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Preparation of diesel emulsion using auxiliary emulsifier mono ethylene glycol and utilization in a turbocharged diesel engine

Emre Yilmaz [a], Hamit Solmaz [a,*], Seyfi Polat [b], Ahmet Uyumaz [c], Fatih Şahin [a], M. Sahir Salman [a]

[a] Gazi University, Faculty of Technology, Automotive Engineering Department, 06500 Ankara, Turkey
[b] Michigan Technological University, Department of Mechanical Engineering-Engineering Mechanics, 49931 Houghton, USA
[c] Mehmet Akif Ersoy University, Vocational High School of Technical Sciences, Automotive Technologies, 15100 Burdur, Turkey

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ABSTRACT

Diesel engines are used widely as they have lower fuel consumption and higher thermal efficiency in transportation sector. However, the emitted high NO_x, CO and soot emissions have led researchers to search different alternative fuels. At this point, diesel fuels emulsions help to reduce exhaust emissions. In this study, the effects of diesel fuel emulsions containing 5% (E5) and 10% (E10) water on engine performance an exhaust emissions has been investigated. Mono ethylene glycol was used as an auxiliary emulsifier in the preparation of the emulsion. Use of the mono ethylene glycol reduced the subsidence rate of the E5 and E10 about 34.5% and 47.1% respectively. The experiments were conducted at full load condition and at 2500, 3250 and 4000 rpm engine speeds. Engine torque and power increased according to diesel fuel between 2400 and 3600 engine speed range when emulsified fuels were used. But significant reductions were observed after that engine speed range. It was observed that the nitrogenoxide (NO_x) emission reduced 5.42% and 11.01% with using E5 and E10 fuel respectively according to diesel fuel at 2500 rpm. Also the soot emissions reduced 12.39% and 22.97% with using E5 and E10.

1. Introduction

Diesel engines are widely used in road and ship transportation because of their high thermal efficiency and compatibility of heavy-duty conditions. The greatest danger facing to internal combustion engines are the progressive decline in oil reserves and increase of the emission restrictions. Therefore, many researchers have been conducted several study to develop more economical, renewable and clean alternative fuel for the diesel engines [1]. NO_x, CO, particulate matter and SO_x arise from diesel engines are the most harmful exhaust gas emissions for environment and human beings. In order to reduce these harmful gases, several emission reduction systems are used such as EGR (Exhaust Gas Recirculation), SCR (Selective Catalytic Reduction), particulate filter and catalytic converters. These systems increase the cost and they will be insufficient in the long term due to the emission restrictions. Preventing the formation of the harmful gases by improving the combustion process is the most intelligent solution for the emission problem. But in the present case, it is inevitable that the use of cleaner fuels (biofuels, alcohols, etc.) or fuel additives. Also diesel fuel emulsions, which are effective in reducing the harmful exhaust emissions, attract attention of researchers [2–8].

The diesel fuel emulsions obtained by adding water to diesel, especially helps to reduce NO_x and soot emissions. The water emulsified with diesel has a larger impact on exhaust emissions in comparison with engine performance [9–11]. Especially the positive impact of diesel fuel emulsions on NO_x and soot emissions has encouraged the researchers to study on emulsion fuels. Another advantage of the emulsion fuels is that the engine does not need any modification to use the emulsions [10–13].

Emulsions formed by dispersion of two immiscible liquid in each other are heterogeneous systems which seen as homogeneous. If the emulsion contains oil droplets in water, it defined as O/W emulsion. If the emulsion contains water droplets in oil, it defined as W/O emulsion. If the emulsion consists both O/W and W/O it is called as multiple emulsions. Also multiple emulsions can be obtained as W/O/W and O/W/O. While the O/W and the W/O emulsions are two phase emulsions, the W/O/W and the O/W/O emulsions are three phase emulsions [11–16]. Lin and Chen [16] determined that the three-phase emulsions are more efficient than two-phase emulsions on reduction in NO_x and CO emissions.

* Corresponding author.
E-mail addresses: emreylmz@gazi.edu.tr (E. Yilmaz), hsolmaz@gazi.edu.tr (H. Solmaz), seyfipolat@hitit.edu.tr (S. Polat), auyumaz@mehmetakif.edu.tr (A. Uyumaz), fasahin@gazi.edu.tr (F. Şahin), sahirs@gazi.edu.tr (M.S. Salman).

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The emulsions should not be affected by temperature variations and should protect their stability for an acceptable time. For this purpose the surfactant emulsifiers are used. In addition to provide spreading of a liquid in the other one, an adequate mixing should be applied. Emulsifiers consist of carbon, oxygen and hydrogen, thereby they prevent soot formations by enabling a rapid combustion [14,15]. In emulsification process water droplets in oil are divided into many small pieces. It is known that the boiling point of the water is lower than oil. Therefore in combustion process, under high pressure and temperature, the water droplets surrounded by water vaporizes earlier than oil. The vapor, which volume reaches about 1000 times of the liquid water, explodes through the surrounding oil layer. This phenomenon is called as micro-explosion. During micro-explosion, the atomized oil broken into fairly small droplets and reaction surface area increase. Thereby the combustion efficiency is increased and fuel saving, the reduction of particulate matter, NO_x, CO and other emissions are achieved [16,17].

Badran et al. [6] carried out an investigation in order to determine the effects diesel–water emulsion on engine performance in a single cylinder diesel engine. They showed that water–diesel emulsion improved the engine performance. They observed that engine torque increased with the increase of the percentage of water in the emulsion fuels. They claimed that it could be attributed with extra force on the piston provided by the vapor of emulsified fuel. Higher vapor pressure occurred in combustion chamber when charge mixture was combusted. They also said that emulsified fuel promoted atomization of the mixture due to higher viscosity compared to diesel engine and engine efficiency increased.

Tsukahara et al. [18,19] remarked a reduction in burning time due to improved atomization because of the micro-explosion of the water droplets. Gunnerman and Russell [20] have seen a reduction in NO_x and particulate matter emissions and an increase in thermal efficiency in the emulsion fuel experiments. Ghojel et al. [21] examined NO_x, HC and specific fuel consumption variations in a diesel engine fueled with diesel emulsion. They determined a reduction in NO_x and HC emissions and an increase in specific fuel consumption. Abu-Zaid [22] investigated the effects of the emulsion fuel on engine performance and exhaust gas temperature in a diesel engine. The brake thermal efficiency increased 3.5% with emulsion fuel containing 20% of water. He stated that the increasing the water percent in the emulsion increases torque, power and brake thermal efficiency. Samec et al. [23] measured reduction in NO_x and soot emissions 15% and 50% respectively with emulsion fuel consisting 10–15% water. Subramanian [24] indicated the effects of emulsion and water injection on engine performance, combustion and emission characteristics. Water–diesel emulsion was injected during the compression stroke and water was injected into the intake manifold. He showed that both methods could reduce NO emission. He also showed that the reduction in NO emissions with injection was lesser than emulsion at part loads. He determined that peak cylinder pressure increased with water–diesel emulsion compared to diesel and maximum rate of pressure rise increased using water–diesel emulsion and injection method compared to diesel fuel. Liang et al. [25] investigated the effects of oxygen enriched combustion on engine performance and emissions with water diesel emulsion in a turbocharged diesel engine. They determined that higher cylinder pressure and shorter ignition delay were observed when oxygen enriched was applied. At any oxygen concentration, higher power output was obtained with water–diesel emulsion fuels according to diesel fuel. Wamankar and Murugan [26] researched the effects of carbon black-water–diesel emulsion fuels in a single cylinder, four stroke diesel engine. They observed that higher brake specific energy consumption with carbon black-water–diesel emulsion fuels than diesel fuel. NO emissions reduced by using emulsions compared to diesel fuel at full load. They also showed that smoke emissions were higher for all the emulsions compared to diesel. Armas et al. [27] investigated the effect water–oil emulsions on the engine performance and emissions. They reported that water emulsification improved the brake efficiency. It was also observed that thermal NO formation, soot and HC emissions were reduced in a turbocharged, indirect injection diesel engine. The faster combustion for emulsion fuel resulted higher brake efficiency [28]. Alahmer et al. [29] investigated the effects of emulsion fuels on engine performance and emission in a four stroke, four cylinder, direct injection diesel engine. They have seen that thermal efficiency increased and NO emissions reduced When emulsion fuel was used. They reported that higher engine torque was obtained with 5% water-emulsified fuel compared to diesel fuel. They claimed that the additional force on the piston provided by the steam pressure caused higher cylinder pressure. Fahd et al. [5] conducted an experimental study to evaluate the effect of 10% water emulsion diesel fuel on engine performance and emissions. They showed that 10% water emulsion diesel fuel (ED10) had an ability to produce in-cylinder pressure and heat release rate like diesel fuel at full load. Besides exhaust gas temperature and NO emissions reduced using ED10 fuel compared to diesel fuel.

In the present study diesel O/W/O three phase emulsion fuels containing 5% and 10% water were tested in a four stroke four cylinder turbocharged diesel engine. Unlike the other studies, in this study an auxiliary emulsifier mono ethylene glycol is used to increase the stability of emulsion. Experiments were conducted five different brake mean effective pressures at 10, 30, 50, 70 and 90 Nm engine torque and three different engine speeds 2500, 3250 and 4000 rpm. The torque and specific fuel consumption of the engine and NO_x, CO and soot emissions variations were examined.

2. Material and method

2.1. Preparation of multiple emulsion

An emulsion is prepared by dispersion a large number of liquid droplets in the other liquid. Thus, it is needed to prevent the droplets to approach each other and to provide the stabilization of formed droplets. For this purpose used instruments could be examined in the four categories [30–32]:

- Mechanical mixers.
- Homogenizers.
- Colloid mills.
- Ultrasonification tools.

Emulsions may be prepared by various methods depending on the size of production. Small-scale emulsions can be prepared in the laboratory, in a mortar or hand-held mixer devices. In the industry, the instruments mentioned above are used to prepare large-scale emulsion.

In general two-step emulsification is prepared by one-step emulsification and phase transformation methods [31,32]. Mixing speed, time and temperature are very important in the formulation development. The type of mixer, and mixing speed affects the size of droplet of emulsion and viscosity. It is recommended that mixing speed should be high for primer emulsion and low for seconder emulsion [33,34]. The temperature should be controlled for both preparation of primer and multiple emulsion. The temperature has a great effect on the interfacial tension, the lipophilicity of surfactant and the dispersion of a phase into the other one. The temperature is usually requested to be 70 °C for primer emulsion and 25 °C for seconder emulsion. Two-step preparation method at