Study And Evaluation of Injection Timing of CIDI Engine Injection Pump Using Alternate Fuel i.e Biodiesel Fuel

P.K.Singh*[1] , Rohit Shrivastava[2] and K.G. Sinha[3]

1.* Research Scholar, Department of Mechanical Engineering, GLA University, Mathura (U.P.)India. e-mail : prdpsngh35@gmail.com

2. Asst. Professor, Department of Mechanical Engineering, S R Institute of Management & Technology, Lucknow (U.P.)-India

3. Assistant Professor, Department of Mechanical Engineering, School of Management Science, Lucknow (U.P.), India. e-mail : kgsinha.2007@rediffmail.com

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***Corresponding author :**
Yadvendra Pratap Singh
e-mail : yadvendra.mnnit@gmail.com;

Abstract

In this investigation an experimental study of the effects of FIP injection timing on Specific Fuel Consumption(SFC), Brake Thermal Efficiency(BTE), Engine Exhaust Gas Temperature(EEGT), CO, HC, NOX and Smoke of "Kirloskar-6R1080TA, 6-CylinderInline, Direct Injection, Turbocharged Intercooled, 191 hp Diesel Engine" has been conducted. Injection Timing retardation method has been utilised to reduce SFC, EEGT, CO, HC, NOX, Smoke and increase BTE of Kirloskar-6R1080TA Diesel Engine. The Kirloskar 6R1080TA engine has been tested for six different injection timings (23°, 21°, 20°, 19°, 18° & 17° CA BTC) at same engine speeds & load conditions. The SFC,EEGT, CO, HC, NOX & Smoke of engine are approximately higher and BTE lower for injection timings at 23°, 21°, 20°, 18° & 17° CA BTC than 19° CA BTC at same speed and load. The results are showing that SFC,EEGT,CO,HC,NOX & Smoke are approximately reduces and BTE increases by reducing injection timing from 23° CA BTC to 19° CA BTC. Optimum FIP injection timing for Kirloskar 6R1080TA engine has been achieved at 19° CA BTC.

1. INTRODUCTION

Air pollution, increasing prices and uncertainties to availability of mineral fuel necessitates the search for alternative fuels. Biodiesel fuels from soybean oil, Jatropha oil, sunflower oil, rice bran oil etc., offer a interesting alternative fuel with respect to harmful emissions, engine wear, cost, and availability.[1,2] Biodiesel fuels have comparable energy density and cetane number than mineral fuels but have small sulfur and much oxygen. However the high viscosity and molecular weight, low volatility etc. of biodiesel fuels may lead to engine problems in some cases like severe engine deposits, injector cooking and piston ring sticking.

At present most diesel engines have been developed for working with mineral diesel fuels. Biodiesel fuels can not be used without any precautions to these engines. Due to these reasons some investigations are necessary to prevent or at least mitigate different engine or environmental problems.

Biodiesel and biodiesel blends generally show lower CO, smoke, and HC emissions but higher NO_x emission and higher specific fuel consumption than mineral diesel.[2-6] Biodiesel from waste olive oil methyl easter may increase the NO_2 emissions up to 81%; the emissions of CO, NO, and SO_2 may decrease, whereas the combustion efficiency remains constant using either biodiesel or mineral diesel.[7]

Many research scholars investigate an advance in fuel-injection timing due to higher bulk modulus of biodiesel than mineral diesel.[8-10] A higher bulk modulus, thus higher sound velocity causes the pressure waves from the fuel pump to the hydraulically opened fuel injector to travel faster and thus advancing the fuel-injection timing. Also due to advance injection timing an increase in the amount of fuel consumed during the premixed phase of combustion leads to increased NO_x emissions. An opposite trend is observed with paraffinic fuels; this leads to a retarded injection timing because they have a lower bulk modulus of compressibility than mineral diesel and supports the observation that paraffinic fuels leads to lower NO_x emissions.

Sometimes biodiesel fuels show an improved engine performance with lower emissions therefore biodiesel fuels meet future emission norms by tuning the engine optimally for biodiesel fuels without any change in engine hardware.[11]

Modern diesel engines are also checked for emissions from biodiesel fuels. The use of biodiesel in modern diesel engines resulted in lower emissions of HC, CO and PM with some increase in emissions of NO_x.[12] There are some variations in results depends upon engine.

Due to oxidation of neat biodiesel and biodiesel blends from soybean, engine performance and emissions at a single engine speed for three different injection timings results NO_x emissions 13-14% higher than mineral diesel and CO, HC, and smoke emission decreased.[13]

In this investigation an optimal injection-pump timing that reduces harmful emissions even NO_x of a Kirloskar Backholoader diesel engine is achieved .Investigation is done into three parts as follows: (1) Effect of injection— pump timing on engine characteristics is discussed with those parameters that have been taken into account to determine the optimal injection-pump timing when using neat biodiesel (2) Both fuels, neat D2 diesel and neat biodiesel are then compared with the injection-pump timing recommended by manufacturer (for D2 diesel). (3) Afterward, the effect of injection-pump timing for neat biodiesel is investigated. On the basis of the obtained results, we determined the optimal injection-pump timing for neat biodiesel.

2. INJECTION-PUMP TIMING

Injection timing or start of injection influences all engine characteristics due to the mixing quality of the air-fuel mixture, combustion process and harmful emissions also[14,15]. Retarded injection decreases maximum pressure in the cylinder and leads to lower peak rate of heat transfer and lower combustion noise. Because the delayed injection leads to lower temperatures, the NO_x emissions are also reduced. On the other hand retarded injection leads to an increase in fuel consumption. Smoke emissions are also decreases. For a direct-injection diesel engine at high load, HC emissions are low and vary with injection timing. At partial loads, HC emissions are higher and increase as the injection start is shifted from the optimum at idle load condition.

Start of injection means start of injection-pump delivery, which can be set easily to any desired value. In this paper, the start of injection-pump delivery is known as injection-pump timing.

Table-1: Engine Specifications

Engine model	Kirloskar-6R1080TA
Engine type	4 stroke, 6 cylinder in line, Turbocharged, Water cooled with direct injection system
Fuel-injection pump	Bosch PES 6A 95D I 625 M 326
Displacement	6480 cm
Compression ratio	14.5:1
Bore and stroke	115 mm and 145 mm
Maximum power	142 kW at 2200 rpm

Table-2: Physical properties of Biodiesel and Diesel

	D2	B100
Density @ 30 °C (kg/m^3)	840	876
Kinematic viscosity @ 30 °C (mm /s)	4.59	5.8
Flash point (°C)	75	170
Fire point	80	184
calorific value (Kj/kg)	42390	38450
cetane number	45-55	50

3. EXPERIMENTAL SETUP AND DIAGNOSTICS

A six cylinder four stroke direct injection water cooled diesel engine was employed. The engine specifications are given in Table 1. The engine was coupled to an eddy current dynamometer to provide brake load. Biodiesel produced from jatropha was injected into the engine through the existing injection system. However two separate fuel tanks with a fuel switching system were used, one for diesel and other for biodiesel. Some measured properties of these fuels are given in Table 2. The fuel consumption was measured with the aid of a burrete and stopwatch on the mass basis. A high speed digital data acquisition system was used to measure instantaneous pressure in the cylinder and injection pressure also with the help of a piezoelectric transducer and the temperatures of cooling water in and out of the engine and the exhaust gases also with the help of thermocouple.

A flame ionization detector was used to measure the HC emission level in the exhaust. To measure NO_X and CO concentration in the exhaust gas, a chemiluminescent analyzer and a Maihak CO analyzer were used respectively. Smoke levels were measured with the help of Bosch smoke meter.

Measurements are divided into three parts to study the following:

(1) Effect of fuels on engine characteristics is studied. Both fuels have been used to run the engine with an injection-pump timing of α_i=23°CA BTC, which is recommended by manufacturer (for D2 diesel). The tests were performed at full-load, partial-load, and idling conditions.

(2)Effect of variable pump-injection timing α_i on engine characteristics using B100 fuel. The tests were performed at full-load, partial-load, and idling conditions and optimal injection timing is obtained.

(3) Comparision between engine characteristics obtained by using D2 fuel with α_i=23°CA BTC and B100 with biodiesel optimized injection-pump timing is done.

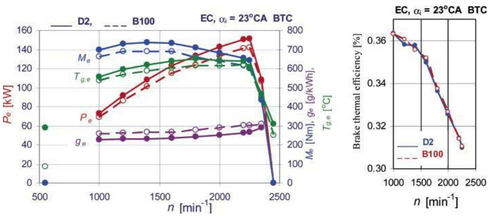

Fig.1: Influence of fuel on engine performance at idle and full load conditions

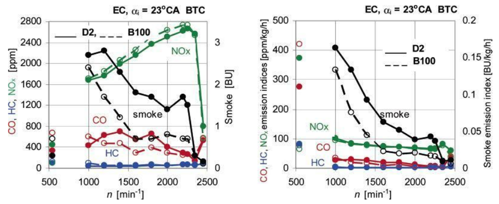

Fig.2: Influence of fuel on engine emissions at idle and full load conditions

4. EFFECT OF FUELS ON ENGINE CHARACTERISTICS

Engine is run for recommended injection timing of D2 fuel to check the effect of fuel on engine characteristics. Some engine characteristics of D2 and B100 are compared at idle and full load conditions (EC characteristics) shown in Figure 1. At full load M_e and P_e decreases approx 5.5% using B100 while g_e increases approx 9% at all engine speeds while Tg,e decreases approx 28°C due to lower calorific value of B100.

Figure 1 shows the brake thermal efficiency. BTE is ratio of actual effective power to the chemical energy (fuel consumption rate x calorific value of fuel). As B100 fuel has higher effective specific fuel consumption ge at all engine speeds however BTE is almost same for both fuels due to different calorific values.

Figure 2 shows emissions of NOx, Smoke, CO and unburned HC. At full load NOx emission increases when B100 is used however at idle it decreases. At full load smoke emission decreases and at idle it increases with B100. CO and HC emissions decreases with B100 at almost all engine speeds excluding at slow speeds.

Figure 2 also shows CO, NOX , HC and smoke emission index for D2 and B100 at idle and full load. The ratio of corresponding emission(ppm/BU) to the corresponding fuel consumption rate (Kg/h) is known as emission index. As NO_x emission increases with increasing engine speeds while opposite for NO_x emission index. With increasing engine speed CO emission and CO emission index decrease slightly while HC emission and HC emission index are almost same.

At idle CO and HC emission indices are higher than that at full load. The CO emission index at idle with B100 is approx 55% higher than that for D2 while difference in HC emission index is negligible.

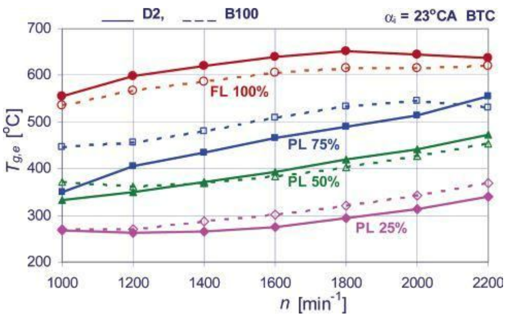

Fig.3 : Influence of fuel on exhaust gas temperature at partial loads

Figure 3 shows that Tg,e with B100 at PL 25%, 50% and 75% is higher than that for D2 at almost all engine speeds. At FL D2 has higher Tg,e .

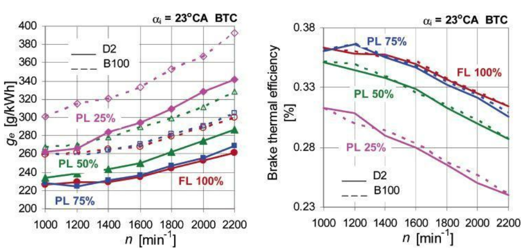

Fig.4 : Influence of fuel on specific fuel consumption and brake thermal efficiency at partial loads

Figure 4 shows that SFC (ge) with B100 is higher at all engine speeds while BTE is same for D2 as well as B100. SFC ge increases with small engine loads and higher engine speeds while opposite for BTE.

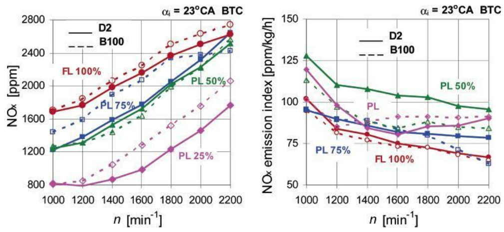

Fig.5 : Influence of fuel on NO_x emission at partial loads

Figure 5 shows that with B100 NO_x emission is higher at all loads excluding 50% load where NO_x emission is almost same for D2 and B100. As already discussed with respect to fuel consumption rate NO_x emission index decreases with increasing engine speed at almost all engine loads. At 50% PL, NO_x emission index is higher with D2 at several engine speeds however at all other loads differences between D2 and B100 are lower.

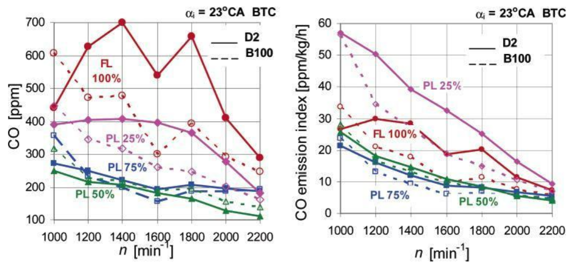

Fig.6 : Influence of fuel on CO emission at partial loads

Figure 6 shows that CO emissions with B100 are higher than D2 for slow engine speeds while at other speeds CO emissions for B100 are lower than D2 especially for 100% and 25% loads. Lowest CO emissions are achieved at 75% and 50% loads with D2 and B100. CO emissions are lower at 50% for D2.CO emission and CO emission index increases at 25% PL than 50% and 75%PL.

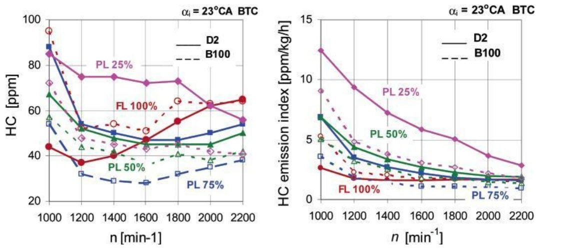

Fig.7 : Influence of fuel on HC emission at partial loads

Figure 7 shows that HC emissions with B100 are always lower at PL than D2 excluding FL.At full load opposite trend is seen. HC emission index is increased at PL.

Figure 8 shows smoke level is higher with B100 at slower engine speeds for 25%PL only. Smoke level increases for increasing loads. Since B100 has more oxygen than D2 therefore B100 has lower smoke emissions.

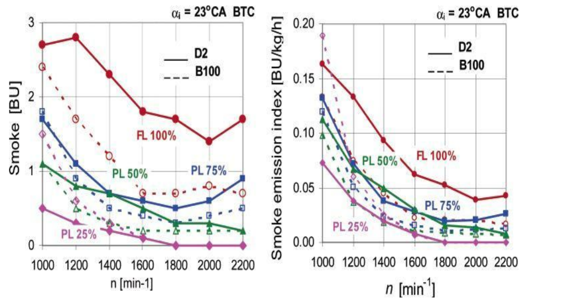

Fig.8 : Influence of fuel on smoke emission at partial loads

5. RESULT

With achieved results it can be seen that effect of fuels on engine characteristics depends upon engine loads and speeds.

At 25% PL with D2 NOX emissions obtained its lowest value.

At 75% PL with B100 for medium engine speeds CO emissions achieved its lowest value while at other speeds D2 at 50%PL gives lowest CO emissions.

At 75% PL with B100 for all engine speeds HC emissions achieved its lowest value.

At 25%PL with D2 smoke emissions achieved its lowest value.

5.1 Effect of Variable Injection Timing on Engine Characteristics

Effect of injection-pump timing on engine characteristics is tested with B100 fuel. Engine is tested for pump timing α_i (°CA BTC) in degree of crankshaft angle before top centre as 23, 21, 20, 19, 18 and 17 °CA BTC.

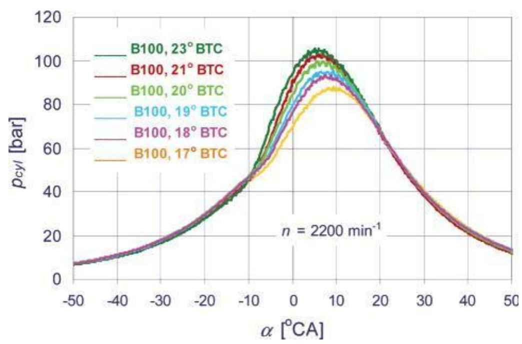

Fig.9 : Influence of injection pump timing on cylinder pressure at rated conditions

Figure 9 shows the effect of these pump timings on the pressure in the cylinder. With the retarded injection timing, injection occurs closer to the compression stroke therefore max in-cylinder pressure decreases and peak is shifted from top centre.

Figure 10 shows Tg,e at idle and FL conditions. Tg,e is lowest at αi = 19°CA BTC and αi = 20°CA BTC for idle and full load. Same is for ge.

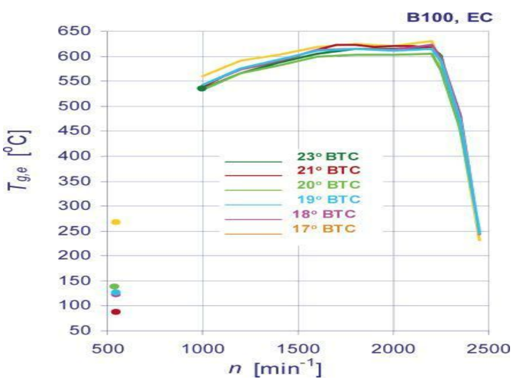

Fig.10: Influence of injection pump timing on Tg,e at idle and full load

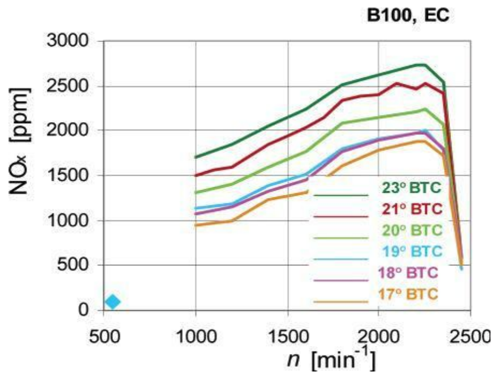

Fig.11: Influence of injection pump timing on NOX emission at idle and full load

Figure 11 shows decrement in NO_X emissions till αi = 19°CA BTC.Further retarding shows minor effect.

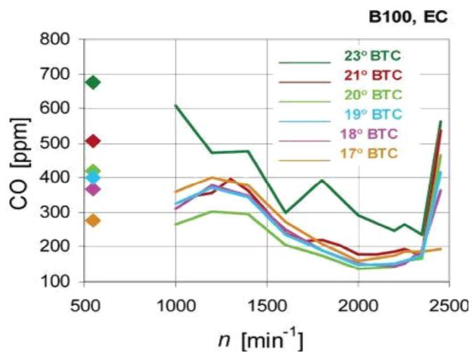

Fig.12: Influence of injection pump timing on CO emission at idle and full load

Figure 12 shows CO emissions decrement at idle condition till αi = 19°CA BTC but CO increases for αi less than 20°CA BTC.For αi between 19° and 20° CA BTC ge and CO emissions have its minimum value.

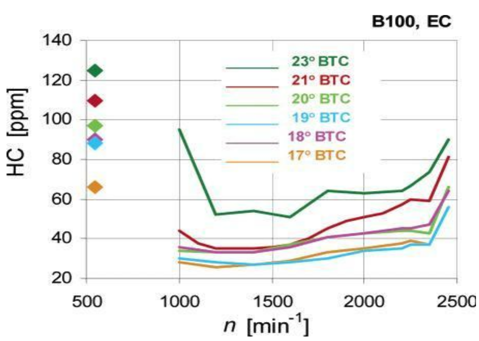

Fig.13: Influence of injection pump timing on HC emission at idle and full load

Figure 13 shows that HC emissions decreases till αi =19°CA BTC and then increment in HC emissions.

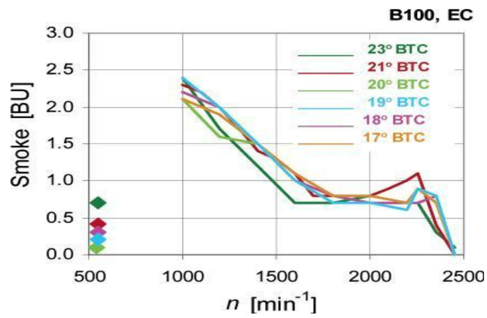

Fig.14: Influence of injection pump timing on smoke emission at idle and full load

Figure 14 shows that smoke increases more or less in general while retarding the αi .

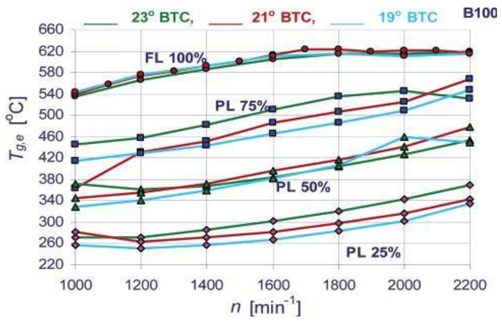

Fig.15: Influence of injection pump timing on $T_{g,e}$ at partial loads

Figure 15 shows Tg,e for three different angles and four loads.

At 25% , 50%, 75% PL and 100% FL Tg,e varies about 37°C, 29°C, 55°C and 7°C respectively. At all loads Tg,e is lowest at αi = 19°CA BTC.

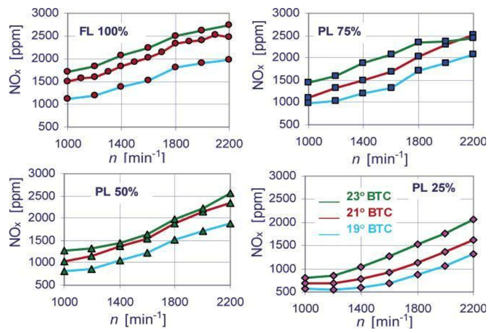

Fig.16: Influence of injection pump timing on NO_X emission at partial loads

Figure 16 shows that At all loads NO_X emissions decreases for decrement in αi. At 25 %PL, 75%PL and 100%FL differences in NO_X emissions are approx 695ppm while at 50%PL, 510ppm.

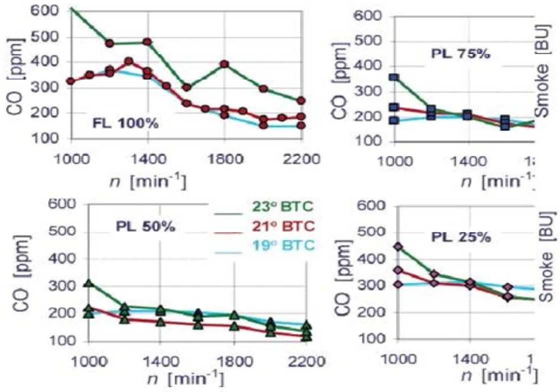

Fig.17: Influence of injection pump timing on CO emission at partial loads

Figure 17 shows that at full load pump-timing has most effect where a difference in CO emissions is approx 196ppm while at partial loads minor effect can be seen.

Figure 18 shows that at full load effect of injection timing is significant for HC emissions while at partial loads minor effect can be seen. At 75% PL HC emissions shows its lowest value. At smaller loads HC emissions are higher and increases when injection timing is shifted from optimum.

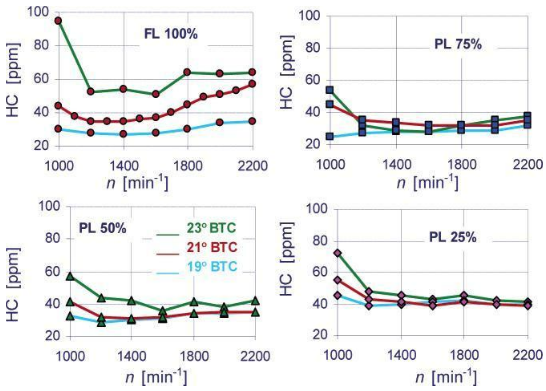

Fig.18: Influence of injection pump timing on HC emission at partial loads

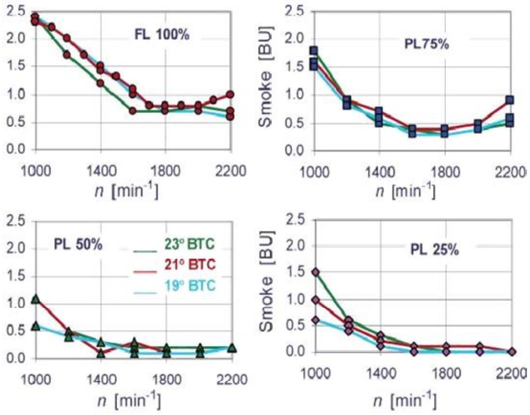

Fig.19: Influence of injection pump timing on smoke emission at partial loads

Figure 19 shows that smoke emissions decreases with smaller loads. At 25% PL smoke decreases with decrement in injection timings while at 100% FL smoke increases.

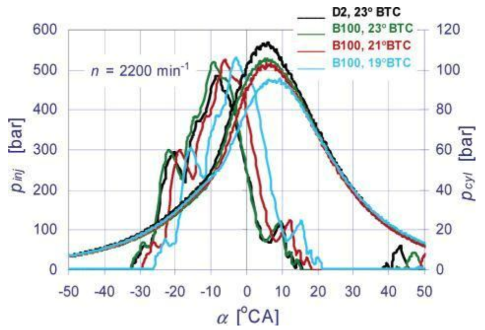

Fig. 20: Injection and in cylinder pressures by fuels with different pump timings

Figure 20 shows that Peak injection pressure for B100 is higher than D2 while peak in-cylinder pressure is highest for D2. Peak injection pressure is shifted towards TC with B100 when injection timing is decreased while peak in cylinder pressures are decreasing.

According to this investigation, retarded injection timing has a considerable effect on start of combustion and air-fuel mixture thus on all engine performances.

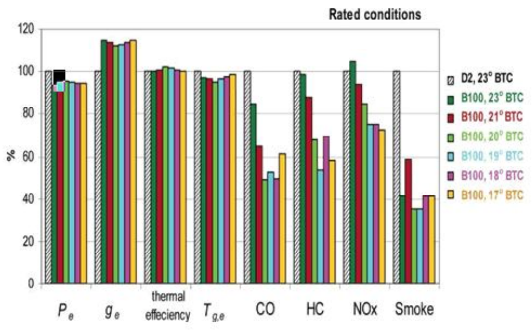

Fig.21: Influence of injection pump timing and fuel on engine characteristics at rated conditions

Figure 21 shows a comparison between Pe, ge, BTE, Tg,e, CO, HC, NO_X and smoke at rated conditions for D2 at recommended injection timing with B100 at different injection timings.

Figure 22 shows a comparison between Pe, ge, BTE, Tg,e, CO, HC, NO_X and smoke at peak torque conditions for D2 at recommended injection timing with B100 at different injection timings.

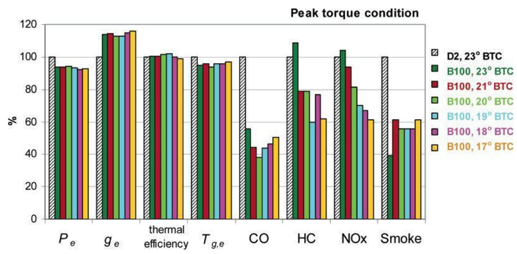

Fig.22: Influence of injection pump timing and fuel on engine characteristics at peak torque

Figure 23 shows a comparison between Pe, ge, BTE, Tg,e, CO, HC, NO_X and smoke at 75% PL and at 1600rpm for D2 at recommended injection timing with B100 at different injection timings. In this case CO emissions increases with decreased injection timings.

As can be seen with obtained results that a compromise is reached with optimization of injection timing at αi =19 °CA BTC for Pe, ge, BTE, Tg,e ,CO, HC, NO_X and smoke at several engine loads and speed conditions.

5.2 Optimized Injection Timing and Discussion

Figures 21-23 shows that for B100, the minimal ge is obtained with αi =19 °CA BTC.

Figure 23 shows that at ái =19 °CA BTC max cylinder pressure is decreased approx 14 bar compared to D2 with αi = 23 °CA TDC.

Figures 10, 15 and 21-23 shows that temperatures of exhaust gases are also at low levels.

On the basis of this investigation the injection timing αi =19 °CA BTC is the best injection timing for 6R1080TA diesel engine and biodiesel fuel produced from Jatropha. All emission levels and emission indices are essentially reduced. As per obtained results biodiesel used shows itself attractive fuel in future as alternate fuel. During test engine is ran with B100 fuel for approx one week and engine performed completely normally.

6. CONCLUSION

This investigation is done on Kirloskar 6R1080TA diesel engine with direct-injection system with a recommended injection timing of αi= 23 °CA TDC for D2 fuel.

Biodiesel used is neat biodiesel B100 produced from Jatropha oil. To investigate optimal injection timing for B100, attention is focused on harmful emissions keeping other engine performances parameters within acceptable limits. As per results following conclusions can be made:

1. All engine characteristics at all engine conditions changes significantly when D2 fuel is replaced by B100.
2. These variations depend upon the injection timing.

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3. At optimal injection timing for B100 all harmful emissions are reduced while Pe, ge, Tg,e, cylinder pressure and other engine characteristics are kept within acceptable limits.

4. Optimized injection timing as αi = 19°CA BTC for B100 fuel shows reduction in CO and NOx , HC and smoke emissions approx 25% and 25%, 30%, 50% repectively. Reduction in CO and smoke emission indexes are not so significant while HC and NOx emission indexes are reduced by 40%.

5. Due to lower heating value of B100 fuel, Pe is reduced approx 5.5% and ge is increased approx 9%, while the thermal efficiency is almost same for D2 and B100 fuels.

6. Tg,e and in-cylinder pressures is lower than D2 fuel.

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