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Performance and emission properties of preheated and blended fennel vegetable oil in a coated diesel engine

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ABSTRACT

The use of crude fennel seed oil in a diesel engine, whose combustion chamber was thermally insulated, with diesel fuel at specific rates was investigated in the present study. A single-cylinder air cooled diesel engine was used as the test engine. Plasma spray method (coated with Cr3C2 in a thickness of 300 µm) was used as the coating method. Since the atomisation and vaporisation of fennel oil are highly affected by the physical properties of the fuel, a preheating process of 100 °C was applied. Crude fennel oil mixed with diesel fuel at 30% and 50% by volume. It was shown that a preheating process of 100 °C provided a proper fuel flow and reduced the viscosity of the funnel oil and additionally, the coating process decreased carbon monoxide (CO), smoke, and hydrocarbon (HC) emissions but increased nitrogen oxides (NOx), thermal efficiency, and exhaust gas temperature (EGT).

1. Introduction

An important part of the transportation and agriculture sector in the world depends on internal combustion engines, especially diesel engines. Increasing cost and decreasing amount of fossil fuels in recent years have led the researchers to investigate the feasibility of various alternative fuels. Having a high fuel efficiency at a certain level, some vegetable oils are more cost-effective than diesel fuel. For this reason, these vegetable oils function as a suitable alternative fuel. The primary feature of such alternative fuels is that they are non-toxic, biodegradable, and sulphide-free [1–3].

While many researchers have been investigating the vegetable oils, they have used them either by converting to biodiesel or directly as a fuel in CI engines. However, directly using vegetable oils in diesel engines without any treatment raises poor combustion characteristics such as injector adhesion, poor atomisation, carbon deposits and cold starting [4,5]. The spray properties and the post-spraying atomisation in diesel engines are very important in terms of improvement of the combustion process.

Viscosity, density, and surface tension are the properties having an impact on atomisation in a liquid diesel fuel [6].

Bad atomisation has a negative effect on combustion [7]. For this reason, the control strategy based on preheating is a good method for the use of vegetable oils in diesel engines.

Previous studies [8,9] have shown that many different problems arise during the use of pure forms of the vegetable oils in diesel engines. These problems suggest that in the event of utilisation of vegetable oils as a fuel in diesel engines, their viscosity is required to be reduced. One of the most efficient methods for the use of vegetable oil in diesel engines is the preheating of the fuel [10]. It was reported in a study that an acceptable viscosity value was obtained for a fuel to be used in diesel engines by heating the vegetable oil up to 140 °C [11].

Heat energy considerably releases in a diesel engine as a result of the combustion of the fuel. However, about two-thirds of the released energy are not effectively used and lose. According to the second law of thermodynamics, if heat loss can be reduced, thermal efficiency will increase. Therefore, thermal insulation of the combustion chamber elements will minimise energy losses. For this purpose, the method of coating the combustion chamber elements using a ceramic material is among those used to increase the combustion efficiency of vehicles.

When the combustion chamber is isolated in diesel engines, the end-of-combustion temperature increases so that the efficiency of the chemical combustion reaction will increase. These engines are called as low heat loss or adiabatic engines. Combustion temperature of these engines increases as a result of coating the combustion chamber elements partially or fully using a material with low thermal conductivity. Thus, the combustion reaction becomes more efficient and also the pollutant emissions reduce. The fact that temperature of combustion chamber is...
higher in such engines compared to the uncoated engines enables the use of a lower quality fuel in a wide range of distillation. High carbon content of diesel fuel leads to a decrease in the combustion efficiency. Improved combustion conditions result in an increase in the combustion efficiency. In addition, the reduced heat losses in the cooling system leads to an increase in gas temperature at the end of compression in the diesel engines. As a new idea in this study, the use of crude oils in the combustion chamber of an insulated engine has been investigated. Thus, the use of less quality oils in diesel engines will be increased. It is thought that this study will make a significant contribution to the literature.

In the present study, the coating process was applied to the combustion chamber parts of the engine for the purpose of increasing the efficiency of using fennel seed oil in the diesel engine. The variation in the performance and emission values of preheated fennel seed oil in the coated and standard engines was investigated. The data obtained from the standard (SE) and coated engines (CE) were compared comparatively.

2. Experimental setup and methods

Experiments were performed in 4 stages. In standard (SE) and coated (CE) engines. ASTM NO. 2D (100% pure) diesel fuel was used in the 1st Stage. The mixture of preheated (heated at 100 °C) crude vegetable oil + diesel fuel was used in the 2nd Stage. The mixture of unheated crude vegetable oil + diesel fuel was used in the 3rd Stage. All tests in the first three stages were repeated under the same conditions in the coated engine in the 4th stage. The results obtained in 4 stages in both engines were recorded and compared with each other comparatively. The experimental study was carried out using a 4-stroke, direct injection, normally aspirated diesel engine. Table 1 shows the technical properties of the test engine.

The inlet valve, exhaust valve, and upper surface of the piston, which was one of the combustion chamber elements, were coated using a ceramic material via the plasma method such a way to have a 300-μm thickness. After the chips were removed from the upper surface of the piston, the coating process was started so that the piston was brought into its original sizes. Thus, a 300-μm thick coating layer was obtained on the upper surface of the piston. Fig. 1 shows the scanning electron microscopy (SEM) image of the section of the coated piston.

2.1. Applied coating layer

Fig. 1 shows the SEM image taken from the section of the coated piston of the test engine. It can be seen from the Fig. 1 that the transition of the ceramic coating (coating layer) to the piston material had a suitable structure.

Fennel seed oil was used as the crude oil. Mixture ratios were specified as 30% and 50% for crude vegetable oil. Just before the preheated tests, the crude oils were heated. The heating process was carried out in the oven at 100 °C. Tests in the test engine were carried out at different rpm values and 1/2 load. As shown in Fig. 2, the tests were conducted on a Cusson P8160 brand electrical dynamometer mechanism. Mixtures were prepared just before the experiments.

In the experimental study, brake thermal efficiency, exhaust gas temperature (EGT), NOx (ppm), CO (%), HC (ppm) and smoke values were measured. The measurement of exhaust gas temperature was performed using Operating Instructions Model (W) 502 K/J device installed on the test set. NO 2D (diesel fuel) were supplied from commercial gas stations in Turkey. Furthermore, the test fuels were analysed in terms of their chemical and physical properties. ASTM No. 2D diesel fuel was supplied from the gas station. Before all experiments are started, the test engine was run for 30 min in order to reach to the operating temperature. After the engine was hold for a while at each speed, the measurement values were recorded. All measurements were repeated at least 3 times at each speed. While technical properties of the gas analysis device are present in Table 2, physical and chemical properties of the test fuels are present in Table 3. During the experimental studies, some differences in measurement results occurred for the same tests. This situation was caused by conditions of experiments, observation, calibration of test devices and unknown effects. According to the uncertainty of the devices, the total uncertainty of entire tests was calculated by a method of propagation of errors. The uncertainties of the measurement parameters were determined with Eq. (1). UR is the uncertainty in the results. \( R \) is a function which depends on the independent variables such as \( a_1, a_2, a_3, \ldots, a_n \). In addition, \( w_1, w_2, w_3, \ldots, w_n \) are the uncertainty of each independent variables.

\[
UR = \sqrt{[(\partial R/\partial a_1)w_1]^2 + [(\partial R/\partial a_2)w_2]^2 + \ldots + [(\partial R/\partial a_n)w_n]^2]} / 2
\]  

Total uncertainty of experiment = square root of \( [(uncertainty \ of \ NOx)^2 + (uncertainty \ of \ CO)^2 + (uncertainty \ of \ HC)^2 + (uncertainty \ of \ smoke \ density)^2 + (uncertainty \ of \ thermocouple)^2 + (uncertainty \ of \ brake \ thermal \ efficiency)^2 + (uncertainty \ of \ load \ cell)^2 + (uncertainty \ of \ speed \ meter)^2] = \sqrt{[(1.03)^2 + (0.57)^2 + (2.16)^2 + (0.95)^2 + (0.82)^2 + (0.44)^2 + (0.55)^2 + (0.79)^2]} \)  

The total uncertainty for the experiments was calculated as 2.957%.

Table 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of engine</td>
<td>Lombardini 6LD 400</td>
</tr>
<tr>
<td>Stroke</td>
<td>4</td>
</tr>
<tr>
<td>Number of cylinders</td>
<td>1</td>
</tr>
<tr>
<td>Bore/stroke (mm)</td>
<td>86/68</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>18:1</td>
</tr>
<tr>
<td>Maximum engine power (kW)</td>
<td>6.25 (3600 1/min)</td>
</tr>
<tr>
<td>Fuel type</td>
<td>Diesel</td>
</tr>
<tr>
<td>Lubricating</td>
<td>Full pressure</td>
</tr>
<tr>
<td>Type of injection</td>
<td>Direct injection</td>
</tr>
<tr>
<td>Type of coolant</td>
<td>Air coolant</td>
</tr>
<tr>
<td>Maximum engine speed (1/min)</td>
<td>3600</td>
</tr>
<tr>
<td>Engine volume (mm³)</td>
<td>382 × 427 × 491</td>
</tr>
</tbody>
</table>
3. Results and discussion

3.1. Comparison of carbon monoxide (CO) emission

In internal combustion engines, CO emissions occur due to incomplete inadequate combustion [12,13]. All the factors on combustion efficiency also affect CO emission. Figs. 3 and 4 show CO emission changes of the fuels used in test engines.

Under injection conditions, fuel jet is usually formed in cone-shaped at the end of the injector nozzle outlet in diesel engine. This type of action is described as the atomisation distribution regime and the resultant droplet diameters are much smaller than the nozzle diameter. The viscosity of the fuel is among the most important factors affecting this formation. Reducing the viscosity of fennel + diesel fuel and diesel fuel through preheating process was thought to have a positive effect on the atomisation distribution regime. The preheating process reduces the size of the fuel particles and increases the surface area of the fuel. Thus, this was considered to provide the possibility of the fuel to react with more oxygen (within the limited combustion period). Due to the thermal barrier applied to the combustion chamber elements via the preheating process, increased temperature at the end of combustion reaction was thought to improve the combustion efficiency. As seen in Fig. 3, the lowest CO emission was obtained in HFE-30 fuel and the highest CO emission was obtained in NO2 fuel in the standard engine. On the other hand, the lowest CO emission was obtained in HFE-30 fuel and the highest CO emission was obtained in HNO2 fuel in CE. As seen in the graph in Fig. 3, it was found that CO value of the diesel engine was higher at low rpm due to low turbulence in the cylinders at low engine speeds, the poor atomisation and vaporisation of the fuel and since CO cannot fully be converted to CO2 because of low gas temperature [14]. Fig. 4 shows that CO decreased at moderate rpm values for all fuels and increased again at high rpm values. It was considered that increasing of the end-of-combustion temperature at moderate rpm values and thus improvement of combustion conditions were associated with the fact that some unburned HCs did not react with the oxygen. It was thought that the increased fuel amount taken to the combustion chamber at high rpm values and decreased time and oxygen amount required for combustion increased the CO emission. This can be explained with the increased end-of-combustion temperature due to the decrease of heat transfer occurring over the combustion chamber.

<table>
<thead>
<tr>
<th>Components</th>
<th>Measurement Range</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.00–10.00% Vol.</td>
<td>0.001% Vol.</td>
</tr>
<tr>
<td>CO2</td>
<td>0.00–18.00% Vol.</td>
<td>0.01% Vol.</td>
</tr>
<tr>
<td>HC</td>
<td>0–9.999 ppm Vol.</td>
<td>1 ppm Vol.</td>
</tr>
<tr>
<td>O2</td>
<td>0.00–22.00% Vol.</td>
<td>0.01% Vol.</td>
</tr>
<tr>
<td>Lambda</td>
<td>0.500–9.999</td>
<td>1 ppm Vol.</td>
</tr>
<tr>
<td>NO</td>
<td>0–5000 ppm Vol.</td>
<td>≤ 1 ppm Vol.</td>
</tr>
</tbody>
</table>

Table 3

Physicochemical properties of the fuels.

<table>
<thead>
<tr>
<th>Properties</th>
<th>FE-50</th>
<th>FE-30</th>
<th>Diesel (ASTM-D:2)</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density at 15 °C (kg/m³)</td>
<td>874.5</td>
<td>859.8</td>
<td>838</td>
<td>TS EN ISO 12185</td>
</tr>
<tr>
<td>Kinematic viscosity at 40 °C (cst)</td>
<td>8.769</td>
<td>4.912</td>
<td>3.05</td>
<td>TS 1451 EN ISO 3104</td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>61.0</td>
<td>55.5</td>
<td>56</td>
<td>TS EN ISO 2719</td>
</tr>
<tr>
<td>Appearance</td>
<td>Brown, blurred</td>
<td>Brown, blurred</td>
<td></td>
<td>SA-AY-050</td>
</tr>
</tbody>
</table>
elements. It was considered that the time of ignition delay shortened and thus the combustion improved. The effects of preheating process on CO emissions are shown in Figs. 3 and 4. It was understood from the experimental results that the injection properties enhanced and more homogeneous air-fuel mixtures were obtained when the test fuels were subjected to preheating process. Owing to this positive situation, a decrease of 8.09% in HNO2 fuel compared to non-preheated NO2 fuel, a decrease of 11.58% in HFE-30 fuel compared to FE-30 fuel, and a decrease of 13.02% occurred in HFE-50 fuel compared to FE-50 fuel. Compared to the standard engine, a decrease of 21.87% in NO2 fuel, a decrease of 10.43% in FE-30 fuel and a decrease of 11.12% in FE-50 fuel took place in the coated engine. As the figure shows, CO emissions were low in the engine covered as the average of all cycles. Preheating process was thought to have a positive effect on more atomisation of fuel [15].

3.2. Comparison of NOx (Nitrogen oxide) emission

Figs. 5 and 6 show comparatively the change of NOx emissions in terms of engine rotations.

NOx emission of both engines was determined to increase in proportion to the increasing rpm. The intake of more fuel and oxygen, shortening of the time between cycles and the increase of the end-of-combustion temperature had effects on the increased NOx emission for all test fuels along with the increasing rpm values. When the mixtures of the vegetable oils were compared with diesel fuel, diesel fuel generally caused lower NOx emissions. The fact that oxygen content was higher in vegetable oils [16] than the diesel fuel caused to increase the NOx emissions. In addition, high NOx emissions for all test fuels were obtained at moderate rpm values of the engine namely in the ideal operation area under the combustion conditions having maximum temperature and adequate time. In diesel engines, fuel is injected into the cylinder just before the combustion starts. Therefore, the fuel-air mixture is not uniform at the injection time. Many exhaust emissions occur during the injection time.

As the in-cylinder temperature increases, the mixture burns faster and the combustion fractions of unburned gases develop faster [17]. Both physical and chemical properties of the fuel have a significant effect on ignition delay (TG). The chemical characteristics of the fuel (e.g. the cetane number) are even more important. When the fuel is sprayed into the cylinder, it evaporates and draws some heat. This decreases the heat temperature. This is less effective because the coated motor operates at a higher temperature. The higher cetane number and oxygen content of vegetable oils shorten the ignition delay time [18]. It was thought that a series of injection mixing and combustion characteristics such as ignition, combustion, air mixing, fuel spray formation, vaporisation and atomisation developed with the preheating process (heating up to 100 °C). The results obtained from the tests also support this opinion.

An increase of 11.43% in HNO2 fuel compared to the non-preheated NO2 fuel, an increase of 7.05% in HFE-30 fuel compared to FE-30 fuel, and an increase of 10.12% in HFE-50 fuel compared to FE-50% fuel occurred. An increase of 23.13% in NO2 fuel, an increase of 14.84% in FE-30 fuel, and an increase of 17.08% in FE-50 fuel occurred in the coated engine compared to the standard engine. When the Figs. 5 and 6 are examined, it is seen that the NOx emission between 1700 rpm and 2700 rpm has increased in the coated and uncoated motor. In general, however, it is seen that the NOx emission of 2700 rpm has decreased slightly. This can be explained by the reduction in combustion efficiency at high engine speeds.

3.3. Comparison of soot density emission

Figs. 7 and 8 show comparatively the changes of the smoke emissions in terms of the rpm.

It was thought that the preheating process led to the dispersions in atomisation regime of fuel at jet speed and the formation of droplets in smaller sizes and reduced smoke emission for all test fuels. Aerodynamic interactions on the surfaces of liquid or gas appeared as a major component of the atomisation mechanism in this regime. Due to the applied coating process, the entire combustion chamber and thus the cylinder walls became warmer which developed the combustion efficiency. Because, the fuel is required to hit warmer cylinder walls due to thermal isolation. Thus, the ignition delay is shortened and the combustion efficiency is increased. The fact that the standard engine had a colder cylinder wall than the coated engine causes the liquid fuel impacts on the cold surfaces without turbulence and increases their unburned or partially burnt emission products [17].

The formation of smoke emission depends on the combustion parameters during combustion [19,20]. The main factor is that although the actual air/fuel ratio (A/F) is greater than the theoretical full combustion value, there is no enough air around the fuel droplets in the cylinder. This leads to the formation of smoke which is the product of incomplete combustion. The end-of-combustion temperature is among the factors affecting smoke. Since the heat transferred to the external medium from the combustion chamber decreased because of the coating process, the smoke emissions also decreased in the coating engine compared to the standard engine as seen in the figure.

When examined in Figs. 7 and 8, it is seen that in the coated and uncoated motor between 1700 rpm and 2100 rpm the smoke emission decreases by around 2400 rpm and increases at high revolutions. In both engines it is expected that work emission in the range of 1700–2100 revolutions will be high. It is considered that this is because of the poor combustion efficiency at low revolutions. The increase in combustion efficiency in the mid-cycle has led to a decrease in work emissions. Figs. 7 and 8, it is thought that the decrease in the combustion efficiency increases the emission of work because of the insufficiency of the time allocated to combustion especially at high speed.

The combustion duration is the time period elapsed throughout the combustion. The ignition delay is an important parameter affecting the onset of the combustion [21]. The decrease of ignition delay due to the coating was thought to have a positive effect on the combustion efficiency. It was observed that the smoke emission increased for both engines in parallel with the increase of the rpm after the moderate rpm. This is an expected situation. Since the increased fuel amount taken to the combustion chamber together with the increased rpm after the moderate rpm. The combustion duration is the time period elapsed throughout the combustion. The ignition delay is an important parameter affecting the onset of the combustion [21]. The decrease of ignition delay due to the coating was thought to have a positive effect on the combustion efficiency. It was observed that the smoke emission increased for both engines in parallel with the increase of the rpm after the moderate rpm. This is an expected situation. Since the increased fuel amount taken to the combustion chamber together with the increased rpm [22] and decreased time and oxygen required for the combustion were considered to increase smoke emission. When considering high viscosity and low volatility of vegetable oil compared to diesel fuel, it was an expected result to have higher amount of smoke compared to the diesel fuel. When it was considered that the unheated fennel oil caused a poor atomisation, pulverisation and nonhomogeneous air-fuel mixture regions, all of these factors caused incomplete combustion and high smoke emission. As seen in Figs. 7 and 8, the smoke emission caused by the fuels decreased in all test fuels by means of the preheating. There
were a decrease of 7.62% in HNO2 fuel compared to NO2 fuel, a decrease of 11.62% in HFE-30 fuel compared to FE-30 fuel, and a decrease of 10.51% in HFE-50 fuel compared to FE-50 fuel. There were also a decrease of 17.22% in NO2 fuel, a decrease of 15.83% in FE-30 fuel, and a decrease of 14.58% in FE-50 fuel in coated engine compared to the standard engine.

3.4. Comparison of HC (Hydrocarbon) emission

HC emission is an emission forming after incomplete combustion. Unburned HCs among the combustion products were caused by low ignition temperature of the fuel and unsuccessful oxidation or semi-oxidation of the fuel due to insufficient oxygen in the environment [23,24]. Figs. 9 and 10 show comparatively the variation of the HC emissions according to the rpm.

Since the in-cylinder temperature was low at low engine speeds, it was an expected result to have high HC for all test fuels. It was considered that the coating process increased the in-cylinder temperature, allowed more efficient combustion in the pilot flame and thus caused more HC to enter the combustion reaction. As the rpm increased, HC decreased for both engines and all test fuels. However, the amount of heat transferred through the combustion chamber decreased due to the coating; therefore, the in-cylinder temperature was higher than the SE engine. It was considered that this advantage of the coating process increased combustion efficiency and decreased CO and HC. In the comparison of SE and CE, HC emission decreased for all test fuels in CE because of the coating process.

The liquid fuel injected into the combustion chamber is decomposed into small droplets at the injector nozzle outlet to form a spray and must vaporise before mixing with air and combustion [17]. It was thought that decreasing the viscosity of the fuel through preheating process (by heating up to 100 °C) helped to obtain smaller-sized fuel droplets at the nozzle outlet. Thus, the frequency of combining of hydrocarbons with oxygen increased and the combustion efficiency developed. It was considered that the improved atomisation and fluidity of the fuel by means of the preheating process applied to fennel oil positively affected the combustion efficiency. In Figs. 9 and 10, it is seen that in both test engines, HC emission is low at low engine speeds (approximately 1700–2000 rpm), decreases at mid-engine speeds (about 2400 rpm) and increases at higher engine speeds. A decrease of 5.55% in HNO2 fuel compared to NO2 fuel, a decrease of 7.89% in HFE-30 fuel compared to FE-30 fuel, and a decrease of 7.69% in HFE-50 fuel compared to FE-50 fuel occurred. Compared to standard engine, a decrease of 22.22% in NO2 fuel, a decrease of 15.78% in FE-30 fuel, a decrease of 12.82% in FE-50 fuel occurred in the coated engine.

3.5. Comparison of exhaust gas temperature (EGT)

Figs. 11 and 12 show EGT changes of test engines.

When examining the Figs. 11 and 12, the highest EGT occurred in NO2 fuel among all test fuels in both engines. In comparison of SE and CE, EGT increased for all test fuels in CE due to the coating process. EGT increased for both engines in parallel with the increased rpm. The reason for the increase in EGT for all test fuels in CE compared to SE was the thermal barrier. The decreased amount of heat transferred from the combustion chamber elements to the cooling and outer environment after the coating process caused an increase in chemical reaction temperature and an increase in the combustion efficiency [25,26]. It was considered that the applied coating process had a positive effect on both physical and chemical ignition delay since the temperature increase in the combustion chamber reduced the ignition delay. The EGT for both test engines increased in parallel with the increase in the
An increase of 4.02% in HNO2 fuel compared to NO2 fuel, an increase of 0.80% in HFE-30 fuel compared to FE-30 fuel, and an increase of 0.00% in HNO2 fuel compared to non-preheated HNO2 fuel, and an increase of 3.62% in NO2 fuel, an increase of 2.10% in FE-30 fuel, and an increase of 1.40% in HFE-50 fuel compared to FE-50 fuel. There were an increase of 0.80% in HNO2 fuel compared to non-preheated NO2 fuel, an increase of 0.80% in HFE-30 fuel compared to FE-30 fuel, and an increase of 2.10% in FE-30 fuel, and an increase of 2.20% in FE-50 fuel in coated engine compared to standard engine.

3.6. Comparison of brake thermal efficiency

The spray geometry of the actual diesel combustion (especially the unstable turbulence diffusion of the diesel flame) is quite complex. The structure of each fuel spray is composed of a narrow core with liquid content (filled densely with drops with a diameter of 20 μm) surrounded by a much larger gas jet region containing fuel vapour [17]. This is very important in terms of combustion efficiency. The applied coating process improved the combustion efficiency. With the applied coating process, the duration of ignition delay decreases and the combustion develops. The increase in combustion efficiency caused the thermal efficiency to increase as shown in Fig. 14. Because one of the most important factors on thermal efficiency is the improvement of combustion efficiency.

There were an increase of 0.00% in HNO2 fuel compared to non-preheated NO2 fuel, an increase of 0.80% in HFE-30 fuel compared to FE-30 fuel, and an increase of 1.40% in HFE-50 fuel compared to FE-50 fuel. There were an increase of 3.62% in NO2 fuel, an increase of 2.10% in FE-30 fuel, and an increase of 2.20% in FE-50 fuel in coated engine compared to standard engine. Fig. 14 shows thermal images of the standard and coated engines. It can be seen in Fig. 14 that the surface temperature of the coated engine was higher than the standard engine. This temperature increase in the coated engine was thought to be a result of reduced heat transferred from the combustion chamber to the external environment as a result of the coating process.

4. Conclusions

In the present study, particularly their physical characteristics (such as viscosity and density) were improved by applying the preheating process of 100 °C to the crude fennel oil + diesel fuel mixtures to enhance their combustion properties. In addition, the piston, exhaust and intake valves were coated with Cr3C2, a ceramic material, to provide insulation for the combustion chamber of the diesel engine. According to the experimental results, it can be concluded that:

- Applying the preheating process of 100 °C to the fennel oil + diesel fuel mixtures improved the physical properties of the fuel,
- Preheating process increased the brake thermal efficiency (avg. 1.12%) and EGT (avg. 5.35%),
- The preheating process of 100 °C decreased CO, HC and smoke emissions (avg. 9.30%, 10.69%, 9.84%, respectively) but increased the NOx emission (avg. 8.07%),
- The applied coating process improved the combustion efficiency and increased the brake thermal efficiency (avg. 2.08%) as well as EGT (avg. 5.10%) for all test fuels,
- CO, HC, and smoke emissions decreased (avg. 11.09%, 15.64%, 12.82%, respectively) but NOx emission increased (avg. 12.48%) for all test fuels used in the coated engine,
- Coating of combustion chamber with Cr3C2 in diesel engines is a system that can be applied without causing any serious change in the construction of an existing internal combustion engine,
- Fuels in less quality can be used in diesel engines with isolated combustion chamber together with the preheating process.
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References


