A STUDY ON EFFECT OF EXAHAUST GAS RECIRCULATION ON THE PERFORMANCE AND EMISSION CHARACTERISTICS OF A CI ENGINE USING MILK SCUM BIO DIESEL AS A FUEL

Sairam R[1], Vinayak Ingale[1], Chandrashekhar N D[1], Bharath K V[1], Veerbadhrappa T[2]

School of Mechanical Engineering, REVA University, Bangalore, India[1]

Assistant Professor, School of Mechanical Engineering, REVA University[2]

ABSTRACT: In present situation global warming and air pollution are the major concern for the living world. One of the relatively eco-friendly fuel to replace diesel is biodiesel. Milkscum is one of the feedstocks available in many countries of the world. In the present experiment biodiesel produced from dairy waste by transesterification process. Further the effect of exhaust gas recirculation on the performance and emission characteristics of a CI engine was evaluated. The usage of biodiesel gives higher NO_x emission from CI engine. For the present work four different blends of fuels are used i.e. Diesel& MSMEB20 (milk scum methyl ester 20% + diesel 80%). The different EGR rates used are 0%, 10%, 20% and 30% are considered for this study. The BTE is increased by 17.95% and BSFC is reduced by 13.33% in terms of performance. The emission characteristics, CO, UHC was increased by 46.93 and 24.2 % respectively whereas the NO_x and CO_2 was reduced by 54.90 and 22.03 % respectively for MSMEB20 blend at full load condition.

Key words: **-EGR, Performance, Emission, Milk scum methylester**

1. INTRODUCTION

The increase in the demand for the petroleum products and the depletion of fossil fuels has caused to make research on the study of the alternative fuels for internal combustion engines. The environmental pollution and greenhouse gas emission has become as serious problem. So the emission of the green house gases can be reduced by using EGR.

S. A. Ransing et al. [1] have studied the Critical Review of EGR on CI engine running on biodiesel and its blends with vegetable derived biodiesel is compared with conventional diesel fuel. Use of Biodiesel in CI engine gives higher NOx emission and lowers HC, CO emission. EGR reduces NOx emission from the engine. Higher rate of EGR reduces NOx to greater extent but deteriorates of engine performance in terms of thermal efficiency and specific fuel consumption. Lower percentage of biodiesel blends and lower EGR rate can be safely used without effecting the performance of the engine. M.
Anandan et al. [2] have worked on Jatropha and Pongamia biodiesel and its blends with variable compression ratio of engine. He has concluded that effect on EGR. Decreases NOx, Exhaust gas temperature, Thermal efficiency and increases unburnt hydrocarbons and carbon monoxide.
Mohd Hafizil Mat Yasin [3] have conducted experimental study on a Mitsubishi 4D68 four stroke, water cooled DI diesel engine fueled with neat palm-biodiesel operating with diaphragm exhaust gas recirculation. He has concluded that both EGR and Biodiesel have increased the SFC and reduce the performance of an engine including engine power and torque as well as brake thermal efficiency. Other emission such as CO and HC also found to have decreased with the use of bio diesel fuel.
A. Paykani et al. [4]. Have worked on canola oil ethyl ester. He has concluded that the calorific value of biodiesel was lower than that of diesel fuel, so, there was a slight reduction in brake thermal efficiency. The high viscous oil causes injector coking and contaminates the lubricating oil. The brake thermal efficiency increases at low EGR rate. It is observed that the NOx emission increases, the emission of CO and UHC was found to be lowered directly with increasing biodiesel percentage. The NOx emission was decreased, the emission of HC and CO with increase in EGR flow percentage.

Dr. K Srinivasa Rao [5] have worked on cotton seed biodiesel and its blends, with 0% to 20% EGR and he has found the better engine characteristics were obtained with EGR rate of 15% for all fuel blends. He has also found that the NOx emission, BTE and EGT decreases with the increase in EGR. The emission of HC and CO increases with increase in EGR rate.

Deepak Agarwal et al. [6] have worked on exhaust gas recirculation and performance of compression ignition engine fueled with petroleum diesel. Thermal efficiency is found to have slightlyincreased with EGR at lower engine loads. BSFC is found to be decreased at lower loads with EGR compared to without EGR. But at higher loads, thermal efficiency and BSFC are almost similar with EGR than without EGR, exhaust gas temperature is decreased with EGR. Hydrocarbons, carbon monoxide, and smoke opacity are increased with EGR, but NOx emission decreases significantly.

N. Sunil Naik & B. Balakrishna [7] has worked on balanites aegyptiaca diesel blends with different EGR rates. He has found that the increase in BTE and decrease of BSFC with increase in blend percentage. With increase in EGR rate EGT, CO, HC and NOx have significantly reduced.

M Krishnamoorthi and R Malayalamurthi [8] have worked on bael oil blends with different EGR. They have found that BTE has been decreased with increasing Charge inlet temperature, BTE and BSFC decreases with increase in EGR rate. The emission of NOx decreases and CO and HC increase with increase in EGR rate.

Domenico De Serio et al. [9] have worked on diesel oil containing 7% biodiesel. They have concluded that the emission of NOx is reduced with increase in EGR rate. With increasing EGR rate, thein-cylinder peak pressure and the peak heat release ratedecreased. In most situations, the use of EGR increasedCO2, CO and THC emissions, especially at high loads. However, under certain load conditions and EGR rates, decreased levels of those components were observed with the use of EGR.

Ming Zheng et al. [10] have worked on soy; Canola and yellow grease derived B100 biodieselfuels and an ultra-low Sulphur diesel fuel. They have concluded that the engine-out NOx emissions were dependent on the fuel CN,the biodiesel fuel with a CN similar to the diesel fuel produced higher NOx emissions than the diesel fuel. a weaker mixture would be generated and burnt during the premixed phase resulting in relatively reduced NOx formation.

2. MATERIALS AND METHODS

2.1. Materials

We have purchased the following chemicals Sulphuric acid (H2SO4), Methanol (CH3OH), Isopropanol, Potassium hydroxide (KOH), Phenolphthalein solution, from **VASA SCIENTIFIC CO., Avenue road, Bangalore-560002**

2.2. METHODOLOGY

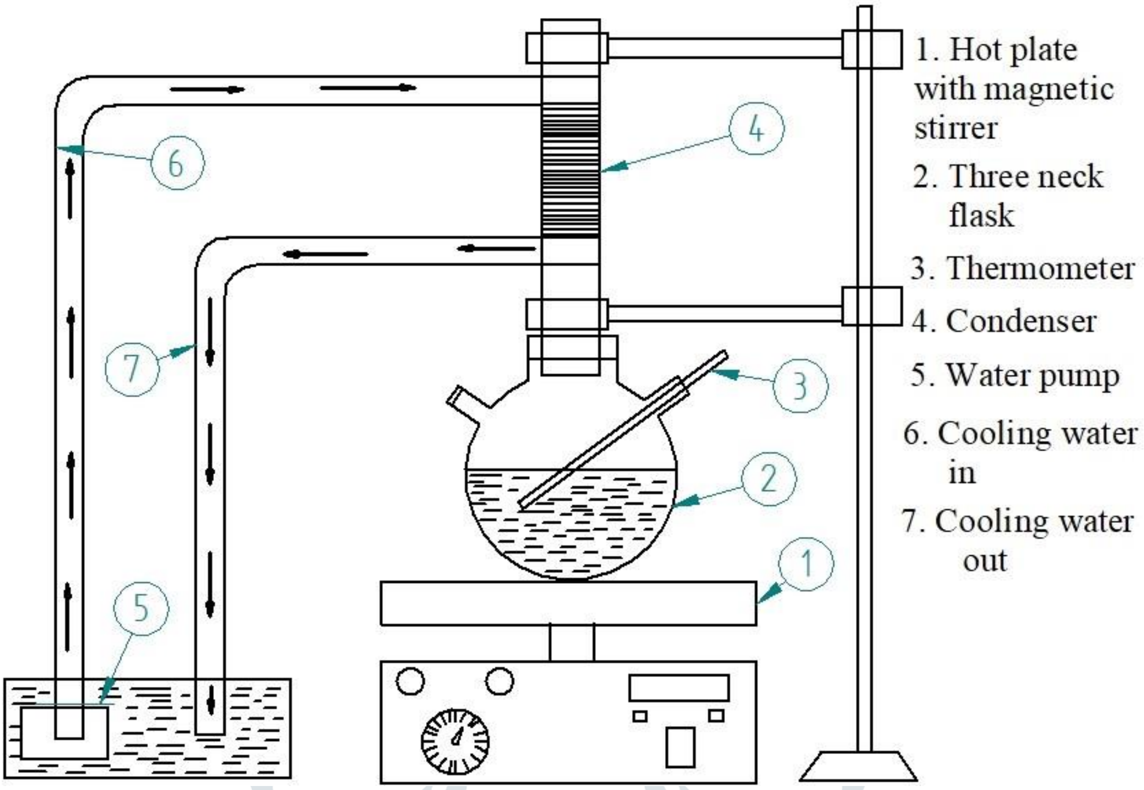

Figure 1 Transesterification setup

The figure one shows the Transesterification setup. The experimental setup consists of Hot plate with magnetic stirrer, Three neck flask, Thermometer, Condenser, Water pump, Cooling water in pipe, Cooling water out pipe. Hot plate is used to heat the milk scum inside the three-neck flask and magnetic stirrer is used to stir the milk scumthoroughly. The three-neck flask is a flask which contains three neck in which one is closed another is used to insert the thermometer and another neck is connected to condenser. A thermometer is used to measure the temperature of milk scum inside the flask. A condenser is used to restrict the evaporation of methanol and Sulphuric acid. A water pump is used to pump the water from reservoir to condenser to cool the vapors.

2.2.1. FFA CALCULATION

$$FFA\% = \frac{(\mathrm{v} - \mathrm{b}) * \mathrm{N} * 28.2}{\mathrm{W}}$$

Where
v volume of KOH solution in ml
b blank volume in ml
N Normality of KOH
W Weight of the oil used in grams

Calculations of %FFA for Milk Scum

$$FFA\% = \frac{(v-b)*N*28.2}{W}$$

$$FFA\% = \frac{(22.5-14.8)*0.1*28.2}{1.03}$$

=**21.08**%

In first step calculation, % of FFA of Milk Scum is **21.08%** so, according to the methodology % of FFA is > 2.5 hence esterification process is down.

2.2.2. ESTERIFICATION

Esterification is the process of reacting a triglyceride with alcohol in the presence of a catalyst to produce fatty acid esters and glycerol. It is difficult to produce ester from scum oil using an alkaline catalyst (NaOH/KOH) because scum oil used is having high free fatty acid (FFA). Therefore, a two-step transesterification process is chosen to convert the nonedible scum oil to its methyl ester. The first step acid catalyzed esterification reduces the FFA value of the oil to about 2%. The second step, alkaline catalyzed transesterification process converts the products of the first step to its mono-esters and glycerol. In acid esterification, 850 ml scum oil is heated to about 50° C; 200 ml methanol is added and stirred for a few minutes. With this mixture 10ml H_2SO_4 is also added and stirred at a constant rate with 50 to 55 °C for three-hour. After the reaction is over, the solution is allowed to settle for 24 hours in a separating funnel.

2.2.3. TRANSESTERIFICATION

In Transesterification process,850 ml of scum is heated to 55° C and is transferred to the round bottom flask of the esterification setup. 200ml of methanol and 4.84 gm of KOH pellets is added into a beaker in the setup and slowly allowed into the flask containing scum. This mixture of milk scum, methanol and KOH pellet is stirred continuously until the FFA forms a separate top layer. The mixture is then stirred until glycerol forms a separate layer, once glycerol forms a separate layer, the mixture is allowed to settle for around 12 hours and the FFA, Impurities floating on the top surface is removed.

2.2.4. PURIFICATION

The biodiesel obtained is washed 12 times with hot of 70°c water to remove the catalyst. If clear wash water is got back it indicates that the catalyst is not present in the biodiesel. First stage of water wash, fifth stage of water wash with well shaking, Tenth stage of water wash, Final stage of water wash with clean water at bottom. Water washed biodiesel is later heated to 120°C to get dry biodiesel which is free from moisture. After that moisture free biodiesel is filtered by using filter paper, thus neat biodiesel is obtained. Heating of obtained Biodiesel, Filtering of Heated Biodiesel.

3. EXPERIMENTAL SETUP

The figure.2 shows the Schematic diagram of experimental setup. It consists of Four stroke Diesel engine coupled with Eddy current dynamometer, Laminar flow equipment, Fresh air temperature measuring sensor, Mixed air temperature measuring sensor, Exhaust gas temperature measuring sensor, Exhaust gas recirculation control valve, Exhaust gas analyzer, Back pressure valve, Exhaust muffler, Air box, Orifice, Exhaust gas recirculation loop.

The fresh air is drawn to the engine with the help of laminar flow equipment and its temperature is measured with the help of fresh air temperature measuring sensor. The engine draws the air and compresses the air. The fuel Diesel, MB10 (Milk scum Biodiesel 10% and Diesel 90%), MB20 (Milk scum Biodiesel 20% and Diesel 80%), and MB30 (Milk scum Biodiesel 30% and Diesel 70%) is injected to the engine cylinder. The engine is loaded with the Eddy current dynamometer which helps to vary the load applied to the engine. The Exhaust gas temperature is measured with the help of Exhaust temperature measuring sensor. The emission parameters of the exhaust gas are measured with help of Exhaust Gas Analyzer. The remaining exhaust gas is passes through back pressure valve, Exhaust muffler and left to the atmosphere.

In the case of EGR, the exhaust gas is forced into EGR loop by closing the Back pressure valve up to the requirement level. The rate EGR is controlled by varying the EGR valve. The Exhaust gas enters the air box and then passes through the orifice which helps to measure the amount of exhaust gas supplied to the engine. The temperature of exhaust gas is measured with the help of EGR temperature measuring sensor. The EGR and Fresh air is mixed and the mixed gas temperature is measured with the help of mixed gas temperature measuring sensor and supplied to the engine. The detailed specifications of the Engine used and Exhaust gas analyzer are given in Table 1 and Table 2 respectively.

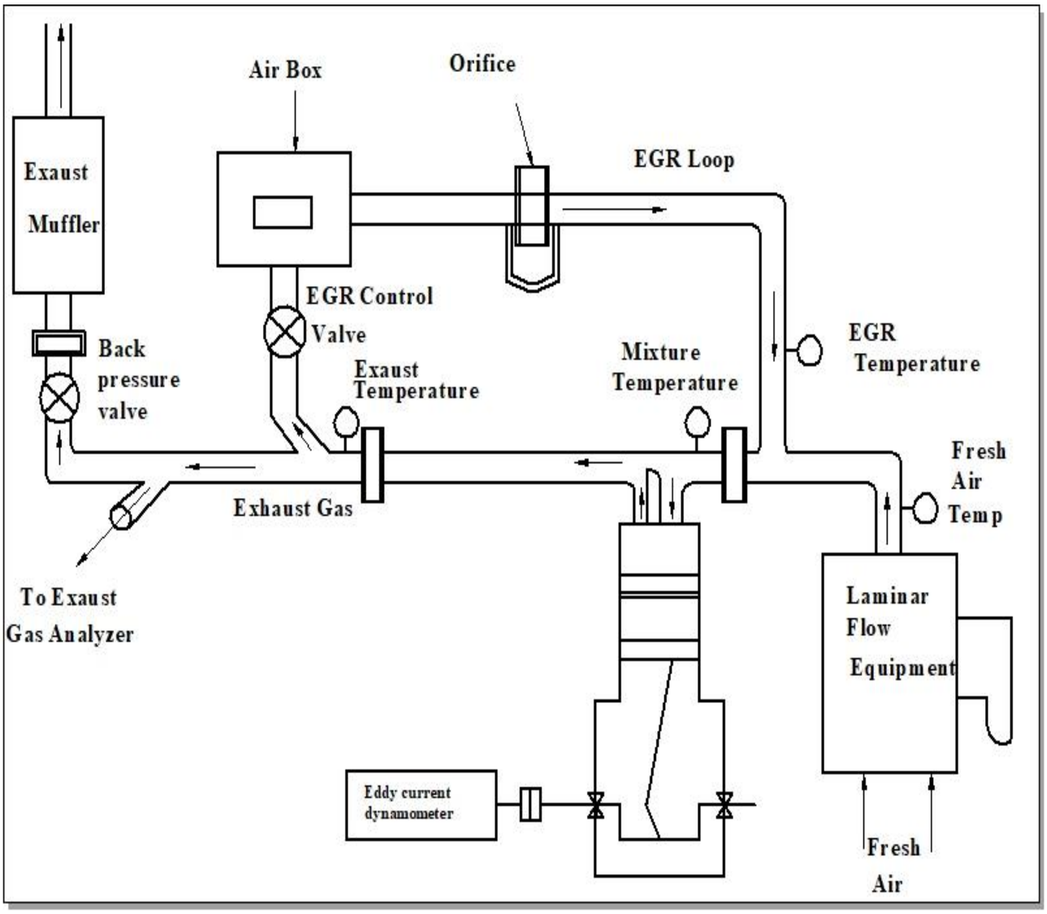

Figure 2 Schematic diagram of experimental setup

Table 1 Specifications Computerized Research Engine Test Rig

SLNO	PARAMETER	SPECIFICATION
1	Engine	Brand New KIRLOSKAR Engine, Single Cylinder, 4stroke, 553cc Power up to 5HPMax, water cooled.
2	Auxiliary head	TECH-ED make, water cooled
3	Compression Ratio	Variable from 12:1 to20:1
4	Dynamometer	Eddy Current Dynamometer
5	Bore	80 mm
6	Stroke length	110 mm
7	Max. Power	5BHP
08	Max.Torque	25N-m
9	Speed range	1500 – 3000 RPM
10	Starting method	Self-start arrangement with battery

Table 2 Specifications Computerized Research Engine Test Rig

Pollutant	Range	Accuracy
C0	0-15%	±0.06%
HC	0-30000ppm as hexane	±12ppm
CO_2	0-20%	±0.5%
O_2	0-25%	±0.1%
NO_x	0-5000ppm	1ppm

3.1. PROPERTIES OF FUEL USED

Table 3 Properties of Diesel, Milk scum oil and Milk scum Biodiesel

Properties	Diesel	Milk scum oil	Bio diesel
Flash point	52°c	189°c	142°c
Fire point	96°c	210°c	156°c
Density	850 kg/m^3	885 kg/m^3	895 kg/m^3
Calorific Value	45500 kJ/Kg	37560 kJ/Kg	40099 kJ/Kg

The flash and fire point are found out by using Pensky martin apparatus. The calorific value is found out by using bomb's gas calorimeter. The obtained results are tabulated in table 3.

4. RESULT AND DISCUSSION

In this study the engine was run on different load conditions at speed 1500 rpm and the speed is kept constant with different EGR rates (from 0% to 30%) to study the effect of EGR on engine performance and the emission characteristics. The performance parameters analyzed are Brake thermal efficiency, Brake specific fuel consumption. The emission parameters analyzed are Exhaust gas temperature, Unburnt hydrocarbons, Carbon-dioxide, Carbon monoxide and Oxides of nitrogen.

4.1. PERFORMANCE PARAMETERS

4.1.1. Brake specific fuel consumption (BSFC)

The Figure 3 shows the trends of brake specific fuel consumption for different EGR rates. The BSFC will be less at lower engine loads with EGR when compared to without EGR. At higher engine loads there will be not much difference between BSFC with EGR and BSFC without EGR. At maximum load condition, the fuel supplied to the engine increases and the availability of O_2 will be less. So, the air fuel ratio will be changed and thus increases BSFC. The BSFC decreases 3.33% at maximum load with 10%EGR. The BSFC decreases 6.66% at maximum load with 20% EGR. The BSFC decreases 13.33% at maximum load with 30%EGR.The Similar trends are obtained in [4-7,14], Opposite trends are obtained in [1,3,12,19,20] and mixed trends are obtained in [2,13].

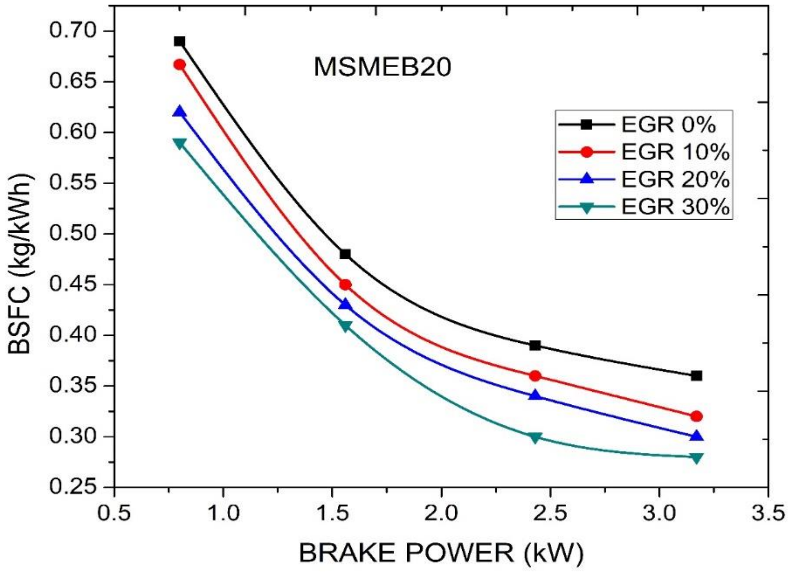

Figure 3 BSFC VS BRAKE POWER

4.1.2. Brake thermal efficiency (BTE)

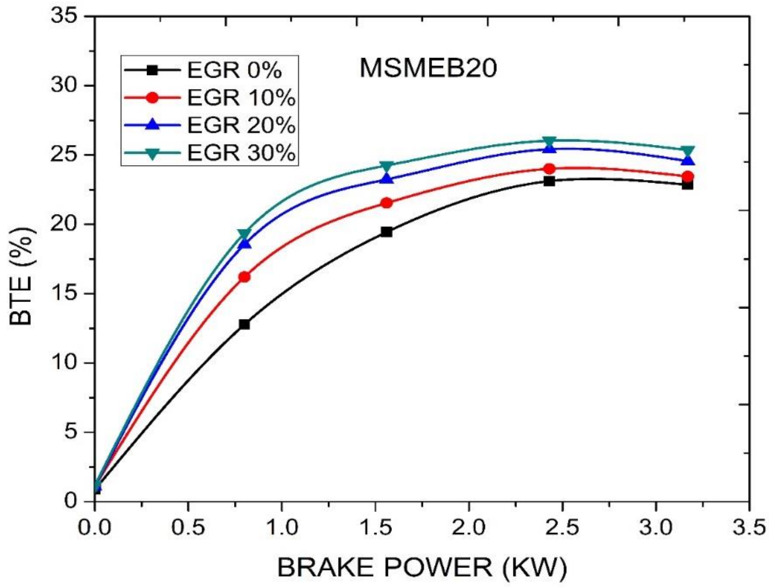

Figure 4 BTE v/s Brake power

The Figure 4 shows the trends of brake thermal efficiency. The thermal efficiency tends to increase with EGR at lower engine loads. The reason for increasing may be because of hydrocarbons which are present in the exhaust gas which enters the combustion chamber with recirculated exhaust gas. At lesser loads, exhaust gas will contain less amount of CO_2 and fair amount of O_2. Also, the recirculated air acts as preheater for the intake mixture. When exhaust gas is recirculated into the cylinder, the unburnt HC in exhaust gas burns because of fair availability of O_2 present in the combustion chamber and increased intake temperature. At maximum engine loads, the thermal efficiency will not be affected by EGR. At maximum load condition, the exhaust gas contains higher amount of CO_2, which will reduce the maximum combustion temperature in the chamber. The availability of O_2 at maximum load will be less so, there will be no significant burning of HC. The BTE increases 2.72% at second maximum load with 10%EGR. The BTE increases 14.10% at second maximum load with 20%EGR. The BTE increases 17.95% at second maximum load with 30%EGR. Similar trends are obtained in [2,3,5-7,11], Opposite trends are obtained in [4,12-14,20], Mixed trends are obtained in [1,19].

4.1. Engine Emission Analysis

4.1.1. Carbon monoxide (CO) and Unburnt hydrocarbons (HC)

The effect of EGR on unburnt hydro carbon (HC) and carbon monoxide (CO) are shown in figure 5 and 6 respectively. The trends will show HC and CO emissions increases with increase in EGR. As EGR is increased the availability of oxygen is less so that it forms rich mixture of fuel inside the combustion chamber. Due to less availability of oxygen due to less availability of oxygen the heterogeneous mixture will not burn completely so that there will be rise in amount of HC and CO in the exhaust gas. The HC increases 11.2% at maximum load with 10%EGR. The HC increases 21% at maximum load with 20%EGR. The HC increases 24.2% at maximum load with 30%EGR. The CO increases 12.3% at maximum load with 10%EGR. The CO increases 14.8% at maximum load with 20%EGR. The CO increases 46.9% at maximum load with 30%EGR. For CO Similar trends are obtained in [1,2,5-7,16,19], Opposite trends are obtained in [9,11,17,20] and mixed trends are also obtained in [3,4], and for HC Similar trends are also obtained in [1-6], Opposite trends are obtained in [7,9,19,20], Mixed trends are also obtained in [4,11].

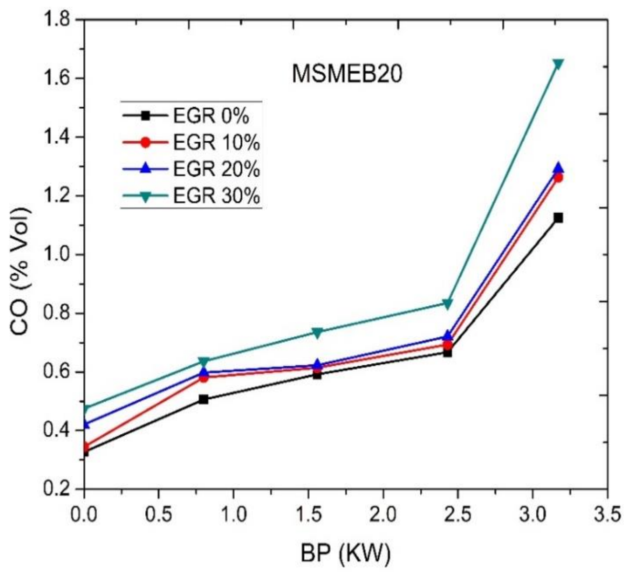

Figure 5 CO v/s Brake power

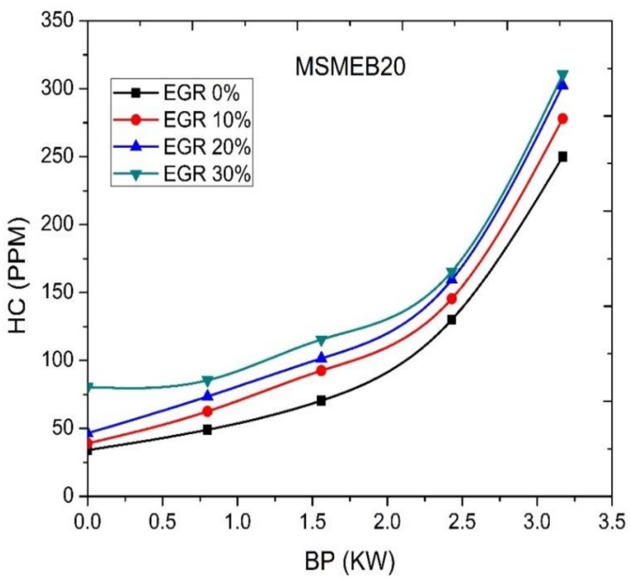

Figure 6 HC v/s Brake power

4.2.2. Carbon dioxide (CO_2)

The figure 7 shows the graph of carbon dioxide emission (CO_2). At maximum load condition the emission of carbon dioxide will be increase when there is no EGR. The emission of the carbon dioxide will be reduced with the increase in EGR. As the EGR increased the amount of oxygen supplied to the combustion chamber. So, there will be less availability of oxygen to form carbon dioxide. Because of this the emission of carbon dioxide will be reduced as the EGR rate increase. The CO_2 decreases 1.38% at maximum load with 10%EGR. The CO_2decreases 20.6% at maximum load with 20%EGR. The CO_2 decreases 22% at maximum load with 30%EGR. Similar trends are obtained in [2,9,11,16,17] and opposite trends are obtained in [3,14].

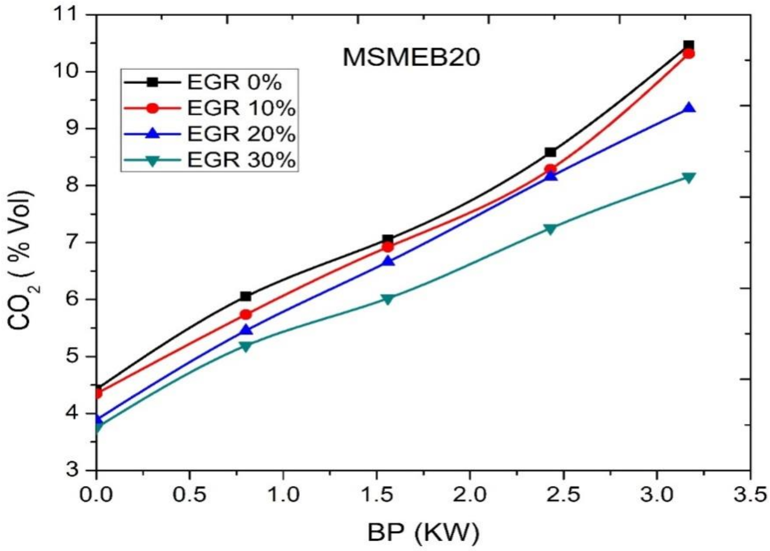

Figure 7 CO_2v/s Brake power

4.1.2. Exhaust gas temperature (EGT)

The figure 8shows trends of exhaust gas temperatures (EGT). When the load is increased it has been observed that the exhaust gas temperature will also increase. If the Engine is operated with partly cooled EGR, the exhaust gas temperature will be decreased when compared to normal operating conditions. The exhaust gas temperatures reduce with the increase of EGR because of lower availability of oxygen when EGR rate is increased. The EGT decreases 0.17% at maximum load with 10%EGR. The EGT decreases 2.84% at maximum load with 20%EGR. The EGT decreases 5.7% at maximum load with 30%EGR.The Similar trends are obtained in [1,2,5-7,14,15].

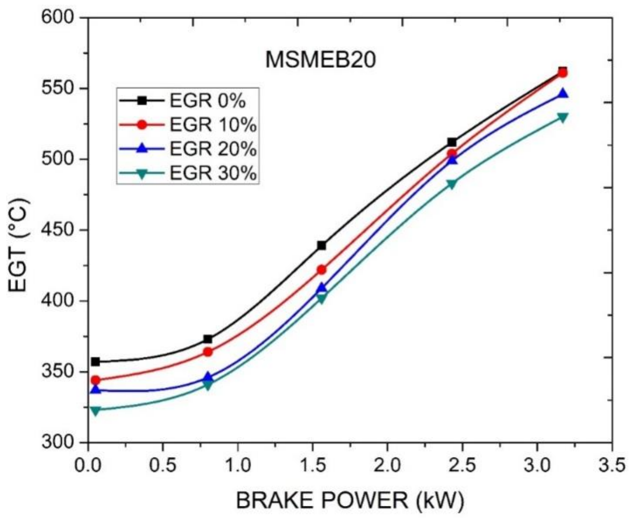

Figure8 EGT v/s Brake power

4.2.4. Oxides of Nitrogen (NO_x)

The figure 9 shows the role of EGR in reducing oxides of nitrogen (NO_x) emission from diesel engine. The higher amount of NO_x is reduced at higher loads. The reason behind the reduction of NO_x is because of the lesser concentration of oxygen in the EGR and reduction in combustion temperature. At lesser load condition the availability of oxygen is sufficient and at higher load conditions the availability of oxygen is available but in higher load condition the availability of oxygen reduces considerably, therefore NO_x is reduced more at higher load condition when compared to lower load. The NO_x decreases 25.09% at maximum load with 10% EGR. The NO_x decreases 40.9% at maximum load with 20% EGR. The NO_x decreases 54.9% at maximum load with 30% EGR. Similar trends are obtained in [1-7,9,10,13], Opposite trends are obtained in [12,19] and mixed trends are obtained in [14,20].

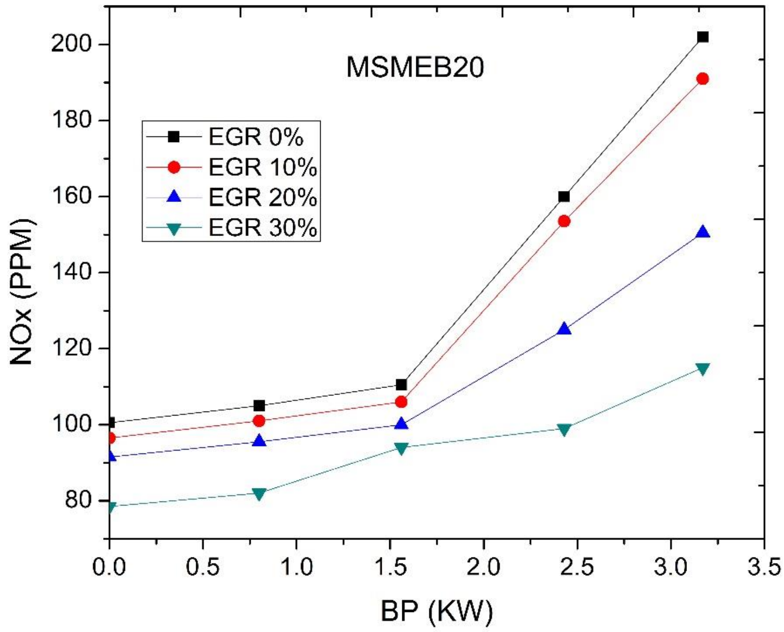

Figure 9 NO_x v/s Brake power

5. CONCLUSIONS

- The BTE increases 17.95% when compared with EGR 0% and EGR30% at 2.43 kW load. The main reason could be the remaining HC in the recirculated gas and the recirculated gas acts as the preheater for intake air.
- The BSFC decreases 13.33% when compared with EGR 0% and EGR 30% 3.17 kW load. The main reason for the reduction of may be, the BSFC will be less at lower engine loads with EGR when compared to without EGR. At higher engine loads there will be not much difference between BSFC with EGR and BSFC without EGR.
- The CO and HC increases 24.2% and 46.9% respectively when compared with EGR 0% and EGR 30% at 3.17 kW load. The main reason for the increase of CO and HC isas EGR is increased the availability of oxygen is less so that it forms rich mixture of fuel inside the combustion chamber. Due to less availability of oxygen due to less availability of oxygen the heterogeneous mixture will not burn completely so that there will be rise in amount of HC and CO in the exhaust gas.
- The CO_2 decreases 22% when compared with EGR 0% and EGR 30% at 3.17 kW load. The main cause of reduction in the CO_2 is the emission of the carbon dioxide will be reduced with the increase in EGR. As the EGR increased the amount of oxygen supplied to the combustion chamber. So, there will be less availability of oxygen to form carbon dioxide.

- The EGT decreases 5.7% when compared with EGR 0% and EGR 30% at 3.17 kW load. The main reason for decrease of EGT is if the Engine is operated with partly cooled EGR, the exhaust gas temperature will be decreased when compared to normal operating conditions. The exhaust gas temperatures reduce with the increase of EGR because of lower availability of oxygen when EGR rate is increased.
- The NO_x decreases 54.9 % when compared with EGR 0% and EGR 30% at 3.17 kW load. The main reason for decrease of NO_x is because of the lesser concentration of oxygen in the EGR and reduction in combustion temperature. At lesser load condition the availability of oxygen is sufficient and at higher load conditions the availability of oxygen is available but in higher load condition the availability of oxygen reduces considerably, therefore NO_x is reduced more at higher load condition when compared to lower load

REFERENCES

[1]. S.A.Ransing et al,. Critical review of effect of EGR on CI Engine running on bio diesel and its blends. International journal on theoretical and applied research in mechanical engineering ISSN: 2319-3182, Volume-4, Issue-1, 2015

[2]. M. Anandan et al,. Effect of compression ratio and exhaust gas recirculation (EGR) of Combustion, Emission and Performance of DI Diesel Engine with Biodiesel Blends. Global Journal Of Researches in Engineering: A Mechanical and Mechanics engineering. Volume 14 Issue 7 Version 1.0 year 2014.

[3]. MohdHafizil Mat Yasin et al,. Effects of Exhaust Gas Recirculation (EGR) on a Diesel Engine fueled with Palm-Biodiesel. Elsevier The 7th International Conference On Applied Energy 1876-6102, ICAE-2015.

[4]. A. Paykani et al, Experimental Investigation of the Effect of Exhaust gas Recirculation on Performance and Emissions Characteristics of Diesel Engine Fueled with Biodiesel. IACSIT International Journal of Engineering Technology, Volume.3.No 3.June 2011.

[5]. Dr.K. Srinivasa Rao, Effect of EGR on Diesel Engine Performance and Exhaust Emission Running With Cotton Seed Biodiesel, International Journal of Mechanical and Mechatronics Engineering IJMME-IJENS Vol:16 No:02.

[6]. Deepak Agarwal et al,. Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits and durability of a constant speed compression ignition engine. Applied Energy 88 (2011) 2900–2907.

[7]. N. Sunil Naik & B. Balakrishna, Effects of EGR on performance and emissions of a diesel engine fuelled with balanitesaegyptiaca/diesel blends.International Journal of Sustainable Engineering. ISSN: 1939-7038 (Print) 1939-7046

[8]. M Krishnamoorthi and R Malayalamurthi. Effect of exhaust gas recirculation and charge inlet temperature on performance, combustion, and emission characteristics of diesel engine with bael oil blends. Energy & Environment 0(0) 1–20 ! The Author(s) 2018

[9]. Domenico De Serio et al,. Effects of EGR rate on performance and emissions of a diesel power generator fueled by B7.J Braz. Soc. Mech. Sci. Eng. (2017) 39:1919–1927 DOI 10.1007/s40430-017-0777-x

[10]. Ming Zheng et al,. Biodiesel engine performance and emissions in low temperature combustion. ScienceDirect. Fuel 87 (2008) 714–722

[11]. Jeya Jeevahan et al Investigation of Engine Performance and Emissions of B20 Biodiesel Blend and Effect of EGR on NOx Emissions Reduction journal of chemical pharmaceutical science ISSN:0974-2115 October -December 2016 JCPS volume 9 Issue 4

[12]. S. Ghosh1 et al The Effects of EGR on the Performance and Exhaust Emissions of a Diesel Engine Operated on Diesel Oil and Pongamia Pinata Methyl Ester (PPME) International Journal of Engineering InventionsISSN: 2278-7461, ISBN: 2319-6491Volume 1, Issue 12 (December 2012) PP: 39-44

[13]. S. Ghosh et al The Effects of EGR on the Performance and Exhaust Emissions of a Diesel Engine Operated on Diesel Oil and Soybean Oil Methyl Ester (SOME) IOSR Journal of Engineering **e-** ISSN: 2250-3021, -ISSN: 2278-8719, Vol. 2, Issue 12 (Dec. 2012)

[14]. Mohd Riyazuddin and Srinivas Valmiki Effect of Exhaust Gas Recirculation on Performance and Emission Characteristics of a Diesel Engine Running with Corn Oil Biodiesel Biodiesel International Journal of Engineering and Techniques - Volume 4 Issue 2, Mar-Apr 2018

[15]. Mohd hafizil Mat Yasin et al The Effects of Exhaust Gas Recirculation on the Performance and Emission Characteristics of a Diesel Engine – A Critical Review, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017).

[16]. Mohd Hafizil Mat Yasina at el Effects of Exhaust Gas Recirculation (EGR) on a Diesel Engine fuelled with Palm-Biodiesel The 7th International Conference on Applied Energy – ICAE2015 Energy Procedia 75 (2015) 30 – 36

[17]. Jun Cong Ge at el Effects of Pilot Injection Timing and EGR on Combustion, Performance and Exhaust Emissions in a Common Rail Diesel Engine Fueled with a Canola Oil Biodiesel-Diesel Blend ISSN 1996-1073 journal/energies 2015,8,7312-7325

[18]. Ajinkya B at el Effect of exhaust gas recirculation (EGR) in internal combustion engine International Research Journal of Engineering and Technology (IRJET) -ISSN: 2395 -0056

[19]. Mohammed Mustafa Badri at el Performance and Emissions of a Modern Small DI Diesel Engine Fueled by Diesel-Biodiesel-Iso-Butanol Blends with EGR Mohammed Mustafa Badri Int. Journal of Engineering Research and Application www.ijera.com ISSN : 2248-9622, Vol. 8, Issue5 (Part - III) May 2018, pp58-67

[20]. K Srinivasa Rao at el Effect of exhaust gas reciculation on performance and Emission Characteristics of Diesel engine fuelled with waste cooking oil methyl ester ARPN Journal of Engineering and Applied Sciences ISSN 1819-6608 Vol`. 10, NO. 11, June 2015