# Performance and Emission Characteristics of Diesel Engine with Exhaust Gas Recirculation (EGR) on Diesel and Neem Biodiesel Blends with Ethanol as Additive

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**Abstract –** *In the present study the production of biodiesel from neem oil, monoester of neem oil is produced using transesterification process. It is a clean burning fuel and can be used as a fuel in existing unmodified 4-stroke, water cooled, single cylinder diesel engine and has a capacity of developing 5.2kW rated power. The fuel properties of neem oil such as flash point and fire point were examined. The main of this study is to find out the performance and pollutant emissions of oxides of nitrogen ($NO_x$), hydrocarbons (HC) and carbon-monoxide (CO) characteristics at varying load and at different percentages of biodiesel along with ethanol as a additive with exhaust gas recirculation (EGR). The results shows that the biodiesel produced using neem oil could reduce Carbon monoxide and smoke emissions significantly while the Nitrogen oxide emission changed slightly with varying EGR rate.*

***Key Words:* *4-stroke DI engine, biodiesel, EGR etc.***

## 1. Introduction

In the day to day life the increase in the population in the whole world is also a reason for increase in the number of automobiles parallel there is an increase in demand of petroleum products. For this demand the developing countries like India spending huge amount for the import of petroleum products from other countries which will become huge burden on Indian financial economy. And after some 50years the depletion of fossil fuels may become a huge worse impact on the whole world and increase in release of oxides of nitrogen, carbon monoxide, carbon dioxide, hydrocarbons, oxides of sulphur etc, from the automobiles were polluting the air and causing harmful diseases to the livelihood. In order to overcome this worse impact many research works are being carried out to find a solution for an alternate fuel for the automobiles. Some of the non renewable sources like CNG compressed natural gas, liquefied petroleum gas LPG, solar power etc, were also being used to run the automobiles to reduce the air pollution and becoming an environmental friendly.

In the present study we have undergone research and found neem oil is also a better option to use it as a biodiesel in an automobile. Even though neem tree has huge medicinal values and this tree is available everywhere in the whole world and it is grown in any type of land except desert areas. This feasibility and availability of neem tree made researchers to use neem seeds as one of the fuel component. The neem seeds are collected and crushed to extract oil from it and treated chemically to convert it into a useful biofuel by a process called trans-esterification process. This biofuel is blended with diesel and ethanol as additive. The use of this biodiesel is environ friendly and releases fewer amounts of CO, HC, $CO_2$ etc. But there is slightly increase in $NO_x$.

## 2. Experimental Setup and Properties of fuels used

The experimental investigation of performance and emission characteristics of diesel engine working on diesel as neem biodiesel and ethanol with exhaust gas recirculation EGR. The experimental setup for neem biodiesel and diesel with EGR is done is as shown in the below Fig.1 and notations of Fig.1 is mentioned in the Table.1.

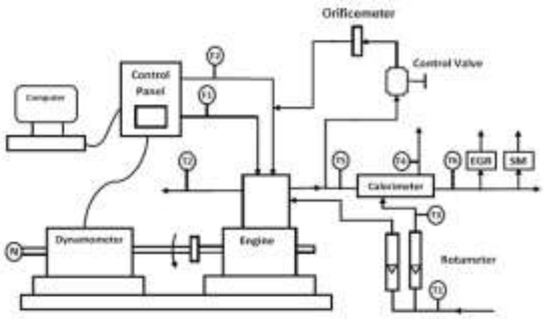


**Fig.1** Experimental setup of Diesel Engine with EGR

**Table.1 Notations of Diesel Engine with EGR**

| Sl No | Parameters | Specification |
|---|---|---|
| 01 | Manufacturer | Kirloskar oil engines Ltd. India |
| 02 | Model | TV1- SR, naturally aspirated |
| 03 | Engine | Single cylinder, DI |
| 04 | Bore/Stroke | 87.5mm/110mm |
| 05 | Compression Ratio | 17.5:1 |
| 06 | Speed | 1500 RPM, constant |

| | | |
|---|---|---|
| 07 | Rated power | 5.2 KW |
| 08 | Working cycle | Four stroke |
| 09 | Response time | 4 micro seconds |
| 10 | Type of sensor | Piezo electric |
| 11 | Crank angle sensor | 1-degree crank angle |
| 12 | Injection pressure | 200 bar/23 deg TDC |
| 13 | Resolution of 1deg | 360 deg with a resolution |

The different properties like kinematic viscosity, calorific value, sp.gravity, density, flash and fire point of each oils is conducted in different apparatus of neem biodiesel, diesel and ethanol were mentioned in the below (Table.2).

**Table.2 Properties of Fuel**

| Sl. No | Characteristics | Diesel | Neem | Ethanol | Apparatus |
|---|---|---|---|---|---|
| 1 | Density (kg/m3) | 830 | 880 | 780.8 | Hydrometer |
| 2 | Lower calorific value (kj/kg) | 42600 | 37850 | 27800 | Bomb Calorimeter |
| 3 | Kinematic Viscosity (cst) | 3.21 | 5.70 | 6.04 | Redwood Viscometer |
| 4 | Flash Point (°C) | 50 | 173 | 14 | Pensky Marten's Apparatus |
| 5 | Fire Point (°C) | 55 | 189 | 26 | Pensky Marten's Apparatus |

## 3. Results and Discussions

This section consists of three trial investigation of initial one is performance characteristics such as break thermal efficiency (BTHE), specific fuel consumption (SFC), and Exhaust gas temperature against break power (BP). Second one is combustion attributes like pressure and release rate against crank angle. Finally on its emission characteristics like carbon monoxide (CO), carbon-di-oxide ($Co_2$), unburnt hydrocarbons (HC) and oxides of nitrogen ($NO_x$) against break power (BP).

### 3.1 Performance characteristics

### 3.1.1 Variation of BTHE vs BP of Fuels

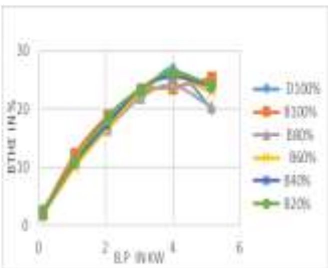

**Fig.2** variation of BTHE vs BP for different fuels and concentrations

The above Fig.2 shows that the variation of BTHE vs BP for different fuels and concentrations. From figure it is clearly shows that the BTHE of the blends is lower than pure diesel. But the BTHE of B20% is 26.32% and B40% is 25.6% were almost near to the BTHE of pure diesel of 26.9% at a constant pressure of 180 bars.

### 3.1.2 Variation of BTHE vs BP of Fuels with/without EGR

Comparison of BTHE vs BP of both the blends of B20% (Fig.3) and B40% (Fig.4) blends of neem biodiesel with 5% ethanol and 5%, 10% with EGR and without EGR.

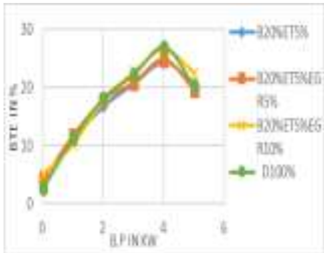

**Fig.3** Variation of BTHE vs BP for blend B20% with ethanol 5% without EGR, with EGR 5% and 10%.

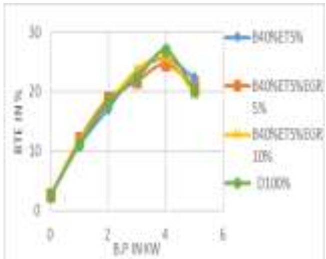

**Fig.4** Variation of BTHE vs BP for blend B40% with ethanol 5% without EGR, with EGR 5% and 10%.

### 3.1.3 Variation of BTHE vs BP of Fuels with/without EGR

The (Fig.5-7) demonstrates the variation of SFC and BP for diesel and for blended fuels of B20% and B40% on diesel engine.

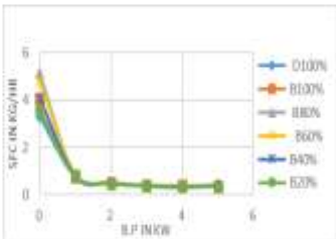

**Fig.5** Variation SFC vs BP for diesel and different blends.

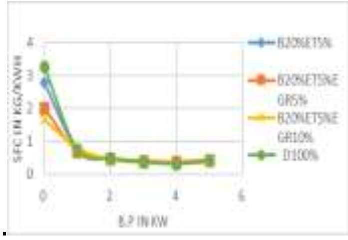


**Fig.6** Variation of BTHE vs BP for blend B20% with ethanol 5% without EGR, with EGR 5% and 10%.

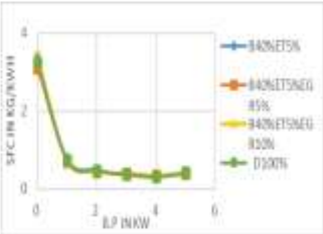


**Fig.7** Variation of BTHE vs BP for blend B40% with ethanol 5% without EGR, with EGR 5% and 10%.

Neem biodiesel on diesel engine without EGR, 5%, 10% and 15% EGR with unadulterated biodiesel on LHR engine. SFC neem biodiesel for 5%, 10%, and 15% EGR biodiesel is higher than diesel at lower load. At part stack the SFC steady (level) for all the fuels exception of diesel. At the full load SFC is more for biodiesel for blends B20% and B40% and different percentage of EGR compared to diesel. At the rated load SFC of biodiesel without EGR is 0.36 kg/kW-hr, against 0.34kg/kW-hr of diesel. With expanding of EGR that is 5%, 10% and 15% with biodiesel expands the SFC. SFC at appraised load for 5%, 10%, and 15% EGR biodiesel is observed to be 0.38 kg/kW-hr, 0.39 kg/kW-hr and 0.41 kg/kW-hr respectively. It is found that SFC is 23.3% expanded in 15% EGR than that of biodiesel without EGR at full load. However the base SFC for diesel is 0.34 kg/kW-hr against 0.36 kg/kW-hr Neem biodiesel on engine without EGR. As compared to all the blends B20% with ethanol 5% with EGR 10% is the best blend for low fuel consumption.

### 3.1.4 Variation of Exhaust Gas Temperature (EGT) vs BP of Fuels with and without EGR

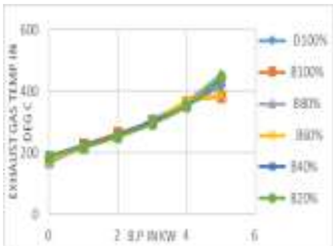


**Fig.8** Variation of exhaust gas temperature vs brake power for diesel and different blends.

The variation of exhaust emission temperature with brake power for diesel, and other blends of neem biodiesel are shown in Fig.8. This shows that at maximum loads the EGT of B20%, B80% is higher than the normal diesel and B100%, B60% EGT at higher loads is lesser than D100%.

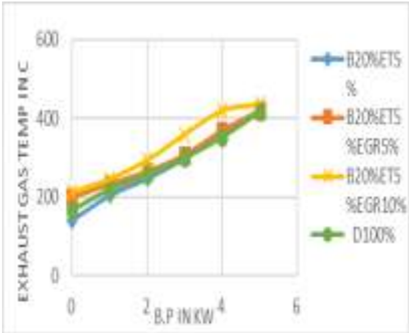


**Fig.9** Variation of EGT vs BP for blend B20% with 5% ethanol without EGR, with EGR 5%

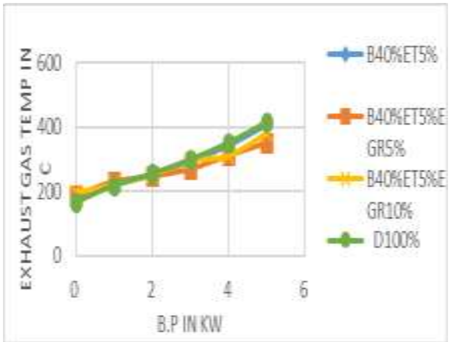


**Fig.10** Variation of EGT vs BP for blend B40% with 5% ethanol without EGR, with EGR 5% and 10%.

Fig-9-10 shows the comparison of exhaust gas temperature with brake power for B20% and B40% blends of neem biodiesel with ethanol 5% and EGR 5%, 10% and pure diesel. The exhaust gas temperature of B20% and B40% with ethanol 5% and without EGR at full load was 416.64 0c and 408.26 0C respectively at constant pressure 180bar and the exhaust temperature of B20% and B40% with ethanol 5% with EGR 5% at full load, it can be observed that 419.98 0C and 354.06 0C respectively. The exhaust temperature of B20% and B40% blends with ethanol 5% with EGR 10% at full load values can be found to be 435.87 0C and 383.36 0C respectively at constant pressure 180 bar, the pure diesel exhaust temperature found to be 417.68 0C. As a result of increased combustion duration, a higher exhaust gas temperature is recorded for B20% with ethanol 5% with EGR 10% blend exhaust gas temperature was higher in biodiesel compare with diesel at all load conditions. The possible reason for this temperature increased may be relatively higher availability of oxygen in biodiesel for combustion and because at full load the chemically correct ratio of air and fuel is used, because of chemically correct ratio of air and fuel, there is a generation of high heat inside the cylinder.

### 3.2 Emission Ccharacteristics

#### 3.2.1 Variation of CO emission with BP

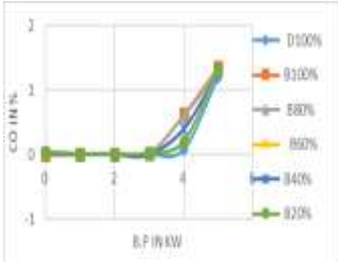


**Fig.11** Variation of emission of CO vs BP for diesel and different blends.

Fig.11 shows variation of CO with load for different blends. The CO emission increases with increasing the load. From the fig we can say that 100% of biodiesel the CO emission is more as compare to other blends this is because of high viscosity and poor atomization, tendency of neem biodiesel which leads to poor combustion and higher carbon monoxide emission.CO emission increase as air-fuel ratio becomes greater than stoichiometric value. As compared to the biodiesel blends diesel emits more CO under all loading conditions. B20% shows less emission of carbon monoxide.

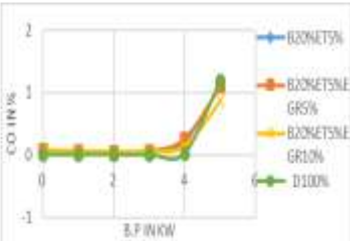


**Fig.12** Variation of emission of CO vs BP for diesel and blend B20% with ethanol 5% without EGR, with EGR 5% and 10%.

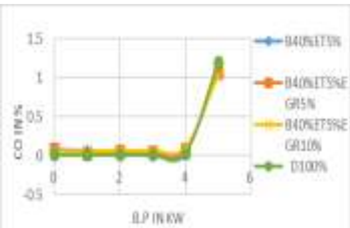


**Fig.13** Variation of emission of CO vs BP for diesel and blend B40% with ethanol 5% without EGR, with EGR 5% and 10%.

The Fig.12-13 shows the comparison of CO emission with brake power for B20% and B40% blends of neem biodiesel with ethanol 5% and EGR 5%, 10% and pure diesel. The CO emissions with ethanol 5% without EGR were obtained from neem biodiesel and its blends B20% and B40% at full load the CO emission is 1.11% and 1.10% respectively in 180 bar injection pressure and CO emission of B20% and B40% with ethanol 5% with EGR 5% is 1.12% and 1.06% respectively, the CO emission of B20% and B40% blends with ethanol 5% with EGR 10% the emission found to be 0.87% and 1.03% and pure diesel CO emission found to be 1.2% , as comparison with diesel the B20% with ethanol 5% with EGR 10% shows less CO emission . This is due to using of ethanol alcohol which reduces the carbon monoxide percentage.

#### 3.2.2 Variation of HC emission with BP

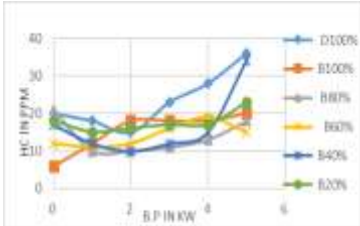


**Fig.14** Variations of emission of unburnt HC vs BP for diesel and different blends.

Fig.14 shows the exhaust of unburnt HC is due to a incomplete combustion of carbon compounds in blends. The HC emission value decreases with increase in biodiesel proportion in the fuel blends. The 100% diesel at full load and part load condition the HC emission is more compared to the other blends. High percentage of oxygen content and cetane number leads to less amount of HC. B80% and B60% the HC emission is less than that of the diesel.

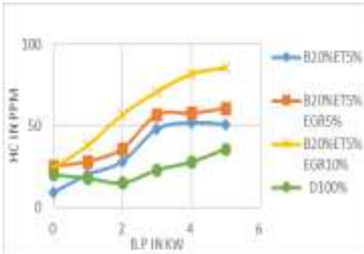


**Fig.15** Variation emission of unburnt hydrocarbon with brake power for blend B20% with ethanol 5% without EGR, with EGR 5% and 10%

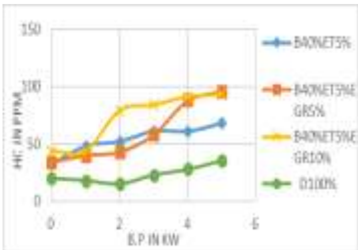


**Fig.16** Variation emission of unburnt hydrocarbon with brake power for blend B40% with ethanol 5% without EGR, with EGR 5% and 10%.

Figure 15-16 shows comparison of Unburnt hydrocarbon with brake power for B20% and B40% blends of neem biodiesel with ethanol 5% and EGR 5%, 10% and pure diesel. The emissions of unburnt hydrocarbon for biodiesel are high as compared to the diesel. At higher load and 180 bar injection pressure. The blends B20% and B40% with ethanol 5% without EGR the values found to be 51ppm and 68 ppm respectively, the blends B20% and B40% with ethanol 5% with EGR 5% the values found to be 61ppm and 92ppm. The blends B20% and B40% with ethanol 5% with EGR 10% the values found to be 86 ppm and 96 ppm.

#### 3.2.3 Variation of $NO_x$ emission with BP

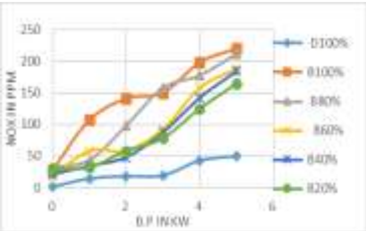


**Fig.17** Variation of $NO_x$ emission vs BP for diesel and different blends.

$NO_x$ is formed by a combination of nitrogen and oxygen at higher temperature and pressure. The main reason for higher $NO_x$ production is the temperature and ignition delay. Due to increase in load on the engine, emission of $NO_x$ rate rises. At maximum load, diesel emits 50ppm, B20% and B40% emits 164ppm and 184ppm. To reduce the $NO_x$, EGR technique is used. EGR is an engine conditioning technique to control $NO_x$ which works by re-circulating a portion of an engine's exhaust gas back to the cylinders of engine. This tends to decrease the excess oxygen during combustion period. This gives better result in a reduction of $NO_x$.

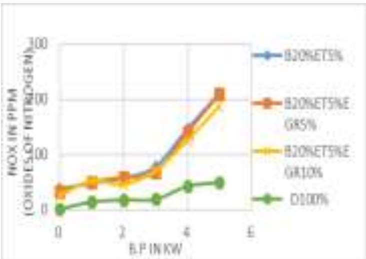


**Fig.18** Variation of emission of $NO_x$ vs BP for blend B20% with ethanol 5% without EGR, with EGR 5% and 10%.

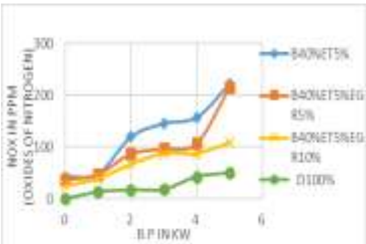


**Fig.19** Variation of emission of $NO_x$ vs BP for blend B40% with ethanol 5% without EGR, with EGR 5% and 10%.

Fig.18-19 shows the $NO_x$ emissions for the blends B20% and B40% with ethanol 5% without EGR at full load the values found to be 212 ppm and 223 ppm respectively. The blends B20% and B40% with ethanol 5% with EGR 5% at full load the values found to be 209 ppm and 216 ppm respectively. The blends of B20% and B40% with ethanol 5% with EGR 10% at full load the values found to be 109 ppm and 188 ppm. It is observed that the lower $NO_x$ emissions are109 ppm at a blend of B20% with ethanol 5% with EGR 10%, with increase in EGR the $NO_x$ level was reduced. Also reductions in brake thermal efficiency were observed.

### 3.3 Combustion Characteristics

#### 3.3.1 Variation of cylinder pressure vs crank angle for diesel and different blends

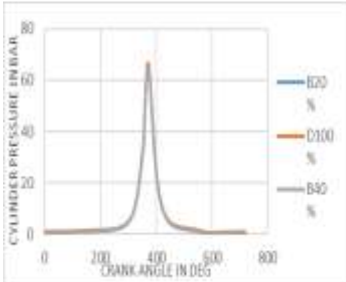


**Fig.20** Variation of cylinder pressure vs crank angle for diesel and different blends.

Fig. 20 indicates the cylinder pressure variation with crank angle, at full load cylinder pressure the diesel and biodiesel B20% and B40%. Peak pressure of D100 found to be 67.05 bar and B20 and B40 found to be 65.32 bars at a crank angle of 371.This is due to a good mixture formation for biodiesel blends at higher loads the temperatures also high. From the test results, we observed that the peak pressure variations are less.

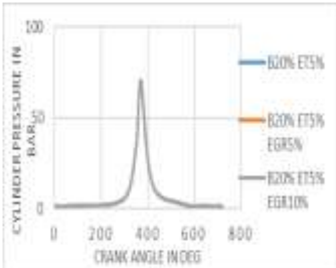


**Fig.21** Variation of cylinder pressure with crank angle for blend B20% with ethanol 5% without EGR, with EGR 5% and 10%.

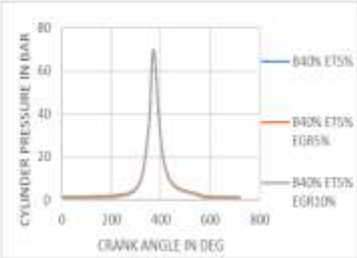


**Fig.22** Variation of cylinder pressure with crank angle for blend B40% with ethanol 5% without EGR, with EGR 5% and 10%.

The variation of cylinder pressure with respect to crank angle for neem biodiesel blends of B20% and B40% at constant pressure 180 bars is shown in figures 21-22. Cylinder pressure of blends B20% and B40% with ethanol 5% without EGR at full load. Peak pressure was found to be 70.94 bar and 69.35 bar respectively. Cylinder pressure of blends B20% and B40% with ethanol 5% with EGR 5% the values found to be 70.31 bar and 69.43 bar respectively. Cylinder pressure of blends B20% and B40% with ethanol 5% with EGR 10% at full load the values found to be 68.94 bar and 69.88 bar respectively. The diesel cylinder pressure at full load found to be 67.05 bars. The cylinder pressure of blend B20% with ethanol 5% without EGR value found to be high, this is due to good mixture formation for bio-diesel at higher loads where temperatures are high, EGR serves as a heat absorbing agent, which reduces the cylinder charge temperature in the combustion chamber during the combustion process.

### 3.3.2 Variation of cumulative heat release rate vs crank angle for diesel and different blends.

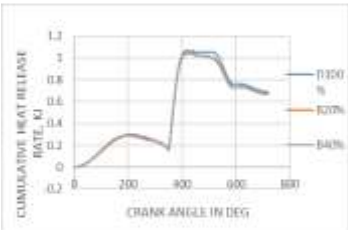


**Fig.23** Variation of cumulative heat release rate vs crank angle for diesel and different blends.

Fig.23 indicates that the neem biodiesel blends are similar to diesel. Maximum net heat release rate of blends B20% and B40% is 1.05 kj and 1.04kj, against 1.06 kj of diesel for diesel engine.

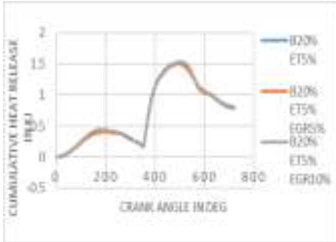


**Fig.24** Variation of cumulative heat release rate with crank angle for blend B20% with ethanol 5% without EGR, with EGR 5% and 10%.

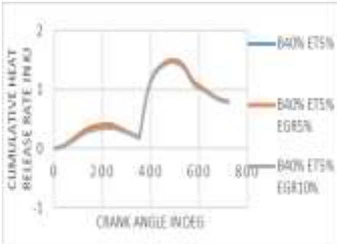


**Fig.25** Variation of cumulative heat release rate with crank angle for blend B40% with ethanol 5% without EGR, with EGR 5% and 10%.

The variation of Cumulative Heat Release Rate with respect to crank angle for diesel and different blends B20% and B40% neem biodiesel at constant pressure of 180 bar is as shown in figures 24-25, At full load condition without EGR cumulative heat release rate of 20% and 40% blends with 5% ethanol values found to be 1.54 kj and 1.49 kj respectively. The blends B20% and B40% with ethanol 5% with EGR 5% the values found to be 1.51 kj and 1.5 kj respectively. The blends B20% and B40% with ethanol 5% with EGR 10% the values found to be 1.53 kj and 1.46 kj respectively. The pure diesel value found to be 1.06 kj. It was observed from the figure that there is an increase in the ignition delay for the blends. From figure Peak cumulative heat release rate was found to be 1.54 kJ for without EGR B20% with 5% ethanol.

### 3.3.3 Variation of net heat release rate vs crank angle for diesel and different blends.

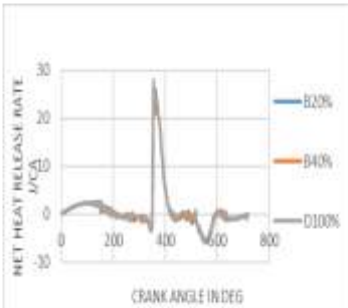


**Fig.26** Variation of net heat release rate vs crank angle for diesel and different blends.

Fig.26 shows the variation of net heat release rate of blends B20% and B40%, pure diesel with crank angle. The net heat release rate for B20% and B40% is 25.1 j/deg CA and 26.42 j/deg CA.the diesel value found to be 28 j/deg CA. The peak heat release rates of neem biodiesel and their blends are lower than that of diesel.

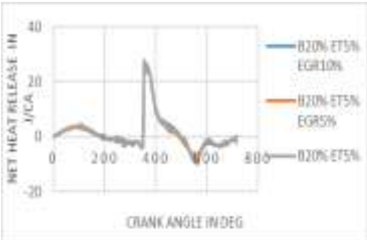


**Fig.27** Variation of net heat release rate with crank angle for blend B20% with ethanol 5% without EGR, with EGR 5% and 10%.

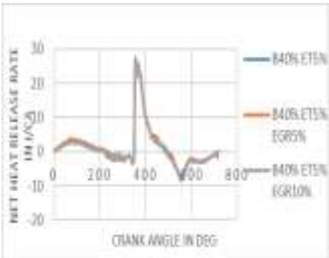


**Fig.28** Variation of net heat release rate with crank angle for blend B40% with ethanol 5% without EGR, with EGR 5% and 10%.

The variation of Net Heat Release Rate with respect to crank angle for diesel and different blends B20% and B40% of neem biodiesel, at constant pressure 180 bar is shown in figures 27-28. At full load condition without EGR heat release rate of 20% and 40% blends with ethanol values found to be 27 j/deg CA and 25.77 j/deg CA. The blends B20% and B40% with ethanol 5% with EGR 5% the values found to be 27.88 j/deg CA and 25.76 j/deg CA. The blends B20% and B40% with ethanol 5% with EGR 10% the values found to be 26.5 j/deg CA. and 27.62 j/deg CA. The pure diesel shows the 28 j/deg CA. It was observed from the figure that there is an increase in the ignition delay for the blends. Among the fuels tested B40% with ethanol 5% with EGR 10% is found to have higher ignition delay. It is observed that the heat release rate curves of the diesel, neem biodiesel and their blends show similar patterns. The peak heat release rates of neem biodiesel and their blends are lower than that of diesel. There is decrease in peak heat release rate for EGR usage. Decrease in heat release rate is indication of incomplete combustion due to a less oxygen content because of using EGR 5% and 10%

## 4. CONCLUSIONS

The conclusion of this experiment is as follows.

- The biodiesel produced from neem oil by transesterification process reduces the viscosity of biodiesel found to be higher than that of diesel and the calorific value of biodiesel is lower than that of the diesel.
- The maximum brake thermal efficiency is obtained in the case of engine with EGR setup. The efficiency of biodiesel is lower than that of diesel fuel. However, the efficiency of the engine with EGR setup the biodiesel fuel is well within the expected limits.
- SFC is low for the 180 bar pressure with EGR because of its high latent heat vaporization. The blend B20% with ethanol 5% with EGR 10% is the best blend for low fuel consumption.
- The CO and HC emission is lower for Neem biodiesel without EGR than that of normal diesel engine for entire load of operation. The increase in EGR increases the CO and HC emissions.
- The NOx emission increases with increase in load and reaches maximum and then decreases. NOx emission is almost all comparable with diesel except a narrow band of part load. By increasing the EGR there is a considerable reduction in the NOx formation. NOx emission with 5%, 10% is respectively lower.
- Properties of 20% of biodiesel are very close to the diesel compared to other blends.
- It is concluded that neem biodiesel B20% with ethanol 5% with 10% EGR at 180 bar pressure can be used as, alternate fuel for DI diesel engine without any major modification.

The above study clearly reveals the possibility of using the biodiesel in DI diesel engine with EGR. The combustion, performance and emission characteristics show the suitability of neem biodiesel in engine with EGR.

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