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Experimental investigation of unmodified diesel engine performance, combustion and emission with multipurpose additive along with water-in-diesel emulsion fuel

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ABSTRACT

The inspiration of the present work emerges from the formulation to enhance the combustion, emission and performance of a single cylinder diesel engine through modifying the fuel by adding an additive together with water-in-diesel emulsion fuel. 1,4-dioxane a hygroscopic, multipurpose substance was considered as one of the irreplaceable additive to be included with the ideal mix of DWS (89.8%diesel + 10%water + 0.2%surfactant) to enhance the engine attributes. In the present work, 1,4-dioxane was mixed with the optimized blend of DWS (10% water and 89.8% diesel), with varying concentrations of 5, 10, 15, 20% and denoted as DWSA5, DWSA10, DWSA15, DWSA20 respectively. With the expansion of 1,4-dioxane, the physical properties were enhanced. The sample fuels were analyzed with Fourier-transform infrared spectroscopy (FTIR) in order to find functional groups. An experiment was conducted with test fuels in a single cylinder, unmodified diesel engine. From the experimental data, it was revealed that, brake thermal efficiency (BTE) of DWSA10 increases up to 7% when compared with diesel fuel. Hydrocarbon (HC) and smoke decreases up to 31.66%, 27.83% respectively with diesel fuel. Brake specific energy consumption (BSEC) and carbon monoxide (CO) of DWSA10 decreased about 7.5%, 15% respectively on par with DWS fuel. From the obtained results, it was identified that test fuel (DWSA10) containing 10% 1,4-dioxane shows significant improvement in the engine performance and reduction in emission. DWSA10 may play a significant role for diesel engine in future without modifying the engine.

1. Introduction

Diesel engines are the prominent source of power for vehicles. The most energy efficient sources in the world are diesel engines when compared with gasoline engines. Majority of fuel was consumed by off road and on road vehicles, marine transportation, agriculture, industrial sectors, generators etc. Due to affordable fuel consumption, high power delivery, rigid structure, higher brake thermal efficiency, diesel engines are preferred over gasoline engines [1]. Diesel engines emit pollutants such as carbon monoxide, hydrocarbon, nitrogen oxides and smoke that are considered to be the important parameters [2]. Modern day researchers are instrumental in finding the sources to reduce emission without modifying the engine. Exposure of continuous emission results in causing suffocation leading to lung damage and irritation to eyes [3,4].

In the present scenario a great challenge for the researchers is to innovate and bring new techniques in order to mitigate emissions, improve the engine efficiency and reduce brake specific energy consumptionof engine without engine modifications. Various types of alternatives such as biodiesel, additives [5,6] (such as metal oxides, nanoparticles, cetane number improver) fuel borne catalyst, oxygen enrichment [7] and water-in-diesel emulsion (W/D) [8] have been

Abbreviations: CO, Carbon Monoxide; HC, Hydro Carbon; NO_x, Oxides of Nitrogen; BTE, Brake Thermal Efficiency; BSEC, Brake Specific Energy Consumption; EGT, Exhaust Gas Temperature in ^{0}C; HRR, Heat Release Rate; CHRR, Cumulative Heat Release Rate; DWS, Diesel 89.8% + 10% Water + 0.2% Surfactant; DWSA5, Diesel 84.8% + 10% Water + 0.2% Surfactant + 5% 1, 4-Dioxane; DWSA10, Diesel 79.8% + 10% Water + 0.2% Surfactant + 10% 1, 4-Dioxane; DWSA15, Diesel 74.8% + 10% Water + 0.2% Surfactant + 15% 1, 4-Dioxane; DWSA20, Diesel 69.8% + 10% Water + 0.2% Surfactant + 20% 1, 4-Dioxane; BTDC, Before Top Dead Center; ASTM, American Society for Testing and Materials; HSU, Hart ridge Smoke Units; FTIR, Fourier Transform Infrared Spectroscopy; SEM, Scanning Electron Microscope; EDS, Energy Dispersive X-ray Spectroscopy

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tested with diesel engines to achieve the aforesaid standards. Among the above-mentioned substitutes, water-in-diesel emulsified fuel could be the major contribution in the form of reducing NO_x and particulate matter (PM) [9]. As the water content increases, the formation of NO_x and smoke reduces. But contrarily, fuel consumption, CO and HC emissions increases [10,11].

The researcher Lin et al. [12], studied the combustion, performance and emission characteristics of diesel engine fueled with oil-in-water-in-oil emulsion fuel along with diglyme additive (combination enhancer) and further compared the results with neat diesel. The study revealed that CO levels of W/D emulsified fuel were higher due to incomplete combustion caused by latent heat of vaporization of water present in emulsion fuel and it is reduced by adding diglyme combustion enhancer. NO_x emissions are reduced due to presence of water content. The investigator Lin et al. [13] experimented the diesel engine with two-phase and three-phase emulsion fuel. They used 10% and 20% water content to prepare the emulsified fuel. From the results, they concluded that emulsified fuels increased the CO levels when compared with diesel fuel. NO_x emission was reduced by 56.82%. Subramanian [14] conducted experiments with diesel-water emulsion fuel and water injection to intake manifold. On his conclusion, he proved that NO_x and smoke decreased by water-diesel emulsion fuel than injection method. CO and HC levels were higher with emulsion fuel. Lin et al. [15] studied the effect of speed with water-in-oil and oil-in-water-in-oil emulsion fuel and they found that specific fuel consumption and CO emissions showed increase whereas NO_x emissions are found to decrease. Yang et al. [16] used novel emulsified fuel with organic additives wherein they found that NO_x reduced by 30.6% while the CO and HC slightly increased. Ogunkoya et al. [17] studied emulsion fuel stabilized with wood lignin. They noted that emulsion fuel increases the BTE, BSFC, CO and HC levels but reduces the NO_x. Sadhik et al. [18] concluded experiments with diesel, W/D and W/D with nano particle additives. Their results proved that specific fuel consumption and BTE have increased for both W/D fuel and nano mixture. NO_x has reduced for both diesel-water fuel and nano particles, but CO and HC of W/D fuel has increased, and it should be reduced by addition of alumina nano particle. Hasannuddin et al. [19] studied the diesel engine with E10 (89% Diesel + 10% water + 1% SPAN 80) and E20 (79% Diesel + 20% water + 1% SPAN 80). Their results proved that NOx was decreased to 14.40% for E10 and 54.45 for E20 respectively on par with neat diesel. PM was lowered by 7.5% for E10 and 15.47% for E20 on par with diesel. Fuel consumption has increased to 28.57% for E10 and 33.33% for E20 in comparison with diesel. CO were increased to 43.64% for E10 and 78.10% for E20 on par with diesel fuel.

Watanabe et al. [20] experiment the diesel engine with two emulsion fuels such as E10 (Diesel + 10% water + 1% SPAN 80) and E20 (Diesel + 20% water + 1% SPAN 80). They found that specific fuel consumption has increased. NO_x and PM decreased by 51% and 14% for W/D emulsion fuel. But the CO has been higher for both E10 and E20 fuels on par with diesel fuel.

Ahmed et al. [21] performed engine test with two different emulsion fuels namely stable emulsified fuel (Diesel + 5% of water + 0.2% SPAN 80) and real time fuel (or) unstable emulsified fuel (Diesel + 5% of water). Both stable and unstable fuels were tested with diesel engine and the result was compared with neat diesel. The unstable emulsified fuel increases BTE up to 3.59% and specific fuel consumption reduced up to 3.89%. NO_x and PM lowered by 31.66% and 16.33%. CO for both stable and unstable emulsified fuel was higher when compared with neat diesel. Nurul et al. [22] investigated a light duty truck with non-surfactant emulsified fuel [RTES – Real Time Emulsion Fuel Supply System]. The RTES fuel was made by different water concentrations of 5% (E5), 6.5% (E6.5), 10.8% (E10.8) and 30% (E30) with Euro5 diesel. RTES device was mounted with the truck in order to make non-surfactant fresh emulsion fuel. They conducted experiment with 1 ton ISUZU diesel engine. Their results reported that NO_x was reduced to a maximum of 45% for E6.5 and also smoke was reduced. However, CO has increased up to 159% for E30 with increase in load. At low load, CO for E5 fuel slightly increases.

Over all, with W/D emulsion fuel, the performance of engine such as BTE and SFC increases. Engine emissions like NOx and smoke was reduced with W/D fuel. But CO and HC always increase with W/D fuel. Some literatures exhibit that CO and HC can be reduced by a multipurpose additive. In this study an endeavor has been made to enhance the performance, emission and combustion by adding 1,4-dioxane with DWS in the proportions of 5%, 10%, 15%, 20% to form DWSA5, DWSA10, DWSA15, and DWSA20 respectively. 1,4-dioxane was not yet used in W/D emulsion fuel.1, 4-dioxane is a multipurpose, colorless, clear liquid with a faint odor, hygroscopic and fully miscible in water. The other names of 1,4-dioxane are dioxan, diethylene dioxide, p-dioxane, dioxane. It is unstable at higher temperatures. 1,4-dioxane was mainly used as solvents in laboratory applications and stabilizer for solvents like 1,1,1, trichloroethane (TCA). 1,4-dioxane can also act as a cleaning agent in making of pharmaceuticals. It is obtained as a by-product, when we process antifreeze agents, dies, grease also in consumer goods like shampoos, cosmetics, deodorants etc. The properties of 1,4-dioxane is shown in Table 1. Sendilvelan et al. [23] investigated the diesel engine with 1,4-dioxane. For this they prepared five fuel blends in different concentrations from 10% to 50%. From the test results, BTE for B10 blend gave superior performance. BSEC of B10 blend was lower when compare to all other blends. Smoke emission was reduced by 18% for B10. NO_x increases for all the blends when compare to diesel fuel. More number of literatures have been shown in the Table 2.

Table 1
Physicochemicalproperties of 1,4-dioxane.

Chemical formula	$C_4H_8O_2$
Molecular weight	88.11 g/mol
Melting point	11.8 °C
Flash point	12 °C
Boiling point	101.1 °C
Water solubility	Miscible
Vapor pressure at 25 °C	38 mm Hg
Density	1.033 g/mL
Self-Ignition temperature	180 °C

2. Materials and methods

2.1. Preparation of test fuels

Based on the literatures [28–30] and from the past experiments, it was identified that 10% of water could improve the engine efficiency and reduce harmful emissions. In the initial stage, 89% of diesel is mixed with 10% water and 0.2% surfactant (Triton X-100) to form DWS. This must be enhanced with high speed homogenization. The mixture is put in to the high-speed homogenizer at the speed of 15,000 rpm for 15 min to get the maximum stability. Triton x-100 is identified as effective surface-active agent in the recent diesel/water emulsion [31]. HLB of triton X-100 is 13.4. In the final stage of test fuel preparation, 1,4-dioxane was added with DWS in the proportions of 5%, 10%, 15%, 20% to form DWSA5, DWSA10, DWSA15, DWSA20 respectively. Adding 1,4-dioxane improves the cetane number and cold flow properties [24,25]. The stability of emulsion could be improved by addition of 1,4-dioxane and the presence of triton x-100. The stability period for DWSA10 fuel is 44 days instead of 28 days as stated by Selim [32]. Fig. 1 shows the ternary plot formed with various percentages of diesel, water, surfactant and 1,4-dioxane. However, adding more amount of 1,4-dioxane (more than 10%) reduces the stability period. All the prepared test fuels were tested for its properties as per the ASTM standards. The properties of the fuel blends are shown in Table 3.