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Experimental Analysis of Exhaust Gas Recirculation on DI Diesel Engine Operating with Biodiesel

V.Manieniyan[1] , S.Sivaprakasam[2]
[1]Department of Mechanical Engineering, Directorate of Distance Education, Annamalai University,
[2]Department of Mechanical Engineering, Annamalai University, Annamalainagar, 608 002, Tamil Nadu, India

ABSTRACT

Automobile Emission is one of the major problems in environment. Engine emits the carbon monoxide (CO), hydrocarbon (HC), Nitrogen oxides (NOx) and smoke density etc. NOx emission leads to dangerous effect in the environment. NOx can travel long distances, causing a variety of health and environmental problems in locations far from their emissions source. These problems include ground level ozone and smog, which are created in the atmosphere by the reaction of nitrogen oxides and hydrocarbons in the presence of sunlight. Various methods are used to reduce the Nox emission. In the present work Exhaust gas recirculation (EGR) technique is used the diesel engine with B20 biodiesel as fuel. Madhua oil is used to prepare the biodiesel in this present work. Experiments are conducted in a single-cylinder, four-stroke, water-cooled, direct-injection diesel engine coupled to an Eddy current Dynamometer with EGR and without EGR at various level (5%, 10%, 15%, and 20%). The result shows that NOx emission is reduced using EGR for diesel and bio diesel.

Keywords: *Biodiesel, combustion, EGR, Emission.*

1. INTRODUCTION

The diesel engines dominate the field of commercial transportation and agricultural machinery due to its ease of operation and higher fuel efficiency. The consumption of diesel is 4-5 times higher than petrol in India. Due to the shortage of petroleum products and its increasing cost, efforts are on to develop alternative fuels especially, to the diesel oil for fully or partial replacement. It has been found that the vegetable oils are promising fuels because their properties are similar to that of diesel and are produced easily and renewably from the crops. Vegetable oils have comparable energy density, cetane number, heat of vaporization and stoichiometric air–fuel ratio with that of the diesel fuel. None other than Rudolph Diesel, the father of diesel engine, demonstrated the first use of vegetable oil in compression ignition engine in 1910. He used peanut oil as fuel for his experimental engine [1]. So the use of vegetable oils as alternative fuels has been around for one hundred years when the inventor of the diesel engine Rudolph Diesel first tested peanut oil, in his compression-ignition engine.

Biodiesel is a renewable fuel which is free from sulfur and aromatic compounds. Biodiesel does not overburden the environment with CO_2 emission as CO_2 from the atmosphere is absorbed by the vegetable oil crop during the photosynthesis process, while the plant is growing. Hence biodiesel offers net CO_2 advantage over conventional fuels. The use of biodiesel in diesel engines does not require any hardware modification [2]. Exhaust gas recirculation is an effective method for NOx control. The exhaust gases mainly consist of inert carbon dioxide, nitrogen and possess high specific heat. When recirculated to engine inlet, it can reduce oxygen concentration and act as a heat sink. This process reduces oxygen concentration and peak combustion temperature, which results in reduced NOx. EGR is one of the most effective techniques currently available for reducing NOx emissions in internal combustion engines. However, the application of EGR also incurs penalties. It can significantly increase smoke, fuel consumption and reduce thermal efficiency unless suitably optimized. The higher NOx emission can be effectively controlled by employing EGR [3].

Results indicated higher nitric oxide (NO) emissions when a single cylinder diesel engine was fuelled with JBD, without EGR. NO emissions were reduced when the engine was operated under HOT EGR levels of 5–25%. However, EGR level was optimized as 15% based on adequate reduction in NO emissions, minimum possible smoke, CO, HC emissions and reasonable brake thermal efficiency. Smoke emissions of JBD in the higher load region were lower than diesel, irrespective of the EGR levels. However, smoke emission was higher in the lower load region. CO and HC emissions were found to be lower for JBD irrespective of EGR levels. Combustion parameters were found to be comparable for both fuels [4].

The aim of this study mainly was to quantify the efficiency of exhaust gas recirculation (EGR) when using JME fuel in a fully instrumented, two-cylinder, naturally aspirated, four-stroke direct injection diesel engine. The tests were made in two sections. Firstly, the measured performance and exhaust emissions of the diesel engine operating with diesel fuel and JME are determined and compared. Secondly, tests were performed at two speeds and loads to investigate the EGR effect on engine performance and exhaust emissions including nitrogenous oxides (NOx), carbon monoxide (CO), unburned hydrocarbons (HC) and exhaust gas temperatures. Also, effect of cooled EGR with high ratio at full load on engine performance and emissions was examined. The results showed that EGR is an effective technique for reducing NOx emissions with JME fuel especially in light duty diesel engines. A better trade-off between HC, CO and NOx emissions can be attained within a limited EGR rate of 5–15% with very little economy penalty[5].

A single cylinder diesel engine was converted to operate on hydrogen-diesel dual fuel mode. Hydrogen was injected in intake port and diesel was injected directly inside the cylinder. The injection timing and injection duration of hydrogen were optimized initially based on the performance and emissions. It was observed that start of injection at 5° before gas exchange top dead center (BGTDC) and injection duration of 30° crank angle gives the best results. The flow rate of hydrogen was optimized as 7.5 lpm for the best start of injection and injection duration of hydrogen. Cold exhaust gas recirculation technique was adopted for the optimized injection parameter of hydrogen and flow rate. Maximum quantity of exhaust gases recycled during the test was 25% beyond this the combustion was not stable resulting in increase in smoke [6].

An experimental study has been conducted on a 2.0 l HSDI automotive diesel engine under low-load and part load conditions in order to distinguish and quantify some effects of EGR on combustion and NOx / PM emissions. The increase of inlet temperature with EGR has contrary effects on combustion and emissions, thus sometimes giving opposite tendencies as traditionally observed, as, for example, the reduction of NOx emissions with increased inlet temperature. For a purely diffusion combustion the ROHR is unchanged when the AFR is maintained when changing in-cylinder ambient gas properties (temperature or EGR rate). At low-load conditions, use of high EGR rates at constant boost pressure is a way to drastically reduce NOx and PM emissions but with an increase of brake-specific fuel consumption (BSFC) and other emissions (CO and hydrocarbon), whereas EGR at constant AFR may drastically reduce NOx emissions without important penalty on BSFC and soot emissions but is limited by the turbo charging system [7].

The present investigation was to study the effect of cooled exhaust gas recirculation (EGR) on four stroke, single cylinder, and direct injection (DI) diesel engine using 100% waste plastic oil. Experimental results showed higher oxides of nitrogen emissions when fueled with waste plastic oil without EGR. NOx emissions were reduced when the engine was operated with cooled EGR. The EGR level was optimized as 20% based on significant reduction in NOx emissions, minimum possible smoke, CO, HC emissions and comparable brake thermal efficiency. Smoke emissions of waste plastic oil were higher at all loads. Combustion parameters were found to be comparable with and without EGR. Compression ignition engines run on waste plastic oil are found to emit higher oxides of nitrogen [8].

When similar percentages (% by volume) of exhaust gas recirculation (EGR) are used in the cases of diesel and RME, NOx emissions are reduced to similar values, but the smoke emissions are significantly lower in the case of RME. The retardation of the injection timing in the case of pure RME and 50/50 (by volume) blend with diesel results in further reduction of NOx at a cost of small increases of smoke and fuel consumption [9]

2. MEASUREMENT OF EXHAUST GAS RE-CIRCULATED AIR

Part of the exhaust gas is to be recirculated and put back to the combustion chamber along with the intake air. The quantity of this EGR is to be measured and controlled accurately; hence a by-pass for the exhaust gas is provided along with the manually controlled EGR valve. The exhaust gas comes out of the engine during the exhaust stroke at high pressure. It is pulsating in nature. It is desirable to remove these pulses in order to make the volumetric flow rate measurements of the recirculated gas possible. For this purpose, another smaller air box is installed in the EGR route. An orifice meter is designed and installed to measure the volumetric flow rate of the EGR. A U-tube manometer is mounted across the orifice in order to measure the EGR flow rate.

EGR ratio is calculated as:

$$\text{EGR}\ (\%) = \frac{M_{\text{EGR}}}{M_{\text{i}}} \times 100$$

Where

M_{EGR} = mass of recirculated gas
M_i = mass of total intake air of the cylinder

3. EXPERIMENTAL SETUP

The engine used for the investigation is a four stroke, water cooled, single cylinder, direct-injection (DI), vertical diesel engine running at a rated power of 5.2 kW and at a rated speed of 1500 rpm shown in fig 1. The specifications of the test engine are shown in Table 1. In the experimental is work conducted at two phase. The first phase is to analysis of the performance, combustion and emissions of the diesel and biodiesel (B20) engine without EGR are studied. In second phase with EGR is using diesel and Biodiesel (20) are studied. The engine was run by using diesel and biodiesel with 5% EGR, 10% EGR, 15% EGR and 20% EGR. In both phase readings are taken in 20%, 40%, 60%, 80% and 100% load. . The emissions like HC, CO, NOx are measured in the AVL DI gas analyzer and smoke density is measured by smoke meter. The exhaust gas temperature is measured using thermo couple. Using AVL combustion analyzer the combustion parameter such as cylinder pressure, heat release and cycle to cycle variation are with pure diesel and bio-diesel.

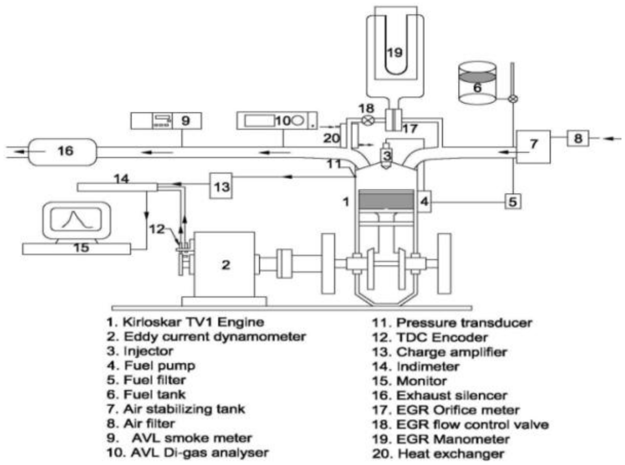

Fig 1 Test Engine

4. RESULTS AND DISCUSSION

In this experiment performance parameters such as specific fuel consumption and brake thermal efficiency, were determined, combustion parameter cylinder pressure, heat release rate were determined, and emissions such as oxides of nitrogen, carbon monoxide, hydrocarbon, smoke density and exhaust gas temperature were measured.

4.1 Specific Fuel Consumption

For diesel and bio diesel, the variation of specific fuel consumption with brake power was shown in Fig 2 and 3. Specific fuel consumption without EGR, under full load was found to be 0.2779 kg/kW-hr for diesel and 0.2794 kg/kW-hr for bio diesel. Full load values of diesel with 5%, 10%, 15%, and 20% EGR were 0.2853, 0.2796, 0.2832 and 0.3050 kg/kW-hr respectively whereas it was 0.2791, 0.2889, 0.2975, and 0.3103 kg/kW-hr for bio diesel. For higher level of EGR 20%, specific fuel consumption increased for both diesel and biodiesel. Slightly higher values of biodiesel were due to lower calorific values and higher viscosity, density and boiling point.

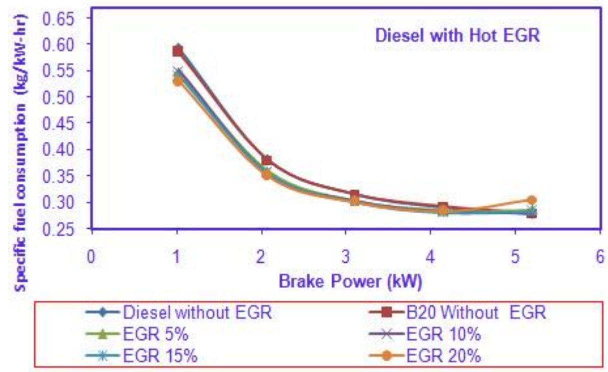

Fig 2 specific fuel consumption (Diesel) Vs Brake power

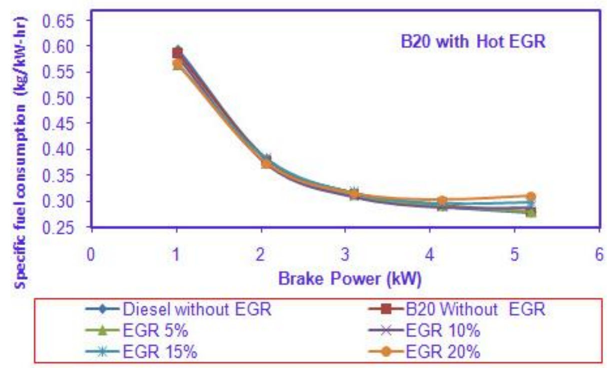

Fig 3 specific fuel consumption (B20) Vs Brake power

4.2 Brake Thermal Efficiency

Figures 4 and 5 indicate the variation in brake thermal efficiency with brake power. Brake thermal efficiency with and without EGR was found to be comparable for diesel and bio diesel. Full load brake thermal efficiency of 29.006% was obtained for diesel without EGR whereas it was 29.4933% using biodiesel without EGR. Brake thermal efficiency at 40% load was also comparable for diesel and bio diesel. Brake thermal efficiency of 20% EGR was maximum for different loads (except at full load) when compared with diesel and biodiesel. This is probably due to increased combustion velocity because of higher intake charge temperature with EGR. With dissociation of carbon monoxide, free radicals were formed. This can also be a cause for improvement in efficiency. In full load 20% EGR, brake thermal efficiency was reduced by 1.5% in diesel and biodiesel. More exhaust gases produced due to predominant dilution effect of EGR in combustion chamber results in efficiency drop.

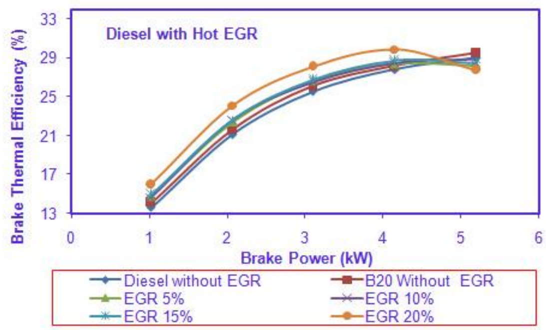

Fig 4 Brake thermal efficiency (Diesel) Vs Brake power

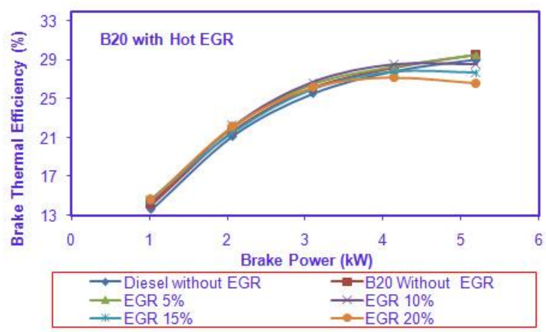

Fig 5 Brake thermal efficiency (B20) Vs Brake power

4.3 Hydro Carbon

Fig. 6 and 7 depicts the variation of hydrocarbon with brake power. With increase in EGR levels, HC emission also increases for biodiesel. This was due to oxygen content in biodiesel compensating for oxygen deficiency and facilitating complete combustion. In Full load condition HC emission was measured as 35 ppm in diesel and 37 ppm in biodiesel without EGR. At the same full load condition with higher EGR level HC emission varies from 35 to 66 ppm in diesel and 37 to 76 ppm in bio diesel. This is due to richer mixture at full load and oxygen deficiency might have dominated as EGR was applied.

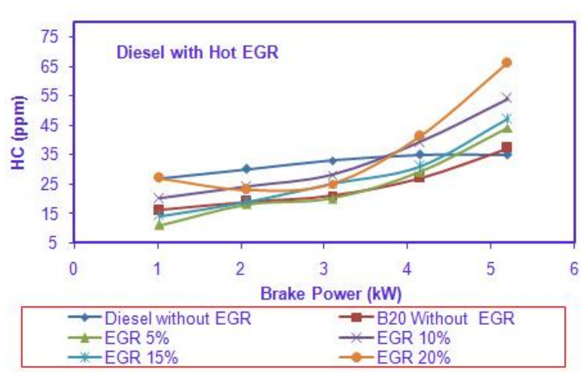

Fig 6 Hydro carbon (Diesel) Vs Brake power

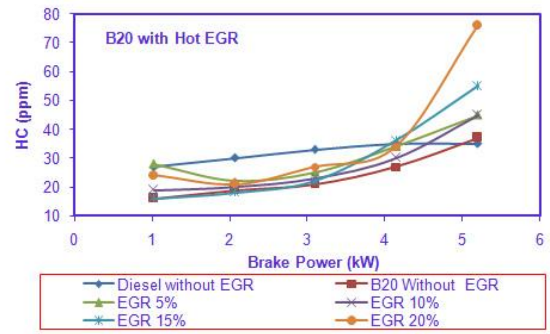

Fig 7 Hydro carbon (B20) Vs Brake power

4.4 Oxides of Nitrogen

Figures 8 and 9 indicate the variation of nitrogen oxide with brake power. NOx value was found to be 736 ppm for diesel and 796 ppm for biodiesel without EGR at full load condition. This was due to peak combustion temperature inside the cylinder. With increases in EGR level, the NOx value gets reduced. With 20% EGR, NOx levels were 157 ppm for diesel and 158 ppm for biodiesel. With increase in EGR level NOx level was reduced. Also reduction in brake thermal efficiency and large increase in smoke density were observed.

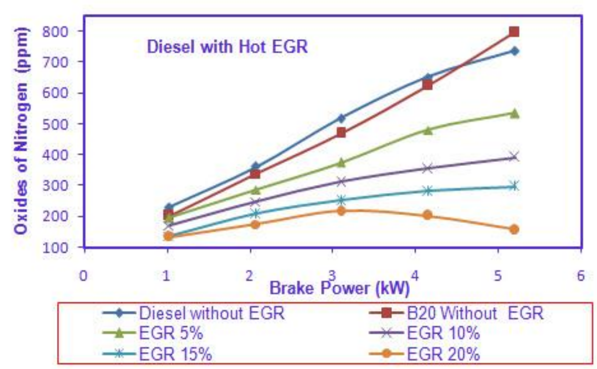

Fig 8 oxides of Nitrogen (Diesel) Vs Brake power

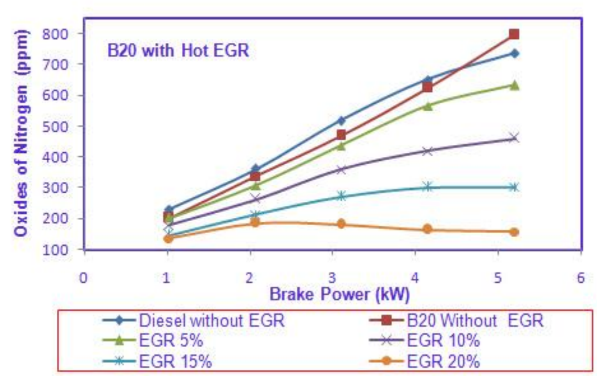

Fig 9 oxides of Nitrogen (B20) Vs Brake power

4.5 Carbon Monoxide

Fig. 10 and 11 depicts the variation in CO levels for diesel and biodiesel operation with various EGR levels for different load conditions. CO level for diesel varies from 0.14 (% by volume) for diesel and 0.18 (% by volume) for biodiesel at full load without EGR. In lean mixture condition engine emits less amount of carbon monoxide. In the case of 20% level EGR CO emission was 0.84 (% by volume) for diesel and 0.93 (% by volume) for biodiesel at full load. This increase in CO emission with EGR might be due to oxygen deficient operation. At 5% EGR for biodiesel a favorable reduction in CO emission can be seen at all loads.

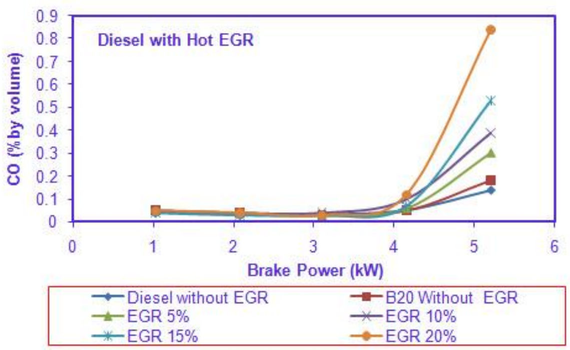

Fig 10 Carbon monoxide (Diesel) Vs Brake power

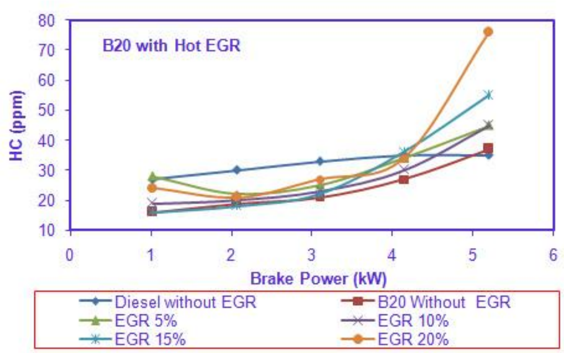

Fig 11 Carbon monoxide (B20) Vs Brake power

4.6 Smoke Density

Variation of smoke density with brake power was shown in fig 12 and 13. Without EGR smoke density was found to be lower for biodiesel compared to diesel for all loads. Presence of oxygen in biodiesel structure can significantly contribute to the reduction in smoke emission for all loads. As EGR level increases, smoke density also increases. In full load condition smoke density was 95.4 HSU for diesel and 99.3 HSU for bio diesel at 20% EGR level. EGR reduces availability of oxygen for combustion of fuel which results is relatively incomplete combustion and increased formation of particulate matter. This results in higher smoke level in case of EGR.

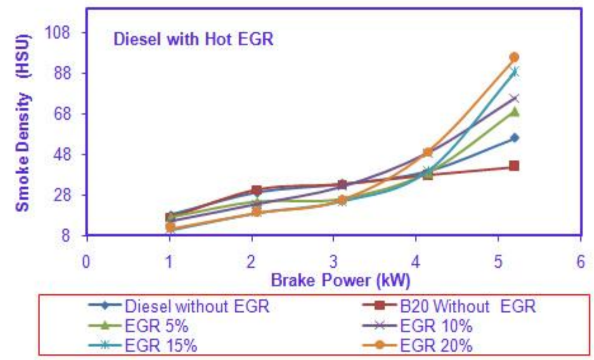

Fig 12 Smoke density (Diesel) Vs Brake power

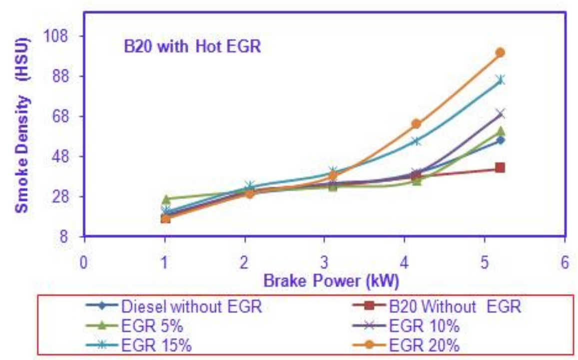

Fig 13 Smoke density (B20) Vs Brake power

4.7 Exhaust Gas Temperature

The variation of exhaust gas temperature with brake power is shown in Fig. 14 and 15. It was observed that with increase in load, exhaust gas temperature also increases. With EGR, exhaust gas temperature was higher in biodiesel compare with diesel at all load conditions. The possible reason for this temperature increased may be relatively higher availability of oxygen in biodiesel for combustion.

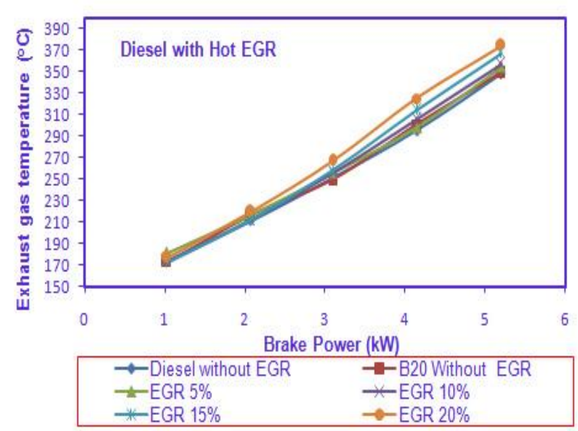

Fig 14 Exhaust Gas Temperature (Diesel) Vs Brake power

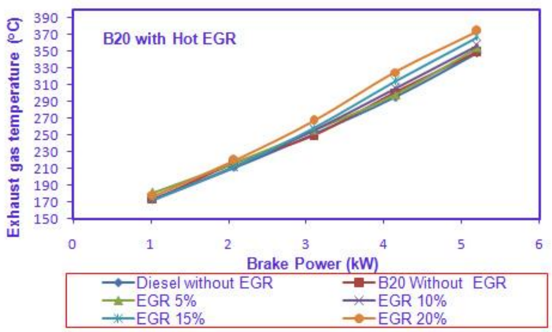

Fig 15 Exhaust Gas Temperature (B20) Vs Brake power

4.8 Cylinder Pressure

Fig. 16 and 17 indicates the cylinder pressure variation with brake power. Cylinder pressure at full load and without EGR condition was found to be comparable for diesel and bio-diesel. Peak pressure was found to be 70.392 bars for diesel and 70.252 bars for bio-diesel under these conditions. This is due to good mixture formation for bio-diesel at higher loads where temperatures are high. At full load values of diesel with 5%, 10%, 15%, and 20% EGR were 68.502, 67.140, 66.960 and 66.033 bars respectively whereas it was 69.189, 66.578, 65.810 and 62.730 bars for bio diesel. This is because the EGR serves as a heat absorbing agent, which reduces the cylinder charge temperature in the combustion chamber during the combustion process.

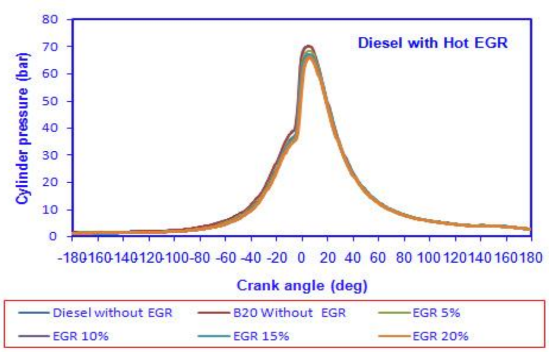

Fig 16 Cylinder pressure (Diesel) Vs Brake power

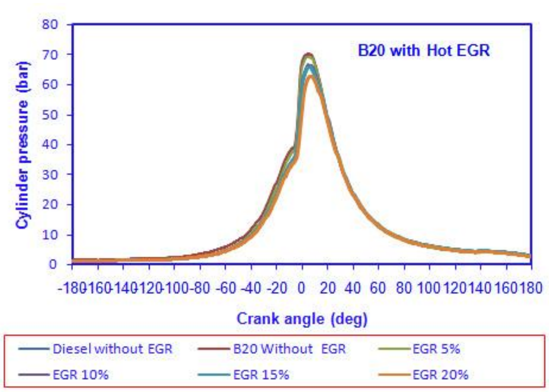

Fig 17

4.9 Heat Release Rate

Fig 18 and 19 shows the heat release rate and brake power. At full load condition heat release rate was 115.139 kJ/m^3 for diesel and 94.331 kJ/m^3 for biodiesel without EGR. There is a reduction in peak heat release rate for EGR operation. Decrease in heat release rate is indicative of incomplete combustion due to presence of less oxygen content when using EGR.

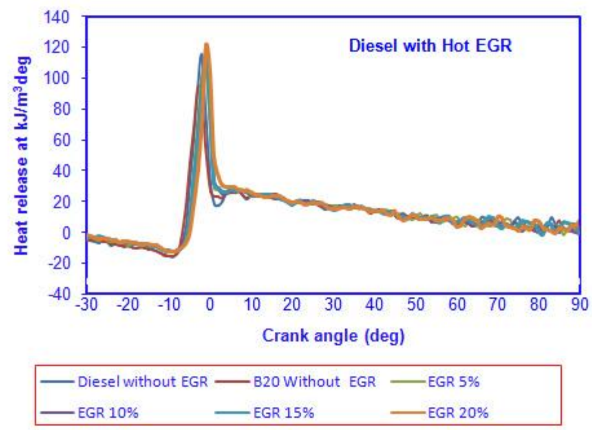

Fig 18 Heat Release rate (Diesel) Vs Brake power

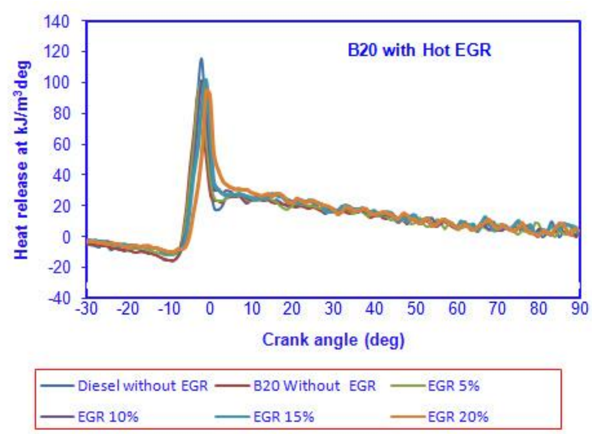

Fig 19 Heat Release rate (B20) Vs Brake power

5. CONCLUSION

The following conclusions are made on the basis of experimental results.

- Specific fuel consumption was lower in 20% EGR with diesel and 10% EGR with Biodiesel compare without EGR.
- Brake thermal efficiency of biodiesel was found to be comparable with diesel, at all loads with and without EGR.
- The EGR level was increased HC emission also increased for biodiesel. This was due to oxygen

content in biodiesel compensating for oxygen deficiency and facilitating complete combustion.

- In all load 20% EGR level NOx was reduced in both diesel and biodiesel. With increases in EGR level, the NOx value gets reduced.

- In EGR CO emission increases due to oxygen deficient operation but still at low level compared to diesel operation without EGR.

- The smoke level increased for biodiesel without EGR compared to neat diesel operation. When EGR was used smoke level increased. EGR reduces availability of oxygen for combustion of fuel, which results in higher smoke level.

- Analysis of combustion parameters have also indicated comparable heat release rates cylinder pressures, and with and without EGR.

Thus the present experimental analysis on a single cylinder diesel engine with diesel and biodiesel blend has proved minimized pollution and improved performance. EGR technique is used for reduction of NOx concentration.

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