Experimental Investigation on Effect of Injection Timing on Performance, Combustion and Emission Characteristics Compression Ignition Engine Fuelled With Vegetable Oil –Ethanol Blend

Nandkishore D. Rao
Dept. of Auto. Engg.
G.N.D.E.C. Bidar, India

Dr. K. Vijay Kumar Reddy
Dept. of Mech. Engg.
JNTU, Hyderabad, India

Dr. B. Sudheer Prem kumar
Dept. of Mech. Engg.
JNTU, Hyderabad, India

Dr. E. Ramjee
Dept. of Mech. Engg.
JNTU, Hyderabad, India

Abstract

Experimental investigations were made on stationery, single cylinder, water cooled constant speed diesel engine to study the effect of variation in injection timing on its performance, combustion and emission characteristics. During investigation, engine was fuelled with vegetable oil-ethanol blend having 70% vegetable oil (Honge oil) and 30% ethanol. The tests were performed at different injection timing by changing the number of shims between the injection pump and engine body. The experimental results show at advanced injection timing (27°CA bTDC) engine performance improved with significant reduction in carbon monoxide and unburnt hydrocarbon emissions as compared to standard injection timing (23°CA bTDC). Retarded injection timing (21°CAbTDC), showed reduction in brake thermal efficiency and higher Carbon monoxide, Hydrocarbon emissions and lower oxides of Nitrogen emissions.

Keywords: Injection timings; blend; Brake power; Oxides of Nitrogen; Smoke

1. Introduction:

Limited amount of petroleum products and growing environmental concerns caused great interest in developing the alternative fuels for internal combustion engines. As an alternative fuels, the vegetable oils and alcohols have received great attention because these are biodegradable and renewable. Use of edible oils creates conflict between food and fuel. Hence the non-edible oils can be used for internal combustion engine.

In India, variety of non-edible oils obtained from plant species like honge, linseed, jatropha, karanji, Jarophа are available in abundance and can be grown on a land which is not suitable for agricultural purpose. Use of straight vegetable oil as an alternative fuel for compression ignition engine is limited due to their very high viscosity. Numbers of methods are available for lowering the viscosity of vegetable oil. Among those the trans-esterification produces the fuel with viscosity and calorific value very close to diesel. But it requires additional logistical support and skilled work force, which adds the cost to the fuel. Blending of vegetable oil with diesel reduces the viscosity, but this negates the concept of complete replacement of petro-diesel. Hence, a blend of vegetable oil and ethanol is prepared for investigation.

For diesel engine, the injection timing determines the state of air in which the fuel is injected. At advanced injection timing, the air temperature and pressure at the time of fuel injection will be lower which increases the ignition delay. But advancing the injection ensures the sufficient time for evaporation larger droplets of highly viscous fuel thereby improves pre-mixed combustion process. If the fuel injection is advanced beyond certain limit, it may causes too long delay periods especially at lower loads which results in unacceptable rate of pressure rise with the knock. This is due to the fact that too much fuel will be ready to take part in pre-mixed combustion. Also the peak pressure occurs well before the TDC. If the injection starts later (retarded timing) the air pressure and temperature will be higher, a decrease in ignition delay results in lower peak pressures, lower combustion temperature and lower combustion noise. Due to lower temperatures at retarded injection timing results in NO_x emissions and higher smoke emission.

Garhard Vellguth et al. [1] conducted performance test on direct injection single cylinder engine with peanut oil and soybean oil. They found that the engine performance with straight vegetable oil was slightly inferior. They concluded that the straight vegetable oils can be used for diesel engine for short term operation. In long term, the engine developed problem like carbon deposit, piston ring sticking and change in engine oil properties, etc.

Samaga B. S. et al. [2] conducted performance test on single cylinder diesel engine with sunflower oil and groundnut oil as an alternative fuel. It was observed that the engine performance with vegetable oil was lower as compared to petro-diesel on account of its higher viscosity. The problem of filter clogging was also observed when the engine was stopped over a day with vegetable oil in the line. **Tripathi R.K. and P.K.Sahoo** [**3]** conducted experimental investigation on single cylinder lower speed IDI diesel engine to investigate the effect of jatropha straight vegetable oil fuelling on engine performance and emission characteristics. The engine performance was inferior with jatropha oil due to higher viscosity, high surface tension, low cetane number and low calorific value of jatropha oil. They concluded that the engine under investigation could not run on jatropha oil because of low BTE, high BSFC and even bad emission characteristics. To improve the fuel properties they suggested some minor modifications in fuel injection system of engine like advancing the fuel injection and changing the injector opening pressure, etc. **N.S. Bari et al. [4]** examined the effect of injection timing on performance, combustion and emissions of single cylinder diesel engine fuelled with waste cooking oil. The engine used in this research had standard injection timing of 15° before top dead centre. With injection timing advanced by 4°, the engine performance improved by about 1.6 percent and reduced the Carbon monoxide emissions significantly. But the NO_x emissions increased by 76.6 percent. **M. Pandian et al. [5]** conducted experiment on Twin Cylinder CIDI engine with bio-diesel blend as fuel. They altered the injection timing from 18° bTDC to 30° bTDC in an interval of 3° crank angle. It was observed that by retarding the injection timing to 18 °CA bTDC from 24°CA bTDC, the NO_x emissions reduced by 35 %. While advancing the injection timing to 30°CA bTDC, the NOx emissions increased by 25% and emissions of unburnt hydrocarbon and carbon monoxide decreased by about 14.4 and 32% respectively. The brake thermal efficiency was reduced with retarded timings whereas it was improved by advancing the injection timing. **GVNSR Ratnakara Rao et al. [6]** used a four stroke single cylinder diesel engine fuelled with diesel to investigate optimum injection pressure and timing. The highest brake thermal efficiency was obtained at 200 bar injector opening pressure and 11°bTDC.However there was slight increase in frictional power at this condition. **V.S.Hariharan [7]** conducted performance and emission tests on single cylinder diesel engine fuelled with diesel, sea lemon oil, methyl esters of sea lemon oil and its blends with diesel. He reported that the brake thermal efficiency with sea lemon oil was lower than diesel due to lower calorific value and high viscosity. The brake thermal efficiency of engine improved by advancing the injection timing to 27°CA bTDC as compared to 23°CA bTDC. This was due to the fact that by advancing the injection timing, the fuel finds sufficient time for vaporization and mixing with air, which leads to better pre-mixed combustion. advanced timings resulted in lower CO and HC emissions and increased NO_x emissions. **K Muralidharan and P Govindrajan [8]** investigated the effect of injection timing on performance and emissions characteristics of a single cylinder direct injection diesel engine performance with pongamia pinnata methyl ester and its blend with diesel from 0% to 30% with increment of 5% ester in diesel at varying loads. The tests were conducted at three different injection timings (19°, 23° andb27°CA bTDC). The experimental works revealed that at advanced timing of 27° CA bTDC, the engine performance was better than standard timing of 23°CA bTDC and significant reduction in emissions of HC and CO at all loading conditions. Retarded injection timings showed improvement over NO_x and CO_2 emissions. **O.M.I Nwafor [9]** carried out at test on duel fuel engine running on Natural gas under various engine load and speed; it was found that advanced timing tended to incur slight increase in fuel consumption as compared to standard injection timing of 30°CA bTDC. 3.5°CA advance resulted in significant reduction in carbon monoxide and carbon dioxide emissions as compared to standard timing. **Cenk Sayin [10]** carried out at test on ethanol-diesel blend engine running under various engine load and speed. Increase in amount of ethanol in blend of ethanol and diesel decreased the CO and HC emissions while increased the NO_x and CO_2 emissions. Advancement of injection timing resulted in significant reduction in carbon monoxide and Hydrocarbon emissions and increased the NO_x and CO_2 emissions as compared to standard timing. Retarded timings resulted in increased HC and CO emissions and lower NO_x and CO_2 emissions. **O.M.I. Nwafor et al. [11]** used rapeseed oil for running diesel engine at different injection timing. They observed that standard injection timing, plant oils exhibited longer ignition delay with slower burning rate. The engine ran smoothly with advance of 3.5 degree as compared to standard injection timing. With advanced injection timing there was significant reduction in carbon monoxide and carbon dioxide emissions.

In present study, a blend BSVO-70 (70% of vegetable oil and 30%) is used as test fuel and the injection timing is varied between 21° CA bTDC to 27 ° CA bTDC to investigate effect of change in injection timing on engine performance, emission and combustion characteristics.

***2. Materials*:**

The test fuel under consideration is a blend of 70% non-edible vegetable oil (honge oil) and 30% ethanol (BSVO-70). Various physical and chemical properties of diesel and BSVO-70 are determined using standard testing procedure and are shown in table 1. The viscosity is measured using redwood viscometer, the calorific value is estimated using bomb calorimeter, the flash and fire point are determined Martine pensky apparatus.

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Table 1: Properties of diesel, ethanol, Honge oil and blend

3. *Experimental setup*

The experiments are conducted on a single cylinder, four stroke, direct injection and naturally aspirated compression ignition engine. The technical details of the engine are given

Properties	Diesel	Ethanol	Neat Honge oil	Blend (BSVO-70)
Viscosity in cSt	4.25	1.2	40.25	10.08
Flash point (°C)	79	21	190	37
Fire point (°C)	85	25	210	42
Calorific value (kJ/kg)	42700	27569	37258	34105
Specific gravity	0.833	0.78	0.925	0.86

in Table 2. A computerized diesel engine test rig supplied by Apex Innovations is used for investigations. The test setup consists of electrical dynamometer for loading the engine. Load on the dynamometer is measured using strain gauge load sensor. An air cooled, piezo-quartz pressure sensors supplied by piezotronics Ltd, USA are mounted in cylinder head and between injection pump and injector to measure cylinder pressure and fuel injection timings respectively. The pressure sensor signals are obtained at every 1° crank angle and data acquisition is done for 80 cycles. Signals from these sensors are passed to charge amplifier for amplification. Crank shaft position is measured by using Kublar-Germany encoder. The Coolant temperature, exhaust temperature and air temperature are measured using thermocouples. The fuel flow rate is measured on volumetric method using burette. Figure 1 shows the schematic diagram of experimental setup. A gas analyser is used to measure the carbon monoxide, unburnt hydrocarbon emissions and oxides of nitrogen emissions and a smoke meter is used for measurement of smoke opacity. The details of exhaust gas analyser and smoke meter are given in table no. 3

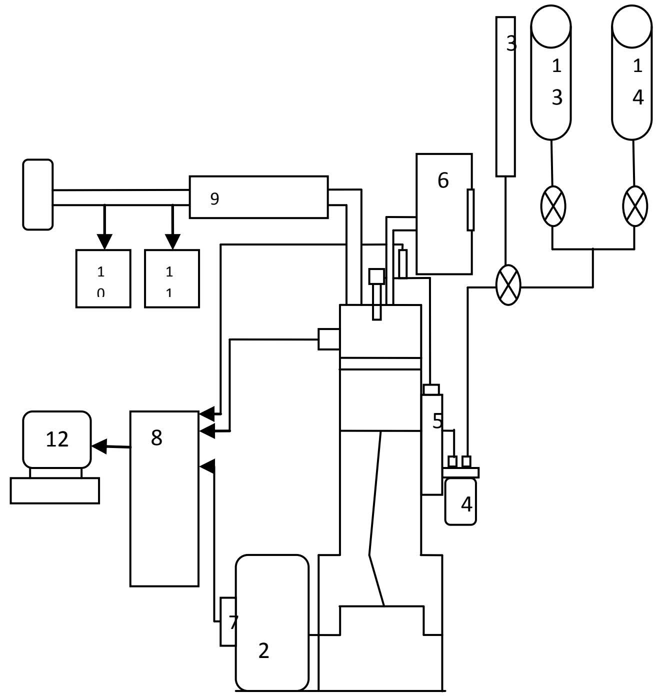

Fig.1: Schematic diagram of experimental setup.

1-Test engine, 2-Eddy current dynamometer, 3-fuel burette, 4-Fuel filter, 5-Fuel injection pump, 6- air box with U tube water Manometer, 7-TDC marker and speed sensor, 8- Data acquisition system and loading device , 9-Exhaust gas calorimeter, 10-Smoke meter, 11-four gas analyzer, 12-computer, 13 & 14 Fuel tanks.

S.No	Parameter	Specification
1	Type	Four stroke direct injection single cylinder diesel engine
2	Software used	Engine soft 8.5
3	Nozzle opening pressure	200 bar
4	Rated power	3.5KW @1500 rpm
5	Cylinder diameter	87.5 mm
6	Stroke	110 mm
7	Compression ratio	17.5:1
8	Injection pressure/timing	200 bar/23° bTDC

Table No 2: Specification of Engine

Machine	Measurement Parameter	Range	Resolution
Gas Analyser	Carbon monoxides(CO)	0-15%	0.01%
	Carbon Dioxide (CO_2)	0-19.9%	0.1%
	NO_x(Oxides of Nitrogen)	0-5000ppm	1ppm
	HC(Hydrocarbon)	0-20000ppm	1ppm
Smoke meter	Smoke Opacity	0-99.9%	0.1%

Table No. 3. Specifications of Gas Analyser and Smoke meter

4. *Experimental Procedure:*

Initially, the engine with standard injector opening pressure of 200 bar and static injection timing 23° CA bTDC is allowed to run on petro- diesel and BSVO-70 at constant speed of 1500 rpm at no load, 25, 50, 75 and 100 percent load condition to obtain base line data. At each load condition, the engine is allowed to run for at least 3 minutes so that the operating conditions can stabilize. The experiment with BSVO-70 is repeated at different injection timings to study the effect of injection timing on engine performance, emission and combustion parameters. Injection timing is varied by adding or removing the shims between the fuel injector pump and the engine body. It is found that by adding or removing each shim of 0.25 mm thickness, the static injection timing is varied by 2 degree. Addition of shims retarded the injection timing, while removing the shims advanced the injection timing. Study is done with normal, 2, 4 degree advance and 2 degree retarded injection timings. Variation in injection timing is monitored by fuel line pressure-crank angle graph. The engine performance, emission and combustion characteristics at different injection timing are evaluated in terms of brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), Cylinder pressure (P_c), Net rate of heat release (NRHR) and emissions of carbon monoxide (CO), un-burnt hydrocarbon (UBHC),oxides of nitrogen (NO_x) and smoke opacity.

5. Results and discussion:

5.1 Performance parameters: The engine performance, emissions and combustion characteristics with vegetable oil blend at different injection timing are discussed in following paragraphs.

5.1.1 Brake thermal efficiency:

The fig.2 shows the variation in brake thermal efficiency at different load conditions and at different injection timing. The brake thermal efficiency is increased with advancement in injection timing. This increase in brake thermal efficiency at advanced injection timing may be attributed to improved combustion due to sufficient time availability for evaporation and better mixing of blend and air, which resulted in higher pre-mixed combustion. Retarded injection timing resulted in lower brake thermal efficiency due to less time for evaporation and better mixing of fuel and air resulting late combustion in operating cycle.

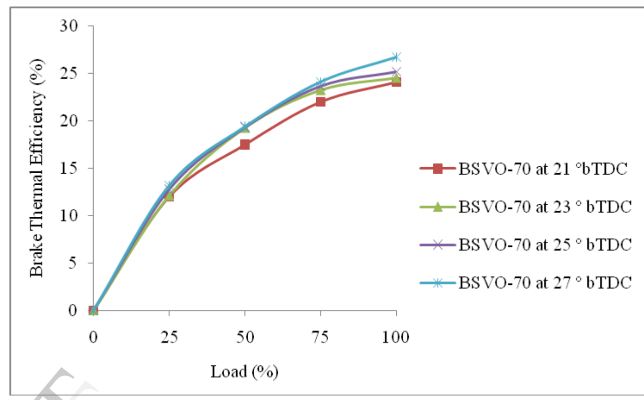

Fig.2: Variation in Brake Thermal efficiency at different injection Timings

5.1.2. Brake Specific Fuel Consumption (BSFC):

From fig. 3 it is observed that the Brake Specific Fuel consumption is decreased by advancing the injection timings. This reduction in BSFC may be due to sufficient time availability for evaporation and mixing of fuel with air with increased pre-mixed combustion and lower diffusion combustion. On other hand, retarding the injection timing resulted in increased the specific fuel consumption due to late combustion.

5.1.3. Exhaust gas temperature.

Exhaust gas temperature indicates the amount of heat lost to atmosphere with exhaust gases. Better combustion results in lower exhaust gas temperature as the most of the heat will be released during pre-mixed combustion. With highly viscous fuels, injection of larger droplets leads to slow evaporation with poor pre-mixed combustion and more heat release during diffused combustion phase. By advancing the injection timing, sufficient time can be made available for evaporation and mixture preparation during delay period which results in better combustion. It is observed that exhaust temperature decreased with increase in advance injection timing. Retarded injection timing resulted in higher exhaust gas temperature due to late combustion of fuel. (Fig. 4)

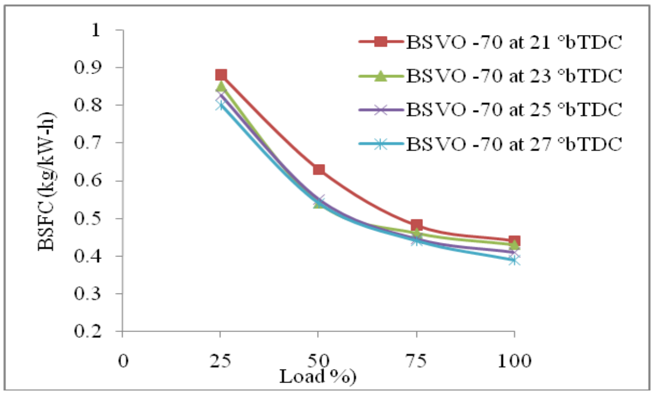

Fig.3: Variation in Brake Specific Fuel Consumption with different injection Timings

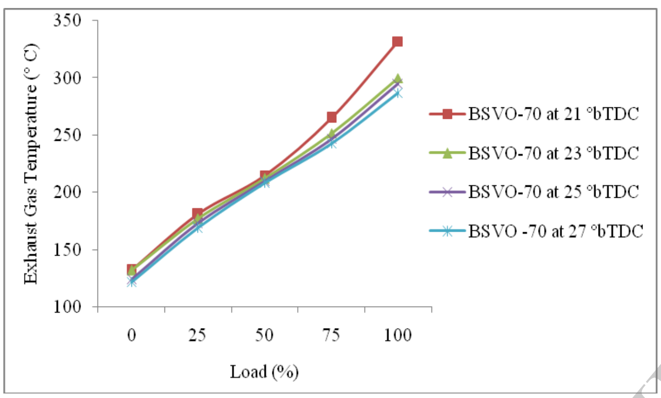

Fig. 4: Variation in Exhaust Gas Temperature at different injection Timings

5.2 Combustion parameters:

5.2.1 Cylinder pressure and net heat release rate:

Fig. 5 and fig. 6 presents the effect of injection timing on cylinder pressure and net heat release rate at full load conditions. With change in injection timing, the in-cylinder pressure and net heat release rate changes due to the change in air temperature and pressure at which the fuel is injected. On advancing the injection timing, the cylinder pressure reaches to higher value and on retarding the timing, cylinder pressure reaches to lower value as compared to original timing. This may be due to the fact that at advanced injection timings, earlier injection of fuel causes longer delay, large amount of fuel available for premixed combustion. At advanced timing, the peak cylinder pressure occurs very close to TDC due to early start of combustion. On retarding the timing, the peak pressure lowers and occurrence of peak pressure shifts away from TDC in expansion stroke, this may be due to shorter delay period, less fuel availability for premixed combustion and late start of combustion. It is also observed that with retarded injection timings, more heat released during diffusion phase. On other hand advanced injection timing indicate more heat is released during premixed phase

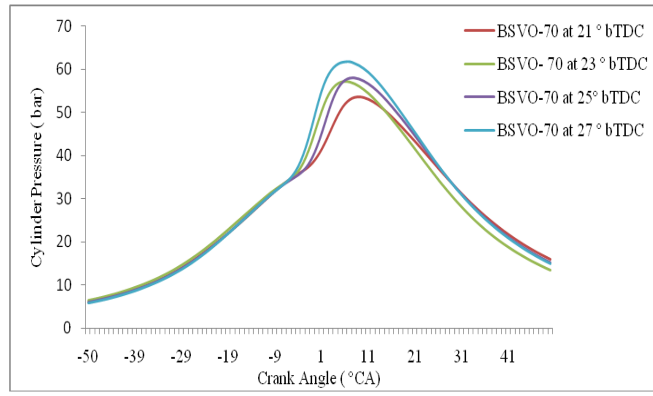

Fig.5: Variation in Cylinder Pressure with different injection Timings

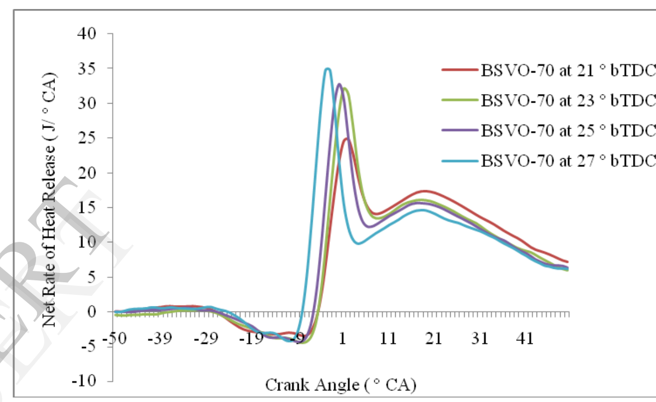

Fig.6: Variation in Net Rate of Heat Release rate with different injection Timings

5.3 Emissions:

5.3.1 Carbon monoxide (CO):

Fig. 7 shows variation of carbon monoxide emissions with injection timing. It is observed that at advanced injection timing, the carbon monoxide emissions are decreased. This reduction in CO emissions may be due to the fact that the advanced injection timing produces higher combustion temperature which accelerates the oxidation reaction between carbon and oxygen molecules. Also by advancing the timing, sufficient time will be available for chemical reaction. However, retarding the injection timing increases the CO emissions. The retarded injection timing causes lower combustion temperature and reduction in oxidation reaction.

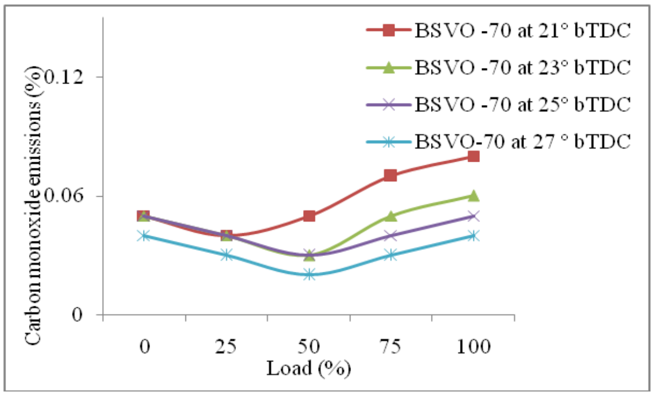

Fig.7: Variation in Carbon Monoxide Emissions with different injection Timings

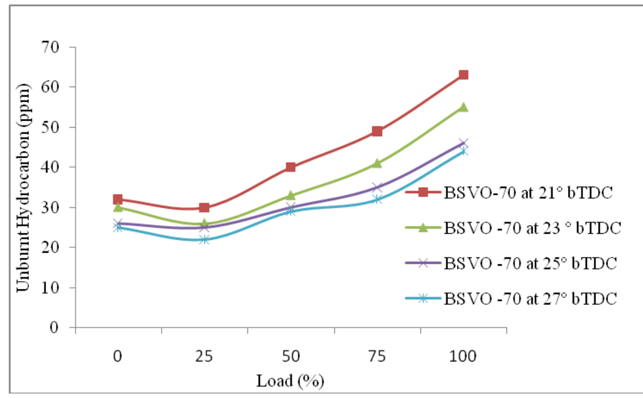

Fig. 8: Variation in Unburnt Hydrocarbon emissions with different injection Timings

5.3.2 Un-burnt Hydrocarbon emissions (UBHC):

Fig.8 Shows variation in UBHC emissions at different injection timings. The concentration of UBHC in exhaust show the traces of fuel present in the exhaust gases. At low loads the hydrocarbon emissions are slightly higher as compared to medium loads due to escaping of fuel from leaner fuel air mixture pockets because of lower combustion temperature Advancing the injection timing causes earlier start of combustion and cylinder charge being compressed by piston moving towards TDC which causes higher temperatures and more complete burning of charge in quench zones leads to lower HC emissions. Retarding the injection timing increases the UBHC emissions due to slow combustion during expansion stroke and lower combustion temperatures.

5.5.3 Oxides of Nitrogen: In CI engines, emission of oxides of nitrogen depends on in-cylinder temperature, the oxygen concentration and residual time for reaction. With retarded injection timing, lower in-cylinder temperature, shorter residence time for reaction at elevated temperature and more fuel burning after TDC resulted in lower NO_x emissions. Advancing in injection timing, results in better combustion, higher combustion temperature and increased residence time for oxidation of nitrogen with higher NOx emissions. It is observed that advancing the timing resulted in increase in NO_x emissions. At 27° bTDC NO_x emissions are marginally lower than diesel. However, by retarding the timing decreased the NO_x.

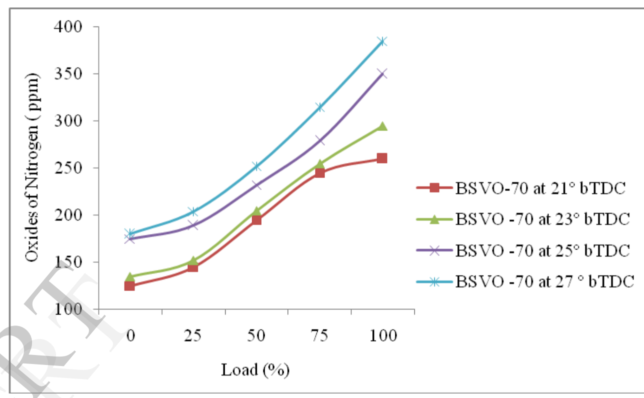

Fig. 9: Variation in Oxides of Nitrogen Emissions with different injection Timings

5.3.4 Smoke Opacity (SO) :

Fig 10 shows variation in smoke opacity with injection timing. It is observed that at advanced timing, the smoke opacity decreased due to more complete oxidation in rich regions. The retarded timing resulted in increase in smoke opacity due to slow and late combustion during expansion stroke.

6. Conclusions:

In this study, the influence of injection timing on performance, emission and combustion characteristics of diesel engine is experimentally investigated using straight vegetable oil-ethanol blend as fuel. The results indicate that advancement of injection timing increased the brake thermal efficiency, lowered brake specific fuel consumption. The exhaust gas temperature also reduced. With retarded injection timings, the brake thermal efficiency decreased with higher brake specific fuel consumption and higher exhaust gas temperature. The longer delay period, increase in in-cylinder pressure and maximum heat release rate are observed with advanced injection timings. However shorter ignition delay, lower peak in-cylinder pressure and maximum heat release rate are observed with retarded injection timings. By advancing the injection timing, emissions like carbon monoxide, unbrunt hydrocarbon and smoke emissions are decreased while NO_x emissions are increased. On other hand retarding the injection timing reduced the NO_x emissions with increased unburnt hydrocarbon, carbon monoxide and smoke emissions.

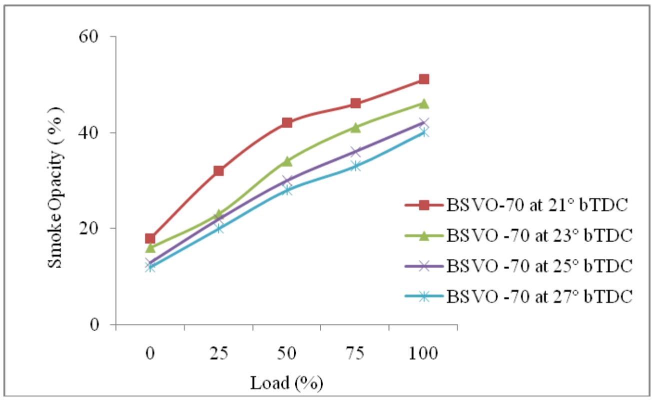

Fig.10: Variation in smoke Opacity at different injection Timings

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