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Effect of Exhaust Gas Recirculation on The Performance and Emission Charecteristics of Calophyllum-Inophyllum Biodiesel Fuelled Di-Ci Engine

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Abstract

In the present investigation, the experimental work was carried out to study the influence of the exhaust gas recirculation on the performance and emission characteristics of the biodiesel fuelled diesel engine and compared with those of diesel by recirculation of the exhaust gas at the inlet valve. The experimental works were conducted by varying the exhaust gas flow rate in terms of percentage followed by 10 %, 20% and 30% for B20 biodiesel and neat diesel. The performance and emission characteristics of the engine were discussed for both the diesel and B20 Calophyllum-Inophyllum biodiesel fuels. The results were reveled that the IP, ME, brake thermal efficiency, indicated thermal efficiency decreases for B20 Calophyllum-Inophyllum biodiesel than compared to diesel fuel and the emissions of CO, CO2, NOx and HC were found to be lower with B20 biodiesel for without EGR. However, with the increase of EGR flow rates resulted in considerable rise in CO, CO2 and HC emissions for both diesel fuel and B20 biodiesel whereas NOx emissions simultaneously reduces in larger quantity. Therefore EGR method is the effective way to reduce the NOx emission which is harmful to the environment.

Keywords:

Diesel engine;
NO_x;
EGR;
BTE;
SFC;
Calophyllum-Inophyllum;
biodiesel;

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1. Introduction

The global scenario is confined with twin crisis of fossil fuel depletion and environmental degradation. The excessive extraction and lavish consumption of fossil fuels have led to reduction of underground based carbon resources. This has led to the search for an alternative fuel, which promises sustainable development, energy conservation, efficiency and environmental preservation. The search for energy independence and concern for a cleaner environment have created significant interest in biodiesel, despite its shortcomings. The use of biodiesel in diesel engines has both economic and environmental benefits. Biodiesel is an alternative diesel fuel which can be obtained from the transesterification of vegetable oils or animal fats. The use of biodiesel in diesel engines does not require any engine modification. An important property of biodiesel is its oxygen content which is usually not contained in diesel fuel. Biodiesel gives considerably lower emissions of PM, Carbon Monoxide (CO) and Hydrocarbon (HC) without any extra fuel consumption or engine performance penalties. Exhaust Gas Recirculation (EGR) can be used with biodiesel in the diesel engines.

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EGR is an effective technique of reducing NO_x emissions from the diesel engine exhaust. Many researchers were studied the performance and emission characteristics of biodiesel fueled diesel engine and few were discussed here. A.K. Agrawal et al. [1] suggested that in diesel engines NO_x formation is very much depends upon temperature. To reduce NO_x emission in the exhaust, it is necessary to keep combustion temperature under control. Yokomura et al. [2] have explained that exhaust gas recirculation is one of the most effective ways for nitrogen oxides reduction process. Ladommatos et al. [3] tested the effect of exhaust gas recirculation on diesel engine emissions. They noticed a large reduction in NO_x emissions at the expense of higher particulate and un-burnt hydrocarbon emissions. D.Agarwal [4] suggested that controlling the NO_x emissions primarily requires reduction of in-cylinder temperatures. Y. Yoshimoto [5] reported that the application of EGR results in higher fuel consumption and emission penalties, also EGR increases HC, CO, and PM emissions along with slightly higher specific fuel consumption. Zheng, G. T. Reader et al. [6] have studied the effect of EGR on NO_x emission and reported that the EGR rates are sufficient for high load, also as the load increases; diesel engines tend to generate more smoke because of reduced oxygen. Therefore, EGR, although effective to reduce NO_x, further increases the smoke and PM emissions. Abu-Jrai et al, [7] have analyzed the effect of exhaust gas recirculation (EGR) on pollutant emission in diesel engine. Santoh et al. [8] carried out experiment on a naturally aspirated single cylinder DI diesel engine with various combinations of EGR, fuel injection pressures, injection timing and intake gas temperatures affect the exhaust emissions, and they found that NO_x reduction ratio has a strong correlation with oxygen concentration regardless of injection pressure or timing. EGR lowers the average combustion temperature and reduces the oxygen intake gases that adversely affect the smoke emission and soot formation. They also suggested that for a given level of oxygen concentration the cooled EGR reduces more NO_x with less EGR rates than does at hot EGR.

Saravanan et al. [9] performed a series of test on a single cylinder water cooled DI diesel engine with hydrogen was used as dual fuel mode with EGR technique. They reported increase in brake thermal efficiency and lowered smoke level, particulate and NO_x emissions due to absence of carbon in hydrogen fuel. Hountalas et al. [10] have presented 3D-multi dimensional model to examine the effect of EGR temperature on a turbocharged DI diesel engine with three different engine speeds. They reported that high EGR temperature affects the engine brake thermal efficiency, peak combustion pressure, air fuel ratio and also soot emissions, and the combined effect of increased temperature and decreased O_2 concentration resulted low NO_x emissions. Also they suggested that EGR cooling is necessary to retain the low NO_x emissions and prevent rising of soot emissions without affecting the engine efficiency at high EGR rates. Abd-Alla et al. [11] have done experiments on a dual fuel (gaseous fuel- methane with diesel as pilot fuel) mode direct injection diesel engine to study the effect of inlet air temperature by the way of mixing of hot EGR and addition of diluents gas such as CO_2 and N_2 .They observed that the addition of CO_2 gas in the intake charge increased un-burnt hydrocarbon emission (UBHC) but moderate reduction of NO_x emission. By increasing the intake charge temperature NO_x emission was increase with decrease in UBHC. Gurumoorthy S. Hebbar and Anant Krishna Bhat [12], were reported that the thermal efficiency decreases as EGR percentage increase for all cases of EGR cooling. It is clearly observed that cooling of EGR slightly improves the efficiency after 30% EGR. Engine torque and brake power slightly reduces as the percentage of EGR increases for all cases of EGR cooling. Mukesh Rameshbhai Zala [13], studied the engine performance and emission by varying EGR Rate (0- 40%) and optimum EGR Rate for the naturally aspirated engine is found out by taking the performance and emission readings at varying load conditions and at 1500 rpm.. The evaluation of experimental data showed that NO_x emission was reduced by about 80% because of EGR. Avinash Kumar Agrawal et al.,[14] investigated and demonstrate the effects of various EGR rates on exhaust emissions from the engine. A long route partially cooled EGR system was choosen. Experiments were carried out by using a setup to prove the efficiency of EGR as a technique for NO_x reduction. It is seen that the exhaust gas temperatures are reduce drastically by employing EGR. Hussain. J et al., [15], they conducted an experimental study on a two cylinder 4 Stroke, 52 HP, 1500 rpm constant speed diesel engine generator set to study the effect of EGR on the performance and emissions of diesel engine components. The results were shown that UHC can be reduced by 20 to 25% from this method. V.Manieniyan and S.Sivaprakasam [16], conducted the experimental analysis of exhaust gas recirculation on DI diesel engine operating with biodiesel they used EGR technique in the diesel engine with B20 biodiesel as fuel with EGR and without EGR at various level (5%, 10%, 15%, and 20%). The result shows that NO_x emission is reduced using EGR for diesel and bio diesel. Donepudi Jagadish, et al., [17] they reported that, effect of EGR is to increase the fuel consumption of the engine; EGR is the best method to reduce the NOx emission. The main objective of the present work is to investigate the effect of exhaust gas re-circulation on the engine performance and exhaust emission for B20 Calophyllum-Inophyllum biodiesel and diesel fuel. The experiment was carried out in a four stroke single cylinder, water cooled diesel engine using diesel and B20 biodiesel at 1500 rpm and different EGR rates to study the effect of EGR on the performance of the engine like brake thermal efficiency and specific fuel consumption and emission characteristics like HC, CO, CO_2 and NO_x emissions.

2. Preparation of biodiesel:

Calophyllum Inophyllum, is known as Tamanu Seed, is the bio oil used as biodiesel to find the performance and emission characteristics of CI engine. Esterification process was performed on the oil and a refined form was produced. This refined form of the bio oil was later subjected to transesterification and the finally biodiesel was obtained. This biodiesel has slightly reduced carbon emission and a similar efficiency to that of diesel. The property comparison of biodiesel and diesel shown in Table 1.

Fig. 1: Tamanu Plant, seed and Tamanu oil

Table 1: Properties of biodiesel and diesel

Properties	Biodiesel	Diesel
Flash point	$160^{O}C$	52
Fire point	$162^{O}C$	58
Kinetic viscosity @ $25^{O}C$	13.5Cst	6Cst
Gross calorific value	9203.0Cal/g	10516.252Cal/g
Net calorific value	8573.0Cal/g	10157.744Cal/g
Specific gravity@$15^{O}C$	0.906	0.83
Free fatty acid	1.95%	-

3. Exhaust gas recirculation system

In exhaust gas recirculation process, the engine exhaust gas is recirculated to the engine. Inter-mixing the incoming air with recirculated exhaust gas basically cuts off some percentage of the oxygen going into the combustion chamber and lowers the adiabatic flame temperature. The exhaust gas increases the specific heat of the mixture and lowers the peak combustion temperature. NO_x formation progresses faster at higher temperatures. EGR serves to limit the formation of NO_x. There is no doubt that EGR is very effective in reducing oxides of nitrogen, but it also has adverse effects on the engine efficiency. As it contains a lot of particulate matter, it may also contaminate the lubricating oil and can also foul the intake manifold [6]. So in the present work exhaust gas is recirculated at the inlet by varying the % of EGR to the performance and emission charecteristics of the B20 biodiesel fueled DICI engine. [18]. The specification of Exhaust gas analyzer shown in Table 2.

Table 2: Gas Analyzer Specification

Sl. No.	Parameters	Resolution
1	Model	AVL DI GAS 444 N (Five Gas Analyser)
2	CO (0-15% Vol)	0.0001% Vol
3	HC (0-20000 ppm Vol)	1ppm/10ppm
4	CO_2 (0-20% Vol)	0.1%Vol
5	O_2 (0-25% Vol)	0.01%Vol
6	NOx (0-6000 ppm Vol)	1ppm Vol

4. Experimentation procedure:

A single-cylinder, four-stroke, water cooled, and naturally aspired direct injection diesel engine was used and shown in the figure 2. The table 3 indicates the engine specifications. The test was conducted firstly with diesel fuel and when the engine reached the operating temperature, it was loaded with DC machine. The fuel consumption was measured with burette with 10 ml volume and a stopwatch. The mass flow rate (kg/hr) was calculated from volumetric flow and fuel density. Smoke density was measured with the help of a smoke-meter which was connected to the exhaust. The same setup is used for testing of B20 biodiesel. The DICI engine was operated for diesel, B20 biodiesel, D-10%EGR, D-20%EGR, D-30%EGR, B20-10%EGR, B20-20%EGR and B20-30%EGR for studying the performance in terms of IP, BTHE, ITHE, ME, SFC and CO, HC, CO_2 and NOx emission quality. The experimental results were discussed in the next section.

Fig. 2: DI-CI Engine Test Rig

Table 3: Engine Specifications

Sl. No.	Parameters	Dimensions
1	Type	Four stroke, single cylinder vertical water-cooled Diesel Engine
2	Rated power	5.2 kW
3	Rated speed	1500 rpm
4	Bore diameter (D)	87.5 mm
5	Stroke length (L)	110 mm
6	Compression Ratio	17.5: 1
7	C.V of Diesel	42,000 kJ/kg
8	Density of Diesel	830 kg/m^3
9	C.V of Blend B20	4178.6 kJ/kg
10	Density of Blend B20	845 kg/m^3

5. Results and Discussions

5.1 *Performance of DICI engine*

Figure 3 illustrates the variation of the IP on engine load for diesel and B20 biodiesel by varying the percentage of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^O bTDC. The IP enhances as the load increases on the engine. The IP was higher for diesel compared to B20 biodiesel and also IP was higher for diesel with EGR compared to B20 biodiesel with EGR for all percentage of loads. The IP decreases by 2.42% when the diesel is replaced by B20 biodiesel. The IP decreases by 2.14% when the diesel is replaced by B20 biodiesel with 10% EGR at 100% engine load. This is due to low heating value and high viscosity nature in B20 fuel and EGR rate.

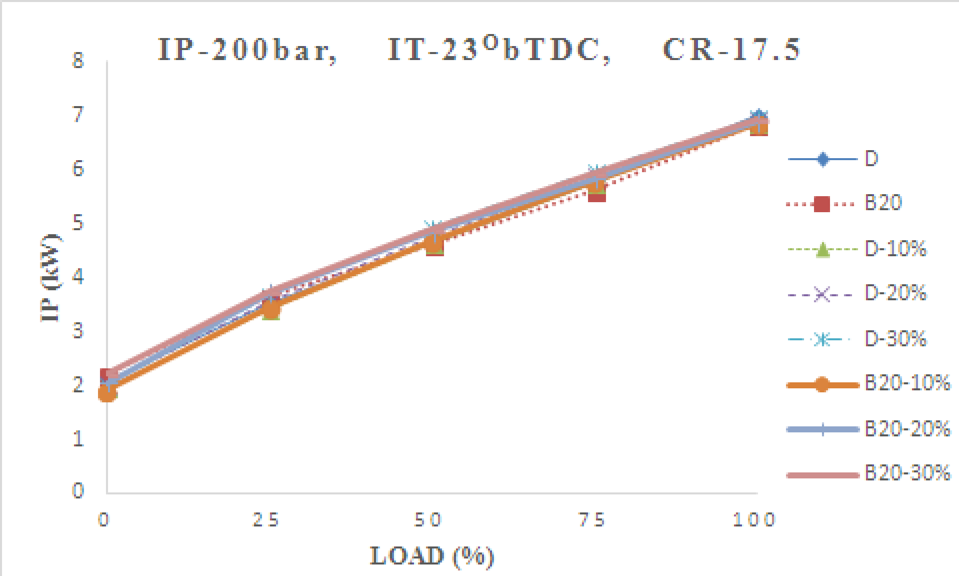

Fig. 3: Variation of IP on load for diesel and B20 biodiesel with different % of EGR

Figure 4 illustrates the variation of the ITHE on engine load for diesel and B20 biodiesel by varying the percentage of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^{O} bTDC. The ITHE declines as the load increases on the engine. The ITHE was higher for diesel compared to B20 biodiesel. The ITHE decreases by 4.78% when the diesel is replaced by B20 biodiesel. The ITHE decreases when the diesel is replaced by B20 biodiesel with 10% EGR while ITHE decreases by 5.92% when the B20 biodiesel is replaced by B20 biodiesel with 10% EGR at 100% engine load. This effects due to less Indicated power and higher fire point temperature.

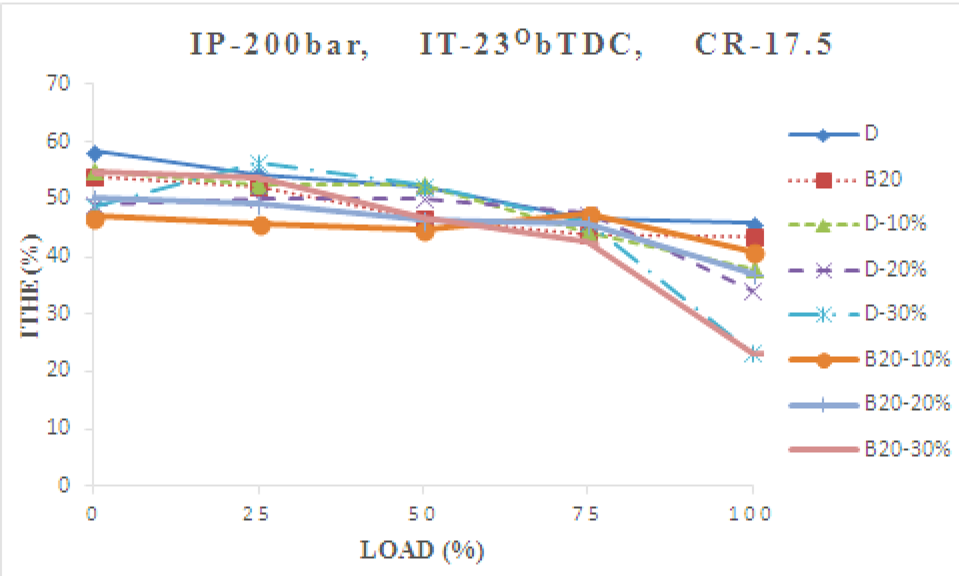

Fig. 4: Variation of ITHE on load for diesel and B20 biodiesel with different % of EGR

Figure 5 illustrates the variation of the BTHE on engine load for diesel and B20 biodiesel by varying the percentage of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^{O} bTDC. The BTHE enhances as the load increases on the engine. The BTHE was higher for diesel compared to B20 biodiesel. The BTHE decreases by 2.85% when the diesel is replaced by B20 biodiesel. The BTHE decreases by 10.11% when the diesel is replaced by B20 biodiesel with 10% EGR while BTHE decreases by 7.47% when the B20 biodiesel is replaced by B20 biodiesel with 10% EGR at 100% engine load. This is due to high density of B20 fuel.

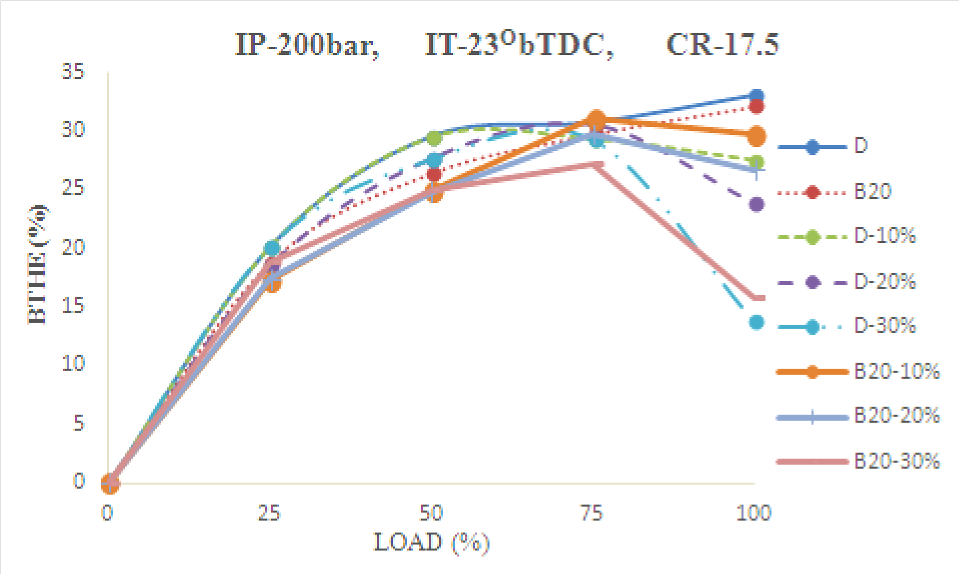

Fig. 5: Variation of BTHE on load for diesel and B20 biodiesel with different % of EGR

Figure 6 illustrates the variation of the ME on engine load for diesel and B20 biodiesel by varying the percentage of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^{O} bTDC. The ME enhances as the load increases on the engine. The ME decreases by 1.92% when the diesel is replaced by B20 biodiesel. The ME decreases by 13.9% when the diesel is replaced by B20 biodiesel with 10% EGR while BTHE decreases by 0.33% when the B20 biodiesel is replaced by B20 biodiesel with 10% EGR at 100% engine load. This is due to duel reduction in brake power and indicated power.

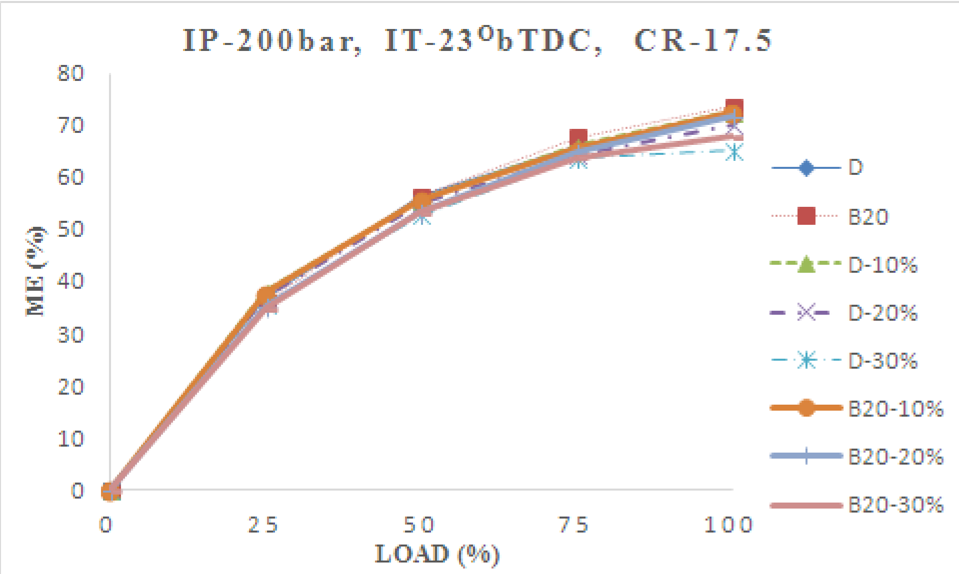

Fig. 6: Variation of ME on load for diesel and B20 biodiesel with different % of EGR

Figure 7 illustrates the variation of the SFC on engine load for diesel and B20 biodiesel by varying the percentage of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^{O} bTDC. The SFC declines as the load increases on the engine. The SFC decreases by 3.85% when the diesel is replaced by B20 biodiesel. This is due to high viscosity of biodiesel. The SFC decreases by 7.69% when the diesel is replaced by B20 biodiesel with 10% EGR while SFC increases by 3.7% when the B20 biodiesel is replaced by B20 biodiesel with 10% EGR at 100% engine load.

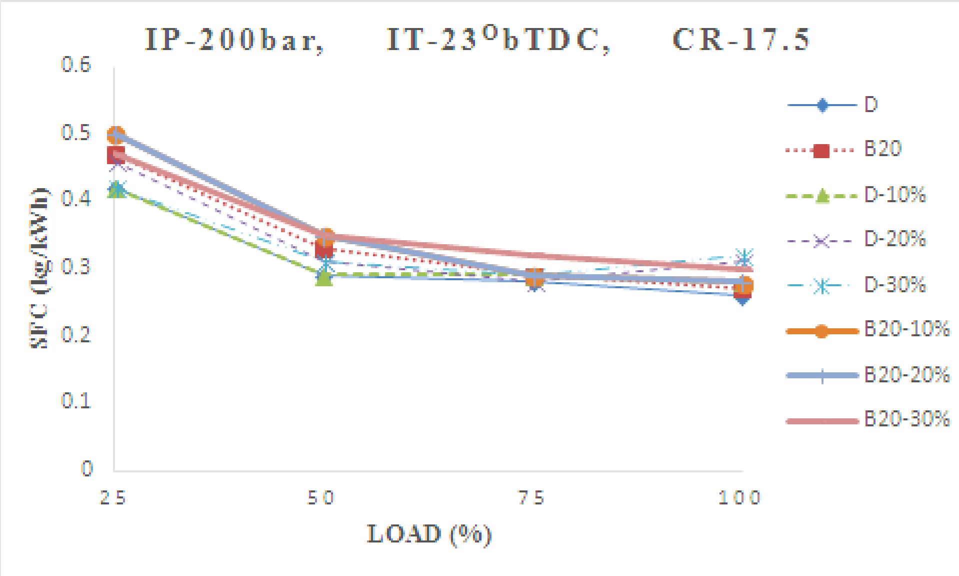

Fig. 7: Variation of SFC on load for diesel and B20 biodiesel with different % of EGR

5.2 Emission charecteristics of DICI engine

Figure 8 illustrates the variation of the CO emissions on engine load for diesel and B20 biodiesel by varying the percentage of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^O bTDC. The CO emissions enhances as the load on the engine increases. The CO emission decreases by 6.22% when the diesel is replaced by B20 biodiesel. This is due to high oxygen availability in biodiesel. The CO emission increases when the diesel is replaced by B20 biodiesel with 10% EGR while CO emission increases when the B20 biodiesel is replaced by B20 biodiesel with 10% EGR at 100% engine load. The CO emissions were enhances as the percentage of EGR increases with diesel and with B20 biodiesel for all engine loads. This is because of less oxygen availability at the inlet manifold during exhaust gas recirculation.

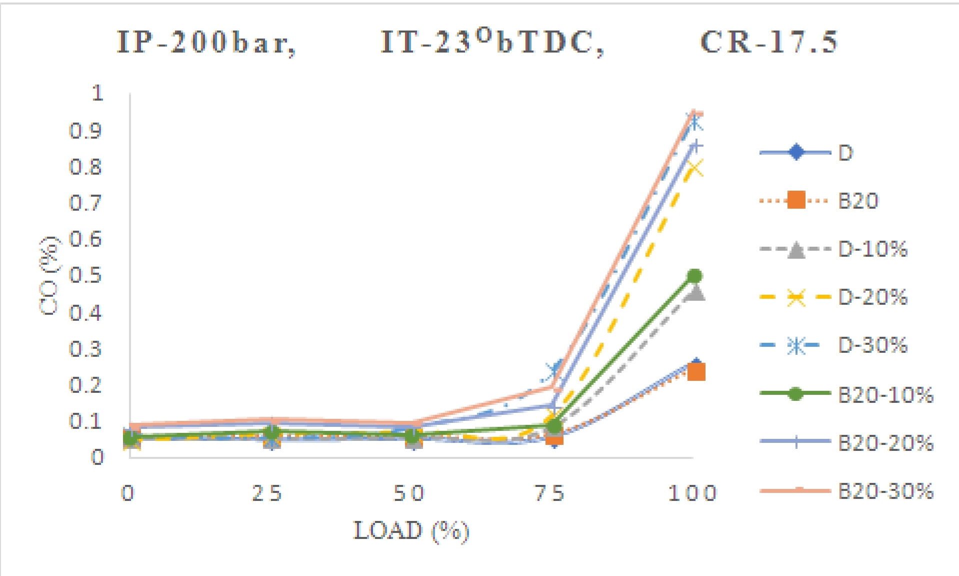

Fig. 8: Variation of CO emissions on load for diesel and B20 biodiesel with different % of EGR

Figure 9 shows the variation of the HC emissions on engine load for diesel and B20 biodiesel for different % of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^O bTDC. The HC emissions enhances as the load on the engine increases. The HC emission decreases by 16.32% when the diesel is replaced by B20 biodiesel. This is also due to complete combustion and less carbon content in biodiesel. The HC emission increases when the diesel is replaced by B20 biodiesel with 10% EGR while HC emission increases when the B20 biodiesel is replaced by B20 biodiesel with 10% EGR at 100% engine load. The HC emissions were enhances as the percentage of EGR increases with diesel and with B20 biodiesel for all engine loads.

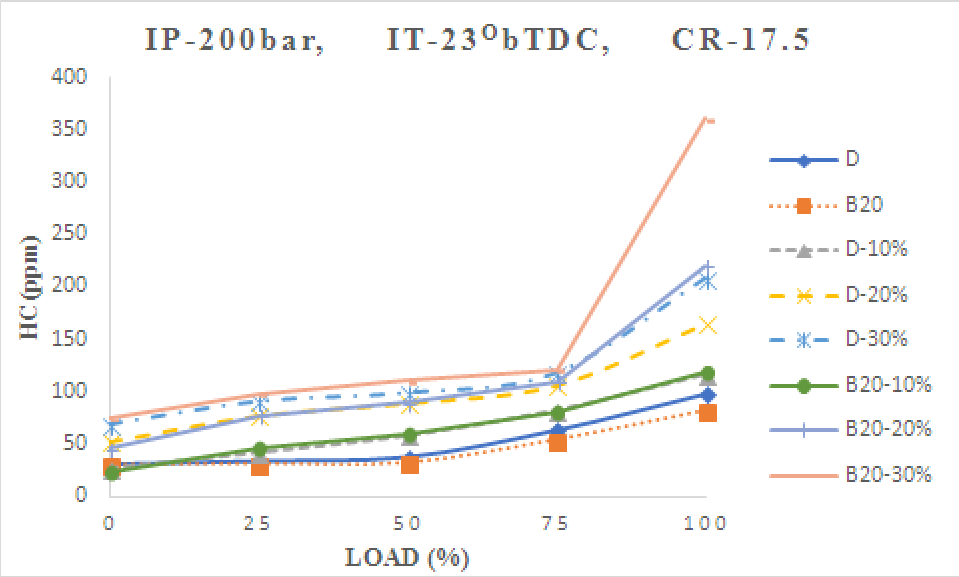

Fig. 9: Variation of HC emissions on load for diesel and B20 biodiesel with different % of EGR

Figure 10 illustrates the variation of the CO_2 emissions on engine load for diesel and B20 biodiesel by varying the percentage of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^{O} bTDC. The CO_2 emissions enhances as the load on the engine increases. The CO_2 emission decreases by 3.93% when the diesel is replaced by B20 biodiesel. The CO_2 emission increases by 15.53% when the diesel is replaced by B20 biodiesel with 10% EGR while CO_2 emission increases when the B20 biodiesel is replaced by B20 biodiesel with 10% EGR at 100% engine load. The CO_2 emissions were enhances as the percentage of EGR increases with diesel and with B20 biodiesel for all engine loads.

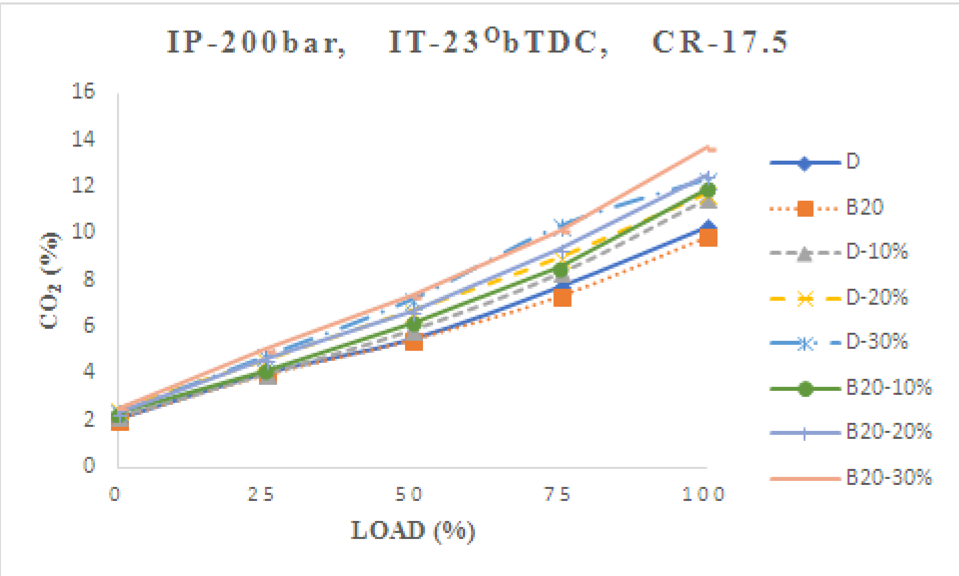

Fig. 10: Variation of CO_2 emissions on load for diesel and B20 biodiesel with different % of EGR

Figure 10 illustrates the variation of the NOx emissions on engine load for diesel and B20 biodiesel by varying the percentage of EGR from 10% to 30% at IP of 200 bar, CR of 17.5 and IT of 23^{O} bTDC. The NOx emissions enhances as the load on the engine increases to 75% then further NOx emission decreases as the engine load enhances. The NOx emission decreases by 0.2% when the diesel is replaced by B20 biodiesel. The NOx emission decreases by 34.32% when the diesel is replaced by B20 biodiesel with 10% EGR while NOx emission decreases by 33.02% when the B20 biodiesel is replaced by B20 biodiesel with 10% EGR at 100% engine load. The NOx emissions were declines as the percentage of EGR increases with diesel and with B20 biodiesel for all engine loads. This is high specific heat in mixture which reduces the rise in temperature during combustion.

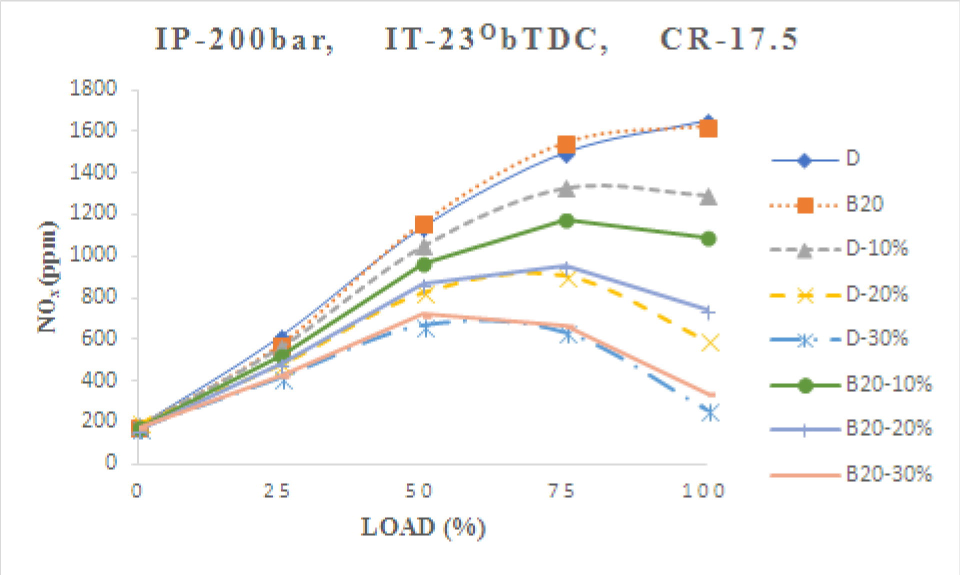

Fig. 11: Variation of NOx emissions on load for diesel and B20 biodiesel with different % of EGR

6. Conclusion

An experimental investigation was done on a single cylinder four stroke, water cooled diesel engine operated on diesel fuel and B20 Calophyllum-Inophyllum biodiesel with exhaust gas recirculation at different proportion such as 10%, 20% and 30%. The effect of EGR on the performance and exhaust emissions of the diesel engine were analyzed. The results of this study may be concluded as follows:

- When the engine was operated with B20 biodiesel, IP, ME, brake thermal efficiency, indicated thermal efficiency decreases due to the lower calorific value and high viscosity of B20 Calophyllum-Inophyllum biodiesel compared to diesel fuel. The brake thermal efficiency was slightly higher at low EGR rates for both the fuels. However, increasing EGR flow rates to high levels resulted in decrease in brake thermal efficiency.
- The specific fuel consumption for B20 Calophyllum-Inophyllum biodiesel was slightly lower than the diesel fuel at all loading conditions when operated with and without EGR. This is may be due high viscosity and density of B20.
- It is observed from the results that the B20 Calophyllum-Inophyllum biodiesel emits lower NOx than diesel fuel at all loading conditions. The NOx emissions were decreased with increase in EGR flow rate for both diesel fuel and B20 biodiesel.
- The emissions of CO, CO_2 and HC were found to be lower with B20 Calophyllum-Inophyllum biodiesel. However, with the increase of EGR flow rates resulted in considerable rise in CO, CO_2 and HC emissions for both diesel fuel and B20 biodiesel may due to oxygen availability and carbon content in the fuel.

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