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Effect of EGR on a sationary VCR diesel engine using cottonseed biodiesel (B20) fuel

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Abstract: This paper presents a view on comparative study of use of diesel fuel with B20 biodiesel-blend (Diesel (80 %, by vol.) and Cotton seed oil (20 %, by vol.)) derived from Cotton seeds. As higher NOx emission and higher brake specific fuel consumption are main challenges for effective utilization of biodiesel fuel in a diesel engine, there is alarming need to find out the long term solution to reduce NOx emission for better utilization of biodiesel fuel in a diesel engine. Exhaust gas recirculation (EGR) is one of the useful technologies to reduce the NOx emission of a diesel engine. In the present research work test is conducted on 3 KW single cylinder, four stroke, water cooled, variable compression ratio (VCR) computerized diesel engine using diesel and B20 cotton seed biodiesel blend to study the effect of exhaust gas recirculation on performance and emissions characteristics of a diesel engine in terms of fuel consumption, thermal efficiency and emissions such as hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NOx) and carbon dioxide (CO_2) of a diesel engine. The constant engine speed of 1500 rpm was maintained through-out the experiment test. The exhaust gas recirculation was varied as 4 % and 6 % at different loading conditions with diesel and B20 biodiesel. The results show that the significant reduction in oxides of nitrogen (NOx) with 4 % and 6 % EGR for B20 whereas marginal increment in CO and HC emissions.

Keywords: EGR, biodiesel (cottonseed), NOx, diesel engine

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1 Introduction: The credit of development of the compression ignition engine goes to Dr. Rudolf Diesel's work in 1892. As we know that today the compression ignition (CI) engine is found to be very important prime mover, which mostly used in buses, trucks, locomotive, tractors and other stationary industrial applications **[1]**. As the world is facing major problem of global warming and environmental pollution to which contribution in the emission is more from engine. It has also seen that there is gradual depletion of fossil fuel so there is need for source of alternative fuel **[2, 3]**. As it is seen from the researchers work that use of biodiesel is increasing because of its low emission impact on environment and having better potential. It has observed that emissions akin to carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbon (HC) found to be least amount by using biodiesel; this is because of inherent oxygen content and fuel properties **[4]**. It has observed that emissions from diesel engine is less but it emits more NOx than other emissions, hence in order to meet environmental legislation it is necessary to reduce NOx in the exhaust gas. In the present survey it has also found that, with the utilization of exhaust gas recirculation there is scope of reduction in the emissions coming out from the compression ignition engine.

It has also observed that there is reduction of NOx by 25 % EGR valve opening for all loads where-as smoke and PM increases with 25 % EGR valve opening with no change in brake thermal efficiency **[5]**. It can be observed that the effect of EGR observed to be leading in reduction of NOx emissions. It has also concluded that there is a slight increase in efficiency of engine due to EGR. With utilization of biodiesel as fuel, there is a problem with increase in NOx emissions as well as there is reduction in performance of the engine. If EGR method is included with using biodiesel, then there would be greater advantage of growing the performance of the engine as well as reduction in all the emissions. Smoke increased slightly with adds to in percentage of EGR. Cold EGR with 15 % recirculation would result in optimum engine performance as well as reduction of emissions **[6]**. It has suggested that it is a combustion system with a relatively good premixing. EGR introduces large benefits (up to 50 %) for raw NOx reduction. The reduction will be even higher if NOx is corrected to 15% O_2 **[7]**.

It has concluded that emission level for biodiesel fuel is lower than diesel fuel used in engine. The test shows that performance of B5, B10, B15, B20, B40 and B100 blend shows high total fuel consumption (TFC) and specific fuel consumption (SFC) for B40 and B100 blends, where as it is stable for B20 blend. It has also observed that B40 and B100 have low efficiency than other remaining blends for various loading. Among the blends B15 and B20, it has a moderate NOx and CO emission formation. Thus the from above test it is seen that 20 % B20 blend with diesel yield the optimum value, with less fuel consumption and higher efficiencies than diesel fuel **[8]**. It has seen that BSFC decrease and brake thermal efficiency increase by increasing inlet air pressure. EGR and inlet air pressure system is economical for reducing NOx, HC, CO, and CO_2 emissions which may reduce by using soot trap and diesel oxidation catalyst treatment method **[9]**. With increasing the EGR from 0-30 %, pressure decreases by 9 %. Heat release occurs at 722 ºC A which increases from 0-30% EGR. It can be seen that there is 75 % reduction of NOx. It's also observed that soot increases by 41.2% with increase in EGR percentage from 0-30 % **[10]**.

It has concluded that insulation reduces soot and indicated specific consumption (ISFC) but increases NOx at part and full load conditions. At 10 % EGR NOx and ISFC reduces at part load, so it can be say that optimum EGR utilization is 10 %. At full load condition 10 % EGR reduces NOx emission but increases soot **[11]**. There is reduction of CO, HC, NOx and CO_2 emission. The darker the fuel color more stables is the biodiesel **[12]**. EGR is one method of reducing NOx amongst other. EGR of 4 to 9 % can reduce NOx by 31 to 71 % and reduced power by 1.6 to 5.6 %, but there is increased specific fuel consumption by 2.5 to 3 % **[13]**. It is observed that with increase in EGR there is decreased in brakes thermal efficiency. The concentration of soot is found higher. At high load, fuel consumption increases as percentage of EGR is increased. There is also decreased in NOx emission **[14]**. The THC, smoke and CO emissions have reduced by around 35 %, 20 % & 19.6 % from D100 to BD20 blend utilization. It is also observing that total mass of particles reduced by around 10 % and 25 % respectively. In spite of this, size of particle under diameter 50nm increases by 1.6 %. With and without utilization of EGR found that number and mass of particles for both BD20 and D100 have reduced by 43% **[15]**.

It can be seen that biodiesel's molecular structure and chemical composition have impact on combustion, emission and noise. It has also observed that biodiesel and its blends have effective impact on emissions. Cotton seed fuel is also effective for reduction of PM and smoke. Good noise emission is observed with biodiesel fuels. It is suggesting that an optimal change in engine parameter is advantageous for human health and environment **[16]**. The effect of cooled EGR with BD 100 has studied with utilization of 7 %, 9 %, 12 %, 20 % and 25 % rate of EGR. Out of all at 12 % EGR rate engine emission gives best results. NO was reduced by 43% whereas CO and HC emissions are increased by 14 % and brake thermal efficiency (BTE) decreased by 7 % at full load. It has observed that for biodiesel, NOx emission reduction is 43% which is higher as compared to 22 % for diesel and 27 % BD20 % at 12 % EGR rate on full load condition. Hence by looking at the results it is recommended to use biodiesel blend B20 CSOME as substitute fuel with 12 % cooled EGR rate for most favorable performance emission characteristics **[17]**.

It has observed that brakes thermal efficiency increases for biodiesel than diesel fuel. There are decreased in smoke as well as emissions. It is also suggested that Blend 20 is optimum that can give better value [18]. From review it has observed that there is low power result obtained whereas B15 gives significant result. There is increased in SFC whereas thermal efficiency increases to some level with increases in biodiesel percentage. An increased in biodiesel minimizes CO_2 and CO emissions [19]. It has observed that there is reduction in temperature because of this NOx formation increased due to higher oxygen content [20].

The FC and BSFC increases and BTE decreases with increased in biodiesel blends. It is also seen that CO, CO_2 and THC emissions are decreased with increased in biodiesel blends. Engine has found like free of SOx and increased in NOx emission. It is concluding that engine life may increases but may cause problems in cold area and winter season which can be solve by adding additives in fuel [21]. There is decreasing of CO, particulate matter and HC. Addition of cetane improver may reduce NOx emission [22]. It has observed that brake thermal efficiency of engine using biodiesel fuel decreases at high compression ratio. On other side at low compression ratio its value increases. It is also seen that engine volume efficiency increases at high load. At lower compression ratio volumetric efficiency is high and it decreases with increased in compression ratio. Volumetric efficiency of cottonseed oil is more than diesel and maize oil [23].

It has also observed that CO, PM and HC emissions found to be less. NOx formation is more in biodiesel fuel than diesel fuel [24]. It has concluded that at advance injection timing combustion parameters like, longer delay period, higher peak pressure in cylinder, higher maximum heat release rate and shorter combustion duration has observed than those at standard injection timing. As a combined effect, it results in increased in maximum heat release rate, delay period, peak pressure and combustion duration. From obtained experimental results it has suggested that NOx and smoke emission can be controlled at the same time with less variation in combustion characteristics of the engine [25].

2. Exhaust gas recirculation:

One way of reducing NOx is by utilization of Exhaust Gas Recirculation (EGR) where exhaust gas coming from engine exhaust manifold is given to inlet manifold in order to reduce NOx [26-29]. When part of this exhaust is recirculation then it works as diluents to combustion mixture. Because of high specific heat of exhaust gas than fresh air, it increases the temperature of intake fresh charge as a result it decreases the temperature rise for the similar [30]. The EGR is defined in percentage as shown in Eq. 1.

$$\%EGR = \frac{Volume\_of\_EGR}{Total\_intake\_charge\_into\_cylinder} \times 100 \qquad \ldots (1)$$

3. Experimental set-up and methodology:

The experimental setup consists of Single cylinder, four strokes; VCR (Variable Compression Ratio) Diesel engine connected to hydraulic type dynamometer for loading is used for the experimentation of present research work. The diesel engine specifications are given in Table 1. The constant volume of EGR is supplied (from gas storage tank made up of mild steel material) to the intake manifold of the diesel engine. At the top of gas storage tank EGR control valve is provided to maintain the accurate flow of EGR. The tests were carried out with diesel and B20 biodiesel blend at various load conditions from 25 % to 100 % with different EGR percentage (4 % and 6 %). Initially, the tests were carried out for performance and emission characteristics of a diesel engine fuelled with base diesel fuel at all loads from 25-100 %. Then same procedure has followed for EGR 4 % and 6 % with diesel. In latter stage, experimentations were carried out for B20 cotton seed biodiesel and EGR 4 % and 6 % with B20.

Table (1): engine specifications.

Sr.No.	Title	Details
1	Product	1 cylinder,4 stroke, Diesel engine
2	Product Code	240
3	Engine	Kirloskar Make, water cooled
4	Power	3.5 Kw at 1500 rpm
5	Stroke	110 mm
6	Bore	87.5 mm
7	Swept volume	661 cc
8	CR	17.5

Figure (1): Experimental set-up.

4. Results and discussion:

It is observed that performance trends of the diesel engine decreased with utilization of exhaust gas recirculation (EGR). Brake power of engine decreased with use of cottonseed biodiesel blend B20 as compared to base diesel fuel as shown in Figure 2. It decreased from 3.2 kW with base diesel to 2.85 kW with B20 at the rated load. It could be due to lower calorific value, longer injection duration and combustion duration with B20 biodiesel fuel. Brake power is also decreased with exhaust gas recirculation from 3.2 kW with base diesel to 3.06 kW and 3 kW with 4 % and 6 % EGR respectively. It could be concluded from Figure 2 that the performance of the engine is decreased with increase in EGR percentage and B20 biodiesel as compared to base diesel. The brake power increased with increase in load.

Brake specific fuel consumption is a measure of fuel efficiency of any prime mover that burns fuel and produces power. It is observing from Figure 3 that the brake specific fuel consumption is decreased with respect to load as brake power is in denominator. The brake specific fuel consumption increased with biodiesel as compared to base diesel. It may be due to lower calorific value (CV) of biodiesel, longer injection duration results in longer combustion duration. Brake specific fuel consumption increased from 0.26 kg/kW-hr with diesel to 0.32 kg/kW-hr with B20 biodiesel. The brake specific fuel consumption also increased in the case of exhaust gas recirculation. It increased from 0.26 kg/kW-hr with diesel and 0.32 kg/kW-hr with B20 biodiesel to 0.28 kg/kW-hr (4 % EGR) and 0.29 kg/kW-hr (6 % EGR) with diesel and 0.34 kg/kW-hr (4 % EGR) and 0.37 kg/kW-hr (6 % EGR) for B20 biodiesel respectively at the rated load.

Mechanical efficiency measures the effectiveness of the engine in transforming the energy and power that is input to the device into an output force and movement. Mechanical efficiency is calculated by the ratio of measured performance (brake power) of the engine to the ideal performance (indicated power) of the engine. It is observed from the Figure 4 that the mechanical efficiency of a diesel engine using diesel and B20 biodiesel increased with respect load. It is also seen from Figure 4 that there is no significance change in mechanical efficiency with diesel and B20 biodiesel. But, the mechanical efficiency with exhaust gas recirculation decreased for both diesel and B20 biodiesel fuel. It may be decreased due to the amount of air replaced by exhaust gas results in less content of oxygen available inside the engine cylinder gives poor measured performance. The mechanical efficiency is decreased from 63.78 % with diesel to 63.42 % with 4 % EGR and 62.05 % with 6 % EGR at the rated load.

Similarly, it decreased from 65.47 % with B20 biodiesel to 65.4 % with 4 % EGR and 54.65 % with 6 % EGR.

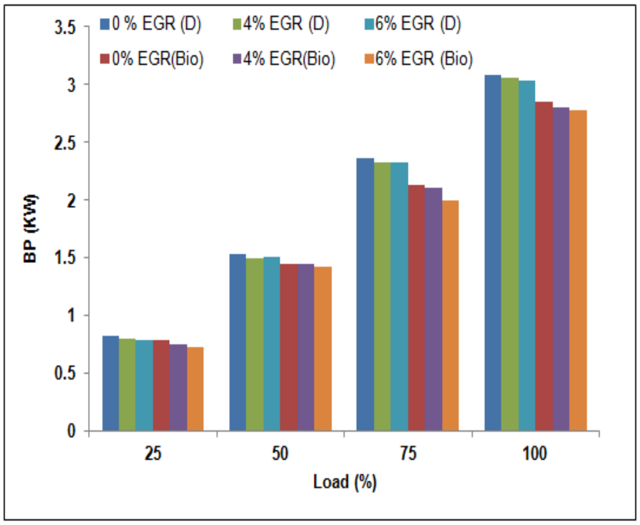

Figure (2): Comparison of brake power.

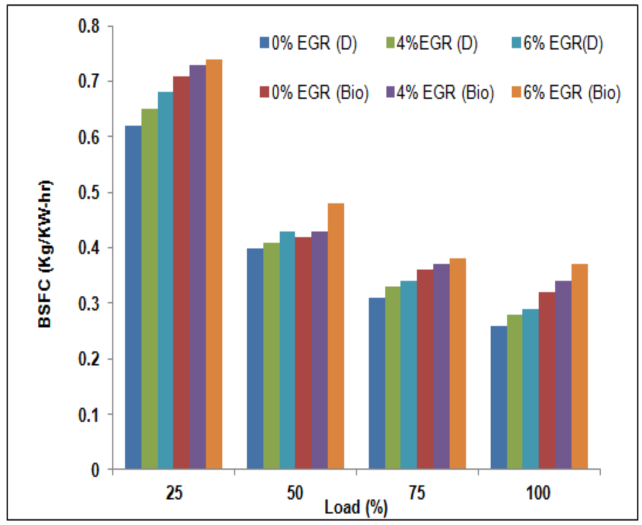

Figure (3): Comparison of BSFC.

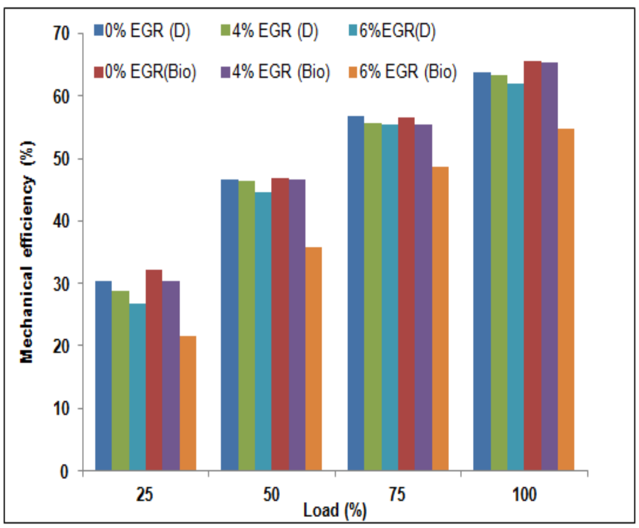

Figure (4): Comparison of mechanical efficiency.

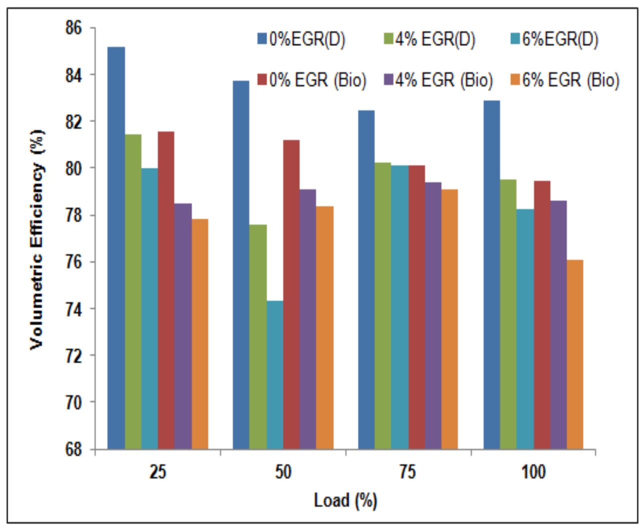

Figure (5): Comparison of volumetric efficiency.

Volumetric efficiency in the internal combustion engine design refers to the efficiency with which the engine can move the charge into and out the cylinders. More particularly, volumetric efficiency is the ratio of the quantity of air that is trapped by the cylinder during induction over the swept volume of the cylinder under static conditions. The volumetric efficiency for diesel and B20 biodiesel with respect load is shown in Figure 5. The volumetric efficiency is nothing but the air breathing capacity of the engine. As exhaust gas is inducted into the intake manifold, the quantity of air is replaced by exhaust gas. The quantity of air is directly proportional to the volumetric efficiency. Therefore, volumetric efficiency is decreased with exhaust gas recirculation. It decreased from 82.9 % with diesel to 79.5 % with 4 % EGR and 78.25 % with 6 % EGR at the rated load. Similarly, it decreased from 79.48 % with B20 biodiesel to 78.62 % with 4 % EGR and 76.09 % with 6 % EGR.

Thermal efficiency indicates the extent to which the energy added by heat is converted to net-work output. The engine performance is mainly checked by this parameter. It is observed from Figure 6 that the thermal efficiency is decreased with B20 biodiesel as compared to base diesel. Thermal efficiency decreased from 30.07 % with diesel to 28.7 % with B20 biodiesel. It may mainly due to lower calorific value of biodiesel results in lower power. Another reason could be due to longer injection duration results in longer combustion duration tends to poor performance. Thermal efficiency also decreased with exhaust gas utilization may be due to lower oxygen content results in lower combustion temperature. It decreased from 30.07 % with diesel to 29.67 % with 4 % EGR and 29.46 % with 6 % EGR at the rated load. Similarly, it decreased from 28.7 % with B20 biodiesel to 28.58 % with 4 % EGR and 28.02 % with 6 % EGR.

The comparison of CO and HC emissions for diesel and B20 biodiesel with respect to load is shown in Figures 7-8. It is clearly seen from the figures that CO and HC emissions are decreased with B20 biodiesel as compared to base diesel. It may be due to oxygen content in the biodiesel results in cleaner and complete combustion. Another reason could be due to biodiesel having higher bulk modulus results in automatic advance in dynamic injection timing and higher cetane number of biodiesel tends to shorter ignition delay. The combined effect of shorter ignition delay and advance in dynamic injection timing results in higher in-cylinder temperature produces lower CO and HC emissions. The CO emission is decreased from 0.02 % with diesel to 0.01 % with B20 biodiesel. Similarly, HC emission decreased from 6 ppm with diesel to 2.5 ppm with B20 biodiesel.

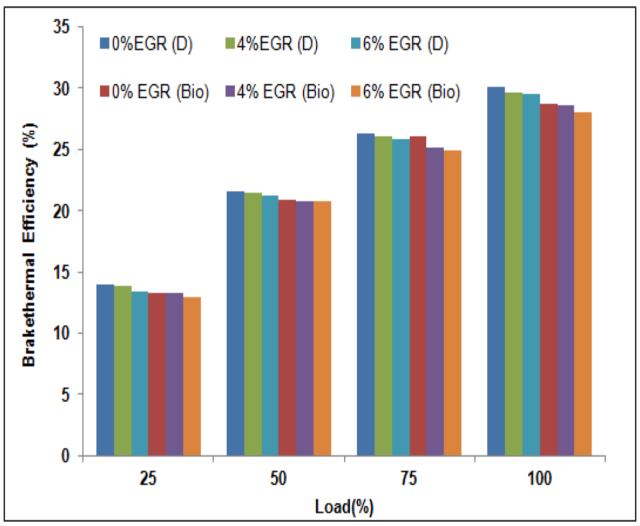

Figure (6): Comparison of brake hermalefficiency.

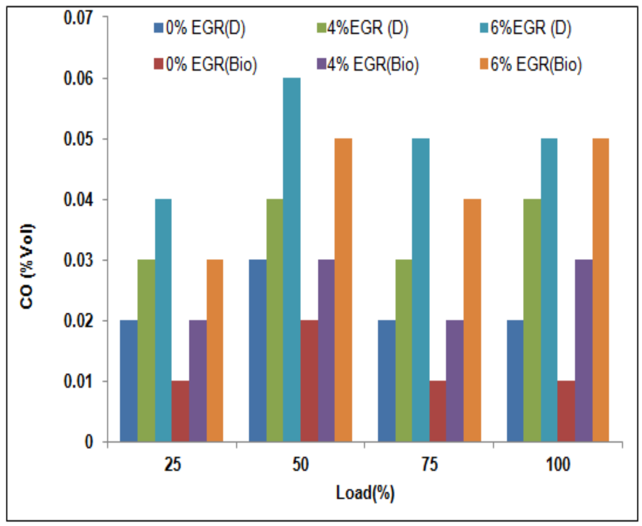

Figure (7): Comparison of CO emission

At 4 % EGR and 6 % EGR, CO and HC emissions are increased with diesel as well as B20 biodiesel. It CO emission increased from 0.02 % with diesel to 0.04 % with 4 % EGR and 0.05 % with 6 % EGR at the rated load. Similarly, it increased from 0.01 % with B20 biodiesel to 0.03 % with 4 % EGR and 0.05 % with 6 % EGR. The HC emission is increased from 6 ppm with diesel to 8 ppm with 4 % EGR and 9 ppm with 6 % EGR at the rated load. Similarly, it increased from 2.5 ppm with B20 biodiesel to 4 ppm with 4 % EGR and 6 ppm with 6 % EGR. In case of EGR, air gets replaced by EGR, the deficiency of oxygen with the increase of EGR percentage can be attributed to the increase in CO and HC emissions. Another reason of increase in CO and HC emissions could be due to increase in the CO_2 content of the inducted mixture instead of fresh-air. Finally, it lowers the in-cylinder (combustion) temperature results in increase in CO and HC emissions.

CO_2 emission increased from 0.9 % with diesel to 1 % with biodiesel as shown in Figure 9. However, CO_2 emission decreased with increase in percentage of EGR. The CO_2 emission is decreased from 0.9 % with diesel to 0.8 % with 4 % EGR and 0.6 % with 6 % EGR at the rated load. Similarly, it decreased from 1 % with B20 biodiesel to 0.9 % with 4 % EGR and 0.7 % with 6 % EGR. As biodiesel is a renewable fuel, higher CO_2 emission is not a major problem (CO_2 cycle).

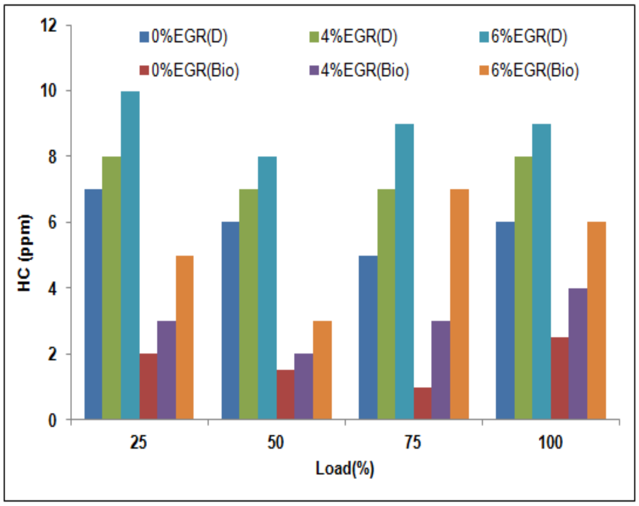

Figure (8): Comparison of HC emission.

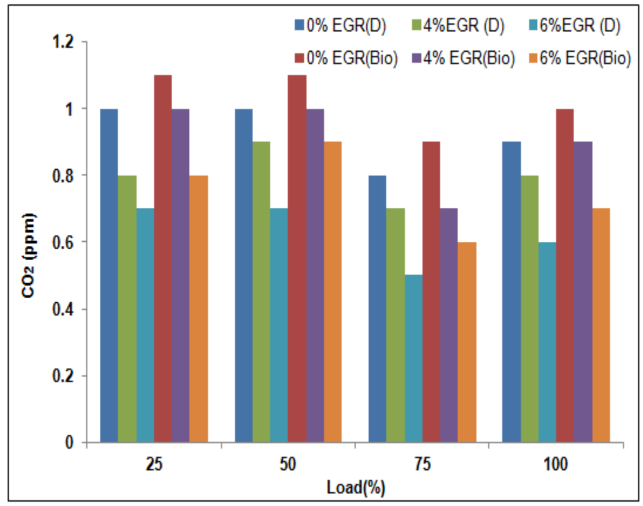

Figure (9): Comparison of CO_2 emission

NOx emission is higher for biodiesel as compared to base diesel. It increased from 259 ppm with diesel to 268 ppm with B20 biodiesel as shown in Figure 10. It may be due to higher bulk modulus of biodiesel results in automatic advance in dynamic injection timing, shorter ignition delay, higher spray penetration, higher in-cylinder temperature and oxygen content. Exhaust gases consists of CO_2, N_2 and water vapor mainly. The part of this exhaust gas is re-circulated to the engine cylinder; it acts as diluents to the combustion mixture. As it replaces the amount of fresh air, it also reduces the O_2 concentration in the combustion chamber **[31]**. The specific heat of EGR is much higher than fresh air; hence EGR increases the heat capacity (specific heat) of the intake charge, thus it decreases the temperature rise for the same heat release in the combustion chamber results in lower NOx emission with EGR. The NOx emission is decreased from 259 ppm with diesel to 249 ppm with 4 % EGR and 241 ppm with 6 % EGR at the rated load. Similarly, it decreased from 268 ppm with B20 to 257 ppm with 4 % EGR and 251 ppm with 6 % EGR.

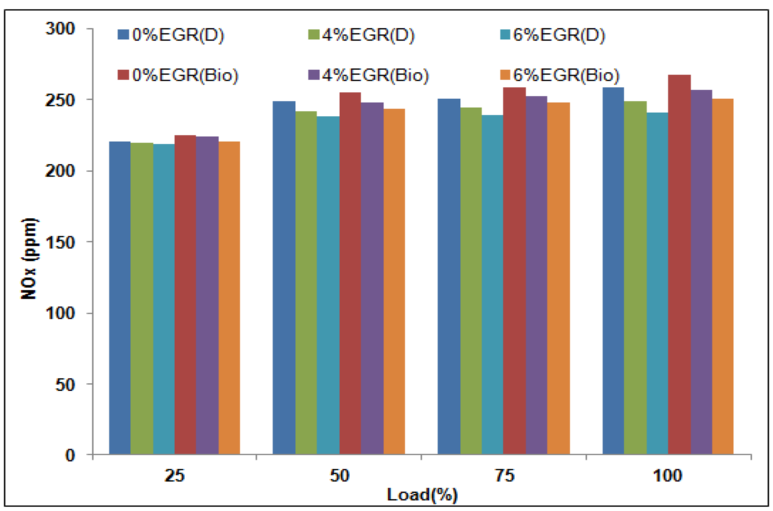

Figure (10): Comparison of NOx emission.

5 Conclusions: BSFC increased with B20 as compared to diesel due to lower CV. BSFC also increases with increase of EGR rate because of formation of rich mixture due to insufficient oxygen supply. The CO and HC emissions decreased with B20 biodiesel as compared to diesel due to oxygenated fuel. However, NOx emission increased with B20. The temperature of exhaust gas continuously decreases with increase of EGR rate. The higher specific heat of intake air and exhaust gas mixture and lower oxygen availability are main reasons for lower in-cylinder (combustion) temperature results in lower NOx emission and higher the CO and HC emissions with EGR.

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