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Comparative Study and Analysis of Performance and Emissions Characteristics of Bio Diesel in Diesel Engine

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Abstract - *The diesel engine has played an important role in transportation and industrial application like, internal combustion engines, aircrafts, marines, generators, irrigation pumps etc. The use of diesel engine is continuously increasing due to enhancement of population and standard of living. There is also continuous effort to improve the performance of diesel engine and reduce the emission of harmful gases. One of the methods to achieve this can be through use of blends with diesel popularly known as biodiesel. Biodiesel may have significant advantages like, domestically produced, clean-burning, great renewability and biodegradability, which provide good lubricity and it contains relatively very small amounts of sulfur. In the present investigation computational studies is applied to study the performance and emission characteristics of various biodiesel blends. The effects of different injection angles on the engine performance and emissions were investigated by using different fuels of palm, soybean methyl ester and coconut. The evaluated parameters are engine power, torque, specific fuel consumption and the emissions of various gases. The performance & emission characteristics were carried out on a single cylinder, direct injection diesel engine operating on different blends with diesel fuel. The performance and emission characteristics of a conventional compression ignition engine have been also obtained. The simulation and optimization were carried out using diesel and biodiesel blends as fuels and compared. Suggestion is given for optimal blends and most efficient biodiesel producing minimum harmful gases as emission.*

Key Words: Diesel engine, Biodiesel, Diesel, Palm, Coconut, Soya bin oil.

1. INTRODUCTION

The transportation sector is an important unit which affects the economy of a nation. Most of the vehicles used today, whether it is commercial passenger cars, buses, motorcycles, or heavy-duty vehicles such as trucks and locomotives are reliant on fossil fuels such as Petrol and Diesel as an energy source [1]. Many a time the automobiles require use of fabrication technique for assemble different parts of it to get final product [2-6,32]. The various types of fabrication technique used are shielded metal arc welding, submerged arc welding, tungsten inert gas welding and gas metal arc welding [3-9]. Out of this the gas metal arc welding specially the advanced version of it of pulse current gas metal arc welding is the most common methods used. The advantage of using it is attainment of better properties and its life [10-13]. Further, the fuels used in automobiles being a product of petroleum are non-renewable and will become scarce in the near future. Further, internal combustion engines are responsible for most of the pollution encountered in major urban centres, thereby increasing health problems and the greenhouse effect. Although they are not a significant source of carbon oxides or hydrocarbon emissions, diesel engines are responsible for high levels of nitrogen oxides and particulate matter [14]. One of the ways to reduce the amount of soot in diesel engines is by using blends of diesel and biodiesel fuel, although this can increase the amount of nitrogen oxides.

Further, the emissions from engines using these fuels cause serious environmental problems of air pollution. Thus, extensive research has is already going on in the field of alternative fuels. In the case of compression ignition engines, such as those running with diesel fuel, biodiesel has emerged as an important alternative [15]. Biodiesel has emerged as a promising alternative due to its favorable properties which are quite close to that of diesel fuel. Further, diesel engines can be run while fuelled with biodiesel with little or no modification. The improvement in IC engine is undeniable and that allows the diesel engines to work with alternative fuels. In spite of not to develop full scale engine block change, the requirements oblige the system to change in little parts. Injection system is one of the most important systems in diesel engine which must be developed more and affects parameters which make the combustion stable [14]. Also, the complicated construction of engines forces the researchers to simulate the entire systems before the engine block cast.

The share of Diesel consumption by cars, utility vehicles and 3-wheeler sector is highest at 28.48%. The agriculture sector is a major consumer of Diesel with about 13% of the total consumption. Diesel consumption by other segments is 17 per cent. Hence, Bio fuels seek to appendage conventional energy resources for meeting rapidly increasing requirements of transportation fuels and meeting energy needs and to diminish the reliance on import of fossil fuels [16].

Biodiesel is an alternative fuel similar to conventional or 'fossil' diesel. Biodiesel can be produced from straight vegetable oil, waste fruits, animal oil/fats, tallow and waste cooking oil. The process used to convert these oils to Biodiesel is called transesterification. The largest possible source of suitable oil comes from oil crops such as rapeseed, palm or soybean. Most biodiesel at present is produced from waste vegetable oil sourced from restaurants, chip shops, industrial food producers such as birdseye etc. Though oil straight from the agricultural industry represents the greatest potential source, it is not being produced commercially simply because the raw oil is too expensive. Waste vegetable oil can often be sourced for free or sourced already treated for a small price. The biodiesel produced from waste vegetable oil can compete with fossil diesel [16]. Using vegetable oil in place of diesel fuel or mixing with petrol-diesel reduces greenhouse gases and particulate pollutants, promotes energy independence and supports domestic industry, and can stimulate the economy by saving you money and keeping more revenue in your community. Inhaling exhaust from vehicles is dangerous and quickly turns lethal, and the combustion of diesel and petroleum products is the major cause of global warming and ecological imbalance. By replacing diesel with vegetable oil we can eliminate these negative impacts because vegetable oil is safe, clean and renewable fuel. Burning biodiesel or vegetable oil instead of diesel will save money and it will save up to 30% to 80% on their fuel costs after a conversion [17].

Shubham Mehta et al. (2016) have observed that soybean biodiesel can be used with advanced injection timing to reduce smoke and PM emissions with slight decrease in performance, while NO_x emissions are taken care of by exhaust gas recirculation technique or with retarded injection timing to reduce NO_x emissions [18]. Gaurav Paula et al. (2013) in their investigation have concluded that the use of jatropha biodiesel in a conventional diesel engine decreases its torque and brake thermal efficiency, the decrease being more with increase in the biodiesel share in the blends. BSFC increases with the percentage of biodiesel in the blended fuels [19]. Y.C. Sharma et al. (2007) described that yield of biodiesel is affected by molar ratio, moisture and water content, reaction temperature, stirring, specific gravity [20]. P Shinoj et al. (2011) analyzed and concluded that given the slow growth in area and yield of sugarcane on the one hand and rising demand for sugar, potable and industrial demand of ethanol on the other, it is highly unlikely that the blending targets of ethanol with petrol would be met as planned by the government [21]. M. Nematullah Nasim et al. (2010) found that at higher speed, there is no significant difference in break specific fuel consumption (BSFC) when the engine is operated with preheated and unheated vegetable oil fuels. The heated fuel showed a marginal decrease in brake thermal efficiency as compared to diesel fuel operation [22]. Sanjay Patil et al. (2012) observed that with increase in compression ratio, the air-fuel mixture compressed to high pressure and temperature which results in better combustion and hence high peak pressure and the brake thermal efficiency is higher with B100 than that of diesel fueled engine due to the presence of oxygen molecule in the biodiesel enhances combustion [23]. Daniel Bichel (2007) analyzed and found that biodiesel produces a higher initial formation rate of nitric oxide for the same temperature and has a higher adiabatic flame temperature across all the equivalence ratios analyse. It is also found that the characteristic time increases as the compression ratio of an engine increases, and increases as the temperature of the cylinder contents increases [24]. G Lakshmi Narayana Rao et al. (2008) used cooking oil which was dehydrated and then transesterified using an alkaline catalyst. The fuel properties and the combustion characteristics of used cooking oil are found to be similar to those of diesel [25]. Nitin Srivastav et al. (2016) has seen that BSFC increases with advancement and decreases by 3.74% for SME with retardation of injection timing for both the fuels. Brake thermal efficiency increases to 32.57% from 31.84% with advanced injection timing and increases with retarded timing for both the fuels [26]. Cory A. Adams et al. (2013) found that at low load (3 bar IMEP), stable combustion was attained. Biodiesel content at the 5% and 10% levels significantly reduced ignition delay and therefore advanced the phasing of combustion compared with operation on neat gasoline [27].

Many experimental studies have been carried out on biodiesel as an alternative fuel, but the effect of variation of injection timing and compression ratio on performance and emissions characteristics have not been addressed much and not easily available in literature. Therefore, the effects of variation of injection timing and compression ratio on performance and emissions characteristics have been addressed in the work with the help of computer simulation. The commercially available engine simulation software Diesel-RK has been used to simulate the performance and emission characteristics of the engine.

2. CHARACTERISTICS OF BIODIESEL BLENDS

Biodiesel is characterized as mono-alkyl esters which can either directly be used for running IC engines without any modification of the engine parameter or by blending with petro-diesel in any proportions. Biodiesel blends can also be used as heat source another purpose. It is a long chain alcohol such as methanol and ethanol. It is typically made by chemically reacting lipids with an alcohol producing fatty acid esters. Blends of biodiesel and conventional hydrocarbon based diesel are designated by "B" factor. Typically, 100% biodiesel is referred to as B100 and a blend of 20% biodiesel, 80% petro-diesel is labeled as B20. Similarly, blend containing any proportion of biodiesel can be created and named accordingly.

The performances of IC engine when running using biodiesel directly depends on its characteristics. The important characteristic of biodiesel that impacts the good performance of IC engine is given in the **Table-1**.

Table-1 Important characteristics of biodiesel and their description

Characteristics	Description
Calorific value or heat of combustion	It is the amount of heating energy released by the combustion of unit value of fuel. One of the most important determinants of heating value is moisture content.
Pour point	It is the temperature at which biodiesel becomes semi solid and losses the property of flowing.
Cloud point	

	It is the temperature at which biodiesel starts to solidify.
Flash point	It is the lowest temp. at which biodiesel can vaporize to form an ignitable mixture in air.
Iodine value	It is the mass of iodine in grams that is present in a sample of biodiesel. Iodine numbers are often used to determine the amount of un saturation in fatty acids.
Viscosity	It is a major of resistance to gradual deformation by shear stress.
Density	It is measured as mass divided by volume.
Sulphur	It is a substance that presence in the fuel and do not contribute in production of heat. It is characterized by its % by mass present in fuel.
Total contamination	It is the impropriates present in the fuel and represented mg/kg.
Acid number	The acid number represented the amount of acid present in the fuel and it is represented by mg KOH/g.

In addition to particulars present in the table, the other characteristics that dictate the performance are: methanol, ester content, diglycerides, triglycerides, free glycerides, total glycerides, phosphorus, alkaline matter and distillation. However, the performance comparisons of biodiesel is highly dependent on composition of it to be discussed further [28]

2.1 Palm Oil

Palm oil is an edible vegetable oil derived from the mesocarp (reddish pulp) of the fruit of the oil palm, primarily the African oil palm and to a lesser extent from the American oil palm and the mirpa palm. Palm oil can be used to produce biodiesel, which is also known as palm oil methyl ester. Palm oil methyl ester is created through a process called as transesterification. Palm oil biodiesel is often blended with other fuel to create palm oil biodiesel blends. Palm oil biodiesel meets the European EN 14214 standard for biodiesel [29].

2.2 Soybean Methyl Ester (SME)

Soya Methyl Ester or Methyl Soyate is a methyl ester derived from soybean oil, and is a methyl ester mixture made up of saturated and unsaturated C16 to C18 fatty acids. SME is a low-cost, readily biodegradable alternative that can replace most of the traditional chlorinated and petroleum solvents. Methyl soyate finds use as a carrier solvent and adjuvant. SME has a high solvency with a Kauri-butanol (KB) value of around 58 and has low toxicity. In addition, soya methyl ester is not an ozone-depleting chemical (ODC), hazardous air pollutant or volatile organic compound (VOC) [30]. In most applications, Soya Oil Methyl Ester (Methyl Soyate, CAS No.67784-80-9) is formulated with co solvents or surfactants to meet specific performance requirements. Blending Soya Oil Methyl Ester (Methyl Soyate, CAS No.67784-80-9) with other organic solvents can synergistically enhance the properties of each individual solvent. The benefits of Soya Oil Methyl Ester (Methyl Soyate, CAS No.67784-80-9) include 100% biodegradable, easy and inexpensive to recycle and renewable- made from soybeans. This Soya Oil Methyl Ester (Methyl Soyate, CAS No.67784-80-9) is widely demanded in the international market due to its high effectively, eco-friendliness & purity, and is offered in different packaging options to meet the varied needs of our clients.

2.3 Coconut

Botanically speaking, a coconut is a fibrous one-seeded drupe, also known as a dry drupe. Coconut oil is a widely used liquid bio fuel that is clean, relatively cheap, easy to extract, non-toxic and aromatic [31]. As engine fuel, coconut oil can be used in three ways as a direct substitute for petroleum diesel, as an additive to petroleum diesel or bio-diesel and as the base ingredient of bio-diesel.

Blended fuels are commonly used if coconut oil is to be used over long periods. A widely-used blend is 49% coconut oil, 49% biodiesel and 2% kerosene, with variations to suit local cost, availability and climate. Fuel performance will vary according to fuel/oil ratio. For single injection engines, an increase in oil concentration leads to an increase in fuel consumption and reduced engine power. This is usually measured by brake mean effective pressure (BMEP), which reduces by ~20% when 100% coconut oil is used, and brake-specific fuel consumption (BSFC), which increases by ~20% in the same scenario. Engine emissions are also related to the fuel/oil ratio. Smoke, NOx and CO_2 emissions decrease as the percentage of coconut oil in the fuel mixture increases, reducing by ~75% for smoke, ~40% for NOx and ~15% for $CO2$ when 100% coconut oil is used. These relationships are linear so emissions estimates for other fuel blends can also be extrapolated from these values. Bio-diesel (coco - diesel) is non-toxic, biodegradable. Biodiesel recycles carbon dioxide. Biodiesel can be used in its pure form but many require certain engine modifications to avoid maintenance and performance problems. It also replaces the exhaust odor of petroleum diesel with a more pleasant smell of popcorn or French fries. Using pure coconut oil in standard engines is very attractive through its low cost. However, it requires special technical supervision and may shorten engine life. As the coconut oil has up to 30 times higher viscosity than the regular diesel at the same temperature, most engine modifications include a fuel heater. As heat is exchanged between the engine coolant and the fuel, the oil viscosity approximates that of diesel. As the coconut oil solidifies below temperatures of 25 ^{o}C, often an electrical heater is incorporated in the fuel tank [31].

2.4 Direct Use and Blending

The direct use of vegetable oil in diesel engine is problematic and has many inherent failings. Although some diesel engine can run on pure vegetable oil where as engines that are turbocharged, direct injection engines such as of trucks are prone to many problems. For short term use energy consumption with the use of pure vegetable oil was found to be similar to that of diesel [2].

3. METHODOLOGY

A commercially available engine simulation software Diesel-RK has been used to simulate the performance and emission characteristics of the engine with varying injection timings of 20°, 22.7° and 23° for Diesel and biodiesel blends fuel.

Diesel-RK is capable to simulate the process such as combustion, performance, and emission analysis. The advanced Diesel-RK model is capable to predict the performance and emissions over the whole operating range and also provides simulation results for bio fuels and their blends with diesel. Diesel-RK has been used since its agreement with actual experimental data and recalibration of the model is not necessary for different operating modes of the engine. Biodiesel can be produced via transesterification process of vegetable oil, seeds using a catalyst. This transforms the large branched molecular structure of oil to smaller straight-chained hydrocarbon structure for combustion in regular diesel engines and also reduces the viscosity of the oil. Further, biodiesel has different lubricity and contains very small quantities of phosphorous and sulphur. Thus, SO_2 emissions are almost negligible. Important properties of biodiesel blends are given in **Table-2**.

Table-2 Properties of various combinations of biodiesel blends

Property	Diesel	SME40	SME100	Palm	Coconut
Mass composition of fuel					
C	0.87	0.8297	0.7731	0.761	0.754
H	0.126	0.123	0.1188	0.124	0.117
O	0.004	0.0473	0.1081	0.113	0.105
Low heating value (MJ/kg)	42.5	39.89	36.22	39.84	38.6
Cetane number	48.00	49.37	51.30	59.80	52.00
Fuel density (kg/m3)	830	852	885	910	1090
Dynamic viscosity (Pa s)	0.0030	0.0037	0.0046	0.0055	0.0077
Molar mass (kg/kmol)	190.0	232.5	292.2	284.0	307.0

Simulation were carried out of a single cylinder four stroke diesel engine with engine running on different biodiesel blends with varying injection timings and compression ratio. The simulation is based on a single cylinder engine with specifications as mentioned in Table-3. Performance parameters of SFC, IMEP, BMEP and emission parameters of NO_x, CO_2, PM, and smoke emissions have been obtained for three different injection timings at a constant speed of 1500 rpm for all the fuels.

Table-3 Engine specifications

Engine Type	4 stroke diesel engine
Number of Cylinders	Single cylinder
Bore (mm)	87.5
Stroke (mm)	110
Compression Ratio	17.5
Nominal Engine Speed (rpm)	1500
Engine Design	Inline
Cooling System	Liquid cooling
Connecting rod length (mm)	238
Injection/Ignition timing (deg.)	23

4. RESULTS AND DISCUSSION

The performance of specific fuel consumption (SFC), brake mean effective pressure (BMEP), indicated mean effective pressure (IMEP) and brake torque (BT), and emission of NO, CO_2, SO_2 and PM as obtained are compared and explained. The results are compared at different injection timing and standard compression ratio of 17.5.

4.1 Performance

The performance parameters of the variations of specific fuel consumption (SFC), brake mean effective pressure (BMEP), indicated mean effective pressure (IMEP) and brake torque (BT) are plotted with different injection timings. The emission parameters of NO, CO_2, SO_2 and PM emissions have been presented in similar fashion.

Fig.1 shows the specific fuel consumption for diesel as well as blends of various biodiesel. It is observed that all the biodiesel blends of Palm, SBE40, SBE100 and coconut require lower specific fuel consumption as compared to pure diesel. Further it can be said that SBE40 require lowest specific fuel consumption of 0.2803 kg/kWh in comparison to either pure diesel or other biodiesel blends. This has happened due to variation of mass composition of fuel and their properties of different biodiesel blends as shown in Table-2.

In Fig.2 the brake mean effective pressure is compared for diesel with various biodiesel blends. The BMEP of diesel is more than the other fuels. The mean effective pressure of palm is very less as compared to soybean and coconut oils. The brake mean effective pressure for diesel and coconut are relatively equal to each other.

The Fig.3 compares the IMEP of diesel and blends of various biodiesel fuels. The IMEP of coconut is approximately same as diesel fuel but IMEP soybean oil is less than diesel fuel. Further the IMEP of palm is least among all the diesel or biodiesel blends.

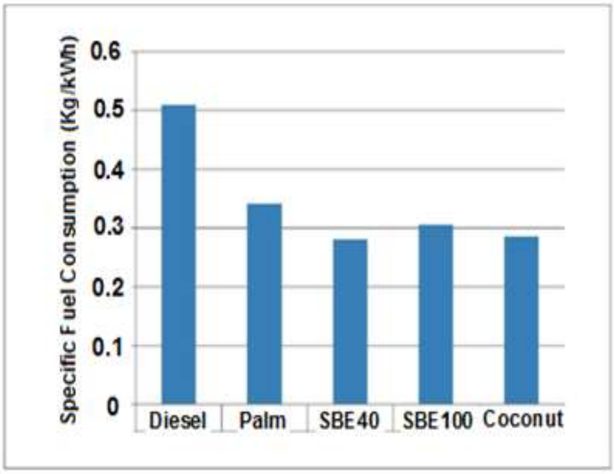

Fig.1 Specific fuel consumption for diesel as well as blends of various biodiesel.

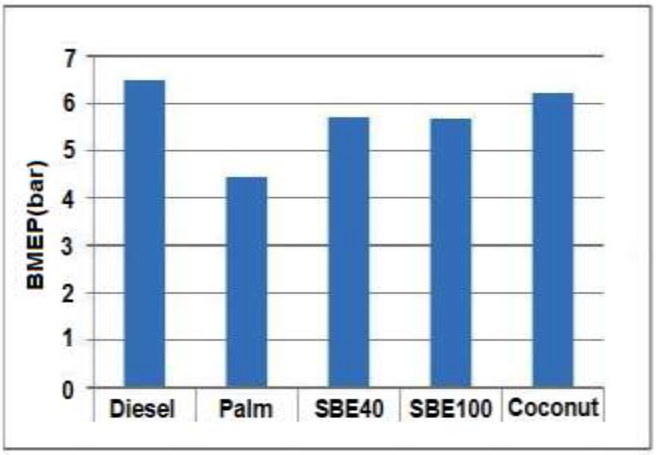

Fig.2 Brake mean effective pressure for diesel as well as blends of various biodiesel

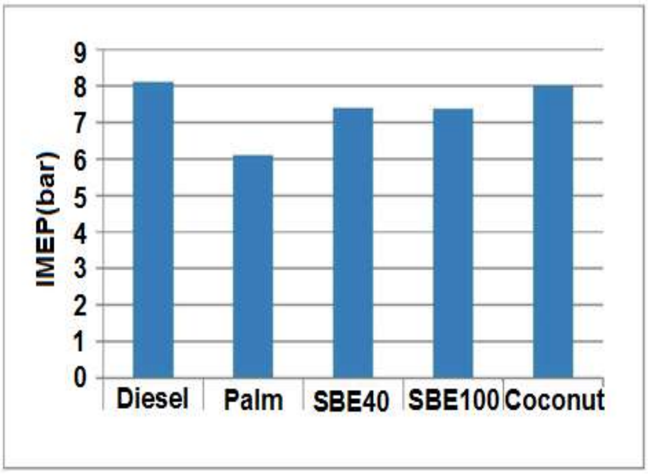

Fig.3 Indicated mean effective pressure for diesel as well as blends of various biodiesel

The Brake Torque for the diesel and biodiesel blends were studied compared as shown in Fig.4. It is observed that the higher brake torque of 34.205 Nm is produced by the diesel fuel and the lower brake torque is obtained by the palm fuel as 23.34 Nm at the constant engine speed for all fuels.

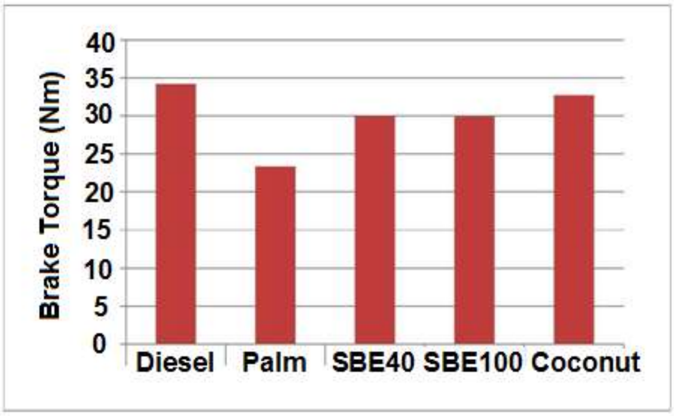

Fig.4 Brake torque for diesel as well as blends of various biodiesel

4.2 Emissions

The variations of CO_2 emissions at different injection timing are shown in **Fig.5**. CO_2 emissions follow increasing trend with advancement and decreasing trend with retardation of injection timing for diesel and different biodiesel blends. The injection timing advance increases the delay period which provides longer time for combustion, hence efficient combustion occurs which increases CO_2 emissions while decreasing CO emission. Advancement in injection timing decreases the thermal energy loss due to incomplete combustion since CO emissions are reported to be decreased. It is to be noted that CO_2 emissions are more for diesel than biodiesel blends with highest emissions occurring for diesel.

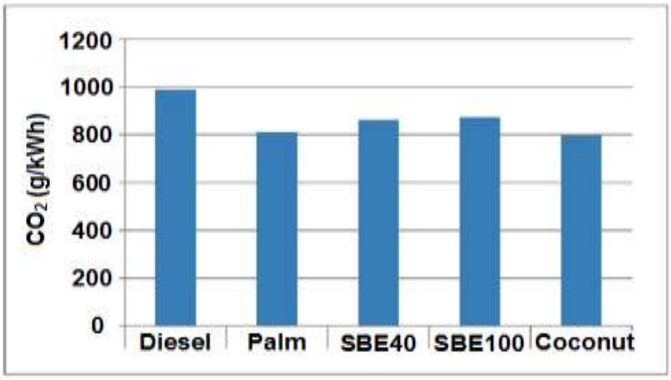

Fig.5 CO_2 emissions at different injection timing for diesel as well as blends of various biodiesel

From the Fig.6 it can be noted that one of the important emission ingredients SO_2 is remarkably less for the biodiesel considered in this study than that of the diesel. In contrast to the diesel, the palm oil and coconut oil produces roughly 50% less SO_2. However, the SBE40 and SBE100 produce very less amount of SO_2 which can be assumed to be negligible.

The emission of NO from diesel and different bio fuel were measured and are shown in Fig.7. It is clearly shown in figure that the NO emission of diesel fuel is relatively more compared to the other fuels. SBE40, SBE100 and coconut oil produces relatively equal value to each other.

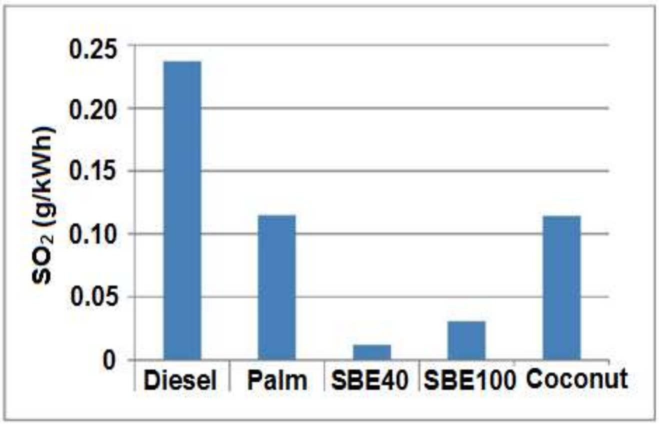

Fig.6 SO_2 emissions at different injection timing for diesel as well as blends of various biodiesel

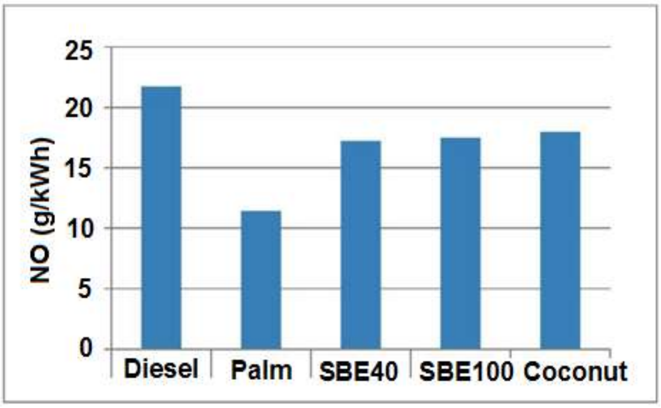

Fig.7 NO emissions at different injection timing for diesel as well as blends of various biodiesel

Particulate matter (PM) is a generic term used for a type of airborne pollution which consists of varying mixtures, complexity and sizes of particles. The emissions of PM from diesel and different bio fuel were measured and are shown in Fig.8. It is observed that the specific particulate matter of diesel is more and other fuels have very less as compared to diesel fuel. So, the PM produced by diesel engine can be reduced by blending (mixing) of biodiesel.

It can be said that the fuel consumption of diesel is more than other fuels. Therefore, the biodiesel fuels are very useful to reduce the emission and increase in performance.

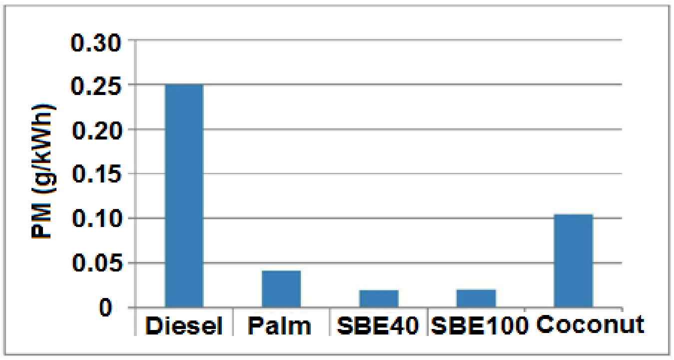

Fig.8 Particulate matter (PM) emissions at different injection timing for diesel as well as blends of various biodiesel

5. CONCLUSIONS

The study was conducted for a single cylinder four stroke diesel engine to investigate the effect of injection timing on performance and emission characteristics when the engine was run with diesel and different biodiesel blends. The following conclusions were drawn from this study:

I. Injection timing influences engine performance and emission characteristics since it affects the ignition delay period.
II. Retarding the injection timing has improved performance characteristics of the engine such as BMEP, IMEP and SFC for different biodiesel blends. Further, significant reductions in emissions are seen for different fuels.
III. The biodiesel blends can be used with advanced injection timing and standard compression ratio to reduce CO and PM emissions with slight decrease in performance. The NOx emissions are taken care of by retarded injection timing to reduce emissions, while PM, CO and Smoke are taken care of by exhaust after treatment system, thus providing a two-fold strategy for trade-off between performance and sustainability to the end user.

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