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Investigation of the effects of tripropylene glycol addition to diesel fuel on combustion and exhaust emissions at an isolated diesel engine

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ABSTRACT

Low emission in diesel engines increases the importance of low fuel consumption and high efficiency. In this experimental study, the parts forming the combustion chamber were coated with ceramic materials, which had low thermal conductivity and resistance to high operating temperature, in order to reduce the loss energy and harmful emissions in a diesel engine. This study was conducted in 3 stages. In the first stage, cylinder liner and the valves were coated by using boronizing method. In the second stage, piston surface was coated by using plasma spray method. In the third stage, tripropylene glycol + diesel mixtures (added as 2%, 4%, and 6% by volume) were used in coated (COE) and uncoated (STE) engines. The results determined that in coated engine, carbon monoxide (CO), hydrocarbon (HC), smoke emissions and brake specific fuel consumption (BSFC) values of diesel fuel and tripropylene glycol + diesel mixtures decreased; whereas, nitrogen oxide (NO_x), exhaust gas temperature (EGT) and brake thermal efficiency increased.

1. Introduction

The recent studies have concentrated on the vehicle emissions and performance. Increasing performance and decreasing harmful exhaust emissions in diesel vehicles contribute to the economy of the countries and also provide the development of more ecological engines. Vehicle emissions have an important effect on global warming and climate changes [1–4].

In diesel engines, a considerable amount of heat is generated by the combustion of the fuel, but a significant quantity of energy is carried away to the cooler and the outside atmosphere. Only one third of the total energy can be converted to useful energy and used efficiently. Heat losses can be prevented by thermally isolating the surface of the combustion chamber elements in diesel engine. By the insulation, as the thermal efficiency increases, engine performance, fuel consumption and exhaust emission values will also change positively.

For this reason, one of the methods for increasing the combustion efficiency of vehicles is to coat the elements of the combustion chamber with a ceramic material. If the combustion chamber is isolated in diesel engines, the combustion end temperature will increase and thus the efficiency of chemical combustion reaction will enhance. These engines are called as adiabatic engines or low heat loss engines [5].

In these engines, combustion temperature increases as a result of coating a part or all the elements of combustion chamber with a material having a low thermal conductivity. Thus, both the combustion reaction becomes more efficient and also the pollutant emissions decrease. The fact that there is higher combustion chamber temperature in these coated engines than the uncoated engines allows to use a lower quality fuel within a wider distillation range. Also, because the compression end gas temperature will increase in diesel engines due to the reduction of the heat loss outgoing from the cooling system, initial start-up (operation) in cold weather is easier and knock and noisy start caused by uncontrolled combustion decreases [6].

Improvement of chemical and physical properties of diesel fuel will make a positive effect on the combustion efficiency and exhaust emissions. One of the methods for developing these properties of diesel fuel is additives. Experimental studies [7–10] have showed that adding oxygen-containing additives in the diesel fuel decreases the exhaust emissions. Additives develop the combustion efficiency, increase the engine performance, and also cause a positive effect on the emissions. One of these additives is tripropylene glycol. In fact, tripropylene glycol is a type of ester. High oxygen content and low viscosity in the content of tripropylene glycol develop the combustion efficiency and had a positive effect on the engine performance and harmful exhaust emissions by developing the combustion efficiency [11,12].

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Nomenclature

TG	Tripropylene Glycol	HC	Hydrocarbon
COE	Coated Engine	LHR	Low Heat Rejection
STE	Standard Engine	NOx	Nitrogen Oxides
STG	Standard Engine Tripropylene Glycol	ppm	Part Per Million
CTG	Coated Engine Tripropylene Glycol	rpm	Revolution Per Minute
BSFC	Brake Specific Fuel Consumption	TBC	Thermal Barrier Coating
LPG	Liquefied Petroleum Gas	EGT	Exhaust Gas Temperature
CO	Carbon Monoxide	μm	Micron Meter
NO 2D	Standard Diesel Fuel	SEM	Scanning Electron Microscopy

However, those previous work just reported the exhaust emissions for a specific tripropylene glycol addition but still lacked of information about the combustion characteristics.

In this study, elements of the combustion chamber of a diesel engine were gained a thermal barrier property. As the test fuel in coated and uncoated engines, standard diesel fuel NO 2D was used as the reference fuel. Experiments were performed by adding tripropylene glycol into the test fuel at certain volumetric rates. The reference fuel NO 2D and its effects were examined in single-cylinder, direct injection, ordinary diesel engine under half load-different rpm conditions.

2. Materials and methods

In the tests; a single-cylinder, 4-stroke, air-cooled diesel engine (6LD 400 Lombardini brand) was used. Cylinder liner, piston, exhaust and inlet valves, which are the elements of the combustion chamber, were coated. Via the coating method applied, a surface with low thermal conduction was obtained. In the coating process, two different methods were used. While the solid boronizing method was used for the cylinder and valves, the plasma spray method was used for the piston. Before the coating process, machining having the same thickness with the coating was performed over the surfaces of the parts. The solid boronizing process includes several steps. For the cylinder liner and valves, the parts are annealed at high temperatures in the coating furnace; after the annealing process, raw cylinder liner and valves are processed; and the processed raw parts are put into the mold and coated with Ekabor-2 powder and deoxidant material (Fe_2B layer). While the commercial Ekabor-2 powder is used as the boronizing element, Ekrit is used as the deoxidant material. The raw parts (the annealing) were heat treated at 950 °C for 4 h, which were specified temperature and time period in the boronizing parameters.

At the end of the process, the parts were cooled at room temperature. Finally, in order to bring the coated cylinder liner to its original size, it was subjected to a honing process at a precision of 0.01 mm. The surface of the coated valves was cleaned and they were made ready for use. In the coating process of the piston, which is one of the combustion chamber elements, the plasma spray method was used. Because the piston material is a material containing Al-Si, its melting heat was about 920 °C [13,14]. Thus, it is not a suitable material for the coating methods applied at 900 °C and over such as boronizing. A temperature of approximately 900 °C will negatively affect the microstructure of the piston. Thus, the plasma spray method was preferred by taking these properties into account while coating the piston. In order to have the piston return to its original sizes, 300 μm machining was performed from the upper surface of the piston before the coating process. The coating process was started by spraying a 50-μm thick CoNiCrAl Yttra bonding material on the surface and then ended by spraying a 250-μm thick NiCrBSi powder on this bonding layer. Thus, a boron-containing 300 μm coating layer was obtained on the upper surface of the piston. Fig. 1 shows molecular structures of tripropylene glycol [15].

2.1. The coating layer

Fig. 2 shows the scanning electron microscopy (SEM) image taken from the cross-section of the cylinder liner is seen. When Fig. 2 was examined, it was seen that substrate transition of the coating layer had a suitable structure.

Tests, as shown in Fig. 3, were performed on a Cusson P8160 electrical dynamometer set-up. CO (%), HC (ppm), smoke (%) and NO_x (ppm) emissions in the exhaust gas are measured by Bosch gas analyzer. Exhaust gas temperature was measured by using the Operating Instructions Model (W) 502 K/J device placed on the test set. Table 1 shows technical properties of the test engine. While NO 2D (diesel fuel) was supplied from the commercial gas stations in Turkey, tripropylene glycol had a purity of 97% and was supplied from the market. Table 2 shows technical properties of the gas analyzing device.

Table 3 shows physical and chemical properties of the test fuels [15]. The mixtures were prepared just before the tests.

Only the surfaces of piston, exhaust and inlet valves facing the combustion chamber were coated. The compression ratio of this engine was thought to change as a result of coating cylinder, piston, exhaust and inlet valves in a thickness of about 0.3 mm. Thus, in order to obtain the compaction ratio of the standard engine in

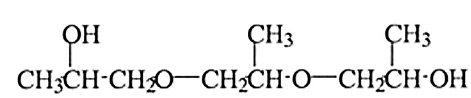

Fig. 1. Molecular structures of tripropylene glycol [15].

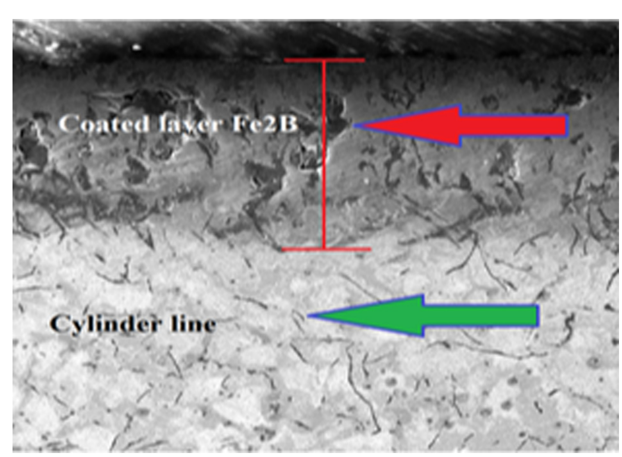

Fig. 2. Scanning electron microscope (SEM) image of coated engine component.