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Experimental investigation of a diesel engine power, torque and noise emission using water–diesel emulsions

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HIGHLIGHTS

- The 2% water–diesel blend showed the highest engine power and torque.
- There are not significant differences between noise emissions of neat diesel and E_2.
- Lower peak HRR at higher engine speed led to weaker and more silent combustion for emulsions than neat diesel.
- Thermal efficiency increase from 25% to 75% engine load may lead to more powerful and louder combustion.
- Engine noise reduction from 75% to 100% load may be due to the effect of ignition delay decrement.

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ABSTRACT

In the present study, the results of an investigation on a Perkins A63544 direct injection diesel engine using water–diesel emulsions (2%, 5%, 8% and 10% water by volume) are reported. The engine was run at different engine speeds ranging from 1400 to 1900 rpm, with steps of 100 rpm, for power and torque analysis. In order to evaluate noise emissions, four engine speeds (1600–1900 rpm with steps of 100 rpm) and four engine load conditions (25%, 50%, 75% and 100%) were selected. No change in engine components and fuel injection systems was made. The statistical analysis results showed that the engine speed and fuel type parameters had significant effects at 1% probability level ($P < 0.01$) on the average values of the engine power and torque. The engine noise emission was affected significantly ($P < 0.01$) by the engine speed, fuel type and engine load parameters. The results showed that adding small amounts of water, 2%, to neat diesel fuel produced a significant increase in the engine power. Furthermore, its engine torque and noise emission were comparable with those of neat diesel fuel. The higher water addition to diesel decreased the engine power and torque, however no such change was found for the engine noise emission. The significant increase in the engine power and comparable engine torque and noise emission for 2% water content showed a good potential for this emulsion to be considered as an appropriate alternative to neat diesel fuel.

1. Introduction

Diesel engines are efficient and economic power sources that are widely used in several applications. However, their noise is louder than spark ignition ones and this may be, in some cases, a big concern in many applications [1]. Previous research studies showed that human beings are affected mentally, physically and socially by excessive noise levels [1–3]. In account of the excessive noise threats on humans, international organizations such as NIOSH developed regulations in order to restrict the duration of human noise exposure. NIOSH defined exposure to a 85 dB(A) noise level for 8-h/day or exposure to 88 dB(A) noise level for 4-h/day as one noise dose [4]. Humans should not be exposed to more than one noise dose per day and it was recommended to reduce noise levels below 80 dB(A). Some countries are promoting noise reduction and control programs to lower noise levels below 75 dB(A) [1].

In diesel-powered vehicles and equipments, the engine is the main source of noise [5,6]. For that reason, researchers have

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Nomenclature

NIOSH	National Institute for Occupational Safety and Health	FFT	Fast Fourier Transform
DI	direct injection	P	engine power (kW)
PM	Particulate Matter	p_{rms}	root mean square sound pressure (Pa)
MF	Massy Ferguson	p	sound pressure
E_0	neat diesel fuel	L_A	overall sound pressure level (dB(A))
E_2	2% water and 98% diesel	L_p	sound pressure level (dB)
E_5	5% water and 95% diesel	p_0	reference pressure (20×10^{-6} Pa)
E_8	8% water and 92% diesel	L_{pi}	sound pressure levels at band-center frequencies of 1/3rd octave frequency band (dB(A))
E_{10}	10% water and 90% diesel	τ	time interval of measurement
HRR	Heat Release Rate	NO_x	Nitrogen oxides
UHC	Unburned Hydro Carbon	h	running hours of the engine
ANOVA	Analysis of Variance		
T	engine torque (Nm)		
PTO	Power take-off		

devoted significant efforts to mitigate diesel engine noise. Combustion noise represents the main contribution to diesel engine noise [7]. Ghaffarpour and Noorpoor [8] used split injection technique in automotive DI diesel engines to control combustion noise by directly acting on the source. Combustion noise may also be affected by the type of fuel. Nguyen and Mikami [9] found a decrease in combustion noise with late diesel fuel injection timings when 10 volumetric percentage hydrogen is added to the intake air. Transient performance of a diesel engine and the overall combustion noise dispersion was evaluated using bio-fuels and minor effects were reported [10].

Together with noise emissions, the stringency of international regulations on exhaust emissions is pushing researchers to investigate alternative fuels. In the last two decades, water–diesel emulsions have been studied as a possible solution to solve the "PM-NOx trade-off" [11,12]. The results of those investigations also revealed that water–diesel emulsions could be used in diesel engines without changing pumps and injectors [13].

A mixture of two or more immiscible liquids is defined as an emulsion. Sufficient stirring of the liquids in presence of an emulsifying agent is necessary to produce a stable emulsion. Chemical reaction rates can be enhanced by using the high power ultrasonic technique [14]. The ultrasonic irradiation to a solution periodically forms cavitation bubbles. Those bubbles grow and collapse impulsively during the adiabatic compression. These phenomena result in formation of hotspots, high speed micro-jets, micro-streaming and generation of a shock-wave. Therefore, the ultrasonic technique would be used beneficially to prepare water–diesel emulsions [15–18].

Using water–diesel emulsions in diesel engines could cause additional momentum on the injection jet and consequently an improved mixing of fuel, air and tiny water particles was achieved. Furthermore, additional momentum leads to micro explosions, which further enhance fuel atomization [19]. Debnath et al. [20] concluded that surfactants are needed for emulsion preparation and for having a good emulsion for diesel engine, the agent should have low Hydrophilic/Lipophilic Balance value. SPAN 80 and TWEEN 20 with the quantity range from 0.2% to 5% (by volume) are commonly used for emulsion preparation. They also reported that ultrasonic agitators yielded more stable emulsions than mechanical mixers. Emulsion spray has a little longer penetration than diesel. Ithnin et al. [21] reported a thermal efficiency increase and a combustion efficiency improvement using water–diesel emulsions. They also concluded that using these emulsions improved the engine brake engine power and torque in some cases. Fahd et al. [13] revealed that the water–diesel emulsion produces less power output as compared to neat diesel fuel. However, at high engine loads, the engine efficiency achieved when using the 10% water–diesel emulsion is comparable to that using neat diesel fuel [13]. The heating value of water–diesel emulsions with a high percentage of water is much lower than that of neat diesel, thus releasing a smaller amount of heat in the cylinders and a lower power output [22].

The experimental results indicated that the ignition delay increases by using water–diesel emulsions [23–25]. The vaporization of water released its latent heat and slowed down the gradient of temperature in the droplet (physical delay) and, at the same time, reduced the fuel concentration (chemical delay) [25]. The increase of 0.2 ms in ignition delay was reported for water–diesel emulsion compared to neat diesel fuel [26]. As ignition delay increases, more time is available for evaporation and mixing and more fuel is burnt during the combustion process, which leads to an increase in the rate of heat release. Enhancing the reaction rate of diesel fuel improves combustion efficiency [26–28].

Diesel engines are widely used in mass transportation, heavy industries and especially agricultural machines because they offer better fuel to power conversion efficiency than spark ignition types. However, most of the diesel engines for those applications are not of the newest technology, even though they are one of the major pollution contributors (especially NO_x) at present time. The use of water–diesel emulsions may contribute to decrease diesel engine pollution without needing the engine modifications. The investigation of the effect of water–diesel emulsions on unmodified diesel engines, which are widely used in developing countries, would be important since it may represent a low cost method to improve emissions. Also, in many cases (especially in agricultural operation), human presence near the diesel engine is needed for a long period of time. Furthermore, the agricultural machines do not offer the same engine mufflers and noise control facilities that are normally used in vehicles. The harmful impact of noise emissions of these machines may affect human beings mentally, physically and socially and it should be avoided.

Literature survey revealed that there is limited information concerning the noise emissions of a DI diesel engine using water–diesel emulsions at part loads and at varying engine speed. The aim of this study is the investigation of a MF399 tractor engine power, torque and noise emission, without any modification in engine systems, at different engine loads and speeds using different percentages of water in water–diesel emulsions.

2. Materials and methods

The neat diesel used in this study was purchased from a gas station in Tehran, Iran. Its characteristics were given in Table 1. A