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DEVELOPMENT OF DIESEL-OXYGENATED BLENDS AND EXHAUST GAS RECIRCULATION IMPACT ON DIESEL ENGINE'S PERFORMANCE AND EMISSION

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Most research studies have focused on reducing NOx emitted from diesel engines by adding oxygenated fuels (such as alcohol and biodiesel) to diesel to prepare a good alternative to conventional diesel fuels. Biofuels produced from vegetable oil and waste cooking oil while alcohol can be produced from sugarcane and corn. In the current study, the biodiesel used in the tests was derived from waste cooking oil. In this study, the influence of adding Exhaust Gas Recirculation (EGR) to diesel, biodiesel (D80B20), diesel-pentanol (D85PEN15), diesel octanol (D90OCT10), diesel-propanol (D95PRO5) and diesel-biodiesel-pentanol (D50B40PEN10) blends on performance and emitted pollutants of a diesel engine was investigated. The practical experiments were divided into two parts, the first section comparing the results of using diesel and other fuels at different speeds 2100, 2400, 2700 and 3000 rpm at constant loads without EGR. The second section studied the effect of adding EGR in variable proportions (5 %, 10 %, 15 % and 20 %) to the studied fuel mixtures at constant loads and speed. The results showed that adding biodiesel to diesel (without EGR) increases brake specific fuel consumption, NOx and CO_2 emissions by 13.66 %, 41.35 % and 30.49 %, respectively, but, the thermal efficiency of the brakes, exhaust gas temperatures, UHC and CO decreases at rates of 12.58 %, 10.22 %, 18.9 % and 21.31 %, respectively, compared to diesel. When EGR was added at 20 %, the maximum increase for D80B20, D95PRO5, ED100, and D85PENT15 was: 18.38 %, 24.60 %, 45.84 %, and 20 %, respectively, compared to when no EGR was added. The thermal efficiency, exhaust gases temperature and NOx levels decreased when EGR rate was raised

Keywords: EGR, biodiesel, pentanol, octanol, propanol, fuel consumption, thermal efficiency, NOx

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1. Introduction

The diesel engine has low fuel consumption, high efficiency, and better economic and dynamic performance compared to spark ignition engines. On the other hand, diesel engines emit high levels of nitrogen oxides and soot emissions [1]. It is especially emphasized the use fullness of the resulting ground humus as a waste material, when producing biogas as a fuel, for the operation of a hybrid energy system operating on the basis of a gas turbine engine [2].The technology of double hardening can be used in the manufacture of other parts, both gas turbine engines and parts of rocket and space technology [3]. Researchers have committed to searching for suitable alternative energy sources. Some have used diesel-water emulsions [4], others added nanoparticles to diesel fuels [5], and the rest proposed several alternative fuels such as biodiesel and alcohol [6]. The consumption of these types of fuels is also considered an urgent issue because of the costs [7]. Therefore, when using any of these alternatives, there is a need to consume large quantities of them to reach the energy generated by diesel fuel [8]. These fuels are environmentally friendly sources, as they have high oxygen content [9]. The production and utilization of alcohol as an alternative to conventional diesel in engine applications has been investigated for many years [10]. Researchers studied the influences of adding biodiesel by 10 % and 20 % (vol.) to diesel under EGR ratios of 0 % and 10 % [11]. The results showed that the Brake-specific fuel consumption lower when the engine was operated by biodiesel 10 % and biodiesel 20 %. However, bsfc was somewhat enhanced when biodiesel 50 % was utilized, compared to diesel fuel. Engine performance parameters deteriorated, CO and UHC emissions increases, and NOx emissions decrease when varied EGR rates were applied to the engine. The exhaust gas temperature (EGT) decreases as the EGR ratio increases by a rate 42–48 % when the EGR rates 35–40 % is used. When the EGR rates was greater than 12 %, about 11 % increase in Brake-specific fuel consumption (BSFC) was obtained. Given the foregoing context and contemporary issues related with the use of biofuels, the following objectives are sought in this article are study of pollutants emitted from running a diesel engine with a number of mixtures of biodiesel (waste cooking oil) and alcohol (pentanol, octanol and propanol), and the application of the Exhaust Gas Recirculation system in certain proportions to all types of fuel used and examination the performance and emissions from the engine.

Therefore, research on improving the performance of a diesel engine and reducing pollutants emitted from running a diesel engine with a number of mixtures of biodiesel (waste cooking oil) and alcohol (Pentanol, Octanol and propanol), as well as the application of the EGR system in certain proportions to all types of fuel used in practical experiments.

2. Literature review and problem statement

The use of renewable energy resources can help solve some of these problems. One such resource is the use of edible or non-edible vegetable oils. The use of oils unfit for human use as fuel would be more useful in overcoming social issues such as food crises and the food-for-fuel argument [12]. Since the price of waste oil is cheaper than new edible oils, this human waste also known as yellow grease (waste cooking oil) is the cheapest biodiesel feedstock [13]. Waste cooking oil cannot be used directly in various combustion engines due to its high viscosity [14]. Higher viscosity results in larger droplets, worse evaporation, and a narrower injection spray angle [15]. At temperatures exceeding 1000 °C, nitrogen oxides are formed inside the combustion chamber, and the rate of generation increases rapidly with increasing temperature [16]. The kinetics of the Zeldovich process makes the production of nitrogen oxides take the same amount of combustion time as a diesel engine [17]. As a result, any effect of biodiesel that extends the life of the mixture inside the cylinder or raises the temperature inside the cylinder can lead to NOx rise [18]. EGR is used to control NOx emissions in engines, and this technology has proven its effectiveness [19]. The technology of adding EGR to the air intake manifold is to dilute partially drawn air, which leads to an increase in areas of localized hypoxia in the combustion chamber. As a result, when the fuel takes a long time to oxidize, the flame becomes slower and more diffuse. This is the reason for the lower maximum flame temperature, which is believed to be the main reason for the decrease in NOx [20]. Several studies have examined biodiesel and EGR, but few have tested the combination of the two technologies. Studied the fact that biodiesel emits more nitrogen oxides than diesel is a controversial, difficult and significant topic. The type of biodiesel, engine design, injection system as well as the conditions accompanying the operation of the engine have a considerable influence on NOx emissions. The fuel oxygen encouraged complete combustion, raising the combustion temperature, and thus, NOx emissions would increase [21]. Cetane number (CN) is another intrinsic factor that affects the quality of combustion. Because of its longer fatty acid carbon chains, biodiesel has a higher proportion of naphthalene than petroleum diesel. Reducing naphthalene often resulted in longer ignition delays, increased pre-mixed air fuel charge, and thus increased NOx emissions [22]. The efficiency of a diesel engine employing EGR addition to intake manifold by levels from 0 % to 50 % is experimentally checked. The study showed that nitrogen oxide emissions decrease with increasing EGR rates. When EGR rates are between 25 %–40 %, a reduction in NOx emissions occurs at an average of 50–55 %. When the EGR increases above 15 %, CO_2 emissions and UHC also increase sharply [23]. Problems statement are influence of diesel-oxygenated blends and on diesel engine's presentation, and the possibility of adding oxygenates fuel such as biofuels extracted from waste cooking oil and heavy alcohols to Iraq high sulphur diesel.

3. The aim and objectives of the study

The aim of the study is show the effects of diesel-oxygenated mixes and exhaust gas recirculation on the output and emissions of diesel engines.

To achieve this aim, the following objectives are accomplished:

– to show the effects of various speed on BSFC with different diesel-oxygenated blends;

– to predict the effects of various speed on the brake thermal efficiency;

– to explain the effects of various speeds on exhaust gas temperature;

– to find the effects of various engine rpm on Nitrogen Oxides and Carbon monoxide emissions;

– to express the effects of various speeds on UHC levels.

4. Materials and methods

4. 1. Engine setup and facilities

A direct-injection (DI) air-cooled single-cylinder diesel engine (Loben – RB170F) was used in the recent practical study. Iraqi high sulphur diesel and several blends of diesel-oxygenated fuels were used in the tests at different engine speeds (2100, 2400, 2700 and 3000 rpm) and a constant load of 8 N·m without EGR. In the second set of experiments, tests were conducted by adding EGR (5 %, 10 %, 15 %, 20 %) to the engine manifold under the same previous operating conditions. A hydraulic dynamometer was used to control the engine load. Fuel consumption was measured using a fixed-volume 100 ml glass tube with a label on it. NOx, UHC, CO and CO concentrations were measured during testing with an emission analyzer type (EGMA type HG-550). Schematic diagram of the experimental setup used in tests was displayed in Fig. 1.

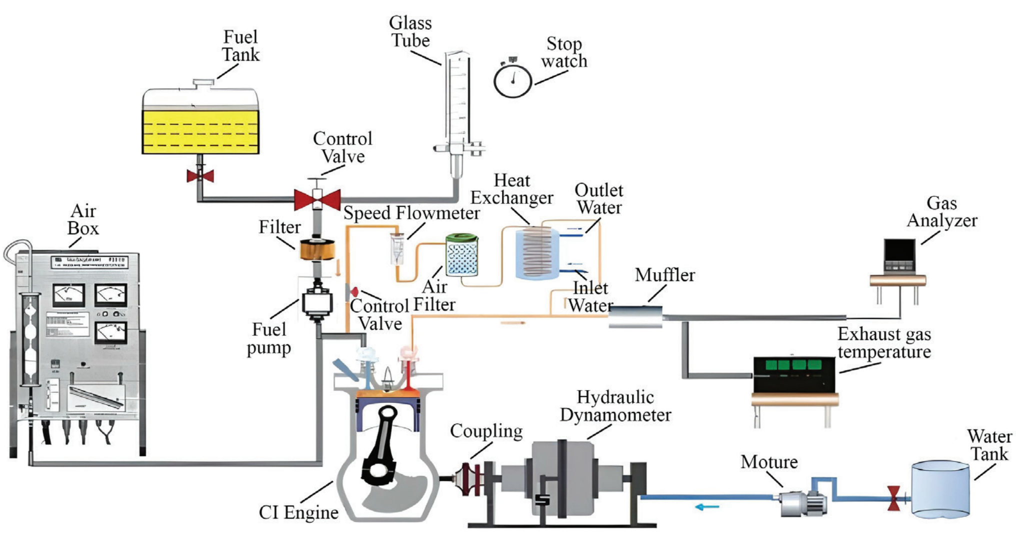

Fig. 1. The test rig schematic diagram

The main technical specifications of the motor used to tune the motor in Table 1.

Table 1

The technical specification of the used engine

Engine model	Loben – RB170F
Engine type	One cylinder, four-stroke
Combustion type	Compression ignition (self-ignition)
Cooling system	Air-cooled system
Fuel system	Direction injection system
Displacement volume	0.221L
Bore	70 mm
Stroke	55 mm
Compression ratio	17
Max. Engine speed	3000–3600 rpm

All gauges used were calibrated and their deviation from standard values were determined.

4. 2. Exhaust gas recirculation Setup

The employed EGR system consists of four main parts: EGR cooler, which is a heat exchanger designed to lower the exhaust gas temperature to the ambient temperature. The heat exchanger is of the shell and coil type. The exhaust gases are entered in the cooler through a filter. These gases transfer part of its heat to water inside the heat exchanger, which has a temperature of (20 °C). The filter absorbs the moisture in the gas after it leaves the heat exchanger and then delivers the filtered gas to flowmeters. Silica gel (1400 g) is contained in the filter. Flowmeters were used to measuring the mass flow rate of EGR. Finally, a thermocouple is placed inside the filter to measure the gases' temperature after being cooled, reaching approximately (20 °C) and then moving to the flow meter. The heat exchange cooling water calculates using a source tank with a capacity of (1 m^3). Added EGR ratio was evaluated using the following equation:

$$EGR = \frac{\mathring{m}_{EGR}}{\mathring{m}_{air} + \mathring{m}_{EGR}}, \quad (1)$$

where $\mathring{m}_{EGR}$ is the EGR mass flow rate while $\mathring{m}_{air}$ is the entering air mass flow rate to the engine.

4. 3. Experimental work calculations

4. 3. 1. Brake Specific Fuel Consumption

$$bsfc = \frac{\dot{m}f \times 3{,}600}{bp}, \text{ (kg/kW·hr)}$$

$\dot{m}f$ – fuel consumption rate (kg/sec);
bp – brake power (kW).

4. 3. 2. Brake Thermal Efficiency

$$\eta_{bth} = \frac{bp}{\dot{m}_{air} \times LHV} \times 100\,\%,$$

$\dot{m}_{air}$ – air consumption rate (kg/sec);
LHV – lower heating value (kJ/kg).

4. 3. 3. Ideal Mass Flow Rate of Air

$$\dot{m}_{air(ideal)} = \frac{v_{dis} \times n \times \rho_a}{60},$$

v_{dis} – displaced volume (m^3);
n – number of working strokes per minute. ($n=N/2$ for four stroke cycle engine);
N – engine speed (rpm).

4. 4. Test Fuel and procedure

Biodiesel was extracted from waste cooking oil (WCO) by transesterification process. In this process methanol and potassium hydroxide (KOH) are added to WCO at 60 °C for 1.5 hours. The fuel blends used in this work, 80 % diesel + 20 % biodiesel (D80B20), 95 % diesel + 5 % propanol (D95PRO5), 90 % diesel + 10 % octanol (D90OCT10), 85 % diesel + 15 % pentanol (D85PEN15) and 50 % diesel + 40 % biodiesel + 10 % pentanol (D50B40PEN10) by volume basis. Table 2 lists all fuels used in this study properties. These properties were examined in the Dura Refinery Laboratories in Baghdad (Iraqi capital).

Table 2

The used fuels properties

Properties	Diesel	D80B20	D95PRO5	D90OCT10	D85PEN15	D50B40PEN10
Flash point (°C)	64	71.6	61.7	65.7	56.15	50.4
Cetane Number	52	52.4	47.2	50.7	46	77.7
Viscosity (mm^2/s) at 40 °C	3.35	3.54	3.22	3.84	2.81	3.64
Density (kg/m^3) at 20 °C	840	850	833.3	837.5	821.1	854
Lower heating value (kJ/kg)	42,500	41,356	40,463	41,831	38,494	39,460

During the experiment, before adding fueling, use a stirrer to fully mixer all the mixture to ensure uniformity. Before the start of the test, preheat the engine for 30 minutes.

5. Results of the influence of adding Exhaust Gas Recirculation (EGR)

5. 1. The Brake Specific Fuel Consumption

Fig. 2 manifests the effects of various speed on The Brake Specific Fuel Consumption BSFC with different diesel-oxygenated blends. At low speeds, the engine suffers from low brake power and low in-cylinder gas temperature. These conditions cause an incomplete and low-efficiency combustion, which leads to a higher BSFC.

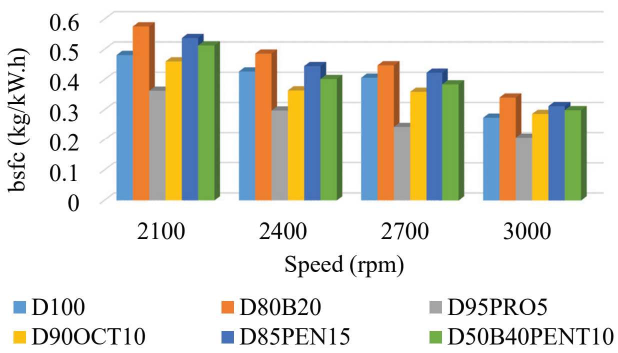

Fig. 2. The Brake Specific Fuel Consumption variation with the different fuel blend at variable engine speeds

The effect of EGR ratio on BSFC is shown in Fig. 3 under constant conditions of engine load and speeds.

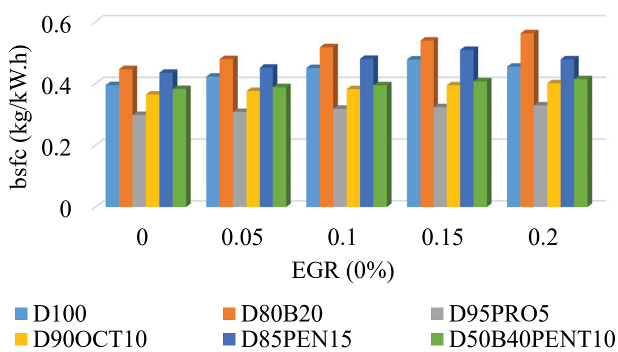

Fig. 3. The variation of BSFC with the different exhaust gas recirculation ratios at constant speed

The results showed that increment by 11.54 %, 9.20 % and 3.21 % in BSFC at EGR 0 % was observed from burning D80B20, D85PEN15 and D50B40PENT10, respectively in comparison with diesel fuel.

5. 2. The Brake Thermal Efficiency

The effects of various speed on Brake Thermal Efficiency ηbth are shown in Fig. 4 with different fuel blends. The reasons are heat loss and a reduction in the BSFC. The results showed that ηbth at EGR 0 % was observed from burning D95PRO5, D90OCT10 and D50B40PENT10 were higher than diesel by 42.45 %, 33.64 % and 26 %, respectively.

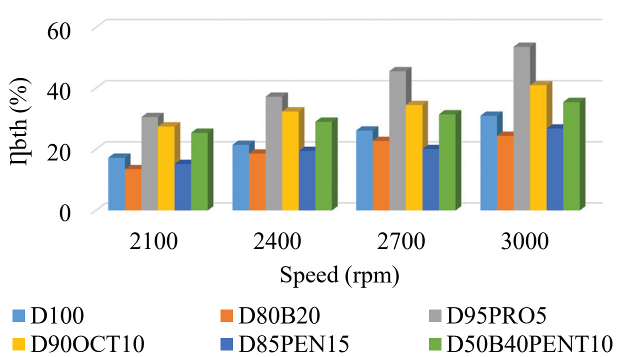

Fig. 4. The brake thermal efficiency variation with different fuel blend at different speeds

Increased EGR ratio caused high reductions in ηbth as depicted in Fig. 5.

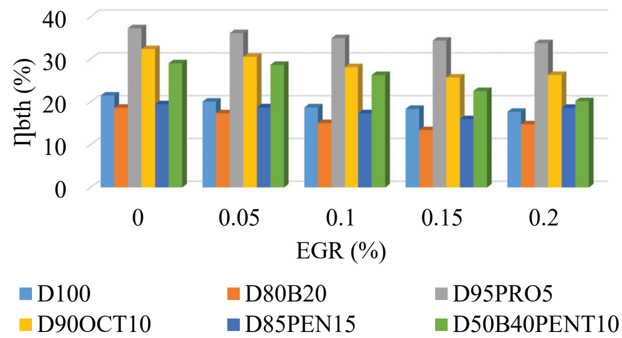

Fig. 5. The brake thermal efficiency variation with the different Exhaust gas recirculation ratios at constant speed

The biodiesel poor combustion properties such as its high density and low calorific value compared to diesel caused a decrease in the ηbth.

5. 3. Exhaust Gas Temperature

The effects of various speeds on Exhaust Gas Temperature EGT are manifested in Fig. 6 with the tested blends. At increased speed, there is less time available for combustion to complete. The results showed that burning D90OCT10, D85PEN15 and D50B40PENT10 increased EGT by 5.48 %, 11.21 % and 21.23 % more than diesel at EGR 0 %, respectively.

Fig. 7 shows the EGR ratio effects on EGT under constant conditions of engine load and speeds.

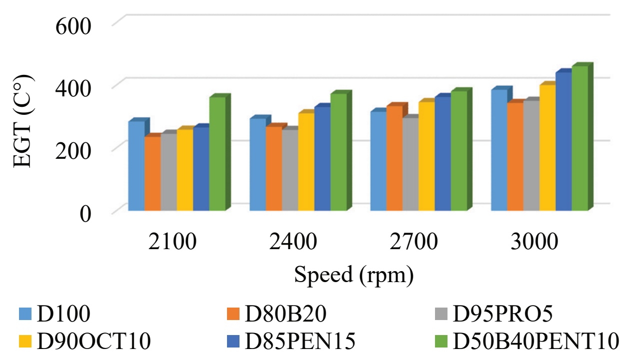

Fig. 6. Exhaust gas temperature variation with different blends at variable engine rpm

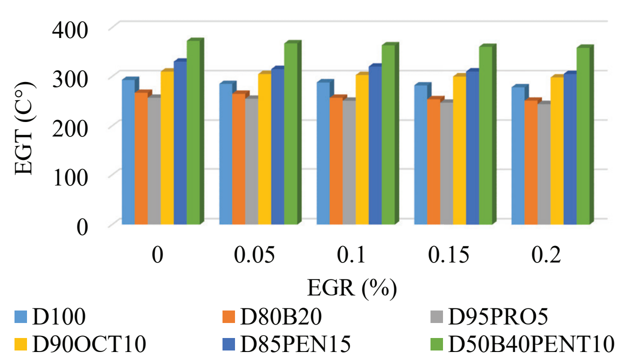

Fig. 7. Exhaust gas temperature variation with the different Exhaust Gas Temperature ratios at constant speed

A significant decrease in EGT with increased EGR ratio is depicted in Fig. 7. The EGR contained some tri-atomic molecules such as CO_2 and H_2O, which increased the blends specific heat capacity.

5. 4. Nitrogen Oxides and Carbon Monoxide Emissions

The effects of various engine rpm on Nitrogen Oxides NOx are illustrated in Fig. 8 with studied blends. The results showed that decreases by 18.18 %, 29.09 %, 49 % and 60 % in NOx emissions at EGR 0 % were observed from burning D95PRO5, D90OCT10, D85PEN15 and D50B40PENT10, respectively.

Fig. 9 shows the effect of EGR ratio on NOx emissions under constant conditions of engine load and speeds. Another cause is reduction in the flame temperature during combustion [24].

The effects of various speed on CO emissions are shown in Fig. 10 with different fuel blends. CO emissions reduce with raising engine speed. The high oxygen content allows better oxidation to air-fuel mixture than diesel.

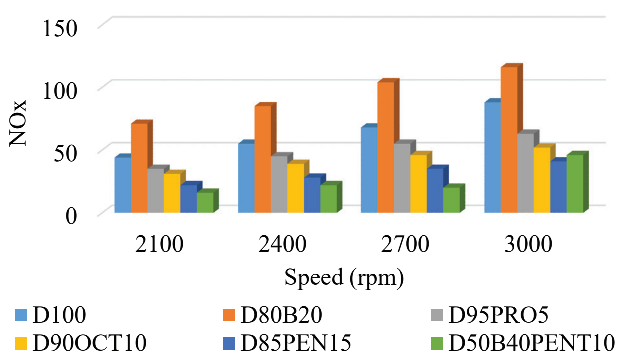

Fig. 8. Nitrogen Oxides emissions level variation with the different fuel blend at different engine speed

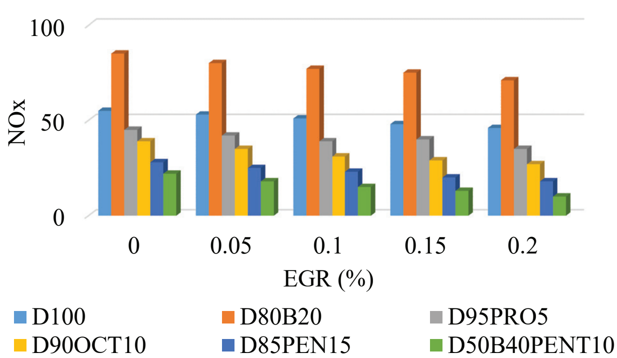

Fig. 9. Nitrogen Oxides emissions level variation with different exhaust gas temperature ratios at constant speed

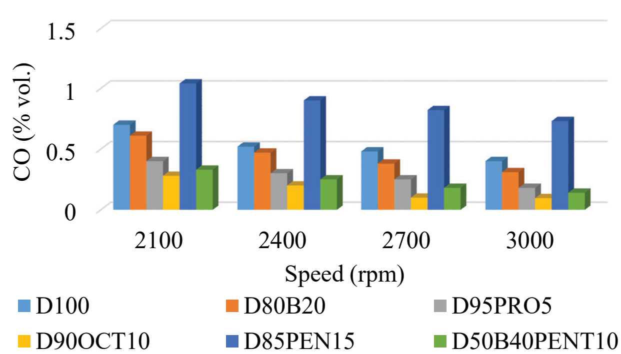

Fig. 10. The variation of carbon monoxide with the different fuel blend at different engine speed

Fig. 11 shows the effect of EGR ratio on CO emissions under constant engine load and speeds. Applied five ratios of EGR lead to increment the CO levels by 13.53 %, 24.05 %, 33.16 % and 36.56 %, compared with EGR 0 %, respectively, for diesel fuel tested.

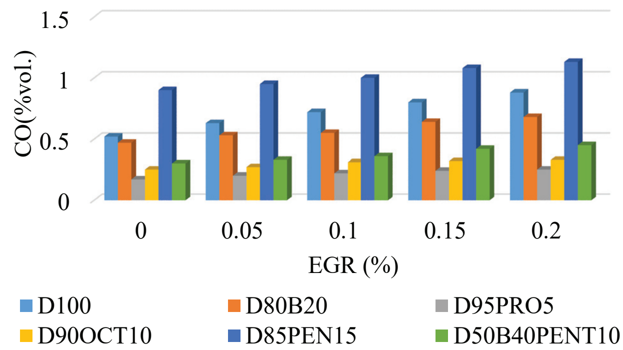

Fig. 11. The variation of carbon monoxide with the different exhaust gas temperature ratios at constant speed

For D80B20 tested, the CO increment rates were 11.76 %, 8.16 %, 27.41 % and 26.22 % compared with EGR 0 %, respectively.

5. 5. Unburned Hydrocarbons Emissions

Fig. 12 declares the effects of various speeds on UHC levels with studied fuel blends. High UHC results from low oxidation rates. When adding more biodiesel to diesel with high cetane number, the ignition delay and combustion timing are reduced. All these factors could lead to a reduction in the engine's UHC emissions [25, 26].

Fig. 13 reveals the effect of EGR ratio on UHC emissions under constant engine's load and speeds.

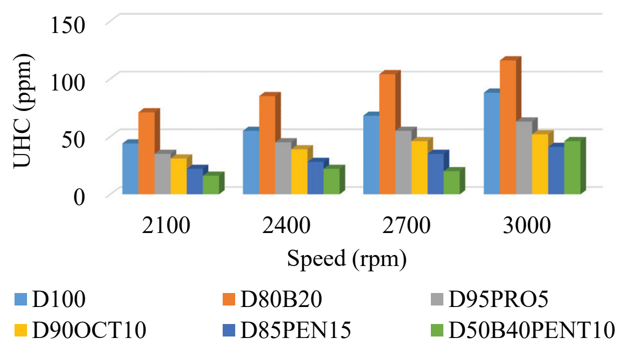

Fig. 12. Unburned hydrocarbons emissions variety with the studied blends at different engine speed

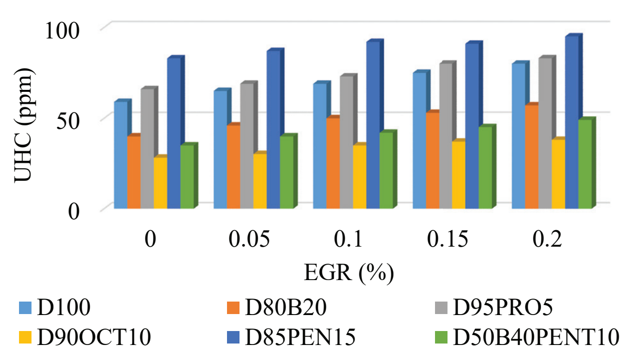

Fig. 13. The variation of unburned hydrocarbons emissions with the different exhaust gas temperature ratios at constant speed

Applied five ratios of EGR lead to increment the UHC emissions by 6.40 %, 12.85 %, 18 % and 22.24 %, compared with EGR 0 %, respectively for diesel fuel operation. For D80B20 tested, the increments rates were 9.12 %, 16.43 %, 20.59 % and 24.60 % compared with EGR 0 %, respectively.

6. Discussion the results of the performance and pollutants

This discussion for the performance and pollutants emitted from the engine by changing the physical properties of the fuel with the exhaust gas recycling system.

The purpose of the study is to obtain alternatives to fossil fuels obtained from consumables such as burnt oils, where the properties of the fuel used have been changed, and thus the value of the heat released from the combustion process will change, as well as the thermal efficiency and the value of fuel consumption. As well as reducing nitrogen oxides pollutants by using the gas recycling system. The use of a cold gas recycling system, as well as the use of long-chain alcohols and bio-diesel made from food waste oils. When using the EGR ratio, the highest percentage that can be used is (20 %). If this percentage exceeds this percentage, it will cause flame loss, because the recycled gases are inert gases. When alcohol is added to diesel fuel, no more than 15 % of it can be used, according to most of the previous researchers, because using more than this percentage leads to an increase in fuel consumption and a decrease in thermal efficiency. In the practical application, a small single-cylinder engine was used, where the amount of air entering was very little, with the application of the gas recirculation system, as an engine with more cylinders must be used. As for the theoretical application, it is difficult to apply in the combustion process such as analysis programs because of the change of properties between the reactants and results. Experiments can be developed using nanoparticles in the mixture as well as using a turbocharger. The results showed that the BSFC reduced when engine speed was raised as in Fig. 2. The results showed that increment by 11.54 %, 9.20 % and 3.21 % in Brake Specific Fuel Consumption BSFC at Exhaust Gas Temperature EGR 0 % was observed from burning D80B20, D85PEN15 and D50B40PENT10, respectively as in Fig. 3. The outcomes showed that increasing engine speed caused an increase in the Brake Thermal Efficiency ηbth as in Fig. 4. Burning D80B20 caused a reduction in ηbth of about 12.58 % at EGR0 % compared to diesel fuel as in Fig. 5. The EGT increase with increasing engine speed as in Fig. 6. The EGR contained some tri-atomic molecules such as CO_2 and H_2O, which increased the blends specific heat capacity as in Fig. 7. NOx emissions increased as a result of in-cylinder gas temperature increase accompanied with engine speed increase as in Fig. 8. decreasing by 32.20 % in UHC emissions at EGR 0 % was observed from burning D80B20 in comparison with diesel fuel as in Fig. 12.

When using the EGR ratio, the highest percentage that can be used is (20 %). If this percentage exceeds this percentage, it will cause flame loss, because the recycled gases are inert gases. When alcohol is added to diesel fuel, no more than 15 % of it can be used, according to most of the previous researchers, because using more than this percentage leads to an increase in fuel consumption and a decrease in thermal efficiency.

The problems that a cooled EGR system has, such as gas cooler corrosion, cooling capacity at higher loads, and extra weight, are eliminated with a hot EGR system. Also, the calorific value of biodiesel is lower than pure diesel, and therefore it is more fuel consuming than pure diesel.

In the practical application, a small single-cylinder engine was used, where the amount of air entering was very little, with the application of the gas recirculation system, as an engine with more cylinders must be used.

7. Conclusions

1. It is suggested that the increase of fuel consumption during combustion from binary blends could be due to reach the same power output generated from the diesel fuel.

2. The results showed that bth at EGR 0 % was observed from burning D95PRO5, D90OCT10 and D50B40PENT10 were higher than diesel by 42.45 %, 33.64 % and 26 %, respectively.

3. The results showed that burning D90OCT10, D85PEN15 and D50B40PENT10 increased EGT by 5.48 %, 11.21 % and 21.23 % more than diesel at EGR 0 %, respectively. With the addition of more alcohols, higher EGT were obtained.

4. The results showed that decreases by 18.18 %, 29.09 %, 49 % and 60 % in NOx emissions at EGR 0 % were observed from burning D95PRO5, D90OCT10, D85PEN15 and D50B40PENT10, respectively, compared to diesel fuel.

5. High UHC results from low oxidation rates. Oxidation rates reduce when the combustion takes place at low temperatures or low oxygen concentrations. As a result, oxygen in the biodiesel chemical structure enhances the fuel oxidation.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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