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Performance and emission characteristics of the diesel engine running on neem *(Azadirachta indica)* biodiesel with effect of exhaust gas recirculation at optimum injection strategies

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ABSTRACT: Environmental pollution and strict emission norms are promoting researchers to explore the methods for reducing pollution and provide optimum solution. By considering these situation as the baseline, study was conducted to analyse the effect of exhaust gas recirculation (EGR) on performance and emission of the DI diesel engine. The effects of Injection Timings (IT), split injection and Exhaust Gas Recirculation on performance, emission characteristics of diesel engine fuelled neem biodiesel blends are investigated. Initially experiments are conducted with diesel, NB5, NB10 with original injection timing of 23° bTDC with direct injection and are considered as base reading. The fuel injection is optimized (at 19° bTDC and 16% split injection) and the effect of EGR rate at this optimized condition is analysed. Significant reduction of about 65.3%, 67% and 57% in the amount of NOx was obtained at full load as compared to base readings. Smoke emissions reduced by 2.8-3.4% and CO emissions reduced by around 52% for diesel and biodiesel blends at full load.

Keywords: Neem biodiesel; Split injection; Exhaust gas recirculation; Diesel engine; emissions.

INTRODUCTION

Energy consumption in the automotive sectors is predicted to increase until 2030. Expected expansion in the requirement of energy leads to increase in pollution and load on the environment (Karmakar et al., 2010; Naveen & Sharma, 2005; Sharma et al., 2008; Veljković et al., 2006). Many unconventional sources have been observed in the transport sector among them, biofuels may play a vital role not only from demand side but also from pollution side (Agarwal et al., 2008; Barik & Vijayaraghavan, 2020; Elkelawy et al., 2020; Sharma et al., 2020; Szabados & Bereczky, 2018). Therefore, biodiesel as an alternative to the diesel may be utilised as optional sustainable environment friendly oil. Many renowned investigators have worked on neem oil

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starting from various biodiesel production techniques to its application in modern day diesel engines. Dhar et al. (Dhar et al., 2012) investigated the performance, emission and combustion characteristics of neem biodiesel and its various blends with mineral diesel were compared with baseline data in a direct injection (DI) diesel engine. Brake specific fuel consumption, CO and HC emissions for biodiesel fuelled engine were lower than mineral diesel but NO emissions were higher for biodiesel blends. Sayin et al (Sayin & Canakci, 2009) reported that the use of ethanol and methanol blends at retarded injection timing reduces NOx emissions. Retarded injection timing delays the combustion that lowers combustion temperature thereby reducing NOx emissions. From published literature, it is understood that retarded injection timing had better performance and lower emissions when biodiesel is used. Split injection is another aspect which facilitates NOx reduction (How et al., 2018). NOx emissions further reduced by employing Exhaust Gas Recirculation (EGR) technique (Ashok et al., 2017; Pan et al., 2018). Due to higher heat capacity of gases, there is a reduction in cylinder temperature leading to lower NOx emissions. But the lower in-cylinder temperature affect oxidation leading to increase in soot formation, CO and HC. Recent studies suggested use of EGR along with oxygenated fuel, after treatment systems, low temperature combustion (Du et al., 2015; Manigandan et al., 2019) are needed to attain the NOx smoke trade off. Rajesh Kumar et al (Rajesh Kumar et al., 2016) reported that both NOx and soot emissions reduced with n-octanol diesel blends up to 20 % EGR.

As cited in the above accessible literature report, it is affirmed that neem oil is extensively available in many parts of the world including India as a major source and is acclaimed as a crucial challenger to the exhausting petro-diesel. From the exhaustive technical literature, the combustion characteristics and fuel economy were witnessed to improve as the pilot injection started approaching towards the main injection. Besides these, in the available experimental findings, no research work has been recorded stating the effects of fuel injection strategies using NME blends in a DI engine.

The objective of this study is to investigate the performance and emission of the diesel engine operating on neem biodiesel at optimum injection timing and pressure.

MATERIALS AND METHODS

Neem oil biodiesel is produced by transesterification process to reduce its unsaturation level (Adepoju, 2020; Singh et al., 2012; Vinayaka et al., 2018). In this process, triglyceride in neem oil reacts with alcohol in the presence of catalyst forming neem oil methyl ester and glycerine. Neem oil liquid of 1000 ml is taken in a round bottom flask and is heated to 70°C. Methanol of 100 ml and 4 grams of potassium hydroxide (KOH) pellets are mixed in another beaker. This methoxide mixture is transferred into a flask and allowed to react with raw neem oil at the same temperature with a stirring speed of 1500 rpm for 2 hours. Then the mixture is allowed to settle for 10-12 hours for reaction to complete. Due to the reaction, neem biodiesel and glycerine are formed. Glycerine that is present at bottom is separated with a separating funnel. Biodiesel is washed with distilled water to remove unreacted alcohol, KOH and glycerine. Hot distilled water is sprayed over the Methyl ester, stirred gently and then allowed to settle down. The purified biodiesel (upper layer) is separated. The washed top layer of ester is again washed with sodium chloride. The purified ester is heated in an oven under vacuum to remove any moisture to obtain liquid biodiesel. A maximum of 800 ml of neem biodiesel is obtained from 1000 ml of raw neem oil. The properties of diesel, raw neem oil and neem oil biodiesel blends are given in Table 1.

In this present work, engine is operated with diesel and neem biodiesel blends (NB5 and NB10). NB5 and NB10 shows the blends of neem biodiesel with diesel in the ratio of 5% and 10% respectively. Experiments are conducted without any modification in the engine.

A four-stroke, single cylinder, constant-speed, water-cooled, direct injection diesel engines (Make: Kirloskar Oil Engines Ltd. India; Model: DM-10) was used to experimentally investigate different neem oil biodiesel blends for engine performance and emissions. Figure 1 shows the schematic image of the engine set up. The detailed specifications of the engine used are given in Table 2. The engine is operated at a constant speed of 1500 rpm.

Table 1. Properties of the fuels tested during the study.

S. No.	Property	Diesel	Raw Neem Oil	Neem Biodiesel Methyl Ester	NB5	NB10
1	Density @ 15°C (kg/m^3)	837	952	893	843	847
2	Kinematic viscosity @ 40°C (cSt)	4.51	41.4	7.23	4.64	4.69
3	Higher Calorific value (MJ/Kg)	45.38	37.82	41.12	44.12	43.71
4	Cetane index	43-56	32	52	48	49
5	Flash point (°C)	50.4	231.7	65.3	52.4	54.1

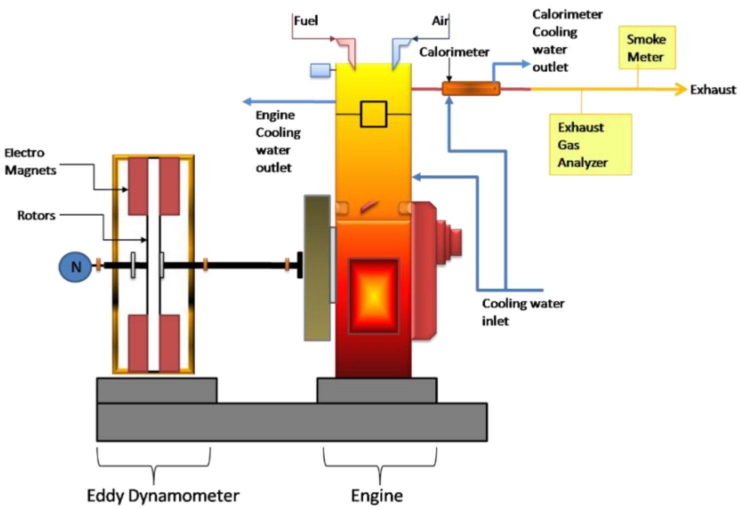

Fig. 1. Schematic image of the engine set up.

Table 2. Technical specification of the DI diesel engine

Technical specifications of test engine	
Make	Kirloskar
Type	4 Stroke, DI diesel engine
Bore and Stroke	87.6 mm and 110 mm
Capacity	0.661 Litre
Compression ratio	17.5:1
RPM	1400-1500
Loading	Eddy current dynamometer (water cooled)
Rated power	5.2 kW at 1500 RPM
Crank angle sensor	Resolution 1ow speed 5500 rpm with TDC pulse
Inlet valve open	4.5 °bTDC
Inlet valve closed	35.5 °aBDC
Exhaust valve open	35.5 °bBDC
Exhaust valve closed	4.5 °aTDC
FIT	23°bTDC
FIP	180 bar
Starting	Manual cranking
Lubrication	Forced

The experiments are conducted with diesel from no load to full load at an original injection timing of 23 ° CA bTDC with single injection and without EGR at a constant speed of 1500 rpm. At this condition, the measurements are made and is taken as base readings. It is observed that the engine has better performance and lower emissions with the combination of 16 % split injection and 4° retarded crank angle (19° bTDC) and is taken as optimized fuel injection conditions. The experiments are conducted at this optimized fuel injection with various EGR rate (5 %, 10 %, 15% and 20 %) with diesel and biodiesel blends. The effect of EGR rate on performance and emission characteristics of engine is further analysed by comparing the readings with the one measured without EGR.

RESULTS AND DISCUSSION

Figure 2 compares the variation of brake thermal efficiency with EGR at optimized fuel injection for diesel and biodiesel blends at full load. It can be seen that brake thermal efficiency reduces with biodiesel blends at all test conditions. The low performance can be attributed to higher viscosity and lower calorific value of neem biodiesel (Gandure et al., 2014). It is observed that brake thermal efficiency marginally reduces at optimized fuel injection conditions. In general, at retarded injection timing, combustion prolongs beyond TDC which is detrimental to the output. It is known that EGR affects the engine performance since the higher heat capacity of exhaust gases may cause lower in cylinder temperature that lead to poor combustion. In addition, the limited availability of oxygen may affect the combustion process. But with introduction of EGR along with split injection overcomes these drawbacks to a certain extent and brake thermal efficiency is hardly reduced with the use of EGR for all the test fuels. The increase in brake thermal efficiency at optimum injection timings has also been reported by Khandal et al. (Khandal et al., 2017). Brake thermal efficiency reduces by 2.6 %, 1.7 % and 2.9 % for diesel, NB5 and NB10 blends at full load as compared to base reading. Similar trend is observed at no load and partial loads for all test fuels. It is in-line with results obtained by Rajesh kumar et.al (Rajesh Kumar & Saravanan, 2016).

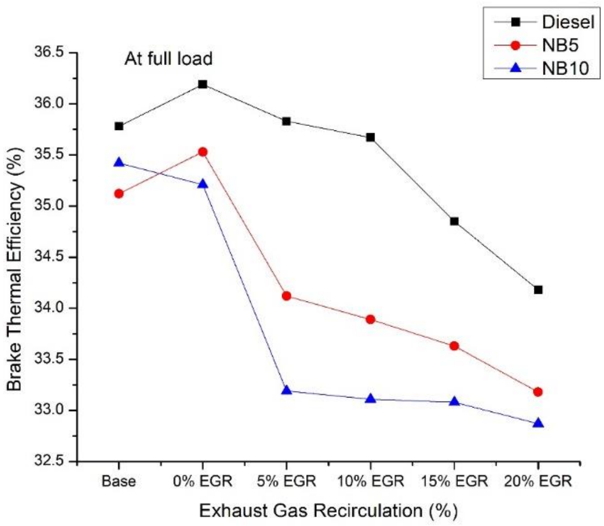

Fig. 2. Brake thermal efficiency vs exhaust gas recirculation at full load.

The BSEC is used to measure the performance of engines when fuels with different calorific values are used. Figure 3 compares the variation of brake specific energy consumption with EGR at optimized fuel injection for diesel and biodiesel blends at full load. The higher viscosity and lower calorific value of biodiesel blends increased BSEC at all test conditions. Similarly, brake specific energy consumption increases at optimized operating conditions. Even though split injection improved the homogeneity of combustion, retarded injection timing delays the combustion process that lead to increase in BSEC. EGR along with retarded injection timing and split injection marginally increases the BSEC. This is due to the dilution effect caused by EGR which affects the air fuel ratio thus altering the burning rate of fuel. Brake specific energy consumption increases by 5.8 %, 4.9 % and 4.8 % for diesel, NB5 and NB10 blends at full load. Similar trend is observed at no load and partial loads for all test fuels and is in-line with results obtained by Ashok et.al (Ashok et al., 2017).

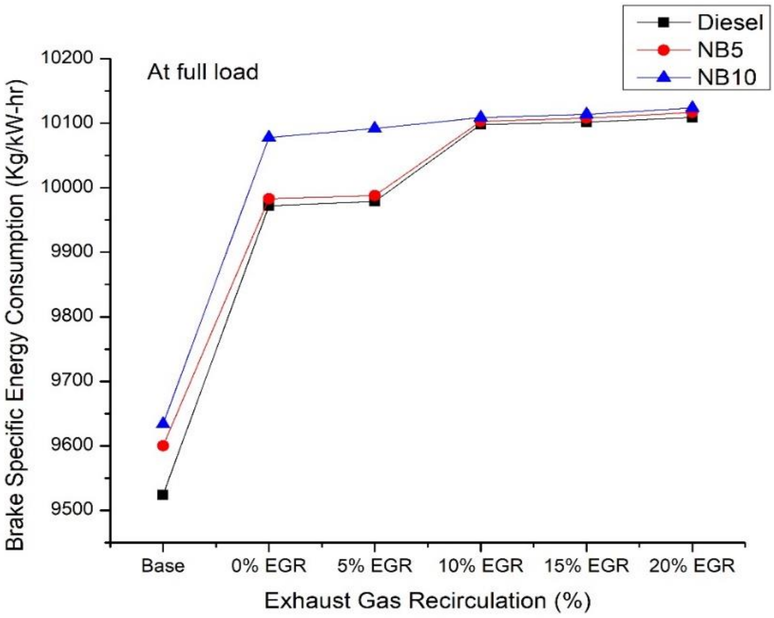

Fig. 3. Brake specific energy consumption vs exhaust gas recirculation at full load.

Figure 4 compares the variation of hydrocarbon emissions with EGR at optimized fuel injection for diesel and biodiesel blends at full load. With split injection, combustion occurs sequentially and helps to improve the oxidation of hydrocarbon. Hence, HC emissions reduces with optimized fuel injection. However, EGR increases hydrocarbon emissions since its lower combustion temperature influences the oxidation of HC and lesser availability of oxygen affects complete combustion. In addition, the use of EGR increases the heat losses resulting in lower in-cylinder temperature. Hydrocarbon emissions increases from base reading of 12 ppm to 16 ppm, 18 ppm to 36 ppm, 31 ppm, 33 ppm for diesel, NB5, NB10 respectively at full load with 20 % EGR at optimized conditions. Similar trend is observed at no load and partial loads for all combination of fuels and results are in-line with those obtained by Jain et.al. (Jain et al., 2017).

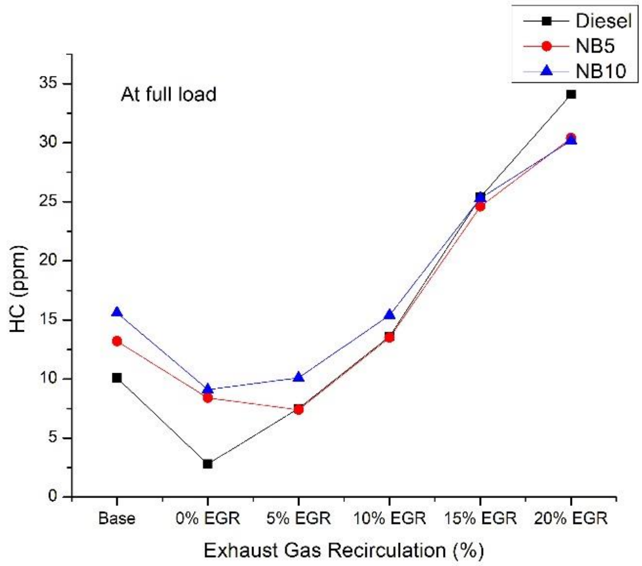

Fig. 4. Hydrocarbon vs EGR at full load.

Figure 5 compares the variation of CO_2 emissions with EGR at optimized fuel injection for diesel and biodiesel blends at full load. It is observed that CO2 emission marginally reduces at optimized conditions. It can also be seen that CO_2 emissions increases with EGR at optimized retarded injection timing and split injection. This is due to increase in charge temperature with increase in EGR rate which oxidises CO into CO_2 and split injection improved mixture quality leading to complete combustion. Carbon-di-oxide emissions increases by 5.8 %, 11.2 %, 12.1 % for diesel, B5 and B10 blends respectively at full load as compared to CO_2 measured without EGR. Similar trend is observed at no load and partial loads for NB5 and NB10 fuel blends (Damodharan et al., 2018).

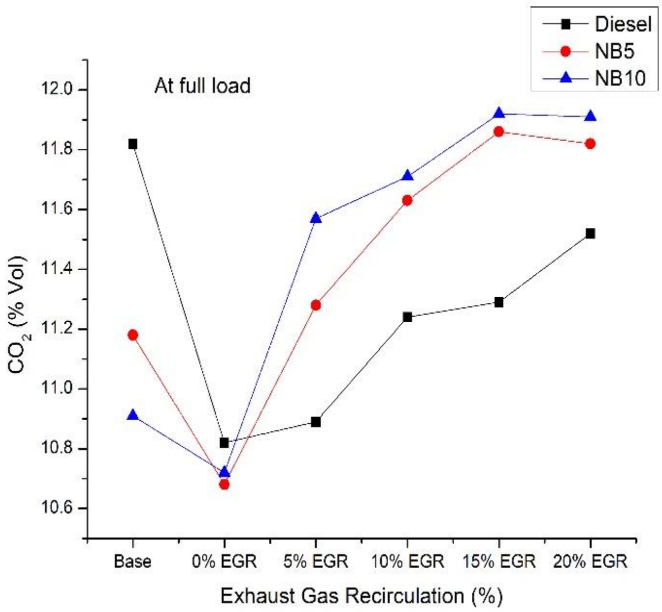

Fig. 5. Carbon dioxide vs EGR at full load.

Figure 6 compares the variation of CO emissions with EGR at optimized fuel injection for diesel and biodiesel blends at full load. It can be seen that CO emissions reduces with biodiesel blends at all loads. CO emissions reduces substantially at optimized conditions and can be attributed to better mixing and absence of fuel rich zones. EGR along with split and retarded injection timing, improves the combustion and air-fuel mixing that lead to oxidation of CO in to carbon-di-oxide that resulted in lower CO emissions (Uzun et al., 2012). In addition, use of EGR increased the charge temperature which improves the oxidation of CO. Carbon monoxide emissions reduces by 52 %, 57.5 % , 52 % for diesel, NB5 and NB10 blends respectively at full load. Similar trend is observed at no load and partial loads for all test fuels and results are in-line with results obtained by Lee et.al (Lee et al., 2017).

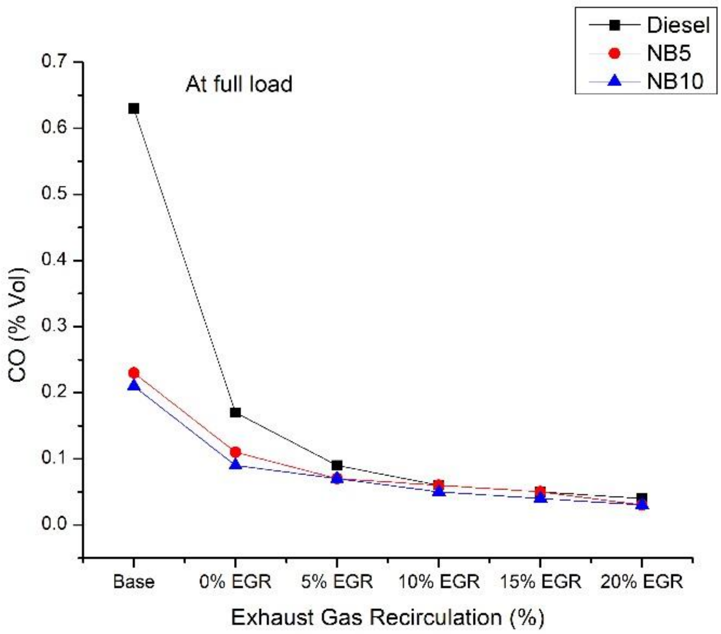

Fig. 6. CO emission.

Figure 7 compares the variation of NOx emissions with EGR at optimized fuel injection for diesel and biodiesel blends at full load. NOx emissions reduced at retarded injection timing and split injection for all the fuel blends due to delay in combustion process leading to lower in-cylinder temperature and heat release rate (HRR). NOx emissions further reduced with use of EGR at optimized fuel injection conditions for all the fuels. The use of EGR increases the amount of inert gas and these gases absorb the heat released during combustion that results in lower cylinder pressure and temperature. When the exhaust gas is diluted with intake air, heat capacity increases which leads to reduction in cylinder temperature (Gad & Jayaraj, 2020). With the use of EGR, there is a retardation in combustion phasing and extended ignition delay that causes reduction in cylinder temperature and all these factors results in lower NOx emissions. NOx emissions reduce by 65.3%, 67 % and 57.3 % for diesel, NB5, NB10 respectively at full load. Similar trends are observed at no load and partial loads and results are in-line with results obtained by Yin et.al (Yin et al., 2014).

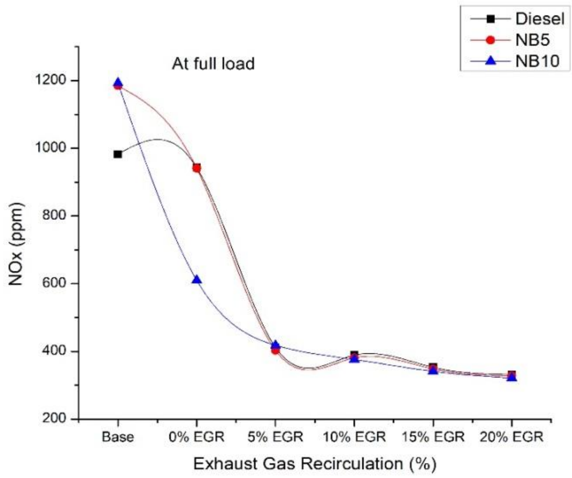

Fig. 7. NOx emission.

Figure 8 compares the variation of soot emissions with EGR at optimized fuel injection for diesel and biodiesel blends at full load. Soot emissions reduced with biodiesel blends at all loads. The reduction in soot was due to the optimum conditions of injection timing selected. Biodiesel blends have higher oxygen content and low sulfur content of 0.07 % that improved the oxidation resulting in lower smoke emissions. The quantity of soot reduction has also been reported in the study conducted by Khandal et al. (Khandal et al., 2017). With optimized split injection, fuel rich region is avoided which improves homogeneous air fuel mixture. Similarly, at optimized injection timing more time is available for preparation of homogeneous air-fuel mixture that leads to lower smoke emissions. It is observed that soot emission marginally increases with increase in EGR as compared to optimized fuel injection without EGR. In general, when EGR is used, the amount of oxygen content is limited, which affects the air fuel mixture and combustion leading to higher smoke. But increase in emissions with EGR is very low since retarded injection timing and split injection improves the mixing process leading to complete combustion. Soot emissions reduces by 2.8- 3.4 % for diesel and biodiesel blends at full load as compared to base reading. Similar trend is observed at no load and partial loads for all test fuels and results are in-line with results obtained by Ge et.al (Ge et al., 2015).

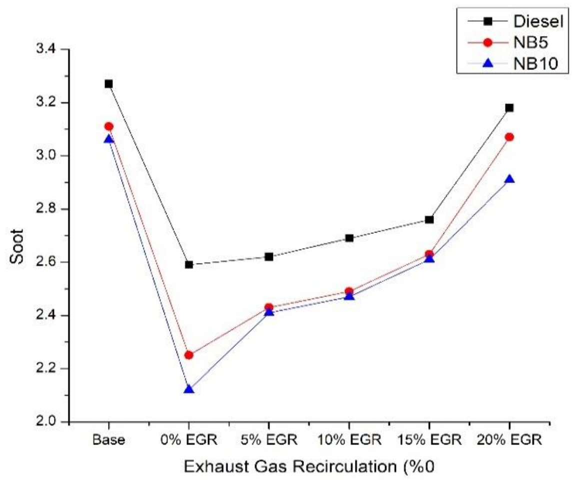

Fig. 8. Variation of soot with EGR.

Exhaust gas temperature can be considered to be an indicator of combustion quality. Figure 9 compares the variation of exhaust gas temperature with EGR at optimized fuel injection for diesel and biodiesel blends at full load. It is clearly seen that exhaust gas temperature reduces with biodiesel blends due to its lower calorific value when compared to diesel. Exhaust gas temperature increases at optimized conditions due to split injection which improves air-fuel mixture leading to complete combustion. It is observed that exhaust gas temperature marginally reduces with EGR rate as a result of lower combustion temperature. Exhaust gas temperature decreases by 3.7 % and 0.8 % for diesel, biodiesel blends at full load as compared to base reading. Similar trend is observed at no load and partial loads for all test fuels and is in-line with results obtained by Huang et.al. (Huang et al., 2019).

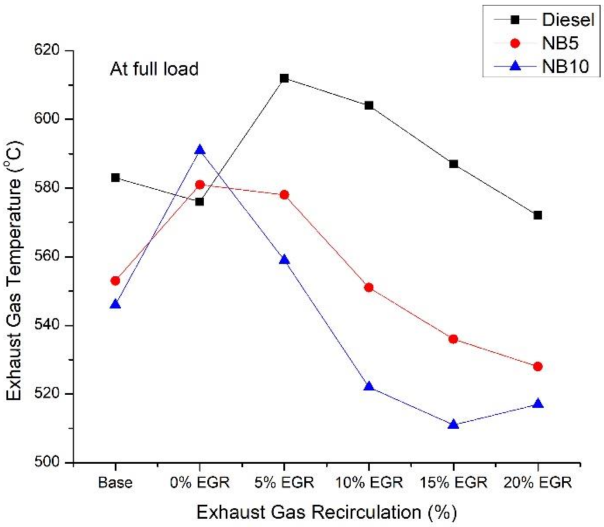

Fig. 9. Variation of EGT with EGR.

CONCLUSION

The effect of exhaust gas recirculation (EGR) on performance and emission characteristics of the engine fuelled with diesel and neem biodiesel blends is investigated. Based on the results, the following observations are made

- The use of EGR along with split injection improved combustion homogeneity to a certain extent. Hence, brake thermal efficiency and brake specific energy consumption is hardly affected for all the test fuels considered.
- Homogenous air fuel mixture and improved combustion is attained when EGR is used along with split and retarded injection timing. So, carbon monoxide emissions reduced by 52 %, 57.5 % and 52 % for diesel, NB5 and NB10 blends respectively at full load as compared to that measured without EGR.
- The use of EGR increases the heat capacity of exhaust gases and extends the ignition delay which leads to lower in-cylinder temperature. NOx emissions reduced by 65.3 %, 67 % and 57 % for diesel, B5, B10 respectively.
- Smoke emissions reduced by 2.8 - 3.4 % for diesel and biodiesel blends at full load. This is due to retarded injection timing and split injection which improved the mixing process leading to complete combustion.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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