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Real-Time Emulsified Fuel Supply Systems: Effects on Diesel Engine Emissions

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ABSTRACT – *Diesel engines are widely used because of their fuel efficiency in producing a higher mechanical energy ratio compared to gasoline engines. The emulsification technology called the Real-Time Emulsified Fuel Supply System (RTES) has been developed to produce fresh emulsified fuel and eliminate the need for additives like surfactants. The goal of this study is to quantify fuel usage and look at the vehicle's diesel engine's emissions of dangerous gases, including carbon monoxide (CO), nitrogen oxides (NOx), and smoke opacity. The RTES has a rotary blade to improve the efficiency of emulsified production by continuously mixing the oil and water phases during processing. Experiments were conducted on a dynamometer using emulsified diesel fuels containing 10% water by volume. Emission tests were performed on a Nissan Navara at idle, with engine speeds ranging from 800 to 2000 rpm. The findings indicate that emulsified fuel provides notable benefits in lowering NOx emissions and smoke opacity compared to conventional diesel fuel, especially at elevated engine speeds. However, it also tends to raise CO emissions under these conditions. Emulsified fuel presents a viable method to mitigate harmful emissions from diesel engines and serves as an effective alternative for reducing NOx and smoke, particularly in high-speed engines, delivering optimal environmental outcomes.*

KEYWORDS: Emulsified, fuel efficiency, diesel, diesel engine

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1. INTRODUCTION

In recent years, growing concerns have emerged regarding the detrimental impact of diesel engine emissions on human health and air quality, prompting increased attention to the risks associated with these pollutants. Diesel fuel in particular releases particulate matter (PM), total gaseous hydrocarbons (THC), sulfur oxides (SOx), carbon dioxide (CO2), nitrogen oxides (NOx), and carbon monoxide (CO). Additionally, diesel combustion produces smoke that contributes to air pollution, leading to acid rain and global warming (EPA, 2000; Hossain et al., 2017). The primary sources of these emissions, especially NOx, PM, and THC, are the insufficient oxygen during combustion and the presence of aromatic compounds in diesel fuel (Nabi et al., 2017). Furthermore, the combustion process in diesel engines, which is best described as heterogeneous, relies on the diffusion of fuel to the oxidizer. This results in a slower flame propagation compared to premixed combustion.

Many initiatives have been undertaken to address this issue, including the development of advanced engine technologies and the implementation of regulatory measures. Numerous studies have aimed to address pollution issues by developing alternative fuels, modifying engine designs, and applying post-combustion treatment technologies (Farinango-Herrera et al., 2024). In recent years, there has been growing interest in oxygenated fuels, as oxygen enhances combustion efficiency and reduces NOx emissions (Zhang et al., 2024). This approach has gained popularity because it does not require modifications to diesel engine hardware. The challenges and environmental threats posed by diesel fuels are expected to be mitigated by producing oxygenated alternative fuels, which can improve the diffusion process (Lungu et al., 2024). Oxygenated fuels, containing oxygen in their chemical structure, contribute to reduced carbon monoxide and soot emissions by promoting more complete combustion. These fuels generally have positive effects on key properties, such as viscosity, density, and cetane number, by stabilizing combustion temperatures and reducing NOx production (Li et al., 2024).

Fuel blending has been widely researched since biofuels were found to be insufficient as standalone diesel engine fuels. Blending diesel with other compatible fuels creates a new fuel with different properties, potentially enhancing engine performance, reducing pollution, and cutting costs (Deviren, 2024). Oxygenated fuels have become popular because they require no engine modifications. Since 2000, the demand for biodiesel and biofuels has surged, leading to extensive research on blending diesel with biodiesel (How et al., 2018), alcohols (Suhaimi et al., 2018; Song et al., 2018), and combinations of all three (Mahmudul et al., 2018). Biodiesel offers advantages, including the absence of sulfur and high oxygen content, which improve combustion and engine efficiency. With a higher cetane number than diesel, biodiesel also reduces ignition delay. Additionally, biodiesel is readily available in Asian countries like Malaysia and Indonesia. Alcohols, known for their high oxygen content and latent heat of vaporization, also face challenges in achieving stable blends.

The researchers have focused on using fuel blends to reduce emissions without compromising engine performance. This approach has gained momentum with the discovery of the micro-explosion phenomenon during the combustion of emulsified fuels with different boiling points (Shen et al., 2024). Adding alcohol or water to diesel and biodiesel blends through emulsification has been shown to reduce NOx emissions while enhancing engine performance (Vellaiyan, 2024). However, despite findings on the dual benefits of emulsified fuels, there is limited research specifically on their effectiveness in reducing NOx emissions and their broader environmental impact.

Recent efforts have focused on an emulsification technology called the Real-Time Emulsified Fuel Supply System (RTES), which uses a rotary blade (Santoso et al., 2024). This innovative system continuously produces fresh emulsified fuel, eliminating the need for additives like surfactants, making it more cost-effective than traditional methods. The RTES system mixes diesel with water using a rotary blade motor, offering a cheaper alternative to conventional emulsified fuels. This emulsified fuel can serve as an alternative or supplementary fuel, helping to reduce emissions and decrease primary fuel consumption. This new technology is a promising solution to mitigate the environmental impact of sulfur compound emissions from diesel engines. Therefore, this study is to examine RTES's effectiveness in reducing fuel consumption and diesel engine emissions, including carbon monoxide (CO), nitrogen oxides (NOx), and smoke opacity.

2. METHODOLOGY

This study's methodology below, shows the systematic measurement and analysis of data on carbon monoxide (CO), nitrogen oxide (NOx) emissions, and smoke opacity using the RTES device.

2.1 Specification of Vehicle

The RTES was tested on the Nissan Navara engine model, with its specifications detailed in Table 1. Petronas Dynamic diesel was used as the fuel for this experimental study.

2.2 Properties of Fuel

The study utilized a commercial diesel fuel known as Dynamic Diesel Fuel B20, as detailed in Table 2. This fuel has a cetane index and is formulated for use in both low and high-speed self-ignited compression engines, ensuring efficient, reliable, and smooth operation. Additionally, an emulsified fuel was prepared by mixing diesel fuel with water in a 10% ratio. This emulsion was created using the RTES device, which incorporates water, Diesel Fuel B20, and a rotary blade mixer.

2.3 Properties of Water

The diesel and water were the only components for the emulsified fuel. Tap water was used, and its characteristics are presented in Table 3. During the testing, a controller was used to regulate the amount of water added to the emulsified fuel. The actual percentage of water in the emulsified was determined using a weighed scale and formula calculation. The emulsified fuel used in the testing had a 10% and 5% water content.

TABLE 1: Properties of test engine

Parameter	Specification
Model	Nissan Navara
Power	190 Hp @ 4000 rpm.
Torque	450 Nm @ 2000 rpm.
Engine location	Front, Transverse
Engine displacement	2488 cm^3
Number of cylinders	4
Position of cylinders	Inline
Cylinder Bore	89 mm
Piston Stroke	100 mm
Compression ratio	15
Number of valves	16
Fuel System	Diesel Common rail
Engine aspiration	Turbocharger, Intercooler

TABLE 2: Properties of PETRONAS Dynamic Diesel fuel

Properties	Value
Cetene Index	45
Density @ 15oC, kg/m3	815
Sulphur, % m/m	0.5
Distillation, recovery @ 300°C, % vol	40
Final Boiling Point, °C Nil Pour Point, °C	18
Flash Point, °C	60
Conradson Carbon Residue, % m/m	0.1
Cooper Corrosion	1
Ash, % m/m	0.01
Sediment, % m/m	0.01
Total Acid No., mg KOH/g	0.6

TABLE 3: Properties of water

Specification	Water
Density, g/cm3 at 25°C	1.02412
Specific conductivity, μS/cm at 25°C	0.0532
Viscosity, millipoise at 25°C	9.02
Vapor pressure, mm Hg at 20°C	17.4
Isothermal compressibility, vol/atm at 0 °C	46.4 E-6
Surface tension, dyne/com at 0 °C	72.74
Specific heat, J/g °C at 17.5oc	3.898
The temperature of maximum density, °C at -3.25	-3.25
Freezing point, °C	-1.91

2.4 Experiment Setup

Figure 1 illustrates the block diagram of the fueling system integrated with the RTES. The RTES employs both a fuel pump and a water pump to enable the flow of fuel and 10% water into the system. Rotary blades mix the fuel and water, promoting efficient combustion and reducing engine emissions. The RTES is installed between the fuel pump and the engine intake. The device is positioned near the engine inlet to ensure the smooth flow of emulsified fuel into the engine, optimizing combustion and enhancing overall system efficiency by promoting effective mixing with air.

The RTES system enhances safety by incorporating a controller that allows the driver to deactivate the system in case of malfunction or unforeseen issues. This controller ensures a smooth switch to diesel fuel without utilizing the RTES, providing an added layer of safety and control. In the RTES, the return fuel is not reintroduced into the tank to avoid potential issues caused by the separation of diesel and water. Instead, the RTES processes the return fuel from the engine to complete the emulsification process.

The RTES system's performance on fuel consumption and exhaust emissions is tested using the roller dynamometer. Exhaust emissions were measured with a smoke analyzer, Horiba MEXA-600S, and a gas analyzer, Sauermann Sica 130 Kit 3BS, while fuel consumption data was obtained from the flow rate sensor. Figure 2 shows the schematic diagram of dynamometer testing. During the idling test, engine conditions at 800 rpm, 1,000 rpm, 1,500 rpm, and 2,000 rpm will be evaluated using the emission test matrix. Pollutant levels will be quantified in Parts Per Million (PPM).

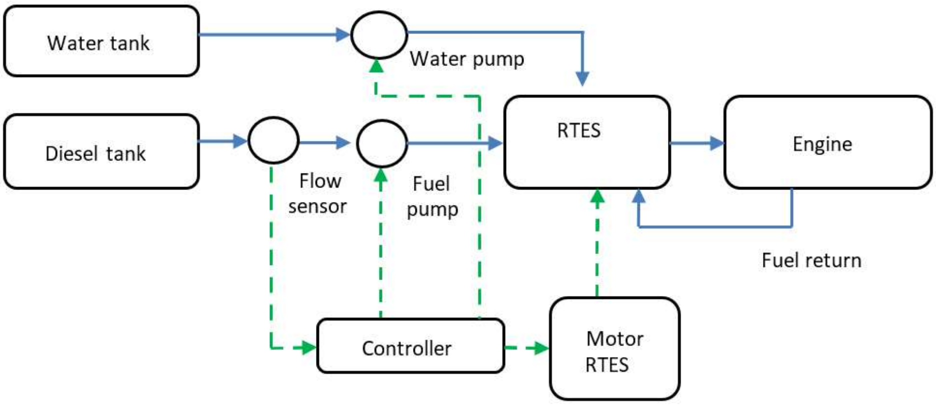

FIGURE 1: Block diagram of RTES device

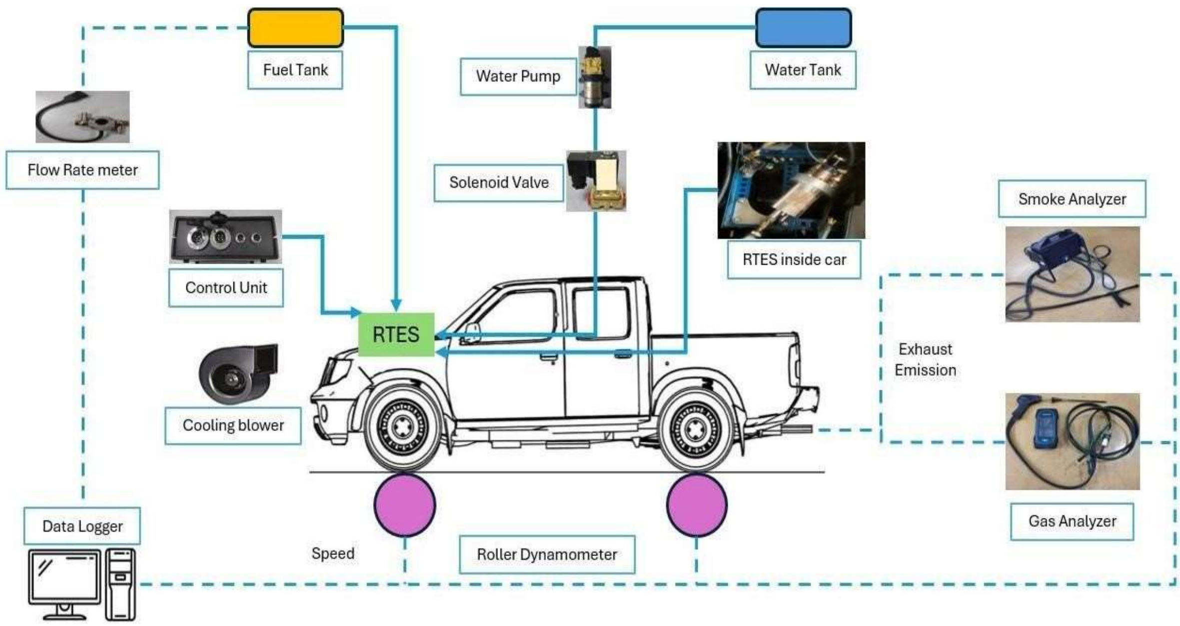

FIGURE 2: Schematic diagram of experimental setup

3. RESULTS AND DISCUSSION

3.1 Carbon Monoxide Gas (CO)

Based on the data shown in Figure 3, there are notable differences in carbon monoxide (CO) emissions between diesel and emulsified fuel at various engine speeds at idle conditions. At 800 rpm engine speeds, diesel fuel produced more CO emissions (275.30 ppm) compared to emulsified fuel (247.80 ppm). A similar pattern is observed at 1000 rpm, where the CO emissions for diesel are 228.40 ppm and for emulsified fuel are slightly lower at 228.10 ppm, indicating a negligible difference. However, as engine speed increases, the trend shifts to 1500 rpm, emulsified fuel produces higher CO emissions (317.85 ppm) compared to diesel (277.18 ppm), showing an increase of about 14.67%. The most significant rise is seen at 2000 rpm, where CO emissions for emulsified fuel reach 422.97 ppm, compared to 307.15 ppm for diesel, indicating a substantial 37.71% increase in emissions. This suggests that while emulsified fuel may reduce CO emissions at lower engine speeds, it leads to significantly higher emissions at higher speeds.

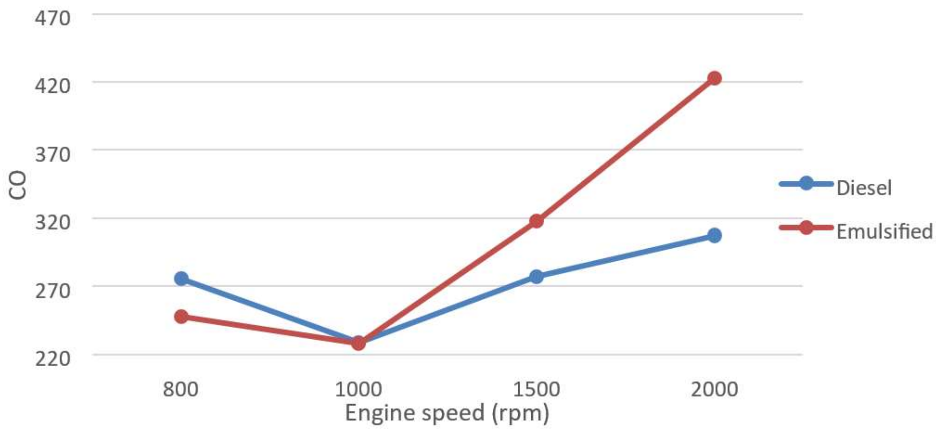

FIGURE 3: Chart of CO gas emission

The higher CO emissions observed when using emulsified fuel can be attributed primarily to the water content present in the emulsion. Water in the fuel mix lowers the overall combustion temperature, which directly affects the chemical reactions necessary for complete combustion. Typically, carbon monoxide (CO) is further oxidized into carbon dioxide (CO2) at high temperatures. However, when the combustion temperature is reduced due to the presence of water, the energy required for this conversion is not achieved. As a result, CO remains in the exhaust gases rather than being converted to CO2.

This incomplete combustion process occurs at higher speeds, where CO emissions from emulsified fuel become significantly greater than those from diesel. The lower flame temperatures hinder the ability of the engine to fully combust the fuel, especially under conditions that demand more energy output, such as at 1500 rpm and 2000 rpm. At these higher speeds, the engine is operating under a heavier load, yet the emulsified fuel, due to its water content, doesn't provide the necessary conditions for efficient combustion, leading to a sharp rise in CO emissions.

3.2 Nitrogen Oxide Gas

The results indicate a reduction in NOx emissions when using emulsified fuel compared to diesel. At 800 rpm, NOx emissions for diesel were measured at 133.10 ppm, while emulsified fuel produced lower emissions at 101.65 ppm. Similarly, at 1000 rpm, NOx emissions were 107.44 ppm for diesel, compared to 87.03 ppm for emulsified fuel. At higher engine speeds, this trend continued, with NOx levels for emulsified fuel recorded at 69.29 ppm and 59.41 ppm at 1500 rpm and 2000 rpm, respectively, compared to 94.7 ppm and 91.36 ppm for diesel.

The reduction in NOx emissions when using emulsified fuel can be attributed to the water content in the fuel mixture, which lowers combustion temperatures. NOx formation is highly temperature-dependent, as higher combustion temperatures facilitate the reaction between nitrogen and oxygen. The presence of water in emulsified fuel absorbs heat during combustion, thereby lowering the peak temperature in the cylinder and inhibiting NOx production. At all engine speeds, emulsified fuel consistently demonstrated lower NOx emissions compared to diesel, with the most significant reductions occurring at the higher engine speeds of 1500 rpm and 2000 rpm. Its potential effectiveness in reducing harmful emissions in high-speed engine operations.

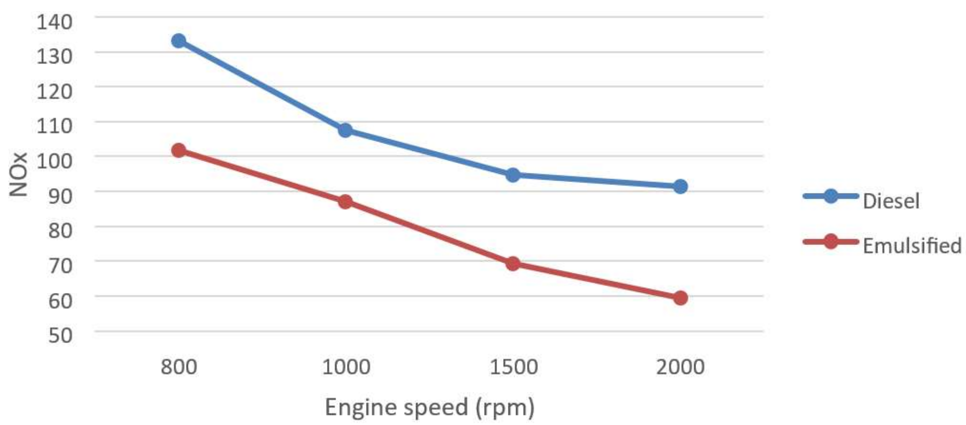

FIGURE 4: NOx gas emission

3.3 Smoke Opacity

The data indicates a notable reduction in smoke opacity when using emulsified fuel compared to diesel across all engine speeds. At 800 rpm, the smoke opacity for diesel was recorded at 1.26%, whereas emulsified fuel produced significantly lower opacity at 0.3%. This trend is consistent at higher engine speeds. At 1000 rpm, smoke opacity was 0.8% for diesel and reduced to 0.2% for emulsified fuel. At 1500 rpm, the opacity dropped further to 0.6% for diesel and 0% for emulsified fuel. At the highest engine speed of 2000 rpm, smoke opacity was 0.2% for diesel and remained at 0% for emulsified fuel. The results show that emulsified fuel effectively reduces smoke opacity compared to traditional diesel fuel, particularly at higher engine speeds. This reduction is likely the water content in the emulsified fuel, which lowers combustion temperatures, leading to more complete combustion and less soot formation.

At lower engine speeds, such as 800 and 1000 rpm, emulsified fuel significantly lowers smoke opacity but does not completely eliminate it. However, at 1500 rpm and 2000 rpm, smoke opacity reaches 0%, demonstrating that the emulsified fuel produces cleaner combustion under higher engine loads. This suggests that emulsified fuel can substantially reduce particulate emissions, which are a major contributor to visible smoke in diesel engines.

These findings highlight the potential of emulsified fuel to improve air quality by reducing smoke emissions, particularly in high-speed engine operations. Combined with its ability to reduce nitrogen oxide (NOx) emissions, emulsified fuel offers a promising alternative for cleaner engine performance, especially in applications where smoke and particulate emissions are of concern.

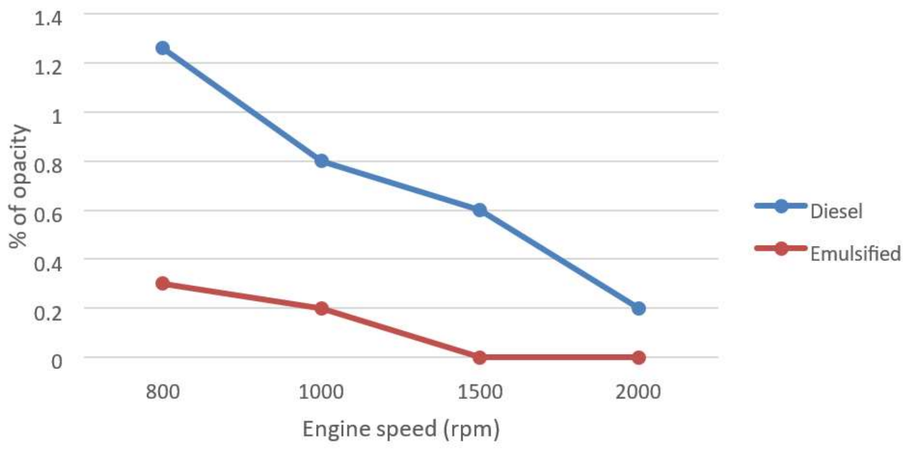

FIGURE 5: Smoke opacity

4. CONCLUSION

The study demonstrates that emulsified fuel offers significant advantages in reducing NOx emissions and smoke opacity compared to diesel fuel, particularly at higher engine speeds. The reduction in NOx emissions is due to the water content in the emulsified fuel, which lowers combustion temperatures and inhibits NOx formation. Additionally, emulsified fuel greatly reduces smoke opacity, effectively eliminating visible smoke at higher engine speeds by promoting more complete combustion and reducing particulate emissions.

However, the research also highlights a key challenge: emulsified fuel tends to increase carbon monoxide (CO) emissions at higher engine speeds. This increase is primarily due to lower combustion temperatures that hinder the complete conversion of CO to carbon dioxide (CO2), leading to higher CO levels in the exhaust.

Overall, emulsified fuel presents a promising alternative for reducing NOx and smoke emissions in diesel engines, especially in high-speed engines. Nevertheless, further research is needed to optimize the fuel's performance, particularly in terms of reducing CO emissions, and to assess its long-term effects on engine efficiency and durability.

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