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Studies on Performance and Exhaust Emissions of a CI Engine operating on Diesel and Diesel Biodiesel blends at different Injection Pressures and Injection Timings

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ABSTRACT

The effect of variation in injection pressure and Injection timing on the performance and exhaust emission characteristics of a direct injection, naturally aspirated Diesel engine operating on Diesel and Diesel-Biodiesel Blends were studied. A three-way factorial design consisting of four levels of injection pressure (150,210, 265,320 bar), four levels of injection timing (19^0 btdc, 21.5^0 btdc, 26^0 btdc, and 30.5^0 btdc) and five different fuel types (D100, B10, B20, B40, and B60) were employed in this test. The experimental analysis shows that when operating with Linseed Oil Methyl Ester-Diesel blends, we could increase the injection pressure by about 25% over the normal value of 20MPa.

The engine performance and exhaust emission characteristics of the engine operating on the ester fuels at advanced injection timing were better than when operating at increased injection pressure. As for environmental protection, the replacement requires advancing the injection timing in order to achieve a pollution level lower than that produced by diesel fuel. This injection timing must be advanced ~ 22% (26^0 btdc to 31.5^0 btdc) from the setting provided by the manufacturer to obtain the best smoke results with the ester fuels. Engine performance deteriorated in an attempt to retarding the injection timing and reduced injection pressure.

INTRODUCTION

Alternative fuels, energy conservation and management, energy efficiency and environmental protection have become important in recent years because of fossil fuel depletion and environmental degradation. The alternative fuels can be better tried for Diesel engines as compared to petrol engines because of the construction of the Diesel engine is very robust and can work at higher compression ratios along with a significant amount of excess air. Biodiesel obtained from vegetable oils has been considered a promising option [1]*.The concept of using vegetable oil as an engine fuel dates back to 1885, when the inventor of Diesel engine, Rudolf Diesel (1858-1913) used vegetable oils (Peanut Oil) as a diesel fuel for demonstration at the 1900 world exhibition in Paris. Speaking to the Engineering Society of St. Louis, Missouri, in 1912, Diesel said, ‘‘The use of vegetable oils for engine fuels may seem insignificant today, but such oils may become in course of time as important as petroleum and the coal tar products of the present times’’.

The major difficulties in using the crude vegetable oils in diesel engines are because of their high viscosity, low volatility and poor cold flow conditions. Vegetable oil when used as a fuel cause nozzle choking and coking, gumming, deposition on the piston top, sticking of piston rings and contamination of the lubricating oil. Injection problem and poor atomization due to its high viscosity are major problems. Apart from these, starting the engine may become difficult especially in cold weather; because of poor atomization and low volatility of the fuel [2]. There are four ways to use vegetable oil in a Diesel Engine.1. Direct use or blending in Diesel fuel. 2. Micro emulsions in Diesel fuel. 3. Thermal cracking of the vegetable oil. 4. Transesterification. Out of these, transesterification appears to be the most popular and the best way to use a vegetable oil.

Biodiesel is produced from straight vegetable oil, animal oil/fats, tallow, waste cooking oil and, renewable resources. Biodiesel contains no petroleum, but it can be

* Numbers in parentheses designate references at the end of paper.

blended at any level with petroleum diesel to create a Biodiesel blend. It can be used in compression-ignition engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics. The process that is used to produce Biodiesel is called transesterification. The largest possible source of suitable oil comes from both edible and non-edible vegetable oils such as Rapeseed, Palm or Soybean, Mahua, Pongamia, Karanja, Linseed, Jatropha and Neem oil [3] [4].

SELECTION OF NON-EDIBLE VEGETABLE OIL

The production of methyl esters from edible oils is currently much more expensive than hydrocarbon-based diesel fuels due to the relatively high costs of vegetable oils. The cost of Biodiesel can be reduced if we consider non-edible oils, and used frying oils instead of edible oils. Non-edible oils such as Neem, Mahua, Karanja, Babassu, Jatropha and Linseed are easily available in many parts of the world including India, and are very cheap compared to edible oils. Vegetable oils offer an advantage of comparable fuel properties with diesel fuel, and it was reported that Diesel engine without any modification would run successfully on a blend of 20% vegetable oil and 80% diesel fuel. Based on the literature survey the choice of oil for the present investigation is dependent upon the following criterion [3] [4]. It should be,

- Easily available at lower cost
- Give the higher Heating value.
- Non-Edible and preferably Crop Oil.
- Have the low Viscosity.

ESTERIFICATION PROCESS

Transesterification is the chemical reaction between triglycerides and alcohol in the presence of catalyst to produce monoesters. The long and branched chain triglyceride molecules are transformed to monoesters and glycerin. Transesterification process consists of a sequence of three consecutive reversible reactions. That is, conversion of triglycerides to diglycerides, followed by the conversion of diglycerides to monoglycerides. The Glycerides are converted into glycerol and yielding one ester molecule in each step. The properties of these esters are comparable to that of diesel. The overall transesterification reaction can be represented by the following reaction scheme [4].

$$\text{Triglyceride + Alcohol} \xleftrightarrow{\text{catalyst}} \text{Alkyl Ester + Glycerol}$$

Stoichiometrically, three moles of alcohol are required for each mole of triglyceride, but in practice, a higher molar ratio is employed in order to displace the equilibrium for getting greater ester production. Though esters are the desired products of the transesterification reactions, glycerin recovery also is important due to its numerous applications in different industrial processes. Commonly used short chain alcohols are methanol, ethanol, propanol and butanol. The yield of esterification is independent of the type of alcohol used. Therefore, the eventual selection of one of these four alcohols will be based on cost and performance considerations. The methanol is used commercially because of its low price, physical and chemical advantages (polar and shortest chain alcohol) and potassium hydroxide (KOH) is easily dissolved in it. Alkaline hydroxides are the most effective transesterification catalysts as compared to acid catalysts. Potassium hydroxide and sodium hydroxide are the commonly used alkaline catalysts. Alkaline catalyzed transesterification of vegetable oils is possible only if the acid value of oil is less than four. Higher percentage of free fatty acid (FFA) in the oil reduces the yield of the esterification process. However, methanol is toxic and its production depends on fossil fuels [3] [4].

BIODIESEL PRODUCTION FROM LINSEED OIL:

In the transesterification process, alcohol reacts with oil to release three "ester chains" from the glycerin backbone of each triglyceride. Production of Biodiesel by transesterification process will consist of the following stages [4] [5].

1. Removal of moisture from the oil.
2. Heating the oil to a required temperature.
3. Mixing of alcohol and catalyst in a required proportion.
4. Reaction of the alkoxide and vegetable oil in the reactor.
5. Separation of the glycerol.
6. Washing of the methyl ester.
7. Removal of the Moisture from the Biodiesel.

PROPERTIES OF BIODIESEL

Since Biodiesel is produced in quite differently scaled plants from vegetable oils of varying origin and quality, it is necessary to install a standardization of fuel quality to guarantee engine performance, so as to evaluate various physical, chemical, and thermal properties. several tests were conducted to characterize Biodiesel in relation to diesel oil. The properties of linseed oil Biodiesel, as given in Table 1, shows many similarities with diesel fuel, and therefore, Biodiesel is rated as a strong candidate as an alternative to diesel.

Table 1 Various Properties of different fuels

Property	ASTM TEST	Diesel	LOME	Linseed Oil
Viscosity at 40 ^{0}C (mm^2/s)	D445	2.246	3.70	22.1
Viscosity at 100 ^{0}C (mm^2/s)	D445	1.10	1.98	9.80
Viscosity index	D445	359.3	256.37	185.71

Calorific value (MJ/Kg)	D240	43.68	40.13	39.20
Specific gravity	D1298	0.856	0.889	0.903
API gravity (^{O}C)	D4052	34.97	30.97	25.19
Flash point (^{O}C)	D93	66	163	238
Cloud point (^{O}C)	D2500	-6	-3.5	2
Pour point(^{O}C)	D97	-16	-14	-4
Aniline point (^{O}C)	-----	72	30 - 100	----
Copper strip corrosion	D130	---	1a	---
Raid vapor pressure (kPa)	D323	---	13.79	---
Acid value (mg KOH/g)	D664	0.54	0.78	3.71
Carbon residue (wt %)	D524	0.015	0.032	0.28
Sulphur Content (ppm)	D5453	349	11	---
Distillation temperature (^{0}C)	D1160	299	350	

EXPERIMENTAL SETUP

A vertical, single cylinder air-cooled direct injection diesel engine was used in the experiments and the principal specifications of the engine are given in Table A.1 of Appendix A. It has the provision of the electrical loading being flexibly coupled with an alternator. Fuel injection system consist of single barrel Bosch fuel pump whose plunger is driven by a cam and tappet mechanism and a nozzle holder assembly with multihole (3holes) nozzle. The exhaust gas of the engine is passed through a manual Smoke meter fitted at the end of exhaust manifold and the parameters like opacity and exhaust temperature were measured. The make of Smoke meter is AVL 437.

Five gas emission analyzer was used to measure HC, CO, CO_2, O_2 and NO_x. Make and model of the emissions analyzer is AVL4000 whose specifications are given in the Table A.2 of Appendix A. Exhaust sample acquisition time is approximately 6 seconds in an operating environment, temperature 0 to 50 deg C and humidity up to 95% is permissible. The measurement system is comprised of a piezoelectric Pressure transducer, Kistler make, model 701A equipped with a water-refrigerated adaptor, specifications of the pressure transducer are given in Table A.3 of Appendix A. ICF 3059 Signal amplifier and a Tektronix TDS 2014 oscilloscope, which sends the signal to data acquisition system i.e. Personal computer. Magnetic pick up (Electro make model 3010AMA) was used to measure the Crank angle.

In this study, a methyl ester Biodiesel was produced from a linseed oil using methanol and sodium hydroxide as a catalyst at a temperature of 65 deg C and atmospheric pressure. The effects of the methyl ester addition to diesel fuel on the performance and emissions of a four cycles, single cylinder, and direct injection Diesel engine were examined at both full and part loads for different injection pressure and injection timing.

EFFECT OF BIODIESEL ON COMBUSTION PROCESS

Combustion in a Diesel engine is a complicated physical and chemical process, starting with the fuel injection into the combustion chamber to exhausting the burnt gases. The reason for the complication is that the combustion depends on many different parameters such as mixing of air and fuel, injection pressure and time. Fuel vaporization itself is also a complex process because, of the fuel contents, the self-ignition of the fuel vapor is directly related to the chemical process in the combustion chamber. The efficiency of a Diesel engine depends upon the conversion rate of the chemical energy of the fuel into heat release. The rate of heat release depends on the amount of fuel injected, ignition at an adequate time and the combustion process [6] [7]. The in cylinder pressure as a function of crank angle of the diesel engine fuelled with the diesel and diesel biodiesel fuel at the same operating conditions are shown in the Fig.1.

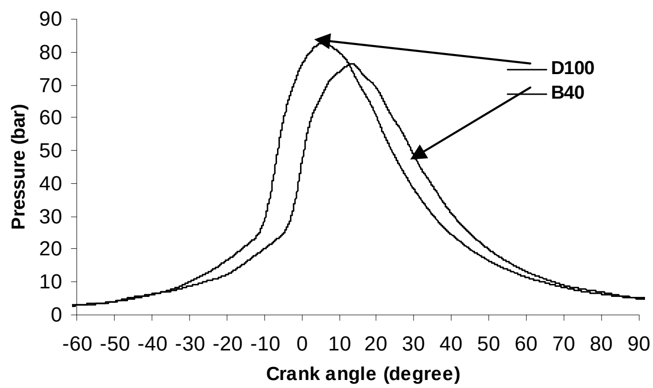

Figure 1 Pressure crank angle diagram for Diesel and Diesel Biodiesel blends

It is clear from the Fig.1 that peak combustion pressure of diesel fuel is more than that of diesel- biodiesel blends; this may be due to reduction in the premixed combustion of the biodiesel blends due to poor volatility of the biodiesel [6]. Such curves were measured for the five load conditions and five fuels examined. Comparing the fuels at equal engine load, it was noted that combustion got worse with biodiesel as compared to diesel fuel.

It is cleared from the Fig.1 that ignition time prolonged and the maximum gas pressure decreased when the diesel engine fuelled with diesel biodiesel blends. Peak pressure mainly depends upon the combustion rate in the initial stages, which is influenced by the fuel taking part in the uncontrolled heat release phase. The high viscosity and low volatility of the diesel biodiesel blends lead to poor atomization and mixture preparation with the air during the ignition delay period.

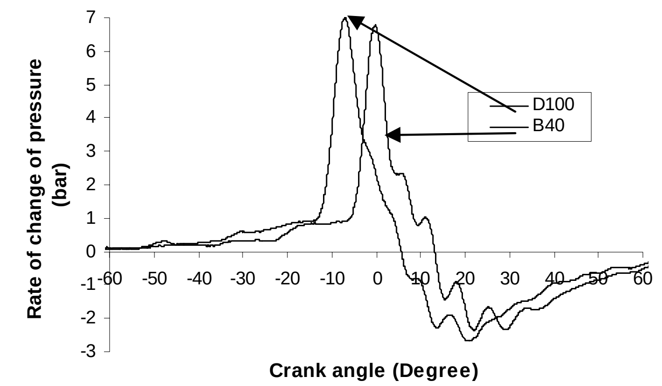

Figure 2 Pressure gradient curves for Diesel and Diesel Biodiesel blend

Figure 2 shows that with biodiesel fuel, the ignition delay time is longer than with traditional diesel fuel at engine full load. Longer delays between injection and ignition lead to unacceptable rates of pressure rise (diesel knock) because too much fuel is ready to burn when combustion eventually occurs. By examining the pressure gradient curves as shown in the Fig.2, it is possible to determine the start of combustion, observing the distance between the sudden increase and Top dead centre [8]. This last analysis suggested that injection timing should be advanced beyond the manufacturer's specifications for the complete combustion of the ester fuel by providing the more time, which helps in effective utilization of pressure developed in conversion of work out put.

Diesel engine performance, combustion efficiency and emissions are simply related to the engine design and running parameters and fuel properties. These parameters are important for optimization of the engine performance and for reducing emissions. The fuel chemical contents and characteristics govern the emissions and power characteristics [9]. One of the reasons for forming exhaust pollutants is insufficient combustion in the engine cylinder. Fuels properties also play a significant role to increase or decrease exhaust pollutants. Hence to overcome some of the above problems studies have been made on the performance and emission characteristics by changing the injection pressure and injection timing [10].

EFFECT OF INJECTION PRESSURE ON PERFORMANCE, AND EXHAUST EMISSION CHARACTERISTICS OF A DIESEL ENGINE

Experiments were conducted for assessing the engine performance with 10%, 20%, 40% and 60%, LOME Biodiesel substitute with diesel fuel at four different injection pressure (150, 210, 265 and 320 bar). Results are analyzed and discussed in below paragraphs with the help of graphs.

Effect of Injection Pressure on Brake power

Figure 3 shows the effects of injection pressures on brake power for diesel and diesel Biodiesel blends at full load. Biodiesel has higher latent heat of vaporization than that of diesel. This causes slow vaporization and mixing of fuel and air. Another reason for poor air fuel mixing is the deflection of spray patterns away from the optimum for that particular combustion system [14].

Increasing the fuel injection pressure decreased the particle diameter and caused the diesel-biodiesel fuel spray to vaporize quickly. However, the liquid fuel cannot penetrate deeply into the combustion chamber. Therefore, higher injection pressures initially generate faster combustion rates, resulting in higher temperatures. However, the initial combustion with the spray was restricted to a small region near the injector, and the flame spreads around the chamber through slow propagation. This caused an inefficient conversion process of heat to work that is the reason the power out put is low at higher injection pressure [15].

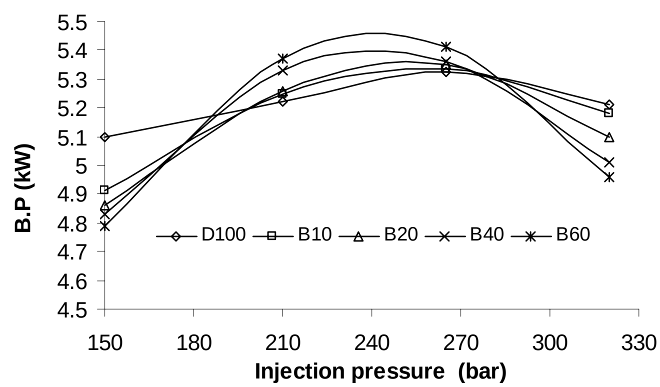

Figure 3 Effect of Injection pressure on brake power

Effect of Injection Pressure on BSFC

The variation of BSFC at different Injection pressures for diesel and diesel Biodiesel blends are shown in Fig.4.

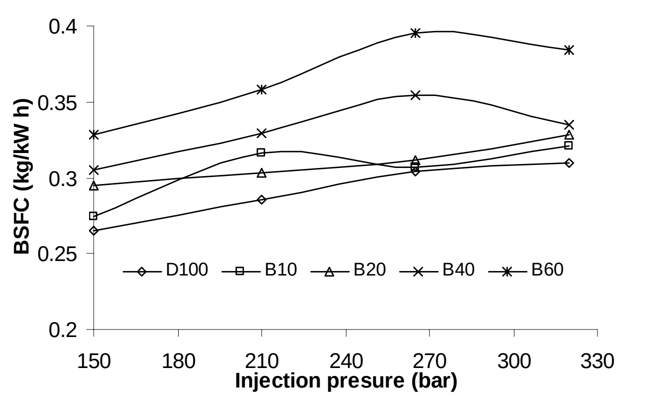

Figure 4 Effect of Injection pressure on BSFC

Operating the engine with increased injection pressure at the lower power range gave slightly better fuel combustion as indicated by the low carbon monoxide and unburned hydrocarbon emissions. However, the engine showed poor fuel combustion near the maximum operating power level. This was evidenced by the increase in the brake-specific fuel consumption together with the decrease in the brake thermal efficiency. The increase in the brake-specific fuel consumption was mainly due to the low heating value of the ester fuels [16] [17].

Effect of Injection Pressure on Exhaust gas temperature

The variation of exhaust gas temperature with respect to applied load for different fuels tested is shown in Fig.5. Increase in injection pressure results in an increase in spray velocity at the out let of the nozzle, which produces smaller Sauter mean diameters of the fuel, hence complete combustion of the fuel results in higher combustion temperature, and consequently higher exhaust gas temperature and higher NO_X in the emission [15] [17].

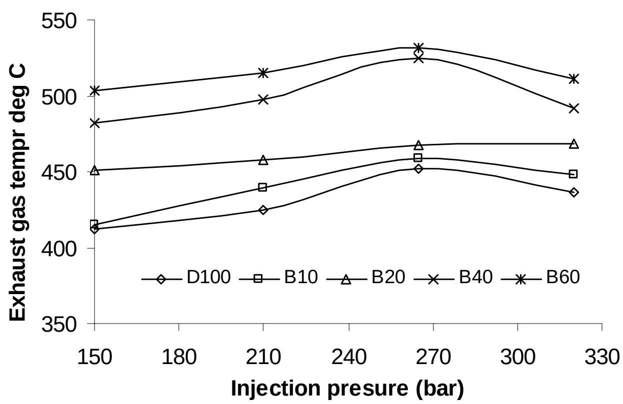

Figure 5 Effect of Injection Pressure on Exhaust gas temperature

The Biodiesel also contains some amount of oxygen molecules in the ester form, this oxygen will helps in the complete combustion of the fuel and hence all the Biodiesel blends will tend to increase the exhaust gas temperature. And also effective combustion is taking place in the early stages of exhaust process, therefore the gas is not in a position to give its heat energy to the piston, and without doing the work gas will comes out of the engine hence this may lead to higher exhaust gas temperature [14].

Effect of Injection Pressure on Oxides of Nitrogen emission

Figure 6 shows the emissions of nitrogen dioxides at different injection pressure with the change in Biodiesel concentration. With increase in the value of exhaust gas temperature, NO_X emission also increases. That is, Biodiesel fueled engines has the potential to emit more NO_X as compared to that of diesel fueled engines. Higher NO_X emissions with increasing injection pressure are due to the effects of active combustion caused by smaller particles of atomized fuel.

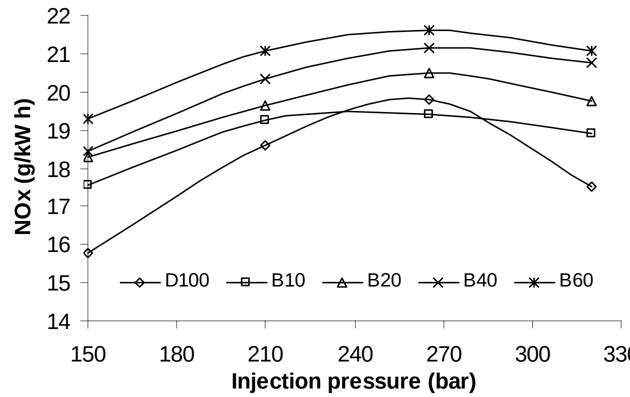

Figure 6 Effect of Injection Pressure on Oxides of Nitrogen emission

The increasing of NOx emission with increasing injection pressure is an expected result as mentioned above. However, increasing the injection pressure to a value higher than a certain value may contribute worse effects on the performance of the engine. This may be a reason for the slightly decreasing NOx at 320bar injection pressure [14]. Three factors affecting the NOx emission are oxygen concentration, combustion temperature and reaction time. Also, it is known that the external oxygen supplied with the air is less effective than the fuel borne oxygen in the production of NOx.

The increase in the local temperature and the oxygen concentration within the fuel spray envelope at increasing power level as mentioned by Springer and Patterson favors the increase in the oxides of nitrogen emissions [15][17]. When pressurized fuel is injected into the engine cylinder, fuel droplets get smaller as the injection pressure increases and NOx formation is increased due to increase in combustion temperature. Beyond a certain limit if the injection pressure is increased fuel droplets get smaller and NOx formation is decreased by reducing the ignition delay [15].

Effect of Injection Pressure on Carbon monoxide emission

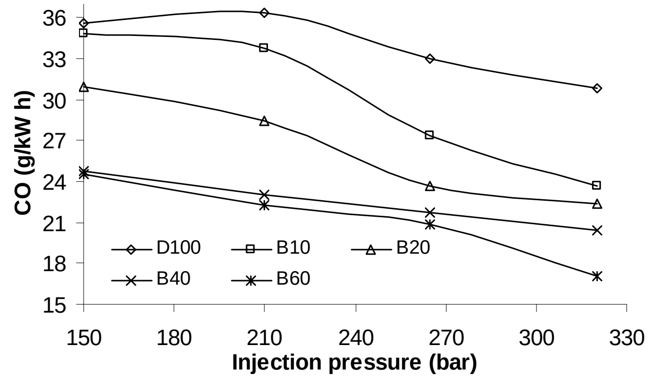

Figure 7 Effect of Injection Pressure on Carbon monoxide emission

Figure 7 shows the plots of carbon monoxide emissions of the diesel and diesel biodiesel blends at different injection pressures. Higher injection pressure is currently favorable for reduction in diesel exhaust emissions, increasing the injection pressure from 150 to 265 bars caused low CO and smoke emissions in all engine loads, due to the good fuel–air mixing and easy and complete combustion of the smaller droplets.

It is interesting to note that, the engine emits more CO using diesel as compared to that of Biodiesel blends under all loading conditions.With increasing Biodiesel percentage, CO emission level decreases. Biodiesel itself has about 11% oxygen content in it. This helps for the complete combustion. Hence, CO emission level decreases with increasing Biodiesel percentage in the fuel. Emissions of CO are greatly dependent on the air-fuel ratio relative to the stoichiometric proportions [16] [17].

Effect of Injection Pressure on Carbon dioxide emission

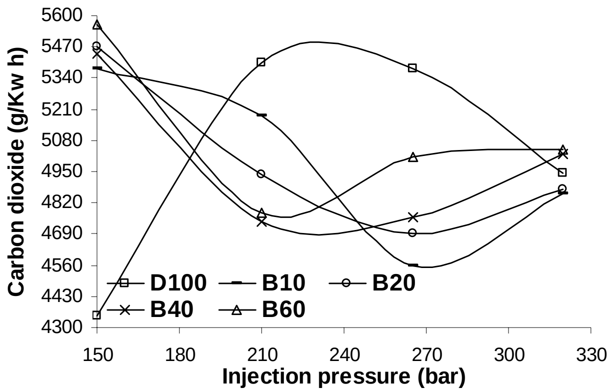

Figure 8 Effect of Injection Pressure on Carbon dioxide emission

Figure 8 compares the CO_2 emissions of various fuels used in the diesel engine with change in injection pressure. As it is known, that the amount of carbon dioxide is proportional to the amount of fuel burned, the rich fuel mixture in the cylinders at a fixed air fuel ratio brings about the production of more CO_2 at low loads [10] [11]. The CO_2 emissions decrease with increasing engine load. In addition, at full load, the CO_2 emissions of the blend were higher than those of the diesel fuel due to the increase in the mass of fuel injected using the blend and better combustion with the fuel borne oxygen. Therefore, as the injection pressure increases the CO_2 emission will also increase. More amount of CO_2 in exhaust emission is an indication of the complete combustion of fuel [17].

Effect of Injection Pressure on Unburned Hydrocarbon emission

Figure 9 shows the hydrocarbon emission trends for diesel and diesel-biodiesel blends at different injection pressures. For efficient combustion, the fuel has to atomize, mix and ignite properly. Atomization and mixing of fuel again depends on the physical properties and fuel injection system. Fuel viscosity and surface tension affect the penetration rate and droplet size, which in turn affect the mixing of fuel and air. Due to increase in injection pressure there is a reduction in Sauter mean diameter of the fuel droplets in the spray, which in turn helps for better combustion .Hence, there is a decrease in unburned hydrocarbons as the injection pressure increases [15] [16].

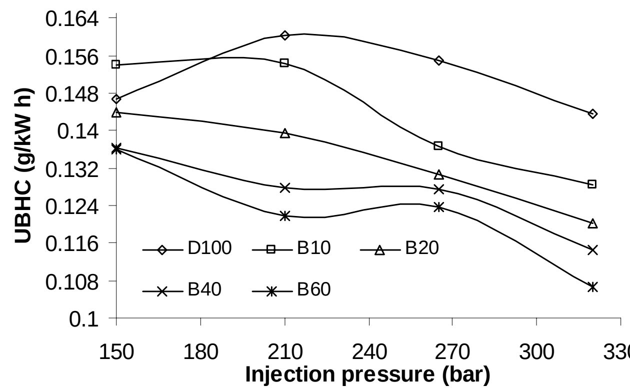

Figure 9 Effect of Injection Pressure on Unburned Hydrocarbon emission

Effect of Injection Pressure on Smoke emission

The variation of smoke density with respect to change in injection pressure for different fuels is shown in Fig.10.

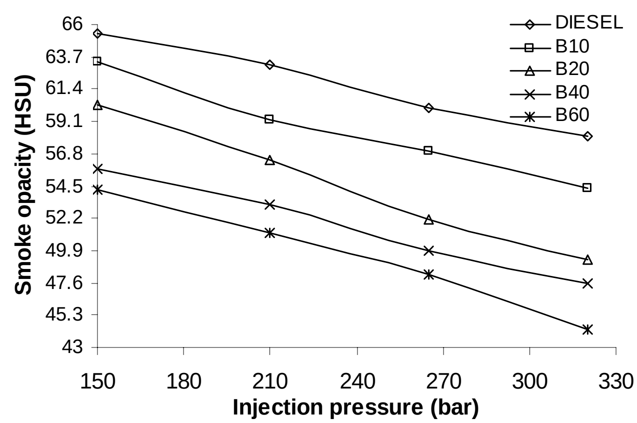

Figure 10 Effect of Injection Pressure on Smoke emission

Smoke density for Biodiesel blend is noticed to be generally lower than that of the diesel oil. Higher power indicates better and complete combustion of fuel. So, lower smoke density values are achieved with Biodiesel blends as compared to that of the diesel. The smoke level is affected by pressure rather than the properties of the fuel. Hence, while the injection pressure is increased from 150 to 320 bars, the smoke level is reduced. The smoke level was very high when the injection pressure was reduced to 150 bars. This seems to depend on the injection pressure rather than fuel properties. It is due to the reduced level of premixing in the combustion process under lower pressure [17].

EFFECT OF INJECTION TIMING ON PERFORMANCE, AND EMISSION CHARACTERISTICS OF A C.I ENGINE

Each test cycle was conducted at constant speed of the engine, so that the engine would then be required to perform the same task. In diesel engines, only about 80% of the air inducted can effectively be utilized during the combustion process, the remainder having insufficient time to mix with the fuel. This is one of the reasons why diesel engines of a given capacity have lower power output than petrol engines of the same capacity and speed.

In addition, maximum power output of the engine demands that the maximum peak cylinder pressure occur between 5 and 20^0 of the crank angle after TDC. To meet these demands Experiments were conducted for assessing the engine performance with 10%, 20%, 40% and 60%, Linseed oil Biodiesel substitute with diesel fuel at four different injection timing (19^0 btdc, 21.5^0btdc, 26^0 btdc and 31.5^0 btdc). Engine performance was improved by advancing as compared to retarding the injection timing. Results are analyzed and discussed in below paragraphs with the help of graphs.

Effect of Injection Timing on Brake power

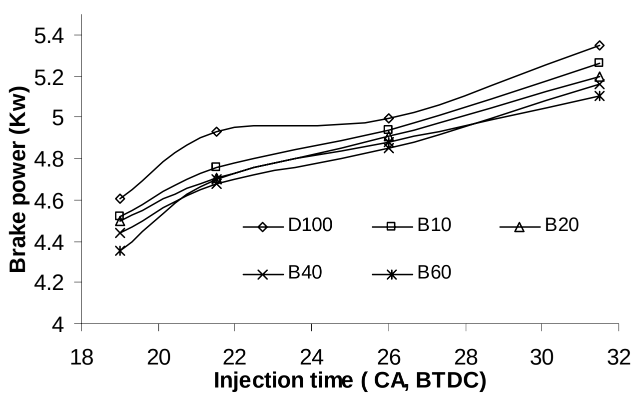

Figure 11 Effect of Injection Timing on Brake power

Figure 11 shows the effect of injection timing on the different fuels. As injection timing is retarded there is a decrease in power out put from the engine, it may be due to the lack of time for mixture formation and lower temperature for fuel evaporation. Other reasons may be very poorer atomization which results in a relatively long delay period, due to the slow development of very fine droplets and also due to the reason that the self-ignition temperature of Biodiesel is higher than that of diesel fuel. It is seen that the poor performance of the engine at retarded injection timing is due to the effect of reduction in combustion efficiency caused by reduced flame propagation speed [18].

Effect of Injection Timing on BSFC

Figure 12 explains the effect of injection timing on the specific fuel consumption of the engine. SFC for diesel fuel will not effected that much with respect to the range (19^0 btdc, to 30.5^0 btdc) of injection timing studied, may be standard injection time is the optimal time for diesel fuel set by the manufacturer. Figure 12 shows that due to increasing (advancing) the injection timing the difference in BSFC between diesel and diesel-biodiesel blends is very significant, this is thought to be due to improved combustion at higher engine load and temperature.

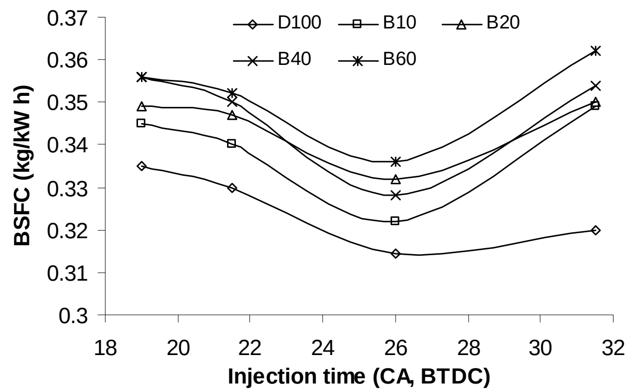

Figure 12 Effect of Injection Timing on BSFC

The data shows that the advanced timing system incurs penalty on fuel consumption for a given operating condition. The governor injects more fuel than when running on standard time units [16] [18].

Effect of Injection Timing on Exhaust gas temperature

There is significant difference between exhaust gas temperatures of Biodiesel blend and pure diesel fuel as shown in Figure 13. Operating with retarded timing shows the highest exhaust gas temperatures, than that of advanced injection timing. At retarded timing the higher viscosity and low volatility of the fuel will retard the rate of combustion and hence higher ignition delay occurs. Due to burning of more fuel after TDC, can results in a higher exhaust gas temperature. Advancement of injection timing will give more time for the ester fuel to evaporate and helps for the smooth combustion with lower ignition delay [18]. Hence exhaust gas temperature due to advancing injection time will be lower than the retarding time.

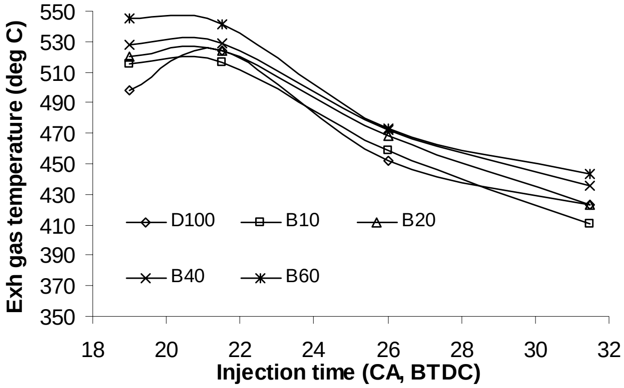

Figure 13 Effect of Injection Timing on Exhaust gas temperature

Effect of Injection Timing on Oxides of Nitrogen emission

Figure 14 shows the effect of injection time on emissions of oxides of nitrogen from diesel and diesel Biodiesel blends. Formation of oxides of nitrogen depends upon, time, availability of oxygen and temperature. But as shown in Fig. 13 temperature of the exhaust gas will decrease due to advancing the injection timing, even though oxides of nitrogen are higher due to more time availability and inherent oxygen present in the fuel.

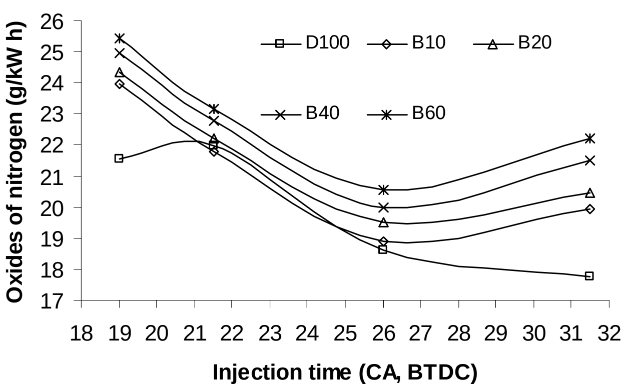

Figure 14 Effect of Injection Timing on Oxides of Nitrogen emission

Generally, retarding the delivery fuel timing can result in higher exhaust gas temperature as shown in the Fig.13, because combustion is postponed; hence NO_X emissions are increased over the entire load range due to higher average temperatures when the injection timing was reduced [19] [20].

Effect of Injection Timing on Carbon monoxide emission

The effect of the injection advance on CO emission measured at maximum power is shown in Fig.15.

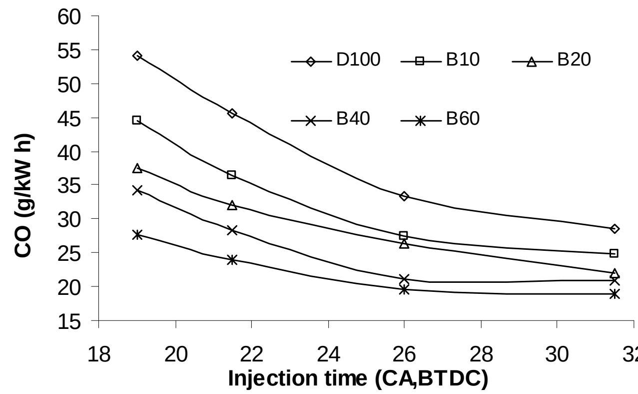

Figure 15 Effect of Injection Timing on Carbon monoxide emission

By increasing the injection advance, CO emission is reduced up to entire loading of the engine, which could be related to improved combustion over the retard timing. Low carbon monoxide and unburned hydrocarbon emissions at high-idle engine operation were due to a much longer residence time for the fuel combustion processes. Generally, retarding the delivery fuel timing can result higher CO emissions because combustion is delayed, especially at later fuel delivery advance angle. Owing to higher self-ignition temperature and high latent heat of evaporation of Biodiesel, CO emissions are higher as compared to diesel fuel [20].

Effect of Injection Timing on Carbon dioxide emission

Figure 16 shows the effect of injection time on the emission of carbon dioxide. Advancement of injection timing results in an increase in the carbon dioxide emission, which is an indication of complete combustion of the fuel due to higher time availability and oxygen presence in the ester fuel. Reduction of injection timing, will, decrease the combustion rate and hence cause for the lower carbon dioxide and higher carbon monoxide [19].

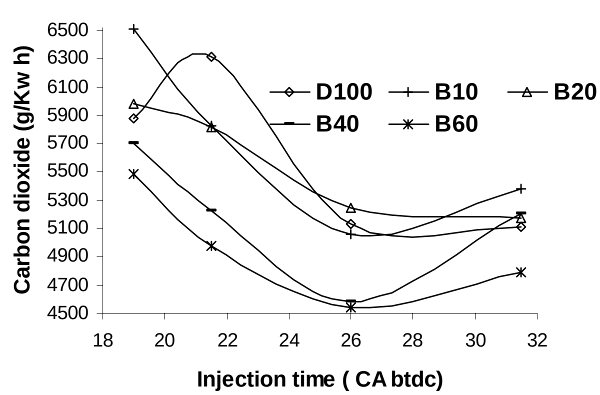

Figure 16 Effect of Injection Timing on Carbon dioxide emission

Effect of Injection Timing on Unburned Hydrocarbon emission

Figure 17 shows the effect of injection timing on the hydrocarbon emission from the diesel and diesel biodiesel blends.

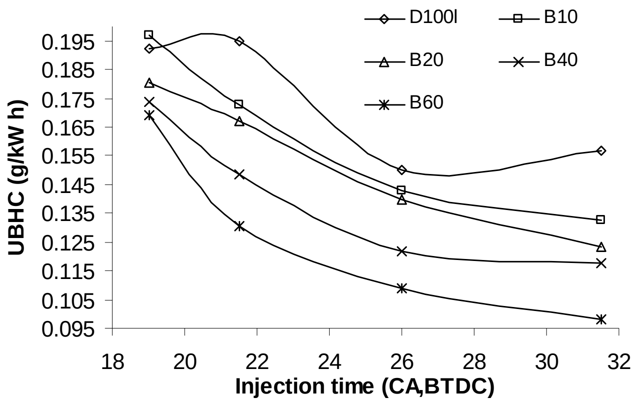

Figure 17 Effect of Injection Timing on Unburned Hydrocarbon emission

The trend shows that the differences were greater at higher injection timing as compared to the retarded values. Low unburned hydrocarbon emission at full load of the engine is due to a much longer residence time for the fuel combustion processes. The resultant combustion process gives rise to reduced delay and complete combustion of the fuel. Hence lower hydrocarbons are present when the engine runs on increased injection timing [18][19].

Effect of Injection Timing on Smoke emission

The variation of smoke density with respect to change in injection timing for different fuels is shown in Fig.18. Smoke density for Biodiesel blend is noticed to be generally lower than that of the diesel oil. Higher power indicates better and complete combustion of fuel. So, lower smoke density values are achieved with Biodiesel blends as compared to that of the diesel [9][14]. The smoke level is affected by injection timing rather than the properties of the fuel. Hence, while the injection timing is advanced from 19 deg btdc to 31.5 deg btdc, the smoke level is reduced. The reason may be more time for the fuel to evaporate and mix with the air and complete combustion, which may leads to lower smoke [15].

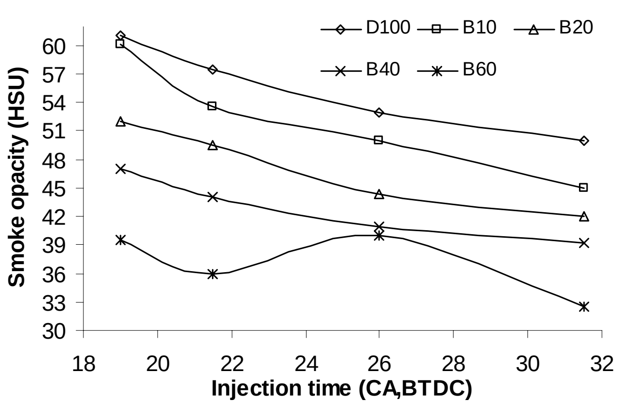

Figure 18 Effect of Injection timing on Smoke emission

The smoke level was very high when the injection timing was kept at 19 deg btdc. The reason may be lesser time availability and lower temperature of the fuel effects the mixture preparation and hence may not complete the combustion of the fuel which in turn leads to more smoke [19] [20].

CONCLUSION

The results obtained from the present investigations shows that, the transesterification process improved the fuel properties of the oil with respect to Specific gravity, Viscosity, Flash point and Acid value. The comparison of these properties with diesel fuel shows that Methyl ester has a relatively closer fuel property values to that of diesel (than that of oil).

Power out put of the blends is lower than diesel fuel when the injection pressure was increased from 265 to 320 bar (0.57, 2.15, 3.92 and 5.025% for B10, B20, B40 and B60 fuels respectively).There was increase in BSFC with increase in injection pressure for all the Biodiesel blends as compared to diesel fuel. (3, 5, 10.3 and 20% for B10, B20, B40, and B60 when the injection pressure has increased from 265 to 320 bars at full load).

With increasing injection pressure, CO emission level decreases by 34, 42, 55 and 85% lower than diesel from B10, B20, B40 and B60 fuels respectively. NOx emissions slightly increased due to the higher combustion temperature and the presence of fuel oxygen with the blend at full load. The CO_2 emissions of the blend were higher (3.8,6,14 and 24.2% from B10, B20, B40 and B60 fuels respectively) than those of the diesel fuel due to the increase in the mass of fuel injected using the blend and improved combustion with the fuel borne oxygen.

Oxygen content and Cetane number of the diesel Biodiesel blends leads low hydrocarbon emission (7.21, 15.3, 18, and 23.8% from B10, B20, B40, and B60 fuels respectively) as compared to diesel fuel.
The smoke level is affected by pressure rather than the properties of the fuel. Hence, while the injection pressure is increased from 150 to 320 bars, the smoke level is reduced.

The engine performance and exhaust emission characteristics of the engine operating on the ester fuels at advanced injection timing were better than when operating at increased injection pressure. As for environmental protection, the replacement requires advancing the injection timing in order to achieve a pollution level lower than that produced by diesel fuel. This injection timing must be advanced ~ 22% (26^0 btdc to 31.5^0 btdc) from the setting provided by the manufacturer to obtain the best smoke results with the ester fuels.

Engine performance deteriorated in an attempt to retarding the injection timing. Operating the engine at advanced timing on the ester fuels could be recommended if the observed increases in the cylinder peak pressure were within the tolerance of the engine, and the increases in the oxides of nitrogen were within acceptable limits.

The comparison of these properties with diesel shows that methyl ester has a relatively closer fuel property values to that of diesel (than that of oil). Hence, no hardware modifications are required for handling this fuel (Biodiesel) in the existing engine. Biodiesel is proved to be a potential candidate for partial substitution of mineral diesel oil.

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APPENDIX A

Table A.1 Specification of the Engine

Sr. No	Description	Data
1.	Name of the Engine Manufacturer (model)	Kirloskar (DAF 8)
2.	Type of the Engine	4- Stroke, Single Cylinder, Vertical, Naturally aspirated Diesel Engine.
3.	IS Rating	5.9 kW at 1500 rpm
4.	Bore Diameter	95mm
5.	Stroke Length	110mm
6.	Cubic Capacity	0.780
7.	Normal Compression ratio	17.5:1
8.	Fuel timing by spill (BTDC) (deg)	26
9.	Inlet Valve Opens BTDC(deg)	4.5
10	Exhaust Valve Closes ATDC (deg)	4.5
11	Exhaust Valve Opens BBDC (deg)	35.5
12	Inlet valve closes ABDC (deg)	35.5
13	Nozzle Opening Pressure (Kg/cm^2)	200-205

Table A.2 Technical Specifications of AVL 5gas Analyzer

Measurement principle	CO, HC, CO_2	Infrared measurement
Measurement principle	O_2	Electrochemical measurement
Operating temperature	+5 …+45 ºC	Keeping measurement accuracy
	+1…. +50 ºC +5 …. +35 ºC	Ready for measurement with integral NO sensor
Storage temperature	-20 …. +60 ºC -20 …..+50 ºC 0 ….. +50 ºC	With integrated O_2 sensor With integrated NO sensor With water in filter and / or Pump
Air humidity	With 90% max	Non condensing
Power drawn	150VA	
Dimensions (mm)	470X431X270	
Weight	AVL DiGas 4000	17.7 kg

Table A.3 Specification of the Pressure Transducer

Sr No	Description	Data
1	Pressure Range (bar)	0-250
2	Calibrated partial ranges (bar)	0-25
3	Overload (bar)	400
4	Sensitivity (pC/bar)	–80
5	Natural frequency (kHz)	70
6	Linearity (%FSO)	< ± 0.5
7	Acceleration sensitivity (bar/g)	< 0. 001
8	Operating temperature range (°C)	-150 ...200
9	Temperature coefficient of sensitivity (°C $^{-1}$)	$<10^{-4}$
10	Insulation resistance (ohm)	$>10^{13}$

11	Shock resistance	5000
12	Capacitance (pF)	9
3	Weight (g)	8.5
14	Connector	10-32 UNF