PERFORMANCE AND EMISSION STUDY OF CI ENGINE FUELLED WITH DIESEL AND MICROALGAE BIODIESEL WITH EGR

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ABSTRACT

An effort has been taken to study performance and emission characteristics of a diesel engine fueled with microalgae biodiesel and diesel fuel using exhaust gas recirculation (EGR). The experimental investigation was conducted on a single-cylinder, four-stroke, water cooled, direct injection CI engine (Kirloskar TV1 model, 0.661 capacity, 5.2 kW) working at a constant speed of 1500 rpm. The results obtained with microalgae biodiesel were compared with the diesel fuel. The brake thermal efficiency (BTHE) obtained using microalgae biodiesel is less as compared to the diesel fuel, which could be attributed to lower calorific value of microalgae biodiesel. Smoke and HC emissions for biodiesel were higher than that of diesel fuel. However, it was observed that a NO_X emission for microalgae biodiesel is lower than that of diesel fuel. Exhaust gas recirculation (EGR) is used to reduce NO_X emissions from a diesel engine. In this study the different rate of EGR (0%, 5%, 10%, 15% and 20%) was used to study the performance and emission characteristics of CI engine.

Keywords: Biodiesel, Microalgae and EGR

1. INTRODUCTION

In recent period the increase in automobile in significantly large number has increased the demand of petroleum products or we can say fossil fuels. With crude oil reserves estimated to last only for few decades, there has been an active search for alternate fuels. The extinction of crude oil in recent year would cause a major impact on the transportation and industrial sector. The various alternate fuels under consideration, biodiesel is one of the promising alternative fuel to conventional diesel fuel. [1,2] Various research works have proved that performance of biodiesel is nearly similar to diesel fuel with fewer emissions. Further, engine parameters such as compression ratio, injection timing and injection pressure are also found to be significant factors contributing on performance and exhaust emissions of diesel engine, fueled with biodiesel. [3,4] The formation of NO_X emissions in diesel engines is predominant as the temperature in the combustion chamber is high, since at higher temperatures the tendency of nitrogen to react with oxygen causes the NO_X formation. This problem of NO_X generation can be overcome by using NO_X reduction techniques like exhaust gas recirculation, which is recirculation of some exhaust gases into intake which aids in reducing the NO_X. [5,6,7] An important property of biodiesel is its oxygen content of about 10 to 20%, which is usually not contained in diesel fuel. Biodiesel fuels have been recently stood out due to some important advantages such as requiring little or no modification for use in diesel engines. Moreover, they are non-toxic, have higher biodegradability and contain almost no sulphur. So in order to reduce NO_X emission various techniques have been developed like SCR, EGR, Humid Air Induction, Water Injection in cylinder, etc. Among this EGR is one of the most effective techniques to reduce NO_X emissions. [8]

2. EXHAUST GAS RECIRCULATION:

EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. This dilutes the O_2 in the incoming air stream and provides gases inert to combustion to act as absorbents of combustion heat to reduce peak in-cylinder temperatures. The effect of EGR on NO_X reduction can be attributed to three theories 1) increased ignition delay, 2) increased heat capacity and 3) dilution of the intake charge with inert gases. The ignition delay theory asserts that because EGR causes an increase in ignition delay, it has the same effect as retarding the injection timing. The heat capacity theory states that the addition of the inert exhaust gas into the intake increases the heat capacity (specific heat) of the non-reacting matter present during the combustion. The increased heat capacity has the effect of lowering the peak combustion temperature. According to dilution theory, the effect of EGR on NO_X is caused by increasing amounts of inert gases in the mixture, which reduces the adiabatic flame temperature [9].

$$\%\ EGR = \frac{M_{EGR}}{M_{TOTAL}} \times 100 \quad [5] \qquad (1)$$

Where, MEGR =Mass of exhaust gas which is recirculated and MTOTAL = Total mass of intake in cylinder i.e. MEGR +MAIR.

3. MICROALGAE OIL:

Biofuels were used and studied in three generations depending upon their availability and the yield produced from them. The 1st generation biofuels include food and oil crop like Sugar beet, rapeseed etc. The sustainability of first generation fuel has been questioned over the concerns such as reported displacement of food crop. The second generation biofuels are manufactured from lignocelluloses biomass or woody crops like Jatropha seeds etc. Microalgae biodiesel is 3rd generation of biofuels and are fastest growing plants in the world. About 50% of dry algae weight is oil and per unit area yield of oil from algae is about 20,000 liter per acre which is far more than next best crop palm oil. Calorific value of algae oil is about 37.018 MJ/kg which is nearer to calorific value of diesel fuel. [10,11]

4. PREPARATION OF BIODIESEL:

Bio-lipid microalgae oil consists of hydrocarbon compounds (triacyglycerides) that are not suitable for most diesel engines. Also, the carbon chains are too viscous for good flow and combustion. The microalgae oil can be modified for use in diesel engines by a chemical process known as "transesterification". [10,12] The end product of the microalgae oil conversion using methyl alcohol is fatty acid methyl esters with the trade name of "Biodiesel". The transesterification process separates the oil into glycerol (fatty acids) and biodiesel.The biodiesel formed is further purified by washing it with water until the pH value of the biodiesel comes out to be neutral. The yield obtained for biodiesel from the microalgae oil is 85 %.

5. EXPERIMENTAL METHODOLOGY:

The test engine is a single cylinder four stroke direct injection water cooled diesel engine (Kirloskar TV1 model, 0.661 capacity, 5.2 kW) working at a constant speed of 1500 rpm. The EGR system, which is designed and fabricated in-house, consists of a piping system taken from the engine exhaust pipe, an orifice meter used to measure the flow rate of the exhaust gases, and a control valve to control the amount of exhaust gas recycling into the inlet manifold. Plenum chambers are installed to damp the exhaust and maintain the regular exhaust gas through pipes. The AVL 437 smoke meter is used to measure the smoke opacity and AVL Digas 4000 light, an infrared type gas analyzer was used to measure CO, CO_2, HC, NO_X and O_2. [13] The Methodology for carrying out the experimental performance is as follows:

- The engine was fuelled with diesel and allowed to run at various loads ranging from 0 to 18kg in steps of 2 kg with 0% EGR and observations were recorded related to performance and emission parameters.
- Then, the experimentation was repeated by supplying different percentage of EGR (5%, 10%, 15% and 20%) in the engine cylinder and observations were recorded.
- Then, the engine was fuelled with microalgae biodiesel (B100) and observations were recorded with 0%, 5%, 10%, 15%, and 20% EGR.

6. RESULTS AND DISCUSSION:

The engine testing is done working at a constant speed of 1500 rpm fuelled with Diesel, B100 and Algae oil at different engine loads, ranging from no-load to full load with different %EGR. In each test, performance, combustion and emission parameters were measured.

6.1 Brake Thermal Efficiency:

The observations recorded at full load (5.2 kW) for BTHE using different fuel and varying EGR rates are shown in figure 1. From the obtained results, it is observed that BTHE reduces with increase in percentage of EGR. The maximum BTHE is obtained with diesel as fuel at 0% EGR (32.81%) and minimum BTHE is observed at when engine is fuelled with B100 with 20% EGR (24.39%). The BTHE obtained for diesel is higher as compared to B100 for all EGR rates. This is because of the lower calorific value and higher viscosity of B100 as compared to diesel.

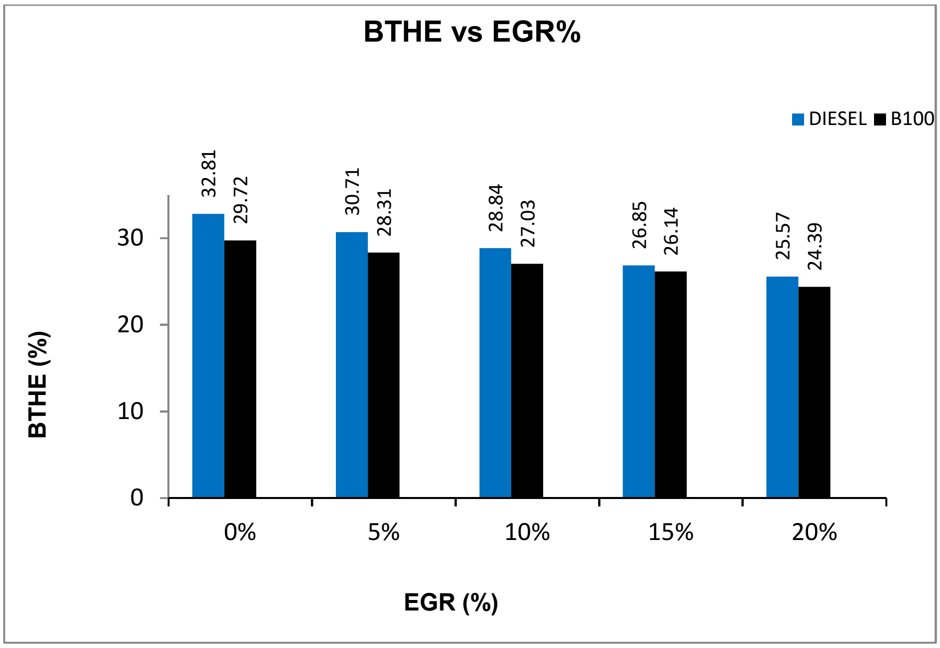

Figure 1. Variation of Brake Thermal Efficiency With EGR %

6.2 Brake Specific Energy Consumption:

The comparison based on brake specific fuel consumption cannot be made since the fuel has different energy content. Therefore, a comparison is made based on brake specific energy consumption is carried out. BSEC is defined as the product of the BSFC and calorific value of a fuel. The observations recorded for BSEC at full load (5.2 kW) with different fuel and EGR rates is shown in fig. 2. The obtained results show that BSEC increases with increase in EGR rate. The minimum BSEC is obtained with diesel at 0% EGR (10.97 kg/kW-hr) and maximum BSEC is observed at B100 with 20% EGR (14.76 kg/kW-hr). The lower BSEC obtained for diesel as compared to B100 is due to higher calorific value of diesel.

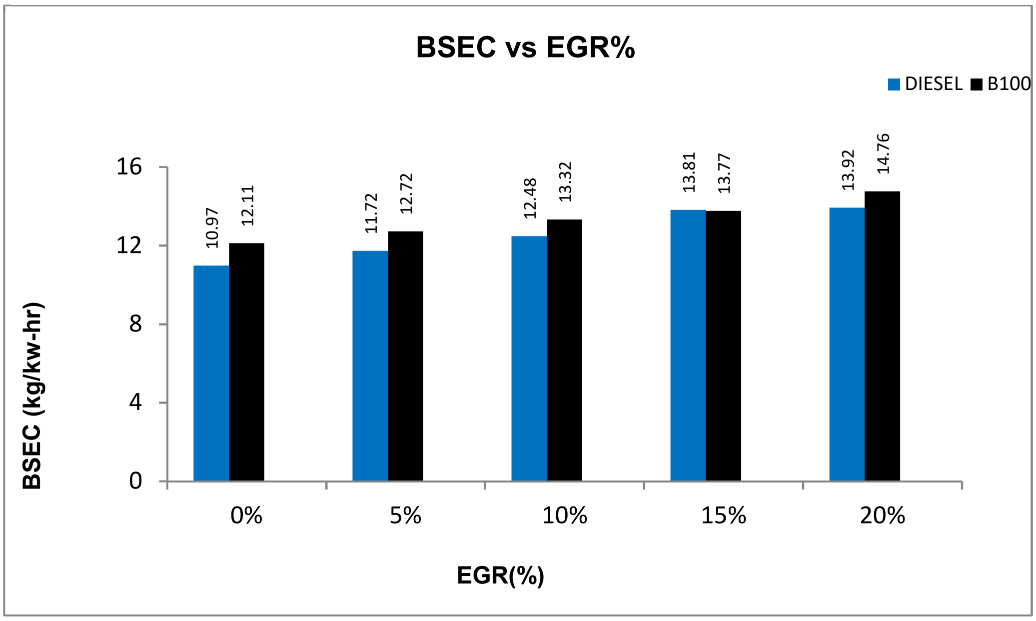

Figure 2. Variation of Brake Specific Energy Consumption With EGR %

6.3 Combustion Peak Pressure:

The observations recorded at full load (5.2 kW) for combustion peak pressure using different fuel and varying EGR rates are shown in figure 3. The combustion peak pressure is directly proportional to BTHE. From fig. 3 it is observed that the combustion peak pressure reduces with increase in EGR percentage. The pressure observed at 0% EGR for diesel and B100 is 64.4bar and 61.32 bar respectively. The lower combustion peak pressure with higher EGR rate is due to dilution of charge with the introduction of exhaust gas resulting in reduction of O_2 concentration.

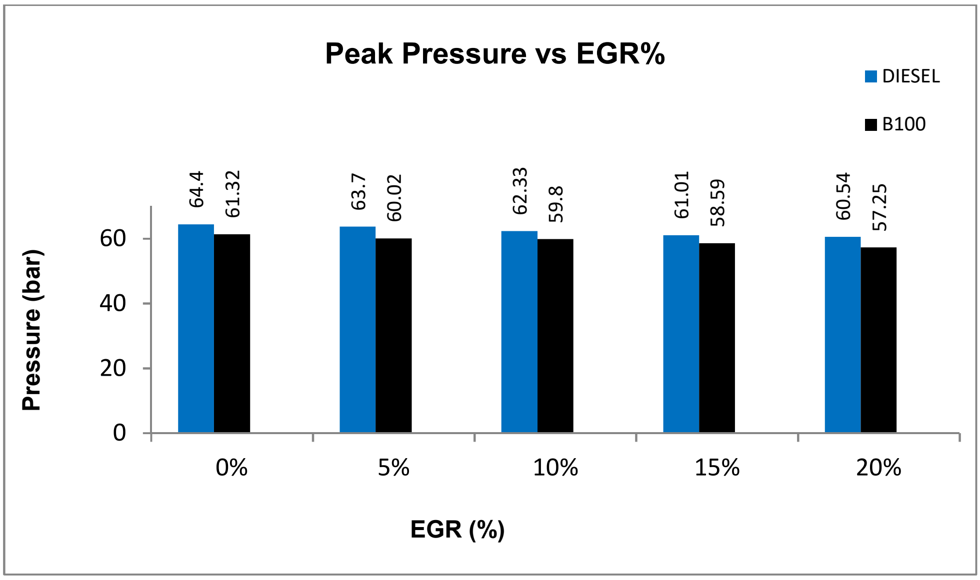

Figure 3. Variation of Peak Pressure with EGR%

6.4 NO_X:

The observations recorded at full load (5.2 kW) for NO_X using different fuel and varying EGR rates are shown in figure 4. It is observed that NO_X decreases with increase in EGR%. There is significant decrease in NO_X emission with the help of EGR is observed.

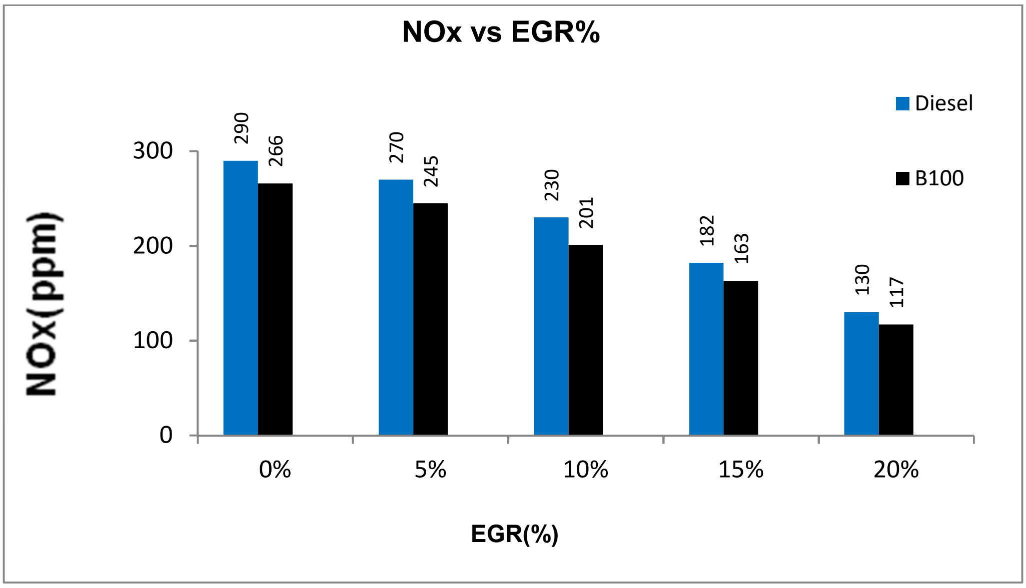

Figure 4. Variation of NO_x with EGR%

The highest NO_X emission was observed using diesel with 0% EGR (290 ppm) and lowest NO_X is observed using B100 with 20 % EGR (117ppm). The lower NO_X formation with higher EGR percentage was observed due to decrease in combustion temperature as there is dilution of charge with the supply of EGR. The other reason for reduction in NO_X is reduction in O_2 concentration which otherwise promote NO_X formation.

6.5 Unburnt Hydrocarbons:

The observations recorded at full load (5.2 kW) for HC using different fuel and varying EGR rates are shown in figure 5. Hydrocarbon shows the trend opposite to that of NO_X. It is observed that HC emission increases with EGR rate for all the fuels. The minimum HC emission is observed using diesel with 0% EGR (24 ppm) and maximum HC emission is observed using B100 with 20% EGR (30ppm). This is probably because of O_2 deficiency resulting in incomplete combustion of fuel which leads to increase HC emission in exhaust due to recirculation of exhaust gases.

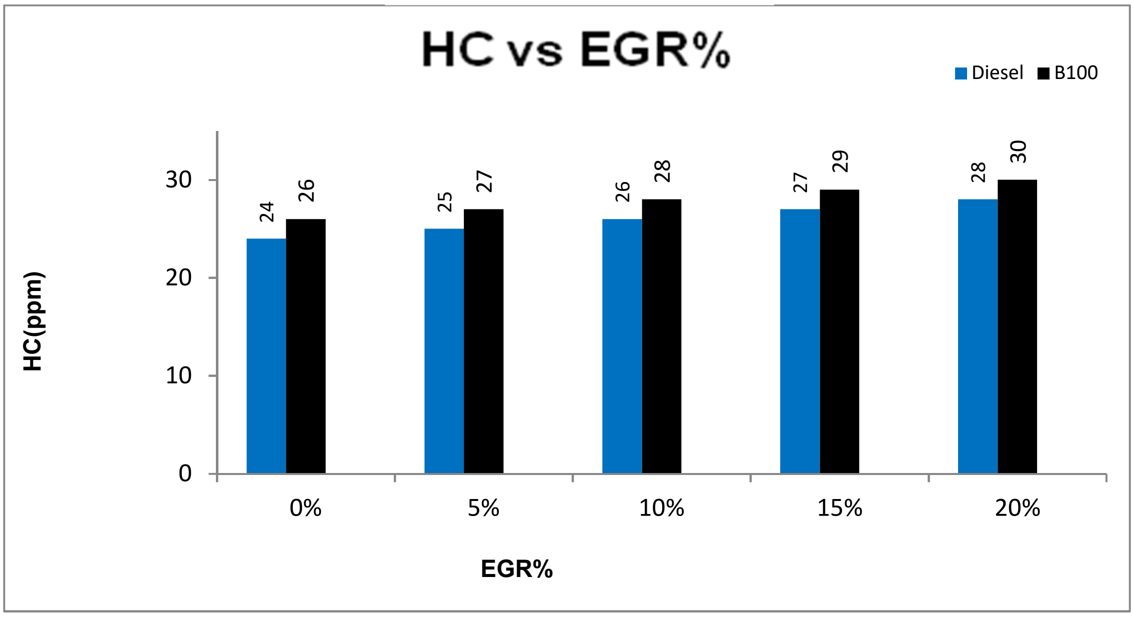

Figure 5. Variation of HC with EGR%

6.6 Smoke:

The observations recorded at full load (5.2 kW) for smoke using different fuel and varying EGR rates are shown in fig.6. The minimum smoke is obtained using diesel with 0% EGR (79.32%) and maximum smoke is observed using B100 with 20 % EGR (100%). The formation of smoke is strongly dependent on engine load and type of fuel used. The air-fuel ratio increase with increase in load and decreases with increase in EGR percentage resulting in higher smoke.

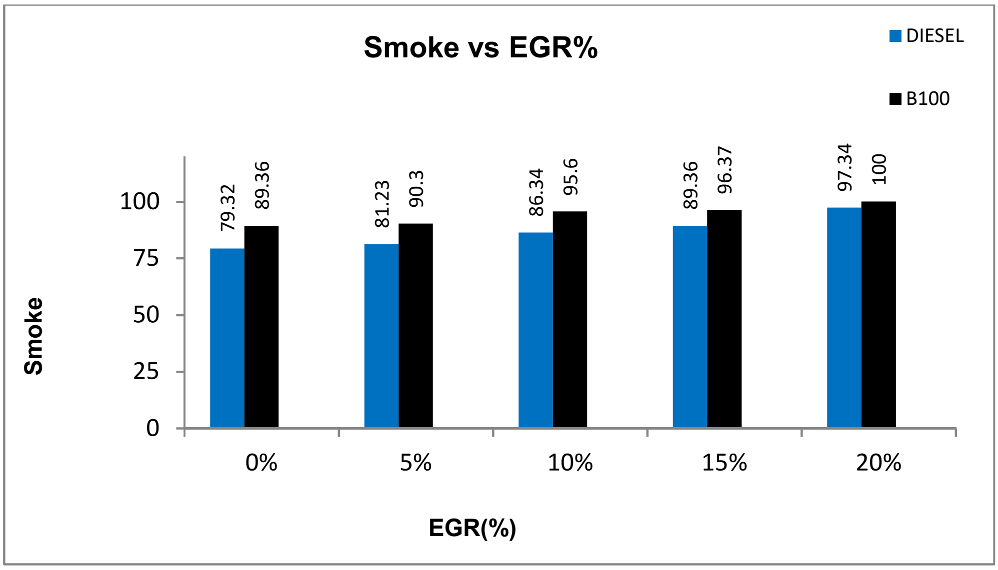

Figure 6. Variation of Smoke with EGR%

7. CONCLUSION

The detailed study of performance and emission characteristics of a diesel engine fueled with microalgae biodiesel and diesel fuel using exhaust gas recirculation (EGR) was carriedout and following inferenceses are presented based on the experimntal investigation.

1. It is observed that BTHE reduces with increase in percentage of EGR. The maximum BTHE is obtained with diesel as fuel at 0% EGR (32.81%) and minimum BTHE is observed at when engine is fuelled with B100 with 20% EGR (24.39%). The BTHE obtained for diesel is higher as compared to B100 for all EGR rates. This is because of the lower calorific value and higher viscosity of B100 as compared to diesel.
2. The obtained results show that BSEC increases with increase in EGR rate. The minimum BSEC is obtained with diesel at 0% EGR (10.97 kg/kW-hr) and maximum BSEC is observed at B100 with 20% EGR (14.76 kg/kW-hr). The lower BSEC obtained for diesel as compared to B100 is due to higher calorific value of diesel.
3. It is observed that the combustion peak pressure reduces with increase in EGR percentage. The pressure observed at 0% EGR for diesel and B100 is 64.4vbar and 61.32 bar respectively. The lower combustion peak pressure with higher EGR rate is due to dilution of charge with the introduction of exhaust gas resulting in reduction of O_2 concentration.
4. There is significant decrease in NO_X emission with the help of EGR is observed. The highest NO_X emission was observed using diesel with 0% EGR (290 ppm) and lowest NO_X is observed using B100 with 20 % EGR (117ppm). The lower NO_X formation with higher EGR percentage was observed due to decrease in combustion temperature as there is dilution of charge with the supply of EGR. The other reason for reduction in NO_X is reduction in O_2 concentration which otherwise promote NOX formation.
5. Hydrocarbon shows the trend opposite to that of NO_X. It is observed that HC emission increases with EGR rate for all the fuels. The minimum HC emission is observed using diesel with 0% EGR (24 ppm) and maximum HC emission is observed using B100 with 20% EGR (30ppm). This is probably because of O_2 deficiency resulting in incomplete combustion of fuel which leads to increase HC emission in exhaust due to recirculation of exhaust gases.

6. The minimum smoke is obtained using diesel with 0% EGR (79.32%) and maximum smoke is observed using B100 with 20 % EGR (100%). The formation of smoke is strongly dependent on engine load and type of fuel used. The air-fuel ratio increase with increase in load and decreases with increase in EGR percentage resulting in higher smoke.

From the above results and discussion it is clear that B20 with 5 % EGR gives higher BTHE, NO_X, Smoke and lower BSEC, HC at full load. B40 with 5 % EGR gives smoke and lower BTHE, BSEC, NO_X at full load. B20 with 10 % EGR gives better results with respect to NO_X emission reduction with marginally less BTHE and similar HC emissions and little increase in smoke emission.

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