Influence of Additives on the Combustion, Emission and Performance Characteristics of a Twin Cylinder CIDI Engine using Biodiesel-diesel blend as fuel

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Abstract – *This study investigates the effect of di-ethylene glycol (DEG) and di-methyl carbonate (DMC) as additive on the performance, emission and combustion characteristics of a Twin Cylinder Compression Ignition DI Engine fuelled with Biodiesel blend as fuel. In this study biodiesel diesel blend of B40 is used as fuel. Di-ethylene Glycol (DEG) and di-methyl Carbonate (DMC) were used as additives in two proportions such as 5 percent and 10 percent by volume of the blend fuel. The results revealed that BSEC reduced with increase in load and also revealed that as percentage of additive increases, the BSEC increased and BTE reduced for DEG added fuels while the reverse trend was witnessed for DMC added blend fuels. The CO and HC emissions were slightly higher on the addition of DEG with the blend fuel whereas the above emissions were low for DMC added fuels. The NO_x emission was increased for DMC added fuels compared with DEG added fuels at all the loads and on increasing the percentage of additives in the blends.*

Keywords: CIDI engine, B40, Di-ethylene Glycol, Di-methyl Carbonate

I. Introduction

The latest emission regulations and the fast depleting of fossil fuel reserves force us to look for alternative fuels which are preferably renewable and also emit low levels of gaseous and particulate pollutants in internal combustion engines. Fuels like vegetable oils, alcohols, natural gas, biogas, hydrogen and liquefied petroleum gas (LPG), etc. were being investigated by researchers for engine applications. Non-edible vegetable oils are easily available in rural areas, are renewable and have a reasonably high cetane number to be used in CI engines with simple modifications. These oils can be easily blended with diesel in the neat and esterified (biodiesel) forms. Neat oils on long run usage resulted in injector coking, deposition of unburned hydrocarbon particles in the crevice regions, cold start problems. Therefore, these oils were modified as biodiesel after subjected to trans-esterification process. Azam et al[1] reported that among the fatty acid profiles of seed oils of 75 plant species having 30% or more fixed oil in their seed / kernel examined, fatty acid methyl esters of oils of 26 species including Azadirachta Indica, Calophyllum inophyllum, Jatropha Carcus and Pongamia Pinnatta were found most suitable for use as Biodiesel and they meet the major specifications of biodiesel standards of USA, Germany and European Standard Organizations. Srivastava et al[2] examined the performance and emission characteristics of the karanja oil methyl ester and stated that the BTE slightly less than that of diesel while BSEC is higher than that of diesel. The CO, HC and NO_x emission of methyl ester and its blends are also higher than those of diesel and concluded that as all properties of methyl ester of karanja oil is closer to diesel, it can be used as alternative renewable sources of energy. Sureshkumar et al[3] reported that the blends of Pongamia pinnatta methyl ester with diesel up to 40 % by volume could replace diesel for running the diesel engine for getting less emissions without sacrificing power output. Rao et al[4] reported that Multi-DM-32 additive can be used as additive to a biodiesel blend which reduces the surface tension between two or more interacting immiscible liquids helping the fuel flow better through the injector and better atomization of the fuel and improved the combustion and performance of the engine at all variable loads. Nabi and Chowdhury[5] had conducted experiments to study the effect of Diethylene Glycol Dimethyl Ether (DGM, also referred as Diglyme) as additive to diesel fuel and reported that there were significant improvements in BSEC, THC, NOx, CO, engine noise and ignition lag. Di et al[6] investigated a diesel engine fuelled with ultralow-sulfur diesel (ULSD) fuel blended with Diglyme and reported that the smoke opacity, particulate mass concentration, brake specific particulate emission and geometric mean diameter of the particles were reduced with the increase of DGM. Wang et al[7] reported that the Di – Methyl Ether (DME) engine with EGR simultaneously reduced smoke and NOx emissions. Smoke and CO reduced and NOx increased with DMC addition. Serdari et al[8] studied the impact of using biodiesels of different origin and additives on the performance of a stationary diesel engine and reported that the biodiesels decreased particulate matter emissions and resulted in a limited change of nitrogen oxide emissions and slightly increased the volumetric fuel consumption. Zannis TC et al[9] investigated the effect of oxygenated additive content of DI diesel engine on its performance and emissions and reported that Diglyme and Diethylene Glycol Di-butyl ether (Butyl-Diglyme) indicated a superior behavior compared to Rapeseed Methyl Ester (RME) however the BSFC and NOx emissions had worsened. Ramadhas et al[10] investigated the effect of diethyl ether as additive in a biodieselled engine and reported that lower percentage addition of diethyl ether with biodiesel improved the engine performance and emission characteristics. Ren et al[11] investigated the effect of addition of Diglyme in diesel fuel on combustion and emissions in a CI engine and concluded that under the high engine load, smoke decreased by 3.7% for a 1 wt % increase of the oxygen mass fraction in the blends. And it was stated that the NOx concentration slightly decreased or remain unchanged with the increase of oxygen mass fraction in the blends. From the literatures it was found that Di-Ethylene Glycol was not being used as additive in a biodiesel fuelled engine though it had the similar characteristics of Diglyme. Hence this paper is aimed at exploring the effect of Di-Ethylene Glycol (DEG) as additive on the combustion, emission and performance characteristics of a twin cylinder CIDI engine fuelled with biodiesel blend and then the results were compared with the characteristics of the engine utilizing Di-Methyl Carbonate (DMC) as additive.

II. Experimental Setup and Test Procedure

The experiments were conducted in the twin cylinder water cooled diesel engine coupled with the alternator. The alternator was loaded by the three water heaters each of 2.5 kW capacity. The engine was always operated at its rated speed of 1500 rpm. The specification of the test engine is given in Table. 1.

TABLE 1: TEST ENGINE SPECIFICATION

Parameters	Specification
Make	Rocket Engineering Corporation, Kohlapur, Maharashtra
No. of cylinders	2
Rated Power	7.5 kW @ 1500 rpm
Cylinder size	80 mm Bore & 110 mm Stroke
Compression ratio	17.5
Dynamometer	Alternator with water heaters
Injection timing	24°CA BTDC
Injection Pressure	200 bar

The fuel used for the experiments was a biodiesel blend of B40 in which 40% by volume of the biodiesel is mixed with 60% by volume of the diesel. The biodiesel was extracted from pongamia seeds by a single alkali trans-esterification process. The properties of biodiesel were tested according to ASTM standards and are listed with that of diesel for comparison in Table. 2.

TABLE 2: PROPERTIES OF BLENDED FUEL AND DIESEL

Parameters	Diesel	B40
Kinematic viscosity @ 40°C (cSt)	2.6	3.85
Cetane No.	50	51
Iodine Value	NA	41
Calorific Value (MJ/kg)	42.5	40.1
Specific Gravity @ 15° C	0.835	0.85 9
Flash point °C	68	81

Initially tests were performed by using a blend of B40 as fuel at 0%, 40%, 60%, 80% and 100% loads. The parameters such as time for 40cc of fuel flow, engine speed, air flow, ammeter and volt meter readings, cooling water flow temperatures and exhaust gas temperature were noted at each load once the engine attained steady state. Then the tests were repeated for fuels of B40 added with 5% by volume and 10 % by volume of the additives. The above parameters were too noted for these tests. Also during the tests the emissions such as CO, HC, smoke opacity and NO_x were recorded from the AVL 5 gas analyzer and AVL Smoke meter. The combustion parameters such as peak pressure, ignition lag, combustion duration and maximum heat release rate were also recorded for all experiments. The in-cylinder pressure was measured using Kistler pressure sensor and the position of piston by TDC marker. The experimental setup is shown in Figure 1.

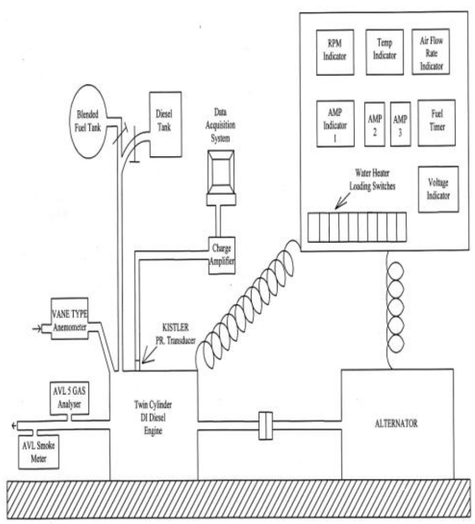

Figure 1. Experimental setup

The properties of the additives used for this work is given in Table 3.

TABLE 3: PROPERTIES OF ADDITIVES

Properties	Di-Ethylene Glycol (DEG)	Di-Methyl Carbonate (DMC)	Diglyme
Physical state & appearance	Clear colorless liquid	Clear colorless liquid	Colorless liquid
Odor	Odorless	Pleasant	-
Molecular Weight (grams/mole)	106.14	90.08	134.17
Boiling point	244 - 245°C	80/90°C	162°C
Melting point	-65°C	2°C	-64°C
Specific gravity @ 20°C	1.118	1.069	0.9451
Vapor pressure	1 mm Hg @ 91.8°C	5.6 kPa @ 20°C	-
Vapor density	3.66	3.1	4.62
Flash point (closed cup)	124°C	18°C	57°C
Auto-ignition Temperature	229°C	220°C	170°C

III. Results and Discussion

The experiments were conducted in the Twin cylinder CIDI engine with the following fuels: B40, B40 + 5% of additive and B40 + 10% of additives. The additives used for the study were Di-Ethylene Glycol (DEG) and Di-Methyl Carbonate (DMC). The results were obtained as given below:

A. Effect of additives on performance:

Figure 2 depicts the influence of additives on the Brake Specific Energy Consumption (BSEC) of the engine.

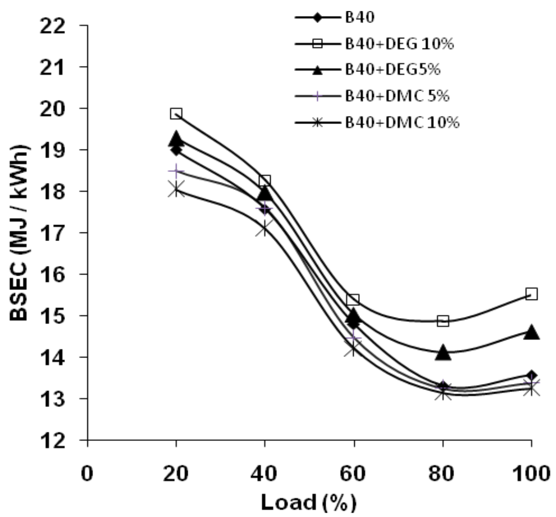

Figure 2. BSEC vs load

It was observed that the BSEC reduced as the load increased for all fuels. The BSEC was found to be higher for DEG additives and lower for DMC additives. Also it was revealed that BSEC increased as the percentage of additive increased. The BSEC increased by 5.6% and 6.07% for the blended fuels B40DEG5 and B40DEG10 respectively whereas it reduced by 0.45% and 1.25% for the blended fuels of B40DMC5 and B40DMC10 respectively. Figure 3 shows the variation of BTE with increase in load.

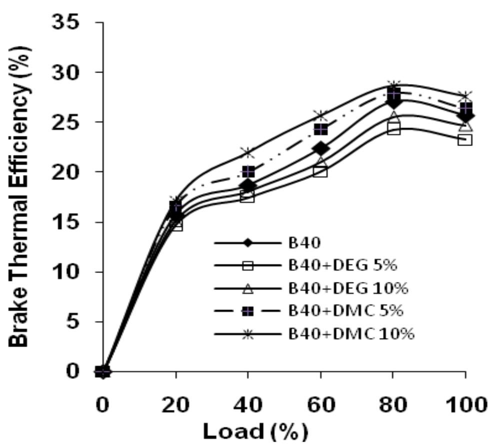

Figure 3. BTE vs load

It is observed from the Figure 3 that the Brake Thermal Efficiency (BTE) was low for DEG additives and high for DMC additives. Also we note that BTE enhanced with the percentage of additive in the blend was more because of better combustion. The BTE reduced by 5.73% and 10.46% for the blended fuels B40DEG5 and B40DEG10 respectively whereas it increased by 2.99% and 5.92% for the blended fuels of B40DMC5 and B40DMC10 respectively. The reason for the above results was relatively higher flash point of the DEG than DMC.

B. Effect of additives on emissions:

Figure 4 shows the variation of CO emission against load for all fuel categories.

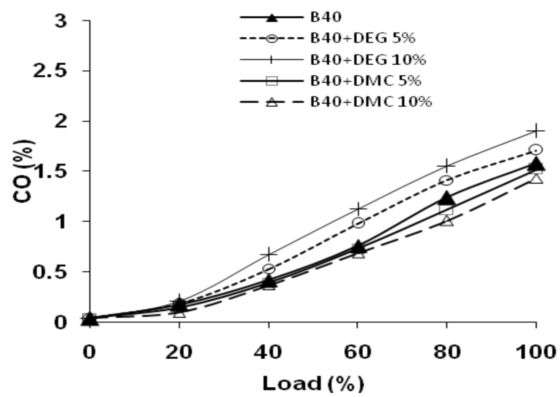

Figure 4. CO emission vs load

It is noticed that the CO emission increases as the load increases. The CO emission was high for DEG added fuels while it was low for DMC added fuels. The CO emission increased by 13.7% and 25% for % for the blended fuels B40DEG5 and B40DEG10 respectively whereas it reduced by 9.67% and 14.95% for the blended fuels of B40DMC5 and B40DMC10 respectively. The CO emission was increasing as the percentage of DEG increase in the fuel whereas the CO emission reduced as the percentage of DMC increase in the fuel. The effect of additives on HC emissions are given in Figure 5.

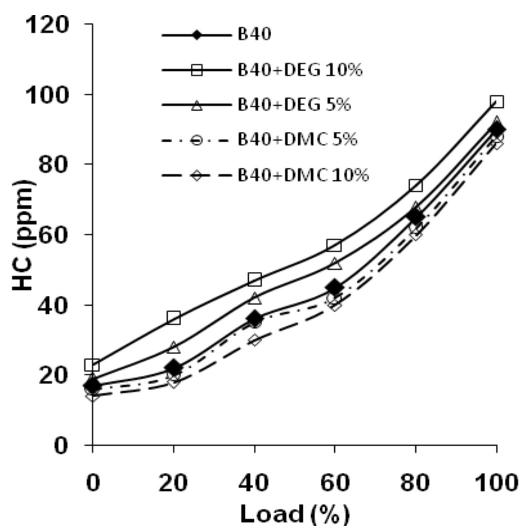

Figure 5. HC emission vs load

It was observed that similar trend as that of CO was noticed for HC emissions too. The HC emission increased by 4.61% and 13.84% for the blended fuels B40DEG5 and B40DEG10 respectively whereas it reduced by 4.61% and 8.33% for the blended fuels of B40DMC5 and B40DMC10 respectively. Figure 6 illustrates the effect of additives on NO_x emission for all fuels.

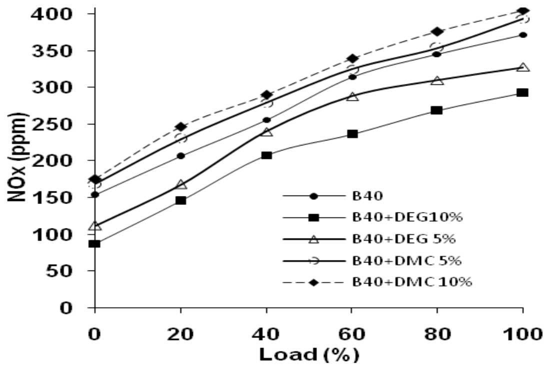

Figure 6. NOx emission vs load

It was found that NO_x emission increases as the load on the engine increases. The NO_x emission was found to be low for DEG added fuels while it was high for DMC added fuels. The NO_x emission reduced by 10.11% and 22.32% for the blended fuels B40DEG5 and B40DEG10 respectively whereas it rose by 2.6% and 8.98% for the blended fuels of B40DMC5 and B40DMC10 respectively. At lower loads no much variation in the emissions were noticed whereas at higher loads the variation is significant. Higher flash point, Boiling point and vapor density of the DEG and relatively lower flash and boiling point and vapor density of DMC would have caused the above results.

C. Effect of additives on Combustion characteristics:

The figures 7, 8, 9 and 10 represent the ignition delay, combustion duration, peak heat release rate, and peak pressure respectively.

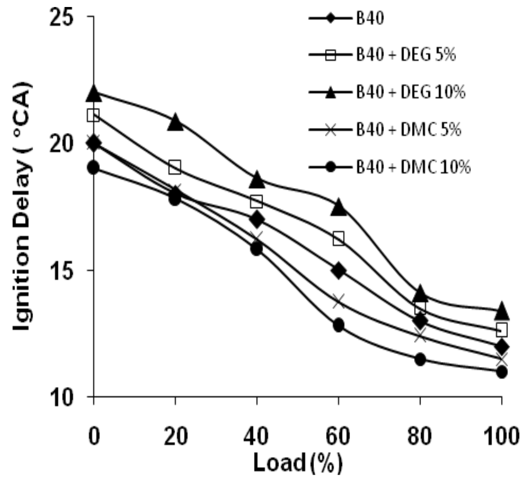

Figure 7. Ignition delay vs load

Figure 7 represents the effect of additives on Ignition delay. It is evident from the figure 7 that the ignition delay comes down as the load on the engine increases. Also it is noticed that the ignition delay was longer for DEG added fuels while shorter for DMC added fuels. Further, the ignition delay period was increasing as the percentage of DEG enhances and shortened as the DMC in the blend increases.

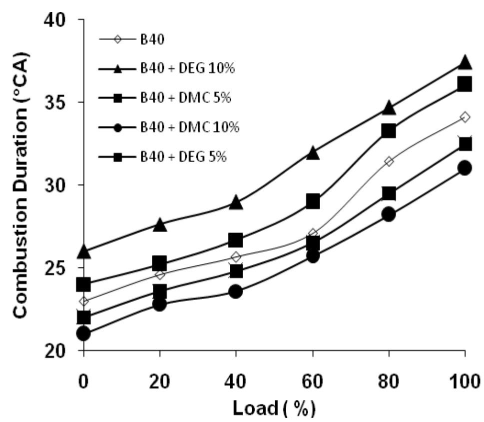

Figure 8 Combustion duration vs load

It was learnt from figure 8 that the combustion duration increased significantly for DEG added fuels while reduced for DMC added fuels. With the addition of DMC and DEG in the fuels, the premixed (kinetic) combustion phase is prolonged, while mixing controlled combustion phase is shortened.

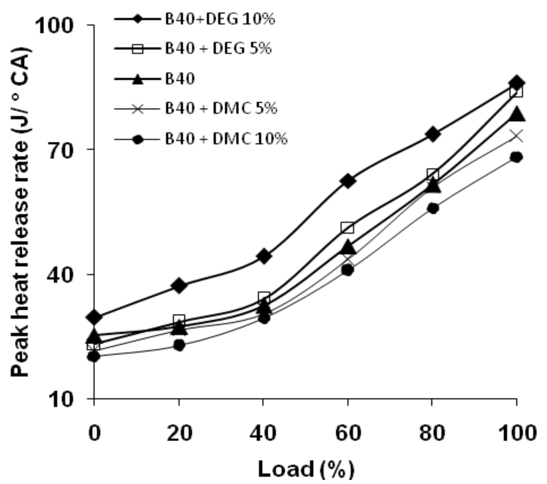

Figure 9 Peak heat release rate vs load

Figure 9 exhibits the peak heat release rate against all loads for different fuel combinations. It is seen that the peak heat release rate increases as the percentage of DEG in the fuel increases while it diminishes as the percentage of DMC in the blends enhanced.

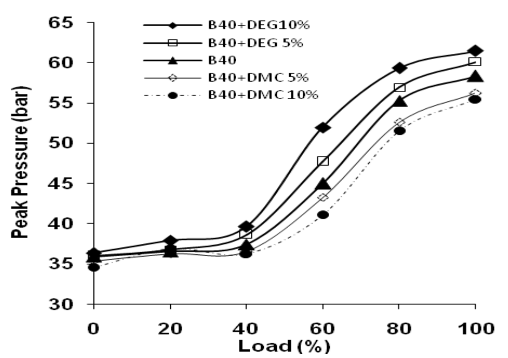

Figure 10 Peak pressure vs load

From figure 10, we learnt that the peak pressure was higher for DEG added fuels than DMC added fuels. The above result was attributed to the fact of high vapor density, low flash point and low boiling point of the DMC than the DEG.

IV. Conclusion

As only diglyme and other additives were tried to study the performance and emission characteristics of the engine so far, An attempt has been made using Diethylene Glycol as additive with the biodiesel blended fuel. The following conclusion was arrived on conducting experiments in the twin cylinder CIDI engine fuelled with bio-diesel blend of B40 with and without additives. The BSEC, CO and HC emissions were found higher for DEG added fuels than for DMC added fuel blends. The BTE and NO_x emission were found low for DEG mixed fuels and high for DMC mixed fuels. Further, as the percentage of DMC mixed in the blend increases the BTE and NOx emission increased and BSEC, CO and HC emissions diminished while the reverse trend was observed when DEG percentage in the blend increased. It is concluded that DEG can be used as an additive considering the control of NO_x emission from bio-diesel fuelled engines since the NOx emission is reduced by 10.11% and 22.32% for the blended fuels B40DEG5 and B40DEG10 respectively.

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Nomenclature

Abbreviations

CIDI – Compression Ignition Direct Injection
DEG – Diethylene Glycol
DMC – Dimethyl Carbonate

BSEC – Brake Specific Energy Consumption (MJ/kWh)
BTE – Brake Thermal Efficiency (%)
CO – Carbon Monoxide (%)
HC – Hydrocarbon (ppm)
NOx – Nitrogen Oxide (ppm)
THC – Total Hydrocarbon (ppm)
ULSD – Ultra Low Sulfur Diesel
DGM – Dietylene Glycol Dimethyl Ether
EGR – Exhaust Gas Recirculation
RME – Rapeseed Methyl Ester
rpm – revolution per minute
TDC – Top Dead Centre
B40 = Blend of 60% by volume of Diesel, 40% by volume of biodiesel
B40DEG5 = Blend of 60% by volume of Diesel, 40% by volume of biodiesel and 5% by volume of DEG
B40DEG10 = Blend of 60% by volume of Diesel, 40% by volume of biodiesel and 10% by volume of DEG
B40DMC5 = Blend of 60% by volume of Diesel, 40% by volume of biodiesel and 5% by volume of DMC
B40DMC10 = Blend of 60% by volume of Diesel, 40% by volume of biodiesel and 10% by volume of DMC
CA bTDC = Crank Angle before Top Dead Centre
ppm = parts per million