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Performance and Emission Characteristics Investigation of Oxygen Enrichment in Diesel Engines

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ABSTRACT:

The present work examines the oxygen enrichment on diesel engine at the fuel side and air side. Oxygenation at the fuel side is done by blending the Dimethyl carbonate (DMC) additive with a maximum percentage of oxygen whereas that of air side is done by coupling a blower to the inlet manifold. The experiment was conducted with four different blends of oxygenated additives with diesel, and then the effects of supercharging in these blends were analyzed. The performance and emission characteristics of DMC blend with diesel fuel were examined and compared with the base engine characteristics. The results show that for 5% of DMC there is an increase in the thermal efficiency of the engine and decrease the CO emissions.

KEYWORDS:

Diesel engine; Dimethyl carbonate; Oxygenated fuel; Oxygen enrichment; Supercharging; Pollutant emissions

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1. Introduction

Diesel engines are mostly used in transport sector due to their reliability, low fuel consumption, and high efficiency. The most important disadvantages of diesel engines are their low power density due to higher stress and compression fraction than in spark ignition engines and the noxiousness of exhaust gases. One of the most common approaches to overcome these is to increase the density and pressure ratios with the help of supercharger in the engine. In normally aspirated engines, the air flow is directly introduced in to the engine cylinders at atmospheric pressure. In supercharged diesel engines air is previously compressed, allowing a huge amount of mass to be entered into the cylinders. A large amount of fuel burns in the same volume, while maintaining the same speed and piston dislocation [1]. In mechanical superchargers, the compressor is driven by the engine. Thus, a fraction of its power is nowhere to be found. In turbocharged diesel engines, the exhaust gases energy is exploited to drive the supercharger.

The improvement of a diesel engine compared to a gasoline engine is the fuel-economy benefits. High smoke and oxides of nitrogen (NOx) emissions always stay as the main obstacles for its development. With an increasing concern in ecological safeguard and implementation of more stringent exhaust gas regulations, further reduction in engine exhaust emissions is essential. Simultaneously, it is not easy to reduce NOx and smoke in a traditional diesel engine because of the trade-off relationship between NOx and smoke [2].

2. Problem analysis

Nibin et al [10] investigated on emission characteristics of engine using various fuel additives. The effect of fuel additive was to control the exhaust emission coming out from a diesel engine and to get better performance. The fuel additive dimethyl carbonate (DMC) was blended with diesel fuel by its volume percentage of 5%, 10%, and 15%. The experimental study was carried out in a multi-cylinder diesel engine. Results show that there is a considerable reduction in emissions such as particulate matter (PM), oxides of nitrogen, smoke density, unfettered emission benzo(a)pyrene and a subsidiary increase in the performance when compared with a normal diesel engine. Zhang et al [11] investigated the effects of DMC fuel additive on diesel engine performance. The experimental results have shown that PM emission can be reduced using the DMC oxygenated compound. The combustion analysis showed that the ignition delay of a diesel engine fuelled with DMC-blended diesel is longer, but combustion time duration is much shorter.

Nabi [12] carried out a theoretical investigation of engine thermal efficiency along with adiabatic flame temperature, NOx emission and combustion parameters for various oxygenated fuels. The results showed that almost all the above combustion parameters are directly related to the oxygen content in the fuels. The ratio of lower calorific value and theoretical air fuel ratio is constant for various types of oxygenated fuels in any case of the oxygen content in their molecular structure. The thermal efficiency of a diesel engine is almost unaffected below oxygen content of 30% by wt, but at the same time gradually decreased when it has above 30% wt. The reduction in NOx emission is directly related to the reduction in adiabatic flame temperature for the oxygenated fuels, at the same time as the reduction of thermal efficiency above 30% wt of oxygen associated with the increase in gas specific heat. Anand et al [14] investigated the effects of oxygen enhancement at intake air in a diesel engine. The result showed that varying oxygen content in the intake air increased the brake thermal efficiency (BTE) of an engine and subsequently decreases the brake specific fuel consumption (BSFC). From the result, it was found that NOx emissions also increased exponentially whereas the smoke intensity decreased from the normal level.

3. Experimental technique and explanation

Fuel additives used in diesel engines have been classified into four categories: Cetane improvers, fuel injection deposit combustion promoters, cleaning detergents, and oxygenates. From the literature survey it has been identified that enhancing the oxygen content in diesel fuel could effectively reduce PM and soot emissions from diesel engines [3-4]. It has been revealed that dimethyl ether (DME), DMC, methanol, and ethanol could be used as either additives or pure fuels [5-7]. Huang et al [8] studied the combustion characteristics and heat release rate analysis of direct injection CI engine fuelled with DMC blends. Lin et al [9] reported reductions in acetylene and benzene by both additives, but found that DMC led to substantially better reductions in emissions when compared to ethanol. The physical and chemical properties [9-10] of some oxygenated compounds are given in Table 1.

Table 1: Property of oxygenated fuels

Brand	Dimethyl ether	Methylal	Dimethyl carbonate	Methanol
Abbreviation	DME	DMM	DMC	MEOH
Formula	C_2H_6O	$C_3H_8O_2$	$C_3H_6O_3$	CH_4O
Molecular weight (g/mol)	46.07	76.1	90	32
Oxygen content (wt%)	34.8	42.1	53.3	50
Boiling point (°C)	-24.9	42.3	90	65.1
Calorific value (MJ/kg)	28.8	22.4	13.5	19.5

The trend towards low emission diesel fuels is emerging worldwide, in which the emission reductions beyond the set targets will require a combination of new engine technology, additives, and reformulated diesel fuels. The production of economically viable low emission diesel fuels will remain a substantial challenge into the years to come. Oxygenates are well known to reduce PM emissions. Low molecular weight alcohols, such as methanol, ethanol, and t-butyl alcohol, have been reported to reduce emissions. Particularly attractive are P-series glycol ethers which contain both ether and a propylene glycol end-group. This work deals with oxygenate selection criterion and emission reductions in modern diesel engines. The prime oxygenate selection criterion includes cost, toxicity, environmental impact, fuel blending properties and engine performance. Critical fuel blending properties to screen and identify the viable oxygenates are high oxygen content, diesel fuel solubility, flashpoint, viscosity, water solubility in the resultant fuel blend, oxygenate extractability from the fuel, and minimal impact on the natural diesel fuel Cetane number [11].

The oxygenate should be soluble in diesel fuel from 1.0 to 5.0% to achieve maximum emission reduction and improved engine performance. As aromatic content in future reformulated diesel fuels is reduced from 35% to 10-20%, oxygenate solubility in the less polar hydrocarbon fuels will become acute [11]. The oxygenated diesel fuel flashpoint needs to be over 52˚C, as specified by ASTM D975 to reduce the transportation flammability risk. DMC is non-toxic and also 100% miscible in diesel fuel. DMC contains about 53% oxygen by weight and has a boiling point of about 90°C. Hence, DMC is selected to be an additive for diesel engines in this research owing to its solubility and oxygen content.

4. Experimental procedure

In this work, diesel is the base fuel and DMC is used as the oxygenated fuel additive. There are four different blends were prepared by volume fractions of DMC with diesel (5,10,15, and 20%) respectively. The experimental work is conducted in a single cylinder water cooled four stroke vertical CI diesel engine coupled with a centrifugal blower (supercharger) at the inlet manifold as shown in Fig. 1. The schematic of experimental setup has been shown in Fig. 2. The major specifications of the diesel engine are listed in Table 2. The load is applied using eddy current dynamometer. The pollutants like NO, NOx, CO_2 and CO have been measured for each load at various blend concentrations by using Kane Automotive Gas Analyser. Primarily the performance and emission characteristics of normal base fuel were examined and then the effects of supercharger coupled with inlet manifold are also measured. Then the combined effect of the supercharger with DMC for various proportions was evaluated. Finally, the comparison between diesel-supercharger with DMC blends and the base diesel fuel was made in order to discuss their effects on the performance and emission in a diesel engine [12].

Fig. 1: Experimental setup

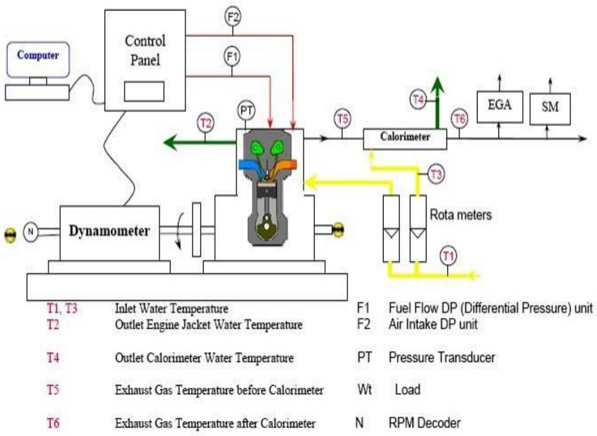

Fig. 2: Schematic diagram of experimental setup

Table 2: Engine specifications

Parameter	Value
Bore diameter in mm	80
Stroke in mm	110
Rated speed in rpm	1500
Rated power output in kW	3.5
Compression ratio	16.5
Diameter of orifice in mm	20
Dynamometer arm length in mm	185

5. Results and discussion

The variation of BTE and ITE for various loads when the engine is coupled with and without a supercharger for various blend ratios of oxygenated additive are shown in Fig. 3 to Fig. 6. The thermal efficiency is increased considerably for 5 % blend ratio. This is due to better combustion of the fuel, as the available oxygen for burning of fuel is increased. Fig. 7 and Fig. 8 show the variation of BSFC for the various loading condition for various blend ratios of DMC with and without blower respectively. The BSFC is reduced considerably for 5% blend ratio due to the better combustion of the fuel. The variation of brake thermal efficiency and BSFC of base fuel are compared with both airside and fuel side oxygen enrichment. The result shows that the BTE of the base engine setup is 32.69% with the SFC of 0.26kg/kW-hr at maximum load condition. The base engine coupled with blower has the increased BTE of about 33.51% and reduced SFC of about 0.25kg/kW-hr. The oxygen addition on fuel side also has the same efficiency and SFC as that of air side enrichment for 10% DMC blend at maximum load condition. The combined effect of air side and fuel side enrichment shows that for 5% DMC blend the BTE is increased to 35.14% and SFC is reduced to 0.24kg/kW-hr.

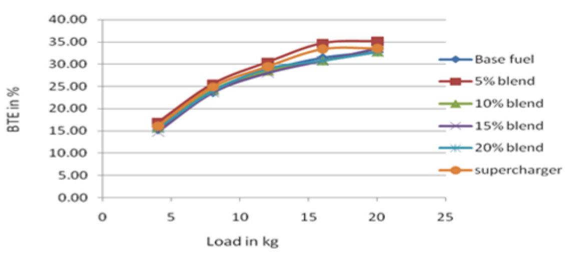

Fig. 3: BTE vs. Load for various blend ratios with blower

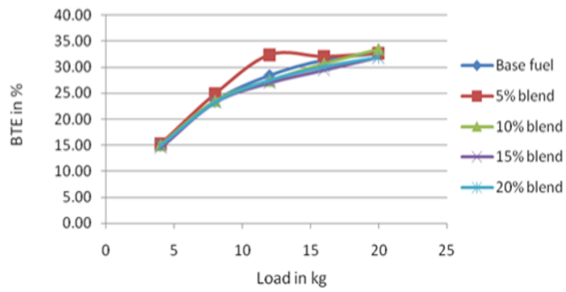

Fig. 4: BTE vs. Load for various blend ratios without blower

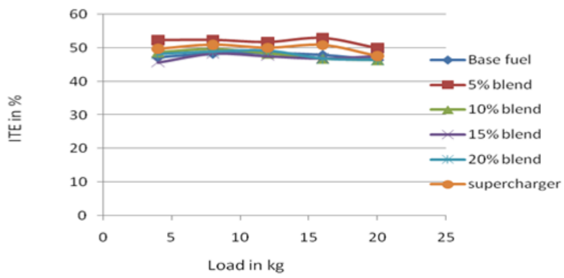

Fig. 5: ITE vs. Load for various blend ratios with blower

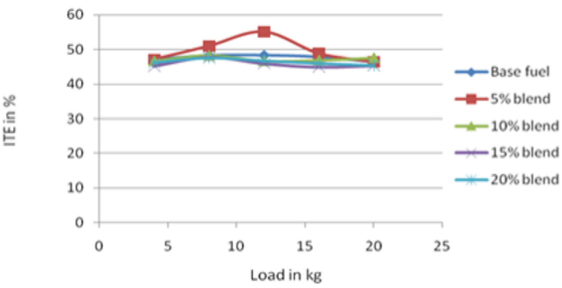

Fig. 6: ITE vs. Load for various blend ratios without blower

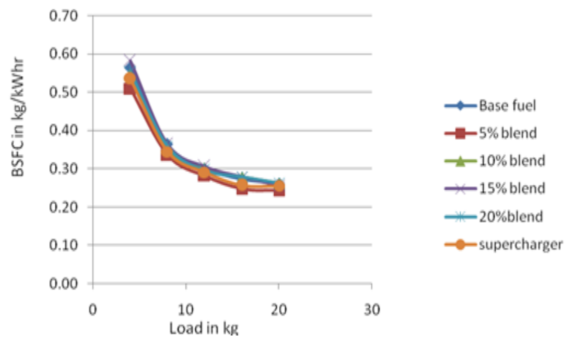

Fig. 7: BSFC vs. Load for various blend ratios with blower

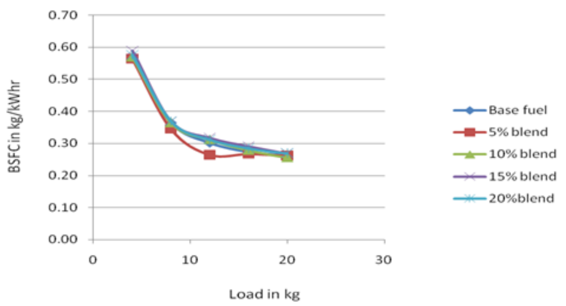

Fig. 8: BSFC vs. Load for various blend ratios without blower

The compression-ignition engine exhaust gases contain oxides of nitrogen (NOx), carbon monoxide (CO), organic compounds that are unburned hydrocarbons (HC), visible smoke and soot. The composition and properties of diesel particulates varies greatly and is therefore difficult to define. The most effect method of reducing particulate emissions is to use lighter distillate fuels. However, this leads to added expense. Additional reductions in particulate emissions can be achieved by increasing the fuel injection pressure to ensure that optimum air-fuel mixing is achieved. However, as fuel injection pressure increases, the reliability of the equipment decreases [13]. In diesel engines, the formation of CO is determined by the air/fuel mixture in the combustion chamber and as diesels have a consistently high air to fuel ratio, formation of this toxic gas is minimal. Incomplete combustion occurs due to large droplet of liquid fuel and also excess air supplied.

Fig. 9 and Fig. 10 show the variation of percentage volume of CO values for various loads and various blend ratios of oxygenated additive when the engine is coupled with and without supercharger respectively. The percentage of CO is reduced considerably for the engine is coupled with blower running at base fuel. This is due to the better combustion of the fuel, as the density of the air available is increased. The CO emissions are reduced for the both the air side and fuel side oxygen enrichment compared to base engine setting. This shows that the complete combustion occurs by adding oxygen in both air side and fuel side.

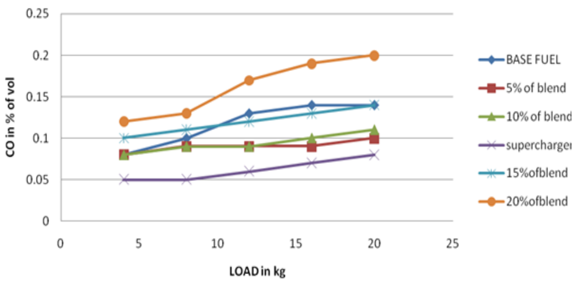

Fig. 9: CO vs. Load for various blend ratios with blower

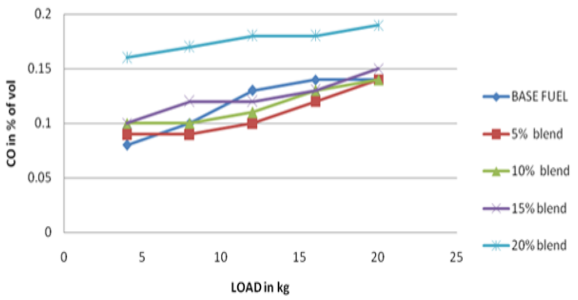

Fig. 10: CO vs. Load for various blend ratios without blower

CO_2 is the prime product of combustion, due to its effect which may create the usage of diesels engines application. Hence the reduction of CO_2 plays a major role in the diesel engine in which, the only way to reduce CO_2 is to burn the fuel completely during combustion. Alternatively, low carbon to hydrogen ratio fuel could be used. Diesel engines currently meet the CO_2 guidelines, however meeting stricter regulations on the permissible production of CO_2 is theoretically possible, but practically achieving these standards would be difficult. Fig. 11 and Fig. 12 show the variation of percentage volume of CO_2 values for various loads and various blend ratios of oxygenated additive when the engine is coupled with and without supercharger respectively. The percentage volume of CO_2 is increased considerably when the engine is coupled with supercharger running at base fuel. This is due to the better and complete combustion of the fuel, as the density of the air available is increased.

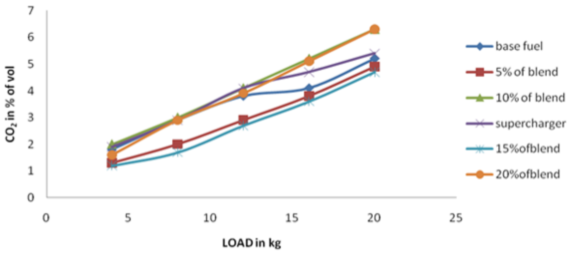

Fig. 11: CO_2 vs. Load for various blend ratios with blower

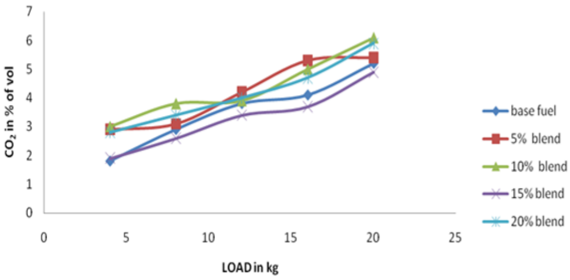

Fig. 12: CO_2 vs. Load for various blend ratios without blower

NOx is formed during the combustion process within the burning fuel sprays. NOx is deemed to be one of the most harmful to the environment. The amount of NOx produced is a function the maximum temperature in the cylinder, oxygen concentrations and residence time. Fig. 13 and Fig. 14 show the variation of percentage volume of NOx values for various loads and various blend ratios of oxygenated additive when the engine is coupled with and without supercharger respectively. It can be seen that the supercharger increases the NOx emission. When 5% DMC is added to diesel fuel, the NOx emission is considerably increases while compared with a normal diesel engine. The increase in NOx while DMC added because of high operating temperature results from the better combustion and oxygen enrichment.

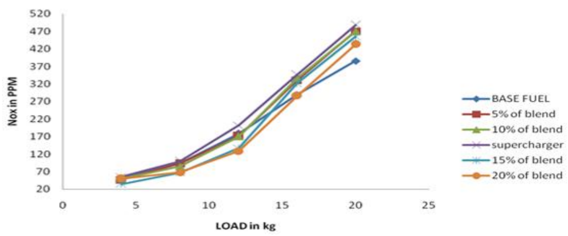

Fig. 13: NOx vs. Load for various blend ratios with blower

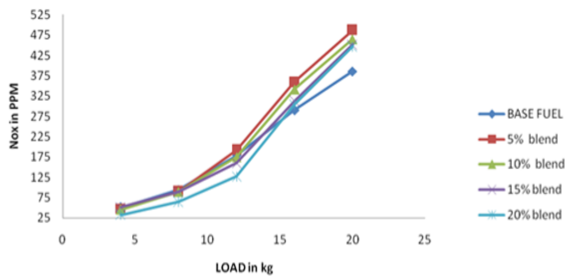

Fig. 14: NOx vs. Load for various blend ratios without blower

Fig. 15 and Fig. 16 show the variation of percentage volume of NO values for various loads and various blend ratios of oxygenated additive when the engine is coupled with and without supercharger respectively. The percentage volume of NO is increased considerably when the engine runs at various blends of oxygenated additive with base fuel. This is due to the better and complete combustion of the fuel, as the increase in oxygen percentage. The percentage volume of NO is increased considerably when the engine is coupled blower and running at base fuel. This is due to the better combustion of the fuel, as the density of the air available is increased.

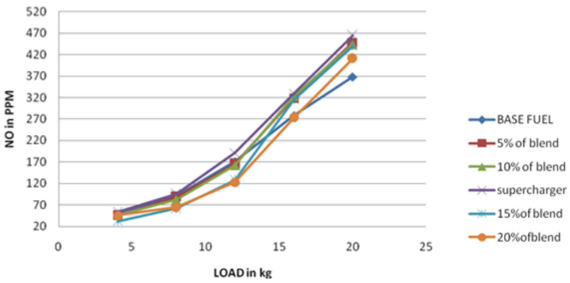

Fig. 15: NO vs. Load for various blend ratios with blower

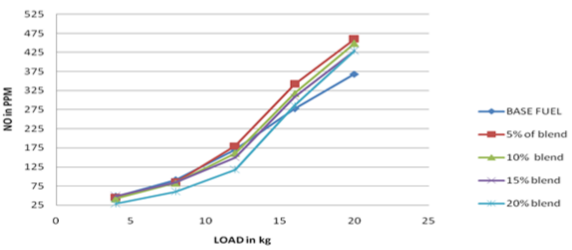

Fig. 16: NO vs. Load for various blend ratios without blower

6. Conclusions

The effect on combustion characteristics and performances of supercharged diesel engines with addition of DMC oxygenates to diesel fuel has been experimentally examined in this research. DMC is one of the best additives for diesel engines owing to its advantages of a high oxygen content, suitable boiling point and soluble with diesel fuel. The physical and chemical properties of DMC determine its suitability for using as an additive to diesel engines. The ignition delay of the DMC blend is longer than that of pure diesel while combustion duration is much shorter so that the thermal efficiency increases 1-3 percent under different operating conditions when the engine operates along with supercharger and 5% blend of DMC in diesel. The CO emissions are reduced due to the effect of the supercharger (blower) coupled with the engine inlet manifold. NOx emissions can be further reduced by increasing the DMC blend percentage with diesel.

REFERENCES:

[1] R. Arul Prakash, R. Vijayanandh, G. Raj Kumar and M. Senthil Kumar. 2017. Experimental investigation of Diesel Engine for various compression ratios using Calophyllum as blend with Diesel, *Nano Hybrids & Composites*, 17, 56-262, https://doi.org/10.4028/www.scientific.net/NHC.17.256.

[2] L. Rubino and M.J. Thomson. 1999. The effect of oxygenated additives on soot precursor formation in a counter flow diffusion flame, *SAE Technical Paper* 1999-01-3589. https://doi.org/10.4271/1999-01-3589.

[3] L.K.L. Shih. 1998. Comparison of the effects of various fuel additives on the diesel engine emissions, *SAE Technical Paper 982573*. https://doi.org/10.4271/982573.

[4] N. Miyamoto, H. Ogawa, N.M. Nurun, K. Obata and T. Arima. 1999. Smokeless, low NOx, high thermal efficiency, and low noise diesel combustion with oxygenated agents as the main fuel, *SAE Technical Paper* 1999-01-1475. https://doi.org/10.4271/980506.

[5] M. Stoner and T. Litzinger. 1999. Effects of structure and the boiling point of oxygenated blending compounds in reducing diesel emissions, *SAE Technical Paper* 1999-01-1475. https://doi.org/10.4271/1999-01-1475.

[6] S. Kajitani, C.L. Chen, M. Oguma, M. Alam and K.T. Rhee. 1998. Direct injection diesel engine operated with propane DME blended fuel, *SAE Technical Paper* 982536. https://doi.org/10.4271/982536.

[7] H. Ogawa, N. Nabi, M. Minami, N. Miyamoto and K. Bong-Seock. 2000. Ultra low emissions and high-performance diesel combustion with a combustion of high EGR, three-way catalyst, and a highly oxygenated fuel, dimethoxymethane(DMM), *SAE Technical Paper* 2000-01-1819. https://doi.org/10.4271/2000-01-1819.

[8] Z.H. Huang, D.M. Jiang, K. Zeng, B. Liu and Z.L. Yang 2003. Combustion characteristics and heat release analysis of a direct injection compression ignition engine fuelled with diesel-dimethyl carbonate blends, Proc. IMechE, Part D: J. Automobile Engineering, 217(7), 595-605. https://doi.org/10.1243/095440703322114979.

[9] C.Y. Lin and K.H. Wang. 2004. Effects of an oxygenated additive on the emulsification characteristics of two and three phase diesel emulsions, *Fuel*, 83(4-5), 507-515. https://doi.org/10.1016/j.fuel.2003.08.014.

[10] T. Nibin, A.P. Sathiyagnanam, S. Sivaprakasam and C.G. Saravanan. 2005. Investigation on emission characteristics of a diesel engine using oxygenated fuel additive, *J. IE (India) Mech. Engg.*, 86, 51-54.

[11] G.D. Zhang, H. Liu, X.X. Xia, W.G. Zhang and J.H. Fang. 2005. Effects of dimethyl carbonate fuel additive on diesel engine performances, Proc. IMechE, Part D: J. Auto. Engg., 219(7), 897-903. https://doi.org/10.1243/095440705X28358.

[12] M.N. Nabi. 2010. Theoretical investigation of engine thermal efficiency, adiabatic flame temperature, NOx emission and combustion-related parameters for different oxygenated fuels, *Appl. Therm. Engg.*, 30(8-9), 839-844. https://doi.org/10.1016/j.applthermaleng.2009.12.015.

[13] C.S. Lee, K.H. Lee, D.H. Whang, S.W. Choi and H.M. Cho. 1997. Supercharging performance of a gasoline engine with a supercharger, *KSME Int. J.*, 11(5), 556-564.

[14] R. Anand and N.V. Mahalakshmi. 2006. The effects of oxygen enrichment with intake air in a direct injection diesel engine, *J. IE (India) Mech. Engg.*, 90, 44-47.