The Effect of Exhaust Gas Recirculation and Di-Tertiary Butyl Peroxide on Diesel-Biodiesel Blends for Performance and Emission Studies

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Abstract

The combined effect of EGR and cetane improver can effectively reduce the Nitrogen Oxides (NO_x) emissions by reducing the combustion temperatures, since NO_x formation is a temperature dependent phenomenon in diesel engines. In the present work, experimental investigations were carried out on a single cylinder four stroke naturally aspirated direct injection air cooled diesel engine with exhaust gas recirculation and cetane improver Di Tertiary Butyl Peroxide (DTBP) as an additive to diesel-biodiesel blends. The combined effect of EGR and DTBP on Brake Thermal Efficiency(BTE), Brake Specific Fuel Consumption (BSFC), cylinder pressure and exhaust emissions is studied. From experimental results it is found that an EGR percentage of around 15% results in maximum BTE and minimum BSFC. It is also found that the combined effect of EGR and cetane improver reduces the NO_x emissions by 25% with a slight increase in Carbon Monoxide (CO), Hydro Carbon (HC) and smoke opacity.

Keywords*: biodiesel, cetane improver, DTBP, EGR, emissions*

1. Introduction

The formation of NO_x emissions in diesel engines is predominant when the temperature in the combustion chamber is high, since at higher temperatures the tendency of nitrogen to react with oxygen causes the NO_x to increase. Many authors reported that biodiesel has the oxygen content which aids in better combustion and reduced emissions of engine exhaust except NO_x emissions [1-5]. This problem can be overcome by using the NO_x reduction techniques like exhaust gas recirculation which is recirculation of a part of the exhaust gases into intake which aids in reducing the NO_x [6]. The researchers have used EGR in diesel engines for the reduction of NO_x emissions. Jatropha Bio Diesel (JBD) which was considered as a potential alternative to diesel produced the higher NO_x in diesel engines like other biodiesel fuels [7]. However JBD combined with EGR operation in diesel engines can reduce NO_x emissions considerably [8]. Sunflower methyl ester biodiesel blend B20 combined with EGR 15% produces 25% less NO_x emissions compared to diesel fuel with an increase in brake thermal efficiency and BSFC [9]. In order for cleaner emissions as is required by emission standards like EURO-V, higher EGR levels can be an effective way [10]. However higher EGR rates are responsible for increased particulate and unburned hydrocarbon (UHC) emissions [11-13]. An alternative to the higher EGR may be the EGR with the proper injection timing and injection pressure which can reduce the NO_x emission with a trade-off on smoke and efficiency. Retarded injection timing with higher injection pressure is the optimum combination for controlling the NO_x emission with lesser effect on smoke density and efficiency [14]. Biodiesel with fuel additives improves the performance of diesel engines and reduces the emissions including NO_x [15]. Hence to reduce the negative effect of the higher EGR on performance and other emissions, biodiesel with fuel additives in combination with the EGR can be a viable alternative since the additives improve the lubricity, ignition and better mixing. In that, oxygenates are the candidates for reducing the particulates since they contain the oxygen content which aids in better combustion and reduced exhaust emissions[16-21]. The addition of Di Methyl Carbonate (DMC) to diesel fuel increases the efficiency marginally with reduction in NO_x emissions while PM and soot emissions were reduced considerably [22, 23]. However the low cetane number and high latent heat of vaporization while low viscosity and insufficient lubricity of DMC are the limiting factors of DMC as an additive [24]. Additives like Diethylene Glycol Dimethyl Ether and liquid cerium showed significant improvements in BSEC and exhaust emissions [25]. Coated engines with the additives exhibited improved efficiency, in addition to the increase in cylinder pressure, reduction in NO_x and reduction in maximum heat release rate. Thermal Barrier Coated (TBC) DI diesel engine with the fuel additives (di iso propyl ether) reduced the smoke density and NO_x emission of the engine exhaust [26]. 1-4 dioxane, an ether derived from alcohol as an additive to the diesel fuel reduced smoke density with slight increase in NO_x and drop in fuel economy. Brake thermal efficiency is improved marginally and smoke reduced significantly with the blends when compared to neat diesel for TBC engines [27]. Cetane improvers reduce the ignition delay, aid in better cold starting, reduced NO_x emissions, and smoother engine operation [28, 29]. Ignition delay in engines also plays an important role in combustion performance and reducing all regulated and unregulated emissions [30, 31]. The cetane improver with oxygenate such as glycol ether reduced particulate, HC, and CO emissions [32]. Ethanol-diesel blends with the Ethyl Hexyl Nitrate(EHN) as an additive increased BTE and reduced significantly the emissions like CO, Total Hydro Carbon(THC), smoke, and particulates in Common Rail Direct Injection(CRDI) diesel engine and also decrease cylinder pressure, ignition delay, the maximum rate of pressure rise, and the combustion noise[33]. Ethanol-diesel blends with cetane improver with advanced fuel injection angle showed a large decrease in exhaust smoke concentration and a small decrease in exhaust NO_x concentration [34].

The objective of this study is to investigate the performance, combustion and emission characteristics of a diesel engine with diesel-biodiesel blends with the cetane improver DTBP as an additive under different EGR conditions.

2. Experimental Set-Up and Procedure

2.1. Experimental Set-up

The experimental set-up as shown in Figure 1, is a computerized single cylinder four stroke, naturally aspirated direct injection and air cooled diesel engine. The specifications of the test engine are given in Table 1. The engine is loaded with an eddy current dynamometer (080CN). The engine is equipped with an AVL GH12D miniature pressure transducer for measuring the pressure variation in the cylinder and AVL 615 Indimeter software which measures the heat release rate from the measured values of cylinder pressure at different crank angles. An AVL five gas analyzer (FGA512) is used for measuring the CO, HC and NO_x, while AVL smoke meter (OMS103) is used for measuring the smoke opacity. For circulation of the exhaust gases into the intake manifold, an EGR set up is provided which consists of a control valve and a manometer. This engine is used for the evaluation of the performance, combustion and emission characteristics of diesel and diesel-biodiesel blends with DTBP.

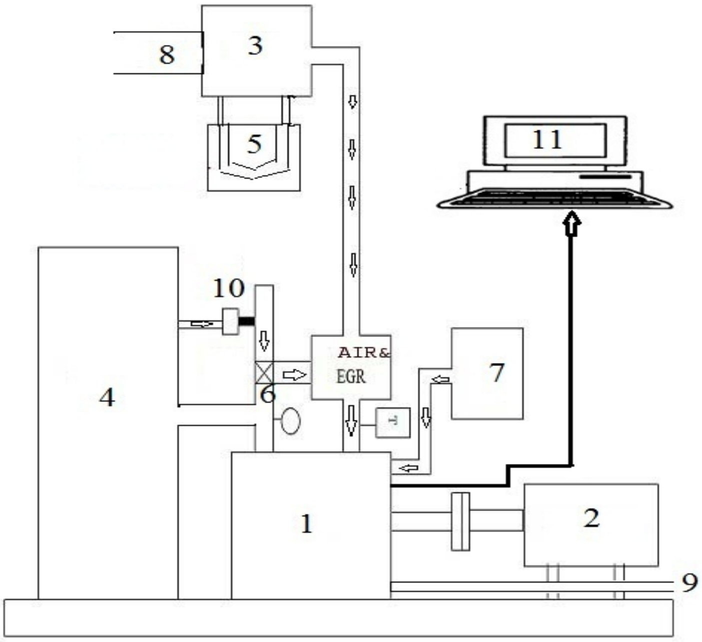


Figure 1. Schematic Diagram of Experimental Set Up. (1) Test Engine; (2) Dynamometer; (3) Air Tank; (4) Exhaust Gas Drum; (5) U-Tube Manometer: (6) EGR Valve; (7) Fuel Tank; (8) Orifice; (9) Exhaust Gas Analyzer; (10) Exhaust Probe; (11) Computer

Table1. Specifications of the Test Engine

Particulars	Specifications
Make	Kirloskar
Rated power	4.4 kW
Bore	87.5 mm
Stroke length	110 mm
Swept volume	0.661 L
Compression ratio	17.5:1
Rated speed	1500 rpm
Injector operating pressure	210 bar
Connecting rod length	220 mm
Start of injection	24.9 ^{0} bTDC

Figure 2. Photograph of the Experimental Set-up

2.2. Test Fuels

For experimental investigation, biodiesel derived from fish oil is added to diesel in varying proportions such as B20, B30 and B40 (*i.e.,* B20 implies biodiesel 20% by volume) and cetane improver DTBP (chemical formula $C_8H_{18}0_2$) is added as 0.5% to diesel-biodiesel blendes. The percentage of DTBP used in this study is 0.5% based on the literature since higher percentages can increase particulates and also cause smoke emissions to increase [27,35]. Diesel- biodiesel blends with cetane improver are designated as B20D0.5 B30D0.5, B40D0.5 (*i.e.,* B20D0.5 implies biodiesel 20% with cetane improver DTBP 0.5%). The properties of test fuels are given in Table 2 which compares the properties of neat diesel and blends with DTBP 0.5%.

Table 2. Properties of Test Fuels

Property	Diesel	B20D0.5	B30D0.5	B40D0.5
Flash Point (°C)	60	37	39	41
Fire point (°C)	62	43	45	47
Density (g/cm^3)	0.83	0.84	0.845	0.849
Kinematic Viscosity (C.S)	3.15	5.14	5.43	5.72

2.3. Experimental Procedure

For experimentation the engine is run at a rated speed of 1500 rpm and an injection advance of 24.9^0.The engine is allowed to run till the warm-up period is reached. Then the engine is loaded in terms of 0%, 25%, 50%, 75% and 100% corresponding to the brake mean effective pressures of 0.9, 1.8, 2.7, 3.62 and 4.52 bars. At each load, the engine is run at a constant speed of 1500 rpm and an injection advance of 24.9^0 with different EGR conditions. The exhaust gases are tapped from exhaust pipe and connected to an inlet airflow passage. A system is devised consisting of a control valve and a manometer set up to control the rate of EGR by manually operating the control valve. After attaining the steady state, the observations are made for various parameters such as exhaust gas temperature, airflow rate, fuel consumption, brake specific fuel consumption, combustion characteristics like pressure rise which are recorded through the data acquisition system which converts analog to digital at various loads. Exhaust emissions CO, HC and NO_x are recorded simultaneously by the flue gas analyzer while smoke density was measured with smoke meter. In this study, the effect of fuel blends (with DTBP) and EGR on engine performance and emissions are evaluated at an engine speed of 1500rpm. At each load the experiment is conducted by varying EGR rates such as 0%, 10% and 20%. The first stage of the experiment is performed with the pure diesel at different loads from no-load to full load with different EGR rates such as 0%, 10% and 20% respectively at constant speed. The reason why higher EGR rates (beyond 20%) are not considered in this study is the reduction in BTE and an increase in CO, HC and smoke emissions with higher EGR rates. The second stage of the experiment is conducted using diesel-biodiesel blends with cetane improver DTBP as an additive and the same procedure is repeated.

EGR mass fraction is determined using the expression [9]

% EGR = (Mass of air admitted without EGR- mass of air admitted with EGR)/ mass of air admitted without EGR.

3. Results and Discussion

3.1. Performance Analysis

The results obtained by performing experiments using diesel and different blends of biodiesel fuel with cetane improver with a variation in percentage mixture of exhaust gas recirculation are presented in the graphical form. Figure 2 shows the variation of BTE at different EGR by varying the percentage of biodiesel under 50% and 100% load. It is found that brake thermal efficiency increases up to an optimum value of EGR and then decreases. BTE is also found to be increasing with increase in biodiesel at a given EGR percentage. The combined effect of optimum EGR and DTBP can increase the BTE by 6-7%. The reason for increase in BTE with EGR is due to re burning of HC that enters combustion chamber with the recirculation of exhaust gases and also EGR increases intake charge temperature which increases the rate of combustion. Cetane number is an indication of ignition quality of fuel, its increment reduces delay period and leads to better combustion. Figure 3 shows the variation of BSFC with EGR by varying the percentage of biodiesel under 50% and 100% load. It is found that brake specific fuel consumption decreases with increase in EGR and reaches a minimum value at about 10% EGR and then increases slightly up to 20% EGR. Further with increase in biodiesel percentage also BSFC increases. It is due to the fact that Biodiesel blends have less energy content than diesel which causes fuel consumption to increase. Figure 4 shows the variation of exhaust gas temperature with EGR mass fraction. It is found that with increase in percentage of EGR as well as biodiesel, the exhaust gas temperatures reduced. This can be attributed to the oxygen deficient operation under EGR which results in lower combustion temperatures and furthermore specific heat of exhaust gas is more than that of intake air which also contributes to the lower combustion temperatures. This reflects an effective utilization of heat energy.

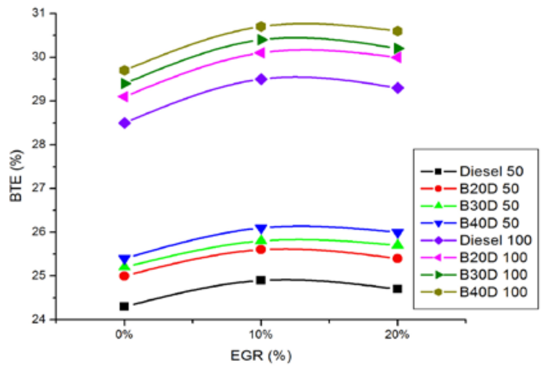


Figure 3. Effect of Exhaust Gas Recirculation on Brake Thermal Efficiency at 50% and 100% Loads

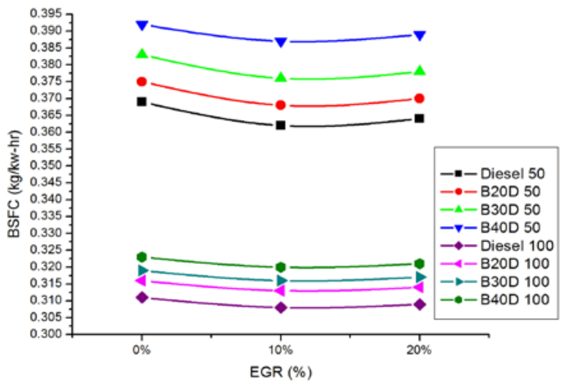


Figure 4. Effect of Exhaust Gas Recirculation on Brake Specific Fuel Consumption at 50% and 100% Load

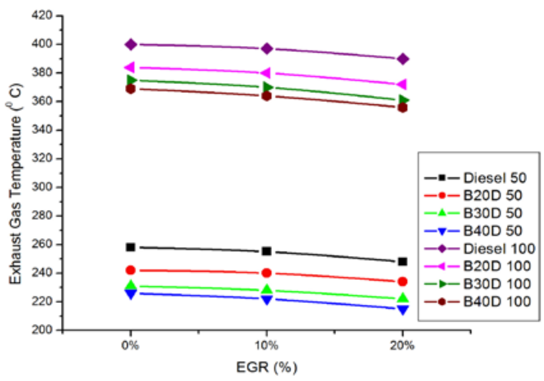
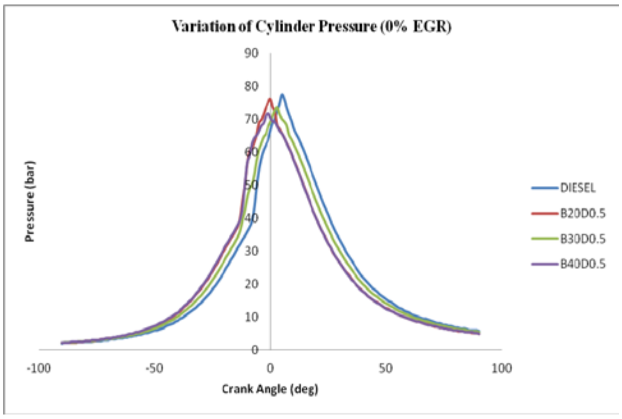


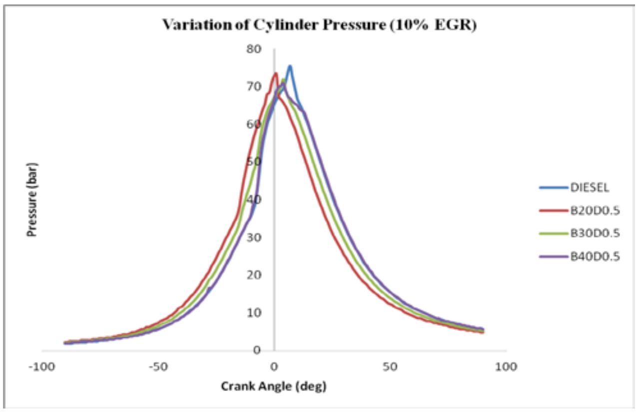
Figure 5. Effect of Exhaust Gas Recirculation on Exhaust Gas Temperature at 50% and 100% Load

3.2. Combustion Analysis

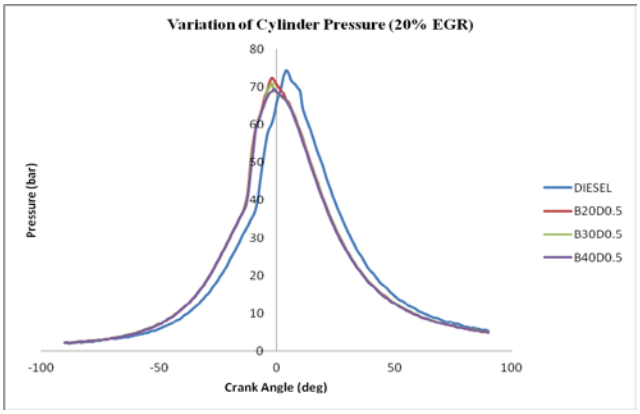
Combustion characteristics results such as cylinder pressure versus crank angle are shown in Figure 6, Figure 6.a, 6.b & 6.c show the variation of cylinder pressure at different crank angle with 0%, 10% and 20% EGR respectively. It can be seen from these figures that the maximum cylinder pressure decreases slightly with the EGR and it can also be seen that the blends ignite earlier and finish the combustion earlier than that of diesel. This may be attributed to the addition of DTBP which decreases ignition delay and reduces the accumulation of unburned fuel in the premixed phase of combustion resulting in reduction of cylinder pressure and delay period, these results are also good in agreement with the literature [8, 19, 36].



6.a)0%EGR



6.b)10%EGR



6.c)10%EGR

Figure 6. Effect of Exhaust Gas Recirculation on Cylinder Pressure at Different Crank Angle

3.3. Exhaust Emission Analysis

The exhaust emission results such as CO, NO_x, HC and smoke opacity of different fuels at different EGR mass fractions are shown in Figures 7-10. Figure 7 shows the variation of CO emissions with increase in percentage of EGR at 50% and 100% loads. It is found that with the increase in the percentage of EGR, CO increases however the effect of CO emission is found less at higher percentages of biodiesel. Further, the emissions are found rapidly increasing with EGR up to 10% and beyond which there is only an insignificant rise. The deficiency of oxygen with the increase in EGR percentage can be attributed to the rapid growth of CO at initial stages of the EGR. However the excess oxygen content in bio-diesel can compensate for the oxygen deficient operation under EGR. Figure 8 shows the variation of NO_x emissions with increase in percentage of EGR at 50% and 100% loads. Figure 8 shows that the combined effect of EGR and DTBP could reduce the NO_x emissions significantly. The reason for reduction in the NO_x with EGR is the reduction of the combustion temperatures as a result of the addition of exhaust gases to the intake air which increases the amount of combustion accompanying gases mainly CO_2 which reduces the combustion temperature. It was shown in literature that higher EGR rates (beyond 20%) are able to reduce NO_x emissions by a large amount, which however is accompanied by a reduction in the BTE and increase in the CO, HC and smoke emissions [4]. Figure 9 shows the variation of HC emissions with increase in percentage of EGR at 50% and 100% loads. It can be seen from the figure that the HC emissions increased slightly from 0% to 10% EGR for all fuels and beyond which there is a reduction. However with the increase in biodiesel percentage, the HC emissions found decreasing. Figure 10 shows the variation of smoke opacity with increase in percentage of EGR at 50% and 100% loads. It shows that the increase in the smoke opacity is insignificant initially and increases with further increase in EGR which also increases with the increase in percentage of biodiesel. This can be attributed to the addition of cetane improver which increases the combustion temperatures and the amount of fuel burned in the diffusive combustion phase resulting in the slight increase of engine smoke.

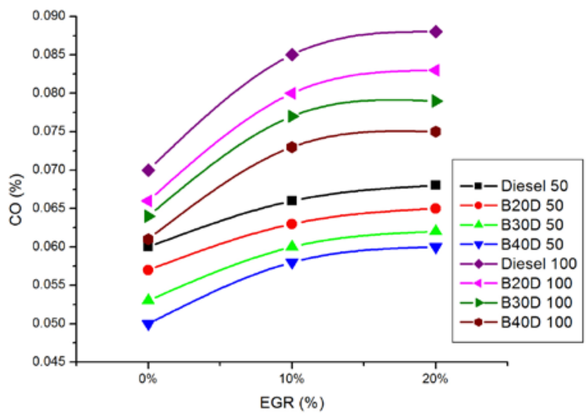


Figure 7. Effect of Exhaust Gas Recirculation on CO Emissions at 50% and 100% Load

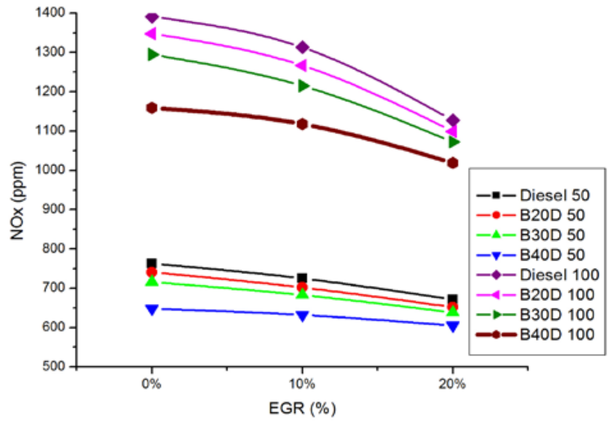


Figure 8. Effect of Exhaust Gas Recirculation on NOx Emissions at 50% and 100% Load

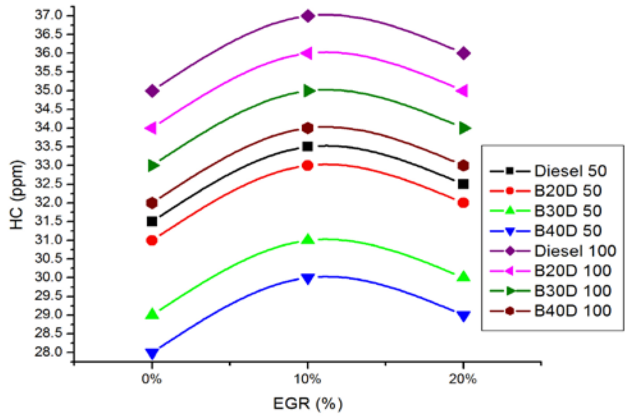


Figure 9. Effect of Exhaust Gas Recirculation on HC Emissions at 50% and 100% Load

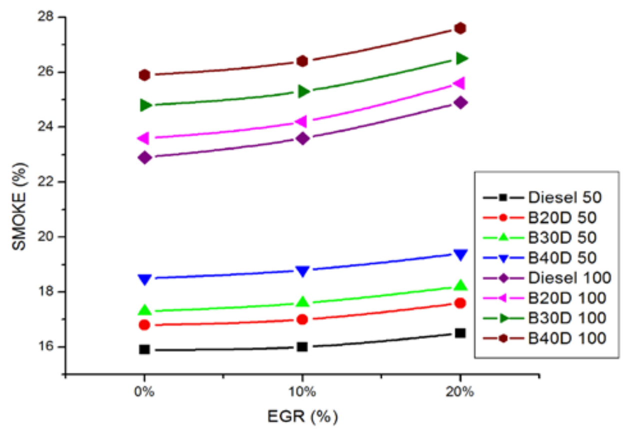


Figure 10. Effect of Exhaust Gas Recirculation on Smoke opacity at 50% and 100% Load

4. Conclusion

The conclusions drawn from present experimental investigation are as follows.

1. With increase in percentage of the EGR, BTE increases initially and then decreases while BSFC decreases initially and then increases. The optimum EGR for maximum BTE and minimum BSFC is found to be around 15%.
2. The peak pressure decreases slightly with the increase in percentage of EGR, further, it is found that the presence of EGR advances the ignition with increase in percentage of biodiesel.
3. NO_x and exhaust gas temperature decrease with increase in percentage of EGR and furthermore at a fixed EGR, they decrease with the increase in percentage of the biodiesel.
5. CO and HC emissions are found increasing with increase in the percentage of EGR. However at a fixed EGR, they are found decreasing with the increase in percentage of biodiesel.
6. The increase in smoke is insignificant initially, which however increases slightly with further increase in EGR which also increase with the increase in percentage of biodiesel.

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