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Study Effect of Exhaust Gas Recirculation upon Emissions and Performance by Using European Diesel and Iraqi diesel

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HIGHLIGHTS

- Iraqi diesel produces higher NOx emissions than European diesel.
- Engine performance degrades with the EGR system.
- NOx emissions are reduced with the increase of EGR.
- CO and UHC emissions increased with the increase of EGR.

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ABSTRACT

This study investigated the effect of exhaust gas re-circulation (EGR) on performance and exhaust emissions in a single-cylinder, air-cooled, and direct-injection diesel engine. The Iraqi diesel fuel (D100) and European diesel fuel (ED100) were utilized at different speeds from (2100 to 3300 in intervals of 300) using the recycling of exhaust gas by a ratio (0%, 5%, 10%, 15%, and 20%. The study showed that European diesel fuel positively impacts engine performance and emissions. Compared to Iraqi diesel fuel, European decreased diesel fuel the brake-specific fuel consumption by (10.96%), increased brake thermal efficiency by (8.67%), decreased exhaust gas temperature by (9.99%), and (NO_X, UHC, and decreased (CO) emissions by (7.94%, 10.07%, and 36.98%) respectively. When using the EGR ratio, the highest percentage that can be used is (20%). If this percentage exceeds this, it will cause a flame loss because the recycled gases are inert. Furthermore, the results indicate that brake-specific fuel consumption increases by (15.395%) and brake thermal efficiency decreases by (13.44%) with increased EGR ratio. In contrast, exhausting gas temperature and NO_X emissions decreases by (4.01% and 14.57%) respectively. Finaly, the UHC and CO emissions increased with the increase of EGR ratio.

1. Introduction

Diesel engines have become widely used in the global transportation sector for commercial and public transportation due to their increased durability and efficiency. However, the transportation sector produces roughly 30% of global greenhouse gas emissions, contributing to global warming [1]. Diesel engines release more (NOx, UHC, and CO) [2]. Controlling exhaust emissions from diesel engines is becoming increasingly critical to meet rigorous car emission requirements and improve the atmosphere. The qualities of the fuel are one of the most important elements determining emissions from vehicle diesel engines. As vehicle fuel requirements become more stringent, the impact of fuel characteristics on harmful emissions from diesel engines is becoming increasingly clear. Sulfur concentration and CN are three significant property characteristics of diesel fuels [3]. The thermal NO_X mechanism dominates NO_X creation, determined by the local temperature in the burned mixture, the local air/fuel ratio, and the duration spent at elevated temperatures in the cylinder until the thermal NO_X formation reaction is frozen during the expansion stroke. Most NO_X would originate on the lean side of the spray throughout the quasi-steady combustion period and in the bulk gases after the primary heat release was completed. A bigger fraction of heat is released during premixed combustion for a fuel with a longer ignition delay, resulting in a faster burning rate. As a result, substantially more NOx is produced. As a result, in diesel engines, NO_X generation is primarily controlled by fuel injection timing, CN, and combustion pattern [4]. EGR is one of the most efficient strategies for decreasing NOx emissions in current engines, according to the study [5]. The fundamental consequence of an EGR system is a partial dilution of the air intake with exhaust gas flow, resulting in bigger localized oxygen deficiency areas in the combustion chamber. As a result, the flame gets slower and more diffused when the fuel requires a long time to oxidize. This is why the flames' peak temperature decline is thought to be the primary cause of NOx reduction [6]. EGR cooling increases the density of the intake charge and, as a result, the mass flow rate, which is just as significant as boost inter-cooling. The inter-cooler is well known for its importance in boosting engine performance and emissions. Recirculated exhaust is generally injected downstream of the inter-cooler to prevent fouling [7]. Agarwal et al. [8] experiment was carried out to evaluate the efficiency and emissions of different EGR rates experimentally by using two-cylinder,

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air-cooled, and direct injection diesel engines with EGR rates (from 0% to 20%). The results showed that EGR was found to improve BTE slightly. When the load and EGR rates were raised, the EGT at the inlet manifold was above the ambient temperature, and EGR was performed as a pre-heater to the incoming intake air. When the EGR rates rise, volumetric efficiency reduces. UHC and CO emissions increment with increasing EGR and decreasing NO_x emissions. Zhu et al. [9] studied the effect of fuel components and EGR system on combustion parameters, fuel efficiency, and emissions of a direct injection diesel engine fed with a diesel-dimethoxymethane (DMM) blend. The EGR ratio is from (4% to 24% in an interval of 4%). The results showed, When the EGR ratio is low, the BTE fluctuates, but as the EGR ratio increases, the BTE drops. NOx emissions are reduced when the EGR ratio increases, whileUHC and CO emissions increase. Labecki et al. [10] studied variable levels of EGR. An attempt was made to examine and evaluate rapeseed oil's combustion and emission characteristics in a multi-cylinder diesel engine using an EGR ratio from (0% to 20%). The outcomes showed that NO_X emissions were reduced even further when the EGR was increased to (20%).In the case of EGR 20%, the NO_X emissions decrease by more than (65%). The benefit of reduced NO_X comes at the expense of increased UHC and CO emissions. Pal et al. [11] studied the effect of using hot EGR and cold EGR on performance and emission by a single-cylinder, four-stroke, and water-cooled diesel engine. The test fuel used was iso-butanol in diesel fuel. The results showed that, due to the quenching effect of the cold EGR impinging proper combustion, fuel indicated higher BTE with hot EGR than cold EGR. The BSFC increased with increased hot and cooled EGR. EGT was found to be lower in engines that used EGR.EGR causes an (80%) increase in CO emissions.. Hot EGR releases more NO_x than EGR cooler, and EGT was decreased. Zhao et al. [12] studied the effect of a cooled external EGR rate on combustion, performance, and emission characteristics of a DME (dimethyl ether) -diesel dual fuel PCCI (premixed charge compression ignition) engine. The results showed that in a DME-diesel dual fuel PCCI engine with EGR, the equivalent BSFC increased, but the BTE declined. NO emissions fell as the EGR rate increased, but CO and UHC emissions increased. Chauhan et al. [13] studied the performance of a direct injection multi-cylinder diesel engine running on diesel-methanol mixtures using hot and cool EGR ratios (20% and 50%). The results showed that EGR, a method for lowering NOx, significantly impacts engine performance. The usage of cool EGR reduced BTE and higher BSFC. Better operating conditions were achieved by combining EGR with lower EGR temperatures. Volumetric efficiency is significantly improved when oxygenated alternative fuels are combined with EGR. Abaas et al. [14] studied the combustion characteristics of diesel fuel and compared them to those obtained by introducing EGR to the air manifold at various ratios (5%, 10%, 20%, and 30%).The findings of the experiments revealed that introducing EGR to a diesel engine resulted in considerable reductions in BTE by (11.7%) and EGT by (26.38%), as well as large increases in BSFC and a (12.28%) reduction in volumetric efficiency. Solmaz et al. [15] soybean biodiesel fuel was mixed (20%) with diesel fuel and tested in a single-cylinder diesel engine with varied EGR rates (5%, 10%, and 15%). The results showed, despite the reduced heating value of the soybean biodiesel fuel, (5% and 10%) EGR rates did not create substantial penalties on the engine performance results. When the EGR raised to (15%) rate, a little boost on the BSFC (up to 6 %) and some reduction in BTE (up to 3 %) was observed. Simultaneously, NO_X emissions were reduced by up to (55%). UHC emissions were decreased by more than 5% EGR. Although CO emissions did not alter significantly, CO_2 emissions, on the other hand, were somewhat higher. Saleh et al. [16] studied the effect of EGR in the spark-ignition engine (SI) on NO_X emissions by using high octane number fuel, Mercedes-Benz, naturally aspirated petrol, four-stroke, and water cooling system utilized a SI engine. The engine was fueled with a varied EGR ratio (5%,10%,15%, and 20%) with gasoline fuel. The outcomes showed that the drop in BTE increased the EGR ratios, the BSFC increased, EGT reduced, and NO_X decreased at the EGR ratio. Chen et al. [20] studied the effect of EGR on combustion and emissions by high n-butanol/diesel ratio with (40%) butanol (Bu40) and compared it with diesel fuel. Experiment and simulation were used to study a modified water-cooled, CR (16), four-stroke, and single-cylinder research engine that was converted from a six-cylinder heavy-duty diesel engine at a constant engine speed of (1400 rpm) and EGR rates (from 0% to 60% in intervals of 10%). The outcomes showed that, at (EGR0%), when compared with diesel fuel, (butanol40%) emits greater NO_X and CO emissions. EGR does not affect UHC and CO emissions until the EGR rates are high. UHC and CO emissions increment when the EGR rate exceeds the threshold level. The (Bu40) threshold appears at a reduced EGR rate than diesel fuel. Diesel fuel and (Bu40) reduce NO_X emissions by using EGR rates. Huang et al. [21] studied the effect of n-pentanol as additive and EGR rates on engine performance and emissions using a four-cylinder and CR (16.5) diesel engine. EGR rates (from 0% to 30% in intervals of 5%) and speed were (1400 rpm). The outcomes showed that the (BSFC) rose as the EGR rates increased. (BDP20) an increase (BSFC) than the other two fuels, but the (η_{bth}) is not significantly different. When the EGR rate is up to (20%), the CO and UHC emissions increase with increasing EGR. As the EGR rate increases, the oxygen content and in-cylinder combustion temperature decrease, decreasing NO_x emissions for all test fuels. Liang [22] studied the combined effects of biodiesel and n-pentanol properties on the performance and emissions of a four-stroke, CN (15.8), water-cooled, and modified single-cylinder common-rail diesel engine at various EGR rates (0%, 10%, 20%, 30%, 40%, 45%, and 50%) were investigated. Diesel fuel, (B10P20) (10% biodiesel, 20% n-pentanol, and 70% diesel, by volume), (B20P10) (20% biodiesel, 10% n-pentanol, and 70% diesel, by volume), (P30) (30% n-pentanol and 70% diesel, by volume), and (B30) (30% n-pentanol and 70% diesel, by volume) were the tested fuel, at constant speed (1500 rpm). When the EGR rate is less than (40%), NO_x emissions for all fuels decrease significantly. When the EGR rate is higher than (40%), NO_x emissions for all fuels reduce significantly. However, as the EGR rate exceeds (40%), NO_x emissions drop to extremely low levels, and the reduction becomes less noticeable as the EGR rates increase. Wang et al. [23] studied the effect of adding (DBE) to a diesel/n-pentanol (DP) mixture on an engine's combustion and emissions performance at various EGR rates. The experiment employed a four-cylinder diesel engine with a CR (16.5) at a constant speed (1500rpm). The EGR rates were from 0% to 25% in intervals of 5%. Diesel fuel, (20%) n-pentanol + (80%) diesel (D80P20) were tested, as well as (20%) DBE and (80%) D80P20 (D64P16DB20) by volume. The results showed that; when n-pentanol is added to diesel fuel, the (η_{bth}) and CO emissions decrease, but the BSFC, NO_X, and UHC emissions are increased for (D80P20) compared with diesel fuel. With an increase in EGR rate, the BSFC of three tested fuels increases, but the BTE reduces. The BTE values of diesel fuel (D80P20) and (D64P16DB20) reduce by (7.8%) when the (EGR25%).The NO_x

emissions of the test fuels are reduced as the EGR rate increases. At (EGR25%), the NO_x emissions of (D64P16DB20) were reduced by (15.4%) compared with that of diesel fuel. The three fuels' UHC and CO emissions increase as the EGR rate increases. This experimental work aims to reduce the flame temperature using the exhaust gas recycling system at variable rates. This, in turn, assists in reducing nitrogen oxide emissions to the minimum possible extent, as well as the effect of these percentages on the performance of the diesel engine using two different types of European diesel fuel, which is the international standard and Iraqi diesel.

2. Experimental Material and Methods

2.1 Test Fuel and Operating Conditions

The fuels utilized in this experiment were Iraqi diesel (D100) and European diesel (ED100). The Iraqi diesel fuels were taken from the Dura Refinery-Ministry of Oil, and the European diesel fuels were purchased from a local fuel station (OPET, Kayseri, Turkey). The fuels were characterized by determining their viscosity, density, flash point, etc. The ASTM -D6751 and EN - 14214 standard test procedures are utilized to determine the fuel parameters. The detailed properties of the tested diesel fuel used are given in Table 1. In this investigation, tests were conducted at five different engine speeds: (2100, 2400, 2700, 3000, and 3300 rpm) while the engine was warmed up and variable EGR ratios (0%, 5%, 10%, 15%, and 20%). Moreover, the coolant temperature was maintained at 80 ± 3 °C, while the intake air temperature was maintained at 20 ± 3 °C. A constant load torque from the engine dynamometer was applied to the test engine at each speed to ensure consistent test conditions. All fuel experiments were conducted on the same day to decrease experimental error, and each experimental point was repeated three times. The experiment was started after 60 seconds of stable engine operating following each modification in EGR rate.

2.2 Test Engine and Experimental Procedure

The tests were carried out in an air-cooled, single-cylinder, direct-injection diesel engine. The load was applied to the engine using a hydraulic dynamometer. The dynamometer operates on dissipating power in fluid friction, consisting of an inner rotating organ or impeller connected to the engine output shaft. The impeller spins inside a water-filled casing, and the output is controlled by gates that open and close, partially or completely blocking the water flow between the impeller and the casing. The exhaust gas temperature, which is utilized as an indicator of the temperature in the combustion chamber, was measured using a k-type thermocouple. The fuel consumption rate was measured using a glass tube with a consistent volume (100ml) marking. The consumption time of such an amount of fuel was measured using a stopwatch. The (EGMA) Type (HG-550) exhaust gas analyzer was used to measure gaseous pollutants such as NOx, CO, and UHC. Figure 1 is the schematic diagram of the test rig. Table 2 lists the main technical specifications for the used engine. Adjust the engine.

2.3 Error Analysis

Instrument selection, condition, calibration, environment, observation, reading, and test preparation can cause experiment errors and uncertainties. As a result, an error analysis must be performed to determine the correctness of the experiments. The magnitudes of error in various measured parameters, namely speed, and exhaust emissions, were estimated from the instruments' minimum output values and accuracy using the root-mean-square method. Table 3 shows the range, accuracy, and uncertainties of the instruments used in this study.

Table 1: Properties of the fuel used in the tests

Properties	Iraqi Diesel (D100)	Euro Diesel (ED100)
Sulphur content (wt. %)	1.0000	0.0004
Flash point (C°)	64	62
Cetane No.	52	54
Viscosity (mm^2/s) at 40C°	3.35	3.16
Density (kg/m^3) at 20C°	840	837
Lower heating value (kJ/kg)	42500	42910
CH composition	$C_{12.3}H_{22.2}$	$C_{12}H_{23}$

Table 2: The technical specification of the used engine

Engine model	Loben – RB170F/ Diesel engine
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	55mm
Compression ratio	17
Max. Engine speed	3000-3600 (rpm)

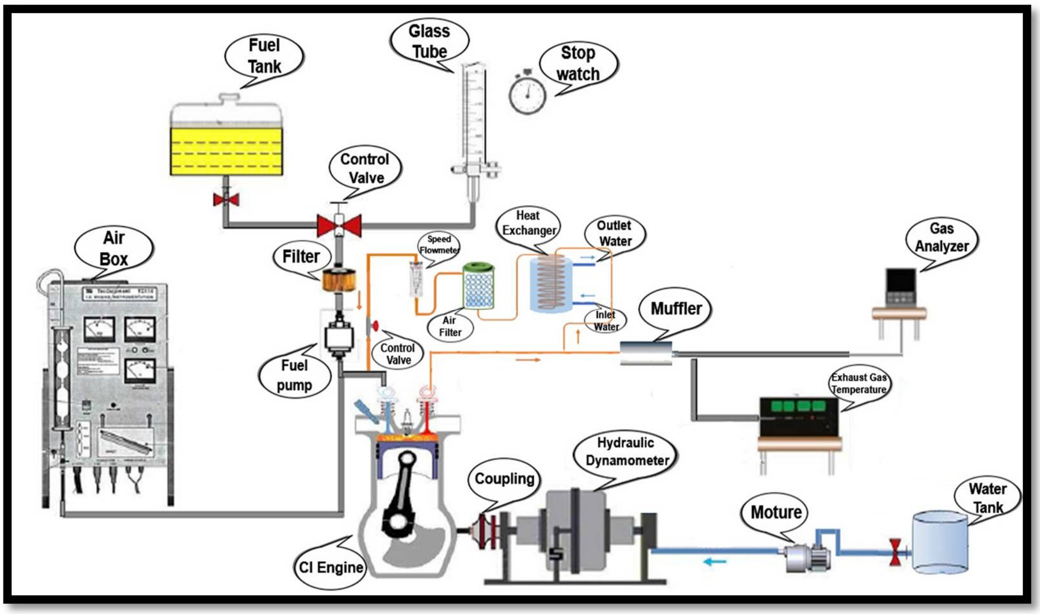


Figure 1: The schematic diagram of the test rig

Table 3: Range, accuracy, and percentage uncertainties of instruments used.

Instrument	Measured quantity	Range	Accuracy	Uncertainties %
Gas analyzer	NO_X	0-5000 ppm	±10 ppm	0.20
	HC	0-10000 ppm	±20 ppm	0.20
	CO	0.00-9.99%	±0.02%	0.15
Speed measuring unit	Engine speed	0-9999 rpm	±10 rpm	0.15

2.4 The EGR System

The EGR system consists of four main parts as follows:

2.4.1 EGR cooler

A heat exchanger was designed to lower the exhaust gas temperature to the ambient temperature. The heat exchanger is of the shell and coil type, with a shell height and diameter of (35*30 cm). Copper coil pipe with (1000*0.95*0.06) cm and ten turns. The cooler's let-out gas (parallel) is delivered to the filter. The water inside the heat exchanger has a temperature of (20℃)

2.4.2 Filter

The filter's function is to absorb the moisture in the gas after it leaves the heat exchanger and then delivers the filtered gas to flowmeters. The silica gel (1400 g) is contained in the filter

2.4.3 Flowmeters

For measuring the mass flow rate of EGR, flowmeters were used. The flowmeter worked with speeds from (0.1 to 1) L/min. The gases pass through the filter and into the flow meter, where they are measured for the required amount of recirculating gases before entering the engine's air intake manifold.

2.4.4 Thermocouple

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 exchanger was connected to a filter, the filter to flowmeters, and the flowmeters to the intake manifold using a plastic pipe. The heat exchange cooling water was calculated using a source tank with a capacity of ($1m^3$).

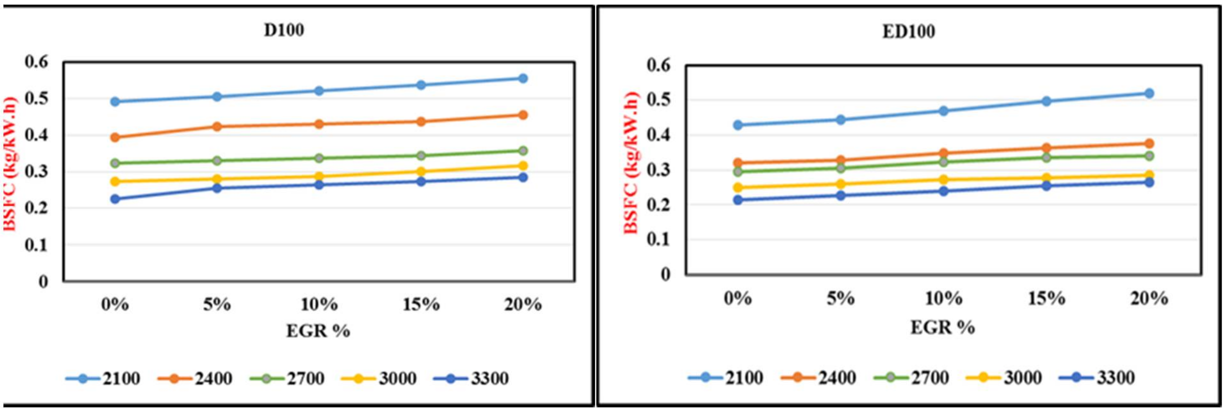
3. Results and Discussion

3.1 The Brake Specific Fuel Consumption (BSFC)

Figure 2 (a and b) demonstrates the variation of BSFC with the different EGR ratios between the D100 and ED100 blend at a different speed. The results showed that, at (EGR0%), the decrease in BSFC for ED100 by (10.96%) compared to D100 at all speeds. In the D100 and ED100, the increased in the BSFC at EGR (5%, 10%, 15% and 20%) by (5%, 7.28%, 10.03% and 13.46%) and (3.87%, 8.85%, 12.81% and 15.39%) compared to (EGR0%), at all speed, respectively. The rate of BSFC increases with the increase in the rate of EGR ratio. Because of the introduction of EGR, the exhaust gas replaced a part of the fresh charge in the cylinder, inhibiting normal fuel combustion and increasing the BSFC. References [12] have reported similar behavior on various engine types and conditions.

3.2 The Brake Thermal Efficiency (BTE)

Figure 3 (a and b) demonstrates the variation of BTE with the different EGR ratios between the D100 and ED100 blend at a different speed. The results showed that at (EGR 0%), the increase in BTE for ED100 by (8.67%) compared to D100, at all speeds. In the D100 and ED100, the decreased in the BTE at EGR (5%, 10%, 15% and 20%) by (4.98%, 7.27%, 10.01% and 13.44%) and (3.85%, 8.84%, 12.79% and 15.37%) compared to (EGR 0%), at all speed, respectively. The O2 concentration in the cylinder lowers as the EGR rate increases and the combustion reaction rate decreases. This leads to longer combustion durations, a lower constant volume ratio, and decreased BTE values. References [9] have reported similar behavior on various engine types and conditions.

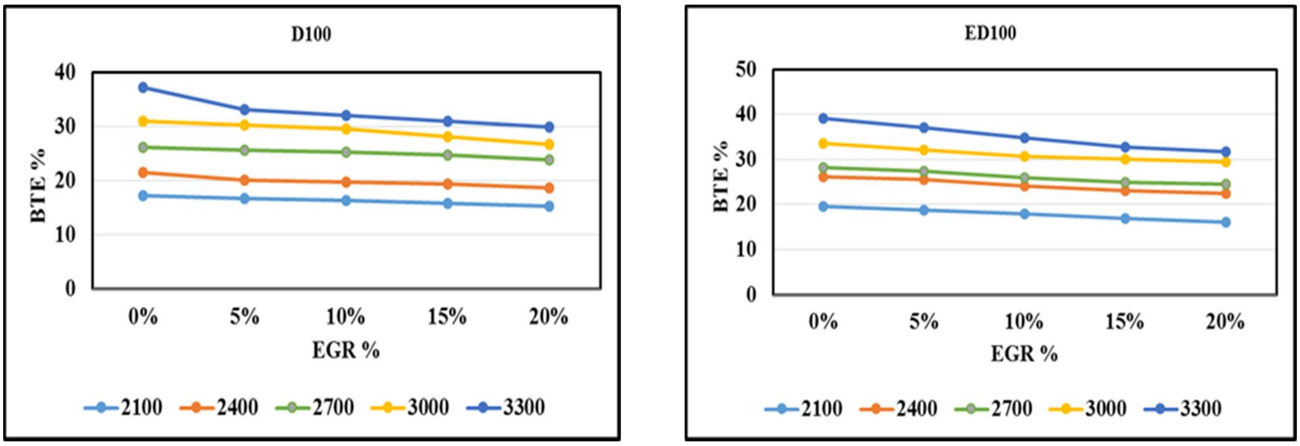


(a) **(b)**

Figure 2: (a) The variation of BSFC of Iraqi diesel with the different EGR ratios and (b)The variation of BSFC of Euro diesel with the different EGR ratios and speed

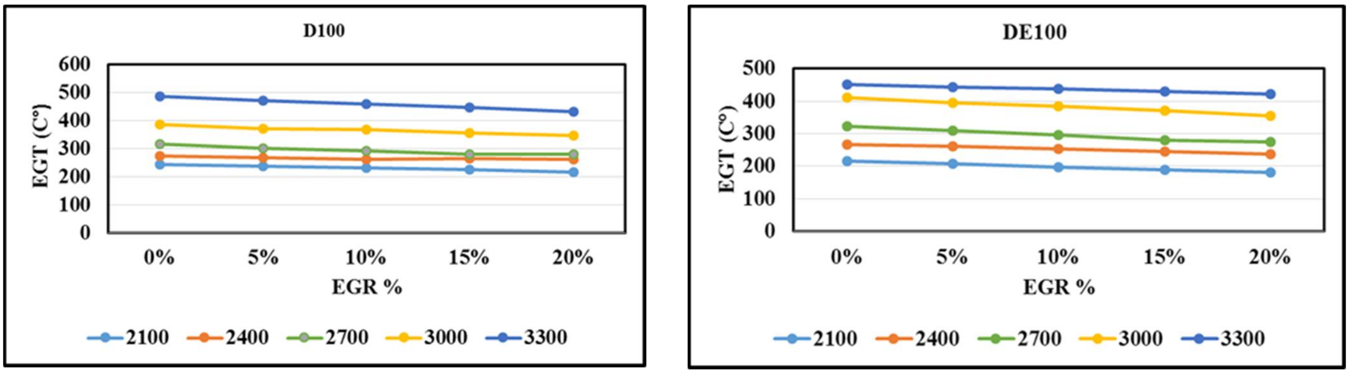
3.3 Exhaust Gas Temperature (EGT)

Figure 4 (a and b) demonstrates the variation of EGT with the different EGR ratios between the D100 and ED100 blend at a different speed. The results showed that at (EGR0%), the decrease in EGT for ED100 by (9.99%) compared to D100 at (2100 rpm and 2400 rpm) speed. While at (EGR 0%), the increase in EGT for ED100 was (5.78%) compared to D100, at (2700, 3000, and 3300rpm) speed. D100 has a lower LHV than ED100. In the D100 and ED100, the decreased in the EGT at EGR (5%, 10%, 15% and 20%) by (1.09%, 2.04%, 3.23% and 4.01%) and (1.50%, 2.54%, 4% and 4.91%) compared to (EGR0%), at all speed, respectively. The reason can be attributed to the dilution of the charge with the EGR, which causes the oxygen-deficient operation due to decreased combustion temperatures. References [8] have reported similar behavior on various engine types and conditions.



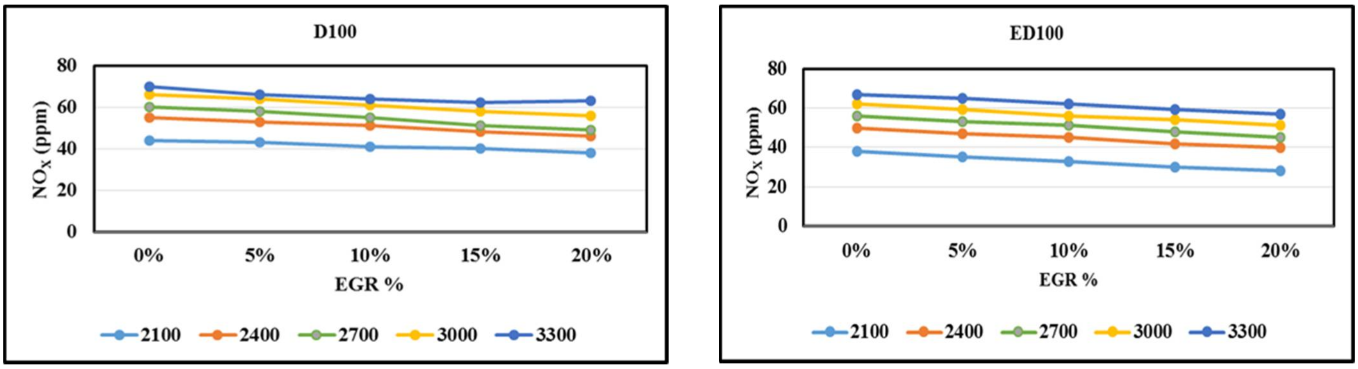
(a) (b)

Figure 3: (a). The variation of BTE of Iraqi diesel with the different EGR ratios and speed (b) The variation of BTE of Euro diesel with the different EGR ratios and speed



(a) (b)

Figure 4: (a) The variation of EGT of Iraqi diesel with the different EGR ratios and speed **(b)** the variation of EGT of Euro diesel with the different EGR ratios and speed



(a) (b)

Figure 5: (a) The variation of NO_X of Iraqi diesel with the different EGR ratios and speed (b) The variation of NO_X of Euro diesel with the different EGR ratios and speed

3.4 Nitrogen Oxides Emissions (NO_X)

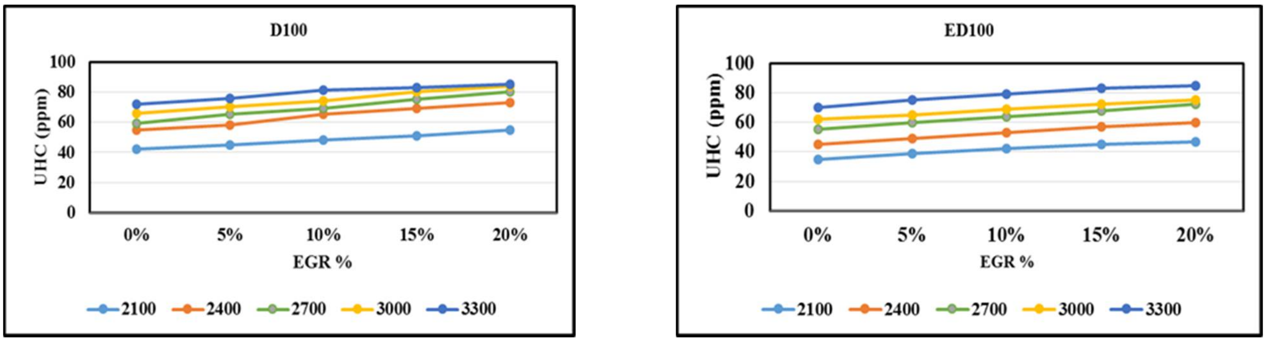
Figure 5 (a and b) demonstrates the variation of NO_X with the different EGR ratios between the D100 and ED100 blend at a different speed. The results showed that, at (EGR0%), the decrease in NO_X for ED100 by (7.94%) compared to D100 at all speeds. In the D100 and ED100, the decreased in the NO_X at EGR (5%, 10%, 15% and 20%) by (3.72%, 7.79%, 12.20% and 14.57%) and (5.12%, 9.52%, 14.65% and 19.04%) compared to (EGR 0%), at all speed, respectively. Logically, an increase in EGR leads to a decrease in the temperature of the burned gases and consequently a decrease in NOx emissions. References [8] have reported similar behavior on various engine types and conditions.

3.5 Unburned Hydrocarbons Emissions (UHC)

Figure 6 (a and b) demonstrates the variation of UHC with the different EGR ratios between the D100 and ED100 blend at a different speed. The results showed that, at (EGR 0%), the decrease in UHC for ED100 by (10.07%) compared to D100 at all speeds. In the D100 and ED100, the increased in the UHC at EGR (5%, 10%, 15% and 20%) by (6.40%, 12.85%, 18% and 22.24%) and (7.60%, 13.46%, 18.38% and 21.82%) compared to (EGR 0%), at all speed, respectively. Cold EGR raised UHC emissions even further. More inert gas was included in the combustion chamber due to the cooling of exhaust gas (due to the increase in density caused by cooling), obstructing the ignition reaction and reducing the combustion chamber temperature. Pal et. al. [11] have reported similar behavior on various engine types and conditions.

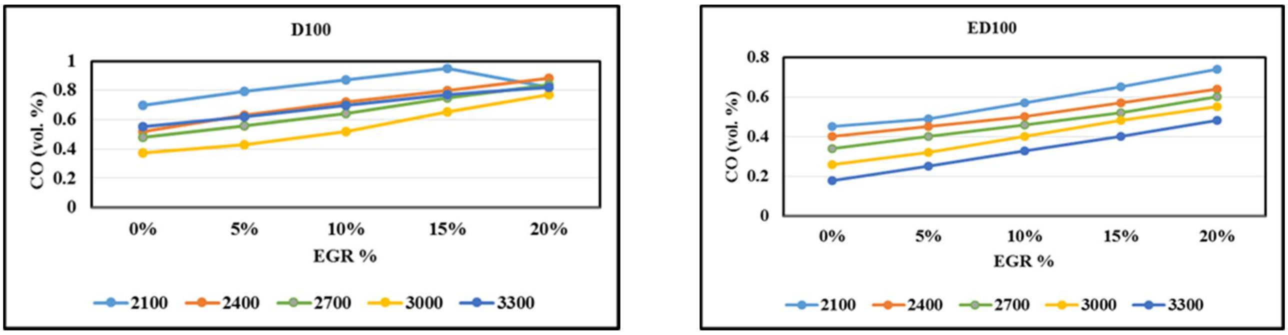
3.6 Carbon Monoxide Emissions (CO)

Figure 6 (a and b) demonstrates the variation of CO with the different EGR ratios between the D100 and ED100 blend at a different speed. The results showed that at EGR 0%, the decrease in CO for ED100 by (36.98%) compared to D100 at all speeds. In the D100 and ED100, the increased in the CO at EGR (5%, 10%, 15% and 20%) by (13.53%, 24.05%, 33.16% and 36.56%) and (14.66%, 27.87%, 37.78% and 45.84%) compared to (EGR0%), at all speed, respectively. The addition of EGR increases CO emissions because it dilutes the intake charge air, lowering the oxygen content and increasing the combustion temperature, favoring CO emission production. Labecki and Ganippa [10] have reported similar behavior on various engine types and conditions.



(a) (b)

Figure 6: (a). The variation of UHC of Iraqi diesel with the different EGR ratios and speed (b) The variation of UHC of Euro diesel with the different EGR ratios and speed

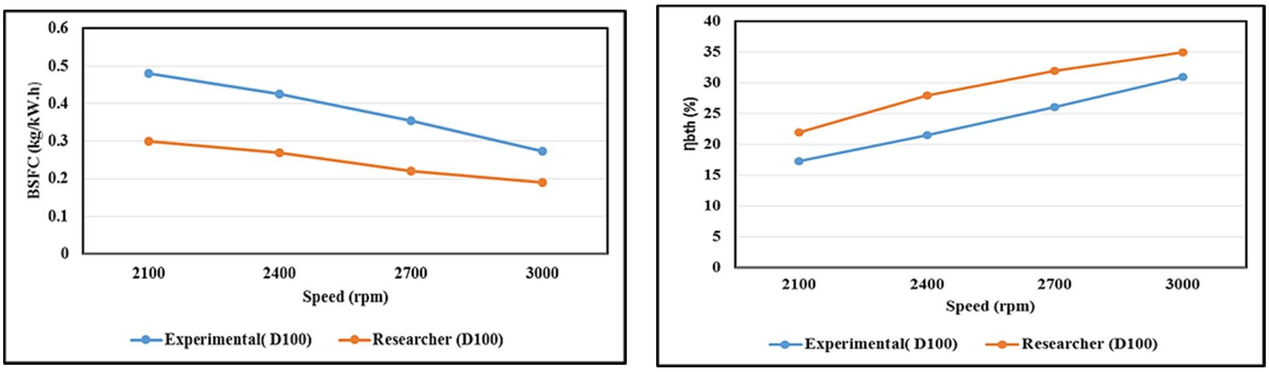


(a) (b)

Figure 7: (a).The variation of CO of Iraqi diesel with the different EGR ratios and speed (b) The variation of CO of Euro diesel with the different EGR ratios and speed

4. The Comparison between the Experimental and Publisher Work

Figures 8 (a and b) compare the experimental and published work results of BTE and BSFC at variable engine speed settings for diesel fuel D100. It's worth noting that all curves follow the same pattern, and the BTE and BSFC are largely dependent on engine speed. When the engine speed was increased, the BTE increased. However, the BSFC decreased at the same engine speed. These graphs show the largest and minimum deviations between the experimental and researcher results. The highest error for both the BTE and BSFC results is (20% and 17%), respectively. This discrepancy in reported results is due to several factors, including system stability, measurement equipment uncertainties and accuracy, and the inability to control some variables in the experimental test.



(a) (b)

Figure 8: (a). The variation of BSFC at different engine speeds (b)The variation of BTE at different engine speeds

5. Conclusions

1) European diesel fuel has less BSFC than Iraqi diesel fuel by a ratio (10.96%). The BSFC increased gradually with the increase in the EGR ratio until it reached the maximum BSFC at (EGR20%) by (13.46% and 15.39%) for D100 and ED100, respectively.
2) European diesel fuel has higher BTE than Iraqi diesel fuel by a ratio (8.67%). The BTE decreased gradually with the EGR ratio increase until it reached the maximum BTE at (EGR20%) by (13.44% and 15.37%) for D100 and ED100, respectively.
3) European diesel fuel has less EGT than Iraqi diesel fuel by a ratio (9.99%). The EGT decreased gradually with the EGR ratio increase until it reached the maximum EGT at (EGR20%) by (4.01% and 4.91%) for D100 and ED100, respectively.

4) European diesel fuel has less NOX, UHC, and CO emissions than Iraqi diesel fuel by a ratio (7.94%, 10.07%, and 36.98%), respectively.
5) The NOX emissions decrease gradually with the increase in the EGR ratio until it reaches the maximum NOX at (EGR20%) by (14.57% and 19.04%) for D100 and ED100, respectively. In addition, the UHC and CO emissions increase with the increase in the EGR ratio.

6. Recommendations for Future Work

1) Studying the effect of using diesel blends with two types of alcohol and EGR on the engine performance and exhaust emissions.
2) Studying the effect of using diesel blends with nanoparticles and EGR on engine performance and exhaust emissions.
3) Studying the effect of using hot EGR on the C.I engine performance and exhaust emissions.

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