AN EXPERIMENTAL INVESTIGATION OF COMBINED EFFECT OF EGR AND SESAME OIL BIODIESEL BLENDS ON CI ENGINE

[1] G. A. Nagargoje, [2] Dr. K. P. Kolhe, [3] Dr. S. S. Ragit
[1]PG Student, [2]Professor, [3]Associate Professor
[1, 2, 3] Department of Mechanical Engineering
[1, 2, 3] JSPM's Imperial College of Engineering & Research, Wagholi, Pune-14, India

Abstract-** In this study, the biodiesel is produced from Trans esterification of sesame oil. Properties of biodiesel are very close to diesel hence it can be used in diesel engine without any modification but use of biodiesel in CI engine will leads to higher NOX emission. Exhaust Gas Recirculation (EGR) is one of the most effective methods to reduce NOX emission. The study is carried out to investigate the emission and performance characteristics of single cylinder, four stroke, direct injection and water cooled CI engine to observe the effect of different EGR rates and blends of sesame oil biodiesel. The rated power and speed of engine were 3.5 KW and 1500 rpm respectively. The engine performance parameters (thermal efficiency, brake specific fuel consumption and temperature of exhaust gas) and exhaust emissions (oxides of nitrogen, unburned hydrocarbon and Carbon monoxide) are evaluated. The experimental results in each case are compared with baseline data of diesel. Improvements have been observed in the performance parameters of the engine as well as exhaust emissions. Result shows that B10 blend and 5% EGR is the best combination for this engine. At this combination the brake thermal efficiency increased by 4.45% at partial load. The reduction in NOX is approximately 400 ppm with application of EGR at high load but HC and CO emissions were increased by 1 ppm and 0.09 % only. The experimental study indicates that sesame oil Biodiesel and EGR both can be employed together in CI engines to obtain reduction of NOX emissions.

Keywords - Trans esterification, SOME, CI engine, EGR, NOX.

1. INTRODUCTION

National interest in generating fuels for internal combustion engines continues to be strong to fulfill the energy demand of the world. The search for energy independence and concern for a cleaner environment have generated significant interest in biodiesel, despite its shortcomings. India is the world's fourth largest consumer of crude and petroleum products after United States, China and Japan. The net oil import dependency of India rose from 43 % in 1990 to 71 % in 2012 that resulted in a huge strain on the current account. India's energy security would remain weak until alternative fuels are developed to substitute or supplement petro-based fuels. Biodiesel is an alternative diesel fuel which can be obtained from the transesterification of vegetable oils or animal fats and methyl or ethyl alcohols in the presence of a catalyst (alkali or acidic). Rudolph Diesel, the father of diesel engine, demonstrated the first use of vegetable oil in compression ignition engine in 1910. He used peanut oil as fuel for his experimental engine.

<u>There are, at least, five reasons that justify the development of biodiesel.</u>

1. It provides a market for excess production of vegetable oils and animal fats.
2. It decreases, although will not eliminate, the country's dependence on imported petroleum.
3. Biodiesel is renewable and does not contribute to global warming due to its closed carbon cycle.
4. The exhaust emissions of carbon monoxide, unburned hydrocarbons, and particulate emissions from biodiesel are lower than with regular diesel fuel. Unfortunately, most emissions tests have shown a slight increase in oxides of nitrogen (NO_X).
5. When added to regular diesel fuel in certain amount, it can convert fuel with poor lubricating properties into an acceptable fuel.

NO_X emissions can be reduced by lowering the cylinder temperatures. This can be done by three ways 1) Enriching the air fuel mixture 2) Lowering the compression ratio and retarding ignition timing 3) Reducing the amount of Oxygen in the cylinder that inhibits the combustion process. The first two methods reduce the efficiency of combustion and so the best way is to reduce the amount of Oxygen. This is done by recirculating some exhaust gas and mixing it into the engine inlet air. This process is known as Exhaust Gas Recirculation (EGR) [2]. Both biodiesel and EGR can be useful for agricultural equipment's such Tractor mounted and self-propelled climber for coconut and mango harvesting developed by K. P. Kolhe [3], [4], [12].

<u>TRANSESTERIFICATION:</u>

The fatty acid triglycerides themselves are esters of fatty acids and the chemical splitting up of the heavy molecules, giving rise to simpler esters, is known as trans esterification. The triglycerides are reacted with a suitable alcohol (Methyl, Ethyl, or others) in the presence of a catalyst under a controlled temperature for a given length of time. The final products are alkyl esters and glycerin. The alkyl esters, having favorable properties as fuels for use in CI engines, are the main product and the glycerin, is a byproduct. The chemical reaction of the triglyceride with methyl alcohol is shown in figure 1. It can be seen from the reaction that one mole of the heavy triglyceride and three moles of methyl alcohol yields one mole of glycerol and three moles of lighter fatty methyl esters. Without the use of a catalyst the reactions would be very slow and also incomplete. A temperature of 60°C to 70°C would be needed for the reactions to become effective. Also a vigorous agitation of the reactants would be needed and so a mechanized stirrer in the reaction vessel becomes necessary. Various catalysts can be used. The most common are the alkalies, like NaOH and KOH. For trans esterification any alcohol can be used. The most popular is methyl alcohol.

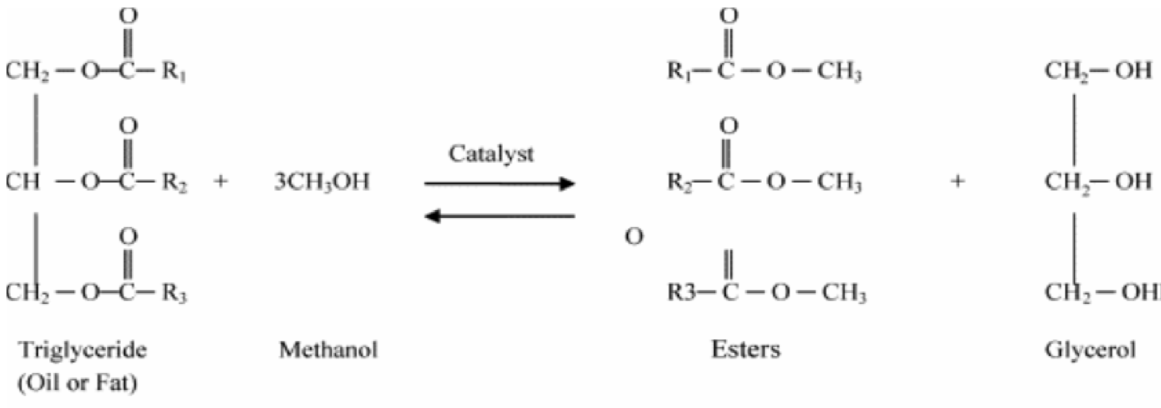

Fig.1 Trans esterification Reaction

NOX FORMATION MECHANISM

Oxides of nitrogen is produced in very small quantities can cause pollution. While prolonged exposure of oxides of nitrogen is dangerous to health. Oxides of nitrogen which occurs only in the engine exhaust are a combination of nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen and oxygen react at relatively high temperature. NO is formed inside the combustion chamber in post-flame combustion process in the high temperature region. The high peak combustion temperature and availability of oxygen are the main reasons for the formation of NOx. In the present of oxygen inside the combustion chamber at high combustion temperatures the following chemical reactions will takes place behind the flame [9].

$$N_2+O_2 = 2NO$$

$$N_2+2H_2O = 2NO+H_2$$

Calculation of chemical equilibrium shows that a significant amount of NO will be formed at the end of combustion. The majority of NO formed will however decompose at the low temperatures of exhaust. But, due to very low reaction rate at the exhaust temperature, a part of NO formed remains in exhaust. The NO formation will be less in rich mixtures than in lean mixtures [9]. The concentration of oxides of nitrogen in the exhaust is closely related peak combustion temperature inside the combustion chamber.

EXHAUST GAS RECIRCULATION (EGR)

Instead of using after treatment systems to comply with exhaust emission legislation, it is also possible to avoid the formation of emissions during the combustion. The raw emissions are reduced and thus no after treatment is needed. It is common practice nowadays, to use EGR to reduce the formation of NO_X emissions. A portion of the exhaust gases is recirculated into the combustion chambers. This can be achieved either internally with the proper valve timing, or externally with some kind of piping, Figure 2 shows this schematically.

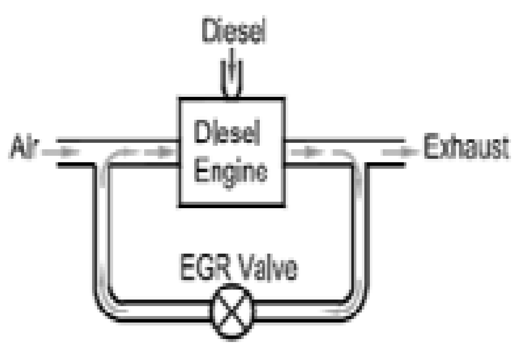

Fig.2 Exhaust Gas Recirculation [13]

The exhaust gas acts as an inert gas in the combustion chamber, it does not participate in the combustion reaction. This leads to a reduction of the combustion temperature by different effects. The fuel molecules need more time to find a oxygen molecule to react with, as there are inert molecules around. This slows down the combustion speed and thus reduces the peak combustion temperature, as the same amount of energy is released over a longer period of time.

The energy is also used to heat up a larger gas portion than it would without EGR. As the air is diluted with exhaust gas, the mass of a gas portion containing the needed amount of oxygen gets bigger. Another effect is the change in heat capacity. Exhaust gas has a higher specific heat capacity than air, due to the CO_2- molecule's higher degree of freedom. So for the same amount of combustion energy a gas mass containing EGR will get a lower temperature than pure air. The lower combustion temperature directly reduces the NO_X formation.

EGR ratio is defined as the ratio of mass of recycled gases to the mass of engine intake. Also %EGR is.

$$\%\,\mathbf{EGR} = \frac{\textbf{Mass of air admitted without EGR} - \textbf{Mass of air admitted with EGR}}{\textbf{Mass of air admitted without EGR}}$$

2. MATERIALS AND METHODS

This section provides a description of the materials and methodology used for production of biodiesel and CI engine test rig. used for performance and emission characteristics of TOME with EGR.

2.1 MATERIALS

The sesame oil used in this study was purchased from reliance mart hadapser, pune. The commercial diesel fuel was purchased from petrol pump which is nearer to Imperial College of Engineering and Research (ICEOR) Wagholi, pune. Other chemicals (Methanol, KOH Catalyst) were procured during experimentation from D Haridas & Company, katraj, pune.

2.2 METHODS

The Biodiesel was produced by transestrification of the sesame oil using 6:1 molar ratio of methanol and 1.5 % of KOH.

Fig.3 Transestrification set up

The trans esterification process was carried out as per the procedure given below:

1 kg refined sesame oil was taken in a 1000 ml capacity conical flask and heated at 55°C selected reaction temperature for 30 min preheating time. Then methyl alcohol was taken to obtain molar ratio of 6:1 and 10 g of Potassium hydroxide (KOH) was mixed thoroughly in it. This mixture was added to 1000 g preheated sesame oil and the mixture was placed on magnetic stirrer to carry out reaction for a period of 90 minutes in at the 60°C reaction temperature. After that the liquid which was a mixture of biodiesel (SOME) and glycerol is poured in a separating funnel and left it for the settling down for separation of biodiesel and glycerol. The glycerol settled at the bottom of separating funnel was separated by draining it. Then the biodiesel remaining in the funnel was washed with distilled water for and allowed it to settle down. The water accumulated along with traces of glycerol at the bottom of the separating was drained. Washing of biodiesel is carried out three times to remove the remaining glycerol, alcohol and KOH in the biodiesel.

Fig.4 Biodiesel glycerol separation **Fig.5** Water washing of biodiesel

At last the washed biodiesel was dried by silica gel it absorbs moisture and final biodiesel was ready to use.[10][11].Viscosity, density and calorific value were measured by redwood viscometer, hydrometer and bomb calorimeter respectively. The fuel properties of sesame oil methyl ester and diesel are summarized in Table 1.Methyl ester was compared with diesel fuel.

Table 1 Properties of Diesel and SOME

Property of oil	ASTM std	Diesel	sesame oil biodiesel
Density (kg/m3)	----	830	869
Kinematic viscosity (cSt)	1.9 to6.0	3.5	4.2
Flash point (°C)	>130	56	170
Fire point, (°C)	>153	62	187
Cloud point(°C)	-3 to -12	-10	-17
Pour point, (°C)	-15 to 10	-6	-5
Calorific value(kJ/kg)	> 33000	42000	39895

3. EXPERIMENTAL SETUP

In the present experimental work single cylinder, four stroke and CI engine was used. The engine was Kirloskar Make and water cooled. The engine is connected to Eddy current dynamometer for measurement of brake power. Engine torque was measured using load cell. The specifications of engine are given in Table 2.

Table 2 Engine Specification

Make	Kirloskar Engine
Model	TV1
No of cylinders	1
No of strokes	4
Cylinder Bore	87.5mm
Stroke length	110
Type of cooling	Water cooled
Power	3.5 KW
Rated Speed	1500 rpm
Compression Ratio	18:1
Loading device	Eddy current dynamometer

The experimental set up is shown in fig.6. It has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, RTD and thermocouples are used for air and water temperature measurement at various points. Signals from sensors are interfaced to computer through high speed data acquisition

Fig.6 Experimental Setup

device. Rotameters are used for cooling water and calorimeter water flow measurement. The exhaust gas emissions were measured by using AIRREX HG-540 exhaust gas analyser. Water cooled EGR cooler connected to engine by appropriate plumbing for cooling and recirculation of exhaust gas. The quantity of exhaust gas recirculation can be controlled by valve fitted in EGR path.

4. EXPERIMENTAL PROCEDURE

To achieve objective of experimental study engine was run at normal condition. Tests were conducted at 1500 rpm engine speed. B10 and B20 blends of sesame oil methyl ester were prepared on volumetric basis. Engine was started at no load and varied to rated load in number of steps. Set of reading is obtained without EGR and with 5% and 10% of EGR for pure diesel fuel [9]. Similar set of reading is obtained for B10 and B20 blends of SOME. Engine performance parameter like Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC), and emission parameters such as Nitrogen monoxide (NO_X), Carbon monoxide (CO), Unburned Hydrocarbons (HC) were measured during test. Then these engine parameters were compared for different blends and EGR combinations.

5. RESULTS AND DISCUSSION

In this section fuel properties are discussed. Engine performance and emission data is analyzed and presented in graphical from for thermal efficiency, SFC, HC, CO, $NO_{X,}$ emissions.

5.1 FUEL PROPERTIES

The experimental results indicated that the density of sesame oil methyl ester is slightly high to that of diesel. The kinematic viscosities of diesel and sesame oil methyl ester were found as 3.5 and 4.2 cSt at 40°C. The calorific values of diesel and sesame oil methyl ester were found as 42 and 39.9 MJ/kg respectively. The calorific value of sesame oil methyl ester is 5 % less as compared to diesel fuel. The sesame oil methyl ester was found to have higher flash and fire point than diesel fuel hence it can be stored and transported safely. Cloud point of sesame oil methyl ester is higher than that of diesel.

5.2 EFFECTS ON ENGINE PERFORMANCE

5.2.1 Brake thermal efficiency (BTE)

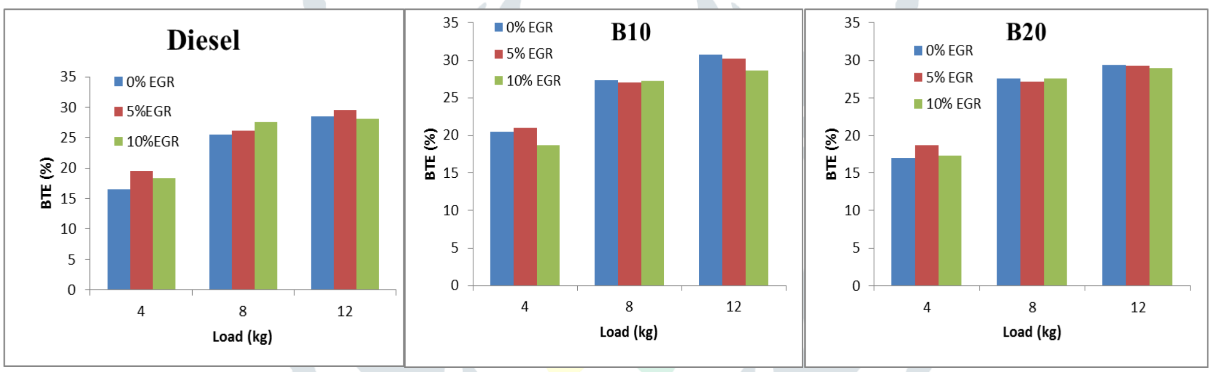

Fig.7 Variation of Brake thermal efficiency with load

Fig.7 indicates that efficiency slightly increases at lower load with EGR but it will not affects significantly at higher load this is because at lower load exhaust gas contains higher amount of oxygen hence when exhaust gas recirculated to cylinder unburned hydrocarbons in exhaust gas will get sufficient oxygen for burning but at higher loads due to less oxygen concentration re-burning of unburned hydrocarbon is not possible. Maximum brake thermal efficiency found 30.17 % at full load for B10 blend with 5% of EGR. Maximum increment in BTE is 4.45% is also found at same blend and EGR at lower load.

5.2.2 Specific Fuel Consumption (SFC)

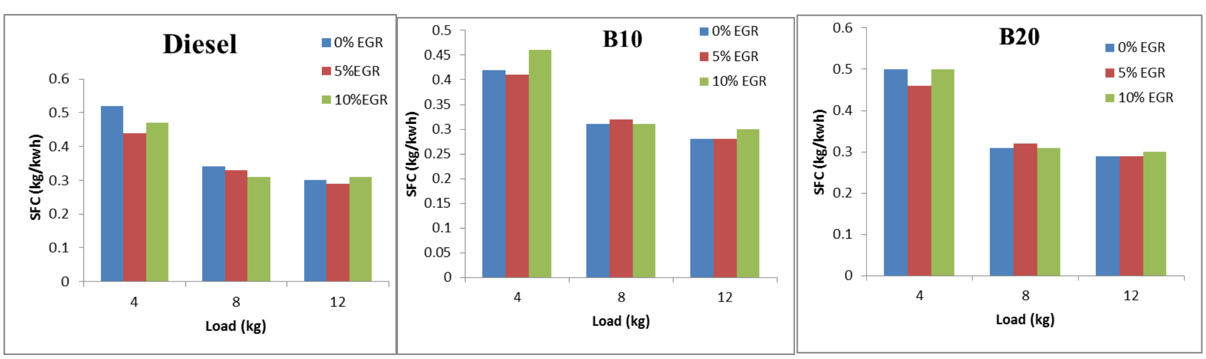

Fig.8 Variation Specific Fuel Consumption with load

Fig.8 represents variation of SFC with load at different blends with and without EGR. The results show that the SFC decreases with increasing load. SFC fuel consumption is reduced with application of EGR at lower loads but at higher load there is no considerable change in SFC. It is also seen that if blend percentage increases the effect of EGR on SFC decreases. Maximum reduction in SFC 15.39 % has been found at low load for diesel with 5 % EGR as compared to without EGR.

5.3 EFFECT ON ENGINE EMISSION

5.3.1Unburned Hydrocarbon emission

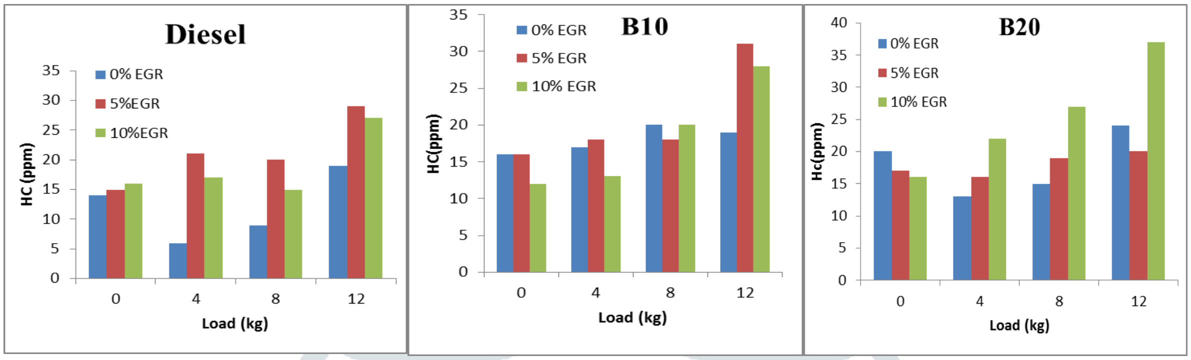

Fig.9 Variation of Unburned Hydrocarbon emissions with load

Effect of EGR on unburned hydrocarbon emission is represented in Fig.9. It indicates that HC emission increases as load increases. It is also observed that HC emission are higher with EGR as compared to without EGR for all at high load but at low load there is no significant effect of EGR on HC emission. This may be due to lower amount oxygen in re-circulated exhaust gas at higher load which causes incomplete combustion as explained earlier.

5.3.2 Carbon monoxide emission

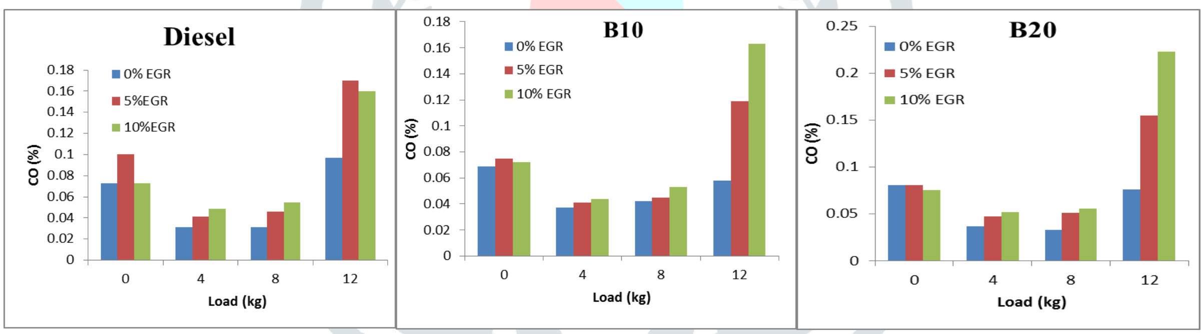

Fig.10 Variation of Carbon monoxide emission with load

From Fig.10 It is observed that at lower load there no large changes in CO emission with and without EGR but at high load CO emissions are higher with the effect of EGR. Less oxygen concentration in exhaust gas at higher load cause incomplete combustion and results in higher CO emission. At full load condition with 10% EGR CO emission increases by 0.087 %, 0.09 % and 0.14 % for diesel, B10 and B20 respectively.

5.3.3 NO_X emissions

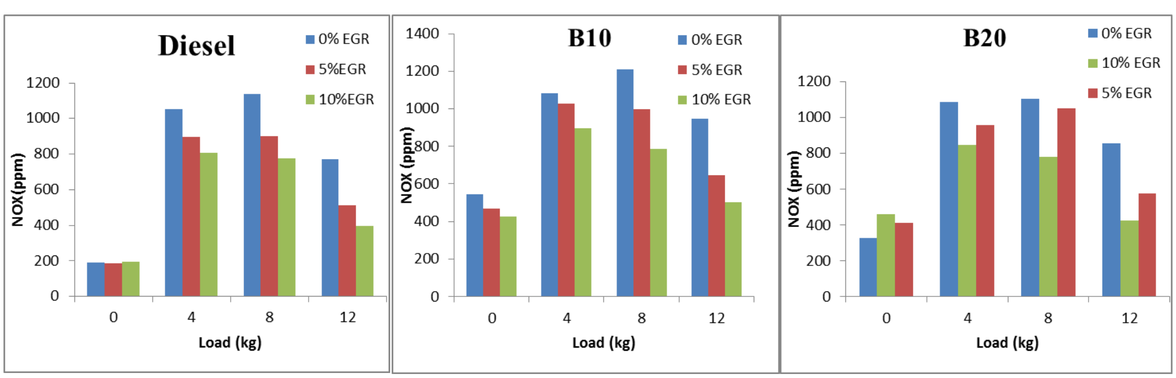

Fig.11 Variation NO_X emissions with load

Fig.11 shows effect of EGR on reduction in NO_X emission which is main advantage of EGR. It has been seen that NO_X emission increases with increment in load and blend percent of biodiesel. But NO_X emission decreases with EGR for all blends. EGR reduces the NO_X emissions by decreasing combustion temperature and lowering O_2 concentration of intake air. NO_X reduction due to EGR is higher at high load but as load decrease reduction in NO_X emission decreases because high oxygen concentration in exhaust gas at low load. With application of EGR NO_X emission was reduced approximately by 100 ppm for low loads and 400 ppm at full load condition.

6. CONCLSIONS

Based on the above outcomes, following conclusions can be made.

1. The brake thermal efficiency increases slightly at low load with EGR. The maximum increment in brake thermal efficiency 4.45% is observed when B10 and 5 % EGR used at partial load.
2. SFC fuel consumption is reduced with application of EGR at lower loads but at higher load there is no considerable change in SFC. SFC is reduced by 15.39 % when diesel with 5% EGR is used at lower load.
3. HC and CO emission are higher for blends and EGR.
4. From partial load to full load condition CO emission increases considerably with EGR. At full load condition with 10% EGR CO emission increases by 0.087 %, 0.09 % and 0.14 % for diesel, B10 and B20 respectively
5. EGR reduces the NO_X emission. This reduction is higher at high loads for all blends.
6. With application of EGR NO_X emission was reduced approximately by 100 ppm for low loads and 400 ppm at full load condition.
7. Effect of EGR on emission is more at high load and less at low load where performance of the engine increased slightly at low load and remains very close normal performance at high load. Hence EGR can be applied at high load to reduce NO_X emission.

REFERENCES

[1] M. Hassan and Md. AbulKalam,(2013), An overview of biofuel as a renewable energy source: development and challenge, Procedia Engineering, vol. 56, pp. 39 – 53.

[2] G. A. Nagargoje1, K. P. Kolhe, S.S.Ragit (2016), Effect of Exhaust Gas Recirculation (EGR) on C.I.engine performance and emission - A review JETIR Volume 3,

[3] K. P. Kolhe (2015). Testing of Tractor Mounted and Self Propelled Coconut Climbe for Coconut Harvesting. World Journal of Engineering vol. 12 Pp. 399-406.

[4] K. P. Kolhe and B. B. Jadhav (2011), Testing and Performance Evaluation of Tractor Mounted Hydraulic Elevator for Mango Orchard. American Journal of Engineering and applied sciences, vol. 4, Pp. 179-186.

[5] B. De and R. Panua, (2014), An experimental study on performance and emission characteristics of vegetable oil blends with diesel in a direct injection variable compression ignition engine, Procedia Engineering, vol. 90, pp. 431 – 438

[6] X. Zhang and W. Huang, (2011), Biodiesel Fuel Production through Transesterification of Chinese Tallow Kernel Oil Using KNO3/MgO Catalyst. Procedia Environmental Sciences, vol. 15, pp. 11757 – 762

[7] S. Ragit, S. Mohapatra, P. Gill and K. Kundu, (2012), Comparative study of engine performance and exhaust emission characteristics of a single cylinder 4-stroke CI engine operated on the esters of hemp oil and neem oil, Indian Journal of Engineering & Materials Sciences, Vol. 18, pp. 204-210.

[8] K. NanthaGopal, A. Pal, S. Sharma, C. Samanchi, K. Sathyanarayanan, T. Elango, (2014), Investigation of emissions and combustion characteristics of a CI engine fuelled with waste cooking oil methyl ester and diesel blends, Alexandria Engineering Journal, vol.53, pp. 281–287.

[9] J. Hussain, K. Palaniradja, N. Alagumurthi, R. Manimaran, (2012), Effect of Exhaust Gas Recirculation (EGR) on Performance and Emission characteristics of a Three Cylinder Direct Injection Compression Ignition Engine, Alexandria Engineering Journal, vol.51, pp. 241–247.

[10] B. Jothithirumal and E. Jamesgunasekaran, (2012), Combined Impact of Biodiesel and Exhaust Gas Recirculation (EGR) on NO_X Emission in Diesel Engine,Procedia Engineering,Vol. 38, pp.1457-1466.

[11] S. Ragit, S. Mohapatra, P. Gill and K. Kundu, (2012), Brown hemp methyl ester: Transesterification process and evaluation of fuel properties, Biomass and bio energy, vol. 41, pp. 14-20.

[12] K.P. Kolhe, (2009) Development and testing of tree climbing and harvesting device for mango and coconut trees. Indian coconut journal, published by Ministry of Agriculture, CDB board Kochi Kerla, vol.3 Pp. 15-19.

[13] V. Achuthanunni and B. Baiju, (2014), Experimental Investigation of a Diesel-Biodiesel Fuelled Compression Ignition Engine with Exhaust Gas Recirculation (EGR), International Journal of Engineering and Advanced Technology (IJEAT),Vol. 4, pp. 7-10.