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EXPERIMENTAL EXAMINATION ON PERFORMANCE AND EMISSION OF A COATED DIESEL ENGINE FUELED WITH DIESEL AND PRE-HEATED CORIANDER OIL BLENDS

Hanbey HAZAR*,1, Ahmet Beyzade DEMIRPOLAT[2]

[1]*Department of Automotive Engineering,*

Firat University, Elazig 23119, Turkey

[2]*Department of Electronics and Automation,*
Turgut Ozal University, Malatya 44800, Turkey
[1]hanbeyhazar@hotmail.com
[2]ahmetbdemirpolat@gmail.com

Abstract

The aim of the study is to determine the effects of the preheated coriander seed oil, used as fuel, on the performance and the emission characteristics of the ceramic coated single-cylinder diesel engine. In this study, the piston, exhaust, and inlet valve of a single-cylinder air-cooled diesel engine were coated with Cr_3C_2 at 300 µm thickness. Pure coriander oil was mixed with diesel fuel volumetrically at the rates of 30% and 50%. The plasma spray method was used as the coating method. It was determined that the preheating process provided a more suitable fuel flow, decreased the viscosity of the coriander oil and also the coating process decreased CO, soot and HC emissions but increased NOx, thermal efficiency, and EGT.

Key words: *diesel engine; coriander oil; pollutant emissions; thermal barrier coating*

1. Introduction

Nomenclature

NA	Naturally Aspirated	µm	Micron Meter
LHR	Low Heat Rejection	CO	Carbon Monoxide
BHT	Butylated Hydroxyl Toluene	HC	Hydrocarbon
BTE	Brake Thermal Efficiency	DF	Diesel Fuel
SEM	Scanning Electron Microscope	NOx	Nitrogen Oxides

* Corresponding author at: Department of Automotive Engineering, Technology Faculty, Firat University, Elazig 23119, Turkey
E-mail address: hanbeyhazar@hotmail.com, hhazar@firat.edu.tr

HCO-30	Heated Coriander Oil 30 %+Diesel Fuel 70 %	Ppm	Part Per Million
HCO-50	Heated Coriander Oil 50 %+Diesel Fuel 50 %	Rpm	Revolution Per Minute
CO-30	Coriander Seed Oil 30 %+Diesel Fuel 70 %	TBC	Thermal Barrier Coating
CO-50	Coriander Seed Oil50%+Diesel Fuel50%	HDF	Heated Diesel Fuel
ASTM	American Society for Testing and Materials	SE	Standard Engine
EGT	Exhaust Gas Temperature	CE	Coated Engine

A significant part of the transport and agricultural sector in the world is dependent on the internal combustion engines in particular. Diesel engines are an important part of the transport sector. Especially in the last few decades, increasing price of diesel fuel has led researchers to focus on alternative fuels [1-5].

In recent years, it has been observed that the ceramic coating applied on the combustion chamber elements of internal combustion engines increases combustion efficiency and contributes to the performance of the system and reduces harmful exhaust emissions (CO, HC, smoke intensity, PM; used in this method has increased the number of studies [6].

Considering that two-thirds of the heat obtained at the end of combustion are emitted to cooling and the outer environment with exhaust, it is very important to recover this emitted energy. Insulation applied in the combustion chamber increases the combustion efficiency of diesel fuel and increases the thermal efficiency of low quality fuels. The combustion chamber elements are coated via various methods. Plasma spray method is one of these methods. With this method, the elements of the combustion chamber are successfully coated. In diesel engines; although the use of vegetable oils covers a wide range, the use of crude vegetable oils is limited due to their high viscosity values, and they have an inadequate combustion efficiency if not treated. One of the methods used to increase efficiency is to mix vegetable oils with certain percentages of diesel fuel and send them to the combustion chamber after preheating. In diesel fuel, the features affecting atomization are viscosity, density, and surface tension.

Poor atomization affects combustion negatively [7], therefore when using vegetable oils in diesel engines, pre-heating based control strategy becomes a good method.

In previous studies [8-12], the use of pure vegetable oils in diesel engines has been observed to cause many problems. These problems are caused by the fact that the viscosity and density of pure vegetable oils are above normal, their volatility is insufficient and they have poor atomization.

Because of these reasons; the use of pure vegetable oils in diesel engines causes clogging in the fuel injection system, causing a problematic combustion. Heating of vegetable oils before being used as fuel is one of the more preferred methods [13].

However, it has been reported that NO_x emissions slightly increase with this method. On the other hand, another study stated that after the vegetable oils are heated up to 70-90 ºC, they can be used in the diesel engines for the purpose of preventing the clogging in the fuel filter [14].

If the studies in the literature are examined, heating vegetable oils up to 140 ° C before use in diesel engines; showed that the oil achieved a viscosity value suitable for use in the system [15].

In this experimental study; the performance and emission variability of heated coriander seed oil when used as fuel in a single cylinder, ceramic coated and air cooled diesel engine with the same properties of the coating process were investigated.

2. Materials and methods

A four-stroke, direct injection, normally aspirated 6LD 400 diesel engine was utilized to carry out the experimental study. The upper surface of the piston, inlet, and exhaust valves, all of which were the combustion chamber elements, were coated with ceramic using a plasma spray method (Cr_3C_2). In order to obtain a true piston, the top surface of the piston was machined to 300 µm before the coating process was started.

2.1. The coating layer

The tests were carried out in the coated engine (CE) and the uncoated engine (SE). ASTM No.2D diesel fuel was used as the diesel fuel. As the test fuel, the preheated (100 ºC heated) crude vegetable oil+diesel fuel mixtures and unheated crude vegetable oil+diesel fuel mixtures were used. The coriander seed oil was used as the raw oil. The heat treatment was realized in the oven. Before the tests of preheating treatment, the raw oils were heated at 100 ºC. The mixture rates for raw vegetable oil were determined as 30% and 50%. The tests in the test engine were performed under 1/2 load and at different rpm values. Within the scope of the experimental study, CO (%), NO_x (ppm), HC, smoke (soot), exhaust gas temperature (EGT) and thermal efficiency values were measured. Also, the test fuels were analyzed in terms of their chemical and physical qualities. Before the tests, the test engine reached the operating temperature by being operated for 30 minutes. ASTM No.2D diesel fuel was supplied from the market. The data obtained were compared and more necessary inferences were made. A Cuss on P8160 electric dynamometer mechanism was used to carry out the tests (Figure 1).

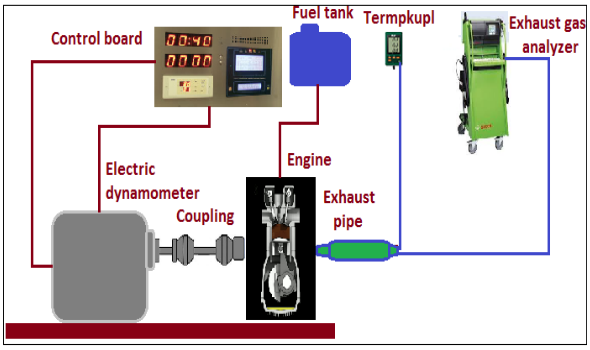


Figure 1 The schematic diagram of the test engine and experimental setup

Table 1 Diesel test engine specifications

Item	Specification
Engine model	Lombardini 6LD 400
Stroke	4
Number of cylinders	1
Bore/stroke (mm)	86/68
Static compression ratio	18:1
Maximum engine power (kW)	6.25 (3600 1/min)
Lubricating	Full pressure
Injection mode	Direct injection
Coolant type	Air coolant
Max. RPM	3600
Volume of engine (mm^3)	382 x 427 x 491

Table 2 Physicochemical properties of the fuels

Properties	CO-30	CO-50	Diesel (ASTM-D:2)	Standard
Density at 15 ^{0}C (kg/m^3)	859.9	881.3	830	TS EN ISO 12185
Kinematic viscosity at 40 ^{0}C (cst)	7.985	9.112	3.05	TS 1451 EN ISO 3104
Flash point (^{0}C)	57.0	59.5	56	TS EN ISO 2719
Appearance	Yellow, blurred	Dense yellow, blurred		SA-AY-050

Table 3 Technical properties of the gas analyzing device

Components	Measurement Range	Precision
CO	0.00 – 10.00 % Vol.	0.001 % Vol.
CO_2	0.00 – 18.00 % Vol.	0.01 % Vol.
HC	0 – 9.999 ppm Vol.	1 ppm Vol.
O_2	0.00 – 22.00 % Vol.	0.01 % Vol.
Lambda	0.500 – 9.999	0.001
NO	0 – 5000 ppm Vol.	≤ 1 ppm Vol.

The exhaust gas temperature was determined using the operating instructions model 502 K / J (W). Table 1, 2 gives the characteristics and description of all the details used in the experimental setup. Table 3 shows the technical properties of the gas analyzing device. The fuels to be used in the tests were made ready in a period close to the beginning of the experiments. Experiments were performed under hot start engine conditions. After the engine has been run at each revolution for a certain period of time, the ideal data obtained after the experiments were repeated 3 times to obtain the required data were recorded.

3. Results and discussion

3.1. CO Emissions

Figure 2 and 3 show comparatively CO emission changes according to the rpm values.

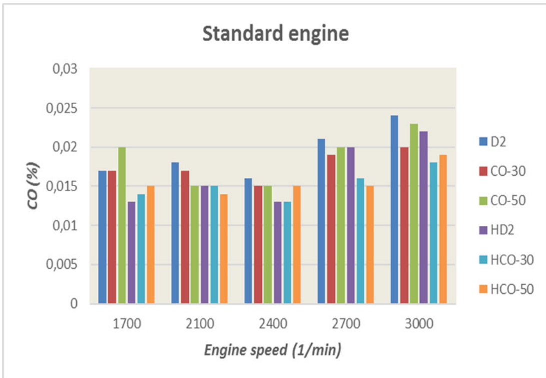


Figure 2 Comparison of CO emission depending on rpm for various fuels in the uncoated engine

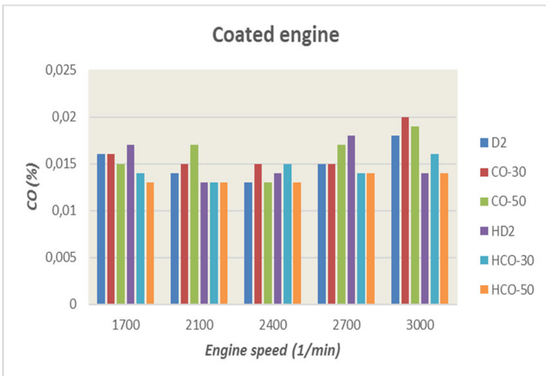


Figure 3 Comparison of CO emission depending on rpm for various fuels in the coated engine

The physical properties and chemical quality of the fuel determines the CO emission. Some of these qualities are the calorific value of fuel, oxygen content, and cetane number. The plots in Figure 2 and 3 demonstrate that the amount of CO exhausted at low rpm is higher. It is attributed to the low turbulence in cylinders at low engine speed, the atomization and the evaporation of the fuel were poor and at low gas temperature CO did not completely convert into CO_2 [17].

As seen in Figures 2 and 3, it is observed that CO emission is minimum at 2400 rpm and increases at high rpm in all fuels used. This is thought to be related to improving combustion conditions, rising end-of-combustion temperature and combustion reaction of some unburned HCs with oxygen. The increase in CO emissions at high rpm was caused by the reduction of oxygen, the increase in fuel in the combustion chamber and the lower time available for completion of a combustion cycle. When the coated and uncoated engines were compared, it was seen in the figures that the CO emissions of the coated engines were lower than those of uncoated engines for almost all the fuels. With the ceramic coating of the engine, the temperature increased and there was a decrease in heat transfer from the cylinder, shortening of the ignition delay time and improvement in combustion.

Figure 2 and Figure 3 show the impacts of the preheating process on CO gas emissions. When the test fuels were preheated, it was observed that this process had a positive impact on the efficiency of the injection and a more homogeneous air-fuel mixture was obtained. As a result of these developments there was a decrease of 13.54% in CO emission in the D2 fuel compared to the non-preheated DF fuel; a decrease of 14.44% in the HCO-30 fuel compared to CO-30 fuel; and a decrease of 13.63% in the HCO-50 fuel compared to the CO-50 fuel in the standard engine. In comparison to the standard uncoated engine, there was a decrease of CO emission of 21.87% in D2 fuel, 13.63% in CO-30 fuel, and 12.90% in CO-50 fuel was observed for the coated engine.

3.2. NO_x Emissions

Figure 4 and 5 show comparatively the NO_x emission changes according to the rpm values.

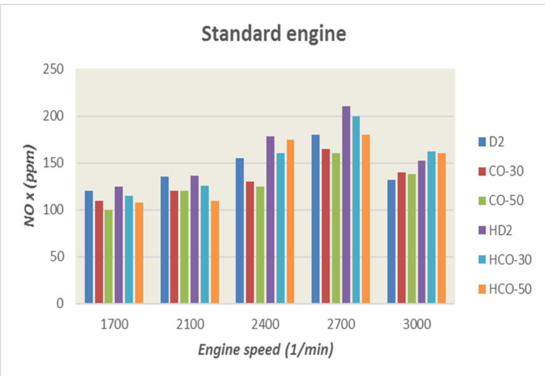


Figure 4 The changes in NO_x emission depending on rpm for the uncoated engine

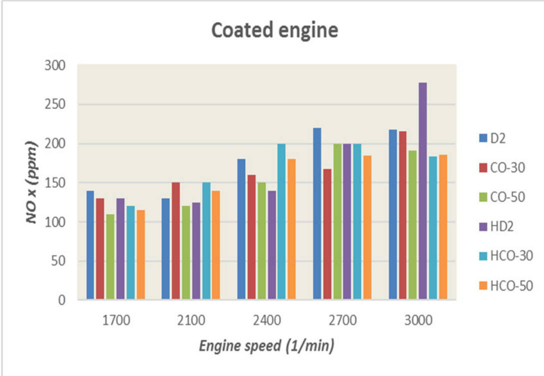


Figure 5 The changes in NO_x emission depending on rpm for the coated engine

NO_x emission was found to increase generally in use of the vegetable oils in the diesel engine. It is a well-known situation that this is caused by the fact that the vegetable oils contain more oxygen than the diesel fuel. Depending on the increase rpm rate, it was determined that oxides of nitrogen NO_x in the exhaust gas increased in both engines. More than normal fuel and oxygen to the system; it was found that due to the short time interval between cycles and the increased end of combustion temperature [17], the emissions of NO_x was found to be increased for all test fuels. Vegetable oils contain more oxygen content than diesel fuels, leading to an increase in NO_x emissions and increased NO_x emissions at moderate rpm for all test fuels when ideal conditions were established.

The increase in NO_x emission rate was found 11.43% in HD2 fuel than the non-preheated D2 fuel; 16.00% in HCO-30 fuel than the CO-30 fuel; and 14.00% in the HCO-50 fuel than the CO-50 fuel at the standard engine. This rate was 23.13% in D2 fuel, 24.17% in CO-30 fuel, and 20.42% in CO-50 fuel in the coated engine fuel compared to uncoated engine.

3.3. Soot Emissions

Figure 6 and 7 show comparatively the soot emission changes according to the rpm values.

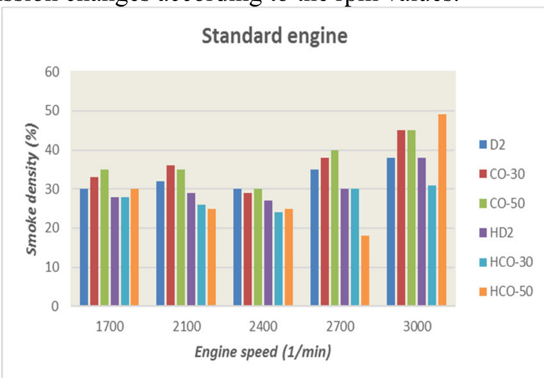


Figure 6 The soot emission changes depending on rpm for the uncoated engine

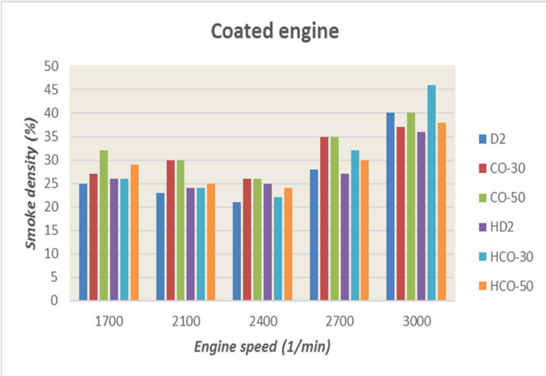


Figure 7 The soot emission changes depending on rpm for the uncoated engine

During combustion, the formation of soot emission is observed because the various parameters are different from the ideal values. These parameters are due to the fact that the actual air / fuel ratio (A / F) is higher than the theoretical full combustion value and there isn't air required in addition to the fuel droplets in the cylinder. On the basis of these reasons, insufficient combustion occurs and soot is formed.

In addition to these reasons, one of the factors that cause soot is the post combustion temperature. It has been observed that soot emission is reduced due to engine coating because it hinders the heat transfer from combustion chamber to external environment. The combustion time is the time interval during which the combustion takes place. One of the most critical factors causing the change in combustion efficiency is the delay of ignition. There are two types; physical ignition delay is the chemical ignition delay [18].

The coating process was found to reduce the ignition delay and consequently increase the combustion efficiency. Soot emission due to high rpm in both engines increased after the same period. This is a normal result; it was concluded that as a result of increase in rpm, soot emission increased as a result of the increase in fuel, combustion time and oxygen amount in the combustion chamber. Due to low volatility and high viscosity compared to diesel fuel results in higher amount of soot. It is completely a normal thing because coriander oil causes poor atomization, crumbling and heterogeneous air-fuel mixture; incomplete combustion that causes excessive soot to occur.

The decrease rate was 8.20% in HD2 fuel than the D2 fuel; 23.20% in HCO-30 fuel than the CO-30 fuel; and 21.68% in the HCO-50 fuel than the CO-50 fuel at the standard engine. This rate was 17.22% in D2 fuel, 15.28% in CO-30 fuel, and 12.32% in CO-50 fuel in the coated engine than the standard engine.

3.4. HC Emissions

Figures 8 and 9 show the HC emissions according to their rpm data by comparing their behavior. With the end of combustion, HC emissions occur. If there is insufficient oxygen in the environment, the fuel is semi-oxidized or not oxidized at all; this is because the fuel has a low ignition temperature. For this reason, it is not present in any unburned product.

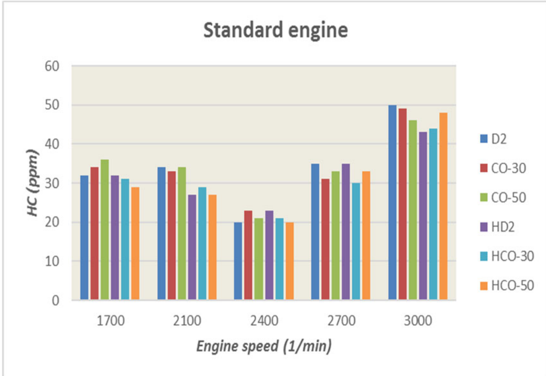


Figure 8 The HC emission depending on rpm for uncoated engine

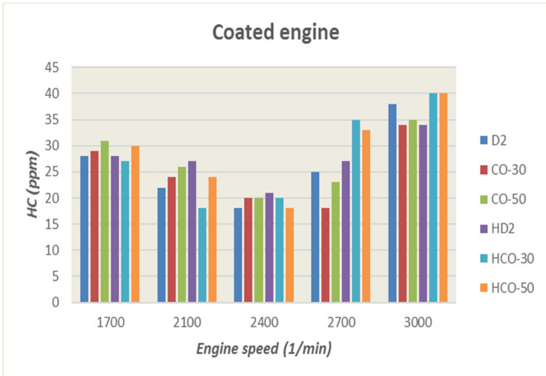


Figure 9 The HC emission depending on rpm for coated engine

The high HC emission for various fuels tested in experiment indicates that the temperature inside the cylinder is not sufficient at low rpm. The pilot flame varies according to the temperature inside the cylinder [19].

The positive effect of the coating process resulted in an increase in the temperature of the cylinder, which resulted in an increase in the performance of the pilot flame and greater participation of HC in the combustion reaction. HC; decreased in all engine and test fuels at high speed. In addition, coating also reduces the heat transfer from the combustion chamber and the interior temperature of the SE engine was higher. The coating process positively affects combustion efficiency; it has been concluded that it causes a decrease in CO and HC. The preheating process applied to coriander oil; it has been concluded that thanks to the positive improvement in the atomization and fluidity of the fuel, it provides positive benefits to combustion efficiency.

The decrease rate was 6.43 in HD2 fuel than the D2 fuel, 9.35 in HCO-30% fuel than the CO-30% fuel; and 7.89 in the HCO-50% fuel than the CO-50% fuel at the standard engine. This rate was 23.39% in D2 fuel, 25.81 % in CO-30% fuel, 20.58% in CO-50% fuel in the coated engine than the standard engine.

3.5. The EGT values

Figure 10 and 11 show comparatively the EGT (ºC) values changes according to the rpm values.

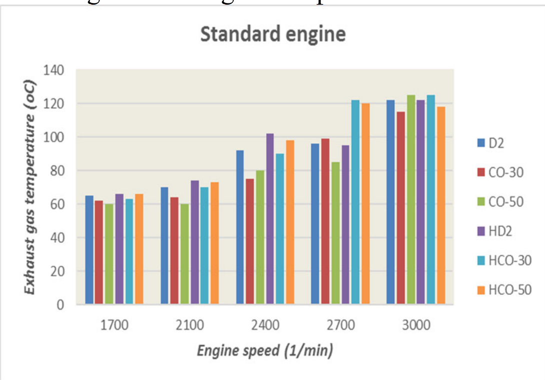


Figure 10 The EGT emission for uncoated engine at various rpm.

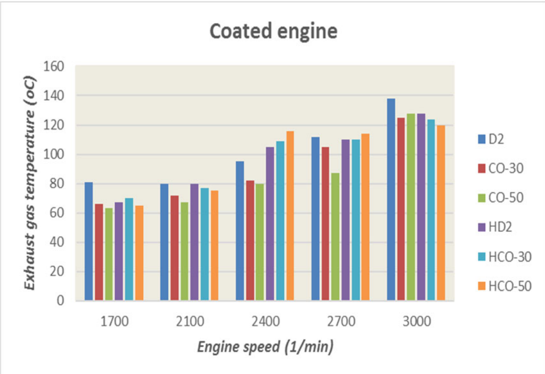


Figure 11 The EGT emission for coated engine at various rpm.

Among all the fuels tested in coated and uncoated engines, it has been observed that D2 has the highest EGT, and increased EGT in engines due to increasing speed.

When SE and CE are compared; EGT for all used fuels is increased due to coating and thermal barrier in CE. Covering; chemical reactions occurring in the combustion chamber due to it is thought to contribute positively to combustion efficiency [19,20].

In addition, the coating contributes positively to the physical and chemical ignition delay and reduces the ignition delay. It has been observed that the quantity of fuel to the combustion chamber increases with the increase in rpm and increases the EGT at the same time. It was observed that the coriander oil mixtures had lower EGT values compared to DF fuel due to higher viscosity value and lower combustibility of the vegetable oil. The increase rate was 3.37% in HD2 fuel than DF fuel, 13.25% in HCO-30 fuel than CO-30 fuel, and 15.85 in HCO-50 fuel than CO-50 fuel at the standard engine. The increase rate was 13.70% in D2 fuel, 8.43% in CO-30 fuel, and 3.65% in CO-50 fuel in the coated engine than that of standard uncoated engine was founded.

3.6. Brake thermal efficiency

As seen in Figure 12 and 13, if it is necessary to make a general evaluation, its found that the thermal efficiency increased as the rpm increased for all the fuel types.

It was also seen that the thermal efficiency increased for all test fuels in CE, compared to SE. The coating induced increase in the combustion chamber led an increase in the end of combustion temperature. The increased combustion environment temperature, and thus the increased resultant temperature of chemical reaction are thought to ensure complete combustion of unburned fuel within the combustion duration. The comparison of SE with CE revealed that D2 fuel increased by 3.63% in CE, as the mean of all the rpm values.

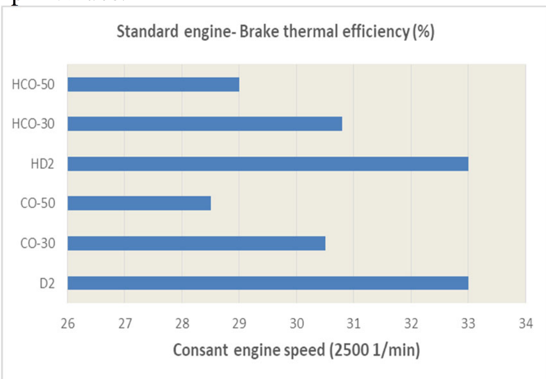


Figure 12 The brake thermal efficiency variation with rpm for uncoated engine

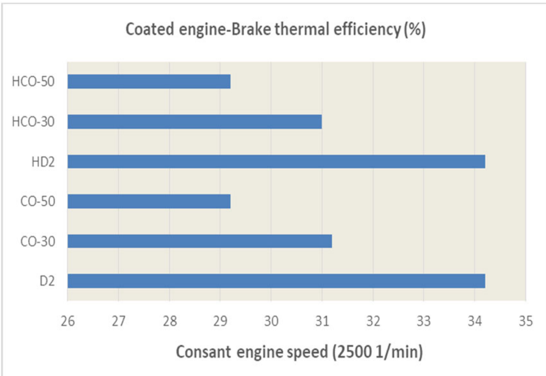
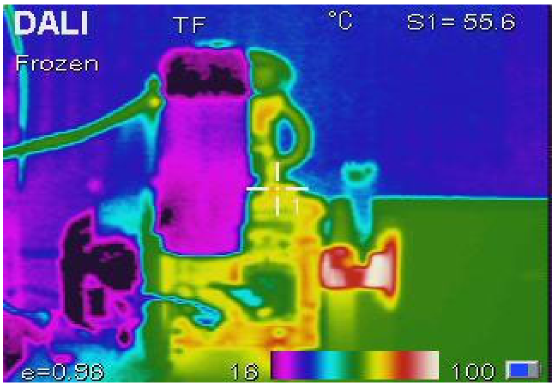
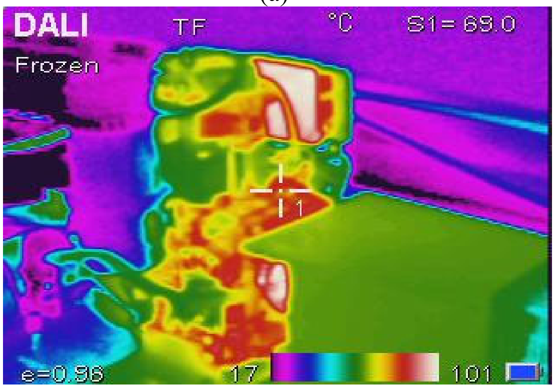


Figure 13 The brake thermal efficiency variation with rpm for coated engine

The increase rate was 0.00% in HD2 fuel compared to the non-preheated DF fuel, 0.98% in HCO-30 fuel compared to CO-30 fuel, and 1.75% in HCO-50 fuel compared to CO-50 fuel in the standard engine. In comparison on other side, this rate was 2.29% in CO-30 fuel, and 2.45% in CO-50 fuel in the coated engine. Figure 14 shows thermal image of uncoated (a) and coated (b) engines.



(a)



(b)

Figure 14 Thermal images for the uncoated (a) and coated (b) engine

4. Conclusions

The effect of the mixture of the coriander seed oil with the preheated 30% and 50% diesel fuel, in a diesel engine, whose piston and valves were ceramic-coated (Cr_3C_2), on engine was studied. The engine performance and emissions was investigated in this study. When the exhaust emissions for coated and uncoated test engines were compared in the tests, there was a decrease in the CO, HC, smoke density emission values and some increase in the NOx emission values in coriander oil+diesel fuel mixtures in the coated engine than the diesel fuel was observed. Also, it was found that coating engine increases the thermal efficiency and temperature of the exhasut gas. Its believed that thermal isolation provided by the coating causes the change in these emission values in the coated engine. Also, it was determined that preheating the coriander oil improve the combustion efficiency of the fuel in standard and coated diesel engines. At the end of the study, it was concluded that the ceramic coating was a system, that may be used without making a significant change in production of combustion engine (a system for mass production), and thus, it was possible to use fuels with lower quality in the diesel engines.

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