EVALUATION OF ALUMINUM OXIDE NANOPARTICLE BLENDED WITH ALCOHOL BASED BIODIESEL AT VARIABLE COMPRESSION RATIOS

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SUMMARY

This paper highlights the use of aluminum oxide nanoparticles as an additive in diesel-butanol blends to show its effect on fuel consumption, emissions and performance. In the present experiment, different concentrations of aluminium oxide nanoadditives (30, 50, and 70 ppm) are used in alcohol-based biodiesel. Butanol has been used in concentrations of 5 and 10 % in diesel and therefore all blends are termed as B5 and B10 in addition to nanoparticle concentration to avoid complexity. These different blends (B5+30, B5+50, B5+70, B10+30, B10+50, B10+70) are tested for various engine loads at a constant speed of 1500 rpm. The experiment was performed on a Variable compression ratio (VCR) engine at varying compression ratios of 16, 17, and 18. Engine characteristics at different compositions of the blend at different compression ratios were provided by the interfaced computer through the software. The enhanced performance effects can be easily seen from the outcomes in the increment in brake thermal efficiency of the blends as compared to neat diesel. Considerable decrement can be observed in carbon monoxide (CO) and unburnt hydrocarbon (HC) values with an increase in compression ratio. Moderate reduction can be observed in NO_x at higher loads in contrast to neat diesel.

KEYWORDS

Biodiesel, VCR Engine, Blends, Performance, Emissions

1. INTRODUCTION

Diesel engines have continuously undergone many developments over the years in the fields of heavy-duty transportation, agriculture, electricity generation, and marine applications. The technology is upgraded over time based on engine design, fuel modification, emissions and power. A complete transformation in transportation sector from internal combustion engines to electrical vehicle is not that accessible for coming decades and will require a huge outlay (Bhatt and Shrivastava, 2022). For now it is easy to adapt sustainable and renewable energy sources in place of diesel fuel without modification in existing engine design (Demirbas, 2003; Saraswat et al., 2020). Biodiesels, alcohols and nanoadditives are viable and proven to be effective in many research works (Fayad and Dhahad, 2021; Saraswat and Chauhan, 2018). Biodiesels are good alternative fuels that also have favorable impact on emissions and are economically and environmentally admissible in all diesel engine applications (Van Gerpen, 2005). Biodiesel fuels are also nature friendly substitutes to reduce toxic emissions from marine transportation which causes air pollution across sea. Biodiesels can also be modified with nanoadditives addition and have proven results in reduction of emissions (Dubey et al., 2018; Balaji and Cheralathan, 2017). M. Channappagoudra (2019) experimented on a modified fuel by mixing 75ppm aluminum oxide nanoparticle with 20% dairy scum biodiesel (B20) and petro diesel and compared it with baseline engine run. Alumina nanoparticle blended biodiesel revealed better performance than baseline engine run with sole B20 fuel blend (Channappagoudra, 2021). M. A. Adzmi et al. (2019) evaluated characteristics of aluminum oxide and silicon oxide nanoparticles (50 and 100ppm) in palm oil methyl ester (POME) and compared it with regular POME fuel. They recorded a remarkable increase in torque and power with reduction in emissions as well. There are many latent sources for producing biodiesel which can be comprehended for higher yields (Adzmi, M.A., A. Abdullah, Z Abdullah, 2019). P. Anchupogu et al. (2018) reformulated C. inophyllum biodiesel by adding 40ppm alumina nanoparticles to study the outcomes on combustion, performance and emissions characteristics. Blend was prepared by adding 20% C. inophyllum to diesel with addition of nanoparticles (CIB20ANP40) and they concluded 5.04% increase in brake thermal efficiency (BTE) in comparison to CIB20 with a significant drop in emissions (Anchupogu et al., 2018).

Nanoparticles function as ignition catalyst furthermore augments the properties of fuel they are blended with

(Gad et al., 2021). Blending nanoparticles with fuel tend to bring down the emissions to a notable value as compared to diesel with striking balance with combustion and performance characteristics (Lv et al., 2022). Nanoparticles have also been experimented with biodiesel in marine engine applications showing their vast field of research. Marine engines are very similar to automotive engines just they are bigger in size and operate with some complex systems. C.W. Mohd Noor et. al. (2018) provided a review on use of biodiesel and its challenges in marine engines (Mohd Noor et. al., 2020). K. Nanthagopal et al. (2020) reviewed the consequences of oxygenated abilities of alcohol and nanoadditives in compression ignition (CI) engines. They analyzed many nanoparticles and stated that all the nanoparticles proclaimed preferable combustion, performance and emission properties. They concluded that for utilization of nanoadditives in commercialized applications, substantial amount of research work is still left to be done (Nanthagopal et al., 2020).Currently many researches are also attracted towards coated nanoparticles because of their distinctive structure. Carbon coating metal and alloy nanoparticles claim to perpetuate exceptional thermal properties and also preserve metal core in ambient circumstances. Q. Wu (2018) analyzed carbon coated aluminum nanoparticles (30ppm) in diesel biodiesel blend (B10) with 4% ethanol (B10E4N30) and compared it with basic diesel biodiesel blend (B10) and diesel biodiesel blend with 4% ethanol (B10E4). The outcomes were very captivating as there was 6% by average reduction in Brake specific fuel consumption (BSFC) with 6% fall in NO_x emission, 19% fall in CO emission and reduction in other emissions as well for the carbon coated nanoparticle mixed blend. After combustion study of nanoparticles in fuel revealed that the carbon coated alumina nanoparticles were altered to alumina nanoparticles only (Wu et al., 2018).

The probe for addition level of nanoparticles to fuel blend arises a lot of times. Most of the researches are focused on nanoparticle addition in the range of 10 to 70 ppm. More than that if taken results in wear and tear of surfaces, produce atomization problems, clogging in fuel injectors and also led to poor stability of the fuel blend suspensions. Smaller size nanoparticles effortlessly disseminate and do not create any trouble in the physiochemical properties of the base fuel (Gumus et al., 2016).

2. FUEL PREPARATION

Blending of nanoparticle in base fuel is very crucial for further process. Al_2O_3 nanoparticles (30-50 nm) were procured from Adnano Technologies Pvt. Ltd. Blends were prepared by mixing diesel with 5 and 10 % butanol alongside 30, 50 and 70 ppm Al_2O_3 nanoadditives and stored in different containers. The physiochemical characteristics

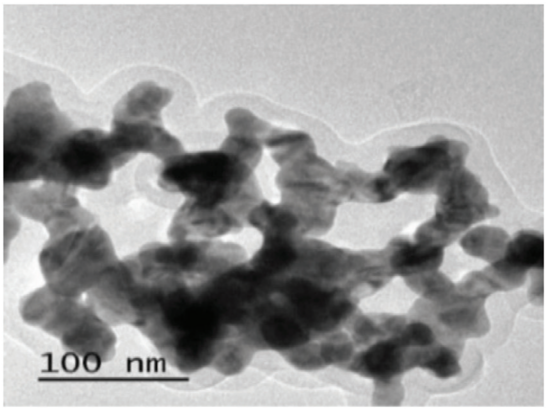

Figure 1. TEM image of aluminum oxide nanoparticle

of the standard diesel and blends in presented in table 1. The composed samples are as follows.

B5+30 (Diesel+5%Butanol+30ppm Al_2O_3)
B5+50 (Diesel +5%Butanol+50ppm Al_2O_3)
B5+70 (Diesel +5%Butanol+70ppm Al_2O_3)
B10+30 (Diesel +10%Butanol+30ppm Al_2O_3)
B10+50 (Diesel +10%Butanol+50ppm Al_2O_3)
B10+70 (Diesel +10%Butanol+70ppm Al_2O_3)

Transmission scanning microscopy (TEM) is used for morphological characterization of aluminum oxide nanoparticles. Near spherical morphology can be seen from the given TEM image in fig. 1.

3. EXPERIMENTAL SETUP

The study was performed on VCR (Variable Compression Ratio) Research engine at compression ratios of 16, 17 and 18. The engine was employed at a constant speed of 1500rpm with varying load conditions of 0, 2, 4, 6 kg. All necessary instruments for combustion pressure, crank-angle, airflow, fuel flow, temperatures and load measurement, eddy current dynamometer, air box, twin fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and piezo powering unit are requisite for the setup. High speed data acquisition devices are essential for interaction of signals to the computer. Water flow measurement and water cooling is done by rotameter. VCR engine setup facilitate the study of brake power (BP), indicated power (IP), frictional power (FP), brake mean effective pressure (BMEP), indicated mean effective pressure (IMEP), brake thermal efficiency (BTE), indicated thermal efficiency (ITE), mechanical efficiency (ME), volumetric efficiency (VE), specific fuel consumption (SFC), Air fuel ratio (A/F), heat balance and combustion analysis. The evaluation of the emissions can be done by exhaust gas analyzer.

Table 1. Physiochemical characteristics of the standard diesel and blends

Fuel Samples	**Density (Kg/m^3) at 15 ˚C**	**Kinematic Viscosity (mm^2/s) at 40 ˚C**	**Lower Heating Value (Kj/Kg)**	**Flash Point (˚C)**	**Fire Point (˚C)**	**Ash Content (%)**	**Cetane Number**
Diesel	838	3.93	43380	67.5	77.6	0.01	60.5
B5+30	823	2.45	42791	40.2	49.4	<0.01	61.7
B5+50	819	2.36	45377	40.8	51.3	<0.01	62.4
B5+70	810	2.21	49500	41.6	52.5	<0.01	64.1
B10+30	821	2.52	43827	41.4	50.4	<0.01	62.6
B10+50	816	2.43	48230	41.8	52.7	<0.01	64.5
B10+70	815	2.35	52082	42.0	56.0	<0.01	65.2

4. RESULTS AND DISCUSSION

4.1 PERFORMANCE CHARACTERISTICS

4.1 (a) Brake Thermal Efficiency

The brake thermal efficiency increased with increased load because of increase in power output. The BTE of blends is improved as compared to neat diesel which may be attributed to lower viscosity and higher latent heat value of butanol which supports to enhance the combustion of blends. This substantial increment in BTE can also be attributed to the impact of aluminum nanoparticle addition in diesel blends. Proper dispersion of aluminum nanoparticles augments the heat transfer properties of the blends and tends to enhance ignition delay. The average enhancement in thermal efficiency obtained is 12.01 % and 15.23 % for B5+70 and B10+70 respectively at 18 compression ratio with 23.31% enhancement in thermal efficiency by B10+70 at full load at the same compression ratio.

For all the tested fuels, BTE increased on increasing compression ratio from 16 to 18. At high compression ratios and high loads, ignition delay period is reduced and effective combustion can be achieved. Comparatively at higher load and high compression ratio there is an increment of 8-12% for 5% butanol samples and 10-15% increment for 10% butanol samples.

Fig 2 and fig 3 present brake thermal efficiency with load for all blended fuels of 5% butanol and 10% butanol respectively at different compression ratios of 16, 17 and 18.

4.1 (b) Specific Fuel Consumption

For all fuel blends, SFC decrease with increase in load. Maximum SFC was obtained at no load and on further increasing load, it stays just about constant. Superior results can be obtained on increasing the compression ratio as fuel consumption decreases. As previously quoted, at higher compression ratios effective combustion process

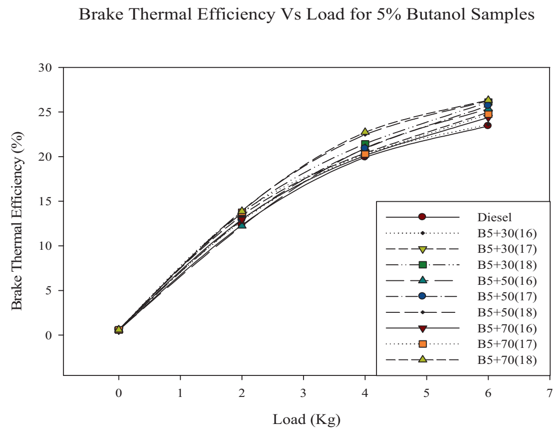

Figure 2. Brake thermal efficiency Vs load for B5+30, B5+50, B5+70 at varying compression ratios

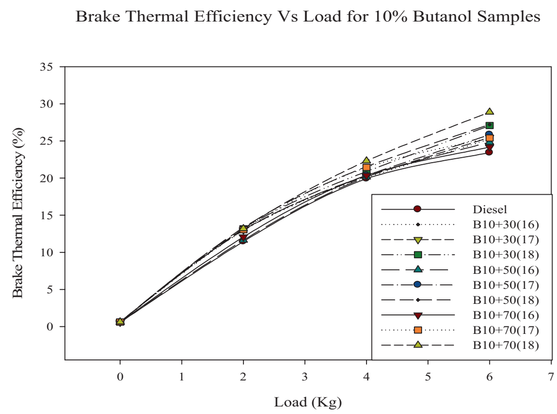

Figure 3. Brake thermal efficiency Vs load for B10+30, B10+50, B10+70 at varying compression ratios

takes place with reduced ignition delays thereby enhancing thermal efficiency and at the same time reducing SFC.

Fig 4 and fig 5 represent specific fuel consumption with load for all blended fuels of 5% butanol and 10% butanol respectively at different compression ratios of 16, 17 and 18.

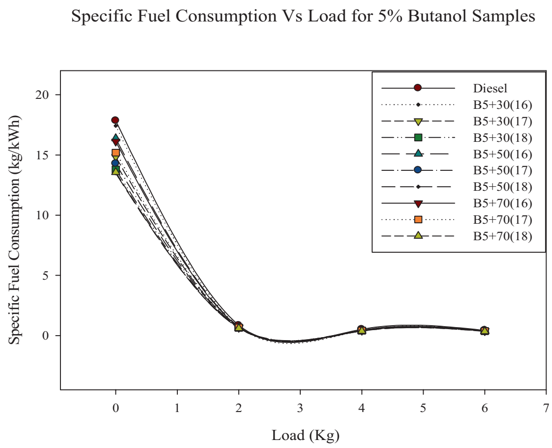

Figure 4. Specific fuel consumption Vs load for B5+30, B5+50, B5+70 at varying compression ratio

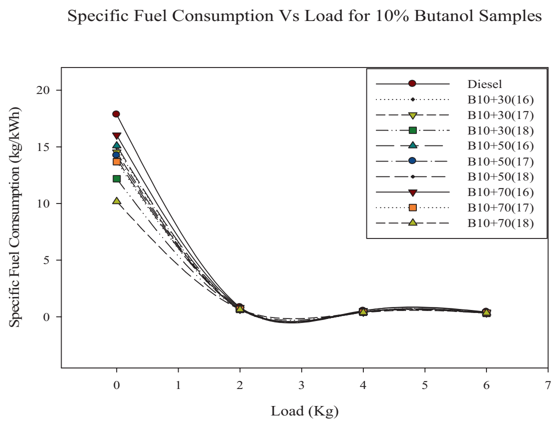

Figure 5. Specific fuel consumption Vs load for B10+30, B10+50, B10+70 at varying compression ratio

The SFC of blended fuels is lower than base diesel at all loads. At full load and highest compression ratio which is 18 here, decrement in SFC as compared to neat diesel was found to be28.59% for B10+70.

4.2 EMISSION CHARACTERISTICS

4.2 (a) Carbon Monoxide (CO)

Carbon monoxide (CO) versus load at varying loads and different compression ratios are represented in figures 6, 7 and 8. Complete combustion is encouraged by aluminum oxide nanoparticle which acts as oxidation catalyst in the blend which thereby reduces the ignition delay resulting in significant reduction in CO. A moderate decrement is been observed in CO emissions on increasing the compression ratio for all fuel samples because of increment in temperature of air in cylinder on increase in compression ratio thereby strengthening the combustion process and thus reducing CO emissions. CO emissions tend to reduce

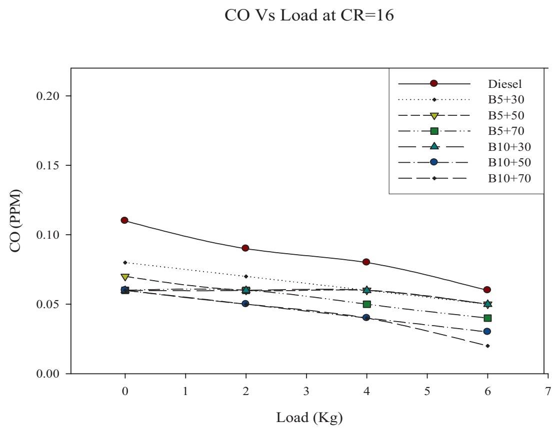

Figure 6. Carbon monoxide (CO) Vs load for all blends at CR=16

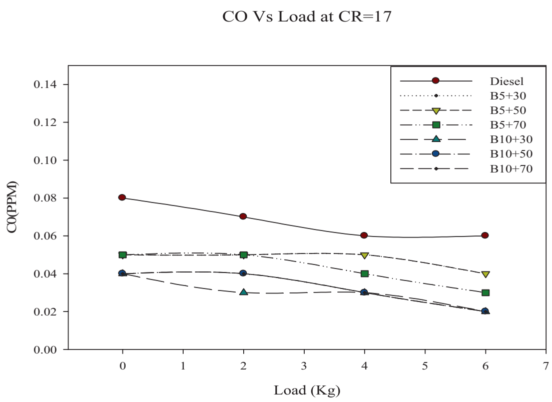

Figure 7. Carbon monoxide (CO) Vs load for all blends at CR=17

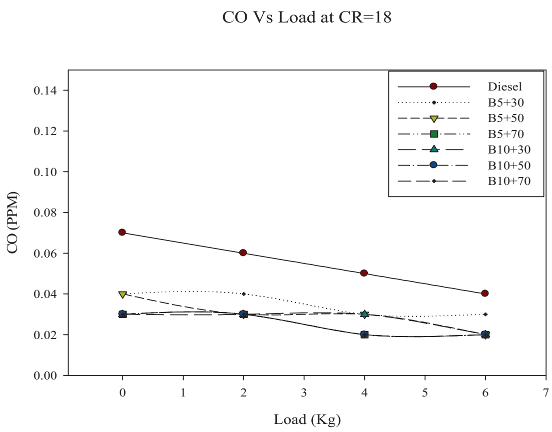

Figure 8. Carbon monoxide (CO) Vs load for all blends at CR=18

on increasing load which can be ascribed to the rich air fuel ratio at higher loads. It can be noted from the given figures, that CO emissions are reduced for all fuel blends i.e. 5% and 10% butanol blends as compared to neat diesel. Also

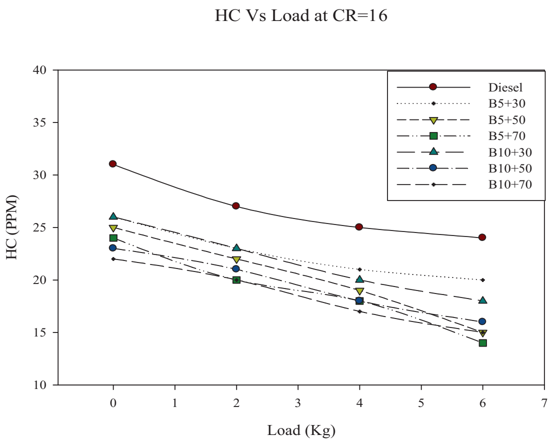

Figure 9. Hydrocarbon (HC) Vs load for all blends at CR=16

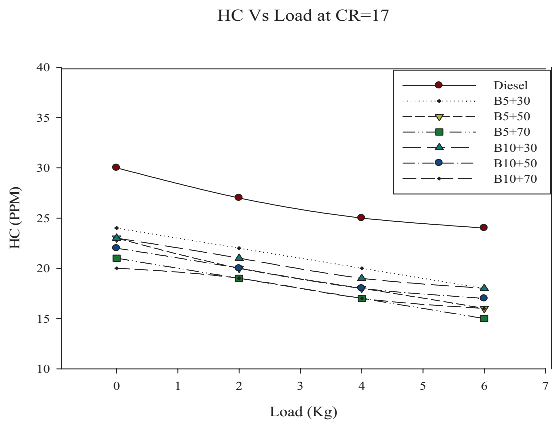

Figure 10. Hydrocarbon (HC) Vs load for all blends at CR=17

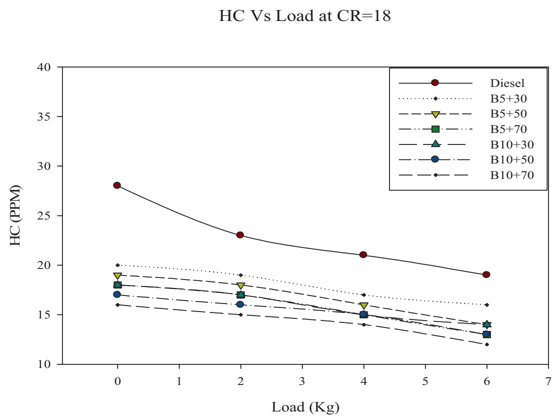

Figure 11. Hydrocarbon (HC) Vs load for all blends at CR=18

a decrement in CO emissions can be noticed, when the dosage level of aluminum oxide nanoparticles is increased in B5 and B10 samples on the account of increase in oxygen content boosting the complete combustion. Maximum average reduction of 54.28% was found for B10+70 at compression ratio 18 as compared to neat diesel.

4.2 (b) Unburnt Hydrocarbons (HC)

CO and HC emissions are the consequence of incomplete combustion and are generally maximum at no load condition. Addition of aluminum oxide nanoparticles in the blends has augmented the combustion phenomenon leading to reduction in the unburnt HC of all the blends as compared to diesel. Also it can be seen there is a notable reduction in HC emissions on increase in compression ratio from 16 to18. From the given figures 9, 10 and 11, the decreasing trend of HC for all butanol blends can be taken into account and that decrement in HC for all blends at all compression ratios are lower than neat diesel. The observed maximum reduction in HC emissions for B10+70 at compression ratio 16, 17 and 18 are 31.11%, 32.07% and 36.95% as compared to neat diesel.

4.2 (c) Nitrogen Oxide (NO_x) Emissions

NO_x emissions tend to increase at higher load values and also at higher compression ratios. The variation of NO_x versus load for the present study is shown in figures 12, 13 and 14 for varying compression ratios. In cylinder pressure and temperature has considerable influence on NO_x formation. The addition of butanol in diesel tends to lower the in cylinder pressure than baseline diesel and it decreases on increase in addition of alcohol in diesel (Siwale et al., 2013). In cylinder temperature of butanol diesel blends is also moderately low than neat diesel owing to high latent heat of evaporation (Chen et al., 2013). Percentage of butanol used in present research is quite low though, however for ternary blends the oxidizing catalyst present in the blends truncate the ignition delay and reduce the duration of combustion to contribute to high heat release rates than neat diesel (Lujaji et al., 2011). Al_2O_3 nanoparticles which are present here in the concentrations of 30, 50 and 70ppm incline to increase the in cylinder pressure and temperature of blends with high dosage of addition of nanoparticle (Bharathiraja et al., 2015).

High surface area to volume ratio of Al_2O_3 nanoparticles, abundance of oxygen due to presence of butanol and Al_2O_3 nanoparticle in the blends assists in pressure rise inside cylinder during combustion. Many researches with diesel-Al_2O_3 nanoparticles blends have shown a substantial reduction in NO_x emissions than neat diesel ascribed to catalytic effect and support in complete combustion by Al_2O_3 nanoparticle (Shaafi and Velraj, 2015; Soukht Saraee et al., 2016). However, in ternary blends as in biodiesel-diesel blends with Al_2O_3 nanoparticles or alcohol diesel blends with Al_2O_3 nanoparticles, the emissions are unpredictable. In the present research NO_x emissions are increasing with increase in load for all blends as well as

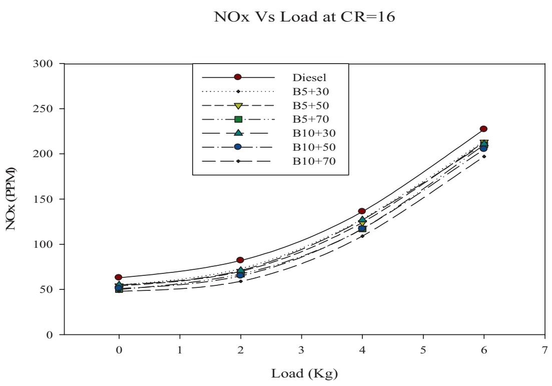

Figure 12. Nitrogen Oxide (NO_x) Vs load for all blends at CR=16

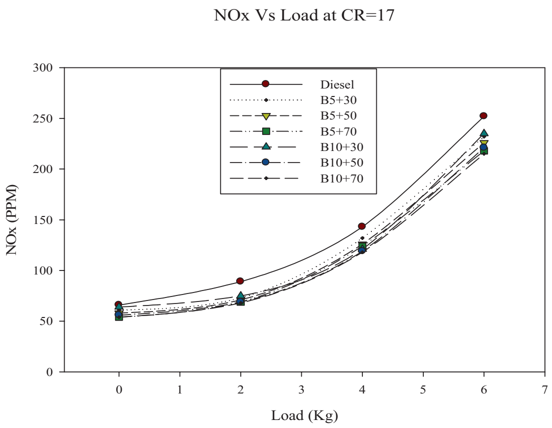

Figure 13. Nitrogen Oxide (NO_x) Vs load for all blends at CR=17

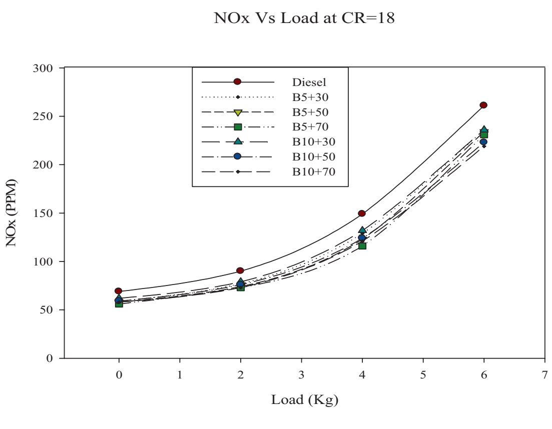

Figure 14. Nitrogen Oxide (NO_x) Vs load for all blends at CR=18

neat diesel. Blends have shown notable reduction when equated to diesel at higher loads. All blends and neat diesel have been observed to have higher emissions on increase in compression ratio. From the experimental data, noted reduction of14.68% and 16.09% for B10+70 at full load at compression ratio 17 and 18 respectively is achieved. Maximum average reduction was achieved at compression ratio 16 which is 21.23% for B10+70.

5. CONCLUSIONS

In the present study, aluminum oxide nanoparticles (30, 50 and 70 ppm) were blended in diesel mixed with 5 and 10% butanol to study the effect on performance and emission properties. The blends were tested on VCR (variable compression ratio) engine to study the effects at varying compression ratios. Present work is performed on compression ratios of 16, 17 and 18. Performance and emissions of engine are analyzed on a single cylinder, four stroke VCR engine at a constant speed of 1500 rpm. The results were collected and following inference is drawn.

Aluminum oxide nanoparticle addition in diesel led to increase in its calorific value. Noteworthy improvement in thermal conductivity can be seen with catalytic behavior of nanoparticle in base diesel. The satisfactory results for BTE are obtained on increasing the compression ratio for all blends. Maximum BTE of 12.01 % and 15.23 % was obtained for B5+70 and B10+70 at compression ratio 18.

Calorific value of butanol is less than diesel which calls for more amount of fuel for same power output. A substantial drop can be noticed in SFC on increasing compression ratio. However decrement in SFC can be noticed with increase in dosage level of aluminum oxide nanoparticles. At full load and highest compression ratio which is 18, maximum average reduction achieved in SFC is 28.59 % for B10+70.

Significant reduction has been observed in CO and HC emissions for all blends as compared to neat diesel with even notable reduction in NO_X emissions when equated to diesel at all loads. Appreciable results obtained for B10+70 with maximum average reductions of 54.28% and 36.95% in CO and HC emissions respectively at compression ratio 18 with maximum average NOx reduction of 21.23% at compression ratio 16.

The catalytic effect of aluminum oxide nanoparticle with diesel/biodiesel blends can effectively reduce toxic emissions and this fuel can be used without any modification in diesel engines making it suitable for automotive diesel engine, agriculture, all types of heavy duty transportation and marine applications.

6. DECLARATION OF CONFLICTING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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