International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-10, Issue-1, February 2023
https://doi.org/10.55524/ijirem.2023.10.1.18
Article ID IJIR2331, Pages 100-108
www.ijirem.org

Performance and Emission of Single Cylinder Four-Stroke Diesel Engine Using Waste Animal Fat

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ABSTRACT- Synthesis of biodiesel from waste animal fat was the first step in this research. Biodiesel was made using a traditional chemical process called transesterification. In transesterification process pure fat was reacted with methanol in presence of KOH as catalyst. For every 100 ml of pure liquid fat 1 gram of KOH with 20ml of methanol was used for reaction at around 60ºc temperature. Following the production of biodiesel, blends of biodiesel and neat diesel in various mixing ratios, such as AFME5 (95 % D+5 % BD), AFME10 (90 % D+10 % BD), and AFME20 (80 % D+20 % BD) were prepared for carrying out the performance and emission tests on four-stroke single-cylinder diesel engine. The primary physico-chemical properties such as Calorific value, density, kinematic viscosity and CFPP of fat-based biodiesel and its blends were determined prior to testing. All of the properties measured were found to be in agreement with ASTM requirements.

The four-stroke diesel engine was run on different fuels and its performance and emission characteristics have been tested at all the modes of operation. The thesis includes a full discussion and analysis of engine data and performance factors. The brake thermal efficiency (BTE) of AFME10 was the maximum among all the test fuels, with value of 29.85% at full load capacity of test rig. Brake specific energy consumption of all the blended fuels was found to be more than that of pure diesel fuel. However, among the blends AFME5 has lowest BSEC values, with value of 12.50KJ/KW-hr at full load capacity. Because of the large amount of oxygen available in AFME20, exhaust emissions such as CO, HC, and smoke were lowest for this mix, the values of these emissions for AFME20 came out to be 0.4% of carbon monoxide, 75ppm of unburnt hydrocarbons and 63% of smoke opacity. As a result of the oxygenated environment, NO_X emissions were greater in blended fuels, 20% mix has maximum NO_X emissions. NO_X emissions value of AFME20 comes out to be 2560ppm at full load capacity. During the trials, smooth engine operation was noted. As a result, it has been discovered that the test fuels up to 20% mixing can be used as a cleaner fuel in any diesel engine without modification.

KEYWORDS- Biodiesel, Neat diesel, Transesterification, AFME, Engine tests, Performance parameters, Emissions, CFPP

I. INTRODUCTION

Most of the energy used in today's world is derived from fossil fuels. The huge demand for energy for different purposes has led to the swift consumption of non-renewable sources of energy like petroleum derivatives, and it has become a cause for rising apprehensions about energy crises in the near future. Burning fossil fuels has also been the cause of the emission of harmful gases and other hazardous particulates like NOx, CO, etc., which have horrendous effects on our ecosystem. Thus, to support the drive for sustainable living, it is the need of the hour to shift towards the sources of clean and renewable energy. Taking the initiative ahead and exploring new sources of energy, such as biodiesel, is of growing importance in coming years.

A. Global Fuel Scenario

In recent years, the global energy system has been marked by rapidly changing dominant trends and events, between the rapid expansion of shale oil and gas, the phase-out of nuclear energy, the drop in oil prices, and the internationally coordinated efforts to mitigate climate change since the November 2015 COP21 summit. This rapidly changing scenario in the energy sector significantly increases the need for decision-makers to understand the underlying inter-linkages and implications of these emerging trends. This rings particularly true for the European Energy Union and its efforts towards achieving the goals stated in the 2030 climate & energy framework. An attempt to transition towards a decarbonised and fully-integrated single energy market necessarily looks several years, even decades ahead. It is therefore no surprise that a successful energy transition for Europe is contingent on understanding if and how emerging trends nowadays may actually be (weak) signals of forthcoming threats and opportunities. In order to successfully navigate towards a de-carbonized future and differentiate relevant signposts from 'white noise', it is more often than not necessary for decision-makers to rely on science to produce models that can estimate the long-term effects of individual policies and technologies on the energy system. While scenarios have become more and more popular, they have at the same time been quite often misunderstood and misused.

One of the most authoritative sources of forward-looking energy analysis is the annual World Energy Outlook (WEO), published by the International Energy Agency

(IEA). It provides a projection of trends in energy demand and supply alongside explanations of their implications for energy security, environmental protection, and economic development. Several international oil companies also issue their own energy outlooks, projecting several decades ahead. Shell continues to periodically publish its scenarios for the global energy future, which, in the latest scenario study made public under the title 'New Lens', are mainly driven by the degree of rigidity and centralisation of the overall decision-making apparatus.

Four large-scale shifts in the global energy system set the scene for the World Energy Outlook the rapid deployment and falling costs of clean energy technologies, the growing electrification of energy, the shift to a more services-oriented economy and a cleaner energy mix in China, and the resilience of shale gas and tight oil in the United States. These shifts come at a time when traditional distinctions between energy producers and consumers are being blurred and a new group of major developing countries, led by India, moves towards centre stage. How these developments play out and interact is the story of this year's Outlook.

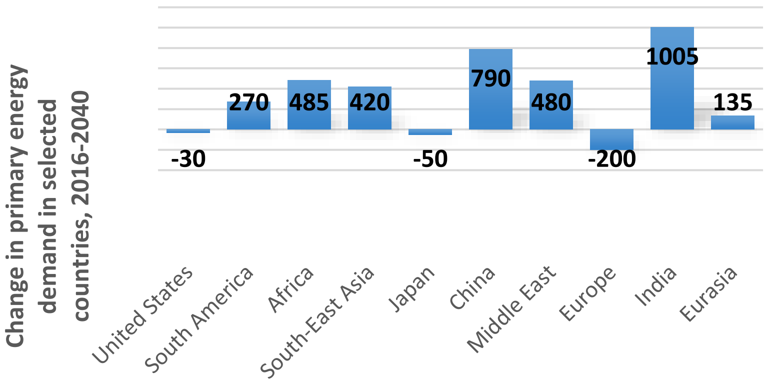

Figure 1: Change in primary energy demand in selected countries, 2016-2040

A. *Indian Fuel Scenario*

India, being one of the highly populated countries, has a huge reliance on non-renewable energy sources to meet its galloping energy needs. Typically, fossil fuels, particularly crude oil, are used to meet this energy need. The OPEC World Oil Outlook 2040 was published in 2018, and it projected that India is expected to be the primary driver of energy and oil demand growth up to 2040. It estimates that oil demand in India will reach 9.9 thousand barrels each day in 2040, from 3.9 thousand barrels each day in 2015. It is anticipated that India will have the fastest energy demand growth of 3.8 percent per year. At this growth rate, India is going to surpass the mark of 10 million barrels per day approximately in the year 2040. The world oil outlook reports estimate crude oil will remain one of the largest sources of energy in India. Out of all the sources of energy, the percentage share of oil will rise from 23.2% in 2016 to 25.2% in 2040. It has been estimated by World Oil Outlook 2040 that crude oil production in India will dwindle to 0.41 mb/d in 2040 from 0.69 mb/d in 2017, hence depicting an increase in India's crude oil imports by a good margin till 2040.

Despite significant progress in renewable energy capacity expansion and generation, estimations and projections imply that our country will continue to rely heavily on non-renewable fuels, particularly conventional crude oil and coal. As a result, it becomes clear that increased research and development efforts to find alternate energy sources are needed to solve these worrisome challenges.

Table 1: Indian Fuel Scenario

	Levels (mbeo/d)				Growth (% p.a.)	Fuel shares (%)			
	2015	2020	2030	2040	2015-2040	2015	2020	2030	2040
Crude Oil	3.91	5.2	7.5	10.2	6.43	22.98	24.8	24.5	25.88
Coal	7.7	9.6	14.0	18.0	5.35	45.29	45.78	45.75	45.68
Gas	0.8	1.2	2.2	3.1	11.5	4.7	5.72	7.19	7.86
Nuclear	0.2	0.29	0.8	1.1	18	1.17	1.38	2.61	2.79
Hydro	0.2	0.28	0.6	0.7	10	1.17	1.37	1.96	1.77
Biomass	4.0	4.1	4.5	4.6	2.4	23.52	19.55	14.70	11.67
Other Renewables	0.2	0.3	1.0	1.7	6	1.17	1.40	3.26	4.3
Total	17.01	20.97	30.6	39.4	5.26	100	100	100	100

B. *Diesel Engines and Need of Alternative Fuel*

Projections for the 30-year period from 1990 to 2020 indicate that vehicle travel, and consequently, fossil-fuel demand, will almost triple and the resulting emissions will pose a serious problem. The main reason for increased pollution levels, in spite of the stringent emission standards that have been enforced, is the increased demand for energy in all sectors and most significantly the increased use of internal combustion engines for mobility and power. As elaborated in the previous sections, a major chunk of imported crude oil derivatives are used as fuel in internal combustion engines. The most popular petroleum fuels are gasoline and diesel used as motor fuels in spark ignition and compression ignition engines respectively. Amongst them, diesel engines have proven their utility in the transportation and power sectors due to their higher efficiency and ruggedness and hence play a pivotal role in rural as well as urban Indian economy. With respect to usage diesel engines are largely favored across a wide spectrum of activities like automotive application, small and decentralized power generation, prime mover for farm and agricultural machineries, small scale industrial prime mover and so on. Therefore, in Indian context, diesel consumption is always disproportionately higher than gasoline. Fig. 2 shows the consumption of motor gasoline and high speed diesel oil during the period 2005 to 2012. It may be observed that diesel to gasoline consumption ratio was 4.80 in 2005 which was dropped to 4.31 in 2012. This indicated that the consumption of gasoline is increasing at a faster rate than the consumption of diesel, still diesel consumption in India is nearly four and half times higher than gasoline.

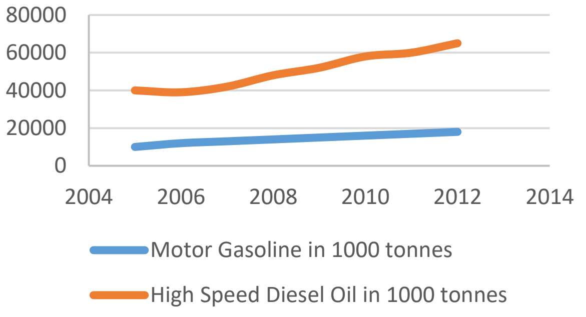

Figure 2: Consumption of gasoline and diesel during the period 2005 to 2012[9]

Therefore, even a partial substitution of mineral diesel by any renewable and carbon neutral alternative fuel can have significant positive effect on economy and environment in terms of reduction in carbon footprints and dependence on imported crude oil. In the light of the apprehensions about long-term availability of petroleum diesel, stringent environmental norms and environmental impacts due to extensive use in fast growing Indian economy have mandated the search for a renewable alternative of diesel fuel.

C. Problems with Fossil Fuels

Nonetheless, diesel fuel is one of the premium fuels available today for harnessing energy, yet it has some issues that have become cause for finding its alternatives. The following are some of the most common issues related to the use of diesel fuel.

- ***Depletion of Fossil Fuels***

The depletion of fossil fuels is because their consumption rate is far higher than they are being regenerated by nature. Carbonaceous fuels provide energy that is used in the operation of power plants, furnaces, automobiles, and other heavy machines. These fuels provide feed stock for many industries for the production of essentials. However, persistent usage of these fossil fuels has become the cause of their depletion in the near future. The globe currently consumes 136.22 million barrels of oil every day. This number is predicted to rise by 60 to 70 percent by 2030. This exponential rise in the consumption of oil reserves will result in an energy crisis ahead. So we must employ multi-pronged strategies like investigating new technological solutions and bolstering the current technology to minimize the consumption of fossil fuels for an optimum supply of energy. Hence, it mitigates the energy turmoil in the offing.

- ***Emissions and effects on Environment and health Hazard***

People's increasingly opulent lifestyles have disastrous consequences for our environment, as new technology is implemented without regard to its adverse effects. One such issue is air pollution, which is mostly caused by the excessive use of fossil fuels in numerous engineering systems. Deterioration of air quality has resulted in numerous diseases which have become the cause of about 4.2 million deaths every year. Around 91 percent of the world's population lives in locations where air quality is poorer than WHO guidelines. Including both affluent and developing countries, low-and middle-income countries also bear the brunt of air pollution, with the highest toll in the WHO Western Pacific and South-East Asia areas. Air pollution comes from a variety of places, each with its own set of problems. Vehicles, power generation, and industries that use fuel for production are all major producers of outdoor pollution. Policies that encourage the use of more sustainable and cleaner energy can help to minimize major sources of pollution in the atmosphere. Globally, air quality is inextricably tied to the earth's climate and ecosystems. Many of the factors that contribute to air pollution (such as the burning of fossil fuels) also contribute to emissions of greenhouse gases.

Global carbon emissions from fossil fuels have significantly increased since 1900. Since 1970, CO_2 emissions have increased by about 90%, with emissions from fossil fuel combustion and industrial processes contributing about 78% of the total greenhouse gas emissions increase from 1970 to 2011 (fig. 3). Agriculture, deforestation, and other land-use changes have been the second-largest contributors.

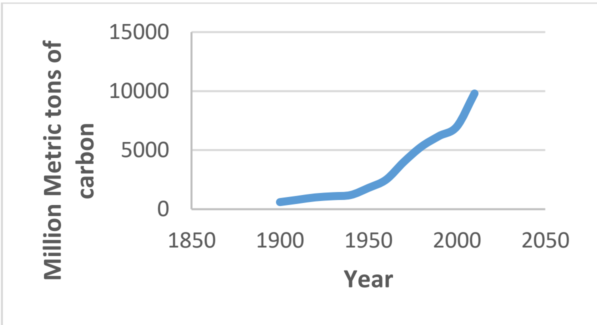

Figure 3: Global Carbon Emissions From Fossil Fuels 1900-2014

D. Biodiesel

Biodiesel has been found as one among the best alternatives to petroleum-based fuels like Diesel. Biodiesel can be extracted from vegetable oils or animal fats by a chemical process called Transesterification. Animal fats and vegetable oils are chemically triglycerides which are trans esterified using an alcohol like methanol or ethanol in the presence of an alkali or acid catalyst to produce alkyl-esters called Biodiesel. Glycerol as a by-product is also produced during this reaction process. The world has a large percentage of the population who consume meat, because of which a large quantity of animal fat is generated. This wasted animal fat could be one of the low-cost renewable sources to produce biodiesel.

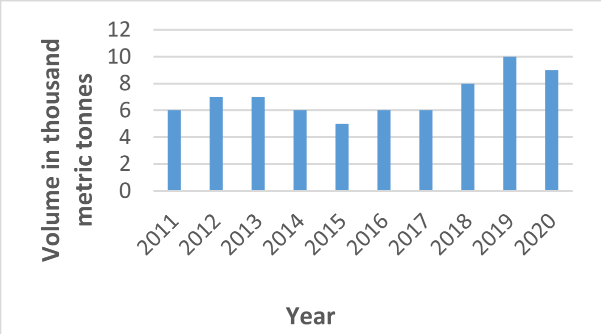

Figure 4: Tallow and animal fat as feedstock for fuel biodiesel production in India from 2011 to 2020(in 1,000 metric tons)

Figure 4 shows the amount of tallow and animal fat as feed stock available for fat production of biodiesel in India. Data depicts the increasing availability of feed stock, hence projects India as a country with good source of biofuel production.

E. Transesterification for Producing Biodiesel from Animal Fats

Biodiesel is prepared by a chemical process called the transesterification reaction in which animal fats or vegetable oils which are triglycerides are made to react with a short-chain alcohol in the presence of an acid or alkali-based catalyst. A variety of catalysts like sodium hydroxide, potassium hydroxide, potassium methoxide, sulphuric acid, hydrochloric acid, etc. are used for carrying out this transesterification process. Alkali catalysts have a quicker reaction rate for transesterification of animal fats than acid catalysts, which are 4000 times faster, less expensive, and more widely available. Methoxides function better but are more expensive than sodium and potassium hydroxides. It is vital to maintain the temperature of the fat at roughly 60ºC before beginning the transesterification process. Once the temperature has been maintained, the combination of methanol and catalyst (KOH) is added at 15-minute intervals and the reaction is carried out for roughly one hour with continuous stirring using a magnetic stirrer provided.

Because of the low cost of methanol, it is mostly used as a short-chain alcohol for carrying out transesterification. However, other higher alcohols like ethanol, propanol, and butanol can also be employed. The process of transesterification involves converting triacylglycerols to diacylglycerols and releasing one fatty acid. The second fatty acid is released when diacylglycerols are transformed into monoacylglycerols, and finally, when monoacylglycerols are converted to glycerol, the third fatty acid is released. Transesterification has high conversion efficiency and a low cost in general. There are various factors that influence the efficiency of the transesterification reaction, including the reaction time, temperature at which the reaction is carried out, the type of alcohol used, the molar ratio of alcohol used, and the catalyst utilised, both in terms of type and quantity. The other factors, like impurities and the amount of water present in the reaction medium, are to be considered as well. In industrial processing plants, for every kilogram of fat, we need about 0.1kg of alcohol, like methanol, mixed with an alkaline catalyst such as potassium hydroxide or sodium hydroxide, to produce one kilogram of biodiesel and 0.1 kilogram of glycerine as a by-product.

II. LITERATURE SURVEY

- With some exceptions, most of the non-edible oils have high free fatty acid contents leading to a two stage transesterification process to produce biodiesel.
- The energy consumption in two stage transesterification is higher. Therefore, optimization of process parameters is must in high FFA non-edible oil seeds for commercial scale production.
- In many reported cases the final biodiesel sample produced did not comply with the designated standards of ASTM/EN/ISO etc. resulting in further addition of additives and post-processing.
- Depending upon the feedstocks, some of the biodiesels showed improved brake thermal efficiency and reduced brake specific fuel consumption with increased biodiesel volume fraction in the test fuel where as some others exhibited exactly opposite trend. Therefore, engine performance using biodiesel directly depends upon the property of the corresponding feedstock and the transesterification process.
- Most of the literatures agreed on the common denominator that emissions of carbon monoxide and unburnt hydro carbons were reduced with biodiesel, whereas that of oxides of nitrogen increased. However, the same was not linear. In many cases even, reduction in oxides of nitrogen was reported
- With increase in volume fraction of biodiesel, reduction in combustion heat release was reported in major cases. However, in some cases a marginal increase was reported at lower blends.
- Increased heat release in the diffusion phase, smoother engine operation etc. are some of the major conclusions in most of the literatures.

III. RESEARCH GAP

- A number of authors have investigated edible and non-edible oils for biodiesel generation, but waste animal fat has not been investigated for biodiesel synthesis or engine use.
- In India, the disposal of waste animal fat has not been thoroughly investigated in recent years. India, on the other hand, is the world's second-largest meat exporter.
- Local demand for fuel can be addressed by the use of biodiesel.
- Prolonged storage of biodiesel need to be achieved.
- Extensive work needs to be done in exploring additives for biodiesel so that it can be made usable in all weather conditions.

IV. RESEARCH OBJECTIVE

- To prepare test fuels of biodiesel and its blends.
- To determine verify and validate the physico-chemical properties of biodiesel as per ASTM standards.

- To create an engine setup for testing the performance and emissions of test fuels.
- To investigate the blends of the waste animal fat biodiesel and compare them with respect to the base line data.

V. LITERATURE SURVEY

A decent amount of research has been carried out in the past on biodiesel. This chapter consists of a summarized background of both the analytical and experimental studies on the use of biofuels that have been carried out by researchers over a vast period of time.

A. Biodiesel Production, Characterization and Optimization

Atadashi et.al.[1] explored the production of fatty acid methyl esters or biodiesel from high free fatty acid containing feedstocks like some non-edible vegetable oils, animal fats etc. to bring their properties close to mineral diesel. The results concluded that the properties of the biodiesel produced closely matched the corresponding ASTM standards and cost of production was reported to be 25% less compared to refined low FFA feedstocks.

Chen et. al.[2] studied the feasibility of biodiesel production from "Tung" (Vernicia montana) oil with respect to the transesterification yield and biodiesel properties. The findings indicated high cold filter plugging point of 11^{O}C, 94.9 wt.% of ester content and oxidation stability of 0.3 hours at 110^{O}C for the biodiesel sample produced. Moreover, the tung oil biodiesel exhibited high density of 903 kg/m3at 15 ^{O}C, kinematic viscosity of 7.84 mm2/s at 40 ^{O}C, and iodine value of 161.1 g I2/100 g. The properties of the tung oil biodiesel were found to be improved by blending with canola and palm oil biodiesels to satisfy the biodiesel specifications.

Usta et. al. [3]evaluated tobacco seed oil as a feedstock for biodiesel production. Various physicochemical and fuel properties of the tobacco biodiesel were examined and compared with European Biodiesel Standard EN14214. The results showed oxidation stability and iodine number of the biodiesel were not within the standards limit. Oxidation stability was improved by six different anti-oxidants, out of which "pyrogallol" was found to be the most effective. Poor iodine number was improved by blending it with biodiesel containing more unsaturated fatty acids. The resultant reduction in cold flow plugging point was addressed by adding "octadecene-1-maleic anhydride copolymer" as cold flow property improver.

Teixeira da Silva de La Salles et.al.[4] studied the production and physicochemical characterisation of biodiesel from the fruits of the Syagrus coronate (Mart.) Becc., popularly known in Brazil as "licuri" or "ouricuri". The oil was transesterified using conventional catalysts and methanol, to obtain biodiesel. The properties of the biodiesel produced were comparable with standards.

Silitonga et. al. [5] investigated biodiesel characterization and production from Ceiba pentandra seed oil. The production was conducted by two step acid–base transesterification. The results found that properties of C. pentandra methyl ester fall within the recommended biodiesel standards (ASTM D6751and EN 14214). Beside, this study also suggested biodiesel–diesel blending to improve the properties such as viscosity, density, flash point, calorific value and oxidation stability.

Lin et. al.[6] carried out a three stage transesterification process to produce biodiesel from crude rice bran oil (RBO) The influence of variables on conversion efficiency to methyl ester, i.e., methanol/RBO molar ratio, catalyst amount, reaction temperature and reaction time, was studied. The content of methyl ester was analysed by chromatographic analysis. Through orthogonal analysis of parameters in a four-factor and three-level test, the optimum reaction conditions for the transesterification were obtained: methanol/ RBO molar ratio 6:1, usage amount of KOH 0.9% w/w, reaction temperature 60 ^{O}C and reaction time 60 minutes. Fuel properties of RBO biodiesel were studied and compared according to ASTM D6751-02 and DIN V51606 standards for biodiesel. Most fuel properties complied with the limits prescribed in the aforementioned standards.

Wang et. al.[7] investigated Siberian apricot (Prunus sibirica L.) seed kernel oil as a promising non-conventional feedstock for preparation of biodiesel. The oil has high oil content (50.18 ± 3.92%), low acid value (0.46 mg/g), low water content (0.17%) and high percentage of oleic acid (65.23 ± 4.97%) and linoleic acid (28.92 ± 4.62%). The measured fuel properties of the Siberian apricot biodiesel, except cetane number and oxidative stability, were conformed to EN 14214-08, ASTM D6751-10 and GB/T 20828-07 standards, especially the cold flow properties were excellent (Cold filter plugging point -14^{O}C).

Wang et. al.[8] studied feasibility of biodiesel production from Datura stramonium L. oil (DSO). The research work explored an optimum yield of 87% using a two-step catalysed reaction conditions. Furthermore, the fuel properties of DSO biodiesel were determined and evaluated. Compared with Jatropha curcas L. (JC) and beef tallow (BT) biodiesel, DSO biodiesel possessed the best kinematic viscosity (4.33 mm2/s) and cold filter plug point (-5^{O}C).

Benjumea et. al.[9] measured some basic properties of several palm oil biodiesels–diesel fuel blends according to the corresponding ASTM standards. In order to predict these properties, mixing rules were evaluated as a function of the volume fraction of biodiesel in the blend. Kay's mixing rule was used for predicting density, heating value, three different points of the distillation curve (T10, T50 and T90), cloud point and calculated cetane index, while an Arrhenius mixing rule was used for viscosity. The absolute average deviations (AAD) obtained was low, demonstrating the suitability of the used mixing rules. It was found that the calculated cetane index of palm oil biodiesel obtained using ASTM D4737 was in better agreement with the reported cetane number than the one corresponding to the ASTM D976.

VI. RESEARCH METHODOLOGY AND DATA SOURCES

A. Introduction

This chapter deals with the systematic execution of all the steps from production of biodiesel from waste animal fat, prepration of blends of AFME and pure diesel, comprehensive characterization of physico-chemical properties, and finally setting up of test rig and carrying out of performance and emission characteristics of four-stroke diesel engine.

B. Production of Biodiesel

Biodiesel was prepared from animal fat by carrying out step wise procedure which is given as follows.

- ***Collection of Fat***

In places where there is a large consumption of meat, animal fat can be obtained from multiple sources, like slaughter houses, household waste fat, etc. For conducting this experimentation, animal fat was bought from a meat shop at 60INR per Kg.

C. Separating Impurities from Fat

The solid fat was heated on an electric heater in a steel vessel, till the insoluble impurities got separated, and pure liquid fat of dark brown color was obtained. This pure fat was now free from all the insoluble impurities and also all the available water content of fat was removed. Now fat can be used for carrying out the transesterification process to convert it into biodiesel.

D. Transesterification for Preparation of Biodiesel

Biodiesel is best prepared by the chemical process called transesterification. There are multiple stages in this process. The stepwise procedure to be followed is discussed.

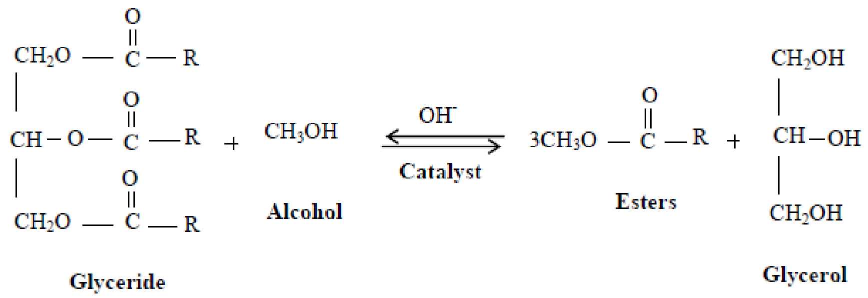

Figure 5: Chemical Reaction of Transesterification Process

1. First of all, cleaning all the equipment required during the course of this process.
2. Put around 200 to 300ml of purified fat in a glass beaker and heat it on a hot plate above 100ºC so that all the moisture content in the fat is evaporated, and this heated fat is ready for transesterification.
3. Before carrying out the reaction, we need to prepare a solution of catalyst (KOH) with methanol. For every 100ml of fat, we used a solution of catalyst containing 1 gram of KOH in 20ml of methanol.
4. Now we begin with the transesterification process, taking 200ml of liquid fat in a beaker. Raise its temperature to 60ºC on a magnetic stirrer with a hot plate and wait for a few minutes till the temperature is stabilized. This reaction is to be carried out for about an hour. During this duration, we have to add 60ml of solution of KOH plus methanol prepared earlier at three intervals of 15 minutes, while stirring the mixture constantly using a magnetic bead.
5. After completion of the reaction, put the mixture in the separating funnel for a period of about 24 hours till the byproduct, i.e. glycerol, settles down and can be easily separated from the biodiesel.
6. Separation of glycerol is done by opening the outlet of the separating funnel and removing the dark colored glycerol from the fatty methyl esters.
7. After glycerol separation, the methyl esters need to be washed. This is done by the water washing technique, in which lukewarm water is added to the separating funnel and then the mixture is shaken slowly and carefully to remove unr

E. Preparation of blends of Biodiesel

The National Biodiesel Mission aimed to replace mineral diesel with biodiesel only up to 20 percent. The scarcity of feedstocks is the primary reason for limiting biodiesel replacements to 20%. Furthermore, long-term durability concerns with biodiesel use in non-modified diesel engines are one of the factors influencing biodiesel's lower substitution targets. In this context, the study looked into AFME blends of 5%, 10%, and 20% in diesel. As a result, AFME5, AFME10, AFME20, and neat diesel were used as engine test fuels. A biodiesel blend is prepared simply by mixing a specified amount of biodiesel with a specific amount of diesel fuel.

Table 2: Fuel blends

S.No.	Nomenclature	Diesel %	AFME Biodiesel %
1.	AEME	0	100
2.	D100	100	0
3.	AFME5	95	5
4.	AFME10	90	10
6.	AFME20	80	20

F. Physico-chemical Characterisation of Fat based Biodiesel

The physico-chemical properties of the biodiesel are necessarily to be determined for its standardization and these values can be used further for determination of engine parameters. Five fuel samples were prepared comprising of neat diesel, neat AFME, AFME5, AFME10, and AFME20. Some important properties such as specific gravity, kinematic viscosity, calorific value, cetane number, and flash point of biodiesel were estimated in laboratory.

VII. RESULT AND DISCUSSION

In this chapter, the various results obtained were categorized as the production physico-chemical characterization of AFME and its blends, Performance, emission and combustion characteristics of diesel engine fueled with various test fuels. Comparative analysis has been carried out between the performance as well as emission characteristics using different fuel blends. A detailed overview has been presented in tabulated and graphical data.

A. Physico-chemical properties of biodiesel and its blends with neat diesel

The physico-chemical properties like kinematic viscosity, density, calorific value, and CFPP of neat diesel, biodiesel, and the blends have been determined.

4.1.1. Kinematic Viscosity

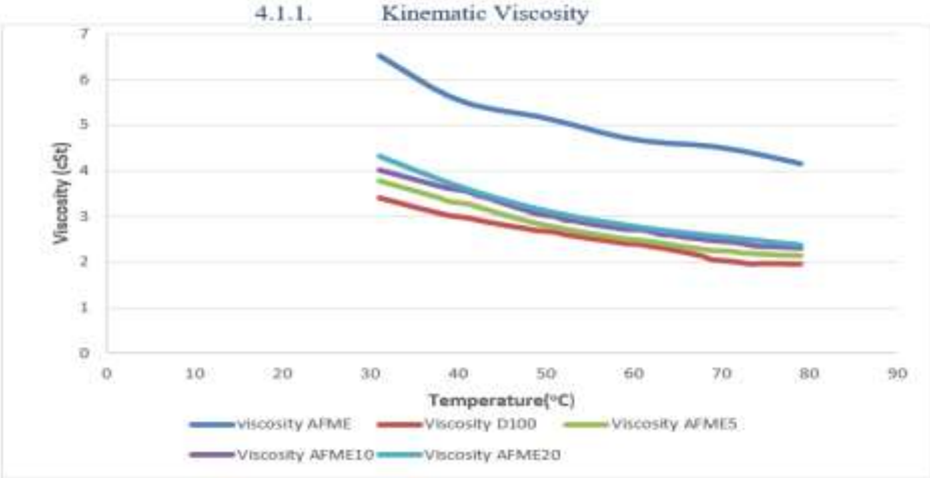

Figure 6: Variation of viscosity with temperature for various test fuels

As mentioned in previous sections, the viscosity was measured using the ZAHN2 dip cup elcometer. The viscosity of AFME and its mixes varies with temperature, as seen in Fig.6. At 40°C, pure AFME had a kinematic viscosity of 5.63 cSt, which was lower than the ASTM standard of 6 cSt. As a result, AFME's viscosity was within the ASTM standard limit. Furthermore, during the full trial range of 30°C to 80°C temperature, all AFME and diesel mixes displayed viscosities within the ASTM norm. For neat AFME, the variation of kinematic viscosity with temperature was observed to be almost 41%. The viscosity variation with temperature was minimal for lower mixtures. At 40°C, diesel had a viscosity of 2.956cSt, whereas neat AFME had nearly twice that value. As a result, AFME's atomization, vaporization, and air-fuel mixing properties are thought to be inferior to mineral diesel.

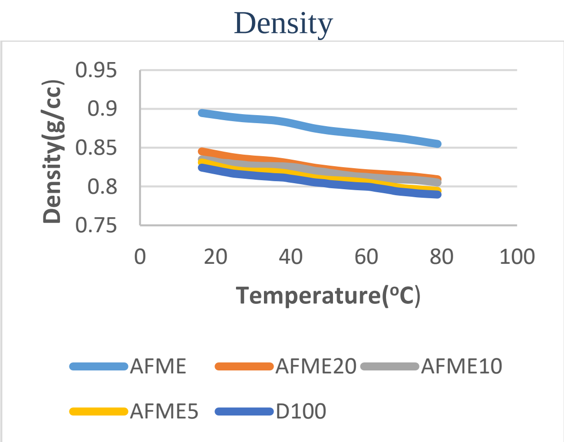

Figure 7: Variation of density with temperature for various test fuels

The density was measured with an oscillating "U" tube density meter, as shown in fig.7. It's also an important fuel attribute that can have a direct impact on engine performance, emissions, and combustion behaviour. The density is linked to a number of significant qualities, including the cetane rating and heating value. Due to a problem with fuel mass injection, fuel density will have an impact on engine output power. The density of AFME and its mixes was measured at temperatures ranging from 15°C to 80°C, with each step increasing by 10°C. At 15°C, neat AFME had a density of 0.894 g/cc, whereas neat diesel had a density of 0.8239 g/cc. AFME and its blends' density was less affected by temperature than viscosity. It's worth noting that the change in density of pristine AFME was only 4.3 percent across the whole temperature range. The density of AFME and all of its blends was well within the ISO12185 norm.

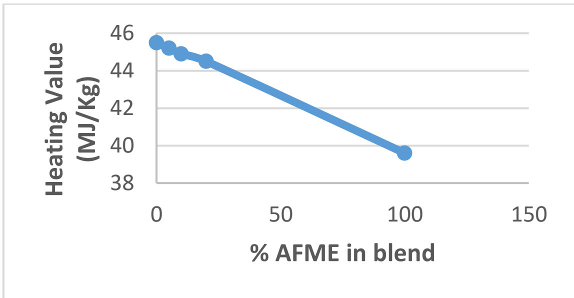

Figure 8: Variation of calorific value with temperature for various test fuels

As mentioned briefly in the previous sections, a bomb calorimeter was utilized to determine the calorific value of the test fuels. Fig.8 shows the calorific value of several AFME and diesel mixtures. It can be shown that AFME has a calorific value of 39.6 MJ/Kg, whereas mineral diesel has a calorific value of 45.5 MJ/Kg.

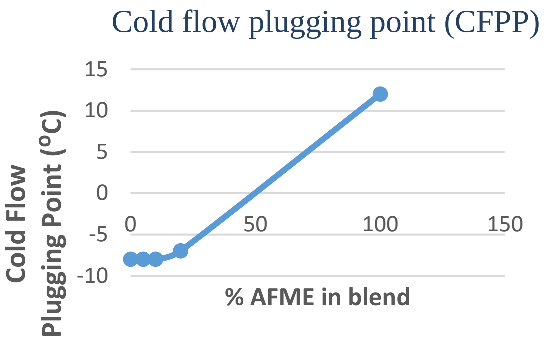

Figure 9: CFPP for various test fuels

Figure 9 depicts the variation in CFPP for the test fuels. It's worth noting that pure diesel has a CFPP of -8°C, whereas pure AFME had a CFPP of 6°C. As a result, AFME's flow characteristics are poorer to diesel's. For AFME, CFPP temperature of 6°C may be inappropriate for diesel engine applications in India especially in cold place like Kashmir. Therefore, some additives need to be looked for increasing the cold flow properties of AFME; however, no such research has yet been conducted.

Various equipment used for determination of physico-chemical and fuel properties and the corresponding standards are provided in table 3. A comparative assessment of various physico-chemical properties of AFME was carried out with Calophyllum Methyl Ester in table 4.

Table 3: List of equipment used for property measurements and the standards

S.NO.	PROPERTY	EQUIPMENT	MANUFACTURER
1	Kinematic Viscosity	ZAHN2 viscosity dip cup	DFT Tech
2	Density	U tube density meter	Anton Parr, UK
3	CFPP	Automatic NTL 450	Normalab, France
4	CALORIFIC VALUE	PARR 6100 BOMB CALORIMETER	IKA, UK

Table 4: Comparison of physico-chemical properties between the methyl esters of Calophyllum and animal fat

S.NO.	PROPERTY	CALOPHYLLUM METHYL ESTER	ANIMAL FAT METHYL ESTER
1	Viscosity at 40°C	5.5cSt	5.63cSt
2	Viscosity at 80°C	4.1cSt	4.13cSt
3	Density at 40°C	0.8838g/cc	0.881g/cc
4	Density at 15°C	0.8952g/cc	0.894g/cc
5	Calorific value	36.12MJ/Kg	39.60MJ/Kg
6	CFPP	0^{O}C	12^{O}C

VIII. CONCLUSION

The performance and emission characteristics of AFME–diesel blended fuels as substitute fuels for diesel engines were investigated in this study. Different experiments were conducted to assess the performance and emissions of AFME–diesel blended fuels as diesel engine alternative fuels. Comparative investigations were conducted between various operational modes. Another aspect of this study was physico-chemical characterization of AFME and its blends. The study's findings are reported below.

- The density of AFME was 0.881 g/cc at 40°C, viscosity was 5.63cSt at 40°C, calorific value was 39.60MJ/Kg and CFPP of 12°C. All the physico-chemical parameters were found to be within the limits of corresponding ASTM standards
- All of the AFME-diesel blends had higher density, CFPP, and viscosity than pure diesel. When compared to straight diesel, all of the blends had lower calorific values.
- Pure biodiesel's physico-chemical properties prevent its use as a substitute fuel in compression ignition engines as they vary greatly from that of pure diesel fuel. However, the majority of the determined properties of the AFME–diesel blended fuels were nearer to the properties of neat diesel, hence they fulfill many requirements to be used as an alternative of diesel fuel.
- AFME5, AFME10 and AFME20 exhibited 26.10%, 29.85% and 28.95% full load brake thermal efficiency respectively as compared to 23.8% illustrated by the diesel baseline. Therefore, for better Brake thermal efficiency 10% blend is preferable as it produces maximum brake thermal efficiency
- Similarly, AFME5, AFME10 and AFME20 brandished full load brake specific energy consumption (BSEC) of 12.5KJ/kWh, 14.02KJ/kWh, and 13.12KJ/kWh respectively as compared to 12.20KJ/kWh illustrated by the baseline diesel operation. Therefore, for better fuel efficiency 5% blend is preferable as it was found to have least Brake specific energy consumption BSEC.
- The full load carbon monoxide, smoke and total hydrocarbon emissions of AFME and its blends were lower than the diesel baseline by a margin of 25% to 45%. All of these emissions were lowest when the engine was run on 20% blended fuel.
- When using AFME–diesel blended fuels, significant reductions in exhaust smoke emissions can be realized. Smoke opacity was lowest in 20% blended mode of operation

However, from the point of view of alternative fuel for diesel, 10% blend of Biodiesel that is AFME10 can be preferably used.

IX. FUTURE WORK

Because biofuels are in such high demand for sustainable living, there is a lot of research and development going on this subject. Many future developments in the use of biodiesel as an alternative fuel in diesel engines can be proposed here. In this study, we only mixed biodiesel with clean diesel up to a 20 percent ratio; larger mixing ratios need to be examined. Engine adjustments can be incorporated to improve performance characteristics. This topic has a lot of potential in terms of using additives with biodiesel to improve its physico-chemical qualities. It is necessary to conduct research on this subject in order to determine how long it can be stored and at what minimum temperature it can be made usable.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

[1] Atadashi I.M, Aroua M.K, Abdul Aziz A.R, Sulaiman N.M.N. Production of biodiesel using high free fatty acid feedstocks. Renewable and Sustainable Energy Reviews 16 (2012) 3275– 3285.

[2] Chen Y.H, Chen J.H, Chang C.Y, Chang C.C. Biodiesel production from tung (Vernicia montana) oil and its blending properties in different fatty acid compositions. Bioresource Technology 101 (2010) 9521–9526.

[3] Usta N, Aydogˇan B, Çon A.H, Ugˇuzdogˇan E, Özkal S.G. Properties and quality verification of biodiesel produced from tobacco seed oil. Energy Conversion and Management 52 (2011) 2031–2039.

[4] Teixeira da Silva de La Salles K, Meneghetti S.M.P, Ferreira de La Salles W, Meneghetti M.R, Dos Santos I.C.F, da Silva J.P.V, de Carvalho S.H.V, Soletti J.I. Characterization of Syagrus coronata (Mart.) Becc. oil and properties of methyl esters for use as biodiesel. Industrial Crops and Products 32 (2010) 518–521.

[5] Silitonga A.S, Ong H.C, Mahlia T.M.I, Masjuki H.H, Chong W.T. Characterization and production of Ceiba pentandra biodiesel and its blends. Fuel 108 (2013) 855–858.

[6] Lin L, Ying D, Chaitep S, Vittayapadung S. Biodiesel production from crude rice bran oil and properties as fuel. Applied Energy 86 (2009) 681–688.

[7] Wang L, Yu H. Biodiesel from Siberian apricot (Prunus sibirica L.) seed kernel oil. Bioresource Technology 112 (2012) 355–358.

[8] Wang R, Zhou W, Hanna M.A, Zhang Y.P, Bhadury P.S, Wang Y, Song B, Yang S. Biodiesel preparation, optimization, and fuel properties from non-edible feedstock, Datura stramonium. Fuel 91 (2012) 182–186.

[9] Benjumea P, Agudelo J, Agudelo A. Basic properties of palm oil biodiesel–diesel blends. Fuel 87 (2008) 2069–2075.