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Performance and Emission Characteristics of a CI Engine Operating on Methyl Esters blended Diesel with Di-Methyl Carbonate Additives

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Abstract – *This paper investigates the effect of an oxygenated additive di-methyl carbonate (DMC), in Calophyllum Inophyllum methyl ester (CIME)-diesel blends, on engine performance and exhaust emission characteristics. The results are compared with those additives in CIME blends with diesel, and presented in this paper. Experiments were conducted at various compression ratios (CR) for the given blends of B20 and B40 using a single cylinder variable compression ratio compression ignition engine. Based on the experimental results, it is observed that the DMC added with CIME –diesel blends has improved the thermal efficiency up to 2.6% and 3% and a rise in brake specific fuel consumption (BSFC) of about 2.7% and 5.3% compared with CIME-diesel blends and diesel respectively, at higher compression ratios. Further, for the B20+A blend there is a marginal reduction in carbon monoxide (CO) emission of 22.7% and unburned hydro carbons (UBHC) emission of 12.7%, at the cost of the rise in oxides of nitrogen (NOx) than in those of diesel.*

Keywords – Additives, Calophyllum inophyllum methyl ester, emissions, performance, variable compression ratio.

1. INTRODUCTION

In today's world, the need to develop enhanced techniques to harvest energy efficiently is greater than ever. On the face of the upcoming energy crisis, vegetable oils have come up as a promising source of alternative fuels. The usage of fossil fuels such as petroleum in engines has affected the environment adversely. Due to the depletion of fossil fuel reserves, environmental hazards of exhaust gases, and increase in their price and usage, it is necessary to look for alternative fuel sources. This has led to tremendous hardships and considerable economic strain, especially to some of the developing countries like India. Hence, there is an urgent need to identify some alternate fuels which are non-fossil in nature and are capable of replacing partly or wholly, the demand for diesel fuel. Alcohols such as ethanol and methanol, hydrogen and vegetable oils are the probable substitutes. In India, there is a tremendous potential for the production of large quantities of ethanol from various agricultural feed stocks, and methanol from coal and natural gas.

Biomass sources, particularly vegetable oil (edible or non-edible) derived from plants and trees have attracted much attention as alternative sources. Though it is renewable, available everywhere, cleaner and eco-friendly than fossil fuels, it has not been paid much attention. Edible oils have been replaced by non-edible oils, owing to their availability and cost of production. Among these fuels, [1] alcohols can be used as either blends with fossil fuels in the engine or as additives in biodiesel production. There are many oxygenated compounds that can be added to diesel, viz., ethanol, acetoacetic esters, dimethyl ether, dimethyl carbonate, dimethoxy methane, and a mixture of methanol and ethanol. The purpose of adding oxygenated additives to diesel is to produce a cleaner burning of diesel fuel [2].

Guarieiro *et al*. [3] evaluated the performance and emission characteristics of a diesel engine run with oxygenated fuels. In this study, three categories of fuels were employed such as B5 (diesel blend with 5% biodiesel), B5E6 (with 6% ethanol) and 100% biodiesel for evaluating the performance and emission characteristics. It is noticed that, the presence of higher oxygen content in biodiesel as well as in additives can increase the fuel consumption for the same power output, irrespective of the blend ratio. However, B5 shows an increase in HC emission with a reduction in NO_x, due to the high latent heat of vaporization and low cetane number. Further, B100 showed a reduction in HC emission with the highest rise in NO_x. Imtenan *et al*. [4] studied the effect of oxygenated additives blended with two different biodiesels on the performance and emissions of a diesel engine. The studies have carried out with jatropha and palm biodiesel-diesel blended with three types of additives, such as ethanol, n-butanol or diethyl ether in the ratio of 80% diesel, 15% biodiesel and 5% additive. Compared with the fuel with no additives, P20 blended with diethyl ether significantly improved the brake power and brake thermal efficiency by about 4.10% and 4.4%, respectively, at 2200 rpm. Further, for the entire operation, the HC emission increased slightly, and the CO and NO_x emissions reduced marginally, for all blends using additives except P20 and J20. With the ethanol additive, the CO emission reduced by up to 40% and with diethyl ether as an additive, NO_x reduced by up to 13%. However, the oxygen content, volatility and latent heat of evaporation of the oxygenated additives can control the emission characteristics of the blends. The effects of the addition of antioxidants to the biodiesel blends have been

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reported by Fattah *et al*.[5] Coconut and Jatropha are two promising feed stocks taken for this investigation, added with synthetic antioxidants, 2(3)-tert-butyl-4-methoxyphenol (BHA) and 2,6-di-tert-butyl-4-methylphenol (BHT). It was reported that, the addition of antioxidants increased the brake power and reduced the BSFC slightly. Further, the NO emission reduced by 2.6–5.0%, and CO and HC increased by 4.9–20.8% and 23.2–40.2% respectively, for the antioxidant blended biodiesel compared to that without the additive blend. Varatharajan *et al*. [6] made an attempt to mitigate NO_x emissions from a diesel engine fueled with jatropha biodiesel, blended with antioxidant additives. The results proved that the addition of p-phenylenediamine additive in 0.025%-m concentration substantially reduced the NO_x level for the entire engine operations compared with that of biodiesel alone. Besides, it is found that, HC and CO emissions were increased significantly with antioxidant additives. Cheung *et al*. [7] investigated the effect of gaseous and particulate emissions of a CI engine with diesel-dimethyl carbonate blends. Four blends comprising of 4.5 to 18.6% by volume of DMC and 3 to 12% respectively, by mass of oxygen blended with diesel were used for the test. Due to the cooling effect of the oxygen content in the biodiesel, the brake specific carbon monoxide (BSCO), brake specific hydro carbon (BSHC) emission increase, and the brake specific nitrous oxide ($BSNO_x$) emissions reduce. However, there is an improvement in the brake thermal efficiency for the diesel-DMC blends, due to improved combustion.

DMC (dimethyl carbonate) which possesses an oxygen content of 53.3% can be used as an oxygenated additive to blend with diesel fuel, to improve combustion and to reduce the emissions of the diesel engines [8]-[9]. Venkateswara Rao *et al*. [10] conducted a performance and combustion characteristics test on a DI diesel engine, using Triacetin (T) as an additive with biodiesel. It was reported that 10% Triacetin additive with biodiesel blends (at different percentages) shows significant improvements in the performance and emissions. Shahabuddin *et al.* [11] conducted an investigation on a DI diesel engine, using IRGANOR NPA (product name) a corrosion inhibitor, as an additive with diesel and biodiesel. The final outcomes were compared with those of diesel fuel. It was observed that 20% biodiesel with 1% additive shows the best performance and reduced emissions of NO_x. Litzinger *et al*. [12] studied the effects of oxygenated additives on the aromatic species in fuel-rich ethane combustion. In this study, 5% oxygen by mass of fuel was added to ethane using dimethyl ether and ethanol. A significant reduction in the aromatic species relative to pure ethane was observed and also, the addition of DME was found to play a vital role in reducing the aromatic species than ethanol. It also influences the conversion of additives into C_2 intermediates, and leads to reduce the PM emissions from diesel engines. The observation recorded by Sivalakshmi *et al*. [13] during the test on diesel engine, using DMC additives blended with biodiesel resulted in improved brake thermal efficiency with biodiesel fuel. However, NO_x emissions reduced for the entire engine operation at the cost of a rise in HC and CO emissions at all loads.

The present investigation is to study the effect of 10% Dimethyl Carbonate (DMC) as an additive blended with Calophyllum Inophyllum methyl ester in different proportions and compression ratios, on a single cylinder variable compression ratio compression ignition engine. The performance and emission parameters were studied, and the test results were compared with the results of biodiesel without additive fuel, and are presented in this paper.

2. MATERIALS AND METHODS

Due to the high viscosity of the vegetable oil, it cannot be used directly in the engine. To reduce its viscosity and to improve its volatility, vegetable oil has to undergo the transesterification process. Depending upon the fatty acid possessed by the vegetable oil, it is processed in three stages. *Calophyllum Inophyllum* oil is processed in two stages; first, the esterification process (acid treatment), followed by transesterification (alkali process), for the preparation of biodiesel. Then, the biodiesel is mixed with diesel in different proportions, such as 20% (B20) and 40% (B40) for the experiment. Fatty acid profile of *Calophyllum Inophyllum* oil is given in table 1[16].

The test setup for this experiment is a single cylinder, direct injection, water cooled, naturally aspirated, kirloskar TV-1 model engine. The schematic diagram of the setup is illustrated in Figure 1. The engine is coupled with an eddy current dynamometer, and load was applied on it. A thermocouple type-K was used to measure the exhaust gas temperature, and a rotameter was provided to measure the water flow.

In order to compare the base line readings with other blends, the engine is run with diesel in the initial stage for the compression ratio of 16 at standard injection timing. Initially, the engine is run at no load condition until it reaches a rated speed of 1500 rpm, and it was loaded to the full load condition with an increment of 25% of load for each run. The observations are recorded and the performance characteristics such as BTE, BSFC and EGT are calculated. The experiment is repeated for the compression ratio of 17 and 18, fueled with blends of biodiesel and diesel in different ratios and blends of additives (10% DMC) with biodiesel. DMC is an oxygenated additive blended with CIME-diesel for the experiment, and it has low viscosity, low cetane number and high latent heat of evaporation. The properties of diesel, CIME and DMC are shown in table 2. A multigas analyser of model NPM-MGA-1 (NETEL India private limited) was used to measure the emissions such as CO, CO_2, UBHC, O_2 and NO_x. In this study, only CO, UBHC and NO_x emissions were measured for analysis. The specifications of the engine are given in Table 3.

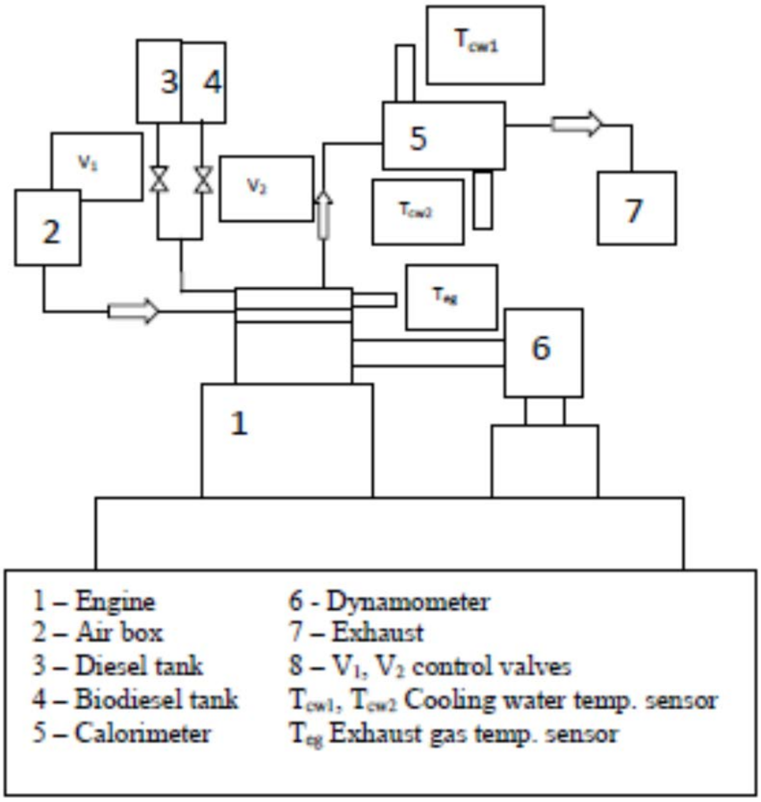

Fig. 1. Schematic diagram of experimental setup.

Table 1. Fatty acid composition of CIO.

Fatty Acid	Percentage of fatty acids (%)
Oleic acid	41.4
Palmitic acid	14.5
Linoleic acid	29.7
Stearic acid	12.9

*Fatty acid composition [16]

Table 2. Properties of diesel, CIO, DMC and CIME blend.

Fuel Property	Diesel	CIO	DMC*	CIME Blend		CIME Blend + Additives	
				B20	B40	B20+A#	B40+A
Chemical Formula	$C_{14}H_{30}$	$C_{18}H_{34}O_2$	$C_3H_6O_3$	--	--	--	--
Calorific Value (MJ/kg)	43.8	35.9	15.8	41.58	40.16	39.0	37.7
Kinematic Viscosity (cSt)	2.56	10.01	--	4.45	5.56	3.6	4.7
Flash Point (°C)	50	142.5	--	69	87	83	94
Fire Point (°C)	58	153	--	77	96	92	108
Density (kg/m^3)	836	861	1069	790	802	818	829
Cetane number	45	56.5	35	--	--	--	--

*DMC properties [7]; A# - Additives

Table 3. Engine specifications.

Particulars	Specifications
Engine make	Kirloskar, Model TV1
No. of cylinder	Single
No. of stroke	Four stroke
Power and speed	3.2 kW and 1500
Dynamometer type	Eddy current
Swept volume	661 cc
Compression ratio	12 to 18 : 1

Table 4. Uncertainty and accuracy of the instruments.

Instruments		Uncertainty	Accuracy
Temperature indicator		0.1	±1°C
Air flow meter		0.1	1mm WC
Fuel flow meter		0.1	2mm WC
Speed sensor		0.1	±10rpm
Load indicator		0.2	±10W
Crank angle sensor		0.1	1 degree
Exhaust gas analyser-			
	NOx	1ppm	±25 ppm
	CO	0.5%	±3 %
	HC	1ppm	±4 ppm

3. ERROR ANALYSIS

Uncertainty is a measure of potential errors that occur in the measuring equipments and it is also known as "degree of goodness" of the data. The uncertainty analysis can be used in the experiment to ensure that the accuracy of various measurements is at a satisfactory level of the final result, with acceptable limits of uncertainty. The best estimate of variable Xi assumed to be the mean value of the N measurements taken at a level of p=0.05 (95% confidence level) were statistically considered. Here, the Gaussian or Normal Distribution method has been used to find the uncertainties in the individual measurements.

Based on the Gausian distribution method the uncertainties of the various parameters and the overall uncertainty of the experiment was calculated using the following equation

$$\Delta R = \text{square root of}\left[\left(\frac{\partial R}{\partial x_1}\Delta x_1\right)^2 + \left(\frac{\partial R}{\partial x_2}\Delta x_2\right)^2 + \cdots\cdots + \left(\frac{\partial R}{\partial x_n}\Delta x_n\right)^2\right]$$

In this study, the maximum uncertainty of the experiment obtained was ±2.5%. Table 4 shows the uncertainty of the instruments used in this investigation.

4. RESULTS AND DISCUSSION

The outcomes obtained from this experimental investigation of CIME with additives in the CI engine and its performance and emission characteristics, are presented and discussed here.

4.1 Effect of Additives on Brake Specific Fuel Consumption (BSFC)

Figures 2 to 4 show the effect of additives with biodiesel and its blends with diesel on BSFC at different percentages of loads for a given compression ratio. It reveals that the BSFC decreases as the load on the engine increases. CR17 showed better results of BSFC on an average of 0.34 kg/kWh for diesel, which rises to 0.37 kg/kWh, 0.36 kg/kWh, 0.37 kg/kWh and 0.38 kg/kWh for B20+A, B20, B40 and B40+A, respectively. It is found that, the BSFC for B40+A is higher compared with diesel, and it is obvious that a higher blend necessarily consumes more fuel per unit power developed. This may be due to the increase in the blend ratio (biodiesel + diesel), which ensures its lower heating value and higher specific gravity.

Due to the inherent nature of the oxygen content in biodiesel, it has a lower heating value and the presence of the additive blend with CIME further reduces its value, which increases the brake specific fuel consumption. However, the addition of oxygenated additives owing to their lower cetane number may lead to more fuel being consumed. This trend has been maintained for higher compression ratios too.

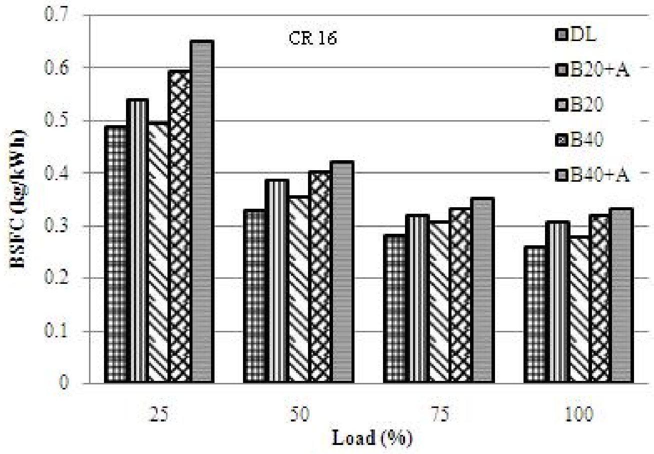

Fig. 2. Effect of additive on BSFC at CR16.

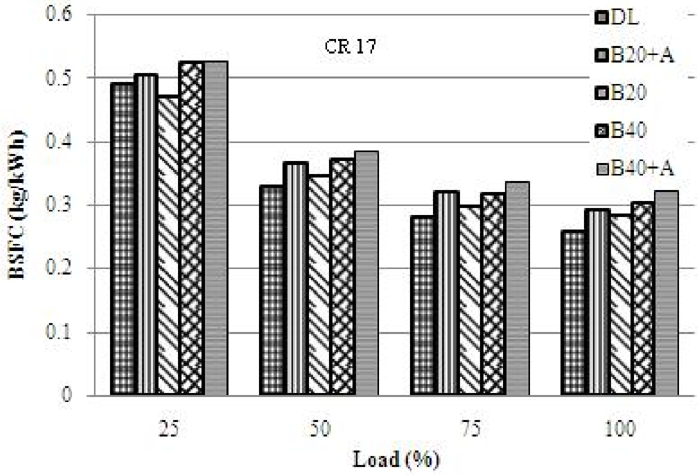

Fig. 3. Effect of additive on BSFC at CR17.

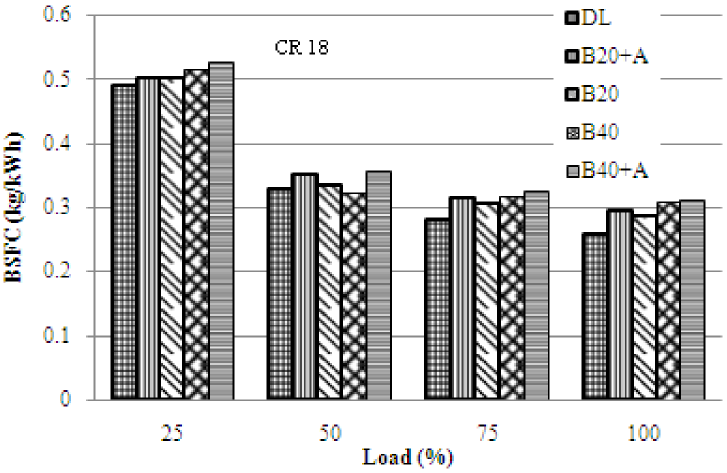

Fig. 4. Effect of additives on BSFC at CR18.

4.2 Effect of Additives on Brake Thermal Efficiency (BTE)

Figures 5 to 7 show the effect of additives with biodiesel and it blends with diesel on BTE at various compression ratios for the full load condition. The results show that the brake thermal efficiency increases with the increase in load, as well as with blends of biodiesel and compression ratios. In addition, it reveals that the mixing of DMC additives with biodiesel blends produces notable outcomes for higher compression ratios when compared to those with no additive blends. The blend B20+A exhibits higher BTE for CR18 among the various blends, followed by CR17 and CR16. It is found that blend B20+A produces an average of 27.48% BTE over other compression ratios which is 2.43%, and 1.24% greater than that of B20 and diesel respectively. It is noticed that the mixing of additives with the CIME blend (*i.e.* B20+A) exhibits higher efficiency due to better combustion, which may be attributed to its inherent nature of oxygen presence in biodiesel and also in additives. However, the improvement of BTE may be the effect of the fuel burnt in the premixed phase during combustion [7].

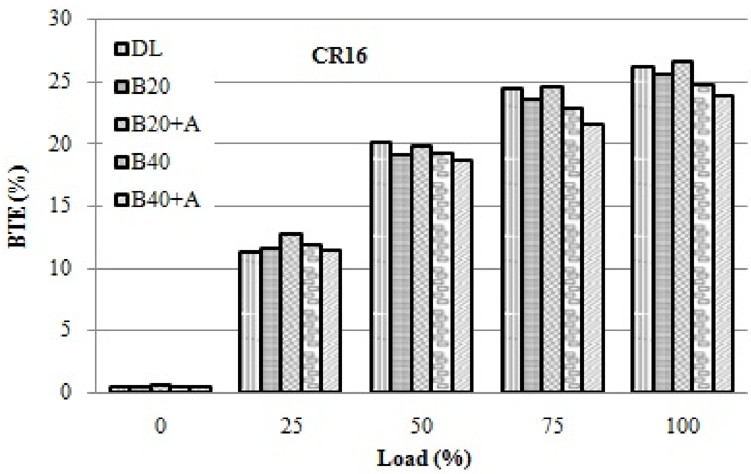

Fig. 5. Effect of additives on BTE at CR16.

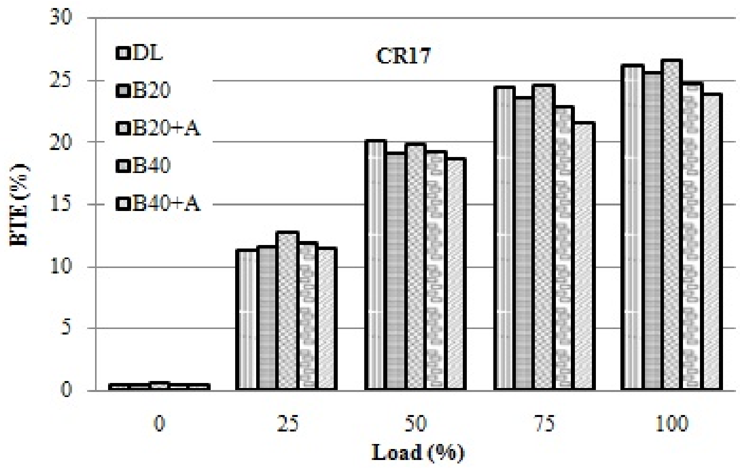

Fig. 6. Effect of additives on BTE at CR17.

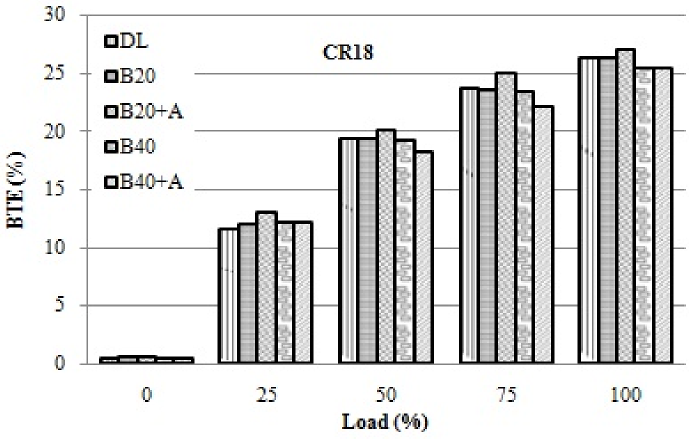

Fig. 7. Effect of additives on BTE at CR18.

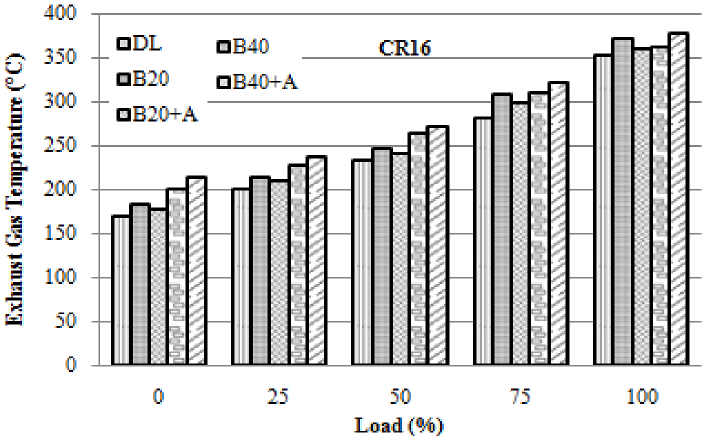

Fig. 8. Effect of additives on EGT at CR16.

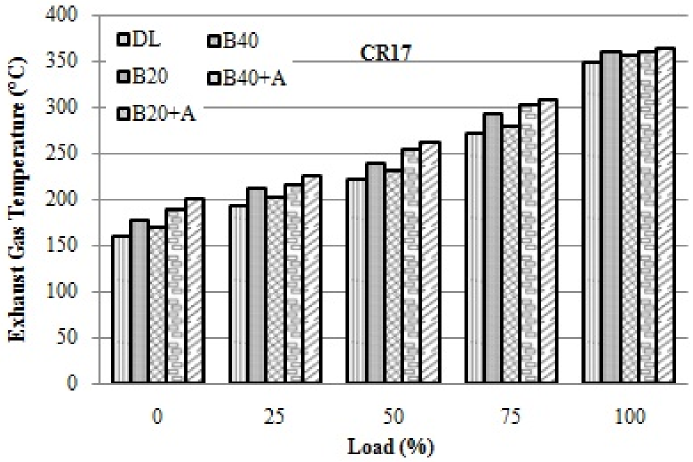

Fig. 9. Effect of additives on EGT at CR17.

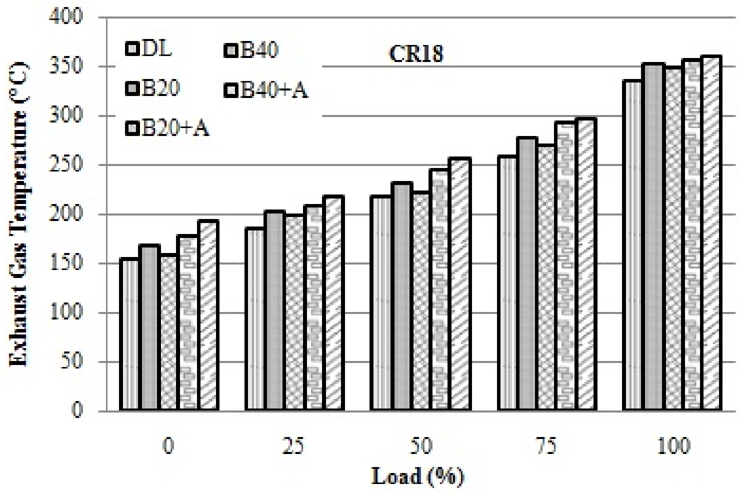

Fig. 10. Effect of additives on EGT at CR18.

4.3 Effect of Additives on Exhaust Gas Temperatures

Figures 8 to 10 show the variations of exhaust gas temperature with load percentage for different compression ratios. EGT represents an indication of the amount of waste heat lost with the exhaust gases, and it shows the condition of combustion inside the combustion chamber. It is observed that there is a fall in gas temperature with compression ratio for diesel, and it has been reduced for all the other blends. This indicates that there is a reduction in heat loss to exhaust gases in the presence of additives, and it may be a sign of the increase in brake thermal efficiency and better combustion. It is noticed that at high loads the exhaust gas temperature is slightly higher for biodiesel with additive, than for diesel. However, at the compression ratio of 18, B20+A provides the least gas temperature than the other blends. This may be attributed to the quantity of fuel injected and better combustion.

4.4. Emission Analysis

Since the performance characters are good at the compression ratio of 18, it is considered for the emissions' analysis.

Insufficient residence time and low flame temperatures are the primary factors for the formation of CO emissions. Even though, it shows an adverse effect on emission, it can be combusted by an additional supply of oxygen in to the combustion chamber. The variation of CO with respect to load percentage for various CIME blends with diesel and with additives is shown in Figure 11. It shows that the CO level increases as the proportion of CIME blend increases with diesel. It is evident that the CO emission decreases with the addition of DMC additives for the CIME-diesel blends, than for diesel and biodiesel. At maximum load, the CO emission is decreased by 47%, 41%, 23.5%, and 11% for B20+A, B20, B40+A, and B40, respectively, compared with diesel [14]. This is due to the greater presence of oxygenated additives in the CIME-diesel blend than in diesel.

In conventional diesel engine combustion, the formation of HC is primarily due to fuel being trapped in the crevice volumes of the combustion chamber, lean or rich mixture in the localized zone, and incomplete fuel combustion [15]. Figure 12 compares the fluctuations of HC emissions for different blends. It is noticed that blend B20+A shows lower HC emission followed by B40, B40+A, and B20, when compared with diesel. At full load conditions, compared with diesel, the reduction in HC for the blend B20+A is found to be 35.5% followed by 28.8%, 21.3%, 18.6% for B40, B40+A, and B20 respectively. The reduction in HC and CO emission is primarily due to the lean effect of the mixture and the presence of oxygenates in the CIME – additive blended fuel.

Figure 13 illustrates the variation of NO_x for various CIME-diesel blends with load. It is seen from Figure 13, that the NO_x emission increased for biodiesel and additive-biodiesel blends in comparison with diesel at full load condition. This could be the effect of the oxygenated additives in CIME-diesel blends, which improves the combustion, and in turn raises the temperature of the combustion products. Since according to the combustion theory, the generation of oxides of nitrogen is primarily the function of temperature and the amount of oxygen present in the fuel mixture. The presence of additives in CIME-diesel mixture, which stimulates the combustion with a rise in temperature results in high NO_x emissions compared with diesel. The NO_x emission increases with the addition of additives in CIME-diesel blends by 32.5%, 24.9%, 17.6%, and 11% for B20+A, B20, B40+A, and B40 respectively, than for diesel. It is evident from the test, that in comparison with diesel, oxides of nitrogen rise for biodiesel and additive-biodiesel blends.

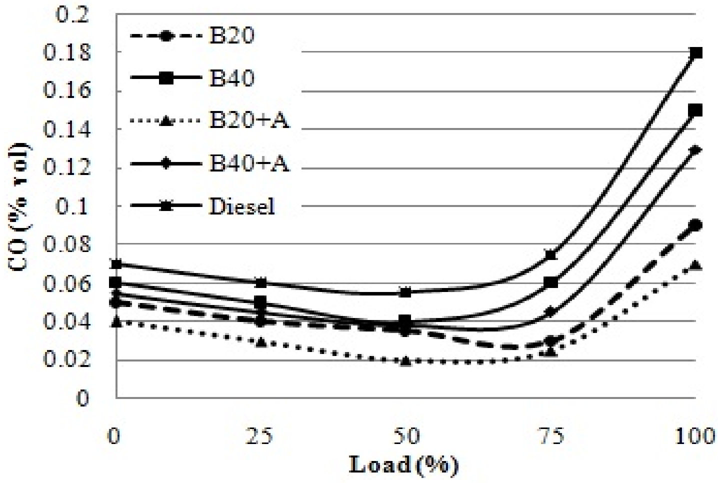

Fig. 11. Effect of additives on CO.

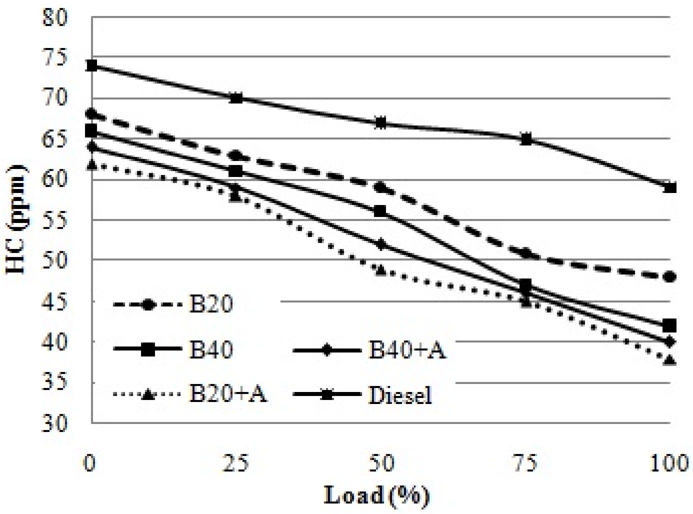

Fig. 12. Effect of additives on HC.

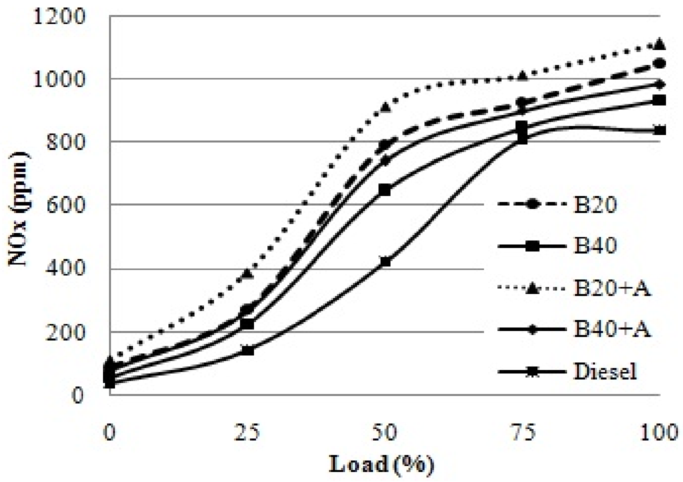

Fig. 13. Effect of additives on NO_x.

5. CONCLUSION

The experimental investigation was performed on a single cylinder, 4 stroke, variable compression ratio diesel engine, to compare and evaluate the performance and exhaust emissions characteristics of Calophyllum Inophyllum methyl ester-diesel blends with dimethyl carbonate additive (B20, B40, B20+A and B40+A). The tests were conducted for the above fuels at different compression ratios, by varying the load from no load to maximum load at a constant speed of 1500 rpm. The performance parameters such as BSFC, BTE and EGT were calculated, and emissions, CO, HC and NOx were measured for each test. The following conclusions have been drawn:

- The additives (DMC) added with biodiesel blend (B20) possesses rich amount of oxygen content compared with diesel fuel, and enhances its performance.
- At low load condition, the BSFC increased significantly for the CIME blend with additive mixture (B20+A) and the mean rise in BSFC decreased much better at maximum load and par with diesel. This may be caused due to its lower heating value and higher density.
- The rise in BSFC was minimum for B20+A at a higher compression ratio (CR18).
- The mean rise in BSFC for the B20+A blend is about 1.3% than for B20.
- The brake thermal efficiency of blend B20+A improved at an average of 4.7% due to good mixture formation and better combustion.
- The exhaust gas temperature reduced for all CIME blends compared to diesel for all the load conditions due to better combustion.
- For higher blend percentages with 10% DMC additive blends, EGT again showed a decreasing trend, and B20+A achieved the lowest exhaust gas temperature among all the blends.
- The HC emissions of B20+A are lower by 35.5% while compared with diesel.
- The CO emissions of B20+A are reduced by 47% compared with diesel.
- Reductions in the CO and HC emissions are mainly due to the lean effect of the mixture and the presence of oxygenates in the CIME-diesel blend.
- Since the formation of NO_x is highly dependent on temperature, it is always at a higher state when compared with diesel and other blends.
- The presence of oxygenates in CIME-diesel blends raises the NO_x emission by 32.5%, 24.9%, 17.6%, and 11% for B20+A, B20, B40+A, and B40 respectively, than for diesel.

The overall performance and emission characteristics of a diesel engine fueled with Calophyllum Inophyllum methyl ester and di-methyl carbonate additive were improved. However, this fuel mixture may be considered as a promising biodiesel-diesel blend with DMC additives, in the aforesaid operating conditions.

NOMENCLATURE

BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
EGT	Exhaust Gas Temperature
DMC	Di-methyl Carbonate
CIO	Calophyllum Inophyllum Oil
CIME	Calophyllum Inophyllum Methyl Esters
CO	Carbon Monoxide
UBHC	Unburned Hydro Carbons (HC)
NO_x	Oxides of Nitrogen
A	Additives
B20	20% CIME – 80% diesel blend
B40	40% CIME – 60% diesel blend
B20+A	20% CIME – 70% diesel – 10% additive
B40+A	40% CIME – 50% diesel – 10% additive

REFERENCES

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

[2] Song K.H., Nag P., Litzinger T.A. and Haworth D.C., 2003. Effects of oxygenated additives on aromatic species in fuel-rich, premixed ethane combustion: a modeling study. *Combustion and Flame* 135: 341-349.

[3] Guarieiro L.N.N., de Almeida Guerreiro E.T., dos Santos Amparo K.K., Manera V.B.N., Regis A.C.D., Santos A.G., Ferreira V.P., Leao D.J., Torres E.A. and de Andrade J.B., 2014. Assessment of the use of oxygenated fuels on emissions and performance of a diesel engine. *Microchemical Journal* 117: 94–99.

[4] Imtenan S., Masjuki H.H., Kalam V.M., Arbab M.A., Sajjad M.I.H. and Ashrafur Rahman S.M., 2014. Impact of oxygenated additives to palm and jatropha biodiesel blends in the context of performance and emissions characteristics of a light-duty diesel engine. *Energy Conversion and Management* 83: 149–158.

[5] Rizwanul Fattah I.M., Masjuki H.H., Kalam M.A., Wakil M.A., Rashedul H.K. and Abedin M.J., 2014. Performance and emission characteristics of a CI engine fueled with Cocos nucifera and Jatropha curcas B20 blends accompanying antioxidants. *Industrial Crops and Products* 57: 132–140.

[6] Varatharajan. K., Cheralathan M. and Velraj R., 2011. Mitigation of NOx emissions from a jatropha biodiesel fuelled DI diesel engine using antioxidant additives. *Fuel* 90: 2721–2725.

[7] Cheung C.S., Zhu R. and Huang Z., 2011. Investigation on the gaseous and particulate emissions of a compression ignition engine fueled

with diesel – dimethyl carbonate blends. *Science of the Total Environment* 409: 523–529.

[8] Daniel K. and A.L. Thomas. 2000. Effects of dimethoxymethane and dimethyl carbonate on soot production in an optically-accessible DI diesel engine. *SAE paper*. doi:10.4271/2000-01-2795.

[9] Kitagawa H., Murayama T., Tosaka S. and Fujiwara Y., 2001. The effects of oxygenated fuel additive on the reduction of diesel exhaust particulates. *SAE paper:* 2001-01-2020.

[10] Venkaaaateswara Rao P. and B.V. Appa Rao Radhakrishna. 2012. Experimental analysis of DI diesel engine performance with blend fuels of oxygenated additive and COME biodiesel. *Iranica Journal of Energy and Environment* 3(2): 109 – 117.

[11] Shahabuddin M., Masjuki H.H., Kalam M.A. Mofijur M., Hazrat M.A. and Liaquat A.M., 2012. Effect of additive on performance of C.I. engine fuelled with biodiesel. *Energy Procedia* 14: 1624 – 1629.

[12] Song K.H., Nag P., Litzinger T.A. and Haworth D.C., 2003. Effects of oxygenated additives on aromatic species in fuel-rich, premixed ethane combustion: a modeling study, *Combustion and Flame* 135: 341–349.

[13] Sivalakshmi S. and T. Balusamy. 2012. Effects of dimethylcarbonate-biodiesel blends on the combustion, performance and exhaust emissions of a DI diesel engine, *SAE Technical Paper*: 2012-01-0870, 2012, doi:10.4271/2012-01-0870.

[14] Tüccar G., Tosun E., Özgür T. and Aydın K., 2014. Diesel engine emissions and performance from blends of citrus sinensis biodiesel and diesel fuel. *Fuel* 132: 7–11[5].

[15] Heywood J.B., 1988. Pollutant Formation and Control. Chapter in *Internal Combustion Engine Fundamentals*, Singapore: McGraw Hill, pp. 601-608.

[16] Savariraj S., Ganapathy T., and Saravanan C.G., 2012. Performance and emission characteristics of diesel engine using high-viscous vegetable oil. *International Journal of Ambient Energy* 33(4): 193 – 203.