4 The Study of High-Temperature Reaction Responding to Diesel Engine Performance and Exhaust Emission by Mixing Aluminum Nanofluid in Diesel Fuel

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Hydrogen burns directly in diesel engine in the presence of active aluminum nanofluid when aluminum nanofluid, which is made by applying a plasma arc welding machine to nano-aluminum-powder submered in water is mixed into diesel fuel, the high temperature inside the cylinder after fuel is burnt can cause the aluminum powder in to decompose the water to yield the hydrogen. Nano aluminum powder exist the nano meter scale, and so provides a large surface area and high activity in the decomposition of hydrogen from water, increasing the heat. The results show that adding certain aluminum nanofluid to diesel fuel burn not only saves fuel, but also reduces the concentrations of smoke, oxides of nitrogen and hydrocarbons in the exhaust emission from diesel engine.

Keywords: **Nano-Aluminum-Powder, Nanofluid, Plasma, Exhaust Emission**

1. INTRODUCTION

Hydrogen gas is clearly a promising alternative, to fossil fuels, since it has higher energy efficiencies and is associated with lower emissions than hydrocarbon fuels [8]. Scientists have applied the nano technologies to human lives in a wide variety such as biomedical, material, computer and fuel engineering fields. The nano fuel, in the form of a powder has extremely powerful energy-saving ability. Adding it to the ordinary fuel increases the combustion efficiency of the fuel and improves the stability of combustion. Studies have shown that water can react with aluminum powder to generate hydrogen and hence increase fuel's heating value. Adding 0.5% nano-aluminum powder to a rocket's solid fuel can improve 10% to 25% combustion efficiency and increase combustion speed by tens of times [1]. The catalytic activity of a metal catalyst (Fe/Al_2O_3) can yield hydrogen by decomposition [8]. Nano-aluminum-powder has a very high activity and can react with water at temperature from 400 to 660 Celsius degrees to generate hydrogen and improve fuel combustion [7]. The cited studies have shown that nano-aluminum-powder promotes fuel combustion. Therefore, in this study, home-made nanofluid in the form of aluminum oxide submerged in water is added to diesel fuel to explore the influence toward fuel consumption, exhaust emission and combustion feature of diesel engine, and display the result to public for reference. According to study made by Department of Energy, University of Chicago [7], OH^- and atomic H_2O will react with aluminum powder to generate hydrogen and promote fuel combustion. The catalyzer of nano aluminum powder to diesel fuel to study its effect on fuel consumption, exhaust emission and the combustion in diesel engine. The results are references for the public. According to the department of Energy, University of Chicago [7], OH^- and molecular H_2O react with aluminum powder to yield hydrogen and promote fuel combustion. The nano aluminum powder catalyzes by decomposing water to yield hydrogen, which burns in the internal combustion cylinder. Accordingly this new fuel, hydrogen, can be obtained from water to burn in diesel engine.

2. COMBUSTION THEOREM OF NANO-ALUMINUM-POWDER

Nano-aluminum-powder can react with water at high-temperature and to generate hydrogen promoting the combustion of the fuel [3] [4] [7]. Due to the nano aluminum powder is in nanometer, it can contribute to more surface area and high activity to decompose the hydrogen from water and increase heat value. With Aluminum Oxide (Al_2O_3) nanofluid, then use ultrasonic vibrator to make vibration in order to produce emulsified nano-aluminum liquid in a chemical molecule structure of $(H_2O)^\cdot(Al_2O_3)$. Then an agitator is applied to constantly agitate the nano-aluminum solution and diesel fuel, before the mixed fuel is ejected into the cylinder to enable the combustion reaction to proceed. When $(H_2O)^\cdot(Al_2O_3)$ is mixed with diesel fuel and burn in cylinder it reacts and create OH^- (Hydroxyl Radical) and atomic H_2O in a high-temperature state. According to the Department of Energy, University of Chicago [7], OH^- and atomic H_2O will react with aluminum powder to generate hydrogen and promote the combustion of fuel; the reaction equation is $2Al + 2(OH)^{-} + (H_2O) \rightarrow (Al_2O_3) + 2H_2$. Diesel fuel ($C_nH_m$) is a stable organic molecule. Its electronic structure, its lack of polarity and any the absence of any functional group make it difficult to decompose into its constituent elements. However, high temperature processes for the thermal decomposition of diesel fuel have been [8]. Nano aluminum powder catalyzes by decomposition the water to form hydrogen which burns in the internal combustion cylinder. Some studies have shown that the hydrogen is a high quality fuel with that burns rapidly and cleanly [9].

3. EXPERIMENTAL PROCEDURE

3-1. Preparing Nanofluid

A plasma electric arc welding machine was improved as a nano production system in the experiment. Figure 1 presents the nano liquid production system which was established by improving the plasma electric arc welding machine.

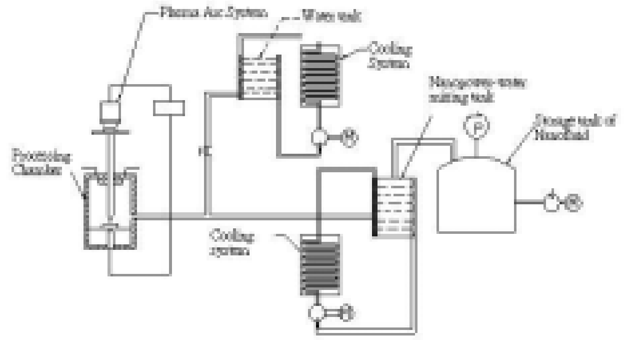

Fig. 1 Schematic diagram of plasma nanofluid system

Experimental results indicate that the plasma nanofluid system has a cooling temperature from 25 to 5 Celsius degrees. At a temperature of 5 Celsius degrees and a current of 50 Amper, system yields aluminum oxide of a preferred size. Figure 2 displays the XRD analysis for the crystalline phase of Aluminum Oxide (Al_2O_3). The crystalline phase was determined by X-ray Diffraction (XRD, MAC-MXP18). All peaks obtained by XRD analysis were assigned by comparison with data from the Joint Committee on Powder Diffraction Standards (JCPDS).

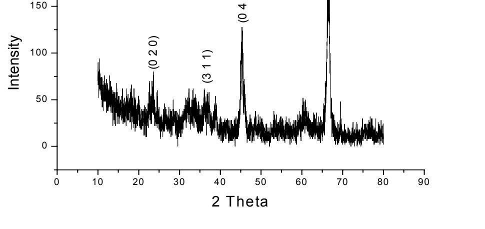

Fig. 2 XRD analysis of nanofluid particles

The microstructure of the prepared nanofluid was determined using a Transmission Electron Microscope (TEM, JEOL JSM-1200EX2). Figure 3 depicts an image of aluminum oxide particles with diameters from 20-50nm.

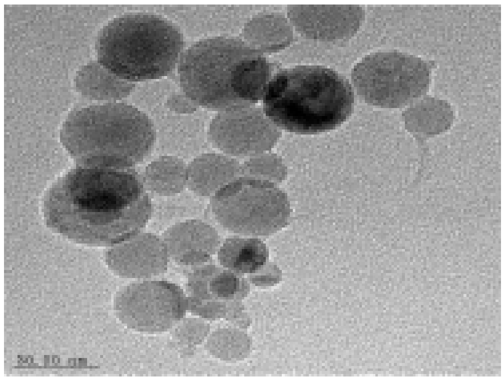

Fig. 3 The TEM image of Aluminum Oxide

Figure 4 displays the experimental equipment used herein. The agitator will continuously agitate the diesel fuel and aluminum nanofluid (AN) to make sufficient mixing to the mixed fuel adequately; the mixed fuel then passes through the diverting valve ③ and is sent to the fuel meter and the stabilized hydraulic pump, it then enters the spray nozzle of the single-cylinder diesel engine. The combustion status of the cylinder in the engine cylinder is transmitted to the combustion analyzer through the pressure transmitter and the encoder, it is transformed there and finally sent to the computer ⑪ .The screen displays the mean combustion pressure inside engine cylinder for 200 combustion cycles and plot the heat release rate curve. Meanwhile, the engine's exhaust emission concentrations are measured by NO_x analyzer, a smoke meter and an HC analyzer as the exhaust passes through the gas-storing tank.

3-2. Experimental procedure

In this experiment, a single-cylinder diesel engine is used in a horsepower testing machine with the specifications indicated in Table 1. After the engine's working temperature reaches about 80 Celsius degrees. Its power output is tested; during the test, the engine is cooled continuously to keep it in a certain temperature range. The cooling water is circulated and the output power data measured under these controlled test conditions. First, the engine's RPM is set to the specified test range, then increase fuel throttle to increase engine load toward the maximum value under stable state. And next we start measuring the experimental data regarding various exhaust emission concentrations and combustion curves after 200 sampling combustion cycles. Followed by repeating the same procedure under reduced loads in the order of 40Nm, 35Nm, 30Nm, 25Nm, 20Nm and

15Nm sequentially till the minimum test load of 12N-m, to measure the fuel consumption, sample exhaust emission concentration values and make combustion analysis curves of different test loads. The test fuel applied in this experiment is high-quality diesel fuel product; the AN additive is from the 40 to 60 nanometer aluminum oxide add from 30cc to 50cc to 1 liter diesel fuel, then use the ultrasonic vibrator developed to vibrate for 15 minutes to form the experimental nano-aluminum diesel fuel.

4. EXPERIMENTAL RESULT AND ANALYSIS

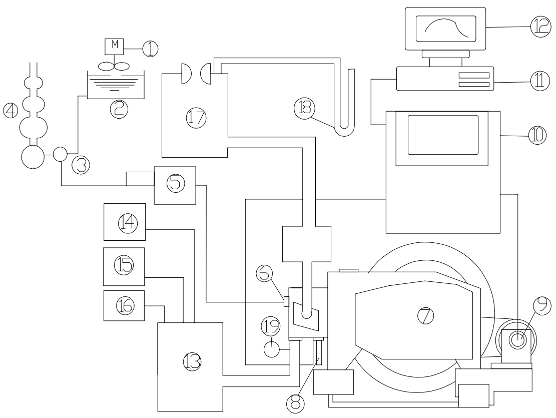

Fig. 4. Layout of experimental equipment

① Mixer
② Fuel tank & Mixed fuel
③ Three way valve
④ Bullet
⑤ Fuel pump with regulator
⑥ Injector
⑦ Single diesel engine
⑧ Transducer
⑨ Rotary encoder
⑩ AVL combustion analyzer
⑪ Mirco computer
⑫ Monitor
⑬ Exhaust gas tank
⑭ NOx meter
⑮ Smoke meter
⑯ HC meter
⑰ Surge tank
⑱ U gauge

Table 1. Experimental diesel engine specification

	Type	YANMAR TF110-F
1	Cycle	4
2	Number of Cylinder	Horizontal Single
3	Bore×Stroke (mm)	88×96
4	Displacement Volume (cc)	583
5	Compression (ε)	17.9
6	Intake System	Naturally Aspirated, Single Valve
7	Exhaust System	Single Valve
8	Diameter of Plunger (mm) Type of Injection Opening Pressure (MPa) Injection Timing Injection Angle	φ8 4-Hole Nozzle 19.6 BTDC 17° 150°
9	Power (HP/rpm)	11/2400

This work uses the experimental equipment described above and follows the specified test procedure to add nano-aluminum-powder additive to diesel fuel to form the mixed fuel (AN+D). Pure diesel fuel (D) is also used. After the experiments were performed using an engine horsepower testing machine, an exhaust emission analyzer and other relevant test equipment/instruments, the resulting, Brake Specific Fuel Consumption (BSFC), exhaust emission concentrations (Smoke, NOx and HC), heat releasing diagram and pressure indicating diagram inside the engine cylinder, were compared. The results of the analysis are presented below.

4-1. BSFC comparison

Table 2 present data on BSFC and BMEP (Brake Mean Effective Pressure) for values of both Diesel (D) and aluminum nanofluid mixed diesel (AN+D) fuels at three rate of revolution of the engine. As indicated, the BSFC values of AN+D fuel at 1200rpm and 1800rpm are lower than those of D fuel. The significant point is at the highest load at 1200rpm. Yet, at 2400rpm the BSFC value of the AN+D fuel slightly exceeded that of D fuel, perhaps because as the engine speed is up, the combustion time is delayed and hence decrease the peak combustion temperature and reduce hydrogen amount generated by aluminum nanofluid (AN).

Table 2. BSFC deviation rate of AN+D fuel and D fuel under varied loads

Tested fuel / Eng. rpm / Eng. load	BSFC (g/kwh) mean-value	
	AN+D	D
At 1200 rpm All loads	239.26 (-1.62%)	243.19
At 1800 rpm All loads	244.35 (-0.39%)	245.30
At 2400 rpm All loads	254.92 (+0.92%)	252.60
Total mean value	246.17 (-0.35%)	247.03

Table 2 shows the BSFC total-mean-deviation rate of the two fuels at three different rpm. As displayed, the BSFC of AN+D fuel is around 0.35% lower than that of D fuel, when averaged over all loads at the three different engine revolutions. The difference is lower as the rate of revolution of the engine increase. Therefore, the fuel saving peak at 1200 rpm and maximum load.

4-2. Smoke comparison

Table 3. Smoke deviation rate of AN+D fuel and D fuel under varied loads

Tested fuel / Eng. rpm / Eng. load	Mean smoke concentration (%)	
	AN+D	D
At 1200 rpm All loads	18.00 (-17.71%)	21.88
At 1800 rpm All loads	19.00 (-14.74%)	22.29
At 2400 rpm All loads	15.83 (+1.06%)	15.67
Total mean value	17.61 (-11.69%)	19.94

As can be seen from Table 3, the smoke concentration of AN+D fuel is lower than that from D fuel in all loads at 1200 and 1800 rpm. This probably because the reason that the nano-aluminum-powder additive contains moisture that make slight explosion on the emulsified fuel drains and hence eliminates the smoke concentration [4-7]. The smoke concentration of the AN+D fuel is about 11.69% lower than that of D fuel in the total-mean value of all loads at three different engine revolutions. The difference falls, as the engine rate of revolution increased. Therefore, the smoke concentration is most effectively reduced at 1200 rpm and maximum load.

4-3. NO_x comparison

Table 4 indicates the NOx concentration versus BMEP curves for D fuel and AN+D fuel of all loads at three engine revolutions. It can be seen that the NO_x concentration of AN+D fuel is lower than that of D fuel in all loads at 1200 and 1800 rpm, probably because the nano-aluminum-powder additive contains moisture causing slight explosions in the emulsified fuel drains. The latent evaporation heat of water and its high thermal capacity also reduce the temperatures in the combustion chamber, thus retarding nitrogen oxide build-up. The NO_x concentration of AN+D fuel is about 2.18% lower than that of D fuel in the total-mean value of all loads at three different engine revolutions. Besides, at 1200 rpm running in maximum load the hydrogen burning makes the combustion not to decrease apparently and thus makes the NO_x concentration caused by AN+D is higher than caused by D [3].

Table 4. NOx deviation rate of AN+D fuel and D fuel under varied loads

Tested fuel / Eng. rpm / Eng. load	Mean NOx concentration (ppm)	
	AN+D	D
At 1200 rpm All loads	366.25 (-3.93%)	381.25
At 1800 rpm All loads	419.29 (-2.75%)	431.14
At 2400 rpm All loads	391.17 (+0.17%)	390.50
Total mean value	392.23 (-2.18%)	400.96

4-4. HC comparison

Table 5 indicates the HC concentration versus BMEP for D fuel and AN+D fuel of at all loads at three engine revolutions. The HC concentration of AN+D fuel is lower than that of D fuel in all loads at 1800 and 2400 rpm, especially apparent for loads in 1800rpm. This is caused from enhancing airflow in the combustion chamber while increasing engine's revolution; second, the hydrogen and slight explosion on the emulsified fuel drains that speed up combustion speed and therefore decrease HC concentration [1]. The HC concentration of AN+D fuel is about 16.6% lower than that of D fuel averaged over all loads at the three different engine revolutions. The difference between HC concentrations is greatest at rates of 1800 rpm and 2400 rpm when it exceeds 20%.

Table 5. HC deviation rate of AN+D fuel and D fuel under varied loads

Tested fuel / Eng. rpm / Eng. load	Mean HC concentration (ppm)	
	AN+D	D
At 1200 rpm All loads	46.50 (+5.08%)	44.25
At 1800 rpm All loads	60.86 (-25.78%)	82.00
At 2400 rpm All loads	35.33 (-21.19%)	44.83
Total mean value	47.56 (-16.60%)	57.03

4-5. Combustion feature comparison

The consumption of diesel fuel to which had been added aluminum nanofluid additive is slightly lower than that of pure diesel fuel. The exhaust emission from AN+D fuel is lower than from D fuel in all respects. This section uses the curves used in combustion analysis, such as the heat releasing rate cure and the combustion pressure curve inside the engine cylinder, to verify if the fuel consumption and exhaust emission result can comply with the actual combustion result or not. Figure 5 and 6 plot the heat releasing rate and the combustion pressure inside the engine cylinder curve for D and AN+D fuels at 1200rpm and the specific load BMEP about 8.4kg/cm^2. Figure5 reveals that at a particular concentration of aluminum powder, the heat release area under cure cover increases slightly according to the water added from 3% to 6%. The heat release rate of diesel is lower than that of any AN+D fuel suggesting that the burning of hydrogen contributes slightly to the heat release rate by thermocatalytic decomposition at water from 3% to 6%.

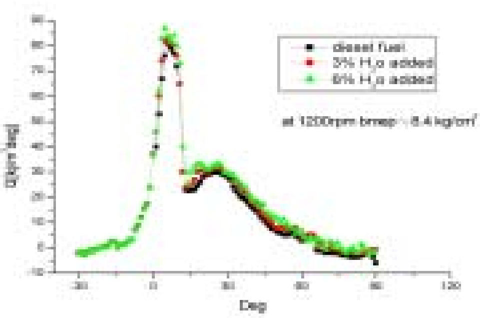

Fig 5. Heat release rate inside engine cylinder for various added volumes of water

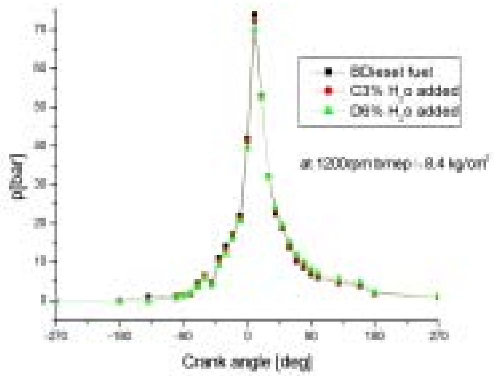

Fig 6. Combustion pressure inside engine cylinder

Figure 5 shows that AN+D fuel has a slightly larger heat release rate for a given amount of water added. Therefore, less fuel is consumed. Although diesel fuel yields a higher peak combustion pressure inside the engine cylinder at 1200 rpm emissions from AN+D has a slightly lower NOx concentration because nitrogen oxide is formed at high pressure and temperature. On the other hand, AN+D fuel has a more active and stable diffusing combustion stage caused the diesel fuel burn completely it thus gets lower HC concentration as well.

5. CONCLUSION

In this study, AN additive is added to diesel fuel to test engine performance, exhaust emission and combustion characteristics, for constant design parameter and a single-cylinder engine. The fixed parameters are fuel injection pressure, injection timing, compression ratio and geometry of the combustion chamber. The experimental results are applied to investigate characteristics of the engine, the exhaust emission and the combustion of the mixed fuel. Following the analysis, the experimental results are compared and several solid conclusions drawn.

1. AN additive was successfully made using a plasma electric arc welding machine.
2. The rate of consumption of AN+D fuel is approximately 0.35% less than that of D fuel. AN+D fuel has an exhaust emission concentration of 11.69% lower than that of D; AN+D fuel emits about 2.18% less NO_x and 16.6% less HC.
3. AN+D fuel has slightly higher heat release rate and so it is consumed more slowly. Besides, AN+D fuel has shorter flaming and delay stages than D one and so the smoke concentration is lower. D fuel has the higher peaks heat release rate and combustion pressure inside the engine cylinder, both fuels have similar premixing periods in the initial stage, AN+D fuel has a lower NO_x concentration in its emission. On the other hand, AN+D fuel has a more active and stable diffusing combustion stage it thus gets lower HC concentration as well.
4. Hydrogen provides low-pollution highly explosive combustion and so forms a valuable fuel when AN is added to diesel fuel for combustion in an engine.
5. The advantages of this method are the efficiency of heat transfer caused by direct hydrogen burning and no need the hydrogen storage.

This work discusses the production of hydrogen via thermocatalytic decomposition for use in diesel engine combustion. Adding a particular quantity of aluminum nanofluid to diesel fuel not only reduces fuel consumption, but also improves the exhaust emission concentration from the diesel engine. As oil resources drop, hydrogen fuel must be used. However, the optimal amount of aluminum nanofluid additive is being examined further to maximize fuel-efficiency and minimize pollution.

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