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REDUCTION OF NO_X AND OPACITY FROM DIESEL ENGINE WITH DIMETHYL CARBONATE AND ISOPROPYL ALCOHOL

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ABSTRACT

The major problem with the diesel engines is the presence of particulate matter that is present in the exhaust emission. The addition of oxygenated additives into fuel oil is one of the possible approaches for reducing this problem. This work aims at to reduce the exhaust emission from the diesel engines using two fuel additives: Dimethyl Carbonate ($C_3H_6O_3$) and Isopropyl Alcohol (C_3H_8O) blends with diesel fuel in the concentration of 5%, 10%, and 15% by volume. The result showed that by using these fuel additives the percentage of opacity and carbon monoxide in the engine exhaust was reduced. Oxides of nitrogen slightly increased during the part load conditions.

Keywords: Additives, Diesel Engine, Dimethyl Carbonate, Isopropyl Alcohol, Emission Control

INTRODUCTION

Internal combustion engines generate undesirable emissions during the combustion process. The main pollutant from the automobile is Carbon Monoxide (CO), Unburnt Hydrocarbons (HC), Oxides of Nitrogen (NO_X), Lead and Particular Emissions (PM).[1,2] Additives are chemicals that are added in relatively small quantities either to enhance fuel performance and or to correct the deficiency. The selection of additives depends on the base fuels in which they are blended. Mainly consists of a single chemical compound or more compounds. A wide range of fuel additives is available.

Oxygenated fuel is nothing more than fuel that has a chemical compound containing oxygen. It is used to help fuel burn more efficiently and cut down on some types of atmospheric pollution. In many cases, it is credited with reducing the smog problem in major urban centers. DMC to be a suitable oxygenated additive with good blend fuel properties, which reduced smoke almost linearly with its concentration, which is directly related to the oxygen content of the fuel. With 10% of DMC contained in the fuel, a smoke reduction of 35-50% was attainable, and also, apparent reductions of HC and CO densities were attained with NOx emissions increasing slightly.[3] The effect of adding fuel-borne oxygen in the form of dimethyl carbonate (DMC) has been reported in (a non-toxic potentially bioderived 53.3% wt oxygenated additive) conventional pump diesel.[4] It was found that nitrogen oxides (NOx) increased and that THCs, CO, and PM were reduced by up to 50% with a 96% diesel, 4% DMC blend. Interestingly 2% DMC in diesel can generate comparable particulate, THCs and CO emissions to RME combustion, at just 1.1% wt oxygen. A DMC blend may also have potential in the reduction of unregulated emissions such as benzene and 1,3-butadiene. It was reported that DMC may be a promising additive for diesel fuel owing to its high oxygen content, no carbon-carbon atomic bonds, suitable boiling point, and solubility in diesel fuel.[5]

The study of combustion, performance, and emissions for a DI diesel engine fuelled with Dimethoxymethane blends[6] showed that brake specific fuel consumption is higher and thermal efficiency increases slightly. Smoke and CO emission decrease and NOx remains almost changed. The performance and emission characteristics of two oxygenate 2-Ethoxy ethyl acetate and 2-Butoxy ethanol with three different blends have been experimentally concluded.[7,8] They observed that a considerable reduction of

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smoke carbon monoxide and hydrocarbon is obtained and nitrogen oxide emissions are increased when the oxygen content is increased from 5% to 15%.

It was also studied and concluded that different blends of low- sulfur diesel fuel with different types of oxygenate. The results confirm the importance of oxygen mass fraction of the fuel blend, but at the same time illustrate the effect of chemical structure.[9,10] The effect of fuel oxygen has been reported on diesel emissions and performance[11,12]. Blended ethanol and biodiesel to diesel fuel show that the brake specific fuel consumption, NOx and CO emissions were increased and HC emissions were reduced. Much work not reported in the literature, comparing dimethyl carbonate and isopropyl alcohol additives added in diesel. In this research work, the engine performance has been studied using 5%, 10% and 15% of additives mixed with diesel.

EXPERIMENTAL

Dimethyl Carbonate

DMC is a combustible, innocuous, odorless liquid; its molecular formula is CHO_3OCH_3, or $C_3H_6O_3$, which is composed of C-H and C-O bonds without of C-C as shown in Fig.-1. The oxygen content is up to 53.3 wt%, which is usually used as an oxygenated additive to blend with diesel fuel to improve combustion and reduce emissions of diesel engines as shown in Table-1. The addition of DMC to fuels to reduce engine emissions without engine modification seems to be more attractive.

Isopropyl Alcohol

Isopropyl alcohol is another promising oxygenated fuel additive with the oxygen content of 35wt%. The low heating value isopropyl alcohol is 30.4MJ/kg, which is higher than that of DMC as shown in Table-1. The boiling point is 80.70C, and is near to that of diesel. Therefore, it can improve the properties of diesel engines that DMC in blends is partly replaced by Isopropyl alcohol. The chemical structure as shown in Fig.-2.

Table -1: Fuel Properties of DMC, IPA and Diesel

Property	DMC	IPA	Diesel
Molecular formula	$C_3H_6O_3$	$C_4H_8O_3$	C_xH_y
Cetane number	35-36	13	40-55
Low heating value (MJ/kg)	15.78	30.4	42.5
Density (kg/m^3)	875	803.4	840
Boiling point	90-91	80.7	180-360
Oxygen content (wt %)	53.3	35	0

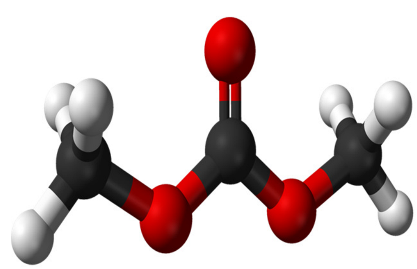

Fig.- 1: Chemical Structure Dimethyl Carbonate ($OC(OCH_3)_2$)

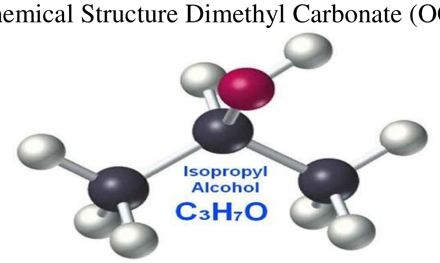

Fig.- 2: Chemical Structure Isopropyl Alcohol (C_3H_7O)

A vertical, water cooled, single cylinder, four strokes direct injection diesel engine was used for this work. The engine was coupled to an eddy current dynamometer for power measurement. AVL 415 variable sampling smoke meter was used to measure the particulate matter in the exhaust. AVL Digas 444 Exhaust Gas Analyzer was used to measure HC, CO and NOx emissions. AVL 615 Indimeter system was used to get pressure crank angle diagram at various loads using AVL GH12D piezoelectric pressure transducer and AVL 364 angle encoder and to process the same for getting various parameters such as heat release rate curve, peak pressure etc. All the AVL equipment were supplied by AVL INDIA, Chennai (India). Experiments were carried out in four different phases. In the first phase bases reading were obtained using neat diesel. In the other three phases, the engine performance was studied using 5%, 10% and 15% of additives mixed with diesel. The engine specifications are given below.
To begin with, the different blends were prepared and the blends containing 5, 10, and 15 percent DMC fuel by volume were denoted as DMC5 (D95), DMC10 (D90), and DMC15 (D85) respectively. Similarly, IPA5, IPA10, and IPA15 were denoted. The engine tests were performed using the pure diesel fuel as a base without any blending covering all engine loads to determine the engine operating characteristics and pollutant emissions to set a base line. Then the readings were recorded at the same operating conditions with the engine fuelled with different blends prepared in the beginning. In the last, the graphs were plotted to analyze the effect of the blends on the emission of the engine.

RESULTS AND DISCUSSION

Performance analysis of dimethyl carbonate additive (ADMC)

Hydrocarbon emissions (HC)

Figure-3 shows that the variation of HC emissions in ppm with a load in % for diesel, diesel with DMCS5%, diesel with DMCS10%, diesel with DMCS15%. It can be seen that with an increase in load, HC emissions increase for all the tested models, and there has been a considerable increase in HC emissions for the entire additives mode than the baseline diesel values. A significant increase in HC emissions is noticed for DMCS 15% additive mode. For diesel, the HC emissions vary from 5 ppm at no load to 36 ppm at full load. For 5% ADMCS, 15% ADMCS, 20% ADMCS the variations are from 17 to 42 ppm, 22 ppm to 56 ppm, and 22 ppm to 77 ppm, respectively. At full load, the Unburnt Hydrocarbon of various modes tested varies from 36 ppm to 77 ppm.

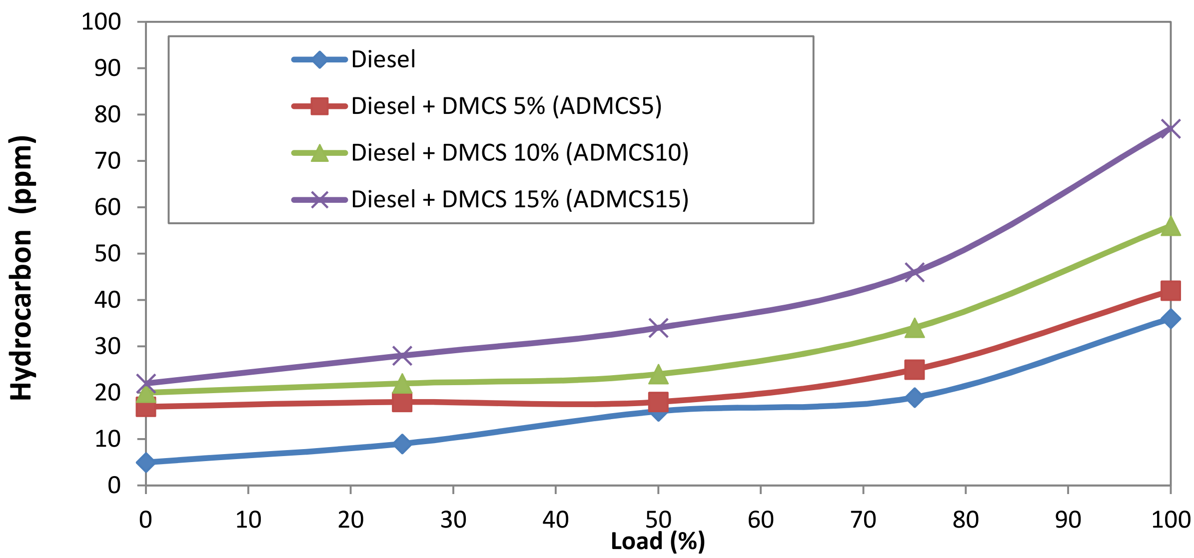

Fig.-3: Variation of Hydrocarbon Emission Vs Load

Carbon monoxide emission

Figure 4 shows that the variation of CO_2 emissions in ppm with a load in % for diesel, diesel with DMCS5%, diesel with DMCS10%, diesel with DMCS15%. It can be seen that with an increase in load, CO emissions increase for all the tested models, and there has been a considerable decrease in CO emissions for the entire additives mode than the baseline diesel values except diesel with DMCS 15% mode. A significant increase in CO emissions is noticed for DMCS 15% additive mode. For diesel, the CO emissions vary from 1.62 ppm at no load to 8.87 ppm at full load. For 5% ADMCS, 15% ADMCS, 20% ADMCS the variations are from 1.6 to 8.38 ppm, 1.61 ppm to 8.36 ppm, and 1.89 ppm to 9.3 ppm, respectively. At full load, the Carbon dioxide of various modes tested varies from 8.36 ppm to 9.3 ppm.

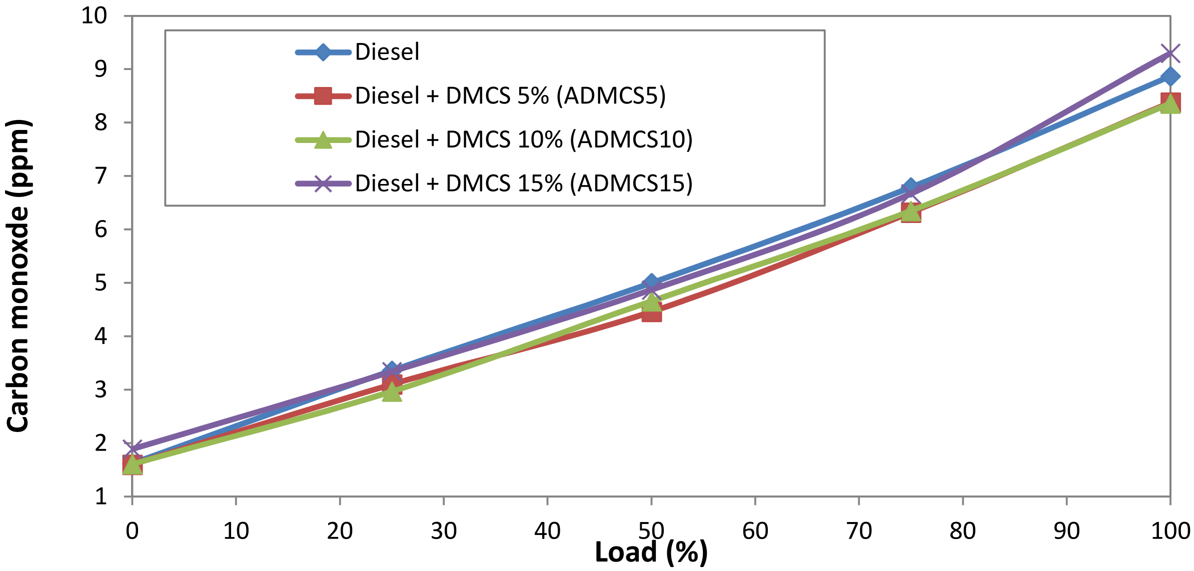

Fig.- 4: Variation of Carbon Monoxide Emission Vs Load

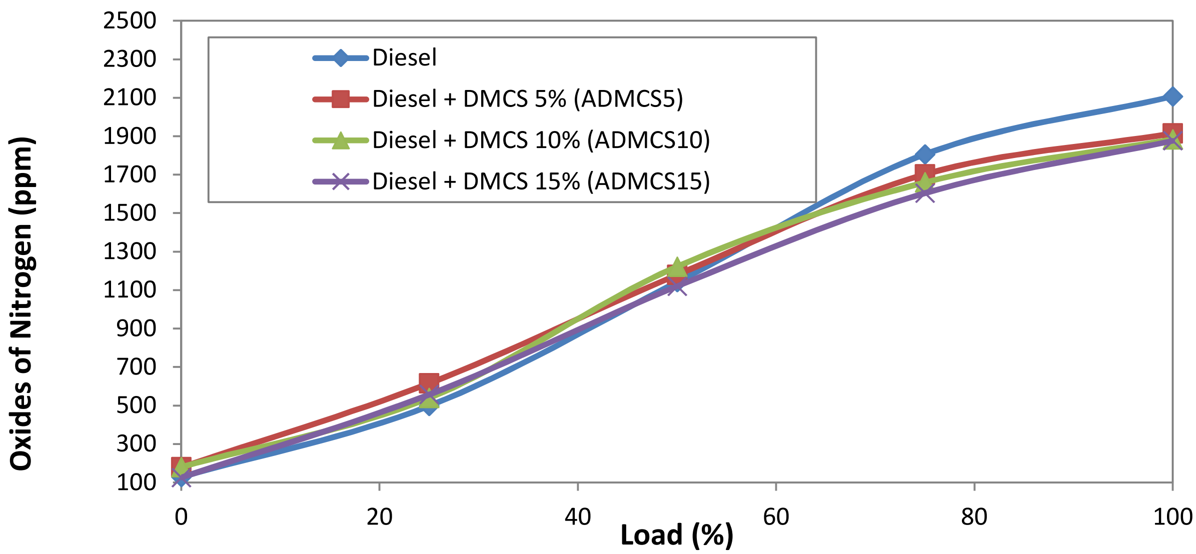

Fig.- 5: Variation of Oxides of Nitrogen Emission Vs Load

Oxides of nitrogen emission

Figure-5 shows that the variation of NOx emissions in ppm with a load in % for diesel, diesel with DMCS5%, diesel with DMCS10%, diesel with DMCS15%. It can be seen that with an increase in load, NOx emissions increase for all the tested models, and there has been a considerable decrease in NOx emissions for the entire additives mode than the baseline diesel values. A significant increase in NOx emissions is noticed for diesel mode at full load. For diesel, the NOx emissions vary from 128 ppm at no load to 2107 ppm at full load. For 5% ADMCS, 15% ADMCS, 20% ADMCS the variations are from 179 to 1915 ppm, 180 ppm to 1884 ppm, and 125 ppm to 1876 ppm, respectively. At full load, the oxides of nitrogen emission of various modes tested vary from 1876 ppm to 2107 ppm.

Opacity

Figure-6 shows that the variation of opacity with a load in % for diesel, diesel with DMCS5%, diesel with DMCS10%, diesel with DMCS15%. It can be seen that with an increase in load, opacity increases for all the tested models, and there has been a considerable decrease in opacity for the entire additives mode than the baseline diesel values other than diesel with DMCS 15% mode.

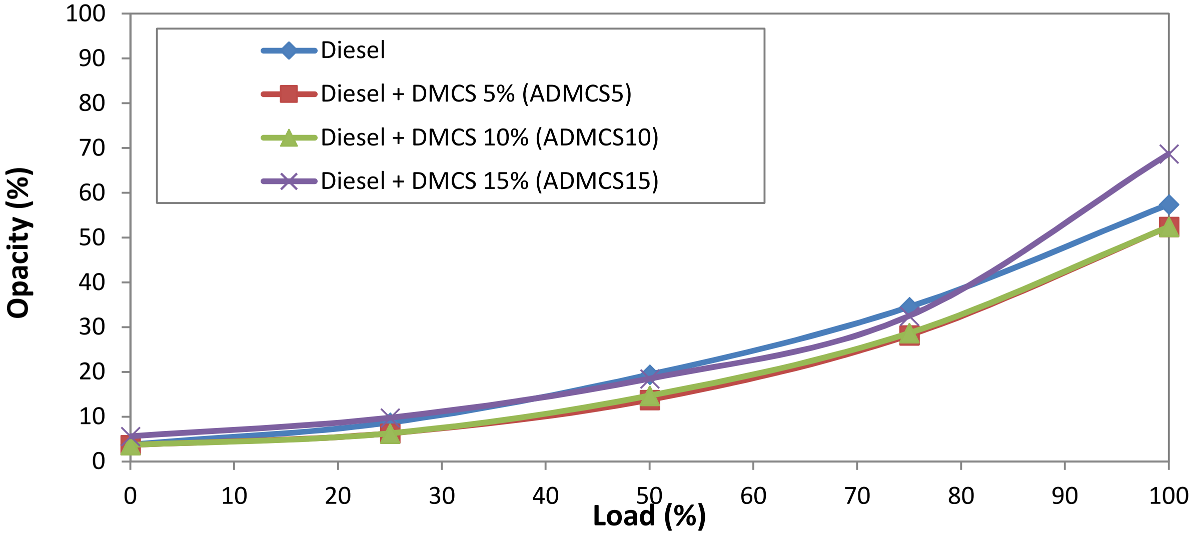

Fig.-6: Variation of Opacity Vs Load

A significant increase in opacity is noticed for with DMCS 15% mode at full load. For diesel, the opacity varies from 3.8 % at no load to 57.4 % full load. For 5% ADMCS, 15% ADMCS, 20% ADMCS the variations are from 3.7 % to 52.4 %, 3.7 % to 52.4 %, and 5.6 % to 68.7 %, respectively. At full load, the opacity of various modes tested varies from 52.4 % to 68.7 %.

Performance analysis of isopropyl alcohol (AIPA)

Hydrocarbon emissions (HC)

Figure-7 shows that the variation of HC emissions in ppm with a load in % for diesel, diesel with AIPA5%, diesel with AIPA10%, diesel with AIPA15%. It can be seen that with an increase in load, HC emissions increase for all the tested models, and there has been a considerable increase in HC emissions for the entire additives mode than the baseline diesel values. A significant increase in HC emissions is noticed for AIPA 15% additive mode. For diesel, the HC emissions vary from 5 ppm at no load to 36 ppm at full load. For 5% AIPA, 15% AIPA, 20% AIPA the variations are from 22 to 79 ppm, 43 ppm to 111 ppm, and 65 ppm to 123 ppm, respectively. At full load, the Unburnt Hydrocarbon of various modes tested varies from 36 ppm to 123 ppm.

Carbon monoxide emission

Figure-8 shows that the variation of CO emissions in ppm with a load in % for diesel, diesel with AIPA5%, diesel with AIPA10%, diesel with AIPA15%. With the increase in load, CO emissions increase for all the tested models, and there has been a considerable decrease in CO emissions for the entire additives mode than the baseline diesel values at full load. A significant decrease in CO emissions is noticed for AIPA15% additive mode at full load condition. For diesel, the CO emissions vary from 1.62 ppm at no load to 8.87 ppm at full load. For 5% AIPA, 15% AIPA, 20% AIPA the variations are from 1.87 ppm to 8.62 ppm, 1.87 ppm to 8.62ppm, and 1.82 ppm to 8.4 ppm, respectively. At full load, the carbon monoxide of various modes tested varies from 8.4 ppm to 8.87 ppm.

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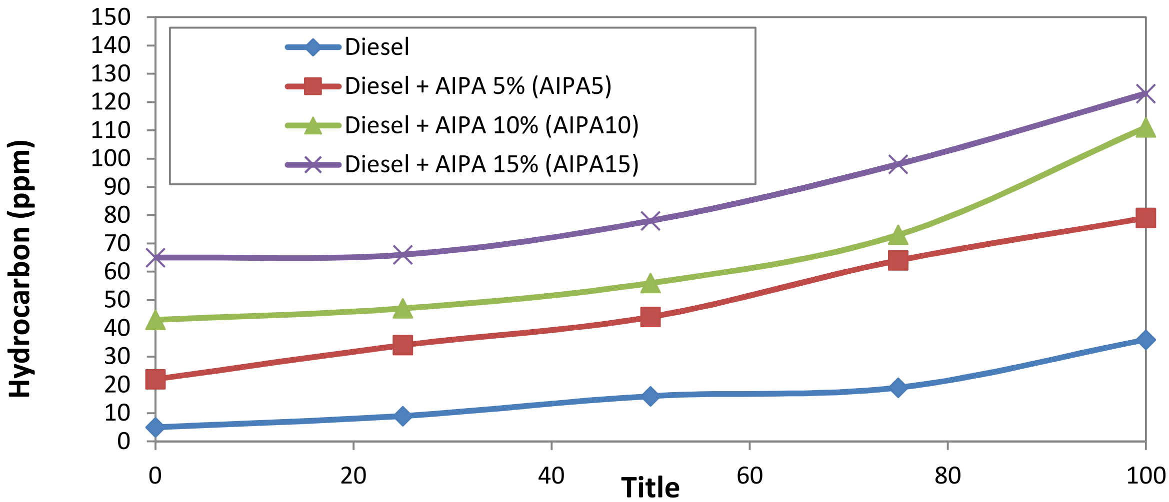

Fig.- 7: Variation of Hydrocarbon Emission Vs Load

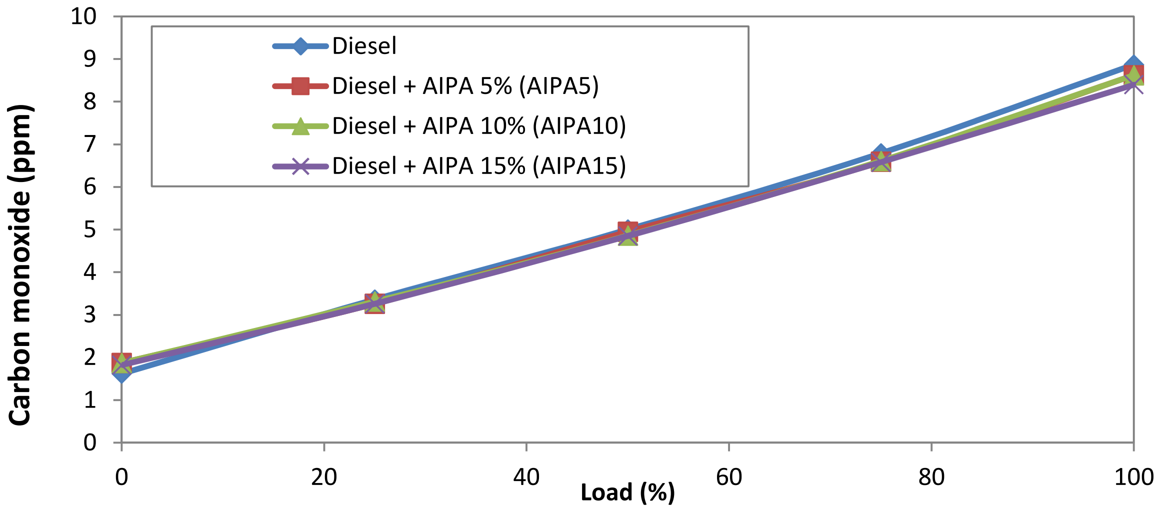

Fig.- 8: Variation of Carbon Monoxide Emission Vs Load

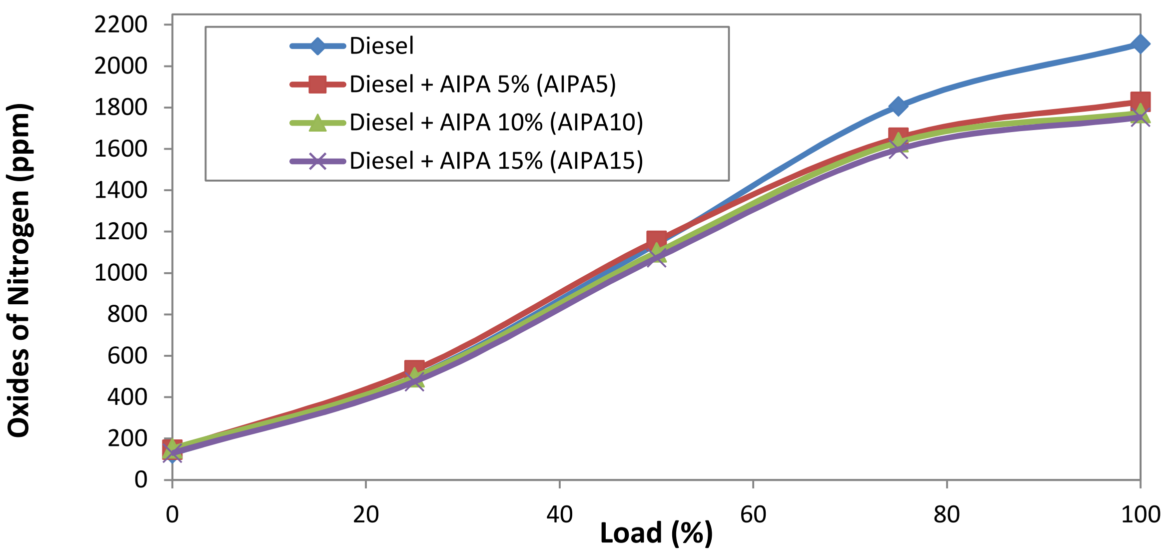

Fig.- 9: Variation of Oxides of Nitrogen Emission Vs Load

Oxides of nitrogen emission

Figure-9 shows that the variation of NOx emissions in ppm with a load in % for diesel, diesel with AIPA5%, diesel with AIPA10%, diesel with AIPA15%. Reports concluded by Chen et al also confirm this experimental work as it shows with increase in load, NOx emissions increase for all the tested models, and there has been a considerable decrease in NOx emissions for the entire additives mode than the baseline diesel values[13]. A significant increase in NOx emissions is noticed for diesel mode at full load. For diesel, the NOx emissions vary from 128 ppm at no load to 2107 ppm at full load. For 5% AIPA, 15% AIPA, 20% AIPA the variations are from 146 to 1828 ppm, 152 ppm to 1774ppm, and 130 ppm to 1753 ppm, respectively. At full load, the oxides of nitrogen emission of various modes tested vary from 1753 ppm to 2107 ppm.

Opacity

Figure-10 show that the variation of opacity with a load in % for diesel, diesel with AIPA5%, diesel with AIPA10%, diesel with AIPA15%. With the increase in load, opacity increases for all the tested models, and there has been a considerable decrease in opacity for the entire additives mode than the baseline diesel values, good agreement with literature.[14] A significant decrease in opacity is noticed for with AIPA15% mode at full load. For diesel, the opacity varies from 3.8 % at no load to 57.4 % full load. For 5% AIPA, 15% AIPA, 20% AIPA the variations are from 3.9 % to 50 %, 4.6 % to 46.7 %, and 5.3 % to 42.7 %, respectively. At full load, the opacity of various modes tested varies from 42.7 % to 57.4 %.

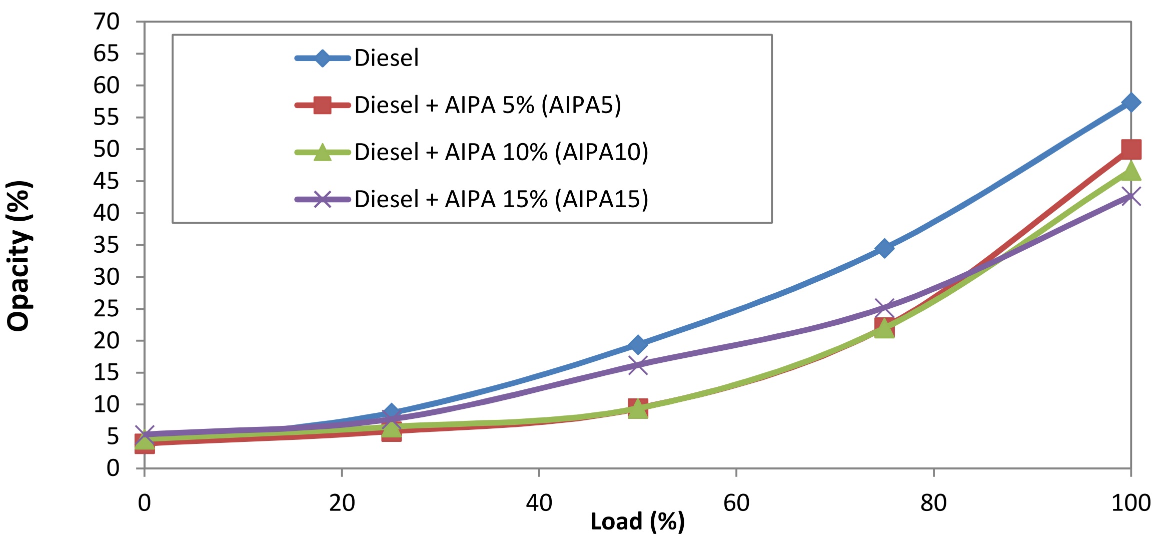

Fig.-10: Variation of Opacity Vs Load

CONCLUSION

In this work, an investigation was carried out to study the effects on exhaust emissions by IPA and DMC blends in a single cylinder direct injection diesel engine. The oxygen contents of IPA and DMC is different, and consequently, their effectiveness as diesel fuel blending agents to reduce emissions should be comparable. Their chemical structures and associated physicochemical properties are distinctly different.[15] The results obtained for constant engine speed with various engine loads can be summarized as follows:

- The effect of oxygenated additives on performance of the engine is not significant as there are marginal differences in the performance characteristics.
- Both IPA and DMC blends substantially lowers the exhaust gas opacity. The maximum reduction nearly of 25% was observed by DMC15 and IPA15 blends as compared to base reference diesel fuel.
- The oxygenated diesel fuel blends have shown a marginal reduction in CO and increase in HC emissions with a slight penalty in NOx emissions at part load, which can be controlled by exhaust gas recirculation (EGR).

- The opacity reduced with both the fuel additives. Isopropyl alcohol performs better than dimethyl carbonate.

From the above analysis, it can be concluded that oxygenated additives addition in diesel fuel in appropriate proportion will reduce the emission characteristics. If the proportion of these additives is more than engine performance declines because the additives have lower calorific value compared to diesel. Other barriers to the use of oxygenated fuel additives are their high price and poor availability.

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