Experimental Investigation on Combined Effect of EGR and Three-way Catalytic Converter for IDI Diesel Engine.

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ABSTRACT

In the past few decades, an alternate source of energy has been the growing concern with respect to environment and energy reserves utilization. Also the enhancement of industrialization and motorization at global level has strengthened further towards the alternate energy sources like bio fuels etc. The objective of the research work was to effectively reduce the nitrogen oxides (NO_X) emissions with the combination of exhaust gas recirculation (EGR) and three-way catalytic converter fuelled with diesel, jatropha biodiesel (JBD) and their blends at full load of indirect injection (IDI) diesel engines. The engine was tested by diesel, 100% biodiesel (JB 100), blends of 80% diesel and 20% biodiesel (JB 20) and other blends like JB 40, JB 60 and JB 80. The engine characteristics with jatropha biodiesel were compared against those obtained using diesel fuel. From results it is observed that nitrogen oxide emissions of JBD are more than that diesel fuel. These high NO_X emissions are due to the presence of unsaturated fatty acids and the advanced injection caused by the higher bulk modulus of JBD and their blends. A four stroke single cylinder water cooled IDI diesel engine was used for investigation. Nitrogen oxides, carbon monoxide, carbon dioxide and smoke were recorded and various engine performance parameters were also evaluated. The results and discussion based on the effect of emission controlling systems on engine performance and emission characteristics of JB 100, JB 80, JB 60, JB 40, JB 20 and diesel fuel without emission controlling systems. The performance parameters and nitrogen oxide emissions are measured and recorded for diesel fuel, JBD and their blends. The results showed that at 5% EGR + three way catalytic converter for JB 100, at 40% EGR + three way catalytic converter for JB 80, JB60 and JB 40. And at 35% EGR + three way catalytic converter for JB 20 and diesel fuels, the $N0_x$ emissions effectively reduced compared to without emission controlling devices.

Keywords --- Three-way catalytic converter, EGR rates, Bio-diesel, Jatropha oil, , ,NOx emissions.

1. Introduction :

Energy has always played an important role in development of a country. It is considered as an index of economic growth and social development. Per capita energy consumption is considered as a measure of prosperity of a country besides GDP and per capita income. The inflation of oil prices has motivated the institutional frame work to promote production of bio fuels, storage, transportation, facilitation of interaction between public and private stake holders and the removal of financial and technical barriers. A special focus is desirable towards the development of bio-energy crops and agro-forestry and enhance the trans of technology to farmers.

The indirect injection compression ignition engine has the highest thermal efficiency of any internal combustion engine and therefore produces the least greenhouse carbon dioxide from its exhaust [1]. Diesel engines are significant contributors of $N0_x$ emissions and PM to ambient air pollutant inventories [2]. The quantity of CO and THC derived from diesel engines is generally small compared with emissions from light duty gasoline vehicles. For this reason the effect of biodiesel on PM and $N0_x$ emissions are the primary concern of this investigation.

During the current research work, development and investigate the effect of exhaust gas recirculation and three way catalytic converter on an indirect injection (IDI) diesel engine fuelled with diesel, JBD blends in order to reduce NO_X and smoke emissions. Biodiesel of jatropha blends (JB20,JB40, JB60, JB80 and JB100) have been produced in the lab and in order to ensure the quality of biodiesel blends produced and investigations of various properties, evaluating the performance characteristics of the biodiesel over the diesel engine. And also evaluating emission characteristic of the biodiesel, diesel and their blends by varying exhaust gas recirculation 5 to 40% with increment of 5% and with the three way catalytic converter at 100% of load.

1.1Formation of Nitrogen Oxides (NO_x):- The higher the compression ratio in a diesel engine and higher energy content of diesel fuel allow diesel engines be more efficient than gasoline engines. The same factor that cause diesel engines to run more efficiently than gasoline engine's also cause to run at a higher temperature. This leads to pollution problem, the creation of Nitrigen oxides (NO_X).[3] Fuel in any engine is burned with extra air, which helps eliminate unburned fuel from the exhaust, this air approximately 79% nitrogen and 21% oxygen.

When air is compressed inside the cylinder of the diesel engine, the temperature of the air increase to more than 1500^0F and the air expands pushing the piston down and rotating crank shaft. Generally the higher the temperature, the more efficient is the engine; 1. Good performance 2.Good economy. Some of the oxygen is used to burn the fuel, but the extra is supposed to just pass through the engine unreacted. The nitrogen, since it does not participate in the combustion reaction, also passes unchanged through the engine. When the peak temperatures are high enough for long periods of time, the nitrogen and oxygen in the air combines to form new compounds, primarily NO and NO_2.[4] These are normally collectively referred to as NO_X.

1.2Three-way catalytic converter:- Pesansky et al.[5] investigated the engines fitted with 3-way catalytic converters are equipped with a computerized closed loop feedback fuel injection systems, which is employing one or more oxygen sensors. While 3-way catalyst was used in an open loop system. NO_X efficiency was lower by 28%. Within a narrow fuel air ratio band surrounding stoichiometry, conversion of all three pollutants is nearly complete. The reduction of NO_X emission is favor, at the expense of CO and HC oxidation. Jonathan et al.[6], suggested that to reduce NO_X on a compression ignition engine, the chemical composition of the exhaust must first be changed. They concluded that two main techniques are used selective catalytic reduction and NO_X traps. Suresh et al.[7] studied that the biodiesel can lower some pollutant and particulate matter emissions. it can be blended with diesel engine without any major modifications. Slightly higher velocity of biodiesel makes it an excellent lubricity additive. Biodiesel is nontoxic and biodegradable when introduced in neat form and it is oxygenated fuel which contributed to a more complete fuel burn. Its cetane number is higher than those of vegetable oil and diesel fuel and hence produces less HC emissions [8-14]. Three way catalytic converters can store oxygen from the exhaust stream, usually when the air fuel ratio goes lean. When insufficient oxygen is available from the exhaust stream the stored oxygen is released and consumed. This happens either when oxygen derived from NO_X emission reduction is unavailable or certain maneuvers such hard acceleration enrich the mixture beyond the ability of the converter to compensate. Rh as a catalyst to release the oxygen atoms stored in NO_X in the reduction reaction. The oxygen atoms made available in the reduction process provide an oxidation environment to oxidize HC and CO [15]. The three main harmful exhaust species, HC, CO, and NO_X are either oxidized or reduced when passing through the catalytic converter.

1.3 Exhaust Gas Recirculation: Exhaust gas recirculation involves diverting a fraction of the exhaust gas into the intake manifold where the re-circulated exhaust gas mixes with the incoming air before being inducted into the combustion chamber[17]. Exhaust gas recirculation is an efficient method to reduce NO_x emissions from the engine. The EGR system is designed to reduce the amount of oxides of nitrogen (NO_x) created by the engine during operating periods that usually results in high combustion temperatures, NO_x is formed in high concentrations whenever combustion temperature exceed about 25000 F. In this recirculation system a portion of an engine's exhaust gases are recirculated back into the engine cylinders. In diesel engines exhaust gas replaces some of the excess oxygen in the combustion chamber. The EGR system reduces NO_x production by recirculation small amount of exhaust gases into the intake manifold where it mixes with the incoming air. By diluting the air mixture under these conditions, peak combustion temperature and pressure are reduced, resulting in an overall reduction of NO_x output. The aim of the present research study is to investigate the effect of EGR on NO_x emissions and performance parameters of indirect injection diesel engines (IDI) fuelled with diesel, JBD and their blends. In this research the engine was operated at high load condition (100% maximum load) and fixed speed 1000 rpm with test fuels for analysis.

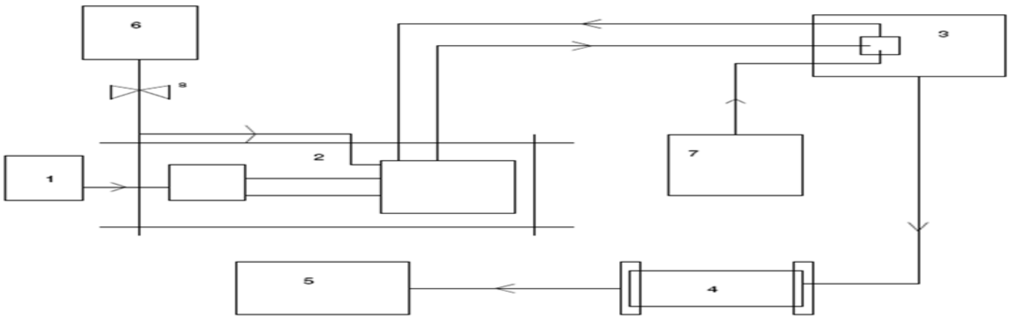
1.4 Both EGR system and Three-way catalytic converter:- The engine system with EGR and three way-catalytic converter is developed to reduce the amount of oxides of nitrogen (NOX) created by the engine during operating periods that usually results in high combustion temperatures[18-21], NOX is formed in high concentrations whenever combustion temperature exceed about 25000 F. After installing the EGR system and three way-catalytic converter on engine the experiment was carried out by fuelling the engine with diesel, JBD, and their blends. The same test matrix, the engine was tested at 100% load, and various EGR rates 0f 5-40% (with 5% increment) with the three way- catalytic converter and data sheet as used before was used to record the observations. The observation of all the parameters is collected at following operating points.

2. METHODOLOGY

2.1 Measurement of Physico-Chemical Properties of JBD, Diesel and Their Blends: The Physico-chemical fuel properties of biodiesel, diesel and their blends has very important role in defining the emissions quality of the fuel. Therefore following properties of JBD, diesel and their blends of different properties are determined. The density of the JBD, diesel and their blends used for the experimentation was found out in the laboratory with the help of hydrometer. The kinematic viscosity of the test fuels was determined with the help of digital rotary viscometer. A bomb calorimeter was used to measure the amount of heat generated when a known amount of matter was burnt in a sealed chamber in an atmosphere of pure oxygen gas. It is a simple inexpensive yet accurate method for determination of heat of combustion, i.e. calorific value.

2.2 Engine Test Procedure:- The applied load on the engine was made zero by withdrawing the plates of loading system fully out and making the current flowing in load circuit to zero. Then the parameters like voltage, current, temperatures of all the 6 points, engine RPM, manometer reading and time for 50 cc fuel consumption is recorded. After recording these parameters the exhaust gas emission parameters like HC, NOx, CO_2, CO were recorded by putting the probe of AVL gas analyzer into the exhaust pipe. For noting down the smoke (opacity) the exhaust gas was directed to AVL smoke meter and the opacity was recorded. After completing all the above data observation work the load on the engine was increased to 100% so that the current flowing through the load circuit is 25 Amp. The engine was allowed to run for about 10-15 minutes to get stabilized. The engine was run to attain the stable condition. After attaining the stable condition the observations were taken at all above mentioned operating points. The engine was run with remaining test fuels like JBD, and their blends for generation of base line data.

The engine was run on different EGR rates 0 to 40% (with incremental value of 5%) for all the above test fuels and at the specified loads. The engine was run with three way-catalytic converter for all the test fuels and at the specified loads. Then the engine was run with the combination of EGR and three way –catalytic converter for all the test fuels and at the specified loads. The maximum NO_X reduction is picked, When engine run with EGR , engine with three – way catalytic converter, and engine with combination of EGR+ three – way catalytic converter. Various performance and emission characteristics were recorded only when stabilized working conditions were achieved. The performance and emission data were duly corrected according to the procedure specified in IS: 10000 (PartIV)-1980 for all test fuels. *2.3 Engine studies:-* The engine used for experimental analysis is a indirect injection (IDI) low speed diesel engine. The engine was mounted on vibration isolators to avoid the excessive vibrations. The coupling of engine and generator is done by V-belt drive power transmission system. The diameters of the pulley mounted on engine and generator was so selected that the engine at designed rpm of 1000 at full load runs the generator at 1500 rpm which is design requirement for this generator to provide rated current and voltage. The electrical loading arrangement was used for loading the engines. The study was carried out by loading the engine at 100% of its rated load. The sub systems of the test rig are integrated and the schematic diagram of experimental test set up is shown below in figure 1.



1. Electrical loading, 2. Single cylinder 4-stroke diesel engine & Alternator 3. Exhaust gas recirculation system 4. Three way catalytic converter, 5. Gas analyzer & Smoke meter 6. Fuel tank, 7. Air drum.

Figure 1. Schematic diagram of EGR and three way catalytic converter system.

Figure 2. Single cylinder IDI diesel engine.

Table 4.2: Specification of single cylinder IDI diesel Engine

Sl. No.	Particulars	Specifications
1	Make	Field marshal Diesel engines
2	Model	FM-4
3	Rated Brake Power (BHP/kW)	10/7.35110
4	Rated speed (rpm)	1000
5	Number of cylinder	One
6	Bore x Stroke (mm)	120x139.7
7	Compression ratio	17:1
8	Coling System	Water Cooled
9	Lubrication System	Forced Feed
10	Cubic Capacity	1580 cc
11	Nozzle	DL30S1202MICO

3. Results And Discussion

Experiments were carried out with an objective of reduction of NOX emissions of IDI diesel engine when JBD, diesel and their blends fuelled in it with the controlling method of the combination of EGR+three-way catalytic converter. For a test fuel like JB 100 having lower NOX emissions at 5% EGR+ three-way catalytic converter, JB 80 having lower NOX emissions at 40% EGR+ three-way catalytic converter, JB 60 having lower NOX emissions at 40% EGR+ three-way catalytic converter, JB 40 having lower NOX emissions at 40% EGR+ three-way catalytic converter, JB 20& diesel and having lower NOX emissions at 35% EGR+ three-way catalytic converter other emissions are in acceptable range without specific changes of brake thermal efficiency compared to other controlling methods.

3.1 The Combined Effect of Three-way Catalytic Converter and EGR Rates on Brake Thermal Efficiency:- Figure 3. shows thermal efficiency of Diesel, JBD and their blends with the combination of distinct EGR rates and three - way catalytic converter of specified loads. The reduction in thermal efficiency only with EGR due to the dilution of the fresh charge with the exhaust gas which results in flame velocity and hence deterioration of the combustion and lead to incomplete combustion of fuel. Three-way catalytic converter is connected to the engine in an open loop model due to this no effect on brake thermal efficiency.

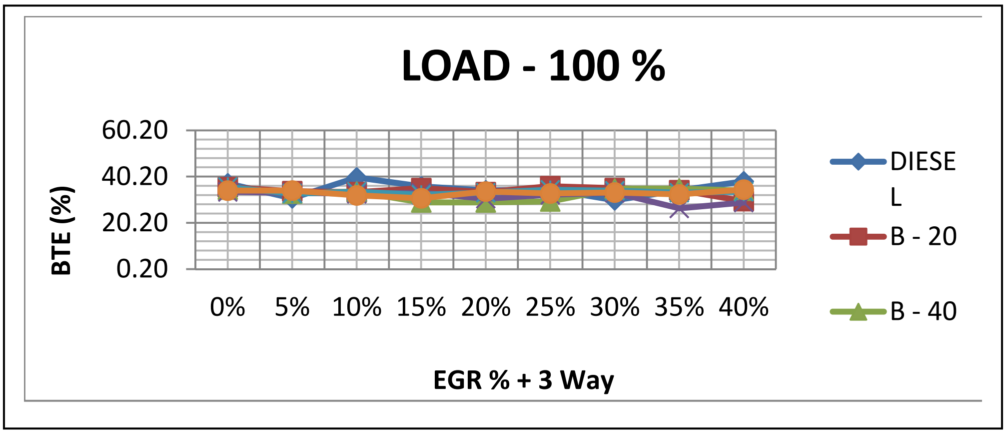


Figure 3. BTE variation with EGR rate + three-way catalytic converter.

3.2 The Combined Effect of Three-way Catalytic Converter and EGR Rates on Brake Specific Fuel Consumption:- Figure 4. shows brake specific fuel consumption of diesel, JBD and their blends with the combination of distinct EGR rates and three way catalytic converter of specified loads. The increase in BSFC only with EGR due to lower calorific value and high viscosity. Three - way catalytic converter is connected to the engine in an open loop model due to this no effect on brake specific fuel consumption. For JB 100 fuel the best NOX emission reduction observed at the combination of 5% of EGR rate and three way catalytic converter.

Here no significant change in BSFC. For other test fuels like JB80, JB60, JB40, JB20 and diesel fuels the best NOX emission reduction observed at the combination of 35% to 40% of EGR rate and three-way catalytic converter.

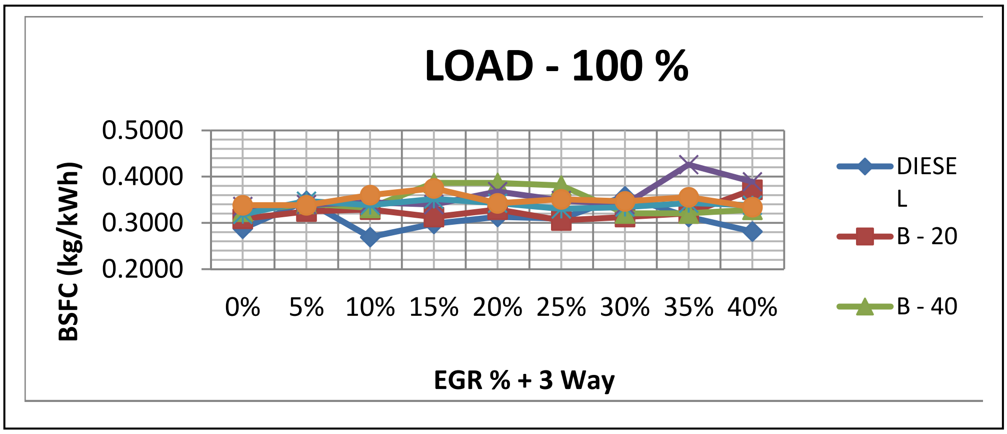


Figure 4. BSFC variation with EGR rate +three-way catalytic converter.

3.3:The Combined Effect of Three-way Catalytic Converter and EGR Rates on NOX Emissions:- Figure 5. shows NOX emissions of diesel, JBD and their blends with the combination of distinct EGR rates and three - way catalytic converter of specified loads. The NOX emissions with the combination of EGR rate and three-way catalytic converter are compared without using EGR rate and three - way catalytic converter at different loads. Here EGR acts as pre-catalyst. The location of the pre-catalyst connected to the engine's exhaust manifold enables decreasing the pollutant concentrations, during the engine's operation. This allows reduce the burden on the in three way catalytic converter. This may be the reason for the maximum amount of NOX reduction occurs by using of EGR+ three-way catalytic converter controlling method.

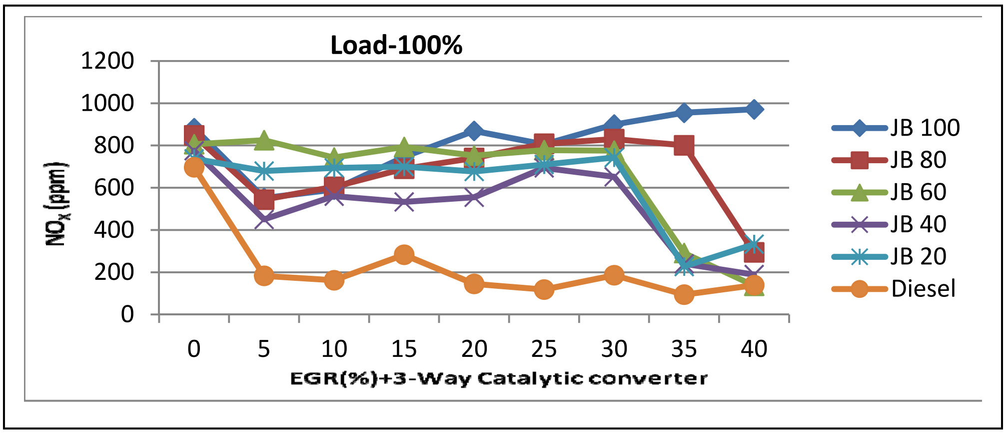


Figure 5. NO_X emission variation with EGR rate +three-way catalytic converter.

3.4: The Combined Effect of Three-way Catalytic Converter and EGR Rates on Carbon monoxide Emissions:- Figure 6. shows CO emissions of diesel, JBD and their blends with the combination of distinct EGR rates and three way catalytic converter at specified loads. In this study EGR connected to engine manifold and then followed by three way catalytic converter. The combination of EGR + three-way catalytic converter have proved that insignificant change in the reducing the carbon monoxide emissions for diesel, JBD and their blends. The values of CO emission were low because the compression ignition engines operate on lean side of the stoichiometric and therefore produce very little CO emission. The combination of EGR rate and three way catalytic converter controlling method is not much effect on CO emission reduction for diesel engines.

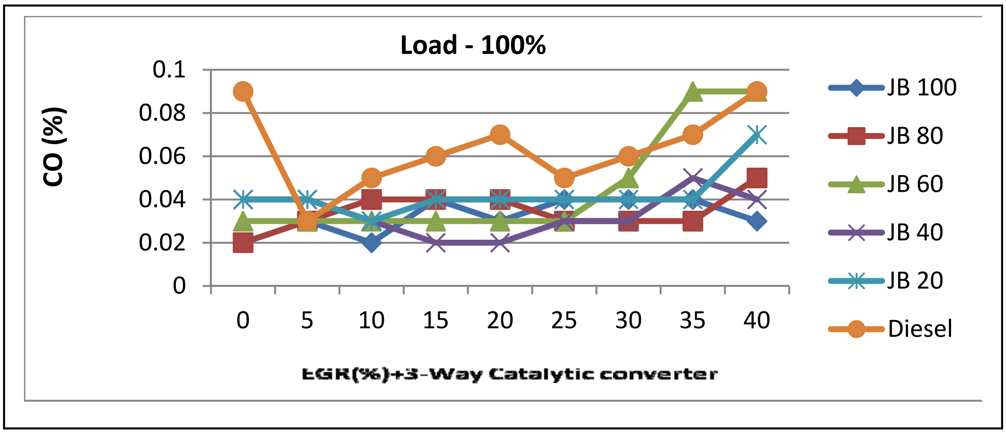


Figure 6. CO variation with EGR rate +three-way catalytic converter

3.5: The Combined Effect of Three-way Catalytic Converter and EGR Rates on Carbon dioxide Emissions:- Figure 7. shows CO2 emissions of diesel, JBD and their blends with the combination of distinct EGR rates and three - way catalytic converter at specified loads. The CO2 emissions with the combination of EGR rate and three- way catalytic converter are compared without using EGR rate and three - way catalytic converter at different loads. The combinationof EGR + three-way catalytic converter have proved that significant change in the carbon dioxide emissions for all test fuels except JB 100 fuel. The combination of EGR rate and three way catalytic converter controlling method is not much effect on CO2 emission reduction for diesel engines.

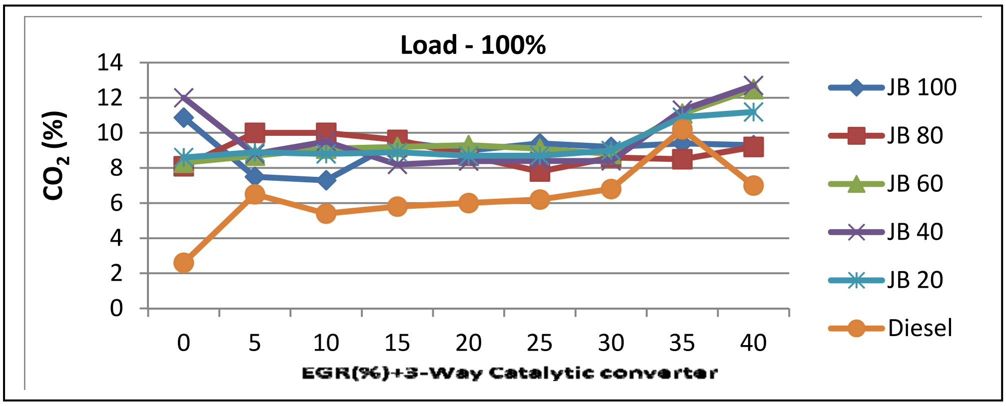


Figure 7. CO_2 variation with EGR rate + three – way catalytic converter

4. Conclusions

The objective of the research work was to effectively reduce the NO_X emissions with the combination of EGR + three-way catalytic converter. These controlling devices are connected to the IDI diesel engine to measure NO_X emission when diesel, Jatropha Biodiesel (JBD) and their blends are fuelled in the engine at 100% load. The data of existing engine was considered as a baseline and analysis was done by comparing the baseline data of engine with emission controlling devices.

- Diesel fuel have lower NO_X emissions at load of when compared to JBD and their blends. It is quite obvious, that biodiesel addition to diesel implies more amount of oxygen present in the combustion chamber, leading to formation of large quantity of NO_X in JBD and their blends fueled engines. For JBD and their blends (JB 100, JB 80, JB 60, JB 40, and JB 20) the maximum amount of NO_X produced at full load (i.e 882, 848, 806, 775, 737 ppm respectively) is comparable to diesel fuel (697 ppm).
- Diesel and JB 20 the better trade- off between smoke opacity and NO_X emission can be attained with the combination of EGR (35 %) +three way-catalytic converter controlling method without any significant change in brake thermal efficiency.
- At full loads for JB 40,JB 60 and JB 80 the combination of EGR (rate is 40 %) +three way-catalytic converter controlling method was preferable to reduce the NO_X emissions.
- Engine fueled with JB 100 fuel at 100% load employing the combination of EGR(rate is 5%)+three way-catalytic converter controlling method was able to reduce the NO_X emission with the insignificant change in smoke opacity and brake thermal efficiency. It may due to the combined effect of EGR and three way- catalytic converter.

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Nomenclature

JB Jatropha bio-diesel

JB 20 20% Jatropha/ 80% diesel

JB 40 40% Jatropha/ 60% diesel

JB 60 60% Jatropha/ 40% diesel

JB 80 80% Jatropha/ 20% diesel

JB100 100%Jatropha

EGR Exhaust gas recirculation

NO Oxides of Nitrogen

Three-way catalytic converter.

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