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REDUCTION OF NO_X EMISSIONS IN JATROPHA SEED OIL-FUELED CI ENGINE

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ABSTRACT

Internal combustion engines, which form an essential part of the transportation as well as mechanized agricultural system, have been badly affected by the twin crisis. Many researchers have done a lot of experiment studies in the field of biodiesel to find an alternative to mineral diesel. It has shown that biodiesel-fueled engines produce less carbon monoxide, unburned hydrocarbon, and smoke emissions compared to diesel fuel but higher NOx emissions. Exhaust gas recirculation (EGR) is effective to reduce NOx from diesel engines because it lowers the flame temperature and the oxygen concentration in the combustion chamber. The objective of this work is to investigate the usage of biodiesel from Jatropha Seed Oil and EGR simultaneously in order to reduce the emissions of all regulated pollutants from diesel engine. A fully automated single-cylinder, water-cooled, constant speed direct injection diesel engine was used for experiments. HC, NOx, CO, and smoke of the exhaust gas were measured to estimate the emissions. Various engine performance parameters such as thermal efficiency, and brake specific fuel consumption were calculated from the acquired data. Application of EGR with biodiesel blends resulted in reductions in NOx emissions without any significant penalty in smoke emissions.

Keywords: NOx, Jatropha seed oil, biodiesel, EGR, transesterification, exhaust emissions.

1. INTRODUCTION

Recent surge in petroleum prices have regenerated interest in bio-fuels. The development of biomass-based diesel substitutes is an attractive proposition, as it helps to improve diesel fuel quality. The fuels of bio-origin may be alcohol, vegetable oils, biomass, and biogas. Some of these fuels can be used directly in the engine, while others need to be formulated to bring the relevant properties close to conventional fuels. Barnwal B. K. *et al.*, (2005) explained the prospects of biodiesel production from vegetable oils in India and reported that biodiesel production and utilization, resource available, process develop/being develop, performance of existing engine, environmental consideration, the economic aspect and advantages in and barriers to the use of biodiesel were elaborated. Bora D. K., *et al.*, (2004) conducted a performance evaluation and emission characteristics of a diesel engine using mahua oil methyl ester and reported that methyl ester of mahua oil oilcan be used in the existing diesel engine without substantial hardware modification.

Kumar N. *et al.*, (2004) reported that fuelling agriculture engine with derivative of palm oil had comparable performance and less emission and suggest to use 10-20% of biodiesel developed from palm oil in diesel engine without any difficulty. Kumar R. *et al.*, (2004) biodiesel from Jatropha curcas and Pongamia pinnata was used as fuel in direct injection diesel engine and reported that 20% blend gives comparable performance and less emission. Leenus Jesu *et al.*, (2005) conducted Performance and emission characteristics of a CI engine fueled with esterified cottonseed oil and reported that engine exhibited a very good performance without any problems of combustion and suggested to use ethyl ester of cotton seed oil as an alternate fuel for diesel engine.

Ramadhas A. S. *et al.*, (2004) conducted a review on use of vegetable oils as CI engine fuels and reported that production and characterization of vegetable oil as well as the experimental work carried out in various countries in this field. Also, the scope and challenges being faced in this area of research are clearly described. Straight vegetable oils or their blends with diesel pose various long-term operational and durability problems in compression ignition engines, e.g., poor fuel atomization, piston ring-sticking, fuel injector coking and deposits, fuel pump failure, and lubricating oil dilution, etc. Naik S. N. *et al.*, (2006) has taken effort to study the technical aspects of biodiesel production by transesterification. He has explained various methods of preparation of biodiesel with different combination of oil and catalyst. Rakopoulos C. D. *et al.*, (2006) have made comparative performance and emission study of a direct injection diesel engine using blends of biodiesel fuel with vegetable oils or bio-diesels of various origins. Vegetable oils have almost similar energy density, cetane number, heat of vaporization, and stoichiometric air/fuel ratio compared to mineral diesel fuel. However, straight vegetable oils cannot be used directly in engines.

Suryawanshi J. G. *et al.*, (2004) have taken investigation the blends of varying proportion of pungamia oil methyl ester and diesel were used to run single cylinder CI engine and significant improvement in engine performance and emission characteristics were observed. The addition pungamia methyl ester to diesel fuel has significantly reduced HC, CO and Smoke emission but increases the NOx emission slightly. Deepak Agarwal *et al.*, (2006) have made investigation of control of NO_x

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emissions in biodiesel-fueled compression ignition engine and reported that simultaneous reduction of NOx and Smoke emission can be possible only when engine run with biodiesel along with EGR system. Senatore A. *et al*., (2001) have made a comparative analysis of combustion process in DI diesel engine fueled with biodiesel and diesel fuel and proved that good overall behavior of biodiesel in terms of performance and exhaust emission even if the reduction in some pollutants (CO and particulate) has been accompanied by more or less marked observations of higher concentration of NOx compared to diesel fuel fueled engine.

Diesel engine combustion generates large amounts of NOx because of high flame temperatures in presence of abundant oxygen and nitrogen in the combustion chamber. Increased environmental concerns and tougher emission norms have led to the development of advanced engine technologies to reduce NOx and Smoke emissions. Ever increasing emission reduction demands present a continuing challenge to engine designers because of NOx-Smoke trade-off associated with most of the emission reduction strategies. Recent engine work focuses on improvements or incorporation of new technologies to power cylinder, air delivery, fuel management, and electronic systems. Very low emissions from engines can be achieved with exhaust gas after treatment and optimized combustion processes.

2. EXHAUST GAS RECIRCULATION (EGR)

Controlling the NOx emissions primarily requires reduction of in-cylinder temperatures. EGR (Figure-1) is an effective technique of reducing NOx emissions from the diesel engine exhaust. EGR has been used by several researchers. EGR involves replacement of oxygen and nitrogen of fresh air entering in the combustion chamber with the carbon dioxide and water vapor from the engine exhaust. The recirculation of part of exhaust gases into the engine intake air increases the specific heat capacity of the mixture and reduces the oxygen concentration of the intake mixture. These two factors combined lead to significant reduction in NOx emissions. EGR (%) is defined as the mass percent of the recirculated exhaust (MEGR) in total intake mixture (Mi). However, the application of EGR results in higher fuel consumption and emission penalties. EGR increases HC, CO, and Smoke emissions along with slightly higher specific fuel consumption. Therefore, EGR, although effective to reduce NOx, further increases the smoke emissions. Engine operation with oxygenated fuel and EGR results in NOx reductions without deteriorating brake specific fuel consumption (BSFC) and emissions.

3. EXPERIMENTAL SET-UP AND MEASUREMENTS

Experiments were conducted in a fully automated single-cylinder, four-stroke, naturally aspirated, direct injection diesel engine (Figure-2) using METPSO. Two separate fuel tanks with a fuel switching system were used, one for diesel and the other for biodiesel. The fuel consumption was measured with the aid of optical sensor. A differential pressure transducer was used to measure air flow rate. The engine was coupled with an eddy current dynamometer which is used to control the engine torque through computer. Engine speed and load were controlled by varying excitation current to the eddy current dynamometer using dynamometer controller. A piezoelectric pressure transducer was installed in the engine cylinder head to measure the combustion pressure. Signals from the pressure transducer were fed to charge amplifier. A high precision crank angle encoder was used to give signals for TDC and the crank angle. The signals from the charge amplifier and crank angle encoder were supplied to data acquisition system. An AVL-five gas analyzer and AVL-Smoke meter were used to measure the emission parameters and smoke intensity respectively. Thermocouples were used to measure different temperatures, such as exhaust temperature, coolant temperature, and inlet air temperature. Load was changed in eight levels from no load to the maximum load. The engine was operated at the rated speed i.e., 1500 rpm for all the tests. Table-1 compares the important properties of Jatropha seed oil with conventional diesel and methyl ester of JO.

Figure-1. Engine system with EGR unit.

Figure-2. Experimental setup.

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Table-1. Properties of fuels used.

PROPERTY	Diesel	JO	MEJO	ASTM code[11]
Calorific value (kJ/kg)	43200	40148	40462	D4809
Specific gravity	0.823	0.92	0.839	D445
Kinematic viscosity(at 40^0C)cSt	3.9	4.8	4.2	D2217
Cetane number	49	42	47	D4737
Color	Light brown	Yellow	Light yellow	D1500-2
Flash point °C	56	128	110	D92
Fire point °C	64	135	120	D92
Cloud point °C	-8	-4	-6	D97
Pour point °C	-20	-7	-8	D97
Ash content %	0.001	0.003	0.003	D976

4. RESULTS AND DISCUSSIONS

To begin with, a CI engine tests were carried out using diesel at the rated speed 1500 rpm and different EGR rates in order to show the effect of EGR on the smoke intensity and NOx concentration in the exhaust. The smoke intensity of the exhaust gas is measured to quantify the PM present in the exhaust gas.

Figure-3 shows the smoke intensity at different EGR rates. Higher smoke intensity of the exhaust is observed when the engine is operated with EGR compared to without EGR. Smoke intensity increases with increasing EGR rates and increasing engine load. At the maximum load, smoke emission level for 5%, 15% and 20% were found to be 1.5, 2.07 and 2.142 times higher, respectively than that of without EGR. This is due to EGR reduces availability of oxygen for combustion of fuel, which results in relatively incomplete combustion and increased formation of smoke emission.

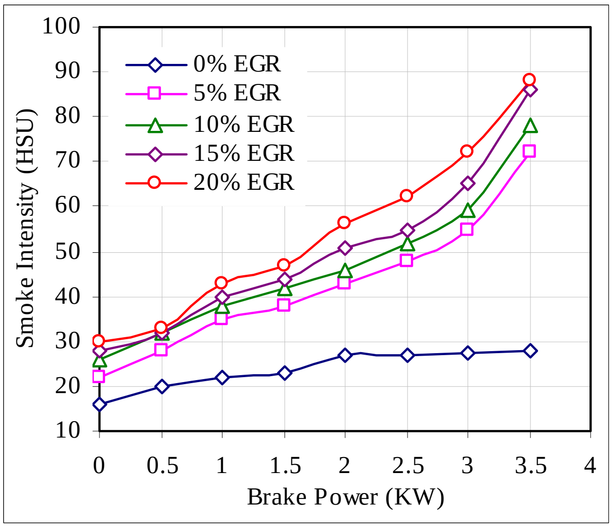

Figure-3. Variation of smoke intensity with brake power.

Figure-4 shows variation of NOx emissions with brake power from diesel engine. When EGR is applied, NOx is decreased with increasing EGR rates. The reasons for reduction in NOx emissions using EGR in diesel engines are reduced oxygen concentration and decreased flame temperatures. At the maximum load, NOx emission level for 5% and 15% were found to be 18.17% and 35.05% decreased respectively than that of without EGR diesel engine. For 20% EGR rate, no appreciable reduction in NOx was observed.

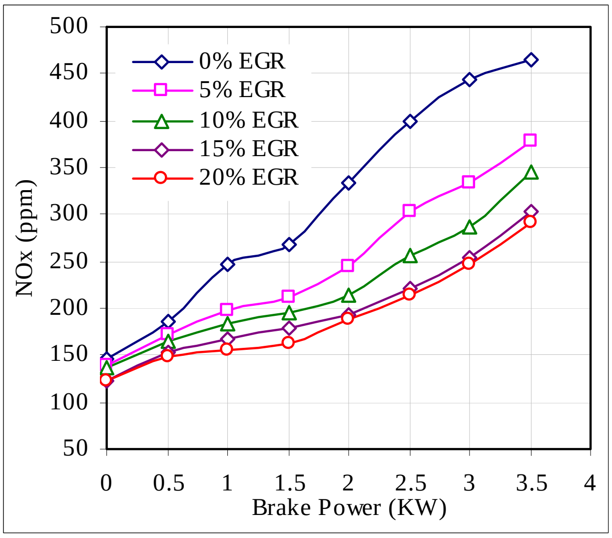

Figure-4. Variation of NOx emission with brake power.

The exhaust gas temperature profile for diesel engine with and without EGR is shown in Figure-5. It can be observed that with increase in load, exhaust gas temperature also increases. Temperature of the exhaust gas was found to be lower in case of EGR-operated engine. At the maximum load, exhaust gas temperature level for 5% and 20% were found to be 14°C and 24°C decreased respectively than that without EGR. The possible reason for this temperature reduction may be relatively lower

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availability of oxygen for combustion and higher specific heat of intake air mixture.

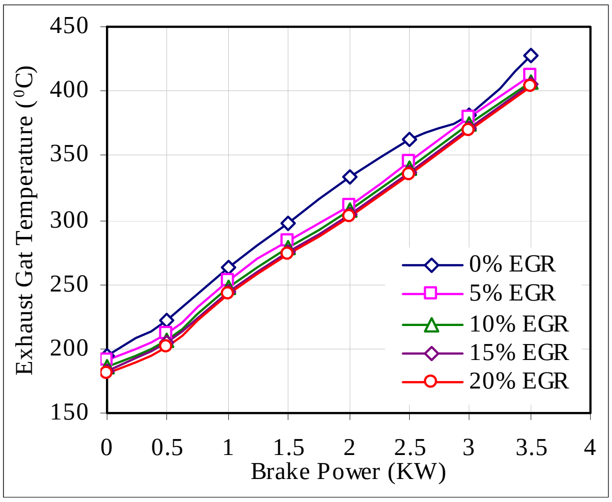

Figure-5. Variation of exhaust gas temperature with brake power.

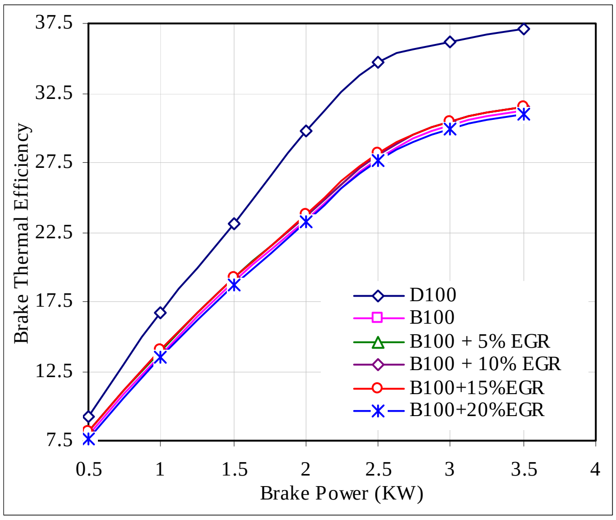

Figure-6. Variation of thermal efficiency with brake power.

As a result, it can be observed that when EGR is applied to diesel engine, NOx is reduced but smoke intensity is increased. This is a well-known trade-off between NOx and smoke. On the other hand, if biodiesel is used in diesel engine, smoke intensity is decreased but NOx is increased. Thus, biodiesel with EGR can be used to reduce NOx and smoke intensity simultaneously. A sequence of comprehensive engine test were carried out using neat methyl ester of TPSO (B100) as a fuel with different EGR rate (0%, 5%, 10%, 15% and 20%) to evaluate the performance and emission pattern of the engine. The performance and emission characteristics such as thermal efficiency, BSFC, exhaust gas temperature; HC, CO, NOx emissions, and smoke intensity were analyzed and compared with base line data.

Figure-6 represents comparison of brake thermal efficiency for biodiesel fueled engine with/without EGR. Thermal efficiency is found to be slightly increased with EGR at all level of engine loads i.e., at the maximum load for 15% EGR, thermal efficiency was increased to 0.31% and for 20% EGR, it was reduced to 0.21% compared to that of B100. The possible reason may be re-burning of HCs that enter the combustion chamber with the re-circulated exhaust gases.

Figure-7 shows the nature of bsfc for biodiesel fueled engine with/without EGR. For diesel, bsfc is lower at all loads for engine operated without EGR compared to engine was operated on biodiesel blends with and without EGR. This increase in bsfc was due to lower calorific value of biodiesel compared to diesel.

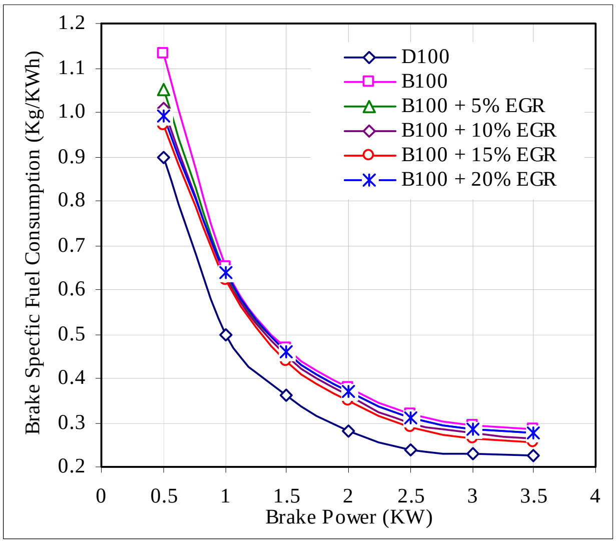

Figure-7. Variation of bsfc with brake power.

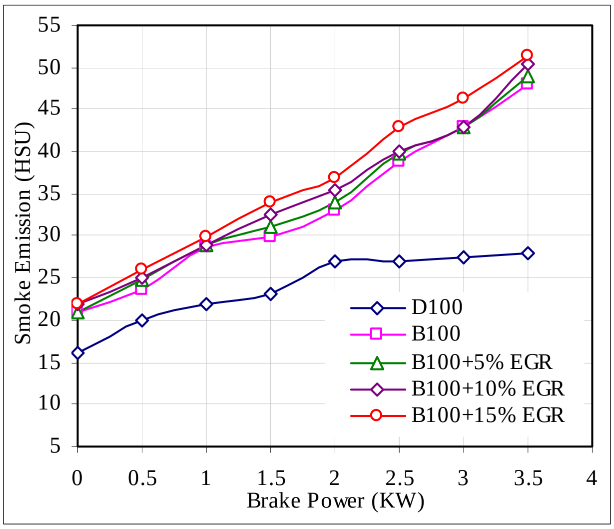

Figure-8. Variation of smoke with brake power.

The variation of smoke intensity for biodiesel fueled engine with and without EGR is shown in Figure-8. Higher smoke intensity of the exhaust is observed when

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the engine is operated with EGR compared to without EGR on diesel. EGR reduces availability of oxygen for combustion of fuel, which results in incomplete combustion and increased formation of smoke. The molecule of biodiesel contains some oxygen that takes part in combustion and this may be a possible reason for improved combustion and thus lower smoke. It is observed that 20% biodiesel blend gives lowest smoke intensity for all data sets with EGR.

Figure-9 shows the well-established benefit of EGR in reducing NOx emissions from diesel engine. The degree of reduction in NOx at higher loads is higher. The reasons for reduction in NOx emissions using EGR in diesel engines are reduced oxygen concentration and decreased flame temperatures. However, NOx emissions in case of biodiesel blends are higher than diesel due to higher temperatures prevalent in the combustion chamber. An important observation is that all biodiesel blends have lower NOx emissions than the baseline data for diesel without EGR. Figure-10 shows the variation of EGT for the same condition.

Effect of EGR and biodiesel on unburned HCs and CO is shown in Figures 11 and 12. These graphs show that HC and CO emissions decrease with EGR and load. The possible reason may be lower excess oxygen available for combustion. Lower excess oxygen concentration results in rich air-fuel mixtures at different locations inside the combustion chamber. This heterogeneous mixture does not combust properly and results in higher HC emissions. Similarly, with EGR, the air-fuel ratio decreases, and CO eventually increases. Adding biodiesel to diesel decreases the oxygen required for combustion because of presence of molecular oxygen in fuel. This results in lower HC and CO emission. It can be observed from Figures 11 and 12 that HC and CO emissions are lower for biodiesel blends than with diesel when the engine was operated employing EGR. However, HC and CO emissions for 20% biodiesel blends are almost same or lower compared to baseline data of diesel without EGR.

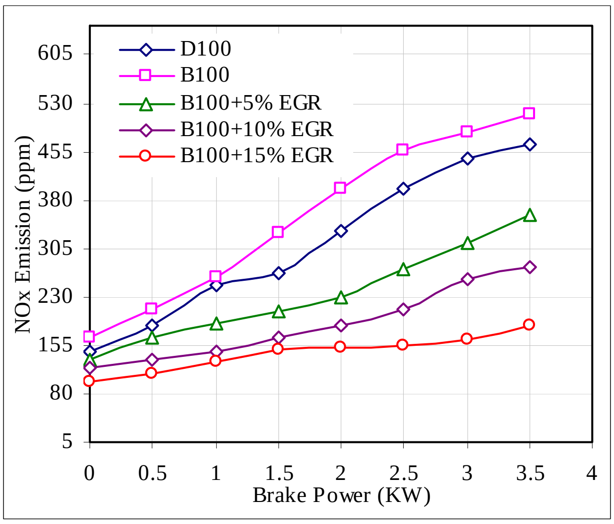

Figure-9. Variation of NOx with brake power.

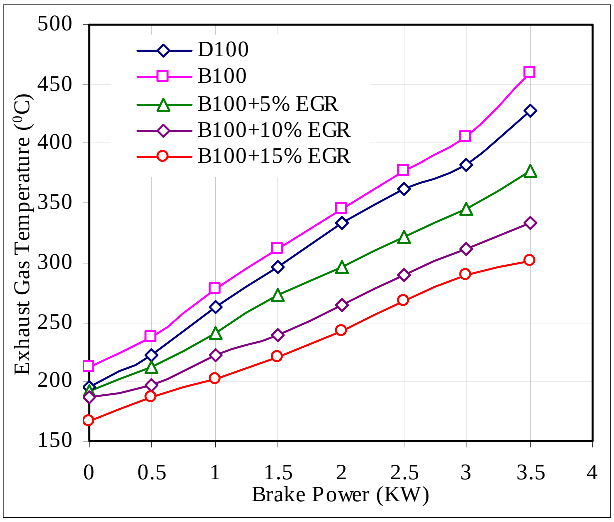

Figure-10. Variation of EGT with brake power.

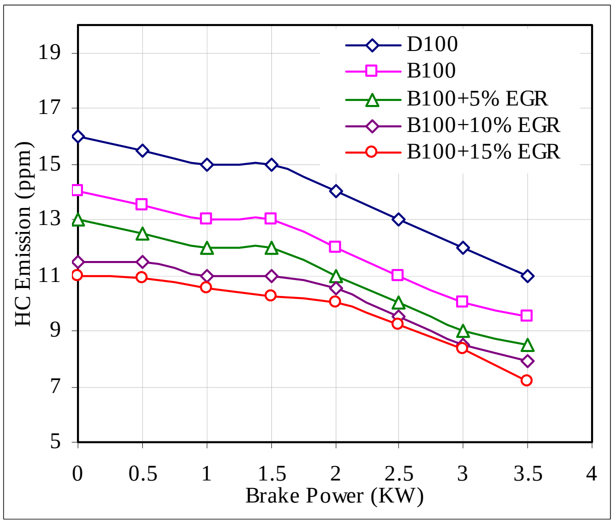

Figure-11. Variation of smoke intensity with brake power.

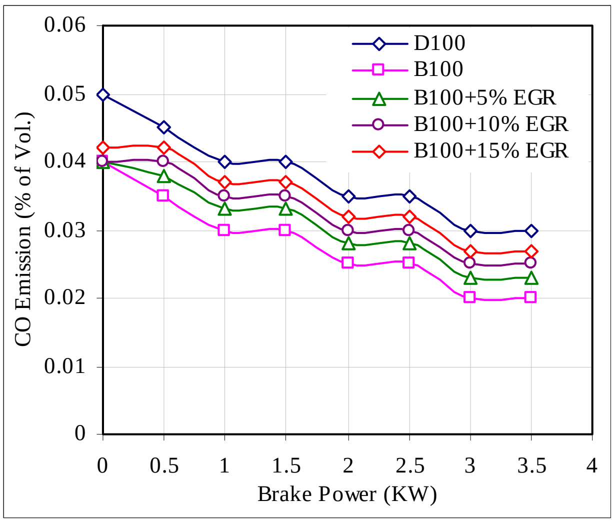

Figure-12. Variation of smoke intensity with brake power.

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6. CONCLUSIONS

Based on the exhaustive engine tests, it can be concluded that

- Biodiesel and EGR both can be employed together in CI engines to obtain simultaneous reduction of NOx and smoke.
- Other emissions such as HC and CO are also found to have decreased.
- 15% EGR is found to be optimum, which improves the thermal efficiency, reduces the exhaust emissions and the BSFC.
- Biodiesel is an oxygenated fuel and it undergoes improved combustion in the engine due to the presence of molecular oxygen which also leads to higher NOx emissions.
- This higher NOx emission can be effectively controlled by employing EGR.
- EGR increases the HC and CO emissions. Also, higher BSFC and particulate emissions were observed.

Thus, EGR with biodiesel can be applied to reduce NOx emissions without increasing smoke emissions. In summary, engine operation with biodiesel while employing EGR results in NOx reductions without compromising engine performance and emissions.

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