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Effect of Exhaust Gas Recirculation (EGR) on Diesel Engine using *Simarouba glauca* Biodiesel Blends

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***Abstract* –** This article deals with the usage of non-edible *Simarouba glauca* (paradise) oil as a biodiesel for single cylinder diesel engine with application of exhaust gas recirculation (EGR) rates. Biodiesel blends B10, B20 with EGR rates of 10%, 15%, and 20% are used for different load conditions. Parameters like brake thermal efficiency (BTE), nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC) and smoke opacity were evaluated from the experimental study.

The results show that *Simarouba glauca* biodiesel usage decreases HC, CO and smoke emissions with slight increase of NOx, also an improvement in the performance was observed for B10 blend. EGR rates 10% and 15% are beneficiated in terms of performance and emission but negative trend is observed for 20% EGR rate. On the whole it is concluded that a better trade-off between NOx and other emissions is attained with simultaneous application of EGR (15%) and biodiesel blend (B10) without compromising engine performance.

***Keywords* –** Biodiesel, Break Thermal Efficiency (BTE), diesel engine, EGR and emissions.

1. INTRODUCTION

The rapid population growth, together with high rate of urbanization and industrialization has resulted in an increase of motorized transport. The transport sector depends purely on crude oil sources, which deposition may dry up in the coming decades [1]. Compared to traditional gasoline engines, diesel engines are widely used in transportation and power generating sectors due to their very favorable thermal efficiency, durability, and low specific fuel consumption [2],[3], but diesel engines churn out harmful and hazardous emissions like particulate matter (PM) and nitrogen oxides (NOx) [2], [4]. Its end users applications include railway, road, agriculture, and captive generation which are concentrated mostly in urban areas. Hence, the ongoing vehicle population explosion has placed a great strain on the world's environment causing serious air pollution, especially in metro cities. Bio-origin renewable fuels which can be produced from resources which are available locally such as vegetable oil, biodiesel or alcohols may provide feasible solutions to the present crises [1], [5].

Biodiesel fuel usage as alternative fuel would reduce the demand gap produced due to forecasted shortage of fossil diesel fuels. Biodiesel fuel is renewable and the fuel-borne oxygen in biodiesels may promote a more complete combustion when compared with conventional diesel fuels [1]-[4].

Simarouba Glauca as Biodiesel

The biodiesel used in the present work is named paradise oil because it is derived from the multipurpose paradise tree; its botanical name is *Simarouba glauca*, and it can be grown on degraded agriculture land.

Paradise tree is flexible to a wide range of temperature variations and altitudes. This tree can yield 2000–2500 kg oil/hectare/year [6], [7]. It is most commonly known as Laxmitaru, Simaba or Maruba in most parts of India. The blending of biodiesel has been done by volume basis where 10% is referred to as B10 and 20% as B20.

2. LITERATURE REVIEW

Labeckas and Slavinskas [9] tested the four-cylinder naturally aspirated diesel engine using biodiesel prepared from rapeseed oil and presented the comparative bench testing results with RME and its blends of 5%, 10%, 20%, and 35% with diesel fuel. B05 and B10 blend showed improved thermal efficiency compared to other blends.CO, HC, and soot emissions decreased, while oxide of nitrogen emissions increased for rapeseed oil methyl ester compared to diesel.

Musculus *et al*. [10], analyzed that low combustion temperatures are attained by utilizing EGR, ignition in conjunction with the fuel injection event and he reviewed that the emission targets can be achieved by using easily applicable exhaust gas recirculation technique and this can reduce the burden of using exhaust gas after treatment systems to end user customers.

According to Demirbas [11] in the review on progress and recent trends in biodiesel fuels, blends up to 20% biodiesel mixed with petroleum diesel fuels can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment [12], [13].

Neat biodiesel and biodiesel blends reduced PM, HC and CO emissions and slightly increased NOx emissions compared with petroleum-based diesel fuel used in an unmodified diesel engine.

Hoekman *et al.* [14] reviewed the effect of biodiesel on NOx emissions and stated that thermal NOx rate generation was high in the cylinder and was believed to be the predominant contributor to total NOx.

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Biodiesel gives higher flame temperature than conventional diesel and hence use of EGR is necessary when using biodiesel. EGR effectively reduces in-cylinder temperatures.

Agarwal *et al.* [15], [16] investigated the effects EGR rates on twin cylinder direct injection air cooled diesel engine running at 1500 rpm. It was found that BTE increased slightly at lower loads with EGR due to reburning of HCs and is unaffected at higher loads. Emissions HC, CO and smoke opacity increased when the engine is operated with a higher amount of EGR. But the main benefit of EGR is that it helps in reducing NOx emissions from the diesel engine.

Saleh [17], in his studies used the jojoba methyl ester (JME) as a renewable fuel in two cylinder diesel engine. The study mainly focused to quantify the efficiency of exhaust gas recirculation. The tests results show that EGR is an effective technique for reducing NOx emissions with JME fuel especially in light-duty diesel engines with a very little penalty of fuel economy. Dommatos *et al.* [18] in particular investigated the High speed direct injection engine in particular using EGR. NOx reductions were large at the expense of CO and HC emissions.

3. EXPERIMENTAL SET-UP, METHODOLOGY AND PROCEDURE

In this work *Simarouba glauca* is chosen as the biodiesel for blending with diesel. This is distilled from the crude soap oil of Simarouba by the trans-esterification process resulting in methyl esters of *Simarouba glauca*. The blends of this biodiesel are used as fuel in diesel engine with fuel injection pressure of 200 bar along with exhaust gas recirculation.

The experimental set up shown in Figure 1 is developed over a four stroke naturally aspirated single cylinder direct injection air cooled Kirloskar DA10 engine. The specifications of the engine are given in Table 1. The engine is coupled with an alternator for loading purpose and is varied from no load to full load condition in step of 25%. The air flow rate was measured using air box method. A standard burette and a digital stop watch were used for fuel flow measurement. EGR rate 10%, 15%, and 20% are used for B10 and B20 biodiesel blend ratios to give an insight into the study of engine performance and emissions.

The exhaust gas emissions mainly HC, CO and NOx were measured using AVL DI Gas 444 gas analyser. The smoke opacity was measured using the AVL 415SE smoke meter which measures soot concentration.

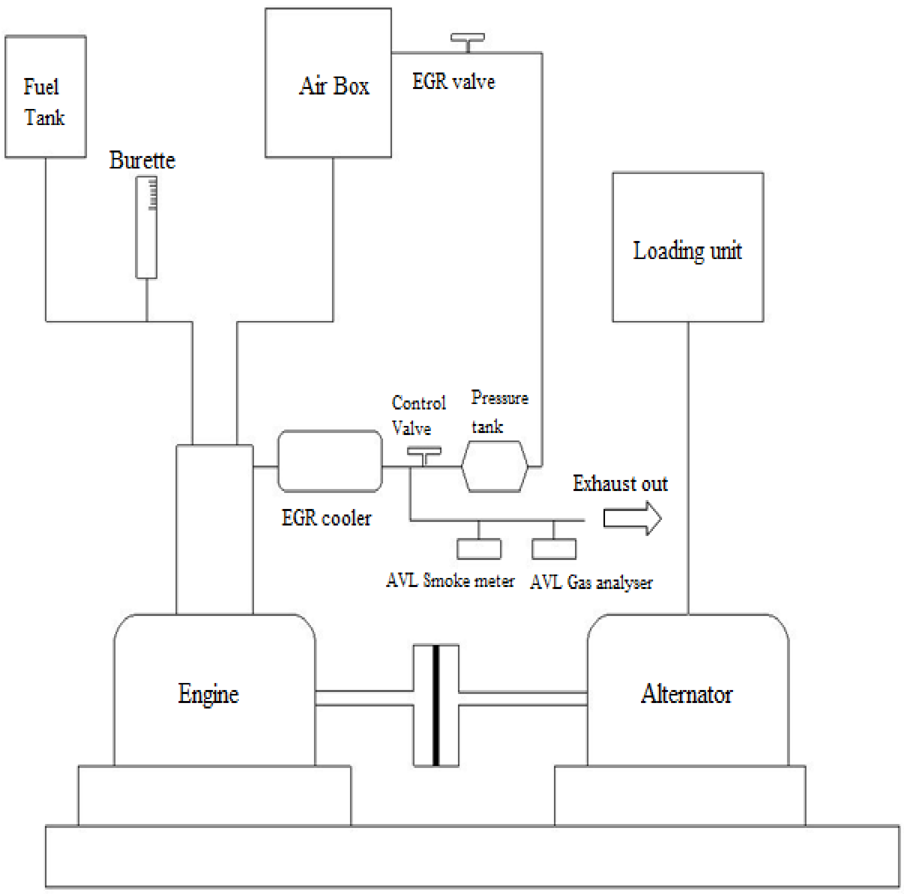

Fig.1. Schematic representation of test set up.

Table 1. Engine specifications.

Parameter	Specification
Engine make	Kirloskar DA10
Rated Brake power	7.4 kW
Number of cylinder	1
Method of cooling	Air cooled (axial fan)
Bore x Stroke	87.5X 110mm
Type of ignition	C I
Compression ratio	17.5:1
Fuel injection Pressure/ type	200 bar/Direct Injection
Injection timing	23^0 Btdc

Table 2. Results different fuel properties investigated.

Diesel and Fuel Blends	Lower Calorific Value	Flash Point	Fire Point	Kinematic Viscosity at 40^0C	Density at 40^0C
	(MJ/kg)	(^{0}C)	(^{0}C)	(cSt)	(kg/m^3)
Diesel	42.062	74	81	3.57	816
Simarouba Glauca	38.304	140	180	5.52	884
B10	41.530	85	99	4.33	822.8
B20	41.060	96	114	4.78	829.6

3.1 Exhaust Gas Recirculation

Exhaust gas recirculation is an effective and simple technique to control engine emissions with no after treatment process [8]. First exhaust gases are cooled by using heat exchanger which is directly connected to the exhaust line then fraction of cooled exhaust gases are again sent to intake manifold where they mixes with fresh air enter the combustion chamber. The following equation is used to estimate the EGR ratio:

$$EGR\ rate = \left\{\frac{mass\ of\ air\ without\ EGR - mass\ of\ air\ with\ EGR}{mass\ of\ air\ without\ EGR} x\ 100\right\} \quad (19,20)$$

3.2 Fuel Properties Analysis

It is necessary to know the various properties of the fuel which are required to determine the performance, emission and combustion characteristics of the engine. Therefore various properties including kinematic viscosity, calorific value, fuel mass density, fire point and flash point are investigated using standard instruments as per ASTM standards. The fuel properties of the reference fuel along with different biodiesel blends are listed in Table 2.

4. RESULTS AND DISCUSSION

4.1 Brake Thermal Efficiency (BTE)

The brake thermal efficiency (BTE) results obtained by using *Simarouba glauca* as biodiesel by varying EGR ratios for different loads are shown in Figures 2a and 2b. The gradual application of the load steadily decreased the heat loss and improved the thermal efficiency.

The improvement in brake thermal efficiency for blend B10 is observed to be 1.40% and 1.86% at medium and high load conditions. With the increase in biodiesel concentration to 20% in diesel, the thermal efficiency is almost equal to neat diesel operation for medium load but at high load condition the decrement is found to be 0.89%.

The improvement in BTE for lower blend concentration may be due to the presence of oxygen molecules in the biodiesel which helps in improving the combustion. The decrement at higher concentration may be due to lower heating values of the blend as shown in Table 2.

With application of EGR rate from 10% to 20%, a slight increase in efficiency is noticed. The maximum improvement is of 0.85% (B10) and 0.80% (B20) observed for 15% EGR. The increase in thermal efficiency with application of EGR may be due to the re-burning of unburnt hydrocarbons which mix with fresh air and entrain into the combustion chamber through the inlet manifold. Increasing of EGR ratio to 20%, a negative trend in BTE observed at full load condition.

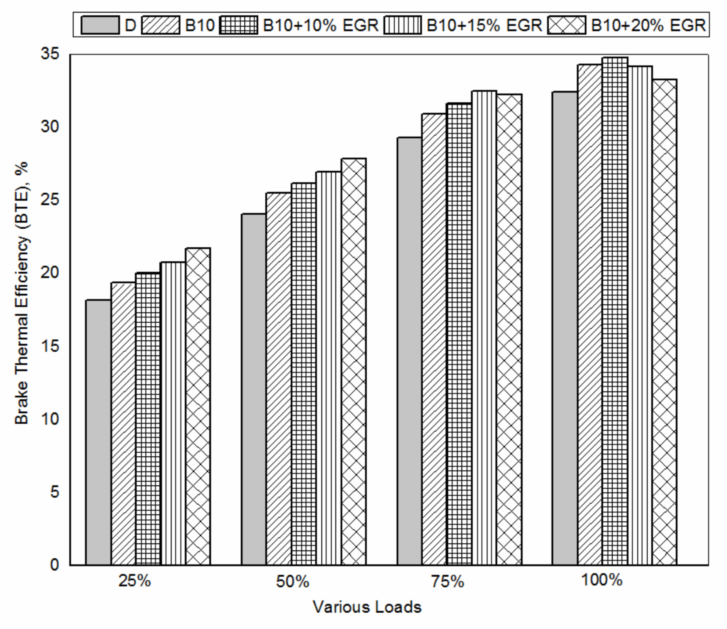

Fig. 2a. Variation of BTE with load.

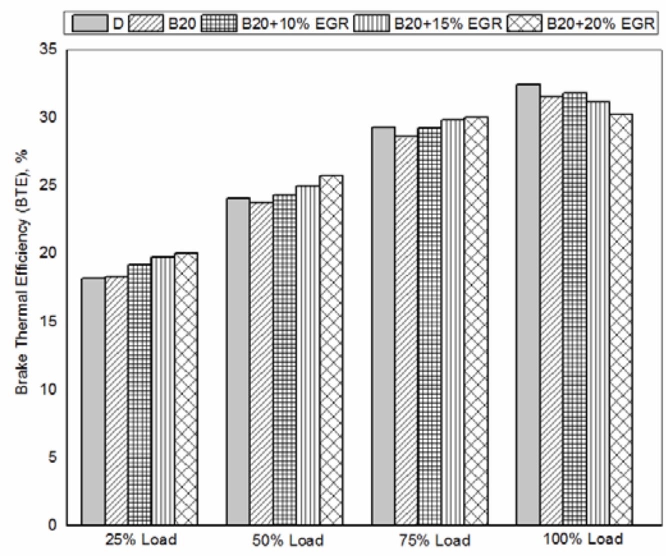

Fig. 2b.Variation of BTE with load.

This reduction may be due to the fact that the exhaust gases may contain higher amounts of CO_2, which limits the peak combustion temperature in the combustion chamber along with the oxygen availability. Hence the remarkable re-burning of HC is not achieved.

4.2 Emissions

4.2.1 Nitrogen Oxides (NOx)

A marginal increase in NOx emissions is observed with the biodiesel blend during the experiments on the diesel engine. This may due to two reasons, firstly by presence of oxygen molecules in the biodiesel and secondly, the availability of high temperatures occurring inside the combustion chamber of the engine.

With the application of EGR rate from 10% to 20% for different biodiesel blends, a decrease in NOx emissions is observed. The percentage of decrease is higher at high loads with higher rate of EGR when compared relatively with medium loads.

This is because of the lesser amount of oxygen available at high loads. The maximum reduction is found to be 41% and 38% for B10 and B20 blend for full load condition with 20% EGR rate when compared against baseline diesel operation.

This is mainly due to the increase of specific heat capacity of re-circulated CO_2 and H_2O (thermal effect), dissociation of H_2O and CO_2 of EGR (chemical effects) and also dilution of the oxygen concentration of the working fluid (dilution effect). The combined effect these lower the flame temperature during combustion, thereby reducing NOx formation as shown in Figures 3a and 3b.

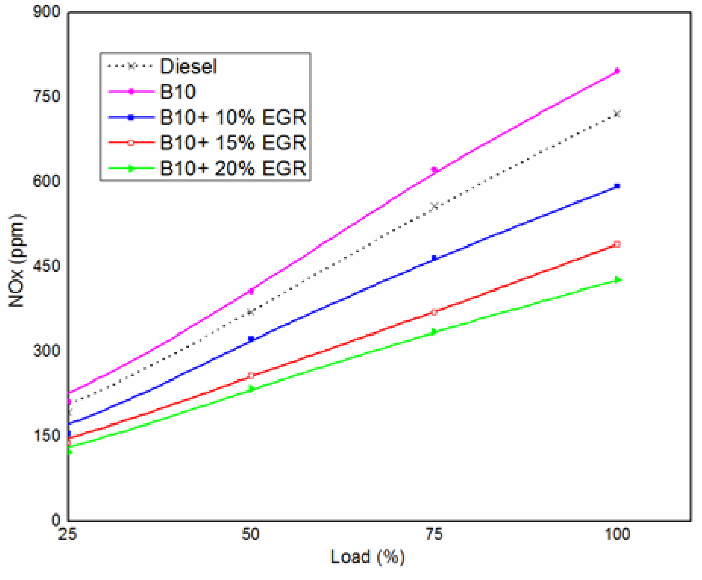

Fig. 3a.Variation of NOx with load.

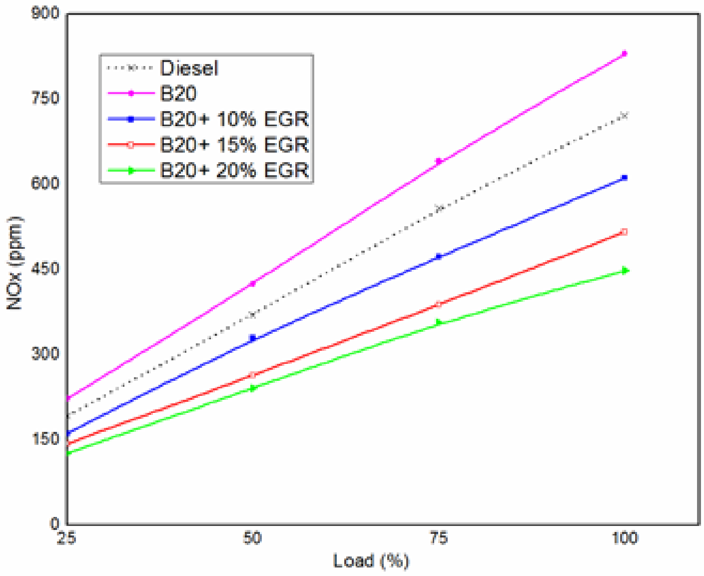

Fig. 3b.Variation of NOx with load.

4.2.2 Opacity

Smoke opacity of biodiesel blend is predominantly lower than that of diesel. The decrease is found to be 25% (B10) and 34% (B20) for high load conditions. This is due to the fact that the molecules of biodiesel have some within in built oxygen that enhances the combustion quality which culminates into lower smoke.

Higher smoke opacity of the exhaust is observed when the engine is operated with EGR compared to without EGR with all fuels tested (Figures 4a and 4b).

The change in the smoke opacity quantity at high loads was higher in contrast with lower loads. At lower amount of EGR (10-15%) opacity emission is less compared to neat diesel operation and but it increases with the increase of EGR rate. At 20% EGR, the opacity value is observed to be higher than diesel by 27% and 22% for B10, B20 blend ratios respectively. Here EGR reduces availability of oxygen for the combustion of fuel, which results in relatively incomplete combustion and greater origination of smoke.

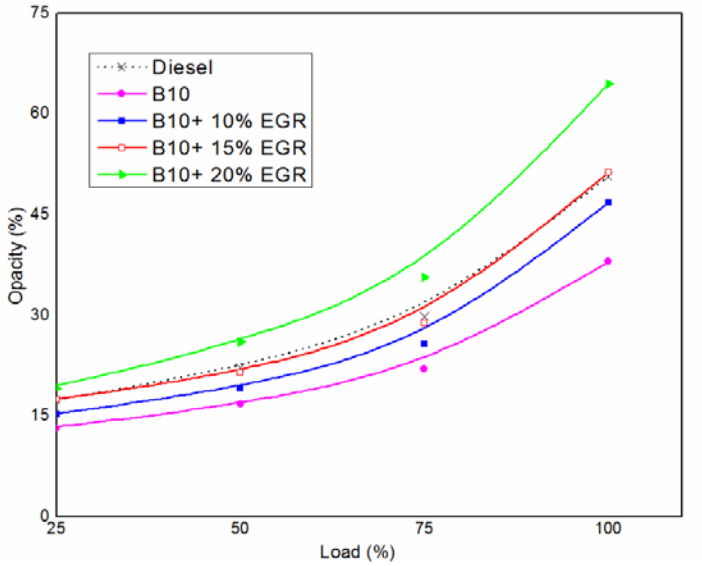

Fig. 4a.Variation of opacity with load.

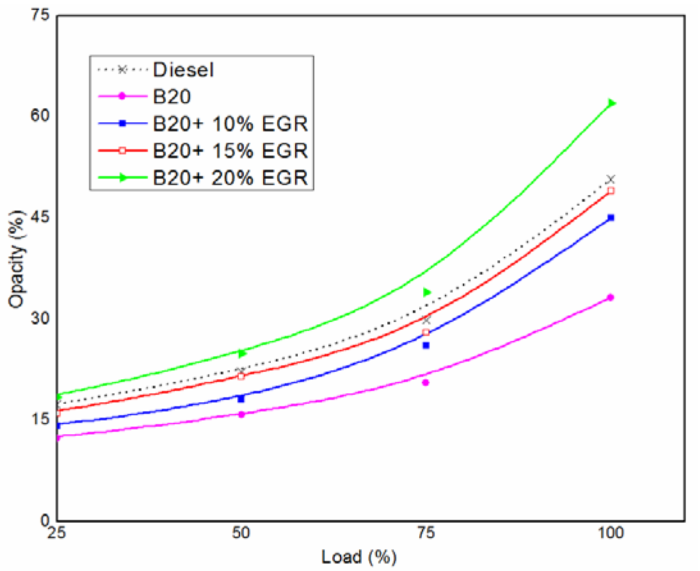

Fig. 4b.Variation of opacity with load.

4.2.3 HC Emissions

Adding biodiesel to diesel decreases the oxygen required for combustion because of the presence of molecular oxygen in the fuel. This excess oxygen molecule improves the combustion resulting in lower HC emissions. The HC emissions are lower by 37%, 40% at full load conditions for B10 and B20 biodiesel blends.

The effects of EGR and biodiesel on unburned HCs are shown in Figures 5a and 5b. These graphs show that HC emissions increase with EGR and load. At lower amount of EGR (10-15%) HC emission is less than or nearer to diesel value. It increases for 20% EGR and is higher by 20%, and 14% at full condition at B10, B20 blend ratio. Presence of lower excess oxygen availability in the cylinder chamber for combustion may be the possible reason. Rich air-fuel mixture at different locations inside the combustion chamber is the consequence of this lower excess oxygen concentration. Hence, this non-homogeneous mixture does not combust accordingly and develops more HC emissions.

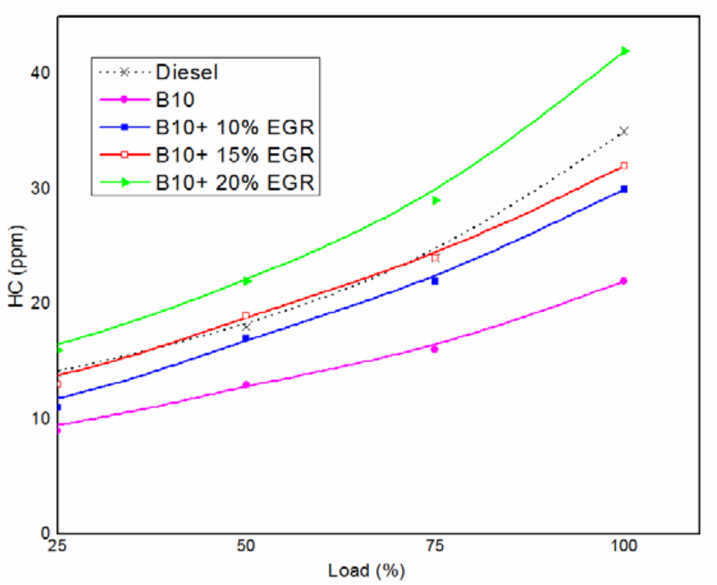

Fig. 5a.Variation of HC with load.

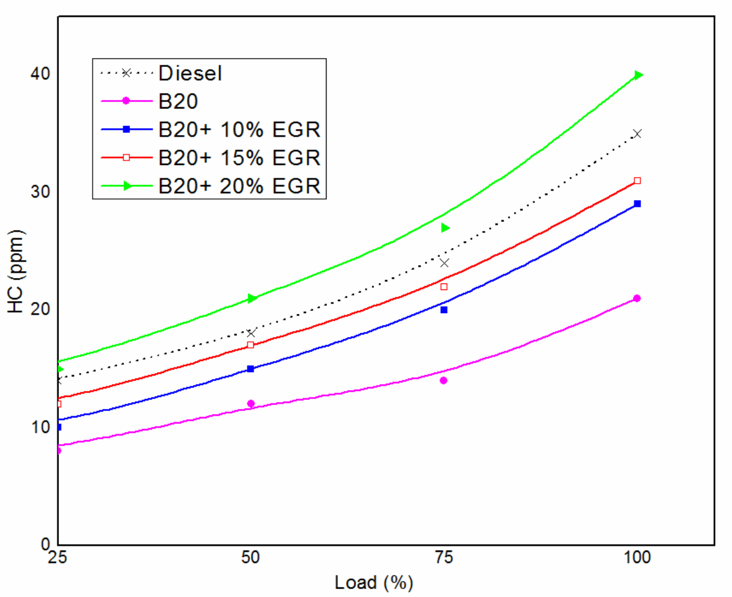

Fig. 5b.Variation of HC with load.

4.2.4 Carbon monoxide (CO)

The enrichment of oxygen due to the biodiesel decreases the CO emission. It can be observed that CO emissions are lower by 35%, 40% at full load condition for B10 and B20 biodiesel blends respectively than with diesel Figures 6a and 6b.

CO emissions are lower than baseline operation for and are higher for 20% EGR rate. The possible reason for the increase in CO emission may due to the increased fuel/air ratio being greater than stoichiometric value. A carbon monoxide concentration in the exhaust is a measure of the combustion efficiency of the system.

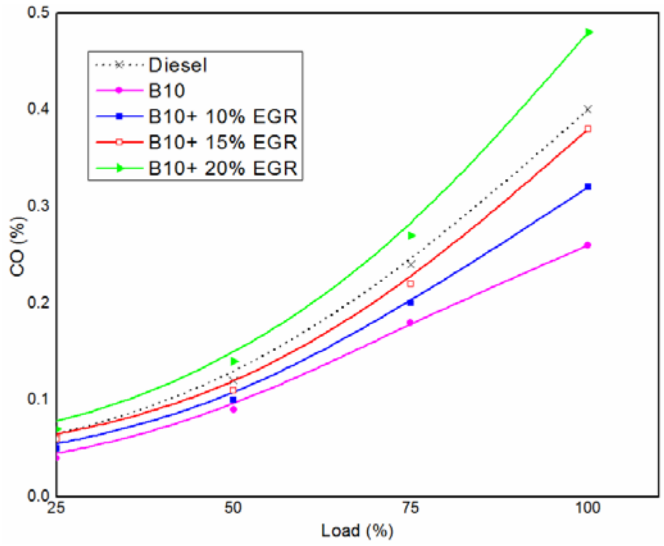

Fig. 6a.Variation of CO with load.

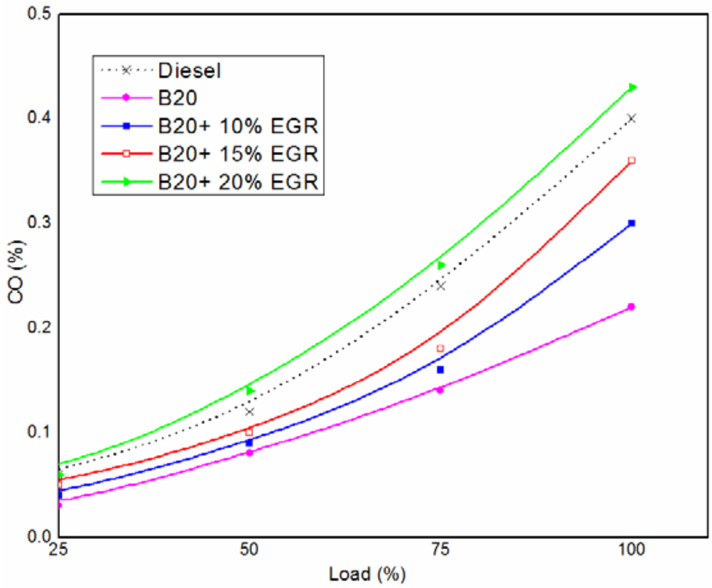

Fig. 6b.Variation of CO with load.

5. CONCLUSIONS

Simaraouba glauca biodiesel blends for various EGR rates with engine were tested and their performance and emission comparisons were made with an conventional diesel fuel. The following conclusions are drawn the from the present investigated conditions and are summarized

1) *Simarouba glauca* biodiesel upto B20 blend can be used as an alternative fuel for diesel engines without any major modifications.
2) The BTE improves in lower concentration of the blend (B10), but for higher concentration (B20) it is almost equal to the neat diesel operation.
3) With the application of EGR, BTE improves for 10% and 15% EGR rate and starts declining with the application of 20% EGR rate.
4) CO, HC and opacity emissions decrease with the use of biodiesel blend but NOx values increase.
5) At EGR rate 20% there is substantial increase in HC, CO, and opacity and NOx values are lesser than the diesel operation.
6) It is optimized that 15% EGR rate and B10 biodiesel blend gives better performance and lower emissions for all operating conditions.

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