Effect of Injection Timing on Performance and Emission Characteristics of 4S-Single Cylinder DI Diesel Engine Using PME Blend as Fuel

P. Vara Prasad [1]
Research Scholar, JNTUA,

Dr. B. Durga Prasad [2]
JNTUCEA, Anantapur, India

Dr. R. Hari Prakash [3]
Professor of Mechanical Engineering,
NBKR College of Engineering, Vakadu

Abstract

The demand for fuels across the world is increasing day to day especially for petroleum derived fuels since in the last 20 years. Among some of alternatives, Bio diesel (Edible and non edible oils) is one of the prime promising fuel because of its properties similar with diesel fuel. The most important challenging factor is to reduce NOx as biodiesel concerned as fuel in engine. One of the NOx reduction methods is to optimize (retarded) the standard fuel injection timing of diesel engine. Experiments were conducted on single cylinder diesel engine using petro-diesel and palm methyl ester blend (PME20) as a fuels under four engine loads with injection timings 17^o, 19^o , 21^o , 23^o ,28^o CA bTDC. The objective of this work is to investigate the optimum injection timing for possibility of reducing the exhaust gas emissions UBHC, CO, NOx without much effect on the performance parameters BSFC, Brake Thermal Efficiency. The effect of injection timing on the biodiesel blend PME20 was investigated and the results were analyzed. With retardation of injection timing NOx emission reduced and UBHC,CO emissions increased while advanced injection timing could reverse the effect .Optimal injection timing for PME20 blend(B20) is 21^{o}CA bTDC for slightly higher thermal efficiency and BSFC at full load operation while 19^{o}CA bTDC could be for low NOx emission with tolerable performance parameters.

Key words: Injection timing, PME20, NOx, CO, UBHC, EGT, single cylinder 4s-diesel engine

1. INTRODUCTION

THE demand for fuels across the world is increasing especially petroleum based fuels because of the drastic growth in usage of diesel fuel in transportation and industrial power plants. It is expected that the fuels consumption for producing energy increase by 50% to 180000 gWh /year by 2020 with rising of fuel and also environmental concerns there is a need of suitable renewable alternative fuels which could satisfy all the aspects with less environmental impact.

And also in view of socio - cultural and economical considerations to promote well balanced development of the state strategy to extend the usage of crop based food and non food products. To cope up the demand for energy is filled with fuels such as ethanol, hydrogen, and biodiesel. Ethanol has been successful commercialized and are a mature technology. However ethanol is used in SI engines and not suitable to use in CI engines because of its low ignition quality. Hydrogen is most suitable alternative for Gasoline engines but there are so many technical problems involved to overcome in production and storage. Accordingly the biodiesel is only an alternative for compression ignition engines.

Biodiesel is a domestically produced, clean-burning, renewable substitute for petroleum diesel. Using biodiesel as a vehicle fuel increases energy security, improves public health and the environment, and provides safety benefits.

Biodiesel also has an excellent energy balance: Biodiesel contains 3.2 times the amount of energy it takes to produce it. This value includes energy used in diesel farm equipment and transportation equipment, such as trucks and locomotives; fossil fuels used to produce fertilizers, pesticides, steam, and electricity; and methanol used in the manufacturing process. Because biodiesel is an energy-efficient fuel, it can extend petroleum supplies.

The diesel engine is a prime mover and its major pollutants are smoke, particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx) and unburnt hydrocarbon (UBHC).
So far, many investigations have been carried out on a variety of vegetable oils, like oil palm, Jatropha oil, pongamia oil, rice bran oil and rapeseed oil, linseed oil, castor oil etc. in diesel engines in the recent 10 years. According to review published by EPA (2002), from diesel to B20 CO, HC and PM decreased by 13%, 20% and 20% respectively, while NOx emissions increased by 4%.But most B20 users report no noticeable difference in performance or fuel economy.

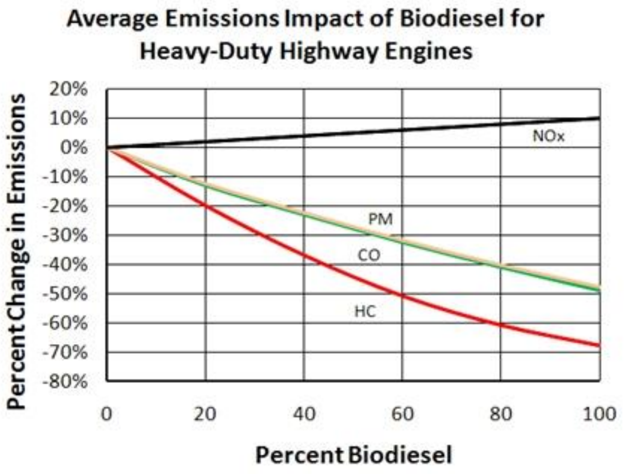

Fig.1. Change of emissions scenario with respect to biodiesel blends (EPA 2002)

Gerhard Vellguth et al., [1] concluded that diesel engines with vegetables oils as fuels produce the same power output but with reduced thermal efficiency and increased emissions. Cngiir.Y et al., [2] observed the particulate emissions of vegetable oils are higher than that of diesel fuel with lower values of NOx emissions. However, their performance is slightly inferior to diesel. Barsic N.J et al. reported that major obstacle in using vegetable oils is its high viscosity, which causes problems of fuel flow in the injector, fuel lines and filter [3]. High viscosity leads to poor atomization of the oil and this leads to high levels of smoke. In order to improve the performance of vegetable oils, different methods like heating, transesterification, dual fuelling etc have been tried [4].Experimental evidence from the several investigations has showed that variety of vegetable oils can be directly used without any modification in compression ignition engine. Monyem et al., [6] observed on using two different soybean oils with 20% blends with diesel fuel that the smoke number, CO and HC decreased while NOx emissions increased.

Biodiesels are mono-alkyl esters containing approximately 10% oxygen by weight. The oxygen improves combustion efficiency, but it takes up space in the blend and therefore slightly increases the apparent fuel consumption rate observed while operating an engine with biodiesel. Kaplan et al. [8] compared sunflower oil biodiesel and diesel fuels at full and partial loads and at different engine speeds in a 2.5 kW engine and the loss of torque and power range between 5% and 10%. According to these values, the commercial diesel fuel has the greatest brake power. Shailendra Sinha et. al., [10] revealed that the overall combustion characteristics were quite similar for biodiesel blend (B20) and mineral diesel. Also reported that ignition delay is lower and combustion duration is longer than diesel. Naveen kumar et.al.,[12]conducted experiments using methyl ester of palm oil, blended in different concentrations with neat diesel to find the performance and emission characteristics in order to evaluate its suitability in diesel engine, the data thus generated were compared with baseline data from neat diesel. It was found that optimal blend of 10-20% methyl ester of palm oil with neat diesel exhibited best performance and smooth engine operation without any symptoms of undesired combustion phenomenon. Nagaraja A.Met.al., [13] reported that optimum blend ratio is 20% methyl ester with neat diesel. He also observed that increasing injection pressure reduce the NOx and improvement in thermal efficiency.

For a diesel engine increase in NOx emissions serves as a major impediment to the application of biodiesel. Fuel injection timing is an important factor to control NOx emission .If the injection starts earlier, the initial air temperature and pressure will be lower, so that the ignition lag will extend while late injection engine will shorten the ignition lag due to slightly higher temperature and pressure of cylinder air. Thereby variation of injection timing has a strong effect on the engine performance and exhaust emissions, particularly on brake thermal efficiency, brake specific fuel consumption and NOx emission, because of changing maximum pressure and temperature in the cylinder [15-16]. Tat et al.,(2000) and Boehman et al.,(2004) investigated the effect of bulk modulus of biodiesel on the fuel injection timing which has a consequence on NOx emission. Furthermore, the literature showed that in general, compared with the diesel fuel, biodiesel could reduce significantly CO, HC and smoke emissions [17-18]. M. Pandian et.al.,(2009) conducted experiments on Twin cylinder at different injection timings(18^o-30^o) using biodiesel blends .It was reported that the injection timing retarded to 18o ,NOx reduced by 35% while increased to 25% by advanced injection timing to 30o .Furthermore BSEC,CO,HC increased by retarded injection timing and decreased by advanced injection timing[19]. S.Jindal et. al., [5] conducted experiments on Jatropha biodiesel with retarded fuel injection and found to be NOx emissions reduced. M.C.Navindgi et al., [9] conducted experiments on castor methyl ester 20% blend at different compression ratios, at different injection timings and different injection pressures. He observed that 18:1 compression ratio,27^o CA advanced injection timing and 240 bar injector pressure were to be optimum operating parameters for diesel engine run on CME20 fuel and it can give better performance.

The present work is aimed to determine optimum injection timing by analyzing the performance and emission characteristics of methyl esters of palm oil at blend ratio of

1:5(B20) on setting the engine to operate at advanced and retarded injection timings.

2. Test Engine and Fuel properties

TABLE1. ENGINE SPECIFICATIONS

Parameter	Specification
Type of the engine	4 s-Single cylinder, water cooled, DI diesel engine
Make	TOP LAND, Rajkot, India
Rated Brake Power	5HP /3.7 kW
Bore X Stroke	80 X 110 mm
Injection timing	23° bTDC
Compression ratio	16.5: 1
Rated speed	1500 rpm
Fuel nozzle opening injection pressure	190 bar
Number of holes in nozzle(standard)	3
Dynamometer	Brake drum dynamometer

TABLE 2. PROPERTIES OF PETRO - DIESEL AND PME

S. No	Parameter	Petro-Diesel	PME
1.	Density at 15°C kg/m^3	840	873
2.	Viscosity at 40°C mm2/sec(cSt)	2-4	4-7
3.	Flash Point °C	56	81
4.	Calorific Value kJ/kg	42500	37500
5.	Cetane Number	47	51

3. EXPERIMENTAL SET-UP AND MEASUREMENTS

The Engine tests were conducted on single cylinder four stroke diesel engine at different fuel injection timings in terms of crank angles on crank shaft. The engine specifications were shown in Table -1. The engine was cranked by hand lever. The engine was coupled to Rope-Brake drum dynamometer in which load increased through adding of dead weights.

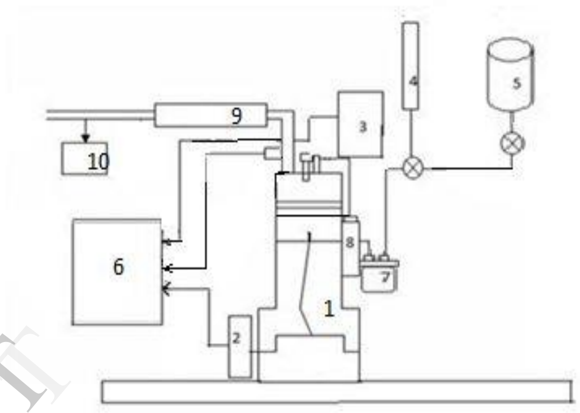

Fig.1 Schematic of Experimental setup

1.Test Engine, 2.Fly wheel with Brake Drum Dynamometer, 3.Air Box, 4.Fuel Burette, 5.Fuel Tanks, 6.Data Acquisition System, 7.Fuel filter , 8.Injection Pump , 9.Exhaust Gas Calorimeter,10.Gas Analyzer .

For each test the engine was run at constant speed of 1500 rpm and the engine cylinder provided with hemispherical shaped combustion chamber. The engine has conventional fuel injection system operated at pressure of 190 bar. This set-up has data acquisition system to measure speed and temperature of emissions and engine water temperature and the fuel consumption measured through graduated measuring burette with stopwatch and the air supply to the engine is measured through orifice - water manometer arrangement (called Air Box Method). The injection of fuel at different crank angles is done by removing and adding of shims at flange of fuel pump. AVL gas analyzer was used to measure exhaust emissions NOx, CO, UBHC.

4. RESULTS AND DISCUSSION

It was reported in many literature that the performance of biodiesel and its blend was inferior to petro-diesel while the emissions CO, UBHC were lower and NOx emission was higher. One such measure to reduce the NOx emission from diesel engine is to retard the fuel injection timing. The results were obtained by conducting the tests on B20 at injection timings 28°, 21°, 19°, and 17° with respect to the standard designated injection timing crank angle 23° bTDC and for petro-diesel tests conducted at standard injection timing only. Further performance and emission tests carried out to identify the optimum injection angles and the variations were shown in the following figures.

4.1 Engine Performance

For each testing mode, the volumetric flow rates of the fuel were measured on which the mass consumption rate of the fuel was calculated. The brake power, the brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) can be calculated using the collected data with engine performance equations.

A. Variation of BSFC with different Injection timings

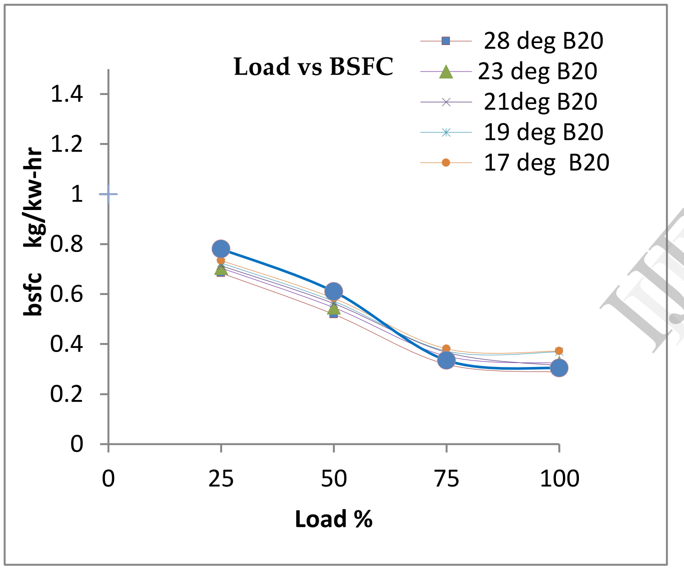

Fig.2 Variation of brake specific fuel consumption with load at different injection angles

The variation of brake specific fuel consumption (BSFC) of petro-diesel at 23° bTDC and PME blends (B20) at different injection angles is shown in fig.2.The BSFC was found to decrease with the increase in engine load from 0 to 100%. This is due to the fact of, under part load operation lower volumetric efficiency which means less availability of oxygen and diffusing of combustion is slow leads to incomplete combustion and hence less power thus higher bsfc. Under full load condition in-cylinder wall temperature was high which helps to better combustion thus lower bsfc. The BSFC is reduced to 11.11% with advanced the injection timing 28° CA bTDC. This is because of nearly homogeneous mixture prepared due to longer ignition delay before premixed combustion and hence better combustion leads to lower bsfc. The bsfc is decreased by 3.08% with retarded injection timing 21°CA while it is increased by 13.88%, 14.81% for 19°, 17° CA respectively at full load condition. But during at part load operation the differences in BSFC is higher compared to full load at rated speed for B20 at different injection angles because of better combustion at full load.

B. Variation of BTE with different Injection timings

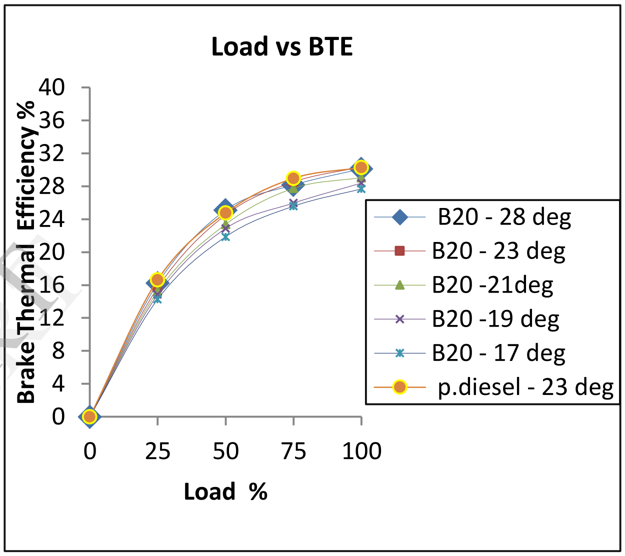

Fig.3 Variation of brake thermal efficiency with load at different injection angles

Fig.3 shows the variation of the brake thermal efficiency BTE) with respect to load at different injection angles. The BTE increases with an increase in engine load from 0 to 100% for all injection timings. Usually when load increases the combustion efficiency improves and hence brake thermal efficiency. At 28° bTDC injection timing the brake thermal efficiency was higher compared to all injection timings while lower at 17° crank angle. However at 21° the brake thermal efficiency of B20 was very close to diesel fuel at full load operation and higher than B20 at 23° bTDC .It may be fuel injection advanced to setting injection angle due to its high molecular density results in nozzle needle lifts early. Moreover its richness in oxygen helps better combustion to promote more combustible regions at the time of combustion begins leads to higher pressure at just after the TDC. But its lower heat value and poor atomization could lower the combustion temperature, pressure and reduce the BTE. These two factors conflicting against each other leading to reduce BTE of B20 at 21° at part load while higher at full load compared with other injection timing and also with diesel fuel (at standard injection timing) . Examining the graph (fig.3) the injection timing 21° CA bTDC is an optimum angle, keeping in view of detonation 28° CA injection timing is not acceptable.

C. Variation of EGT at different injection angles:

The exhaust gas temperature is an indicator of the concentration of emissions of NOx. In general exhaust gas temperature increases with increasing load irrespective of injection timings which was shown in fig.4. This is because of with increase in load the combustion chamber temperature increases as more fuel burned thus resulting in higher exhaust gas temperature. The EGT was higher at 28° CA bTDC while it was low at 17°compare to other remaining injection timings. These results show that EGT was a function of injection timing. It was observed that a little difference in exhaust gas temperatures at low and medium loads and whiles more at higher loads.

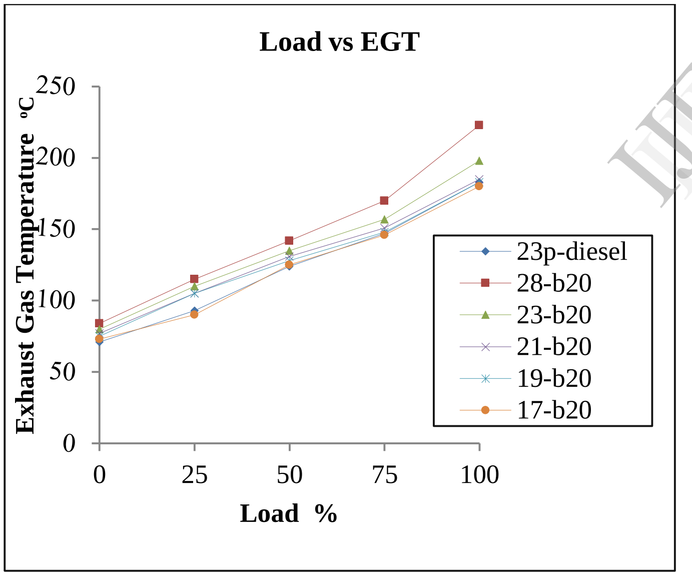

Fig.4. Variation of Exhaust Gas Temperature with load at different injection angles bTDC

4.2 Engine Emissions.

A. Trade off between CO emissions and Injection timings for PME blend (B20)

Fig.5 shows the effect of different injection timings on CO emissions of PME20 at different loads. It reveals that the CO emissions decreases with advancement of fuel injection while increases on retardation of fuel injection .About 28 % reduction in CO emissions was observed on advancement of fuel injection while 17% increment was noticed on retardation. For entire load range it was18.87% by an average reduction on advanced fuel injection and while it was 15% by an average increment on retardation. On advancement the fuel blend had sufficient time to undergo the combustion process whereas it had lesser time on retardation.

B. Trade off between UBHC emissions and Injection angles for PME blend (B20)

The effect of different injection timings on UBHC emissions of PME blend at different loads shown in Fig 6. It was found that UBHC emissions reduced by about 15.69 % on advancing the injection timing to 28°CA bTDC while increased by about12% on retarding the fuel injection timing to 17°CA bTDC at full load operation. Because of advanced injection timing it had sufficient time to mix well i.e. more number of ignitable regions formed in combustion space before premixed combustion consequently there was possibility of complete combustion resulting in lower HC emissions. It was observed 12.34% an average reduction in UBHC emissions during entire load range while 11.72 % average increment on retardation of fuel injection timing. Examining fuel injection at 19° CA bTDC had 6.7% lower than diesel fuel and 8.2% lower than of the same fuel which operated at standard injection timing at full load.

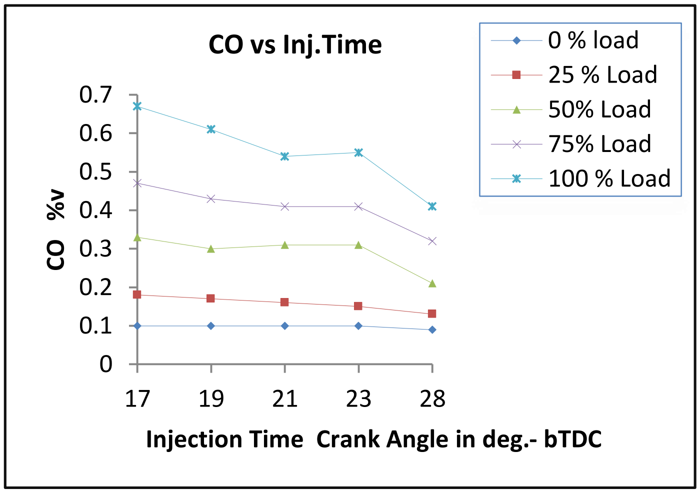

Fig.5. Trade - off between CO and Injection Timing crank Angle of B20 (PME)

B. Effect of NOx with different Injection timings

It was observed from fig.7 the NOx emissions increase as load increases from 0% to 100% at all setting injection timings. In general as load increases more quantity of fuel injected and burns causes the operating in-cylinder temperature increases resulting in higher NOx emissions. With advanced injection timing 28° CA bTDC the NOx emissions are higher compared to other injection timings and also with diesel fuel at all loads. This may be due to more complete combustion of fuel with attaining sufficient time leads to better mixing of fuel with air and more amount of fuel accumulated before the premixed stage of combustion resulting in high temperature and thus the higher NOx. When the injection timing being retarded to 21°, 19°, 17°CA the NOx emissions are decreased in ascending order for all loads. This is probably due to incomplete combustion of fuel for insufficient time and the combustion begins lately resulting in low combustion pressure and temperature even if the fuel rich in oxygen and hence lower NOx emissions. At load range of 0-50% the difference of emissions is low compared to at full loads in the phase of retarded injection timing.

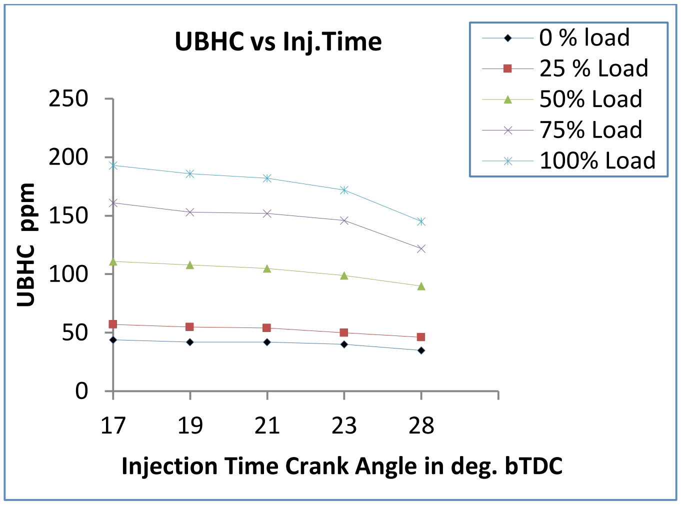

Fig. 6 Trade off between UBHC and Injection Time crank angles of B20 (PME)

The concepts of combustion reveal that NOx emissions increase greatly with temperature of combustion gases and also available oxygen. Among all injection timings 17°CA bTDC has the lesser NOx emissions. In keeping view of knocking tendency, engine behaviour 19° CA showed that optimum fuel injection timing for low NOx emissions with tolerable performance.

CONCLUSIONS

This study investigates an optimum injection timing of diesel engine fuelled with PME20 and the following conclusions were drawn.

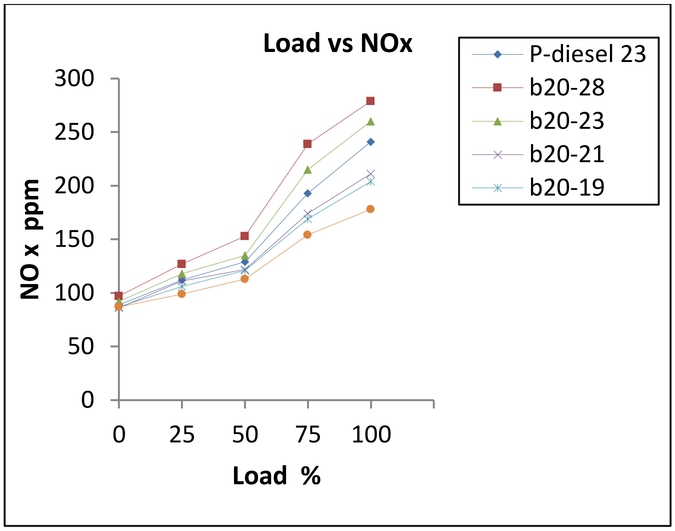

Fig.7 .Variation of NOx at different injection crank angles

1. The brake thermal efficiency increases with advanced injection timing 28°CA for all load range and 2.1% high at full load .While with retarded injection timing 21°CA the BTE reduced at part loads and increased by 2.3% at full load when compared to standard injection timing. The BTE reduced to 3.48%, 8.42% at 19°, 17° CA retarded injection timings respectively.

2. The BSFC is reduced to 11.11% with advanced the injection timing 28° CA bTDC. The basic is decreased by 3.08% with retarded injection timing 21°CA while it it is increased by 13.88%, 14.81% for 19°, 17° CA respectively at full load condition. The BSFC is higher at part load while low at full load by 3.08% for 21°CA.

3. The EGT increased by 21.92% at full load and got reduced to 31.33% at 17 ° CA bTDC.

4. The decrease in CO is found to be 28.07% at full load and at 28° CA bTDC. At 21° CA the CO emission is high at part loads and slightly low at full load by3.5%. At 19° CA CO emission is high for all operating load range and increased by7.01% at full load. The CO at 17° CA high for all load range and increased by 17.54% at full load.

5. At 28° CA bTDC the HC emission is low for all operating range of load and decreased by 15.69% at full load. At 21° CA the HC emissions high for all operating range of load and 5.81% high at full load and for 19° CA it was 8.13% high. The HC emission at 17° CA high for all load range and increased by 12.2% at full load.

6. The NOx emission increases for all loads, when the injection timing is advanced to 28° CA bTDC and increased

by 21.92% at full load. The NOx emissions are decreased by 18.84%, 21.53 %, 31.53% when the injection timings retarded to 21^{o} CA, 19^{o} CA and 17^{o} CA respectively.

By the above conclusion that the retarding the injection timing gives a remarkable impact on exhaust emission parameters but with a penalty on efficiency and bsfc. However 19^{o} CA bTDC is optimum injection timing for moderate thermal efficiency with lower NOx emission.

ACKNOWLEDGEMENT

To carry out this research work, the support provided by the management of DBS Institute of Technology, Kavali, is sincerely acknowledged.

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