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COMBINED EFFECT OF EXHAUST GAS RECIRCULATION (EGR) AND FUEL INJECTION PRESSURE ON CRDI ENGINE OPERATING WITH JATROPHA CURCAS BIODIESEL BLENDS

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Abstract

This work investigates the influence of Exhaust gas recirculation (EGR) and injection pressure on the performance and emissions of CRDI engine using Jatropha curcas biodiesel blends of 10% and 20% (B10 and B20). Experiments were carried out for three fuel injection pressures (FIP) of 300, 400 and 500 bar with 15% and 20% EGR rate at constant speed of 2000 rpm and standard injection timing of 15^0 BTDC. Parameters like brake thermal efficiency and emission characteristics such as smoke opacity, oxides of nitrogen (NOx), hydrocarbon (HC) and carbon mono-oxide (CO) were measured and analysed. The results showed improvement of performance in terms of brake thermal efficiency for blends B10, B20 and with 15%EGR rate. Smoke, HC and CO decreased while slightly increasing NOx emissions when working with biodiesel. In summary, it is optimized that engine running with combination of B20 blend and 15% EGR rate culminates into NOx reductions without affecting engine efficiency and other emissions like smoke opacity, hydrocarbon and carbon mono-oxide.

Keywords: CRDI Engine, Biodiesel blends, EGR, Injection pressure, Emissions.

1. Introduction

In the present scenario biodiesel has received more attention as an alternative energy source for engines mainly for two reasons, first due to diminishing of crude oil sources and secondly to relieve the strain generated on the pollution by transportation sector which has grown very significantly so that the stringent emission norms implemented by the policy makers of environmental division are met [1, 2]. Biodiesel produced by transesterification process is biodegradable, nontoxic and has properties similar to the fossil diesel fuel, Biodiesel may be used in C I engines without any major modification, Many researchers in this area have evaluated that biodiesels exhibit confining engine performance characteristics to conventional diesel with lower harmful exhaust emissions like UBHC, CO, smoke from diesel engines with slight increase of NOx emissions, this impediment can be overcome by using some in cylinder processes like EGR technique, FIP and fuel injection timing optimization which limits emission to an acceptable level [1-4].

The present engine operating parameters are standardised for fossil diesel only, for any other fuel, optimization of the operation parameters have to be carried out with the view of specific fuel properties [4]. FIP is one of the most important operating parameter that plays a very pivotal role in engine performance and emission compared to other parameters [4-6], hence literature survey has been carried in this area and summarised.

Labecki and Ganippa [1] experimented with multi-cylinder turbo-charged diesel engine at 1500 rpm for different FIP with rapeseed biodiesel. They reports that higher FIP reduced soot emission but increased NOx for biodiesel blends compared to diesel. It is concluded that combination of EGR and the injection timing can lower NOx emissions at the cost of CO, UBHC. Agarwal et al. [6], investigated the effects of FIP on CRDI engine with karanja biodiesel (KOME) blends at a constant engine speed. From experimental studies it is reported that BTE of biodiesel blends is higher compared to neat diesel. Lower BSCO and BSHC emissions with KOME10, KOME20 were noticed compared to diesel and KOME50. However higher BSNOx trend is observed with all blends compared to diesel, General trend is that increasing FIP improves the performance.

Sahoo et al. [7], have made Comparative evaluation of performance and emission characteristics for three cylinder tractor engine with ten fuel blends. Methyl esters of non-edible based oil like Jatropha curcas, karanja and polanga (B20, B50 and B100) were tested for different throttle position and engine speeds. The maximum increase in power is observed for 50% jatropha biodiesel with lower HC emission at rated speed. Also the reduction in smoke for all the blends is reported as compared with diesel. Gumus et al. [8], used Lombardini single cylinder engine fuelled with biodiesel blends, from emission analysis it was observed that NOx value increased, whereas smoke opacity, CO and UBHC decreased. Varying FIP results showed that increased injection pressure lowers HC CO and smoke opacity. Similar studies have been done by various researchers including Puhan et al. [9], Can et al. [10] Bakar et al. [11], using various biodiesels.

Exhaust gas recirculation is one of the in cylinder combustion technology to reduce NOx emission from C I engines which lowers the in cylinder temperatures during combustion due to thermal, chemical and dilution effects [12]. Saleh [13] in his studies used the Jojoba methyl ester (JME) as a renewable fuel in two cylinder diesel engine. The investigation was oriented to determine the quantity of exhaust gas recirculation (EGR). The test results show that EGR is an impressive technique to reduce NOx emissions for diesel engines with very little penalty of fuel economy. Agarwal et al. [14] evaluated the drawback of more NOx emissions while employing biodiesel which can be expelled by using EGR.

Simultaneous application of EGR with biodiesel blends resulted in lower NOx emissions with minimum loss in fuel economy.

From the literature survey it is clear that limited work has been done on CRDI engine operating with biodiesel blends, EGR and different FIP. Therefore, the main objective of this experimental study is to analyse the effect of various fuel injection pressures with different levels of EGR and engine load conditions in order to understand the performance, emission and combustion characteristics of Jatropha curcas biodiesel blends in a CRDI diesel engine at constant speed.

2. Experimental Apparatus and Procedure

The experiments were conducted on a Twin cylinder four-stroke CRDI diesel engine with constant speed of 2000rpm. Detailed specifications of the engine are shown in Table 1. Load measurement has done with eddy current type dynamometer coupled directly to engine output shaft and 75%, 100% load is applied during experimentation. Experimental setup of test bench is shown in Fig. 1, which is provided with necessary instruments for combustion pressure and crank-angle measurements. Airflow, fuel flow, temperatures and load measurement are interfaced with computer. The panel box attached to setup consists of fuel tank, air box, manometer, air and fuel flow measurements transmitters. LabVIEW based engine Performance analysis software package “Enginesoft” is provided for online performance evaluation.

The engine exhaust emissions carbon dioxide (CO_2), nitrgen oxides (NOx), carbon monoxide (CO), and unburnt Hydrocarbons (UBHC) were measured using an AVL DI Gas 444 five gas analyser. CO and CO_2 were determined as percentage volumes and NOx, HC were in ppm and the smoke opacity was measured using the AVL 415SE smoke meter which measures soot concentration. Jatropha curcas is chosen as biodiesel for blending with diesel and blending has been done by volume basis in which 10% referred as B10, similarly B20. 15% and 20% exhaust gas recirculation ratio is applied for all blends and different loading conditions. Fuels used in experimental investigation have been tested for various properties as per ASTM standards and listed in the Table 2.

In exhaust gas recirculation (EGR) process, Fraction of exhaust gases are cooled by using heat exchanger which is directly connected in the exhaust line and then this cooled exhaust gas is sent to intake manifold where it mixes with fresh air and enters the engine cylinder. The rate of exhaust gas being re-circulated is calculated by the concentrations of carbon dioxide (CO_2) in intake and exhaust gas using the formula [15, 16].

$$EGR\% = \frac{(CO_2\%)_{\text{int}}}{(CO_2\%)_{exh}} x100$$

where $(CO_2)_{\text{int}}$, $(CO_2)_{\text{ext}}$ are CO_2 concentration at intake and exhaust of the engine.

All the experimental values of the test rig were noted under steady state engine operating conditions. Performance and exhaust emissions obtained with the biofuel blends are analysed and presented in graphs.

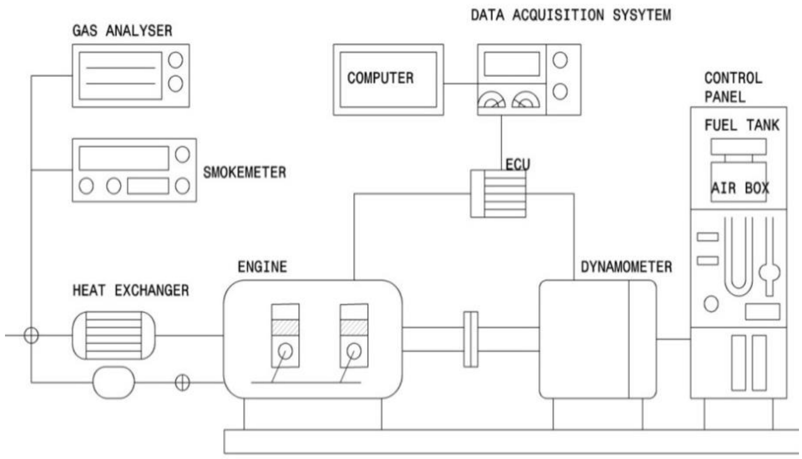

Fig. 1. Experimental set up.

Table 1. Engine specifications.

Parameter	Details
Engine make and Model	Mahindra Maxximo, CRDI
Type	Twin cylinder, four stroke
Stroke x bore	83×84 mm
Power rating	18.4 kW at 3600 rpm
Compression ratio	18.5
Aspiration	Natural aspiration
Cooling system	Water cooled
Dynamometer	Eddy current type with loading unit

Table 2. Fuel properties.

Parameter	Diesel	B10	B20
Lower calorific value (MJ/kg)	42.06	40.650	40.200
Density (kg/m^3)	830	841	847
Kinematic viscosity (cSt)	3.40	3.70	3.85
Flash point (^{0}C)	74	80	84
Fire point (^{0}C)	81	86	89

3. Results and Discussion

The experiments were conducted for initial conditions of 300 bar FIP, 15^0 BTDC for 75% and 100% loading conditions for diesel fuel without EGR. These results were considered as baseline results (represented by Zero line in all graphs). The next set of experiments continued using B10, B20 Jatropha curcas biodiesel blends with application of 15% and 20% EGR rate. Three fuel injection pressures 300, 400 and 500 bar were applied using common rail direct injection system, and then obtained data was compared against the initial engine operating conditions (Zero line) which represents the results in change in percentile.

3.1. Brake thermal efficiency (BTE)

The performance change in terms of brake thermal efficiency (BTE) is as shown in Fig. 2. For initial experimentation with 300 bar FIP for 75% and 100% load, the addition of blends B10,B20 has shown improvement in brake thermal efficiency by 1.9% (B10) and 3.8% (B20) without EGR, compared to mineral diesel as shown with reference fuel (zero axis). This improvement is due to oxygen content of biodiesel which helps in better combustion resulting into higher efficiency; similar trend of results for jatropha curcas blends are reported by authors [7, 16-19] and also with other biodiesel blends by authors [6, 13, 20].

Further when EGR rates of 15% and 20% are applied for blends B10 and B20 at same condition of 300 bar FIP, a slight increase in efficiency is observed with 15% EGR for both blends at 75% and 100% load. The maximum increase in performance is noticed for B20 at 15% EGR, 75% loading (300 bar FIP) condition which is 6.6% higher compared to diesel. This improvement in brake thermal efficiency with application of EGR may be due to the re-burning of unburnt hydrocarbons which mix with fresh air and entrain into the combustion chamber through the inlet manifold [15, 17]. On the other hand, at 20% EGR a reduction in performance is noticed for 100% loading (300 bar FIP) condition, this is due to reduced oxygen concentration as well decreased volumetric efficiency or breathing capacity of the engine [14].

Later when FIP is increased to 400 and 500 bar, better results of the change in the BTE were obtained with increasing fuel injection pressure for most cases. Here higher FIP atomizes fuel spray into fine droplets which culminates into better and faster combustion due to better air entrainment at higher FIP [1, 6, 21]. Thus, there is an overall positive effect of combining biodiesel blends and EGR at different FIP for all cases at 75% load. Similar observations are made at 100% load except for 20% EGR cases where the BTE is lower than base line diesel fuel. The maximum improvement was observed to be 8.47% and 9.12% at 75%, 100% loads (500 bar FIP) respectively for B20 blend with 15% EGR in comparison with base fuel which is marked as zero line in graph.

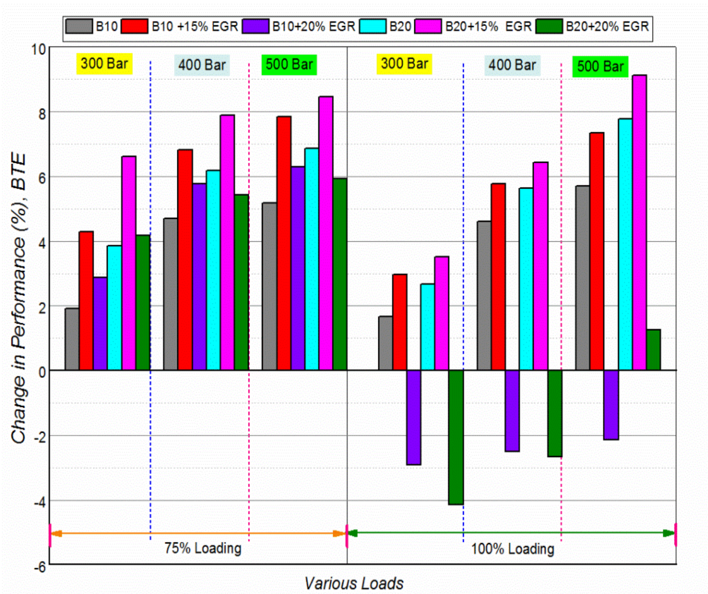

Fig. 2. BTE for 75% and 100% loads at 300, 400 and 500 FIP.

3.2. Oxides of nitrogen (NOx)

NOx emissions in the engine exhaust increases with increase of biodiesel ratio in the fossil diesel fuel. The additional fuel borne oxygen in biodiesel increases the flame temperature in combustion chamber due to better combustion and thus inclines to increase the NOx concentration [6, 8, 18]. The highest increase in NOx emissions of 6.8%, 16.6% for B10 blend and 7.7%, 18.7% for B20 blend is observed at 75% and 100% load condition respectively at 300 bar FIP.

Further, the NOx emission level increases with increasing injection pressure from 300 bar to 500 bar for all non-EGR blend cases. This is because of faster combustion and higher cylinder gas temperature of the combustion chamber. The increase in NOx emission at full load condition in comparison with diesel fuel for B10 is found to be 7.8%, 10% and 16.9% for 300, 400 and 500 bar fuel injection pressures. Similarly for B20 blend and for same fuel injection pressure it was found to be 18.7%, 23% and 25.4%.

With the application of 15% and 20% EGR, NOx reduction was observed due to dilution, chemical and thermal effects. At full loads and higher EGR rates, maximum reduction in NOx emission was observed; this is due to less availability of oxygen for combustion to take place resulting in reduced cylinder temperature [13, 14]. Highest NOx reduction of 37% is observed for 20% EGR rate, 300 bar FIP and at full load condition as shown in Fig. 3.

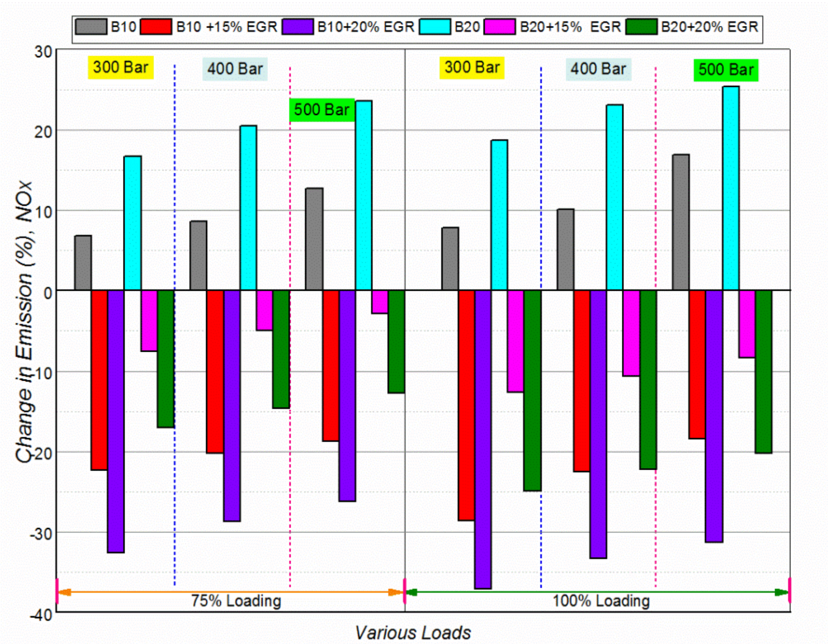

Fig. 3. Oxides of nitrogen for 75% and 100% loads at 300, 400 and 500 FIP.

3.3. Smoke opacity

Smoke opacity of biodiesel blend is predominantly lower than that of diesel. The decrease in smoke opacity is found to be 16% for B10 and 29% for B20 at full load condition. This is due to more oxygen concentration with lower carbon to hydrogen ratio in biodiesel and also the absence of aromatics in biofuel [3, 6, 7, 18] is an added advantage for lower smoke at 300 bar FIP compared to baseline diesel value.

In regard to fuel injection pressure, it was revealed that as FIP increases smoke level steadily decreases. This was mainly due to smaller particle diameter of injected fuel which results in improved mixture formation [8]. At full load condition, smoke level decreased by 35% for B20 blend at 500 bar FIP.

With the application of EGR rate, results obtained were in dual mode. Slight increase in smoke emission was observed at lower FIP condition but at higher FIP and for 15% EGR rate smoke emission was decreased compared to baseline value. With 20% EGR application smoke level observed to be higher compared to baseline value, This due to fact that higher EGR rate reduces availability of oxygen for the combustion of fuel [14], which results in relatively incomplete combustion and greater origination of smoke as shown in Fig. 4. For full load condition, the maximum increment is about 21% for B10 at 20% EGR and 300 bar FIP. For the same load condition, the maximum decrement in smoke level is observed to be 16.1% for B20 at 500 bar FIP and 15% EGR. Thus net effect of combining jatropha biodiesel blends with 15% EGR and 500 bar FIP will reduce the smoke level compared to baseline.

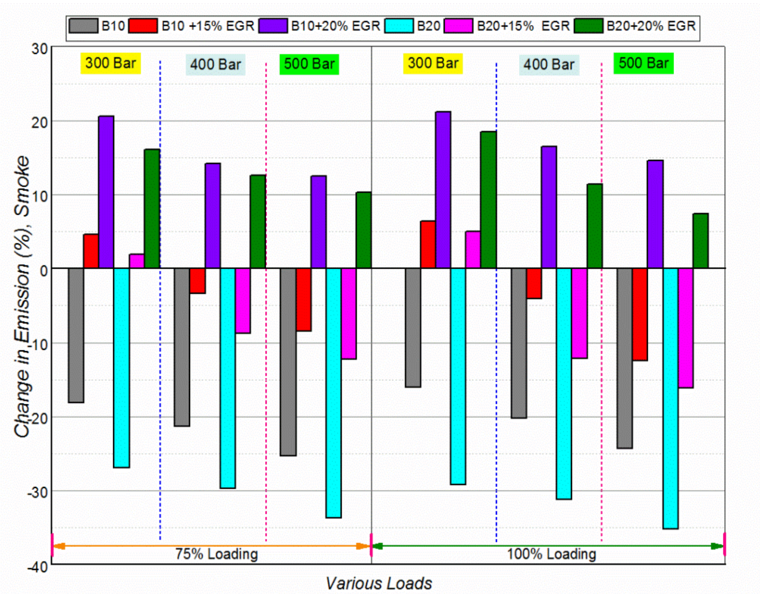

Fig. 4. Smoke emission for 75% and 100% loads at 300, 400 and 500 FIP.

3.4. Hydrocarbon and carbon monoxide

Blending diesel with biodiesel decreases the HC and CO emissions, the decrease level vary with volume of blends. Higher the blend ratio lowers the emission. The maximum decrement at 300 bar FIP is found to be 33% (HC), 16.7% (CO) for B20 blend at full load condition. The hydrocarbon and carbon monoxide emissions level is reduced due to addition of blended fuel and this is the implication of adding oxygenate fuels which can decrease HC from the locally over rich mixture [3]. Moreover oxygen enrichment is also favourable to the oxidation process of HC and CO during expansion and exhaust processes.

The HC, CO emissions are reduced with increase of FIP from 300 bar to 500 bar because of better combustion [1, 3, 8, 21] as shown in Figs. 5 and 6. The max decrement is found to be 45% (HC) and 46% (CO) for B20 blend at 500 bar FIP full load.

With the introduction of EGR at lower FIP, HC and CO emissions were higher than the baseline diesel for all load conditions. Whereas at higher FIP and 15% EGR rate, HC and CO emissions are lower than the baseline diesel value. However at 20% EGR rate, increase in HC, CO emissions is observed at all load conditions. With increase of EGR rate in the inlet air, the engine starts operating with the richer mixture which results in poor air utilization by the fuel leading to increased CO and HC emissions [1]. Thus maximum reduction is achieved by combining 15% EGR and 500 FIP compared to baseline diesel value (zero axis line) for all jatropha blends. CO and HC emission reduced by 29% and 7.5% for B20 blend with 15% EGR at 100% Load and 500 bar FIP.

3.5. In-cylinder pressure

Figure 7 shows the in cylinder pressure history for various crank angle degree (CAD) during combustion for 20% biodiesel blend with 15% and 20% EGR rates. The combustion pressure inside the cylinder is indication of how well a fuel can react and burn by mixing with air.

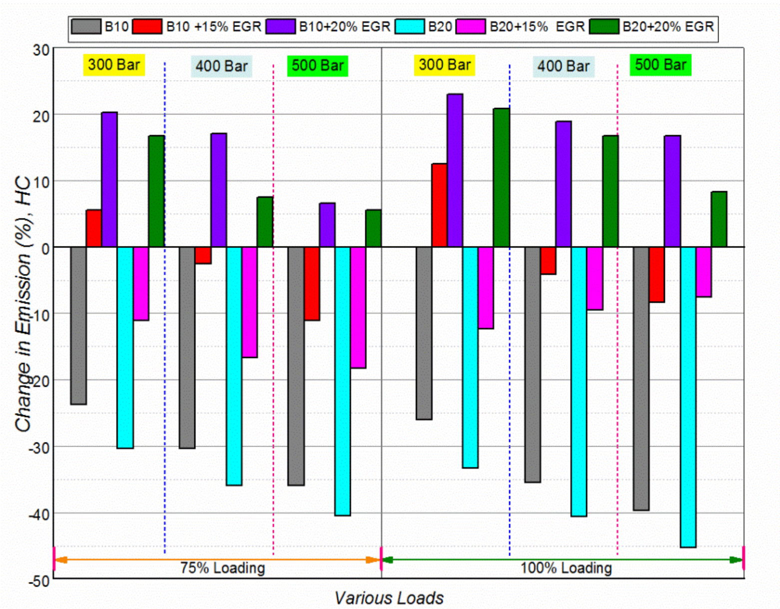

Fig. 5. HC emission for 75% and 100% loads at 300, 400 and 500 FIP.

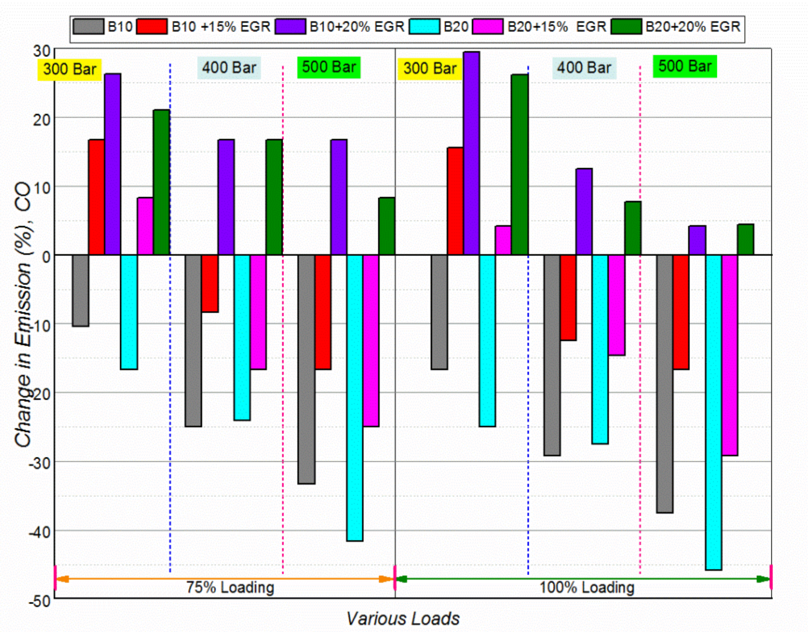

Fig. 6. CO emission for 75% and 100% loads at 300, 400 and 500 FIP.

Biodiesel has higher peak pressure in comparison with the diesel fuel, this may be due to shorter ignition delay which is a result of higher cetane index of Jatropha curcas blend and hence more fuel burnt in diffusion stage combustion. From observation of pressure vs CAD, the difference in peak or maximum in cylinder pressure for different fuels is very minimal such results actually indicate better conversion efficiency of heat energy of a fuel into actual mechanical one for reformed fuel. Maximum peak pressure of 82 bar is observed for B20 blend due to better combustion because of more amount oxygen in the fuel [8]. With the application of EGR rates 10%, 20% and 30% for B20 blend there is a decrease in peak pressure of the fuel [1]. This reduction is may be due to dilution, chemical, thermal and ignition delay effect.

3.6. Net heat release rate (NHRR)

The net heat release trends for diesel and B20 blend for various EGR rates is as shown in Fig. 8. The calculation of net heat release (NHR) is an effort to get more information in relation to combustion process inside the cylinder. Moreover, physical and chemical properties of the fuel used for experimentation affect the heat release rate. Peak value for NHRR is observed to be 77.87 (J/CAD) for B20 blend and appears earlier than other fuel conditions, this is due to better combustion of fuel borne oxygen. With respect to application of EGR rate, the NHRR is lesser because EGR may lead to formation of low temperature flames and also the increased concentration of CO_2 and H_2O in the mixture will lead to slower reaction rate [1]. Hence combination of low temperature combustion and reduced O_2 concentration during combustion period may have resulted in slow formation and propagation of flame rates, resulting in decrease of net heat release rates compared to B20 blend without EGR conditions.

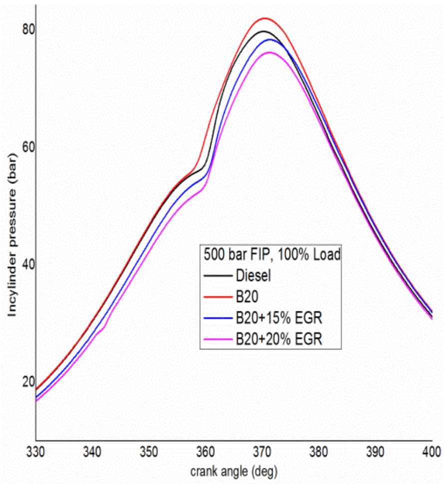

Fig. 7. In cylinder pressure vs. CAD.

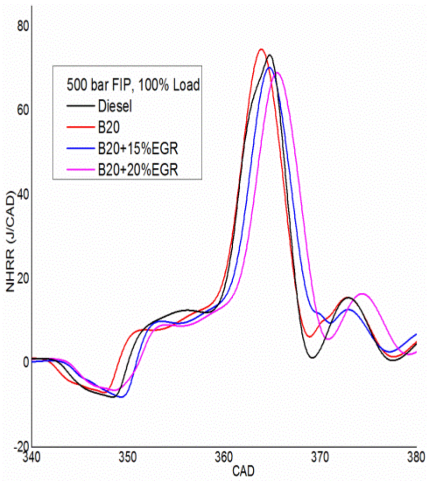

Fig. 8. NHRR vs. CAD.

4. Conclusions

Based on the experimental investigations the following conclusions have been drawn:

- Jatropha curcas biodiesel blend up to 20% can be used in CRDI engine.
- Increasing of blend concentration (up to B20) and fuel injection pressure improves the brake thermal efficiency and decreases smoke, hydrocarbon, carbon monoxide with increase in NOx emissions.
- Net effect of combining biodiesel blend (B20), EGR (15%) and higher fuel injection pressure (500bar) gives better performance with reduced emissions compared against reference fuel (diesel) operating conditions.
- The improvement in performance is observed to be higher by 8.47% and 9.12% at 75%, 100% loads (500 bar FIP) respectively for B20 blend with 15% EGR in comparison with base fuel which is marked as zero line in graph.
- The maximum reduction in smoke opacity, CO and HC emission level is observed to be 16.1%, 29% and 7.5% respectively with B20 at 500 bar FIP and 15% EGR for 100% Load.
- At 20% EGR, reduction in performance, marginal increase of CO, HC and smoke is observed, on contrary highest NOx reduction of 37% (300 bar FIP) occurred at full load condition.
- Maximum peak pressure of 82 bar and peak NHRR 77.8 (J/deg) occurred for B20 blend due to better combustion because of more amount oxygen in the fuel.

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