous Waste frying oil (WFO) was preheated and reduced the viscosity before inlet into the combustion chamber. The characteristics of WFO such as kinematic viscosity, fire point, pour point, calorific value and flash point etc. were tested and calculated. The effect of temperature on the kinematic viscosity was investigated. It was determined that at 130°C temperature, the viscosity of waste frying oil near to diesel fuel viscosity at 30°C. The engine was run on preheated waste frying oil fuel at 135°C and 75°C. The performance test on engine revealed that preheated WFO used as diesel engine fuel. It enhanced the BSFC and BTE. The engine exhaust emission such as Carbon monoxide (CO) and smoke were drop significantly. For preheated waste frying oil, considerably improved the engine performance and reduced the carbon monoxide (CO) at 135°C compared to 75°C. From the experimental investigation, it was concluded that waste frying oil might be utilized as a substitute for diesel fuel by decreasing its kinematic viscosity near to diesel fuel viscosity at 30°C.

Ramadhass et al. [15] conducted the experiment to form methyl ester from high FFA rubber seed oil. Two steps transesterification process has been introduced to transform the high FFA oils to mono-ester. In the two steps transesterification, the first step has been used to reduce the FFA content to less than 2% by acid catalyzed esterification. In the second step, the product of first step has been converted into mono-esters by alkaline catalyzed transesterification. Byproduct of the first and second step is glycerol. The researcher investigated the effect of methanol to oil ratio, concentration of catalyst, temperature of reaction and time of reaction on methyl ester formation. Sulfuric acid (H₂SO₄), sodium hydroxide (NaOH) and methanol (CH₃OH) had used as an acid, catalyst and alcohol respectively in the two-step transesterification process. The final product of the process was biodiesel (rubber seed oil

methyl ester) that's viscosity is near to the diesel and CV (calorific value) was 14% less in comparison to diesel fuel. All other properties of rubber seed biodiesel are found and compare to ASTM standard. The result showed that biodiesel of unrefined rubber seed oil as a substitute for the diesel fuel.

Hebbal et al. [16] conducted the experiments to study the performance and exhaust emission behavior of deccan hemp oil (DHO) on diesel engine. The experiments were tested with blend of DHO with diesel by 25/75, 50/50, 75/25 and 100/0% on volume basis. The blended fuels were heated and variation in viscosity with temperature was analyzed. The engine load was varied from 0.37 to 3.68 kW and rpm kept was constant at 1500rpm. The BTE, BSFC, and BSEC were almost equivalent to diesel and exhaust emission were slightly higher for 25 and 50% blends. The smoke, CO and HC emission were increased by 51.74, 71.42 and 33.3% respectively for 50% blends in comparison to diesel fuel. From the experimental analysis, it had been concluded that up to 25% blend of DHO without heating and up to 50% blend with pre-heating could be utilized in place of pure diesel without any major change in engine geometry.

Nabi et al. [17] evaluated the effect of neem oil methyl ester on combustion and exhaust emission in diesel engine. The biodiesel was prepared from neem oil by esterification. The conventional diesel fuel and methyl ester fuel were used to run the engine. The experimental results of methyl ester were compared to conventional diesel fuel. The observation reading indicated that the exhaust emission including smoke and CO were decreased for neem oil biodiesel compared to conventional diesel whereas nitrogen oxide emission was raised with diesel-neem oil biodiesel blends. The reduction in carbon monoxide emission and incremental in NO_x emission were assorted with the oxygen percentage in the methyl ester fuel. The outcomes results suggested that neem oil biodiesel could be used in place of pure conventional diesel fuel.

Sahoo et al. [18] examined the methyl ester formation from polanga seed oil and the engine performance in a CI engine. Triple stage transesterification process has been utilized to convert the highly viscous (72 cSt at 40°C) and highly acid value polanga seed oil to Biodiesel. Biodiesel blends (B20, B40, B60, B80 and B100) were prepared with high-speed diesel (HSD). The experiments were tested in a single cylinder diesel engine. The methyl ester blended fuel effect were evaluated at varying load condition (0, 20, 40, 60, 80 and 100 %). The result of tested

fuel revealed that the pure biodiesel B100 has been found to give good quality results. It enhanced the brake thermal efficiency (BTE) by 0.1% of the engine and reduced the smoke emissions also by 35 percent for B60 compared to diesel fuel. Reduction in the EGT (exhaust gas temperature) for B100 driven engine lead to around 4% decrement in NO_x formation at full load. Based on the experimental result, it may be concluded that methyl ester of polanga can be accepted in place of diesel fuel.

Agarwal et al. [19] conducted the performance and exhaust emissions test by using diesel, simple Jatropha oil, preheated Jatropha oil and blends of Jatropha oil (10, 20, 30, 40, 50, and 75 %) as an engine fuel at various loads and constant RPM (1500 rpm). Where 10 % indicated 10% Jatropha mixed with 90% diesel by volume. Single cylinder, four stroke, water cooled, direct injection diesel engine was used in the experiments. BSFC and EGT was more for simple Jatropha compared to diesel and heated Jatropha oil. The engine exhaust emission (CO, CO₂, HC, and NO_x) were enhanced for Jatropha oil in comparison to diesel. These exhaust emission values for preheated Jatropha oil were noted to be very near to conventional diesel. Brake specific fuel consumption and EGT were found slightly higher for blended fuel compared to diesel. The engine exhaust mission parameters have increasing nature with increasing to Jatropha oil concentration in diesel fuel.

Karabektas et al. [20] observed the effect on performance and exhaust emission of diesel engine fueled by preheated cottonseed biodiesel. The biodiesel was formed by cottonseed oil. Methyl alcohol and potassium hydroxide was used as alcohol and catalyst respectively. The experiment has been tested at full load condition. Single cylinder, four stroke, direct injection diesel engine was used for experimentation. Biodiesel was preheated before injected into the combustion chamber. At four different preheated temperature 30°C, 60°C, 90°C and 120°C, fuel was preheated. The experimental results showed that up to 90°C preheated biodiesel gave favorable effect on BTE and CO emission with little bit increment in NO_x emission. BP was also little bit increased up to 90°C. When biodiesel was preheated at 120°C, a significant drop was observed in BP due to the excessive fuel leakage caused by reduced fuel viscosity. The outcomes had been suggested that up to 90°C preheated cottonseed biodiesel could be used in place of pure diesel.

Banapurmath et al. [21] investigated the transesterification of Honga, Jatropha and Sesame oil to produce the biodiesel to use as a substitute for diesel fuel in DI compression ignition

engine. This Engine was operated to evaluate performance and exhaust emission characteristics of biodiesel fuelled diesel engine. The methyl ester of honne oil, sesame oil and jatropha oil was mixed with 31.25% diesel and the BTE of these blends was noted as 29.51%, 30.4% and 29% respectively at 80% load condition. The result of all the tested blends was showed that marginal reduction in thermal efficiency with little increment in smoke, HC and CO levels. The higher BSFC (brake specific fuel consumption) and lower emission (HC, CO, NO_x) with sesame oil biodiesel operation were observed compared to other two biodiesel.

Sehmus et al. [22] evaluated the effect of fuel blending of sesame oil with diesel in a direct injection diesel engine. Sesame oil was used for 50 percent blending with diesel. The results of blending fuel in direct injection diesel engine show that the amount of exhaust gas emission had been significantly reduced compare than diesel fuel with little changes in the engine power and torque. Specific fuel consumption (SFC) for sesame blends is slighter greater than diesel. Engine power and Engine torque had been increased with increasing engine speed till a specified speed range after that it decreases with increasing speed. It had been seen that blend of sesame oil with diesel may be used effectively in place of diesel without any major changes in direct injection diesel engine.

Can et al. [23] examined the LHR (low heat rejection) diesel engine by utilization of biodiesel as engine driven fuel and analyzed the performance characteristics behavior. The performance characteristic of the four-stroke, four cylinders with 17.25 compression ration diesel engine was used for experimental purpose. In their study, a turbocharged DI diesel engine was used and modified into a LHR diesel engine. Biodiesel of sunflower oil was used as an engine driven fuel. Experimental result of LHR diesel engine for biodiesel revealed that SFC and BTE were rises compared to a standard diesel engine. EGT was also increased at the entrance of the turbine for both diesel and biodiesel in LHR diesel engine.

Venkanna and Reddy [24] examined the formation of biodiesel from undi oil (*Calophyllum inophyllum* linn). A tree stage process has been implemented for biodiesel formation. They studied and optimized the effect of different reaction parameters such as methanol to oil ratio, concentration of catalyst, temperature of reaction and time of reaction. The methanol to oil was changed from 4:1 to 10:1 and catalyst from 0.75–1.5% (w/w_{oil}). The highest yield of biodiesel by acid esterification process had been found at 0.5 ml anhydrous Sulphuric acid, reaction

temperature $60 \pm 1^\circ\text{C}$, reaction time 2 hour and molar ratio 4:1. The maximum yield of biodiesel is found to be 89% under the optimized condition.

Agarwal et al. [25] studied the engine performance and exhaust emission on a single cylinder agricultural diesel engine. Engine was fuelled by Karanja oil and its blends (K10, K20, K50 and K75) where K10 represents a blend of 10% Karanja oil with 90% diesel by volume. The viscosity of Karanja oil was reduced by special arrangement of heat transfer from exhaust gas. A series of tests have been conducted with or without preheating using Karanja oil and its blend as a fuel and its results compared to diesel fuel. The engine test showed that brake thermal efficiency is nearly 30% for preheated oil blends. And it varied from 24 to 27% for unheated lower blends K10, K20 and K50. BSFC and BSEC (brake specific energy consumption) of the engine has been displayed an increasing trend with preheated lower blends. There was no much more variation in smoke density of exhaust gas for preheated lower blends and unheated lower blends compare to diesel fuel. The hydrocarbon emission (HC) was reduced for preheated and unheated lower blends (K10 and K20) when compared to mineral diesel. The nitrogen oxide (NO_x) emission also reduced for all prepared blends at all load condition compare to mineral diesel.

Jindal et al. [26] investigated the consequence of injection pressure (IP) and compression ratio (CR) on the performance and exhaust emission characteristics in a DI diesel engine fueled by Jatropha methyl ester. The experiment was conducted at 16:1, 17:1 and 18:1 compression ratio. The effect of IP and CR on brake specific fuel consumption, brake thermal efficiency, emission of HC, NO_x , CO, CO_2 and smoke capacity revealed that combined increase in the CR and IP had increased the BTE and BSFC. Emission also reduced with increasing the CR and IP. The optimum injection pressure 250 bar and optimum compression ratio 18:1 was found for agricultural small sized direct injection diesel engine at constant speed.

Panwar et al. [27] examined the characteristic analysis of diesel engine fueled by biodiesel of castor seed oil. The transesterification method was adopted for production of biodiesel using potassium hydroxide as catalyst. The experiment was carried out in 4-stroke, single cylinder VCR type diesel engine at constant speed 1500 rpm with different loading condition. The engine performance was analyzed by using different blended fuel B05, B10, B20 and pure diesel D100. The results revealed that brake thermal efficiency increased for lower blends and also reduced the SFC. The temperature of exhaust emission gas was raised with biodiesel

percentage in the blended fuel. The conclusion is that the biodiesel of castor seed oil is an alternative to diesel to run the compression ignition engine.

Hazar et al. [28] evaluated the effect of the performance and exhaust emission on engine fueled by blends of preheated of raw rapeseed oil (RPO). The blended fuel (O50 and O20) were prepared. Where O20 indicates 20% raw rapeseed oil and 50% diesel. The blended fuels were tested in a single cylinder, 4-stroke direct injection compression ignition engine. The effect of preheating to 100°C showed that preheating reduced the viscosity of fuel and provide smooth flow. Preheating is essential to flow the fuel smoothly and to avoid fuel filtration clogging. BSFC was reduced considerably by using O50 blend. The EGT for O50 blend was significantly high compared to O20 and diesel fuel. Nitrogen oxide emission also reduced. The carbon monoxide (CO) emission reduced for all tested fuel with preheating. Smoke density reduced with preheating for all tested fuels. The investigation concluded that preheated raw rapeseed oil significantly improve the performance and emission characteristic.

Atapour and Kariminia [29] studied the methyl ester formation from BAO by adopting the transesterification reaction process. The reaction occurred in the presence of KOH catalyst. The content of unsaturated fatty acids is high in BAO that is confirmed by fatty acid content analysis. Effect of different parameters including temperature of reaction (30-70°C), concentration of catalyst (0.1-1.7% w/w) and molar ratio (3-11 mol/mol) on product production yield, biodiesel yield and biodiesel purity was examined. The consequence of temperature is little on product yield while temperature varies from 30-50°C. However, the product yield decreased with raising the reaction temperature from 50-70°C. Biodiesel yield and their purity was increased with temperature varies from 30-50°C. The yield of biodiesel was found maximum at 50°C. Further rise the reaction temperature value from 50-70°C then biodiesel purity and yield were starting to decrease when KOH catalyst concentration varies from 0.1 to 0.9% w/w. the biodiesel production yield was almost unaffected. On the other hand biodiesel purity, biodiesel yield and biodiesel purity were increased. The maximum value of biodiesel yield (90.8% w/w) was formed at 0.9% w/w catalyst concentration. Biodiesel yield, product yield and biodiesel purity were increased with increasing the value of molar ratio value 3:1 to 7:1. Further increase the molar ratio, the slight effect on yield of product. On the other hand with increase the methanol to oil ratio value 7:1 to 11:1, the biodiesel yield and biodiesel purity reduced. They also measured the biodiesel properties including density, kinematic viscosity, acid value, saponification value, Cetane number, flash point, cloud point, iodine value, and

pour point. The properties of biodiesel were compared to standard biodiesel properties (ASTM 6751 and EN14214).

Muralidharan et al. [30] examined the combustion, performance and emission characteristics of methyl ester. The experiment was tested on four stroke, single cylinder variable compression ratio (VCR) multi-fuel engine at a constant speed with varying load. The engine was run on blend of waste cooking oil methyl ester (WCOME) with diesel and pure diesel. The samples of blended fuel B20, B40, B60 and B80 were prepared. Compression ratio was fixed at 21. The blended fuel result was compared with standard diesel fuel result. The result showed that the exhaust emission of HC, CO₂ and CO were reduced for blended fuel whereas NO₂ was increased when compared to standard fuel diesel. Engine Brake thermal efficiency (BTE) for the blends were growing while increasing in applied load. 38.49% BTE for B40 which is 4.1% greater than standard diesel at full load condition. Specific fuel consumption (SFC) gradually reduced with rise in load. At full load for B20 and B40, the SFC is 3.8050 kg/kWh and 3.8817 kg/kWh correspondingly. Which is lower than standard diesel SFC 3.9758 kg/kWh. The result has found that combustion characteristics of WCOME blends are very similar to standard diesel.

Jothithirumal et al. [31] estimated the combine effect of biodiesel and exhaust gas recirculation on nitrogen oxide (NO_x) exhaust gas emission in a direct injection diesel engine. The experimental work was conducted at constant speed 1500 rpm, constant compression ratio 18.5:1 in vertical inline four-stroke, two-cylinder direct injection diesel engine. In diesel engine, generally NO_x formation in the diesel engine is highly temperature reliant phenomenon. And it had been taken place when combustion temperature exceed 2000K. So Authors control the combustion temperature to reduce the NO_x formation. Exhaust gas recirculation system was used to control the NO_x emission. The engine was fueled by B20, B50, B75, B100 blends and D100. The experimental results showed that NO_x emission was reduced with pure diesel fuel for all load condition at 25% EGR valve opening. But Smoke emission and Particulate emission was enhanced at this condition. There were no significant changes was observed in Brake thermal efficiency at the 25% EGR valve open condition.

Venkanna and Reddy [32] examined the combustion, performance and emission characteristics of a diesel engine running on blends of undi oil (Honne oil) with diesel fuel. The engine tested with fuel blends H10 to H50. The Combustion characteristics, performance, and

exhaust emission of engine for H20 blend fuel are noted near the value to pure diesel fuelled engine whereas higher blend ratio were obtained to be lower to diesel fuel. The outcomes from the experiments show that undi oil and their blends have good potential to alternate the diesel fuel in the coming time. Up to 20% blend of undi oil with diesel could be utilized for short-term usage without any major changes and harmful effect.

Nayak et al. [33] investigated the engine performance and exhaust emission characteristics of a diesel engine driven by Mahua biodiesel with additive. Mahua oil methyl ester blends (B95, B90, and B85) were prepared with additive. Where B95 indicates the mixer of 95% biodiesel and 5% additive. The biodiesel blended fuels were used to evaluate the effect on engine performance at variable load condition (0, 20, 40, 60, 80 and 100 %). The result of diesel engine test showed that BTE for diesel, B100, B95, B90 and B85 are noted 30.09, 26.63, 28.01, 29.74 and 29.97% respectively at full load. Which revealed that BTE improved significantly when additive concentration in mahua oil biodiesel increase. BSFC is maximum for 100% methyl ester at each load condition due to its high density, high volatility and low heat content of biodiesel compare to diesel. BSFC have decreasing trend with the quantity of additive in biodiesel due to efficient combustion. The emission of carbon monoxide and hydrocarbon tended to falls with rising in additive concentration in mahua oil methyl ester. NO_x emissions had been reduced with rising the quantity of additive to the Mahua biodiesel due to decrease in engine in-cylinder temperature because of smooth combustion.

Abu-Hamdeh and Alnefaie [34] evaluated the performance and exhaust emission of diesel engine derived from almond biodiesel blend with diesel fuel. Biodiesel blends B10, B30 and B50 were prepared on a volume basis. Where B10 represents a blend of 10% almond oil with 90% diesel by volume. the diesel engine was tested and found the result that At a fixed value of torque specific fuel consumption increases with increasing blending percentage, brake thermal efficiency reduced with rising in percentage concentration of biodiesel, emission of carbon monoxide decreases with increasing blending percentage, total particulate emission decreases with increasing blending percentage unburned fuel emission decreases with increasing blending percentage and NO_x emission increases with increasing blending percentage.

Obed et al. [35] studied the formation of biodiesel feasibility from palm oil. Properties of blended fuel were tested for different blended ratio and compare these blended fuel properties

with ASTM D7467 biodiesel standard. The results have found that 30% palm biodiesel blending with diesel come into ASTM D7467 biodiesel standard. The pour point of blended fuel proportionally increases with an increasing blending ratio of palm biodiesel. There are no statistically significant changes in the cloud point of blended fuel. The heating value of palm oil biodiesel is 14% lesser than diesel fuel. Biodiesel became cause a linearly reduction in heating value of the blended fuel. The experimental results on engine reveal that BTE had not changed significantly.

Nagaraja et al. [36] tested the engine emission quality, engine performance and combustion characteristics of the corn oil methyl ester blend with petrodiesel fuel. The experiment was tested on a single cylinder, 4-stroke diesel engine. The corn oil biodiesel was mixed with conventional diesel in different percentage. The five blended fuel sample B20, B40, B60, B80 and B100 was prepared. All blends properties lie within the standard limit specified by ASTM D6751-03. All the Blended fuel combustion properties are compared with pure conventional diesel. The results revealed that corn oil methyl ester has lower engine exhaust emission and enhance the engine performance as compared to conventional diesel D100. At full load, it has found that specific fuel consumption for B100 was 4% lesser compared to pure diesel. The maximum BTE was 8.5% higher for B100 compared to D100. The environmental point of view, emission of Hydrocarbon (HC), Carbon monoxide (CO), Carbon Dioxide (CO₂), and Nitrogen Oxide (NO_x) were found to be 2.3 to 18.8% less as compared to D100 at full as well as at part load condition. The heat release rate to the environment for biodiesel and its blends were noted to 16 to 35% less than to pure conventional diesel at part load condition.

Ashok et al. [37] examined the suitability of *Calophyllum inophyllum* as an alternative source of biodiesel production and its employability in diesel engine. Pure biodiesel and its blends with conventional diesel (B30 and B60) had been used to run the diesel engine. The experimental parameter BTE, BSFC, unburned hydrocarbon, CO₂ and NO_x emission were determined for B100 and compared with conventional diesel fuel. The results revealed that BTE was slightly reduced for B100 and HC and CO emission were also significantly reduced with little bit increment in NO_x emission. In addition, the combustion parameter such as ignition delay period, the pressure inside cylinder and heat release rate were considered and obtained in the acceptable range compared to conventional diesel fuel. Thus it may be concluded that *Calophyllum inophyllum* can serve as an alternative to conventional diesel fuel. It was more environment-friendly in nature.

Barik et al. [38] studied on the performance of direct injection (DI) diesel engine driven by Karanja biodiesel-biogas dual fuel at various injection timings. The study explored the probability of using Karanja biodiesel as a pilot fuel in a biogas driven DI diesel engine of rated power 4.4 kW at 1500 rpm, with CR of 17.5:1. The ejection timing of pilot fuel was ranged from 21.5 °CA bTDC to 27.5 °CA bTDC in steps size 1.5 °CA. biodiesel dual fuel mode with injection timing had been indicated as BDFMX, where X denotes the injection timing. Better performance and lower emission were noted for BDFM24.5 among the all. The experimental results for BDFM24.5 showed that BSFC were increased 23.9% than that of Karanja biodiesel at full load. And about 6.6% enhance in brake thermal efficiency had been noted for BDFM24.5 compared to BDFM23.0 at full load. BDFM24.5 reduced the exhaust gas emission CO, HC and smoke of 17.1%, 18.2% and 2.1% respectively compared to BDFM23.0, at full load. But, No emission was increased 5.5% by BDFM24.5 compared to BDFM23.0 at full load.

Chapter 3

Materials and Methods

This chapter provides a brief overview of procedures followed and methodology adopted to achieve the objective. The prospect of biodiesel obtained from tree seed vegetable oil has been investigated in this research work. This chapter describes the characteristics of fuel and experimental methods to evaluate the properties of biodiesel and their blends. Numerous experiments, experimental setup, analytical tool, engine set up, gas analyzer were used to evaluate the engine performance, emission characteristics for diesel and blend of biodiesel with diesel. The research experiment tests were conducted on VCR engine in IC engine lab of Thapar University, Department of mechanical engineering.

3.1 The Methodology of the research work

The research investigation is divided into the following steps:–

- 1) Selection of potential oils for biodiesel production.
- 2) Biodiesel Production by transesterification process
- 3) Determination of fuel properties of BAO, SO and their methyl esters.
- 4) VCR Engine testing
- 5) Evaluation of performance and exhaust emission characteristics of methyl ester blends.

3.2 Identification of feedstocks

First of all sesame oil and bitter almond oil was selected for the biodiesel production based on the literature survey. Sample of Sesame oil and bitter almond oil was purchased from AOS Products Private Limited, Delhi. Biodiesel was prepared in the laboratory at Mechanical Engineering Lab Thapar University Patiala, Punjab (India). Various materials like potassium hydroxide (KOH), sodium hydroxide (NAOH), methanol, ethanol, phenolphthalein, were used in the preparation of biodiesel.

3.3 Standardization of transesterification process

The influence of process parameters presented in Table 3.1 was considered to stabilize the transesterification process and to recover more ester with lowest possible viscosity from the lipid oils. In order to standardize the process parameters, Molar ratio, reaction temperature, reaction time and catalyst concentration was selected as a variable process parameter.

Table 3.1: Transesterification Process parameter

S/N	Process parameters	Description
1	Process	Alkali catalyzed transesterification
2	Reaction temperature	55 – 60°C
3	Sample oil used	150 ml of neat oil
4	Molar Ratio	6:1, 4:1
5	Catalyst concentration (KOH)	0.50%, 0.67% of oil
6	Reaction time	60 min, 120 min
7	Settling time	8 – 10 hours
8	Water washing	8 – 24 hours
9	Stirring speed	220 – 300 rpm

3.4 Single stage transesterification process

Various steps used in the preparation of biodiesel from oil are described as below:

- 1) In the beginning, the 250mL capacity Borosilicate conical flask was filled with 150gm of oil and heated up to the 45°C to 50°C temperature using the simple heater.
- 2) Accordance to our molar ratio and catalyst concentration, fixed amount of catalyst (KOH) was dissolved into calculated amount of preheated methanol with the help of a standard mixer.
- 3) Completely dissolved mixer of methanol and catalyst was added into the preheated bitter almond oil.
- 4) After mixing of methoxide solution and oil in the borosilicate conical flask, the conical flask was placed into the shaking water bath.
- 5) The reaction was accomplished at 60°C for an hour.
- 6) After completion of the reaction, the conical flask was removed from the water bath shaker and the products of the reaction were transmitted to a separating funnel.

- 7) After 24 h when reaction product was settled down, the reaction product was divided into two layers. Top phase layer is biodiesel and lower is glycerol.
- 8) layers were separately collected into two separate flasks.
- 9) The separated biodiesel was washed three to four times by preheated deionized water (42-45°C) until wash deionized water became translucent.



Figure 3.1: Separation of BAME from glycerol



Figure 3.2: BAME after water wash



Figure 3.3: Separation of SOME from glycerol



Figure 3.4: SOME after water wash

The stepwise methodology adopted for transesterification of bitter almond and sesame oil are shown in Figure 3.5 and Figure 3.7 respectively.

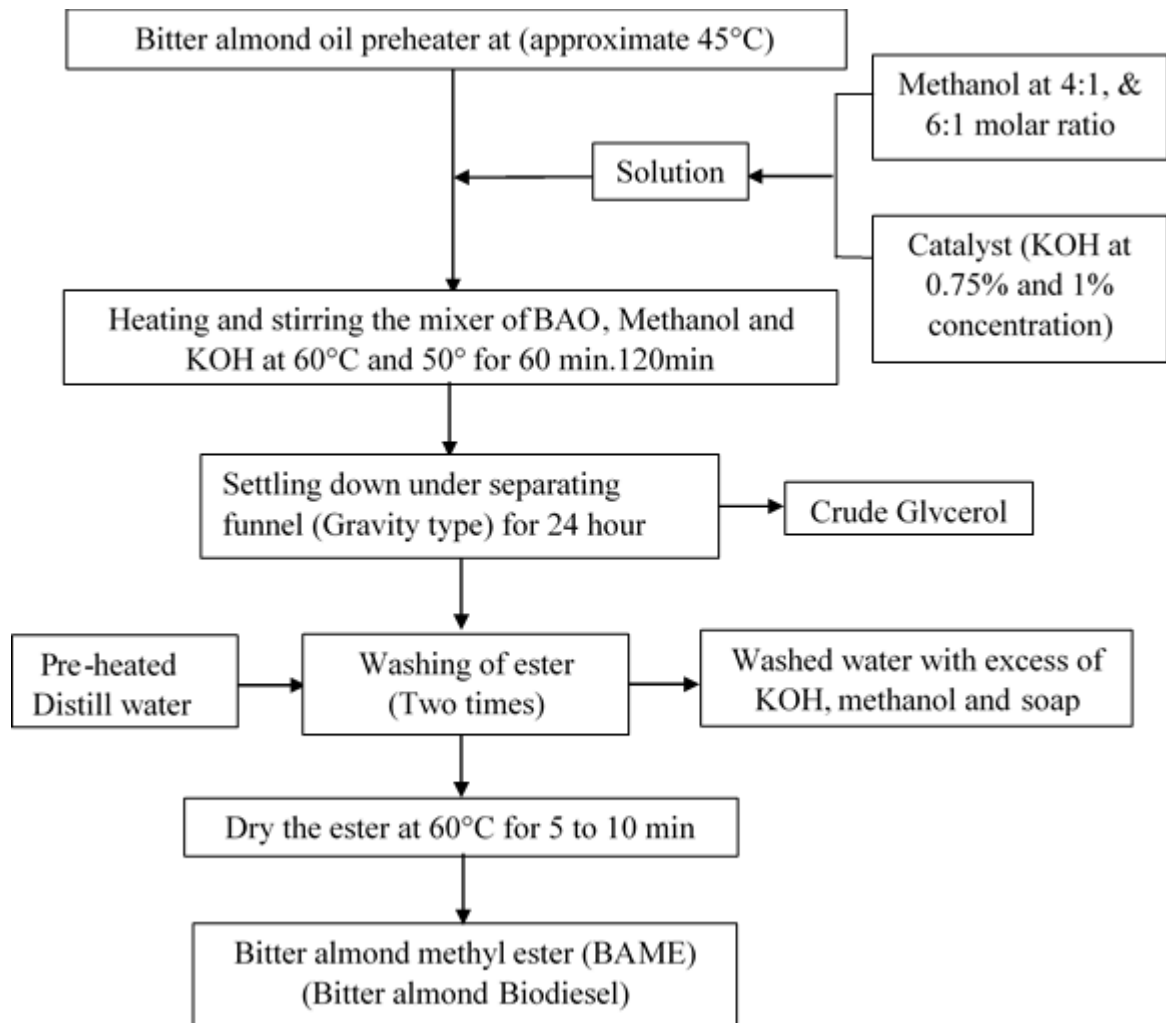


Figure 3.5: Flow Chart of biodiesel Production from bitter almond oil



Figure 3.6: Biodiesel samples from BAO

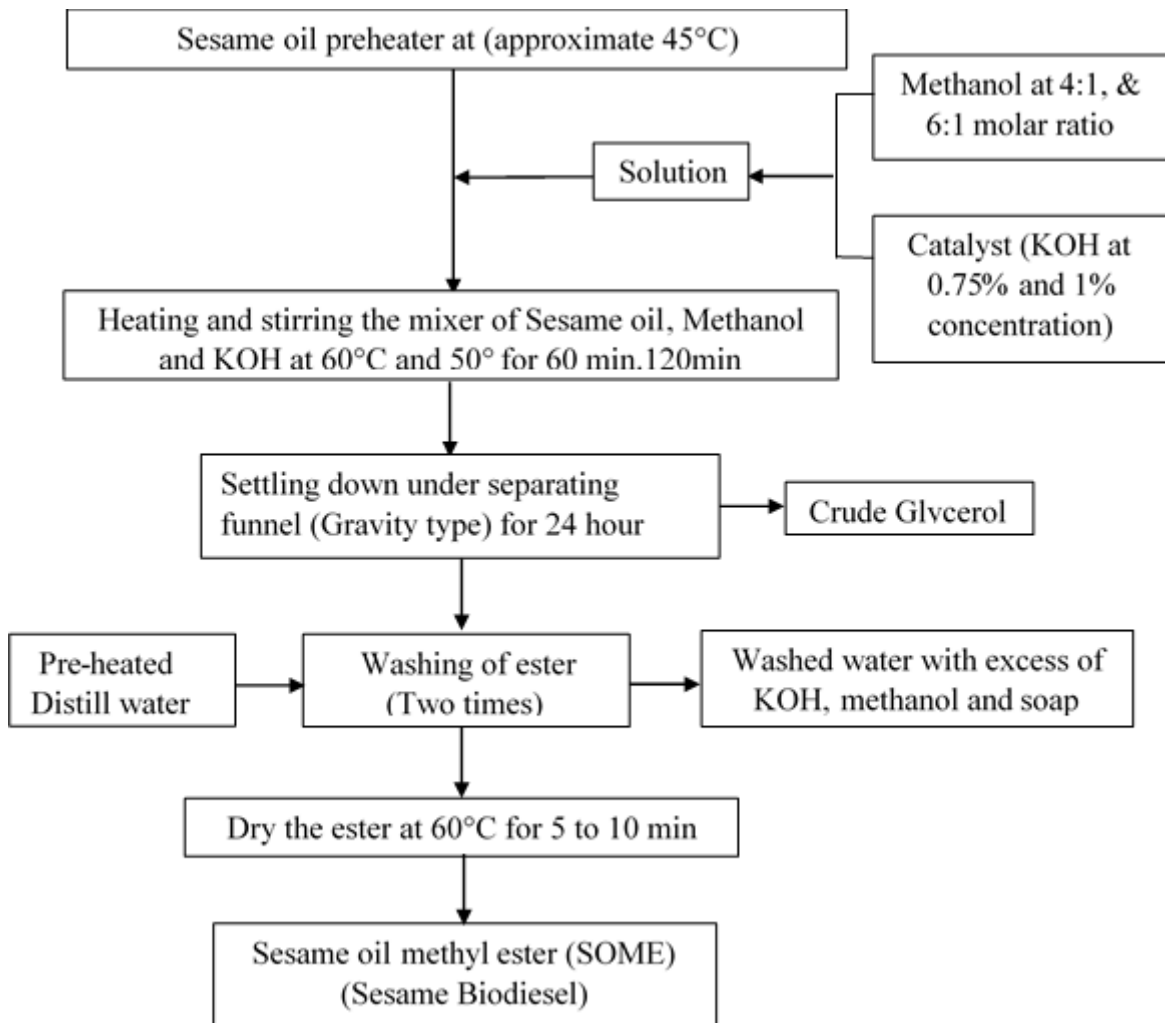


Figure 3.7: Flow Chart of biodiesel Production from sesame oil



Figure 3.8: Biodiesel samples from SO

3.5 Calculation of required quantity of for methanol

The molecular weight of sesame oil and bitter almond oil are 848 gm/mol and 866 gm/mol respectively.

The molecular weight of methanol was calculated. Methanol chemical formula is given by CH₃OH.

The molecular weight of C, H and O are 12, 1 and 16 respectively. So, Molecular weight of Methanol is equal to 32 gm/mol.

For evaluating the amount of methanol required for 150gm of sample oil

$$\frac{X}{32} = \frac{150}{MW_{oil}}$$

Where

X = gm methanol required for 150 gm of sample oil

MW_{OIL} = Molecular weight of oil

Hence,

X=5.54 for bitter almond oil and X=5.66 for sesame oil

Methanol quantity required at 6:1 ratio for the transesterification process

5.54×6 = 33.24 gm of methanol required for 150 gm of bitter almond oil

5.66×6 = 33.96 gm of methanol required for 150 gm of sesame oil

Amount of Methanol required for the transesterification process at 4:1 ratio

5.54×4 = 22.16 gm of methanol required for 150 gm of bitter almond oil

5.66×4 = 22.64 gm of methanol required for 150 gm of sesame oil

The amount of catalyst (KOH) required for transesterification process is 0.33, 0.5 and 1% of oil. The quality of methanol and quality of potassium hydroxide catalyst were 99.6% and 98.5% which was utilized for production of biodiesel.

3.6 Apparatus used for evaluation of properties

The properties of fuel were tested according to ASTM/BIS methods at the fuel testing Laboratory CEFM at Ludhiana. The various procedures followed and instruments used for the purpose as shown in Table 1.3. The following apparatus were employed for the evaluation of biodiesel properties.

3.6.1 The Redwood viscometer

The Redwood viscometer as shown in Figure 3.9 was used to measure the viscosity of lubricating oils. The instrument measures the efflux time of flow through the standard orifice (made in an agate piece as per IS: 1448, P: 25) freely in seconds of a fixed volume of the fluid through specified marks given on the volumetric flask oil. The process to measure kinematic viscosities of liquid by using Redwood viscometer-I is as below:

First of all, the level instrument is placed on a tripod and, depending on the type, either roughly or accurately set to a leveled condition using foot screws (leveling screws). Then the water bath is filled with water to the height corresponding to the tip of indicator up to which the oil is to be filled in the cylindrical cup. The orifice is sealed by keeping the brass ball in position. Then the oil is poured carefully into the oil cup up to the height corresponding to the tip of the indicator. The 50 ml flask is placed in point below the jet. The oil and water are kept well stirred: respectively temperatures are noted. When temperature of the oil and water were observed steady then raise the ball valve and suspend it from the thermometer bracket. Simultaneously stopwatch is started. Then the level of oil dropping into the flask just reaches the 50 ml mark, the stopwatch is stopped. And time is noted in second. The ball is replaced in the original position to prevent the overflow of the oil. The experiment is repeated and the mean value of time (t_m) of flow of 50 ml of oil is reported.

If $t_m < 34$ sec.

$$v = 0.24t_m - 50/t_m \quad \text{Eq. ... (3.1)}$$

If $t_m > 34$ sec.

$$v = 0.26t_m - 179/t_m \quad \text{Eq. ... (3.2)}$$

Where ' t_m ' is mean time in seconds and ' v ' is kinematic viscosity in centistokes.



Figure 3.9: Redwood Viscometer

3.6.2 Relative density and API gravity

The density of biodiesel and their blends at atmospheric temperature was determined as per IS 1448[P: 32]:1992. A clean dry empty measuring cylinder flask is placed on electronic weight balance and its mass is recorded. Then it is filled up with a unit volume of biodiesel, placed over again on weight balance and its mass recorded. Now only mass of biodiesel is calculated and is divided by unit volume of biodiesel taken in measuring cylinder to get the density value of biodiesel sample.

3.6.3 Bomb calorimeter

The calorific value of fuel was tested with the help of closed vessel called bomb calorimeter. Sample fuel (1 gram) was put in the crucible. Pure oxygen then supplied through the oxygen valve till pressure inside the bomb rises to 30 atmospheres. The bomb was then entirely submerged in a measured quantity of water contained in a large copper vessel. Fuse wire was heated up with the help of electric power. When the bomb and its contents have been gained steady temperature. The fuel ignited and continued to burn till the whole of its burnt. The heat, liberated by the combustion of fuel, is gained by this water and apparatus. Then the gross calorific value was calculated using Equation 3.

$$H_c = \frac{(m_w + m_e) C_w (t_2 - t_1)}{m_f} \quad \text{Eq. (3)}$$

Where,

H_c = Heat of combustion of the fuel sample, KJ/kg; m_f = Mass of fuel sample burnt in bomb, kg; m_w = Mass of water filled in the calorimeter, kg; m_e = Water equivalent of apparatus, kg; C_w = Calorific value of water, KJ/kgK; t_2 = Final temperature of water, °C; t_1 = Initial temperature of water, °C.

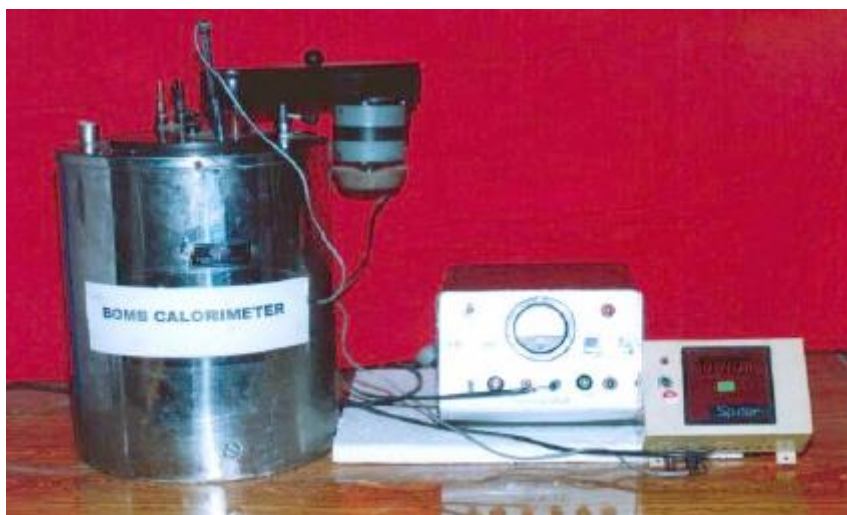


Figure 3.10: Isothermal bomb calorimeter

3.6.4 Cloud and Pour Points apparatus

The Cloud and Pour point of samples were measured as per IS: 1448 [P: 10]: 1970 with the help of the Cloud and Pour point equipment. A glass tube of 3cm diameter and 12cm length was the working apparatus for measure cloud points and pour points and a freezing mixture of crushed ice and sodium chloride crystals were filled in the air jackets where the tubes were sealed. The glass tube having fuel sample was checked out from the jacket at every 10°C temperature interval as the temperature goes down, and observed for cloud formation. The cloud point was that point at which a haze formation was first detected at the base of the sample, was taken as the cloud point.



Figure 3.11: Cloud Point and Pour Point Apparatus

The equipment and the methodology to measure pour point are similar to cloud point. Firstly, preheating of sample is done up to 48°C and then cooled to 35°C in air prior to filling in the glass beaker. Thereafter, the cooled samples were kept in the apparatus and taken out from the cooling bath at 10°C interval for inspecting its ability to flow. The pour point was taken to be the temperature at which fuel remains motionless and studied for five seconds on tilting the tube to a position along the x-axis. Three replacements were made for the fuel. The Cloud point and pour point determination apparatus is shown in Figure 3.11.

3.6.5 Pensky martens apparatus

The flash and fire point of the sample was measured as per IS: 1448. In this experiment, fill the sample in the test cup up to the standard level and heated with the help of the electric heater in such a manner that increase in temperature was around 5°C per minute with uniform stirring. At every 1°C rise in temperature, the flame was introduced for a second with help of a shutter. The temperature at which it gives a flash of light was noted as flash point. At the flash point (a lower temperature) a substance will ignite briefly, but vapour might not be produced at a rate to sustain the fire.

The fire point was noted at that temperature where the fuel gives sufficient vapour that sustains fire at least for five seconds. In general, the fire point can be assumed to be about 10°C higher than the flash point.

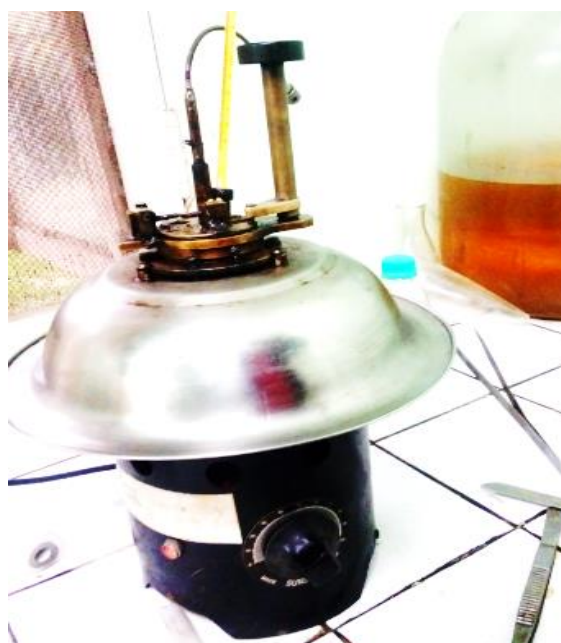


Figure 3.12: Pensky martens apparatus

3.7 Aparture used for evaluation of the engine performance

The experiments have been conducted to evaluate the performance and exhaust emissions of diesel engine. The experiment was performed in internal combustion engine lab at THAPAR UNIVERSITY PATIALA. The following engine and engine accessories were used for experiments.

3.7.1 The Variable compression ratio ignition engine:

A 4–stroke, single cylinder, water cooled VCR diesel engine (3.5 kW) was selected to perform the experiment. The flow of cooling water and calorimeter was controlled with Rotameter. Load cell sensor was used to vary the load on eddy current dynamometer which is coupled to the engine. Windows based engine performance Analysis software package "Enginesoft" is used for online performance evaluation.

Following engine performance parameters were analyzed:

- Brake power (BP)
- Brake thermal efficiency (η_{bth})
- Specific fuel consumption. (SFC)
- Brake mean effective pressure (BMEP)
- Mechanical efficiency (η_{mech})



Figure 3.13: Variable compression ratio engine

Table 3.2: Specification of VCR ignition engine

Make type	Kirloskar
Engine type	Single Cylinder 4-Stroke, Water Cooled diesel engine
Bore	87.5 mm
Stroke	110 mm
Connecting rod length	234 mm
Rated power	3.5 kW@1500 R.P.M
CR	Range from 12-18
Orifice diameter	20 mm
Dynamometer arm length	145 mm
Cooling media	Water cooled
Load indicator	Range 0-50 kg, Supply 230V AC Digital
Load sensor	Load cell, type strain gauge, range 0-50 kg
Loading device	Eddy current dynamometer
Rotameter	Engine cooling 10-400 LPH; Calorimeter 25-250 LPH
Temperature sensor	Thermocouple, Type k
Speed indicator	Digital with non-contact type sensor

3.7.2 Eddy current dynamometer

The engine has an eddy current dynamometer to determine the power and torque. It consists of high accuracy strain gauge load cell to measure the engine torque. By using load cell, several loads 0, 2, 4, 6, 8, 10 kg were put on the engine shaft. Load cell is coupled with load sensor which displayed the load on the load indicator. The SAJ make AG 20 eddy current dynamometer that was employed for evaluating the performance and exhaust emission characteristics of engine. The construction of dynamometer has a notched disc (rotor) which is operated by engine and magnetic poles (stators) are placed outside with a gap. The coil is wound in the circumferential direction which excites the magnetic pole. When current passes through exciting coil loop, a magnetic flux loop is generated around the exciting coil of stator and rotor. Eddy current gets induced when rotor turns in this magnetic field generating braking effect between the rotor and the casing. Strain gauge load cell integrated in the restraining linkage between casing and dynamometer measures exerted rotational torque on the casing. Cooling water is pumped through the corrosion free nickel plated cooling passages of

the casing with the help of water pump to prevent dynamometer from overheating. Figure 3.14 illustrates the eddy current dynamometer.



Figure 3.14: Eddy current dynamometer

3.7.3 Gas analyzer

To examine the engine exhaust emission characteristics of the VCR diesel engine, "Maxicem Portable Gas Analyzer" model ACE-8000 was utilized to get emissions values of Carbon monoxide (CO), hydrocarbon (HC), carbon dioxide (CO₂), oxygen (O₂) and nitrogen oxide (NO). It records CO, HC and CO₂ content by utilizing infrared measurement and O₂ and NO utilizing electrochemical measurement technique.

Following precaution must be followed during experimentation.

1. Do not use the gas analyzer for a long time.
2. Probe of gas analyzer insert into the exhaust pipe only when reading is noted
3. Before shutdown the gas analyzer, 2-3 reading should be taken with fresh ambient air.
4. In a month, minimum one time switched on the Gas analyzer and charge the battery.
5. The necessary filter should be changed as per as schedule.
6. Cross check the calibrations of gas analyzer time to time.
7. Probe of gas analyzer should be inserted at least 30 cm into exhaust pipe.



Figure 3.15: Maxicem Portable Gas Analyzer

3.8 Experimental procedure

Engine is run with conventional diesel fuel for a period of ten minutes to check for engine parameters and to see for proper functioning of various components of engine as well as its related attachments to note down engine characteristics. Step by step procedure followed is as explained below.

- 1) For cooling the engine and eddy current dynamometer water is supplied and it is taken care that there is continuous and constant supply till the experiment is completed.
- 2) Fill the fuel in diesel tank and biodiesel blending tank.
- 3) Initially adjust the compression ratio (18:1) of the engine.
- 4) Water supply is started. Flow rate of cooling water is setup at 250 LPH for engine and 75 LPH for calorimeter.
- 5) Ensuring the acceptable water flow rate for piezo sensor cooling and dynamometer.
- 6) Check the electrical connections and then start the power supply to the computer with the help of UPS.

- 7) Then the engine performance analysis software package “**Enginesoft**” click and opened for the evaluation of engine performance on the screen.
- 8) Open the diesel fuel supply valve to the engine.
- 9) After that select the run option on software and start the engine and let it run for few minutes.
- 10) Then choose the log option in the software. Fuel supply is turned on. After that in one minute the screen changes to input mode at that time water flow value in cooling cover and calorimeter are entered and the file is named in the software. At that time for no load conditions, first reading gets logged on. Then the fuel knob is turned back to previous (normal) position.
- 11) Then the experiment is repeated for different loads.
- 12) The different reading corresponding to the different load will display on the monitor after that which is saved for a particular compression ratio.
- 13) The compression ratio is then changed by adjusting the screw arrangement.
- 14) Then the same experiment is repeated for the different compression ratio and the readings are saved for the same.
- 15) Now for the next fuel blend testing change the fuel in the fuel tank and then accordingly adjust the calorific value and specific gravity of the fuel in the software.
- 16) Repeat the procedure for different fuel at different compression ratio and record the readings in the computer.
- 17) After that bring the engine to no load condition and turn off the computer as well as the engine so as to stop the experiment.

3.8.1 Experiment Safety Precautions

- 1) Before starting the engine, Ensure the oil level in the engine before startup and making sure that sufficient oil is present in the engine.
- 2) UPS should have minimum 5-minute backup power to run the cooling water for the engine, dynamometer and piezo sensor in case of power failure.
- 3) Fuel line and fuel tank should be cleaned before starting engine and should be free from foreign particles.
- 4) The water supply should always be turned on few minutes before starting the engine.

Chapter 4

Results and Discussion

Results and discussion are divided into two parts. The first objective is to produce the biodiesel from bitter almond oil and sesame oil by optimizing the different process parameters that significantly affect the production i.e. molar concentration of methanol to oil, catalyst concentration taken etc. The second objective is to obtain the best blend out of all the blend by considering the performance and emission parameters.

4.1 Biodiesel production and optimization from BAO and SO

Biodiesel production optimization from bitter almond oil and sesame oil by means of transesterification process was determined by varying the different influencing parameters such as molar ratio, reaction time, catalyst concentration and reaction temperature. By varying these reaction parameters, a total of 16 samples were prepared for single oil. On comparing these samples on the basis of minimum viscosity, maximum yield, the optimized result was obtained. The optimized biodiesel production from bitter almond oil was found at molar ratio (mol/mol) of 6:1, catalyst concentration of 1% (%w/w), reaction temperature 60°C and reaction time 60 min for bitter almond oil. Similarly, molar ratio (mol/mol) of 6:1, catalyst concentration of 0.75% (%w/w), reaction temperature 60°C and reaction time 60 min were optimized process parameter of biodiesel production for sesame oil. The maximum yield of 93.13% and 97.28% was obtained for bitter almond oil and sesame oil respectively at the optimized condition. Table 4.1 and 4.2 show the list of experiments conducted to optimize the process parameter of BAME and SOME production respectively.

Table 4.1: Optimization table for the Biodiesel Production from bitter almond oil

Sample no.	Almond Oil (gm)	Methanol (gm)	Catalyst (gm)	Temp. (°C)	Time	Yield (%)	Viscosity (cSt)
1	150	33.24	1	60	1 h	93.13	4.73
2	150	33.24	0.75	60	1 h	94.13	5.81
3	150	33.24	0.75	50	1 h	99.27	7.11
4	150	33.34	1	50	1 h	96.42	6.06

5	150	33.34	0.75	50	2 h	98.38	7.09
6	150	33.34	1	50	2 h	93.25	5.25
7	150	33.34	0.75	60	2 h	94.97	6.63
8	150	33.34	1	60	2 h	92.18	6.08
9	150	22.17	0.75	60	1 h	94.73	6.24
10	150	22.17	1	60	1 h	96.43	5.93
11	150	22.17	0.75	50	1 h	99.80	9.37
12	150	22.17	1	50	1 h	95.51	5.69
13	150	22.17	0.75	60	2 h	99.14	6.00
14	150	22.17	1	60	2 h	94.82	5.23
15	150	22.17	0.75	50	2 h	99.67	NA
16	150	22.17	1	50	2 h	98.79	13.94

Table 4.2: Optimization table for the production of Biodiesel from sesame oil

Sample no.	Sesame oil (gm)	Methanol (gm)	Catalyst (gm)	Temp. (°C)	Time	Yield (%)	Viscosity (cSt)
1	150	33.96	0.75	60	1 h	97.28	4.35
2	150	33.96	0.75	60	2 h	95.71	5.61
3	150	33.96	0.75	50	1 h	98.47	5.62
4	150	33.96	0.75	50	2 h	99.70	6.90
5	150	33.96	1	60	1 h	95.40	5.28
6	150	33.96	1	60	2 h	94.53	5.40
7	150	33.96	1	50	1 h	97.39	4.65
8	150	33.96	1	50	2 h	98.12	5.36
9	150	22.64	0.75	60	1 h	96.35	9.24
10	150	22.64	0.75	60	2 h	96.79	10.17
11	150	22.64	0.75	50	1 h	95.97	9.47
12	150	22.64	0.75	50	2 h	94.37	6.93
13	150	22.64	1	60	1 h	93.68	7.73
14	150	22.64	1	60	2 h	94.74	6.71
15	150	22.64	1	50	1 h	96.39	10.90
16	150	22.64	1	50	2 h	97.56	8.63

4.2 Characteristics of BAO, SO and their biodiesel

The fuel properties (viz. density, kinematic viscosity, flash point, calorific value, cloud and pour point) were found using standard ASTM techniques, which are discussed in Chapter 3. These properties were compared with petroleum diesel fuel. The fuel properties of BAO and SO were given in Table 4.3 and their methyl ester properties were given in Table 4.4. Most of the properties of these oil are not comparable to ASTM standards. Therefore cannot be used directly as a diesel engine fuel.

Table 4.3: Characterization of bitter almond oil, sesame oil

Properties	BAO	SO	Diesel	ASTM D6751	EN 14214
Density at 15°C (kg/m ³)	911	842	839	-	860-900
Viscosity at 40°C (cSt)	34.28	32.50	3.18	1.9-6.0	3.5-5.0
Flash point (°C)	315	285	62	>130	>101
Fire point (°C)	328	296	64	-	Min.120
Cloud point (°C)	-2	-1.2	-14	-	-
Pour point (°C)	-10	-4.9	-19	-	-
Calorific value (MJ/kg)	39.12	38.25	42.97	-	-
Acid value (mg KOH/g)	0.46	0.40	0.35	<0.8	<0.5

Table 4.4: Properties of bitter almond methyl ester, sesame oil methyl ester

Properties	BAME	SOME	Diesel	ASTM D6751	EN 14214
Density at 15°C (kg/m ³)	897	887	839	-	860-900
Viscosity at 40°C (cSt)	4.73	4.35	3.18	1.9-6.0	3.5-5.0
Flash point (°C)	258	218	62	>130	>101
Fire point (°C)	298	232	64	-	Min.120
Cloud point (°C)	-3	-4.9	-14	-	-
Pour point (°C)	-12	-1.2	-19	-	-
Calorific value (MJ/kg)	41.76	38.83	42.97	-	-
Acid value (mg KOH/g)	0.32	0.28	0.35	<0.8	<0.5

4.3 Performance & exhaust emission analysis of BAME blends

Many researchers have extensively studied the use of vegetable oils, biodiesel and blended biodiesel in diesel engine. Most of them have concluded that biodiesel blends starting from B5 to B100 can be used to run the diesel engine without engine modification. In the present investigation fuel blends (B10, B25 and B40 blends) were prepared and characterized. As discussed earlier most of the fuel characteristics of biodiesel were found to be well within the recommended limits for commercial biodiesel of ASTM D67511 as well as EN 14214-07. Engine performance testing and emission testing had been done using the selected blends under identical experimental conditions.

As discussed earlier, performance and emission of a 3.5 kW VCR CI type of engine have been tested for a limited range of loading conditions (randomly chosen 0, 2, 4, 6, 8, 10 kg) for blends of both the biodiesel samples (bitter almond oil and sesame oil biodiesel). Brake power, brake thermal efficiency and specific fuel consumption values as obtained from the computerized engine test rig. The exhaust gas of engine was analyzed corresponding to specific test condition, the details of which are presented in Chapter 3. The results pertaining to the emission of carbon monoxide (CO), nitrous oxide (NO_x) and unburnt hydrocarbon (HC) are obtained from exhaust gas emission analyzer as discussed in Chapter 3.

Comprehensively the test results are analyzed at five relative loading conditions viz., part load (~0%), medium load (~20%, 40%, 60%, and 80%) and high load (~100%). The detailed methodology is presented in Chapter 3 and results are presented and discussed below.

4.3.1 Brake thermal efficiency (BTE)

The variation of brake thermal efficiency (BTE) w.r.t. load for various fuel BAME-10, BAME-25, BAME-40 and diesel at compression ratio 18:1 is illustrated in Figure 4.1. From the graph, it was noted that the BTE increases with increase in load due to reduction in heat loss at higher load compared to lower load hence, increase in power. At lower load, there is not much difference in brake thermal efficiency however at higher load, there is significant variation in brake thermal efficiency for all the tested blend fuel. BMEP of a CI engine is directly connected to the brake power. Brake thermal efficiency of BAME-10 was noted 24.27% higher than the reference diesel fuel at part load whereas at full load, it was increased slightly by 3.51% compared to reference diesel fuel. Brake thermal efficiency of BAME-25 was noted 20.63% more than diesel at part load condition but slightly 0.95% more than to reference diesel fuel at full load condition. BTE was higher than diesel fuel for BAME-10 and BAME-25 due to the

decrease in heat loss and increases in power output with increase the load condition. The BTE of BAME-10, BAME-25 and BAME-40 was obtained 5.12%, 4.97% and 3.36% respectively at part load whereas 29.19%, 28.47% and 26.77% respectively at full load. BTE of diesel fuel was found as 4.12% and 28.20% at part and full load. The comparison the maximum BTE of biodiesel blends and diesel at full load, biodiesel blend BAME-10 had the maximum efficiency of about 3.51% higher than diesel. This may cause due to oxygen percentage increased in biodiesel, which can undergo for complete and high combustion of fuel. The blend BAME-40 gives lower BTE among the selected biodiesels and it is recorded as 18.44% and 5.07% lower than diesel fuel, which may cause due to the high viscosity and high density of the biodiesel fuel.

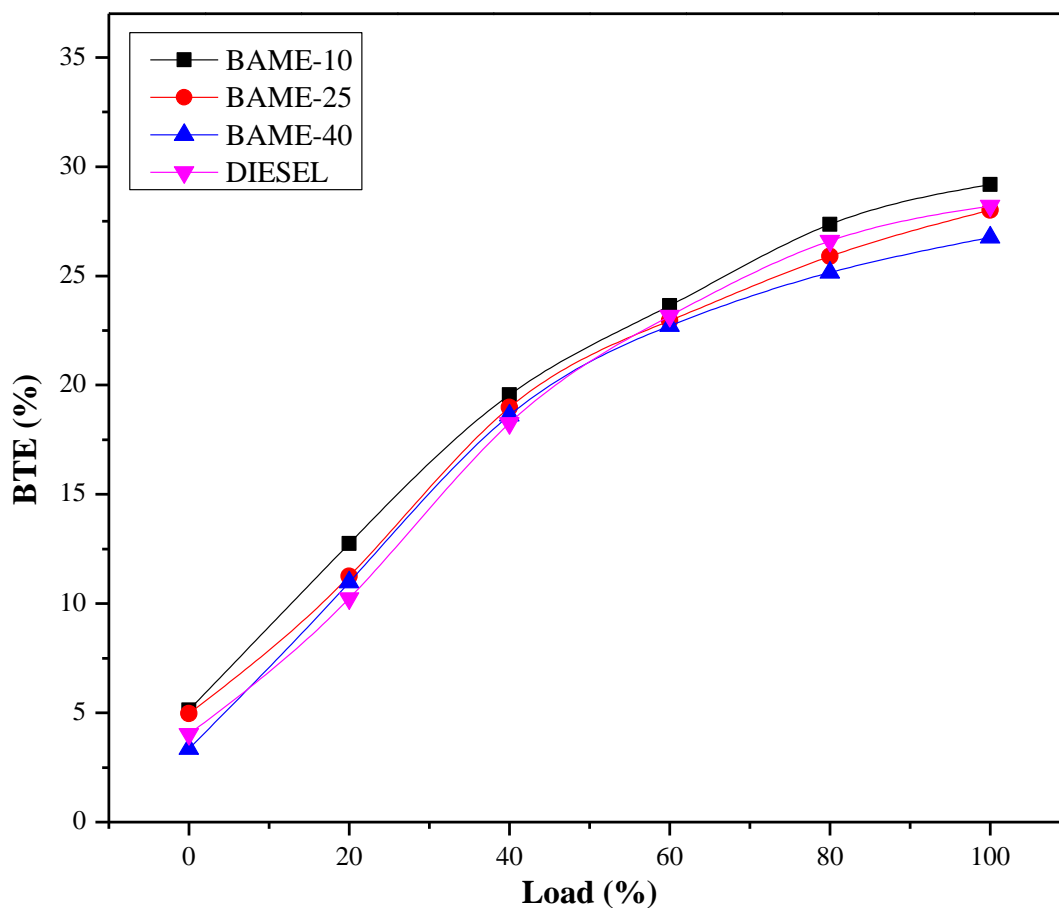


Figure 4.1: Variation of BTE with Engine Load for Diesel and BAME Blends

4.3.2 Specific fuel consumption (SFC)

The variation of specific fuel consumption (SFC) w.r.t. load for different fuel BAME-10, BAME-25, BAME-40 and diesel is illustrated in Figure 4.2 at constant compression ratio 18:1.

As shown in the graph, the SFC of all tested fuel was reduced slowly with increase in load. It caused by the higher percentage increase in BP (brake power) with load as compared with increases in fuel consumption. This also indicates that the engine burns fuel efficiently during high load condition. All tested fuel show almost similar fuel consumption in high load conditions. At lower percentage of biodiesel in biodiesel- diesel blends, the SFC is lower than that of diesel. In the case of BAME-10 and BAME-25, SFC was found 27.55% and 17.3% lower than that of diesel at part load condition and 14.28% and 3.57% decreased at full load.

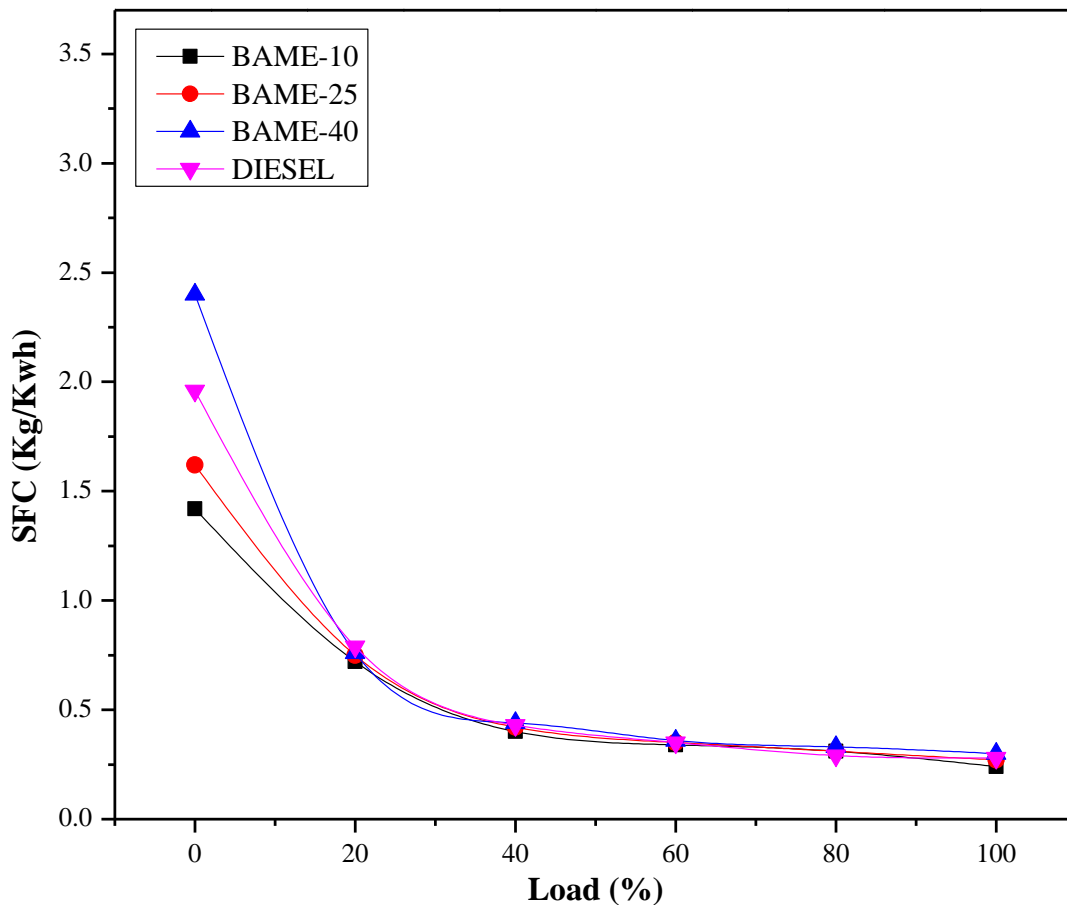


Figure 4.2: Variation of SFC with Engine Load for Diesel and BAME Blends

The SFC was noted to be higher for BAME-40 or higher concentration of biodiesel blend in comparison to diesel fuel. The SFC of BAME-40 was 24.44% higher than diesel fuel at part load whereas 7.14% higher at full load. With increasing in biodiesel concentration in the blends, the calorific value of fuel reduces. Hence, SFC increases for high percentage of biodiesel in biodiesel blends as compared to that of diesel.

4.3.3 Exhaust gas temperature (EGT)

The variation of EGT w.r.t load at compression ratio 18:1 for different fuel BAME-10, BAME-25 BAME-40 and diesel is illustrated in Figure 4.3. The biodiesel has higher amount of oxygen molecules in the ester form compare than diesel fuel. This extra part of oxygen also helps to improve the combustion process.

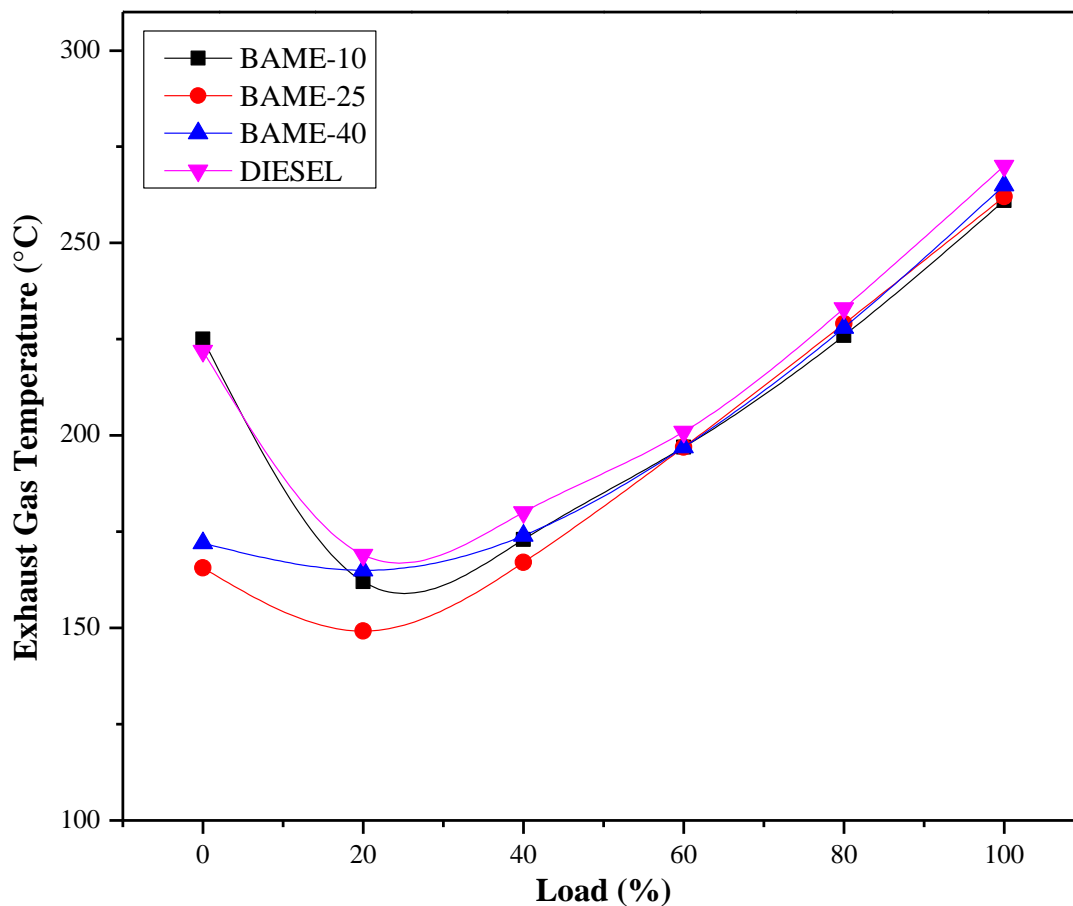


Figure 4.3: Variation of EGT with Engine Load for Diesel and BAME Blends

In the beginning up to 20% load, EGT was decreased with the load after that it was increased with load for all the selected fuels. The exhaust gas temperature for all the blended fuel was lower than that of diesel at all load condition except for BAME-10 at part load condition. From the Figure 4.3, it can be concluded that EGT lines for each selected fuel blends are closer to each other and lie within a narrow band at various higher load conditions. BAME-25 shown maximum temperature drop 25.41% compared to diesel fuel at part load condition whereas 2.96% drop at full load condition.

4.3.4 Hydrocarbon emission

The variation of HC emission at compression ratio 18:1 w.r.t. load for various biodiesel blends BAME-10, BAME-25 BAME-40 and for diesel is indicated in Figure 4.4. As shown in the graph, the HC emission of the all tested fuel was almost linearly increased from part load to 60% load. The injection in advanced may cause of longer delay of ignition which leads to higher HC emissions formation in the exhaust of the diesel engine. From 60% to 80% load, HC emission was decreased after was increased.

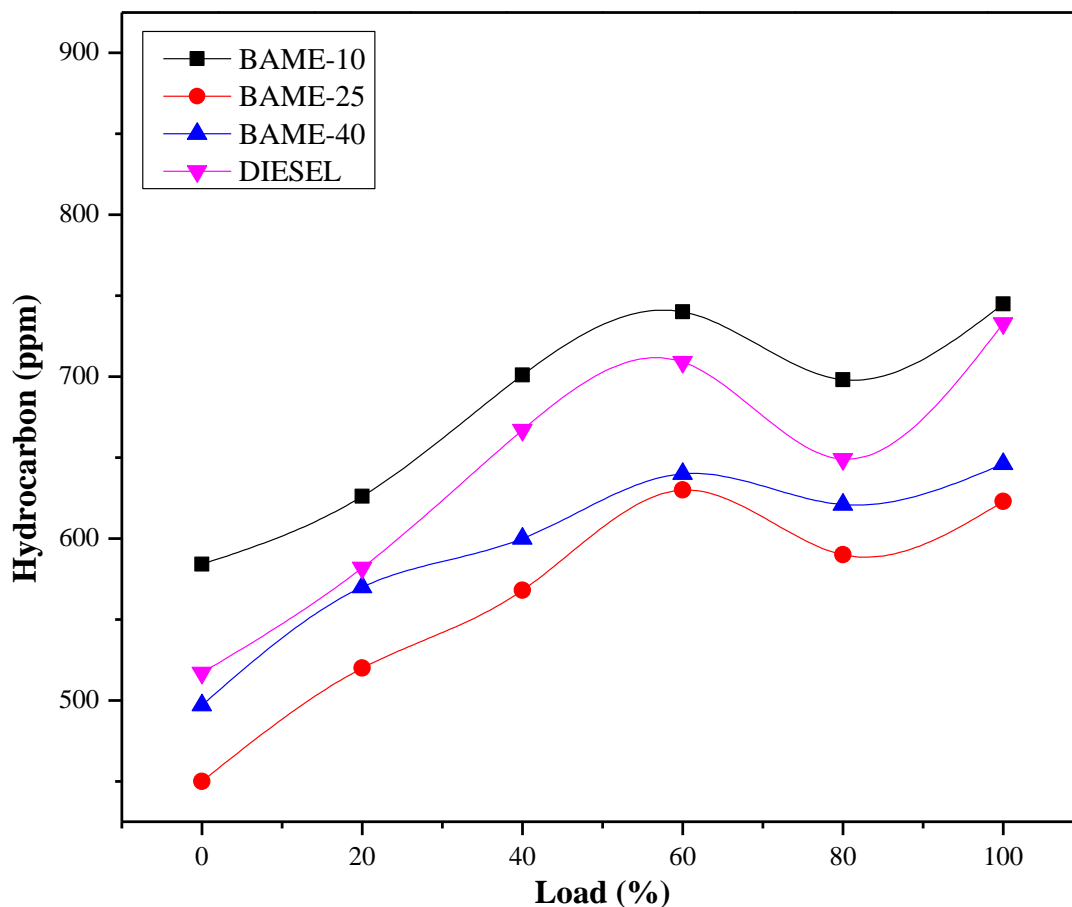


Figure 4.4: Variation of HC emission with Engine Load for Diesel and BAME Blends

HC emission was reduced throughout the entire load condition for BAME-25 and BAME-40 compared to diesel fuel. HC emission of BAME-25 and BAME-40 was observed 12.95%, 3.86% lower than diesel fuel at part load condition whereas 12.37% and 9.12% lower at full load condition. HC emission of low concentration biodiesel blend BAME-10 was observed 12.95% higher than of diesel fuel at part load condition and 1.63% increases at full load

condition. BAME-25 blend with diesel was superior for reduction in HC emission over all other selected blends.

4.3.5 Carbon monoxide emission

The variation of carbon monoxide emission at compression ratio 18:1 w.r.t. load for various biodiesel blends BAME-10, BAME-25 and BAME-40 and for diesel is illustrated in Figure 4.5.

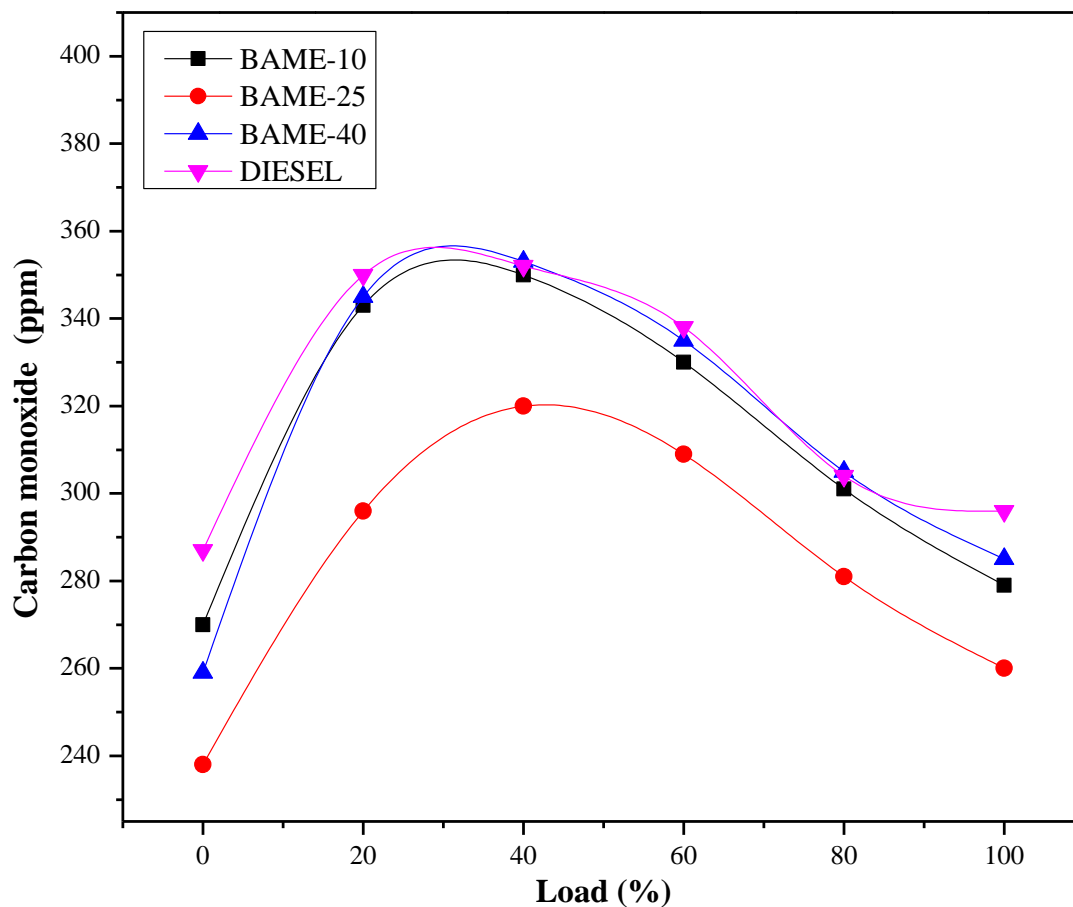


Figure 4.5: Variation of CO emission with Engine Load for Diesel and BAME Blends

As shown in the graph, in the beginning up to 40% load, CO emission was increased with load after that it was decreased for all tested fuels. It is also shown that BAME-10, BAME-25 and BAME-40 reduced the amount of CO emission compared to that of diesel fuel at all load condition. In all the blended fuel, Only BAME-25 had reduced maximum amount of CO emission compared to diesel fuel. CO emission of BAME-25 was observed 17.07% lesser than diesel fuel at part load condition whereas 12.06% lower at full load. CO emission of low

concentration biodiesel blend BAME-10 was observed 5.92% lower than diesel at part load condition whereas 5.74% lower at full load condition. BAME-25 blend with diesel was superior for reduction in CO emission compared to all other selected blends.

4.3.6 Oxides of Nitrogen emission

The variation of NO_x w.r.t. load for different fuel BAME-10, BAME-25, BAME-40 and diesel at constant compression ratio of 18:1 is illustrated in Figure 4.6. As shown in the graph that NO_x emission was increased slowly with increase in engine load. Formation of Nitrogen oxide emission has been investigated by various researchers and found to be increased with biodiesel percentage in biodiesel- diesel blended fuel. However, this experimental data showed reduction in NO_x at some point of the experiment.

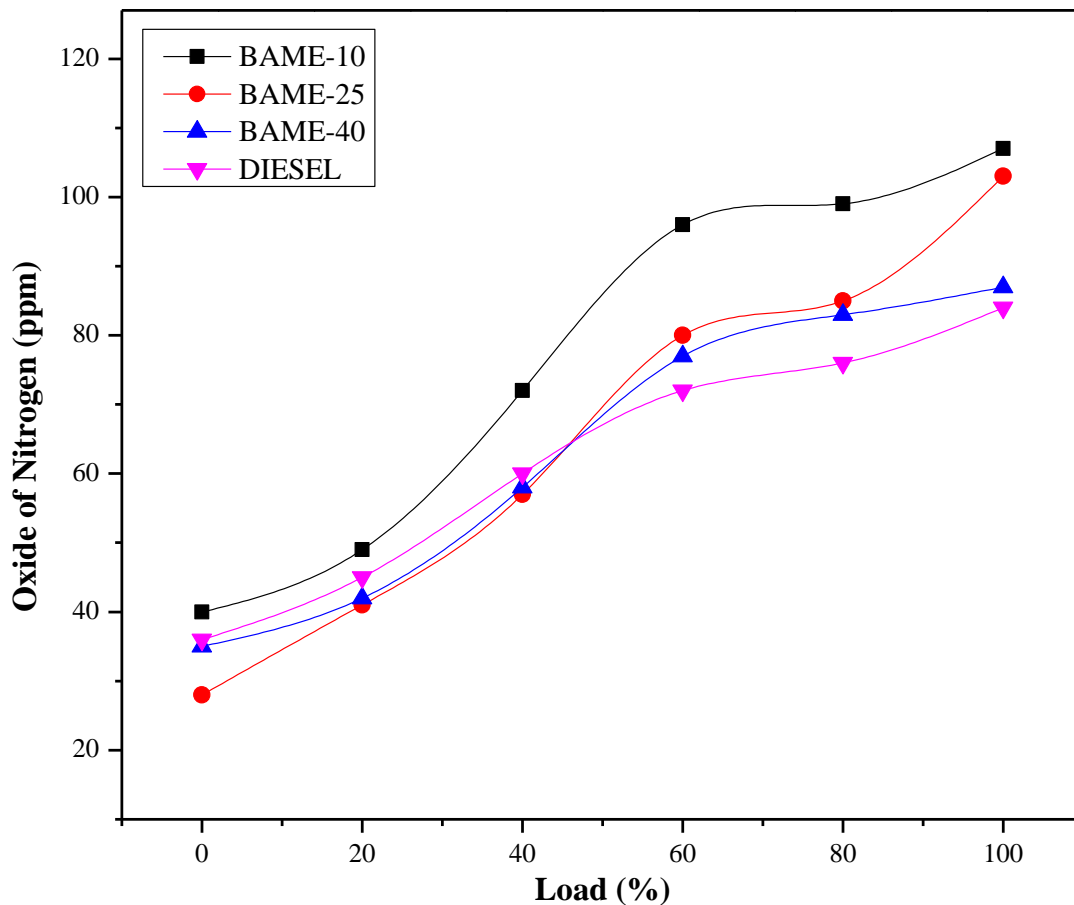


Figure 4.6: Variation of NO_x with Engine Load for Diesel and BAME Blends

NO_x formation during combustion was determined by oxygen concentration, cetane no, peak pressure, combustion temperature, and time. NO_x emission of BAME-10 was higher than diesel

fuel under varied load but the formation of NO_x emission was significantly lower of BAME-25 and BAME-40 compared to diesel at 0, 20 and 40% load. From the experimental data, it was noted that low NO_x formation is caused by significant temperature drop of EGT of BAME-25 and BAME-40 at 0, 20 and 40% load. The NO_x emission of BAME-25 and BAME-40 was reduced by 22.22% and 2.77% at part load condition whereas 22.16% and 3.57 % higher NO_x formation at full load condition.

4.4 Performance & exhaust emission analysis of SOME blends

In the present investigation, fuel blends SOME-10, SOME-25 and SOME-40 blends were prepared and characterized. As discussed earlier (Sec 4.2) most of the fuel characteristics were found to be well within the recommended limits for commercial biodiesel of ASTM D67511 as well as EN 14214-07. Engine performance testing and emission testing are done using the selected blends under identical experimental conditions.

As discussed earlier, performance and emission of a 3.5 kW VCR CI type of engine have been tested for a limited range of loading conditions for SOME blends. BP, SFC and BTE values were obtained from the computerized engine test rig. The exhaust gas of engine was analyzed corresponding to specific test condition, the details of which are presented in Chapter 3. The results pertaining to the emission of carbon monoxide (CO), nitrous oxide (NO_x) and unburnt hydrocarbon (HC) are obtained from exhaust gas emission analyzer as discussed in Chapter 3. Comprehensively the test results are analyzed at five relative loading conditions viz., part load (~0%), medium load (~20, 40, 60, and 80%) and high load (~100%).

4.4.1 Brake thermal efficiency (BTE)

The variation of BTE w.r.t. load for different fuel SOME-10, SOME-25, SOME-40 and diesel at constant compression ratio 18:1 is illustrated in Figure 4.7. It is well known that BTE is inversely proportionate to SFC. It was experientially noted that BTE was increased with rise in load for all operations of diesel and blending fuel because of comparatively less portion of the energy losses at high loads. In another word, relatively fewer portion of the energy was lost at higher load/speed. The maximum BTE was noted at 40% concentration of sesame oil biodiesel in biodiesel- diesel blended fuel as presented in Figure 4.7. BTE of SOME-10, SOME-25 and SOME-40 was observed 17.91%, 2.98% and 2.48% more than diesel at part load condition of diesel engine whereas marginally 0.177%, 0.035% and 0.248% respectively higher at full load condition. It is improved by the drop in energy loss and increase in brake power output with

rise in engine load. BTE of diesel was 4.12% and 28.20% at part and full load. Comparing the maximum brake thermal efficiency for blends of biodiesel and diesel at full load, BAME-40 had the maximum BTE about 0.24% higher than diesel fuel. This is because of the higher concentration of oxygen in the biodiesel compare to diesel, which can go for effective combustion.

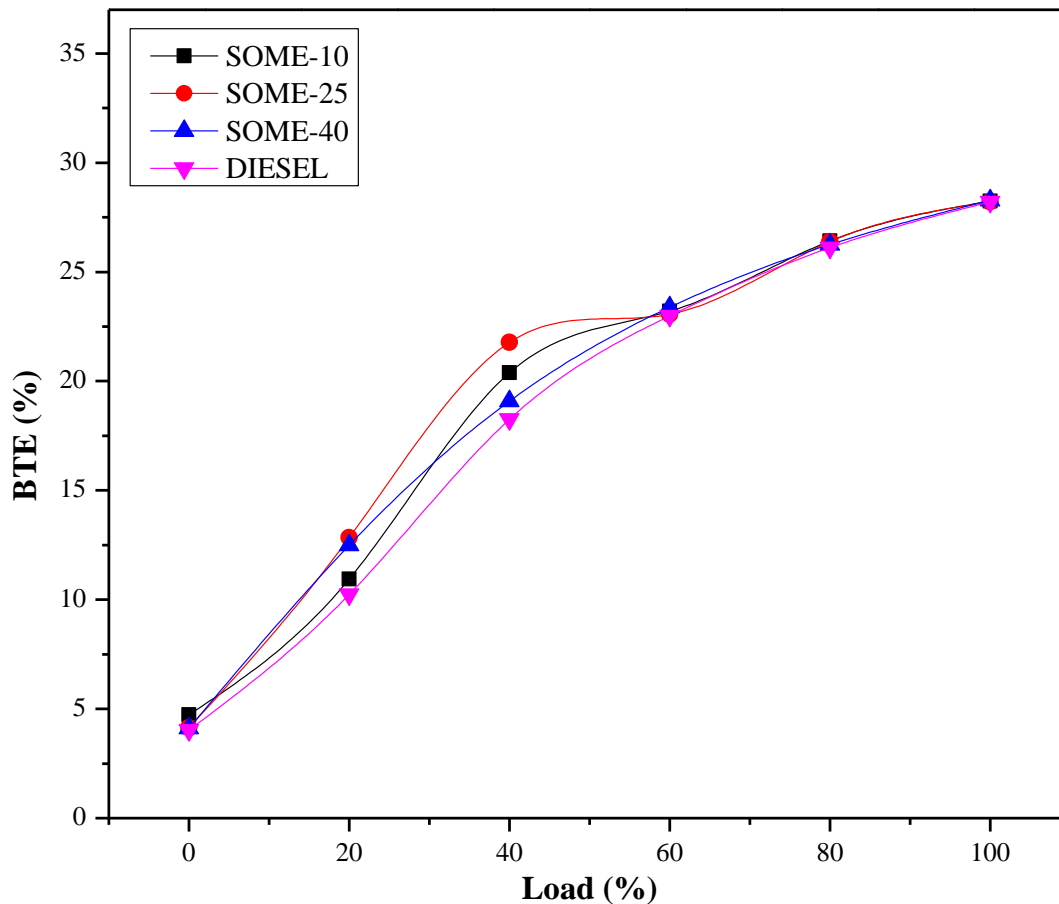


Figure 4.7: Variation of BTE with Engine Load for Diesel and SOME Blends

4.4.2 Specific fuel consumption (SFC)

The variation of SFC w.r.t. load for different fuel SOME-10, SOME-25, SOME-40 and diesel at constant compression ratio 18:1 is illustrated in Figure 4.8. Diesel engine load was varied from 0 to 10 kg at constant speed 1500 RPM. From the Figure 4.8, it can be noticed that the SFC of all type of fuel was gradually reduced with increase in load and little variation after 60% load condition. This is caused by the higher percentage increase in BP with load as compared to increase in fuel consumption. This fact also indicates that the engine burns fuel efficiently during high load condition. It is also shown from the graph that SFC consumption

was decreased with increase biodiesel concentration in biodiesel–diesel blended fuel at low load and raised at high load. The lowest SFC was noted 0.28 kg/kWh, 0.29 kg/kWh, 0.29 kg/kWh, and 0.29 kg/kWh for diesel, SOME-10, SOME-25 and SOME-40 respectively. In the case of SOME-10, SOME-25 and SOME-40, the specific fuel consumption was found 13.26%, 15.81% and 9.18% lower than diesel fuel respectively at part load. The lowermost SFC was exhibited by the blends of SOME-25 as observed from Figure 4.8.

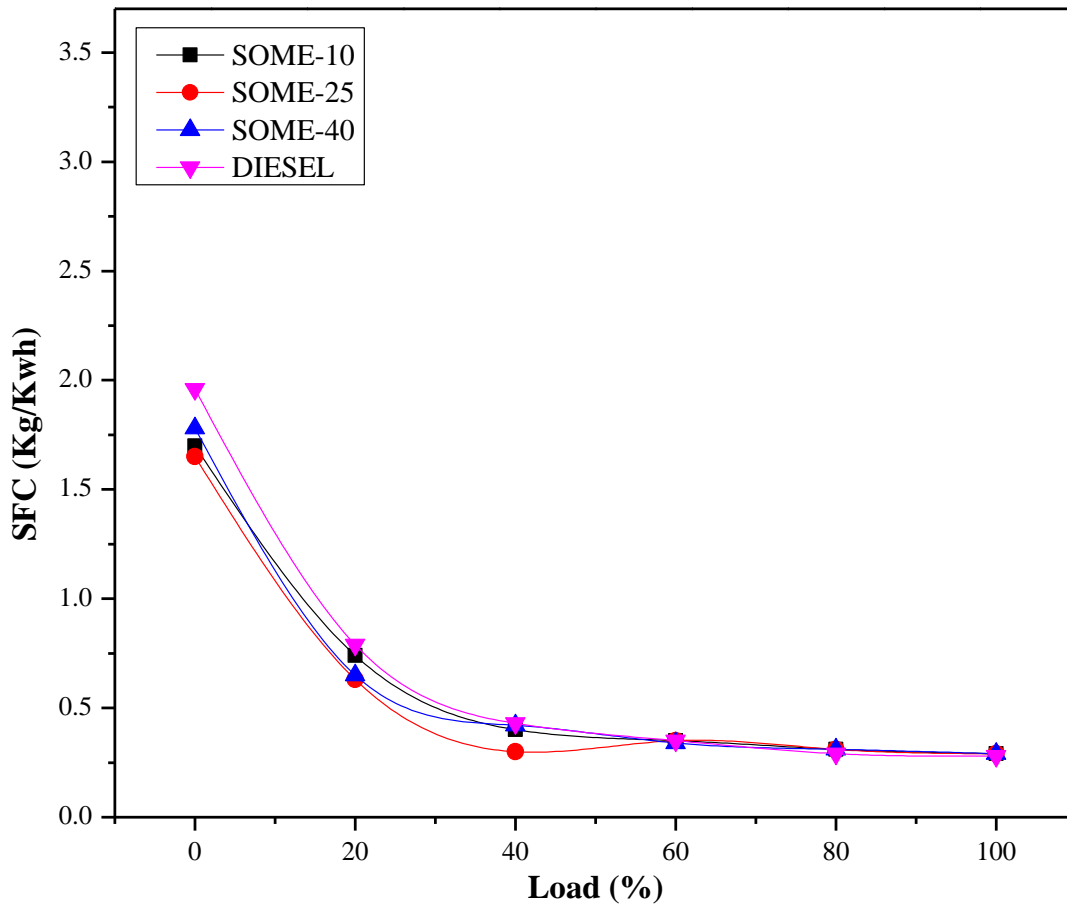


Figure 4.8: Variation of SFC with Engine Load for Diesel and SOME Blends

4.4.3 Exhaust gas temperature (EGT)

The variation of EGT w.r.t. load for different fuel SOME-10, SOME-25, SOME-40 and diesel at constant compression ratio 18:1 is illustrated in Figure 4.9. Generally, exhaust gas temperature rises with increasing order of load percentage for diesel and the blended biodiesel fuel. The highest EGT was experimentally noted for diesel fuel compared to biodiesel blends. The EGT for diesel fuel at part load condition was noted 222.62°C and 270.5°C at full load condition. There was an increase in fuel consumption when the load on diesel engine was

increased in steps. This leads to increase in power output. The blend of sesame oil methyl ester with diesel produced low EGT in comparison to pure diesel fuel. This is because of low heating value and more oxygen composites existing in the biodiesel. The maximum temperature recorded as 270.5°C, 263.75°C, 258.54°C and 260.5°C for diesel, SOME-10, SOME-25 and SOME-40 respectively at full load. SOME-25 shown maximum temperature drop 22.69% compared to diesel fuel at part load condition whereas 4.421% drop at full load condition.

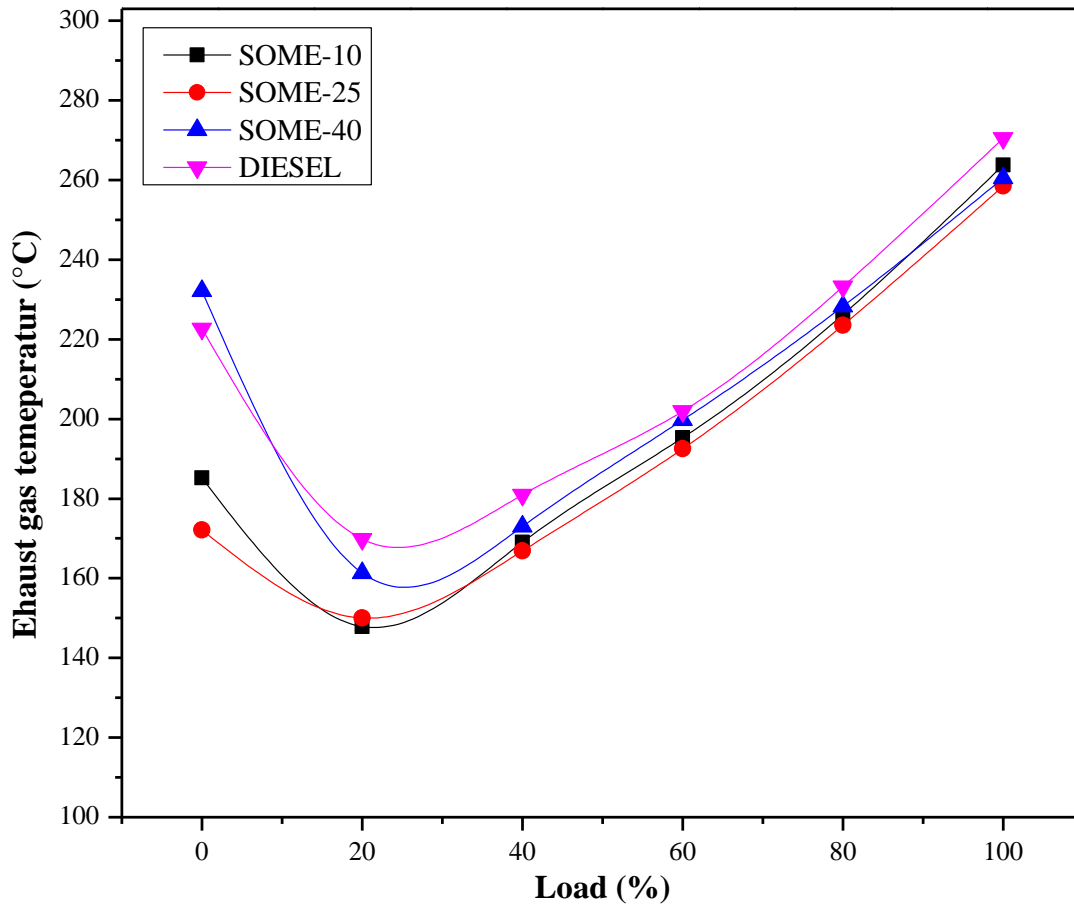


Figure 4.9: Variation of EGT with Engine Load for Diesel and SOME Blends

4.4.4 Hydrocarbon emission

The variation of HC emission w.r.t. load for different fuel SOME-10, SOME-25, SOME-40 and diesel at constant compression ratio 18:1 is illustrated in Figure 4.10. As presented in the graph, the level of HC emission was almost linearly increased from part load to 60% load for diesel, SOME-10 and SOME-25 whereas it was increased from part load to 40% load for SOME-40. After 60% load, HC emission was suddenly decreased and again increased at 100% load as shown in the graph for all tested fuel.

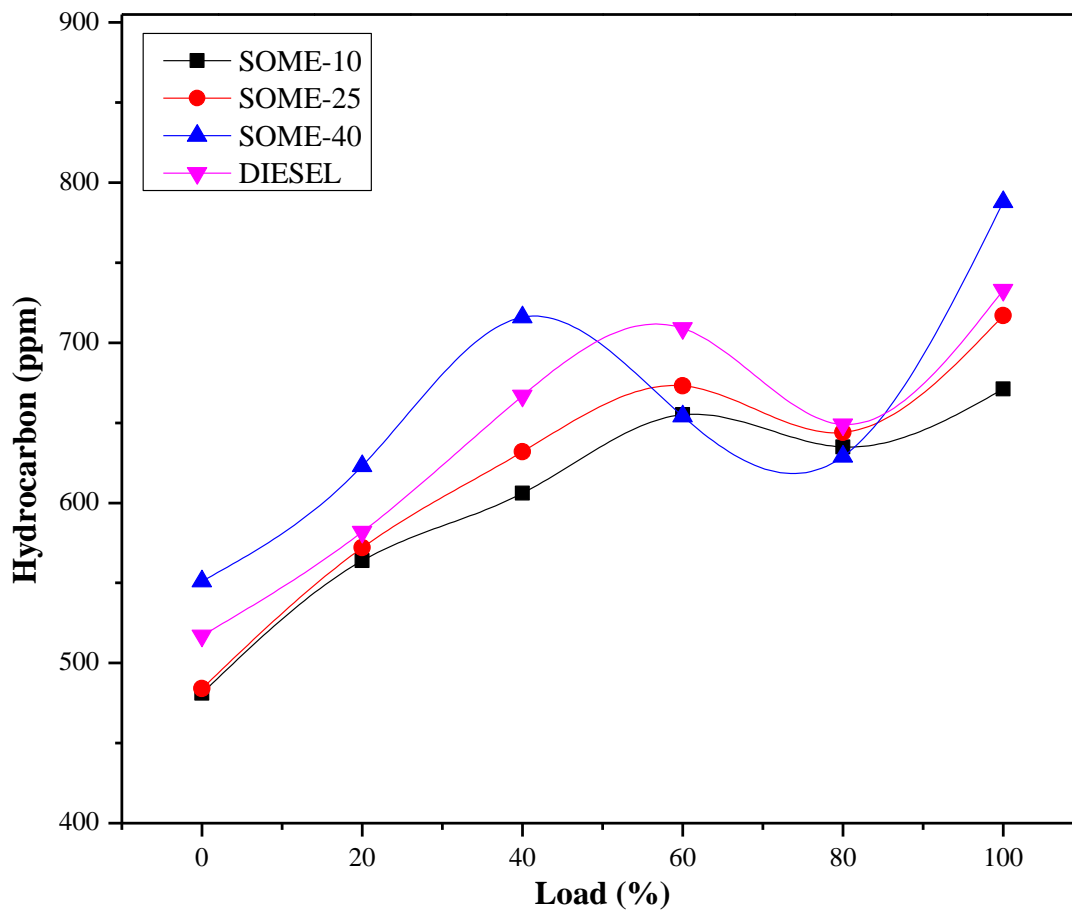


Figure 4.10: Variation of HC emission with Engine Load for Diesel and SOME Blends

HC emission was also influenced by injection timing of the engine fuel. If fuel injection occurs before its standard timing, it results in longer ignition delay which leads to high hydrocarbon emissions in the exhaust of the engine. Hydrocarbon emission was lesser for SOME-10 and SOME-25 as compared to diesel fuel. HC emission of SOME-10 and SOME-25 was noted 6.96% and 6.38% lesser than diesel fuel at part load condition whereas it was 8.45 % and 2.18% lower respectively at full load condition. HC emission for high concentration biodiesel blend SOME-40 was observed 6.57% higher than pure diesel fuel at part load condition whereas 7.50% higher at full load condition. BAME-25 blend with diesel given a good result for a reduction in HC emission compare to all other selected blends at full load condition.

4.4.5 Carbon monoxide emission

The variations of carbon monoxide emission with load at compression ratio 18:1 for diesel and different blends of sesame biodiesel-diesel blends SOME-10, SOME-25 and SOME-40 is

illustrated in Figure 4.11. The load on diesel engine was changed from 0 to 100% at constant 1500 RPM. As shown in the graph, the formation of carbon monoxide emission for SOME-10, SOME-25 and SOME-25 was low as compared to diesel upto 80% load. But at full load condition SOME-10 have higher CO emission formation. It has been also seen that in the beginning, Carbon monoxide emission was increased with engine load after that it was decreased with load for all the tested fuels.

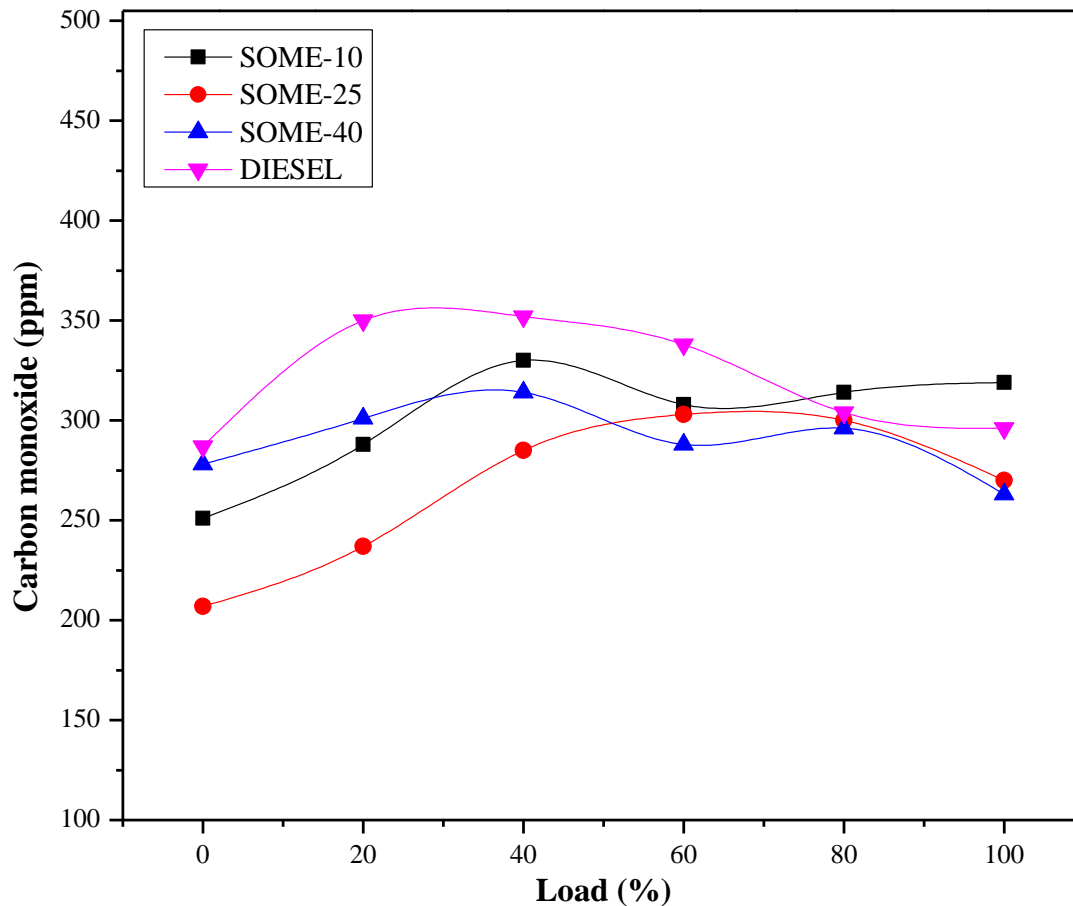


Figure 4.11: Variation of CO emission with Engine Load for Diesel and SOME Blends

From Figure 4.11, SOME-10, SOME-25, SOME-40 and diesel at rated power (3.5 kW) the concentration of CO in the exhaust emission was 251 ppm, 207 ppm, 278 ppm and 287 ppm respectively at part load condition whereas at full load, it was 319 ppm, 270 ppm, 263 ppm and 296 ppm respectively. CO emission of BAME-25 was observed 27.87% lower than pure diesel driven engine at part load condition and 8.78% lower at full load. CO emission of low concentration biodiesel blend BAME-10 was observed 12.54% lower than diesel fuel at part

load condition and 7.77% higher at full load condition. BAME-25 blend with diesel given good result for reduction in CO emission compare to all other selected blends for low load conditions.

4.4.6 Oxides of Nitrogen emission

The variation of oxides of nitrogen emission at compression ratio of 18:1 w.r.t. load for diesel and different sesame biodiesel-diesel blends SOME-10, SOME-25 and SOME-40 is shown in Figure 4.12.

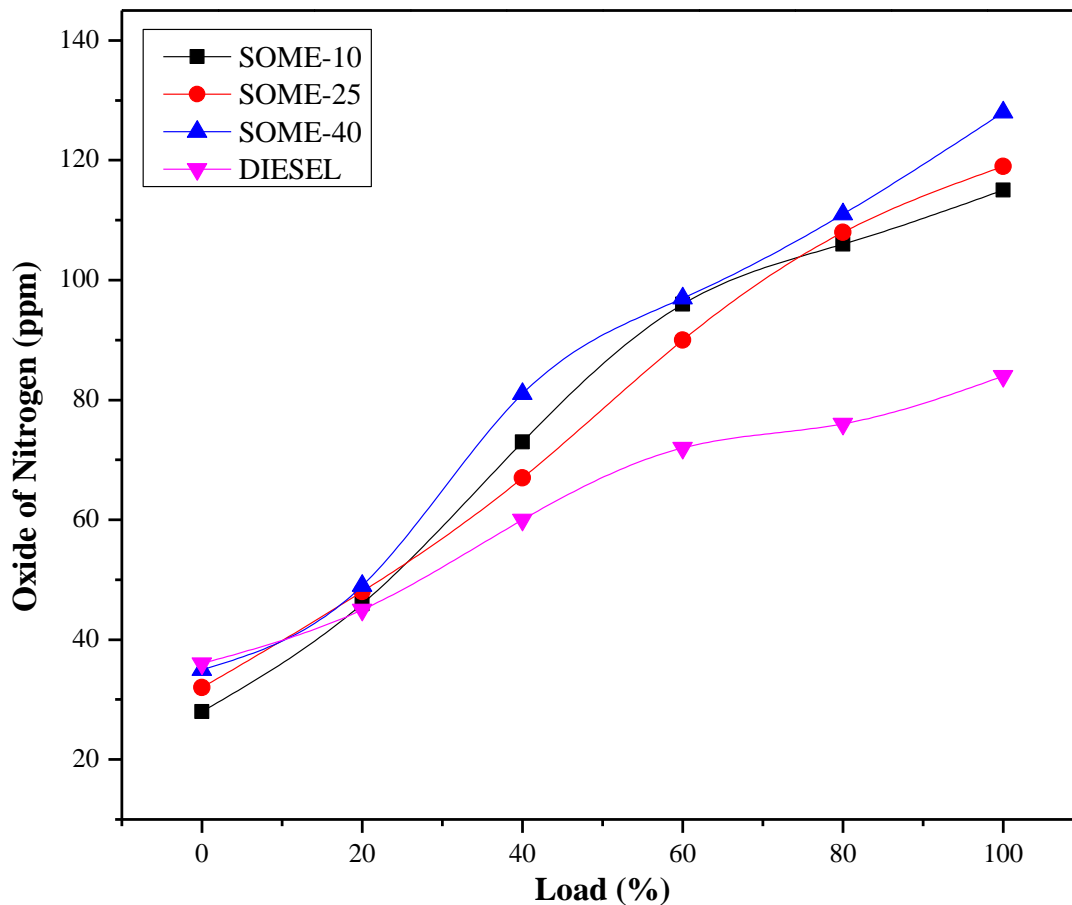


Figure 4.12: Variation of NO_x with Engine Load for Diesel and SOME Blends

As shown in the graph that NO_x emission was raised slowly with increasing load for all tested fuel. It was also observed that the NO_x emission for biodiesel blends was more than standard diesel fuel except at lower load conditions. NO_x emission was increased with increase in biodiesel concentration in biodiesel-diesel blended fuel. Same phenomenon has been described by several investigators. However, this experimental data also indicates enhancement in nitrogen oxide except for some point of the experiment. The formation of nitrogen oxide

emission is caused by oxygen concentration, cetane no, combustion chamber peak pressure, temperature, and time. Figure 4.12 shows the formation of NO_x emission was more than diesel for SOME-10, SOME-25 and SOME-40 fuel except at part load condition. The NO_x emission for diesel and blend SOME-10, SOME-25 and SOME-40 was 84 ppm, 115 ppm, 119 ppm and 128 ppm respectively at full load conditions. The NO_x emission of SOME-10, SOME-25 and SOME-40 was enhanced by 36.90%, 41.66% and 52.38% respectively at full load condition. It was also noted that the formation of NO_x emissions was enhanced with percentage of biodiesel in the blended fuel.

Chapter 5

Conclusions and Future scope

5.1 Summary

The overall investigation established on the production of biodiesel, fuel characterization, VCR engine performance and its exhaust emission characteristics by using diesel, specified blends of sesame oil methyl esters (SOME) and bitter almond oil methyl esters (BAME) with diesel were carried out. An inclusive investigation of current literature has been done on CI engines fuelled with vegetable oils (edible and non-edible oil), methyl ester of oil and their specified blends with diesel to improve and understand the performance, combustion and exhaust emission nature of the engine. In addition to this, a comprehensive literature review was also commenced on biodiesel production methods, utilization, properties and environmental effect of biodiesel. The performance and exhaust emission characteristics of sesame methyl ester blends (SOME-10, SOME-25 and SOME-40) and bitter almond methyl ester blends (BAME-10, BAME-25 and BAME-40) were compared with diesel.

5.2 Conclusions

Based on the outcomes of the present effort, following detailed conclusion is drawn:

- The recovery of sesame oil methyl ester and bitter almond methyl ester of lowest kinematic viscosity 4.35 cSt and 4.73 cSt respectively is possible at the following standardized parametric conditions.

The recovery of sesame oil methyl ester of lowermost kinematic viscosity 4.35 cSt with 97.28% is possible at the following standardized parametric conditions.

- a) Molar ratio: 6:1
- b) Preheating temperature: 45°C
- c) Reaction time: 60 minutes
- d) Catalyst concentration: 0.5%
- e) Reaction temperature: 60°C
- f) Settling time: 24 hrs.

The recovery of bitter almond oil methyl ester of lowermost kinematic viscosity 4.73 cSt with 93.13% is possible at the following standardized parametric conditions.

- a) Molar ratio: 6:1
 - b) Preheating temperature: 40°C
 - c) Reaction time: 60 minutes
 - d) Catalyst concentration: 0.67%
 - e) Reaction temperature: 60°C
 - f) Settling time: 24 hrs.
- The BAME and SOME were found to have higher flash and fire point than those of diesel. The higher flash point of methyl ester makes it safe for supply and storage.
 - The calorific value of BAME and SOME have been found 2.81% and 9.63% lower than that of diesel fuel.
 - The Brake thermal efficiency (BTE) of the engine with BAME-25 sample of bitter almond oil was 28.47% at higher load whereas SOME-25 sample of sesame oil had 28.21%.
 - The similar trend of variation of BTE was also observed at higher level of engine loading for both biodiesel blend BAME-25 and SOME-25.
 - In general, with increase in biodiesel percentage, CO emission level decreases. No definite trend could be observed for CO emission vs. engine loading while considering the entire set of results however, overall emission of CO in biodiesel blended fuel is less than that of diesel. This is true for both Sesame oil biodiesel blend and bitter almond oil biodiesel blends.
 - Higher levels of NO_x emissions were perceived in biodiesel blend of sesame oil methyl ester as compared to diesel for all load condition except for part load.
 - The overall NO_x emission produced by BAME blends was marginally lower as compared to diesel fuel at part load condition. Under condition of higher load, evidently higher NO_x emission was noticed.
 - The maximum emission of NO_x for diesel was 84 ppm at full load condition whereas 107, 103 ppm, 87 ppm, 115 ppm, 119 ppm and 128 ppm respectively for BAME-10, BAME-25, BAME-40, SOME-10, SOME-25 and SOME-40 at full load condition.
 - The hydrocarbon (HC) emission resulted from Sesame oil and bitter almond oil biodiesel blends are quite low as compared to diesel for SOME-10, SOME-25, BAME-25 and BAME-40 blends.

- At full load condition, biodiesel sample of bitter almond oil performed better compared to the biodiesel samples of sesame oil for 25% concentration of biodiesel with the biodiesel-diesel blend.
- Consequently, it was observed that SOME-25 and BAME-25 were superior for better performance of biodiesel blends of SO and BAO as an alternative fuel in CI engine

5.3 Suggestions for future scope

The following are suggested as future work for the investigations on the use of biodiesel in a CI diesel engine.

- Future study is recommended to optimize the process parameters incorporating all possible variable combinations of treatments and formulate a suitable mathematical model for better understanding.
- The remedy for higher sulphur level is not investigated in the present work and suggested as research for future work.
- Long duration engine performance testing at various load conditions including the impact on engine health is recommended, for future work both sesame oil and bitter almond biodiesel.
- Performance and emission tests can be carried out on multi-cylinder generator engines and surface transportation engines like tractor, car, jeep, bus, trucks etc.
- Further studies can also be carried out on material compatibility, storage and utilization of by-product from biodiesel.
- Long-term stability of blends was not studied. So there is scope for the study of long-term stability of blends.

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