An Experimental Investigation of Ferrofluid Diesel Blends on Performance & Emissions Characteristics of A Four Stroke Diesel Engine

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Abstract- *Ferrofluid -diesel blend are fuels for regular diesel engines. The advantages of ferrofluid diesel blend are reductions in the emissions of nitrogen oxides and particulate matters, which are both health hazardous, and reduction in fuel consumption due to better burning efficiency. An important aspect is that ferro diesel can be used without engine modifications. Experimental tests were carried out to investigate the effects of adding water-based ferrofluid to diesel fuel in a diesel engine. These effects included the combustion performance and exhaust emission characteristics of the diesel engine. To this end, emulsified diesel fuels of 0, 0.4, 0.8 and 1.2ferrofluid/diesel ratios by volume were used in a four-stroke diesel engine, operating at 1500 rpm. The results indicate that adding ferrofluid to diesel fuel has a perceptible effect on engine performance, increasing the brake thermal effciency relatively up to 12% and decreasing the brake-specific fuel consumption relatively up to 11% as compared to diesel fuel. Furthermore, from the analysis of gaseous species of engine exhaust, it was found that* NO_x *emissions were lower than that of diesel fuel while the CO emissions increased. In addition, it was found that nanoparticles can be collected at the exhaust flow using a magnetic bar.*

Keywords- Ferrofluid-diesel blend, ferrofluid, nitrogen oxide emission, corbon monoxide, engine performance

I. INTRODUCTION

In recent years, the concept of using water-diesel emulsion to reduce undesirable emissions and fuel conservation in compression ignition engines has been an active area of research. Water injection is an old technique, dating back to the early days of internal combustion engines when it was used to increase power.

Many claims have been made for the use of fuel emulsions, such as reduction of fuel consumption, more complete combustion, and reduced exhaust emissions. Studies have shown that using emulsion fuels in internal combustion engines is an effective method for the reduction of NO_x, soot, and particulate emissions, In addition, it was found that adding water to diesel fuel can lead to reduction of heat flux, metal temperatures, and the thermal loading of combustion chamber components.

Recently, scientists and engineers have applied nanotech-nologies to the field of fuel engineering. Since nanoparticles are small enough, their properties are significantly different from those of large, microsized particles. Studies have shown that nanosized energetic metals and boron parti-cles (with dimensions less than 100 nanometers) possessdesirable combustion characteristics such as high heats of combustion and fast energy release rates. Because of their capability to enhance performance, various metals have been introduced in solid propellant formulations, gel propellants, and solid fuels. According to this study, there are many advantages of incorporating nanosized materials into fuels and propellants, such as shorter ignition delay and shorter burn times. Furthermore, nanosized particles can be dispersed into high-temperature zones for direct oxidation reaction, rapid energy release, and enhanced propulsive performance with increased density impulse.

Studies have been also done to investigate the effect of adding nanoparticles to fluids. It has been reported that adding nanoparticles to a fluid can enhance its physical properties such as thermal conductivity, mass diffusivity, and radiative heat transfer.

In recent years, adding nanoparticles to liquid fuels has been the subject of much investigation, and results have been reported. Using nanoparticles with a high surface area to volume ratio can considerably increase contact between the fuel and oxidizer. In addition, nanoparticles affect the time scale of chemical reactions, and as a result, the ignition delay time will decrease. Furthermore, it has been reported that adding nanoparticles to diesel fuel can significantly increase the ignition probability of the mixture. However, little work has been reported on the effect of adding nanoparticles to diesel fuels.

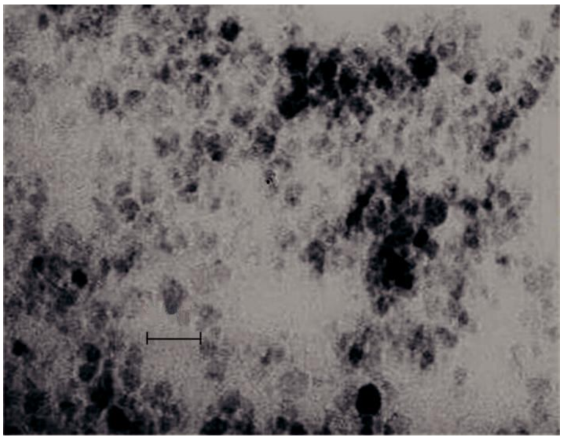

FIGURE 1: TEM graph of $Fe_3 O_4$ particle distribution.

An experimental study on a diesel engine in 2008 showed that adding aqueous aluminum nanofluid to diesel fuel will increase the total combustion heat, while the concentration of smoke and nitrogen oxides in the exhaust emission from diesel engine will decrease. Similar results have been reported in 2010 for adding Cerium oxide nanoparticles to biodiesel. According to this study, adding nanoparticles will improve the brake thermal efficiency and will reduce the emission level of hydrocarbon and NO_x.

The studies cited have shown that emulsified fuels and nanoparticles promote fuel combustion. To our knowledge, Magnetic nanoparticles have not been used before. So in this study, a water-based ferrofluid is added to diesel fuel to explore the effects on engine performance and exhaust emissions of a diesel engine. In addition to the novelty of this study, using water-based ferrofluid has two advantages compared to other nanopowders. First, it can be diluted and can therefore reap the benefits of water-diesel emulsion. Secondly, the most important preference of ferrofluids compared to other nanoparticles is that magnetic nanoparticles can be collected at the exhaust of the engine and they will not cause pollution.

II. FERROFLUID

Ferrofluids are colloidal suspensions of magnetic material in a liquid medium that respond to an external magnetic field. In other words, ferrofluids exhibit liquid-magnetic coupling behavior, in which the liquid's location can be manipulated by an applied magnetic field.

One of the most important features of ferrofluids is their stability, which means that particles in the fluid do not agglomerate and phase-separate even in the presence of strong magnetic fields.

The ferrofluid used in this study is a handmade water-based ferrofluid prepared by the authors. The synthesis was based on reacting iron II ($FeCl_2$) and iron III ($FeCl_3$) ions in an aqueous ammonia solution to form magnetite, Fe_3O_4, as shown in the following equation:

$$FeCl_2 + 2FeCl_3 + 8NH_3 + 4H_2O \rightarrow Fe_3O_4 + 8NH_4Cl.$$

The cited procedure claims that those nanoparticle diameters are on the order of 10 nm. Furthermore, aqueous tetramethylammonium hydroxide ($(CH_3)_4NOH$) solution which was used as a surfactant can surround the magnetite particles with hydroxide anions and tetramethylammonium cations to create electrostatic interparticle repulsion in an aqueous environment. Figure 1 shows a TEM graph of Fe_3O_4 particle distribution. The average particle diameter is about 10 nm, which is in accordance with prediction.

III. EXPERIMENTAL SETUP AND PROCEDURE

Tests were conducted in the engine using the pure diesel, pure diesel and their various blends, at the rated speed. Starting from no load, the engine was loaded to a load, a little above the rated load. Engine was started and stopped at no load. Enough cooling water supply was ensured. The output power was measured from the energy meter readings, using a stopwatch. The time taken for the consumption of 10cc fuel was also noted. Measurements were taken at no load and then the load was gradually increased to higher values.

Table1.Engine specifications

Engine model	Kirloskar
Bore Diameter	80 mm
Stroke Lenth	110 mm
No. of Strokes	4
No. of Cylinders	1
Rated power	5Hp
Rated Speed	1500 rpm
Type of cooling	Water cooled
Type of loading	Electrical type
Alternor efficiency	90%

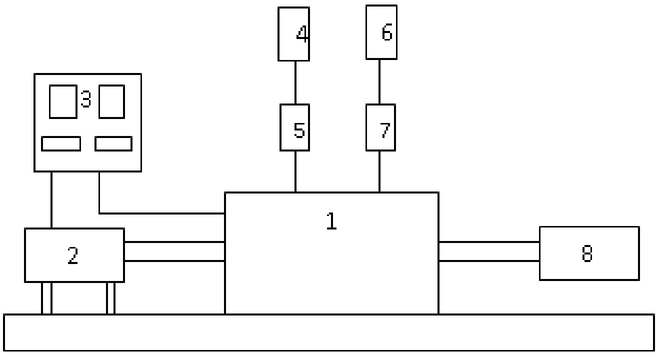

Figure 2: Schematic view of experimental setup. (1) Diesel Engine,(2) Dynamometer, (3) Control panel, (4) Fuel tank, (5) Fuel flow meter, (6) Air tank, (7) Air filter, (8) Gas analyzer.

Ferrofluid mixed diesel was tested in a diesel engine for the performance. Load test was conducted at constant speed and for various percentage of brake power. The setup used for the testing consists of a single cylinder, four-stroke engine, an alternator and an electrical loading arrangement. The alternator is connected to the output shaft of the engine. Bulb type loading was used in the loading arrangement. The various performance measures were found out and plotted against the brake power.

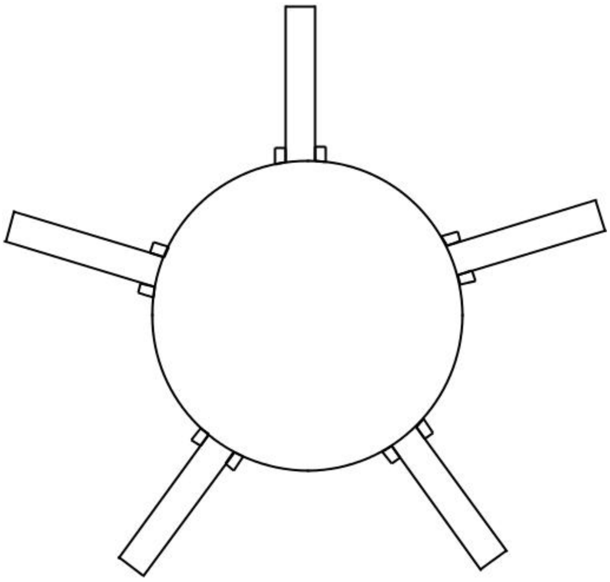
FIGURE 3: Schematic view of magnetic bar located in the exhaust pipe.

To conduct the engine performance and emission test, the ferrofluid obtained by chemical process is blended with petroleum diesel to get a volume proportion of 4%, 8% and 12% volumetric proportions of ferrofluid. The experiments were conducted at no load, 50% of full load, and 75% of full load conditions with ferrofluid blend and pure diesel operation. Data such as fuel flow, exhaust temperature, exhaust smoke opacity etc were recorded at this condition. Steady state performance and emissions readings are taken during each trial run and the average of the experimental results are used for further calculations.

IV. RESULT AND DISCUSSION

4.1. Engine Performance.

The brake-specific fuel consumption (BSFC) and the brake thermal efficiency (BTE) can be calculated by the engine torque, the engine speed, and the mass consumption rate of the fuel. Figures 4 and 5 show the BSFC and the BTE variations under different loads for 1500 rpm. For all fuels, the BSFC decreases with an increase in the engine load, while the BTE increases with the increase in engine load for all different fuels. This is obvious from the fact that the increase in fuel required to operate the engine is less than the increase in brake power at higher loads.

As shown in Figure 4, adding a ferrofluid to diesel fuel will decrease the BSFC. According to experimental results, adding 0.4% ferrofluid to diesel fuel decreased the BSFC relatively by 3.23–6.45%, and adding 0.8% ferrofluid to diesel fuel decreased the BSFC relatively by 5.06–10.85%.

The decrease in BSFC can be due to the positive effects of nanoparticles on physical properties of fuel and also reduction of the ignition delay time, which lead to more complete combustion. In addition, it can be due to effects of nanoparticles on fuel propagation in the combustion chamber. On the other hand, nanoparticles added to diesel fuel increase the mixture momentum and, consequently, the penetration depth in the cylinder. As a result, combustion is improved.This result is also in agreement with similar experiments done.

In addition, the higher viscosity of the emulsified fuel than that of the base fuel and the presence of water promote a finer, cloud-like atomization of the emulsified mixture during injection, resulting in improving combustion efficiency significantly.

It has been claimed that the water in the emulsified fuel improves the combustion process owing to the simultaneous additional braking of the droplets, to the increase in evaporation surface of the droplets and to better mixing of the burning fuel in air

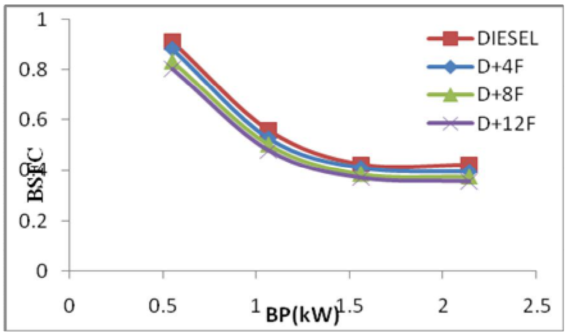

Figure 4; variation of BSFC under different loads for all fuels.

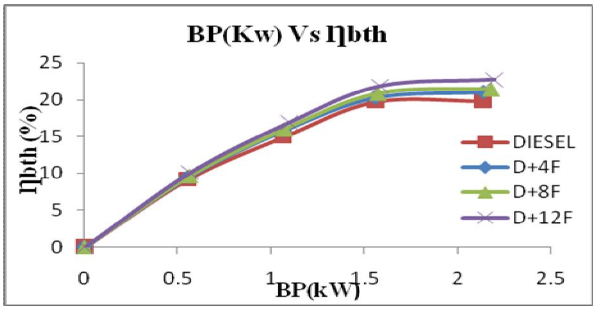

Figure 5;variation of BTE under different loads for all fuels.

BTE is dependent on BSFC, and thus the BTE of D+4F, D+8F and D+12F similarly improved compared to diesel fuel for the same reasons.

As shown in Figure 5, BTE increases with an increase in load for each fuel. Adding 0.4% ferrofluid to diesel fuel increased the BTE by 3.33–6.89% relatively and adding 0.8% ferrofluid to diesel fuel increased the BTE by 5.33–12.17% ang adding 1.2% ferrofluid to diesel fuel increased 7.45-14.56% relatively.

Based on the results, it can be concluded that adding ferrofluid to diesel fuel has a perceptible effect on engine performance.

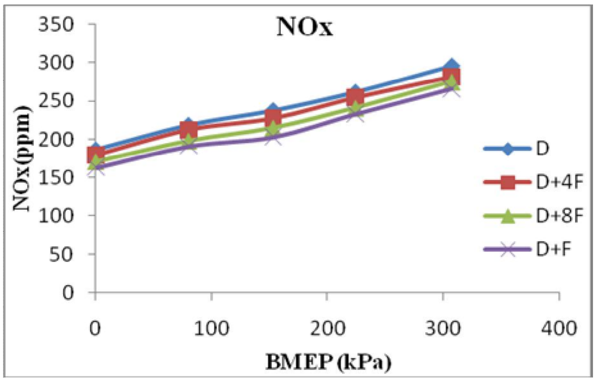

Figure 6;Variation of NOx with respect to engine load at 1500 rpm.

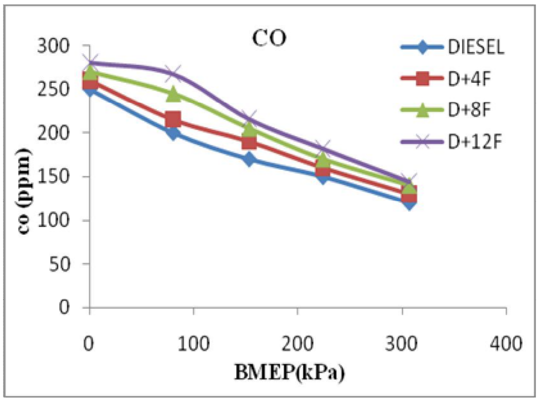

Figure 7; Variation of CO with respect to engine load at 1500 rpm.

4.2 NO_xEmissions.

The variation of nitrogen oxides (NO_x)emissions with load for different fuels. NO_xemissions increase with engine load for all fuels. Furthermore, compared with diesel fuel, D+4F, D+8F and D+12F decreased NO_xemissions at all loads. Adding 4% ferrofluid to diesel fuel decreased NO_xemissions by 8 to 21 ppm, adding 8% ferrofluid to diesel fuel decreased NO*x* emissions by 12 to 25 ppm and adding 12% ferrofluid to diesel fuel decreased NO*x* emissions by 17 to 30 ppm. Many factors contribute to the formation of NO*x* emissions. According to the Zeldovich mechanism, the formation of NO*x* is dependent on oxygen concentration, residence time, and temperature .This reduction may be due to the latent heat of evaporation of water, the high thermal capacity of water, and also nano particles, which can reduce the temperature in the combustion chamber and consequently reduce NO*x* emissions.

4.3. CO Emissions.

Adding ferrofluid to diesel fuel increases CO emissions. Adding 4% ferrofluid to diesel fuel increased CO emissions 11 to 18 ppm, adding 8% ferrofluid to diesel fuel increased CO emissions by 23 to 32 ppm and adding 12% ferrofluid to diesel fuel increased CO emissions by 30 to 43 ppm . CO emission greatly depends on the air-to-fuel ratio relative to stoichiometric proportions. Generally, CI engines operate with lean mixture, and hence CO emissions would be low. Nano particles may have affected fuel propagation in the combustion chamber. The increase in CO emission may be due to operation of the engine using D+4F, D+8F and D+12F in different situation compared to diesel fuel. As mentioned before, nanoparticles may have affected fuel propagation in the combustion chamber. Hence, the increase in CO emission may be due to operation of the engine using D+4F and D+8F in different situation compared to diesel fuel.

4.4. Nanoparticles.

As mentioned previously, a magnetic bar was used to see whether nanoparticles added to diesel fuel can be collected or not.

After all tests, a magnetic bar was placed at the exhaust pipe for five minutes. After removal, it was observed that a portion of the magnetic nanoparticles were collected. Figure 8 shows the collected magnetic nanoparticles. Therefore, the results demonstrate one of the most important advantages of using ferrofluids as compared to other nanofluids; that is, magnetic nanoparticles can be collected and will not cause pollution.

V. CONCLUSION

Experimental measurements and analysis were conducted on a four-stroke diesel engine to investigate the effects of adding water-based ferrofluid to diesel fuel. Engine tests were done for emulsified diesel fuels of 0, 0.4, 0.8 and 1.2ferrofluid/diesel ratios by volume at 1500 rpm.

The test results indicated that adding ferrofluid to diesel fuel not only improves engine performance (increasing BTE and decreasing BSFC) but also reduces NO_x emissions. However, CO emissions increase. Furthermore, the results showed that increasing ferrofluid concentration will magnify the results.

In addition, results indicated that magnetic nanoparticles added to diesel fuel can be collected at the engine exhaust.

However, further research and development on the collection of magnetic particles is also necessary.

VI. ACKNOWLEDGMENT

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