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An Experimental Investigation on the Combined Effect of Exhaust Gas Recirculation and Cetane Improver on Biodiesel-fueled Diesel Engine

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Abstract – *Diesel-biodiesel blends increase Nitrogen Oxides (NO_x) emission of engine exhaust. Exhaust Gas Recirculation (EGR) is an effective way of reducing the NO_x emissions. Cetane improvers on the other hand reduce the ignition delay, which in turn reduces the combustion temperatures as a result of which NO_x emissions decrease. A combination of EGR and the cetane improver Di Tertiary Butyl Peroxide (DTBP) is taken up in the present work to investigate experimentally the performance and emissions on a four stroke single cylinder direct injection diesel engine. DTBP is added such as 0.5% and 1% by volume (B30D0.5 and B30D1) to diesel-biodiesel blend B30 (30% by volume of biodiesel). EGR rate is varied from 0 % to 20% (0%, 10%, and 20%). The combined effect of EGR and cetane improver on Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), cylinder pressure and exhaust emissions like Carbon Monoxide (CO), Hydro Carbon (HC), NO_x and smoke opacity is studied. From experimental results it is found that BTE and BSFC increase with both EGR and DTBP while the exhaust gas temperature decreases. It is also found that NO_x decreases significantly while CO, HC and smoke opacity increase slightly with increase in EGR percentage. However at a particular EGR, CO and HC emissions are low for blends with DTBP than that of pure diesel.*

Keywords – Additives, Diesel-biodiesel blends, DTBP, EGR, NO_x emissions.

1. INTRODUCTION

Exhaust gas recirculation is recirculation of a part of the exhaust gases which aids in reducing the NO_x emissions in diesel engines because, control of NO_x is a major challenge in order to comply with the emission norms [1], [2]. Especially biodiesel increases NO_x in the exhaust of diesel engines which are predominant when the temperature in the combustion chamber is high as reported by many authors [3]-[7]. Jatropha biodiesel (JBD) produces higher NO_x in diesel engines when compared to the other biodiesel fuels due to its lower cetane number [8]. JBD combined with EGR operation in diesel engines reduces NO_X emissions considerably [9], [10]. Sunflower methyl ester biodiesel blend B20 at 15% EGR produces 25% less NO_x emissions compared to that of diesel fuel with an increase in brake thermal efficiency [11]. EGR in combination with high injection pressure can control the NO_x emissions [12]. According to emission standards like EURO norms (as shown in Table 1) the use of higher EGR levels is necessary for lower NO_x emissions [13]. However higher EGR levels are responsible for the development of gaseous emissions like hydrocarbons and for increased particle density and size in the exhaust [14], [15]. Higher EGR levels are also responsible for reduced thermal efficiency [16]. To get the maximum benefit from the EGR, it is advisable to use particulate traps [17]. Recent simulation studies [18] show that the optimum cold EGR of 10% can reduce the BSFC and NO_x considerably while soot emission decreases slightly in the part load compared to the baseline engine. Biodiesel as an alternative to the petroleum diesel improves the performance of diesel engine with lower emissions than diesel except NO_x [19]. However diesel-biodiesel blends require additives for improving the lubricity, ignition and better mixing. Additives used predominantly are oxygenates and cetane improvers. The addition of oxygenates to petroleum fuels has been increasing due to the advantages like better combustion and improved performance and emission effects in diesel engines [20]-[24]. Additives with coated engines exhibited improved efficiency, in addition to the increase in cylinder pressure, reduction in NO_x and reduction in maximum heat release rate [25]. Thermal barrier coated (TBC) direct injection diesel engine with fuel additives (di-isopropyl ether) in diesel reduces the smoke density and NO_x emission of the engine exhaust [26]. The additive 1-4 dioxane reduces smoke density with slight increase in NO_x and drop in fuel economy, which also improved brake thermal efficiency marginally with the blends when compared to neat diesel in TBC engines [27]. Cetane improvers reduce the ignition delay, which aids in better cold starting and smoother engine operation [28], [29]. Reduced ignition delay also aids in lower combustion temperatures which in turn reduce the NO_x emissions [30], [31]. Cetane improver with oxygenate such as glycol ether reduces particulate, HC, and CO emissions [32]. Diesel-methanol blends with cetane improver improve the performance and reduce emissions except smoke [33]. Ethanol-diesel blends with ethyl hexyl nitrate

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(EHN) as an additive increase the BTE and reduce the emissions like CO, total hydro carbon (THC), smoke, and particulates significantly in common rail direct injection (CRDI) diesel engine [34]. Ethanol-diesel blends with cetane improver with advanced fuel injection angle decrease smoke significantly and NO_x marginally [35].

The objective of the present work is experimental investigation on diesel engine to study the combined effect of EGR and cetane improver DTBP on diesel-biodiesel blends for performance and emissions.

2. EXPERIMENTAL SET-UP AND PROCEDURE

2.1 Experimental Set-up

The experimental set-up as shown in Figures 1 and 2, is a computerized single cylinder four stroke, naturally aspirated direct injection and air cooled diesel engine. The specifications of the test engine are given in Table 2. The engine is loaded with an eddy current dynamometer (080CN). The engine is equipped with an AVL GH12D miniature pressure transducer for measuring the pressure variation in the cylinder and AVL 615 Indimeter software which measures the heat release rate from the measured values of cylinder pressure at different crank angles. An AVL five gas analyzer (FGA512) is used for measuring the CO, HC and NO_x, while an AVL smoke meter (OMS103) is used for measuring the smoke opacity. For circulation of the exhaust gases into the intake manifold, an EGR set up is provided which consists of a control valve and a manometer. This engine is used for evaluation of the performance, combustion and emission characteristics of diesel and diesel-biodiesel blend with DTBP.

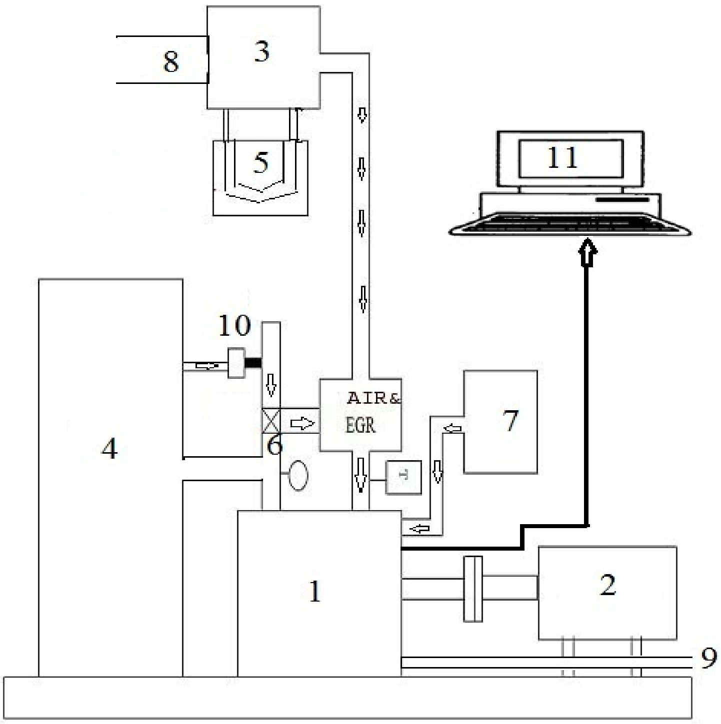
2.2 Test Fuels

For experimental investigation, biodiesel derived from fish oil B30 (biodiesel 30% by volume) is used and two sets of samples of diesel-biodiesel blends with cetane improver DTBP (chemical formula $C_8H_{18}0_2$) are prepared. The percentages of DTBP used in this study are 0.5% and 1% based on the literature since higher percentages can increase particulates [27] and also cause smoke emissions to increase [33]. First set of samples contains diesel-biodiesel blend B30 with cetane improver DTBP 0.5 % by volume while second set of samples contains B30 with DTBP 1% by volume. Diesel-biodiesel blends with cetane improver are designated as B30D0.5 and B30D1 (*i.e.* B30D0.5 implies biodiesel 30% with cetane improver 0.5%). The properties of test fuels are given in Table 3 which compares the properties of neat diesel and B30 with DTBP 0.5% and 1%.

Table 1. Emission levels, g/kWh [36].

	Euro-III	Euro-IV	Euro-V
Year	2000	2005	2008
CO	2.1	1.5	1.5
NO_x	5	3.5	2.0
HC	0.66	0.46	0.46
Particulate Matter(PM)	0.1	0.02	0.02

Fig. 1. Photograph of the experimental set-up.



1. Test Engine 2. Dynamometer 3. Air Tank 4. Exhaust Gas Drum
5. U-Tube Manometer 6. EGR Valve 7. Fuel Tank 8. Orifice
9. Exhaust Gas Analyzer 10. Exhaust Probe 11. Computer

Fig. 2. Schematic diagram of the experimental set-up.

Table 2. Specifications of the test engine.

Particulars	Specifications
Make	Kirloskar
Model	TAF1
Rated power	4.4 kW
Bore	87.5 mm
Stroke length	110 mm
Swept volume	0.661 L
Compression ratio	17.5:1
Rated speed	1500 rpm
Injector operating pressure	210 bar
Start of injection	24.9 ^{0} bTDC

Table 3. Properties of test fuels

Property	D	B30D0.5	B30D1
Flash point(°C)	60	39	37
Fire point (°C)	62	45	43
Density (g/cm^3)	0.83	0.845	0.848
Kinematic viscosity (C.S)	3.15	5.43	5.48

(Where C.S: Centi Stokes and D: Diesel)

2.3 Experimental Procedure

The entire engine experiments are conducted at a rated speed of 1500 rpm with an injection advance of 24.9^0. The engine is allowed to run till the warm-up period is reached. Then the engine is loaded in terms of 0%, 25%, 50%, 75% and 100% corresponding to the brake mean effective pressures of 0.9, 1.8, 2.7, 3.62 and 4.52 bars. At each load, the engine is run at a constant speed of 1500 rpm with different EGR conditions. The exhaust gases are tapped from exhaust pipe and connected to an inlet airflow passage. A system is devised consisting of a control valve and a manometer set up to control the rate of EGR by manually operating the control valve. After attaining the steady state, the following observations are made twice for averaging the parameters such as exhaust gas temperature, airflow rate, fuel consumption, brake specific fuel consumption, combustion characteristics like pressure rise which are recorded through the software at various loads. Exhaust emissions CO, HC and NO_x are recorded simultaneously by the flue gas analyzer while smoke density was measured with AVL smoke meter. In this study, the effect of fuel blends (with DTBP) and EGR on engine performance and emissions are evaluated at an engine speed of 1500rpm. At each load the experiment is conducted by varying EGR rates such as 0%, 10% and 20%. However for results analysis only 50% and 100% loads are considered. The first stage of the experiment is performed with the pure diesel at different loads from no-load to full load with different EGR rates such as 0%, 10% and 20% respectively at constant speed. The reason why higher EGR rates (beyond 20%) are not considered in this study is the reduction in BTE and an increase in CO, HC and smoke emissions with higher EGR rates. The second stage of the experiment is conducted using diesel-biodiesel blend B30 with cetane improver DTBP with 0.5% and 1% and the same procedure is repeated.

EGR mass fraction is determined using the expression % EGR = (mass of air admitted without EGR- mass of air admitted with EGR)/ mass of air admitted without EGR.

3. RESULTS AND DISCUSSION

3.1 Performance Analysis

Performance parameters such as BTE, BSFC and exhaust gas temperature results of blends B30D0.5, B30D1 against pure diesel are compared under different EGR mass fractions at 50% and 100% loads respectively. Figure 3 illustrates the variation of BTE with EGR mass fraction for diesel and B30 with 0.5% and 1% DTBP at 50% and 100% loads, respectively. The brake thermal efficiency is improved by about 5% with the DTBP when compared to the conventional diesel fuel at both the loads. This is due to the improvement in burning which causes higher brake thermal efficiency. Cetane number is an indication of ignition quality of fuel, its increment reduces delay period and leads to better combustion [31]. The increase in BTE further with EGR is due to the increased combustion velocity, as EGR increases intake charge temperature. The slope of the tendency increases from 50% to 100% due to the increased burning efficiency as the engine takes more fuel. Figure 4 shows the variation of BSFC with EGR mass fraction for diesel and B30 with 0.5% and 1% DTBP at 50% and 100% loads, respectively. The BSFC increases with the blends (3.5% to 6%) when compared to the pure diesel and also increases with the EGR. Biodiesel has less energy content and lower heating value which causes the BSFC to increase [37]. The energy content of B30 blend is 96.7% of that of diesel which causes the fuel consumption to increase. Furthermore the charge dilution effect under EGR is also responsible for the BSFC to increase. However at 100% load, BSFC is less when compared with that of 50% load due to the increased brake power at higher loads. Figure 5 shows the variation of the exhaust gas temperature with the EGR mass fraction for diesel and B30 with 0.5% and 1% DTBP at 50% and 100% loads, respectively. The exhaust gas temperatures decrease with EGR and DTBP. The reason for this tendency can be attributed to the dilution of the charge with the EGR, which causes the oxygen deficient operation as a result of which the combustion temperatures decrease.

BTE and BSFC are calculated using the expressions:

$BTE = B.P/ (m_f * C.V)$

$BSFC = m_f / (hr * B.P)$

where, B.P: Brake Power (kW)
C.V: Calorific Value (kJ/kg)
m_f : mass of fuel consumption(kg)

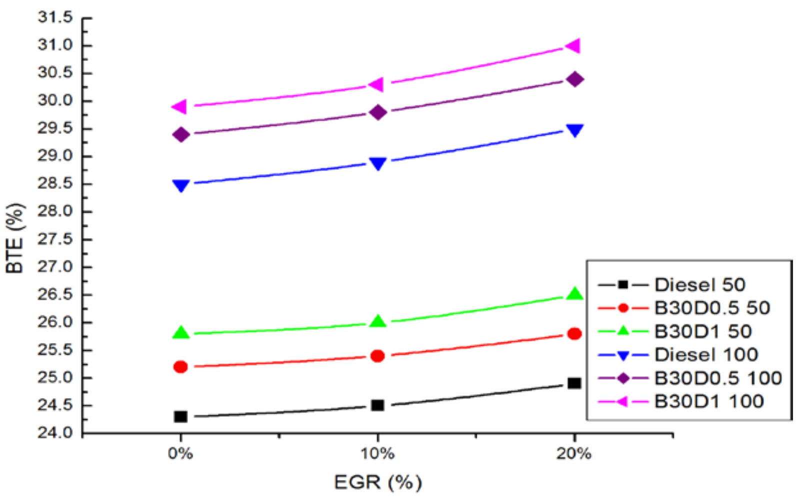


Fig. 3. Variation of brake thermal efficiency with EGR mass fraction at 50% and 100% loads.

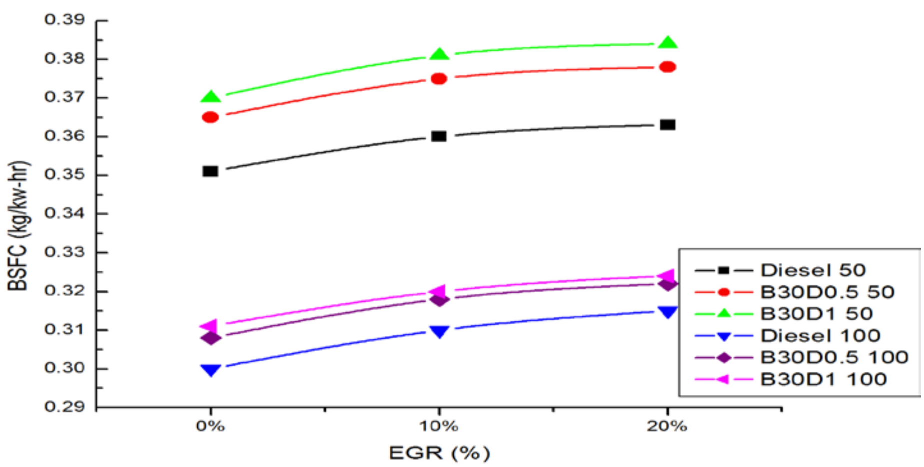


Fig. 4. Variation of BSFC with EGR mass fraction at 50% and 100% loads.

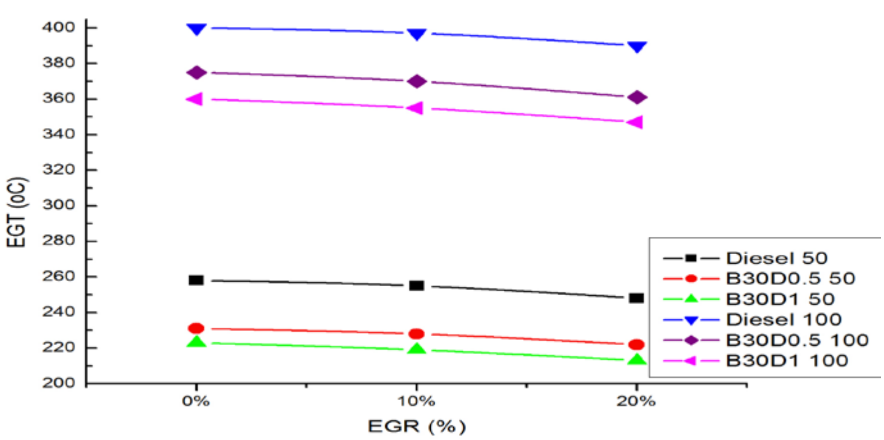


Fig. 5. Variation of exhaust gas temperature with EGR mass fraction at 50% and 100% loads.

3.2 Combustion Analysis

Combustion characteristics results such as cylinder pressure versus crank angle are shown in Figure 6. Figure 6.a, 6.b and 6.c shows the cylinder pressure versus crank angle for diesel, B30D0.5 and B30D1 respectively at different EGR rates such as 0%, 10% and 20% (*i.e*. B30D0.5 0% implies B30D0.5 with 0% EGR). Maximum cylinder pressure decreases slightly with increase in the percentage of EGR. These results also coincide with the literature [10], [20], [35]. Figure 7 shows the cylinder pressure versus crank angle for different fuels at 0% EGR rate. It can be seen from this figure that the blends ignite earlier and finishes the combustion earlier than diesel and the duration of high temperature combustion for blends is shorter than that for diesel and heating value of blends is also less. This means that the premixed combustion duration for the blends is lower than that for diesel which reduces the tendency of NO_x formation significantly. Blends and diesel show the similar trends and comparable results in case of the cylinder pressure which shows that the mixture formation is good for blends and the engine operates with same level of maximum pressure.

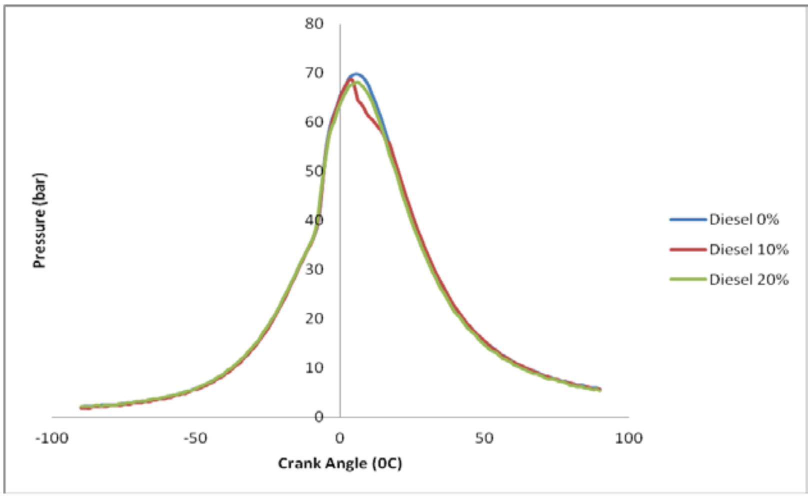


Fig. 6.a. Diesel

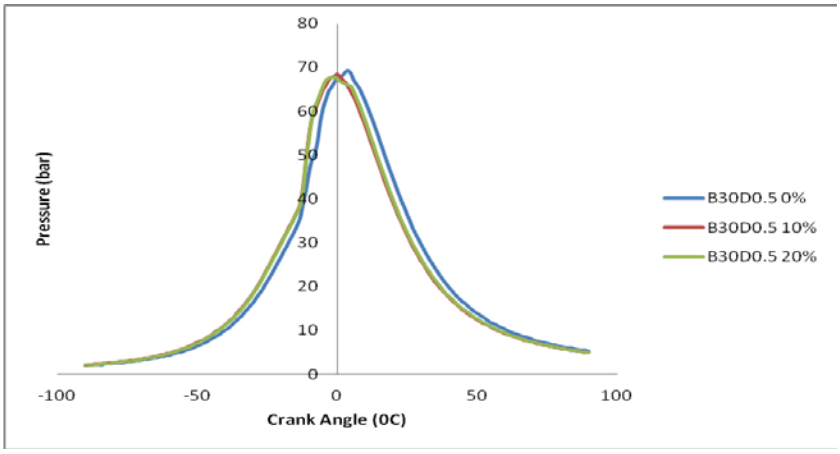
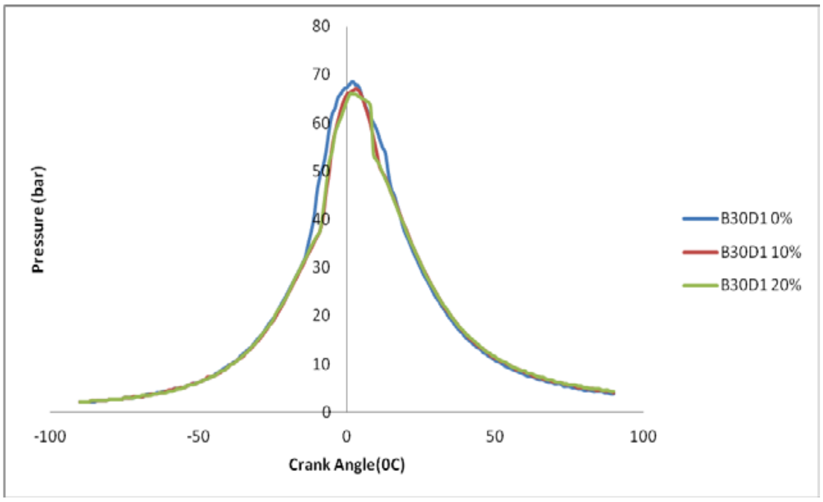


Fig. 6.b. B30D0.5



6.c) B30D1

Fig. 6. Variation of cylinder pressure with crank angle at different EGR rates.

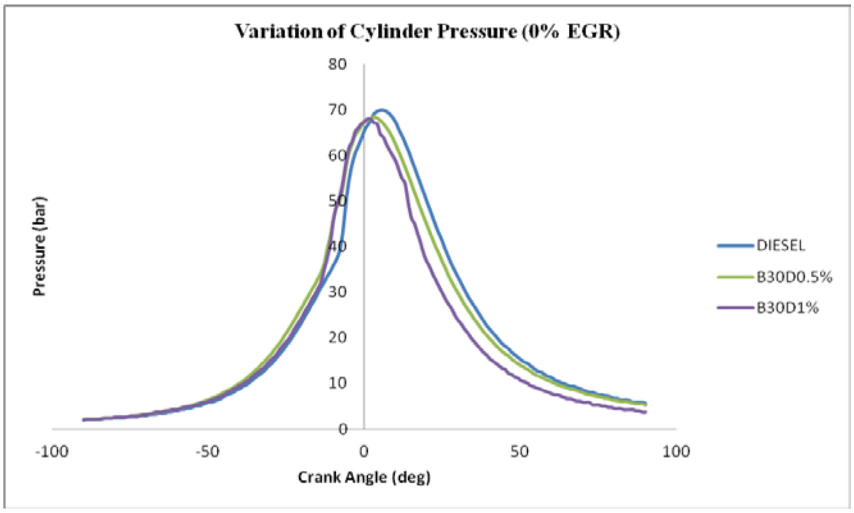


Fig. 7. Variation of cylinder pressure with crank angle for different fuels at 0% EGR.

3.3 Exhaust Emission Analysis

Exhaust emission results such as CO, NO_x, HC and smoke opacity with EGR mass fraction at 50% and 100% loads are shown in Figures 8 through 11. Figure 8 shows that CO emissions increase from 0% to 10% EGR and remain near constant up to 20% for all the fuels while they decrease with DTBP. Full load operation shows very high CO values for diesel at 20% EGR which can be attributed to the deficiency of oxygen. However the excess oxygen content in bio-diesel can compensate for the oxygen deficient operation under EGR. Figure 9 shows that the combined effect of EGR and DTBP could reduce NO_x emissions significantly. For example NO_x for B30 with DTBP 1% at 20% EGR is 950 ppm (1.77g/kw-hr) against 1380 ppm (2.57 g/kw-hr) for diesel without EGR at full load; the reduction is 33%. Furthermore NO_x emissions are considerably lower than engineering standards set for EURO-V norms (*i.e.* 2 g/kw-hr for NO_x). The two reasons for reduction in NO_x with the increase in EGR are the reduction of combustion temperatures as a result of the addition of exhaust gases to the intake air which increases the amount of combustion accompanying gases mainly CO_2 which reduces the combustion temperature. The second reason can be attributed to the oxygen deficient operation under EGR which restrains the generation of NO_x [2]. Still higher EGR rates are able to reduce NO_x emissions by a large amount, which however is accompanied by a reduction in BTE and an increase in CO, HC and smoke emissions [6]. Figure 10 shows that the HC emissions increase slightly from 0% to 10% EGR for all fuels and decrease from 10% to 20% EGR. HC decrease by 16% and 25% with DTBP 0.5% and 1% respectively when compared to diesel at 20% EGR. Figure 11 shows that the increase in smoke opacity is insignificant initially, which however increases slightly with increase in EGR, furthermore with the increase in percentage of DTBP also it increases. This can be attributed to the addition of cetane improver which increases the combustion temperatures and the amount of fuel burned in the diffusive combustion phase resulting in the slight increase of engine smoke [33]. Conversion factors from ppm (particles per million) to g/kw-hr are based on the literature [38].

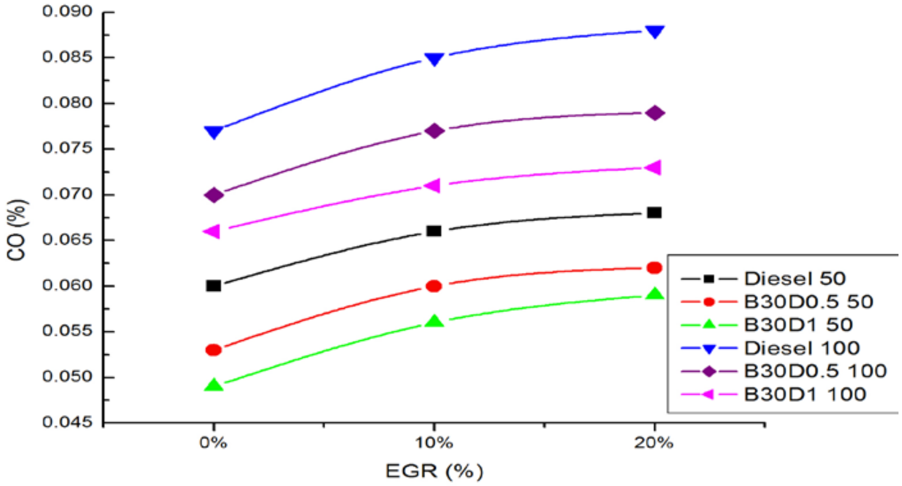


Fig. 8. Variation of CO emissions with EGR mass fraction at 50% and 100% loads.

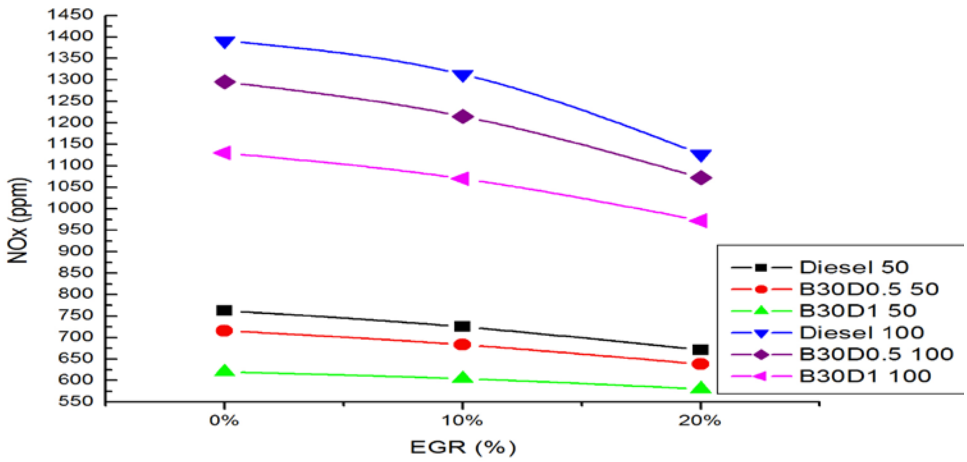


Fig. 9. Variation of NO_X emissions with EGR mass fraction at 50% and 100% loads.

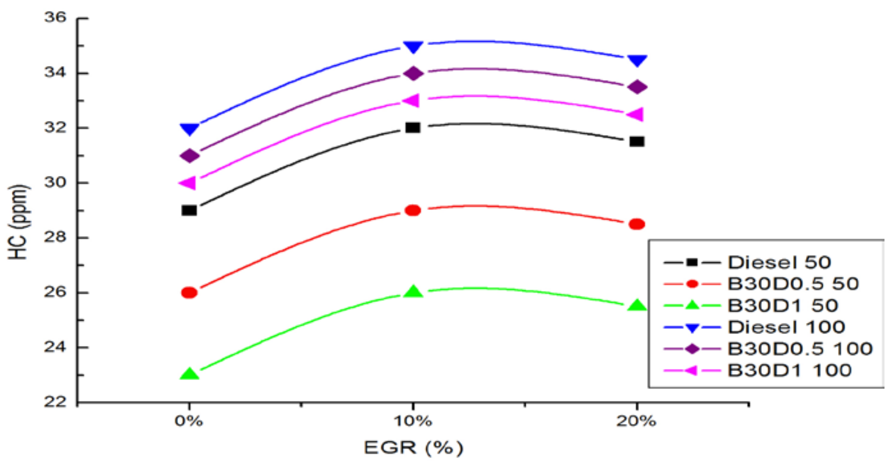


Fig. 10. Variation of HC emissions with EGR mass fraction at 50% and 100% loads.

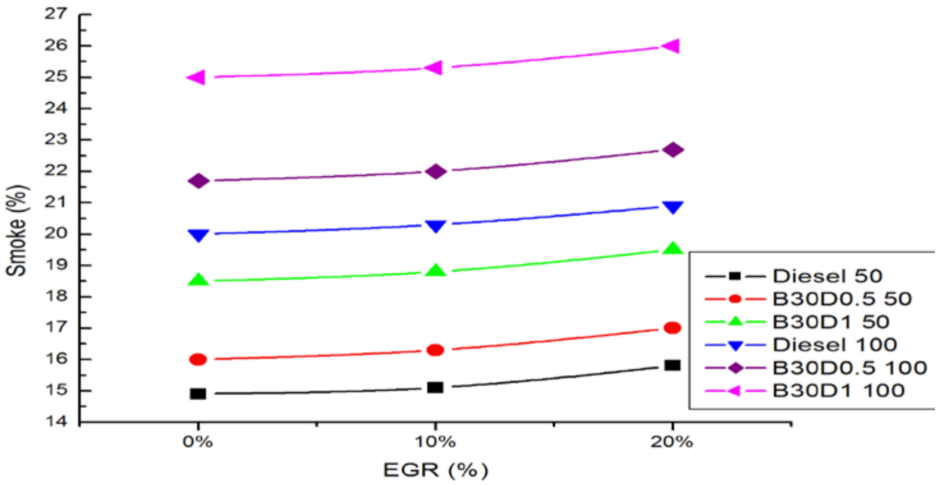


Fig. 11. Variation of smoke opacity with EGR mass fraction at 50% and 100% loads.

4. CONCLUSION

The conclusions drawn from present experimental investigation on a constant speed engine running at a rated speed of 1500 rpm are as follows:

1. BTE and BSFC increase with increase in percentage of EGR, optimum EGR for maximum BTE and minimum BSFC is found to be 20% as the variation in BSFC is insignificant after 10% EGR.
2. Peak pressure decreases slightly with increase in the percentage of EGR.
3. NO_x and exhaust gas temperature decrease with increase in the percentage of EGR and further more at a fixed EGR, they decrease with increase in percentage of DTBP.
4. CO and HC emissions are found increasing with increase in the percentage of EGR. However at a fixed EGR, they are found decreasing with DTBP.
5. The increase in smoke is insignificant initially which however increases slightly with further increase in EGR which also increases with the increase in percentage of DTBP.

Finally from our test findings it is recommended that by using DTBP 0.5%, the rate of EGR can be increased up to 20%, at this higher EGR conditions the engine can improve the BTE with significant reductions in NO_x emissions. The increase in CO and smoke opacity is insignificant from 10% to 20% EGR and further more HC emissions are also lower at 20% EGR than that for 10% EGR. However these results may not agree at other engine operating conditions.

REFERENCES

[1] Ladommatos N., Adelhalim S.M., Zhao H. and Hu Z., 1998. The effects of carbon dioxide in exhaust gas recirculation on diesel engine emissions. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 212(1):1 25-42.

[2] Yokomura H., Kohketsu S., and Mori K., 2003. EGR system in a turbocharged and intercooled heavy-duty diesel engine– expansion of EGR area with venturi EGR System. *Engine Research Department, Research and Development Office, MFTBC*, Technical Review No.15.

[3] Oberweis S. and T.T. Al-Shemmer. 2010. Effect of biodiesel blending on emissions and efficiency in a stationary diesel engine. In *International Conference on Renewable Energies and Power Quality (ICREPQ'10)*. Granada, Spain, 23-25 March, 2010.

[4] Li Y.X., McLaughlin N.B., Patterson B.S. and Burtt S.D., 2006. Fuel efficiency and exhaust emissions for biodiesel blends in an agricultural tractor. In *CSAE/SCGR 2005 Meeting*, Winnipeg, Manitoba, 26-29 June 2005, Paper No. 05-067.

[5] Alagu R.M. and E.G. Sundaram. 2010. Nitrogen oxide emission in biodiesel fuelled CI engines — A review. *Proceedings of Frontiers in Automobile and Mechanical Engineering (FAME*) 25-27 Nov. 2010: 156-163.

[6] Belagur V.K. and V.R. Chitimini. 2010. Effect of injector opening pressures on the performance, emission and combustion characteristics of DI diesel engine running on honne oil and diesel fuel blend. *Thermal Science* 14(4): 1051-1061.

[7] Roy M.M., 2011. Performance and emissions of a diesel engine fueled by diesel-biodiesel blends with special attention to exhaust odor. *Canadian Journal on Mechanical Sciences and Engineering* 2(1).

[8] Gomaa M.,Alimin A.J. and Kamarudin K.A., 2011. The effect of EGR rates on NO_X and smoke emissions of an IDI diesel engine fuelled with jatropha biodiesel blends. *International Journal of Energy and Environment* 2(3): 477-490.

[9] Pramanik K., 2003. Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. *Renewable Energy* 28(2): 239–248

[10] Pradeep V. and R.P. Sharma. 2007. Use of HOT EGR for NOx control in a compression ignition engine fuelled with bio-diesel from jatropha oil. *Renewable Energy* 32: 1136-1154.

[11] Rajana K. and K.R. Senthilkumar. 2009. Effect of exhaust gas recirculation (EGR) on the performance and emission characteristics of diesel engine with sunflower oil methyl ester. *Jordan Journal of Mechanical and Industrial Engineering (JJMIE)* 3(4): 306-311.

[12] Peixoto V., Argachoy C., Trindade I. and Airoldi M., 2009. Combustion optimization of a diesel engine with EGR system using 1D and 3D simulation tools. In the *Fourth European Combustion Meeting,* Department of Engine Design Engineering, MWM International Diesel Engines of South America Ltd. Sao Paulo, Brazil.

[13] Saravanan S., Nagarajan G., Ramanujam R. and Sampath S., 2011. Controlling NOx emission of crude rice bran oil blend for sustainable environment. *CLEAN – Soil, Air, Water* 39(6): 515–521.

[14] Wagner R.M., Green Jr. J.B., Storey J.M. and Daw C.S., 2000. Extending exhaust gas recirculation limits in Diesel engines. In *A&WMA 93rd Annual Conference and Exposition,* Salt lake City, UT, 18-22 June 2000.

[15] Mohamed Selim Y.E., 2003. Effect of exhaust gas recirculation on some combustion characteristics of dual fuel engine. *Energy Conversion and Management* 44: 707–721.

[16] Ladommatosa N., Abdelhalima S. and Zhao H., 1998. Control of oxides of nitrogen from diesel engines using diluents while minimizing the impact on particulate pollutants. *Applied Thermal Engineering* 18(11): 963–980.

[17] Agarawal A.K., Kumar S., Singh S.S. and Shukla M.K., 2004. Effect of EGR on the exhaust gas temperature and exhaust opacity in compression ignition engines. *Sadhana* 29(3): 275–284.

[18] Yousufuddin S., Venkateswarlu K. and Khan N., 2012. A computational study to investigate the effects of insulation and EGR in a diesel engine. *International Journal of Energy and Environment* 3(2): 247-266.

[19] Wang X.G., Zheng B., Huang Z.H., Zhang N., Zhang Y.J. and Hu E.J., 2010. Performance and emissions of a turbocharged, high-pressure common rail diesel engine operating on biodiesel/diesel blends. *Journal of Automobile Engineering, Proceedings of the Institution of Mechanical Engineers*, Part D, 225 127-139.

[20] Zhang G.D., Liu H., Xia X.X., Zhang W.G. and Fang J.H., 2005. Effects of dimethyl carbonate fuel additive on diesel engine performances. *Journal of Automobile Engineering, Proceedings of the Institution of Mechanical Engineers,* Part D, 219, D13904.

[21] Nibin T., Sathiyagnanam A.P., Sivaprakasam S. and Saravanan C.G., 2005. Investigation on emission characteristics of a diesel engine using oxygenated fuel additive. *IE (I) Journal* MC 86: 51-54.

[22] Nurunnabi Md. and Md. Wahid Chowdhury. 2006. Improvement of engine performance using diethylene glycol dimethyl ether (DGM) as additive. *Jurnal Teknologi* 44(a): 1–12.

[23] Zhang N., Huang Z., Wang X., and Zheng B., 2011. A comparative study of two kinds of biodiesels and biodiesel-DEE blends in a common rail diesel engine. *SAE International* 2011-01-0640.

[24] Karabektas M. and M. Hosoz. 2009. Performance and emission characteristics of a diesel engine using isobutanol–diesel fuel blends. *Renewable Energy* 34:1554–1559.

[25] Sundar Raj C., Sendilvelan S. and Arul S., 2010. Performance of a thermally insulated constant speed diesel engine with dioxane bended fuels. *Global Journal of Researches in Engineering* 10(2): 11-17.

[26] Sathiyagnanam A.P., Saravanan C.G. and Dhandapani S., 2010. Effect of thermal-barrier coating plus fuel additive for reducing emission from DI diesel engine. In *Proceedings of the World Congress on Engineering (WCE) 2010, Vol II,* London, U.K. June 30 - July 2, 2010.

[27] Manish Nandi K. The performance of ditertiary-butyl peroxide as cetane improver in diesel fuels. ARCO Chemical Company, Newtown Square, PA 19073.

[28] Suppes G.J., Bockwinkel K., Mason M.H., Botts J.B. and Heppert J.A., Multi functional diesel treatment additive from vegetable oils. *Department of Chemical and Petroleum Engineering, University of Kansas*. 4006 Learned, Lawrence, KS 66045-2223, (785) 864-3864.

[29] Kobori S., Kamimoto T. and Aradi A.A., 2000. A study of ignition delay of diesel fuel sprays. *International Journal of Engine Research* 1(1): 29-39.

[30] Akasaka Y., 1994. Effects of oxygenated fuel and cetane improver on exhaust emission from heavy-duty DI diesel engines. *SAE Technical Paper*. No. 942023.

[31] Kin H., Choi B., Park S. and Kim Y.-K., 2005. Engine performance and emission characteristics of CRDI diesel engine equipped with WCC and DOC using ethanol blended diesel fuel. In *Proceedings of ISAF XV International Symposia on Alcohol Fuels, San Diego, USA. 26-28 September.*

[32] Li W., Ren Y., Wang X.B., Miao H., Jiang D.M. and Huang Z.H., 2008. Combustion characteristics of a compression ignition engine fuelled with diesel—ethanol blends. In *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 222(2): 265-274.

[33] Yu W., Chen G. and Huang Z., 2011. Influence of cetane number improver on performance and emissions of a common-rail diesel engine fueled with biodiesel-methanol blend. *Front. Energy* 5(4): 412–418.

[34] Ren Y., Huang Z.H., Jiang D.M., Li W., Liu B. and Wang X.B., 2008. Effects of the addition of ethanol and cetane number improver on the

combustion and emission characteristics of a compression ignition engine. *Journal of Automobile Engineering, Proceedings of the Institution of Mechanical Engineers,* Part D 222:1077-1087.

[35] Boot M., Frijters P., Luijten C., Somers B., Baert R., Donkerbroek A., Klein-Douwel R.J.H. and Dam N., 2009. Cyclic oxygenates: a new class of second-generation biofuels for diesel engines. *Energy and Fuels* 23: 1808–1817.

[36] Frijters P.J.M. and R.S.G. Baert. 2006. Oxygenated fuels for clean heavy-duty diesel engines. *International Journal of Vehicle Design* 41(1-4): 242-255.

[37] Xue J., Grift T.E. and Hansen A.C., 2011. Effect of biodiesel on engine performances and emissions. *Renewable and Sustainable Energy Reviews* 15: 1098–1116.

[38] Calculating Greenhouse Gas Emissions, April 2003. Canadian Association of Petroleum Products (CAPP) Guide.