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Influence of Aluminum Oxide Nanoparticle Additive on Performance and Exhaust Emissions of Diesel Engine

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Abstract: An Experimental investigation was carried out to determine combustion, performance and emissions characteristics of diesel engine using nano-aluminum oxide (n-Al_2O_3) mixed diesel. The n-Al_2O_3 of size 40 nm was mixed into diesel fuel at the rate of 1g/l and 1.5g/l for formulation of new fuels. The n-$Al_2O_3$was dispersed by means of an ultrasonic vibrator in order to produce uniform dispersion of n-Al_2O_3 in the diesel fuel. Nano-Al_2O_3possess better combustion characteristics and enhanced surface-area-to-volume ratio and hence allows more amount of diesel to react with the oxidizer which in turn enhances the burning efficiency of the test fuels. The diesel fuel with and without n-Al_2O_3 additive were tested in a direct injection diesel engine at different load conditions and the results revealed that a considerable enhancement in the brake thermal efficiency and substantial reduction in content of NO_X and unburnt hydrocarbon (UBHC) at all the loads compared to neat diesel were observed due to nano Al_2O_3's better combustion characteristics and improved degree of mixing with air.

Key words: Fuel additive · Nano-aluminum oxide · Diesel engine · Diesel · Performance · Emissions

INTRODUCTION

The compression ignition engines are generally more efficient than spark ignition engines. However, they emit higher range of hazardous pollutants such as oxides of nitrogen (NO_X), unburnt hydrocarbons (HC), particulate matter, smoke, soot, etc. Due to strict emission regulations, many investigations are carried out to minimize the above emissions by three methods viz. modifying engine design, formulating new fuels and exhaust gas treatments. Numerous researchers have contributed their efforts on formulating new fuels by dissolving ultra-low rate nano metallic based fuel additives in conventional diesel [1-3]. Nano sized metal oxide particles blended fuel exhibits significantly different thermo physical properties when compared to the diesel. At these size, particles surface area per volume increases and this provides a more contact surface area during the rapid oxidation process [4] also it can release more than twice the energy of even the best molecular explosives. Several studies reveal that melting points and heats of fusion decrease with decreasing sizes of metal particles [5-7]. Yetter *et al*. [8] have critically reviewed the reports on metal nano-particles combustion and revealed that the nano size metallic powders possess high specific surface area and potential to accumulate energy, which helps to high reactivity. In their article on combustion of nanoparticle said that adding nano-catalyst to the diesel fuel will reduce the ignition delay and soot emissions. Experimental studies with metal oxide mixed fuels are known to display increased catalytic behavior, causing hydrocarbons oxidation and acting as an oxygen buffer against NO_x formation. In this work, the performance and emission characteristics of the diesel engine using diesel as fuel are taken as the benchmark reading and n-Al_2O_3 was mixed with the diesel and the performance and emission characteristics of diesel engine were compared.

NANO-AL_2O_3 –Diesel Blends Preparation: The arc plasma method was used to synthesis nanocrystalline alumina (n-Al_2O_3) power at atmospheric condition using aluminum electrodes. 1g & 1.5g of n-Al_2O_3 were mixed into one litre of diesel fuel separately for preparing two test fuels. Sonicator at frequency of 24 kHZ, a power of 200w is used to concuss the mixture for 30 minutes to produce a uniform suspension of the experimental test fuels [9].

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Fig. 1: Photograph of the engine test rig

Table 1: Properties of the fuel blends

Properties	D	D+1Al	D+1.5Al
Density @15°C, gm/cc	0.826	0.830	0.8332
Flash Point, °C	52	56	60
Fire Point, °C	62	72	78
Calorific Value, kJ/kg	43425	43584	43602

Table 2: Specification of test rig

Type	Single cylinder, Four stroke,
Bore x stroke	87.5 mm x110 mm
Displacement volume	661.45 cc
Compression Ratio	Variable
Speed	1500r.p.m (constant)
Rated Power	3.5 kW
Cooling	Water cooled
Loading System	Eddy current dynamometer

The test fuels with additives were quoted as D+1Al and D+1.5Al. The density, fire point, flash Point and calorific value of test fuels were measured using ASTM test standards [10] and the properties of the fuel blend are given in the Table 1. Immediately, the fuel blends were used to conduct test on diesel engine after preparation in order to avoid any settling or sedimentation to occur.

Experimental Pocedure: Fig. 1 shows photograph of the test engine. C.I Engine with specifications shown in Table 2 coupled with eddy current dynamometer is used for conducting experiment. The load applied on the engine is measured by the load cell connected to the eddy current dynamometer. Infra-red optical sensor fixed in the burette measures the fuel flow rate. An air flow sensor measures the air flow to the engine. The combustion phenomenon of fuel in the engine cylinder is transmitted to the combustion analyzer through the pressure transducer and the rotary encoder. It is transformed there and finally sent to computer. It displays the combustion pressure and the net heat release curves. AVL make gas analyzer and smoke meter which are used to measure engine's exhaust emission. All tests were performed at 17.5:1 compression ratio of engine and detected values were recorded under steady operating condition of engine.

RESULTS AND DISCUSSION

The performance and emission characteristics of the diesel engine with test fuels were investigated using the experimental setup described above. The observed values are brake thermal efficiency (BTE) and emission concentrations of HC, NO_X, CO and smoke with various values of brake mean effective pressure (BMEP) at 1500 r.p.m. Fig. 2 represents the variation of brake thermal efficiency with brake mean effective pressure. There is minor improvement in brake thermal efficiency is observed for test fuels than neat diesel. Because n-Al_2O_3 additive reduces the evaporation time of the fuel and hence it reduces the physical delay. Thus the fuels were completely burnt and effectively utilized in the combustion chamber. n-Al_2O_3 react with water vapour formed during combustion at high temperature generates hydrogen and improves the fuel combustion. The maximum brake thermal efficiency for D+1.5Al is 33.22% whereas it is 32% for D+1Al compared with 31.29% for base fuel, at the brake mean effective pressure of 4.12bar respectively.

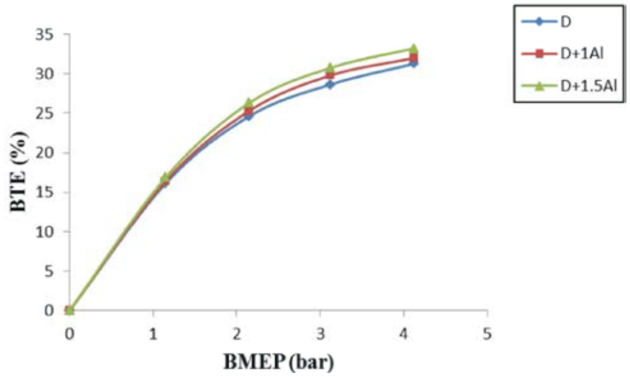

Fig. 2: Variation of brake thermal efficiency with brake mean effective pressure

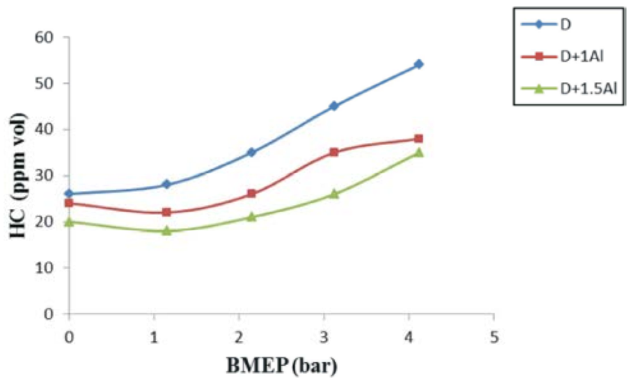

Fig. 3: Variation of hydrocarbon with brake mean effective pressure

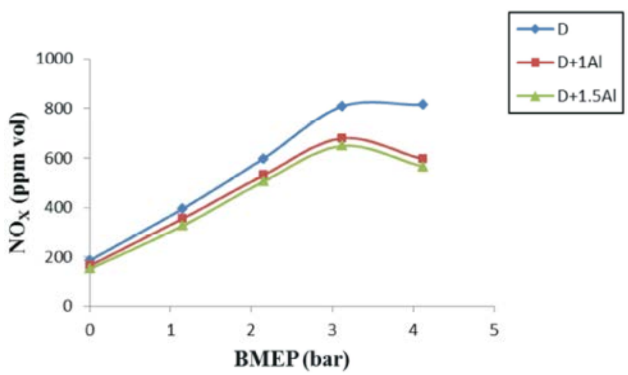

Fig. 4: Variation of oxides of nitrogen with brake mean effective pressure

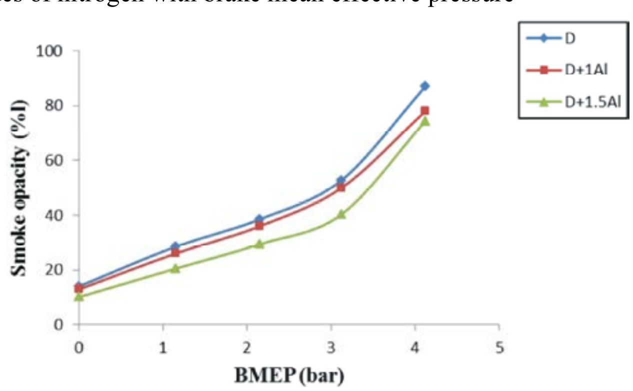

Fig. 5: Variation of smoke opacity with brake mean effective pressure

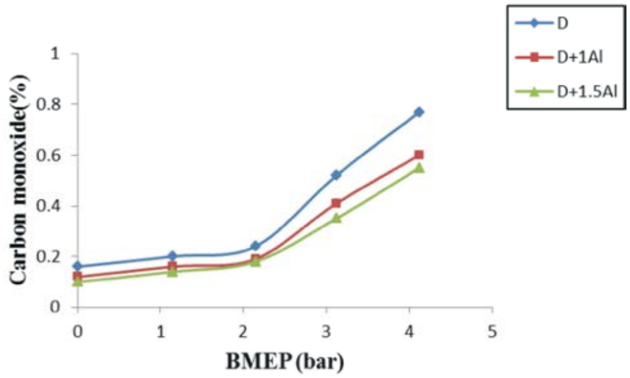

Fig. 6: Variation of carbon monoxide with brake mean effective pressure

The variation of hydrocarbon emission with BMEP is shown in Fig. 3. The n-Al_2O_3 present in the test fuels decreases the HC emission when comparing with base fuel. Aluminum oxide acts as a catalyst and lowers the carbon combustion activation temperature and thus enhances oxidation of hydrocarbon and promoting complete fuel combustion. An average reduction from 22.87% to 36.17% in the HC was attained for additive dosing levels ranging from 1g to 1.5g.

The NO_X concentration of Diesel fuel and test fuels with BMEP is shown in Fig. 4. An oxide of nitrogen emission for blends is lower than that of D fuel at all loads. It was observed that at full load operation, reduction is about 30.67% in case of D+1.5Al. The D+1.5Al shows an improved reduction in NO_X emission at all load when compared with D+1Al. A detailed flame analysis could possibly lead to the exact reasons behind the NO_X formation as the behavior could be due to a complex interaction among factors such as oxygen content, combustion temperature and the reaction time.

Fig. 5 shows the smoke opacity percent for diesel and test fuels at different loads. Reduced smoke is noted in the case of n-Al_2O_3 blended fuels. The reason being decreased ignition delay and better combustion characteristics of n-Al_2O_3blended fuels. The concentration of smoke for D+1.5Al is 74.4% whereas it is 78% for D+1Al, compared to 87% for neat diesel at full load respectively.

The CO emission of Diesel fuel and test fuels with BMEP is given in the Fig. 6. The carbon monoxide emission for diesel fuel is higher compared to n-Al_2O_3 blended fuels due to its lower thermal efficiency resulting in incomplete combustion of fuel. The greater catalytic and improved combustion characteristics of n-$Al_2O_{3,}$ leading to improved combustion of fuel could be the reason for this reduction of CO emission in fuel blends operations. In comparison with base fuel, the reduction was 28.57% with D+1.5Al and 22.77% with D+1Al respectively, at BMEP of 4.12 bar.

CONCLUSION

Experiments were carried out at different dosing levels of the nanoparticles to study the effects of n-Al_2O_3 on engine performance and its emissions. The main observations and inferences are given below.

- The brake thermal efficiency of diesel engine fuelled with n-Al_2O_3 blended fuels is marginally improved as compared to that of diesel. At maximum BMEP, it is 6.17% with D+1.5Al and 2.27% with D+1Al
- The addition of n-Al_2O_3 decreases the HC emission compared to diesel. D+1.5Al blend showing 35.18% reduction in HC whereas, with D+1Al, it is 29.62% at full load.
- n-Al_2O_3 blended fuels showing better reduction in NO_X. A 30.67% NO_X reduction is observed with D+1.5Al whereas it is 27% with D+1Al at maximum BMEP.
- Smoke emission is considerably reduced with n-Al_2O_3. At maximum BMEP, smoke level with D+1.5Al and D+1Al are decreased by14.48% and by10.34% respectively.
- Reduction in CO emission is observed with n-Al_2O_3 blends. Concentrations of CO are decreased by 28.57% and by 22.77% with D+1.5Al and D+1Al respectively at full load.
- It is found that D+1.5Al blend has better performance characteristics and reduced emission on diesel engine than D+1Al blend.

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