Environmental pollution control emitted from diesel engines by Al$_2$O$_3$ nanoparticles.

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Abstract. One of the most important problems for diesel engines is the emissions of nitrogen oxides (NOx) and smoke, the use of emulsification technology is one of the most influential ways to control this emissions. In this present work Aluminum oxide (Al$_2$O$_3$) are blended by rotary-stator homogenizer at three different levels (50,100,150 ppm) with prepared Nano-emulsion at optimum composition and circumstances that are analyzed experimentally by Design Expert software. Alumina nanoparticle with its high thermal conductivity (30 -1 Wm K$^{-1}$ compare to diesel and high calorific value which helps to promote more internal combustion due to making higher thermal efficiency. Direct injection (DI), water cooled four cylinders, in-line, natural aspirated Fiat diesel engine was used and run at a constant speed (1500 rpm) and constant fuel injection pressure (400 bars) with varying the operation load. Multigas analyzer model 4880 was used to measure the concentration of the emission gases such as NOx, unburned total hydrocarbon HC, CO$_2$ and CO. The engine exhaust smoke emissions were measured using the AVL-415 smoke meter. Based on these observations, the rate of CO and NOx would be reduced significantly up to 24 and 5.8 %, at 150ppm to net diesel respectively, noting that the net smoke of diesel would undergo the highest change (up to 26.5 %). The results also indicate a 6.97 % fuel consumption reduction accompanied with 6.2 % improvement in the thermal efficiency, utilizing Al$_2$O$_3$ nanoparticles in blended in Nano-emulsion. Enhancement in break thermal efficiency (BTE), reduction in (NOx) and smoke are noticed after mixing Al$_2$O$_3$ into prepared nano-emulsion.

Keywords: Nanoemulsion, Aluminum oxide , Diesel engine, nanoparticle, emissions.
1. Introduction

In last past years scientists and engineers have applied nanotechnologies to human lives in a wide variety of subjects such as biomedical, material, computer, and fuel engineering fields[1]. Diesel fuel (CnHm) is a stable organic molecule. Its electronic structure, its lack of polarity and in the absence of any functional group makes it difficult to decompose into its constituent parts [2]. Many researchers found that nanoparticles can be used as an additive along with the conventional fossil fuel to enhance the combustion and reduces the emission significantly [3].

Adding metallic powder to ordinary fossil fuel usually increases the combustion efficiency and improves combustion stability[4]. Adding 0.5 % aluminum nanopowder to a rocket’s solid fuel can improve combustion efficiency by 10 to 25 % and increase combustion speed by an order of magnitude [1].

Aluminum nanopowder has a very high activity and can react with water at temperatures from 400 to 660°C to generate hydrogen and improve fuel combustion [5].

Some studies show that the hydrogen is a high quality fuel that burns rapidly and cleanly [6]. Accordingly, hydrogen can be obtained in the proposed manner from water to burn cleanly and efficiently in diesel engines [1].

Research on the topic of water/diesel mixtures in compression ignition engines is aimed at fuel conservation and reduction of undesirable emissions and has been presented in several papers [7–8]. This was explained by the presence of nanoparticles in the emulsified fuel which made the hydrogen atom present in the water molecule to be broken easily which helped in improving the combustion process [3]. Hydrogen is clearly a promising alternative to hydrocarbon fossil fuels since it has higher energy efficiencies and is associated with lower emissions [2]. The reduction in smoke emission was explained by the micro explosion of the emulsified fuel[9,10].

Aluminum nanopowder can react with water at high temperature and generate hydrogen, promoting the combustion of the fuel [11, 12]. Because the aluminum is nanometer size, it has more surface area and higher activity to decompose the hydrogen from water and increase combustion heat.[23]

BTE was enhanced and CO, HC emissions reduced by adding aluminum, iron, and boron nanoparticles with diesel fuel [13]. This enhancement is due to complete combustion by rapid oxidation, decreased in ignition delay and burning period. Enhancement in surface area to volume ratio and catalytic activity is increased by Nano-additive. [14].

Catalytic effects of high energy density nanoparticles have benefits to improve fuel oxidation and shorten the ignition delay time by catalytic effects. The ignition chance for the fuel blends that having nanoparticles was considerably more than that of pure diesel [15].

Peak cycle temperature is reduced by presence of water in emulsified fuel which had high latent heat of vaporization causing in reduction of NOx emission [16]. The carbon monoxide emissions were also found to be lower with water – diesel - nano fluid emulsion as compared to conventional diesel at all power outs[17]. This trend was explained by the presence of nano particles in the emulsified fuel which helped in breaking the water molecule to separate the oxygen atom which resulted in complete oxidation of the carbon atoms in the fuel. It is concluded that water diesel emulsion can be used as a promising fuel for simultaneous reduction of smoke and NOx emissions in diesel engines. In addition the hydrocarbon and carbon monoxide reduction with improved engine performance can be achieved by adding nanofluids along with the emulsified fuel.
2. Materials and methods

First, for preparation of suitable Nano-emulsion with optimum circumstances, response surface method (RSM) is used for analyzing the factors effecting on prepared fuel according to water droplet size in Nano emulsion.

Pure diesel fuel provided by (Doura Refinery) had (320 ppm wt) Total Nitrogen content. Two surfactants are blended to obtain certain required HLB for the optimum Nanoemulsion composition condition. Low HLB surfactant 4.3 had Mwt 428.61 with 0.99 density (g/ml) at 20 °C is lipophilic brown viscous, while high HLB emulsifier 15 had Mwt 1310 and 1.08 density (g/mol) at 20°C , both surfactants are provided by CDH group company.

After preparation the surfactant with HLB 6 it was added (5 wt %) to net diesel fuel, by rotor-stator homogenizer (Heidolph homogenizer DIA X 900 homogenizer) it is dispersed inside the diesel for 30 min at 1500 rpm. Water with 10.8 pH will add with 12wt% form the total weight of solution and stirring for 30 min more at the same speed.

(Al₂O₃) nanoparticles with purity 99% had a diameter around 80nm and specific surface area >15 (Supplied by Hongwu international Group Ltd. company, China). (Al₂O₃) nanoparticles was added directly to a prepared nanoemulsion at different levels (50, 100, 150 ppm) and blended for extra 30 min more for achieving complete distribution in all part on the fuel equally before ignition inside the engine.

The prepared fuel from obvious step will examine in diesel engine type 4cycle; 4 strokes at compression ratio 17. The engine are cooled by water because of with direct injection of fuel into the compression vessel which is directly faced high pressure and temperature by piston lead to explosive of Nano size of water droplets. Hydraulic dynamometer was coupled to the engine through which the load was applied by increasing the torque.

Automotive emission analyzer (Air rex-HG-550) by EGMA Company is used for measure the concentration of HC, CO, NOx and CO₂ for all samples at different loads. All sample are implemented twice to ensure the results and its repeatability, the tests were repeated twice.

AVL – 415 smoke meters is used for the engine exhaust smoke emissions. Its measurement principle are depend on filter paper blackening with the measurement range 0 to 10 FSN and detection limit from 0.002 FSN. The apparatus taking sample 10 sec intake time with resolution from 0.01 mg/m³.
3. RESULTS AND DISCUSSION

Performance Characteristics

For analyzing BSFC experiments diesel engine was conducted with pure diesel, WiDNE and WiDNE+Al₂O₃ in three different levels, (50, 100, 150 ppm) at constant compression ratio 17. The load of the diesel engine was varied from 5 to 15 kg with 2.5 kg step size at constant speed 1500 rpm during the of each run of experiments.

From figure (2) it is noticed that the BSFC decreased when the load was increased for all processes of diesel and Nanoemulsions blends due to the consumption of more fuel [7]. It is observed that WiDNE shows higher BSFC as compared to conventional diesel and nanoparticle blended water in diesel Nanoemulsions. This can be due to the higher viscosity and lower heating value of water diesel emulsions as compared with diesel [8, 9]. It was also observed that BSFC decreases when nanoparticle volume fraction in the Nanoemulsions blend was increased for any given load. This reduction in fuel consumption can be due to increase in calorific value with the addition of the nanoparticle [10, 11].

Potential advantage of the water in diesel Nanoemulsions fuels is the integrated influence of secondary atomization and microexplosion phenomenon, resulting in strong vaporization and mixing better of air, turns in improving the combustion reactions inside the engine cylinders. Influence of Al₂O₃ on BSFC was investigated and it is illustrated through figure 2. There was an apparent effect on reduction of BSFC with increasing of Al₂O₃ concentration in WiDNE. With increasing of Al₂O₃ from 50 ppm to 150 ppm, BSFC reduced. This is due to the shortening of ignition delay features of nanoparticle by virtue of improved surface area to volume ratio. Al₂O₃ nanoparticles with 80 nm with specific surface area > 15 m²/g, makes it require more energy required for atomization.

From figure (3) it was perceived that (BTE) increased when the load was increased for all operations of diesel and nanoemulsion blends as obvious in below figure 3. It was observed that the conventional diesel
shows lower Brake thermal efficiency as compared to WiDNE and nanoparticle blended water in diesel Nanoemulsions [20, 21]. Table (1) show the effect of water for preparation of nanoemulsion with the pure diesel, in spite of addition of water contributes in reduction of emissions but it is also cause reduces in fuel properties as increase flash point and viscosity.

Table 1: Comparison of diesel and Nanoemulsion

| Properties (measured)         | Diesel | Nanoemulsion |
|-------------------------------|--------|--------------|
| 1. Calorific value (kJ/kg)    | 44800  | 38850        |
| 2. Flash point (°C)           | 54     | 61           |
| 3. Viscosity at 40 °C (cSt)   | 3.268  | 4.56         |
| 4. Pour point (°C)            | +9     | +7           |
| 5. Density (g/cm³)            | 0.87   | 0.882        |

![Graph showing brake thermal efficiency vs load (bmeq) kN/m²]
Figure 2: Variation of BSFC with Load (bmep) kN/m²

Figure 3: Variation of BTE with Load (bmep) kN/m²

As concentration of (Al₂O₃) was increased from 50 ppm to 150 ppm, the thermal efficiency increased from 32.3 to 33.2 at higher load. This is due to the Al₂O₃ nanoparticles encapsulation in water molecule, which offers the secondary atomization directly after the primary micro explosion phenomenon taking place due to the Nanoemulsion.

Exhaust Emission Analysis

It was noticed that the NOx emission increases when the load was increasing with the all operations of diesel and Nanoemulsion blends as shown in below figure 4. It is observed that WiDNE reduces NOx emission as compared to conventional diesel. Water molecules present in emulsified fuel possess very high latent heat of vaporization, which tends to reduce the peak cycle temperature, hence oxides of nitrogen emission of water diesel nanoemulsion were found on the lower side as compared to diesel fuel for all the power output. It is found that the water in diesel emulsion with 15% water content produces the least amount of NOx emission as compared to other fuels [22]. The variation of NOx emission was observed with Al₂O₃ nanoparticle blended with nanoemulsion in their respective concentration, as in figure 4. As concentration was increased from 50 ppm to 150 ppm the NOx emission barely changes could be noticed. This is due to the Al₂O₃ nanoparticles size 80 nm.

Diesel fuel showed the higher magnitude of Smoke opacity over the entire load range. It was noticed that the Smoke opacity increased when the load was increased for all operations of diesel and Nanoemulsion mixers, as shown in below figure 5. It is observed that WiDNE reduces Smoke opacity as compared to conventional diesel. Micro explosions of emulsified fuel result in secondary atomization of injected fuel which ends up with reduced smoke intensity as compared to diesel fuel. The presence of nanoparticle in the emulsion tends to separate the oxygen atom in the water molecule which rises up the availability of oxygen. Excess oxygen present in the combustion chamber tends to oxidize the partially burned hydrocarbon; thereby reduced smoke intensity is witnessed for water diesel nanoemulsion as compared to diesel for all power outputs. It was also observed that Smoke opacity reduced when nanoparticle volume fraction in the nanoemulsion blend was increased. The enhancement of Smoke opacity was observed with Al₂O₃ nanoparticle blended with nanoemulsion in their respective concentration, as in figure 6. As concentration was increased from 50 ppm to 150 ppm, Smoke opacity decreased from 5 to 4.7 at higher load.

Carbon dioxide are coming as exhaust resulting from combustion of CO inside cylinder and complete combustion of carbon particles of the fuel. Carbon monoxide is extremely depending upon the air-to-fuel ratio comparing with stoichiometric ratio. In most cases, CI engine functions with lean mixture and thus results in lower CO emission. It was noticed that the CO emission decreased when the load was increased for all operations of diesel and Nanoemulsion blends, as shown in below figure 6.
WiDNE fuel showed the higher magnitude of CO emission over the entire load range. It was also observed that the CO emission decreased when nanoparticle volume fraction in the Nanoemulsions blend was decreased for any given load. This reduction in CO emission because of nanoparticles will easily separate the oxygen atom from the water molecule which ensures complete oxidation of fuel droplets. In addition to it better air and fuel mixing rate was achieved inside the combustion chamber due to finer atomization of emulsified fuel droplets, which ends up with complete combustion. There are some fluctuations in curves with increasing the load, in 250 kN/m² CO is less than net diesel, in continued increasing load, the CO emission again backs to rise. The variation of CO emission was observed with...
Al₂O₃ nanoparticle blended with nanoemulsion in their respective concentration, as in figure6. As concentration was increased from 50 ppm to 150 ppm, CO emission reduced from 0.065 to 0.05. This is due to the Al₂O₃ nanoparticles association in atomization process.

HC emissions are producing due to the incompletion combustion and they tend to decline with load increasing. The total HC emissions are commonly made as a consequence of flame quenching. The formation of higher HC and CO emissions is extremely relied on the viscosity of fuel. More viscosity is also leading to longer spray penetration rate. The formation of higher HC emissions is due to the wetting cylinder of engine by incomplete combustion. It was observed that the HC emission decreased when the load was increased for diesel and Nanoemulsions blends as shown in figure 8 due to the increase of combustion temperature. It is observed that WiDNE showed higher HC emission as compared to conventional diesel and nanoparticle blended water in diesel Nanoemulsions.

It was also noticed that the HC emission decreased as nanoparticle volume fraction in the Nanoemulsions blend was increased for all loads. At peak load condition, the HC emission of water diesel Nanoemulsions was quite higher than diesel fuel.

From figure 7 shows that at low load situation, the HC emission of diesel was less than WiDNE. With increasing the load, the HC emission will reduce with increasing the load. At high load the emissions by WiDNE will be less.

When using diesel fuel, there is a small increase of HC emission with increasing the load, but the curve will back down to become less than the net diesel in HC emission.

The improvement of HC emission was observed with Al₂O₃ nanoparticle. As concentration was increased from 50 ppm to 150 ppm, the HC emission decreased from 72 ppm to 69 ppm at higher load.

4. CONCLUSIONS
According to the obtained results of experiments from the diagram, it was observed decrease in brake specific fuel consumption with the addition of Al₂O₃ nanoparticles. Brake thermal efficiency improved in blending of 150 ppm Al₂O₃ to nanoemulsion in comparison with other fuels. Addition of nanoparticles improve combustion process due to fuel mixing with air which Contribution of nanoparticle in reduction of NOx, HC, CO and smoke emission.

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Abbreviations

| Symbols | Definition                           |
|---------|-------------------------------------|
| APS     | Average particle size               |
| bmep    | Brake mean effective pressure       |
| BP      | Brake power                         |
| BSFC    | Brake specific fuel consumption     |
| BTE     | Break thermal efficiency            |
| CI      | Compression ignition                |
| CO      | Carbon monoxide                     |
| CO₂     | Carbon dioxide                      |
| FSN     | Filter smoke number                 |
| HC      | Unburned hydrocarbon                |
| HLB     | Hydrophilic lipophilic balance      |
| N₂      | Nitrogen                            |
| NO      | Nitrogen oxide                      |
| NOₓ     | Nitrogen oxides                     |
| PM      | Particulate matter                  |
| rpm     | Round per minute                    |
| SSA     | Specific surface area               |
| WiDNE   | Water in diesel nanoemulsion        |
| Al₂O₃   | Zirconium oxide                     |