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Study on the effect of diesel engine oil contaminated with fuel on engine performance

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ABSTRACT

An experiment was conducted to study how SAE 50 engine oil contaminated with diesel fuel affects engine performance. The engine oil was contaminated with diesel fuel at concentrations of 0%, 1%, and 3%. The following performance characteristics were studied: brake-specific fuel consumption, brake thermal efficiency, friction power, and exhaust gas temperature. Each treatment was tested three times. The three treatments (0%, 1%, and 3%) were analyzed statistically with a one-way ANOVA model at the 5% probability level to determine if the three treatments produced significant differences in engine performance. The statistical results showed that there were significant differences in engine performance metrics among the three treatments. The 3% fuel contamination yielded the highest averages for the following characteristics: brake-specific fuel consumption (0.40592 kg/kW·h), friction power (10.1325 kW), and temperature of the exhaust gas (174.5°C). The same contamination level yielded the lowest value for brake thermal efficiency (19.295%). The study demonstrated that the performance of a diesel engine can change when its oil is contaminated with diesel fuel. Therefore, the engine indicators have high performance at low contamination ratios, oppositely, at high contamination ratios.

KEYWORDS

Diesel engine, engine oil, engine performance, oil contaminants

INTRODUCTION

Engine oil is a fluid that reduces friction, corrosion, or both between moving parts inside an engine and removes heat, especially from the underside of the piston [1]. Engine oil is a mixture derived from petroleum and non-petroleum chemicals. Engine oil is contaminated during the normal operation of an internal combustion engine. Among the most common contaminants are water and fuel (unburned or partially burned) [2], which mixes with the motor oil and causes it to oxidize [3]. [4] emphasized that one of the main contaminants of lubricating oils that leads to their deterioration is fuel, which leads to oil dilution and thus reduces its effectiveness by diminishing its ability to reduce friction between metals. Oil dilution thus accelerates engine component wear and reduces the engine oil's performance and useful service life. Engine oil failure can cause engine component failure [5]. Therefore, additives are added to engine oil to reduce the oxidative damage [6] caused by unburned fuels, which lose their properties in oil. Many studies have been conducted on oil-fuel contamination's effect on the physical and chemical properties of the oil and on the engine's moving parts. However, few studies have investigated the effects of contaminated oil on engine performance.

Oil is generally composed of organic compounds and hydrocarbons, which are composed entirely of carbon and hydrogen. In other words, engine oils are manufactured from two parts: base oils (from various sources) and chemical additives to improve the quality of oils [7], including 1) protective additive (surface protection additives and anti-corrosion additives to reduce friction and corrosion and help prevent metal contact [8]; anti-rust-and-corrosion additives to prevent the engine interior from rusting; additives to make the surface free from sediment) and 2) additives to improve engine performance by improving the oil's viscosity to help reduce the rate at which viscosity changes with heat. The primary purpose of oils in internal combustion engines is to lubricate the moving parts [9]. Oils in internal combustion engines also clean deposits off the engine, prevent corrosion, improve performance, and cool the engine by removing heat from its moving parts [10]. Contamination of internal combustion engine lubricants, especially in diesel engines, is a major cause of engine component wear, which results in the loss of engine performance and life. Furthermore, contamination accelerates the breakdown of the engine lubricant oil, which reduces its useful service life. Contaminant particles of different sizes in the lubricating oil separating the surfaces of the moving components cause the corrosion of a large part of the diesel engine [11].

Fuel consumption is an important economic indicator for internal combustion engines. Working at different loads and speeds for long periods of time presents a great challenge. Therefore, fuel consumption plays an important role in selecting and managing towers [12]. [13] [14] indicated that fuel consumption increases with an increase in diesel fuel contamination. The increase in fuel consumption may be due to the increase in frictional power caused by the increased deterioration of the oil's properties as a result of the increased fuel contamination. The engine needs more power to overcome the increased friction and thus uses more fuel. Specific fuel consumption is the amount of fuel mass consumed by the brake power per hour. Specific fuel consumption can be defined as the rate of actual fuel consumption required to produce one unit of energy. Specific fuel consumption is divided into two categories: indicated specific fuel consumption (ISFC) when the rated power output from the engine is the primary source in the specific fuel consumption calculation and brake-specific fuel consumption (BSFC) when the engine output is the brake power. Braking power is important because it is based on the comparison between different engines. Braking power reflects engine performance because it allows direct determination of the engine's economics by calculating the amount of fuel needed to produce energy per unit time. Brake-specific fuel consumption increases as a result of the increased need for fuel consumption. This is because the engine's rotational speed increases while maintaining a constant load.

This means that fuel consumption and brake-specific fuel consumption are directly proportional to the engine load's stability, as indicated by [14] [15]. [13] [14] clarified that brake-specific fuel consumption, compared to any percentage of pollution, is high because the properties of the oil deteriorate, thus increasing the rate of fuel consumption with a constant load. There are two types of thermal efficiency. One is based on the indicated power and is called the thermal efficiency. The other depends on the brake power and is called the brake thermal efficiency. The brake thermal efficiency is defined as the ratio of the braking power to the energy produced by fuel combustion [14]. [13] [14] found that brake thermal efficiency decreases as diesel fuel contamination increases and that this decrease may be due to an increase in the amount of fuel entering the engine as a result of the contaminated oil's diminished properties. Consequently, the frictional force and the engine temperature increased while the thermal efficiency decreased for a constant applied brake power. [16] also showed that thermal efficiency is inversely proportional to the specific consumption of fuel. When the specific consumption increased, the thermal efficiency decreased.

Frictional power is defined as the difference between the indicated power and braking power. The power lost due to friction between the fixed and moving parts inside the engine links the indicated power to braking power [17]. The lower the losses due to friction, the greater the engine's braking power and the lower its fuel consumption. Therefore, friction significantly affects the engine. Friction losses are one source of power loss inside the engine. The places most vulnerable to friction are valves, pistons, cylinder walls, and interfaces between the connecting rod and crankshaft as well as between the camshaft and valves. To reduce friction, oil's properties must be preserved. Frictional power is used to evaluate power and mechanical efficiency. There are several ways to determine frictional power, one of which is the Morse test [18] [19]. [13] [14] and [20] explained that friction power increases with an increase in contamination and that the increase in frictional power is due to the loss of the properties of the oil as a result of its oxidation. This increase in friction power causes an increase in engine temperature [21]. One of the most important factors that affect friction is the contamination of oils. Contaminants cause oil to lose its properties, most importantly its capacity to reduce friction, and thus increase friction power.

The exhaust gas temperature is defined as the amount of heat that exits the exhaust pipe [22]. It is the maximum temperature for combusting fuel and converting it into exhaust gas [23]. Approximately 25% to 40% of the total heat supplied to the engine is transferred away by the exhaust gases, and this is the main way internal combustion engines lose heat [24] [25]. [13] [14] explained that the increase in exhaust temperature observed when engine oil contamination increased may be due to the deterioration of the oil's properties as a result of mixing with fuel, which works to oxidize the oil. This oxidization results in an increase in the force of friction and heat inside the engine, thus increasing the exhaust temperature. In this study, we chose the fuel as a contaminant because of its high chance of interacting with engine oil and thus impact on engine performance, where the three levels (0%, 1%, and 3%) in terms of volume of diesel fuel contamination in SAE 50 engine oil were applied. This research aims to determine which of the three volumetric ratios of oil contamination have a high effect on engine performance.

MATERIALS AND METHODS

The experiment was conducted in an engineering workshop at the College of Agricultural Engineering Sciences in the Department of Agricultural Machines and Equipment at the University of Baghdad using a J2 diesel engine with a 2.7-liter four-stroke water-cooling system. Table1 lists the specifications of the engine. The engine was started at 1500 rpm and one level of electrical load with a value of 5240 W (5.240 kW) using a generator (three phases) connected to the engine. Table 2 lists the specifications of the electric generator. The engine was run at a speed of 1500 rpm for 10–15 min until it stabilized and reached the appropriate temperature for the given constant speed and load, at which time the required readings were taken. These readings included such performance indicators as brake-specific fuel consumption, brake thermal efficiency, friction power, and exhaust gas temperature. Each treatment was repeated three times. A one-way ANOVA was performed to analyze the data from the three treatments (0%, 1%, and 3%) and determine whether there was a significant difference in engine performance among the three treatments.

Table 1. Engine specifications

Engine Manufacturer	**Kia Bongo (Korea)**
Type of engine	J2 2701
Piston Displacement	2694cm^3.
Stroke	95 mm.
Bore	95 mm.
Nominal Output	80 hp at 4000 rev/min.
Maximum Torque	16.8 kg.m at 2400 rev/min.

Table 2. Specifications of the generator set

A.Csynchronous Generator				
Type	STC-24 KW	No	070606256	
30	KVA	3 PHASE	COSØ	0.8
50	Hz	1500	r/min	
380	V	MADE IN CHINA		
45.6	A			

The experiment was conducted with SAE 50 oil purchased from a local market in Baghdad, Iraq. The lubricating oil was contaminated with three different concentrations of diesel fuel (0%, 1%, and 3%). Pure diesel fuel and fuel mixed with oil were used. The oil and fuel analyses were conducted at the Dora Refinery of the Middle Refineries Company's Research and Quality Control Department in Baghdad. Table 3 presents the results of the oil and fuel analyses. The oil-fuel contamination mechanism consisted of an 18-liter plastic container, graduated cylinders, and a graduated needle. For example, to contaminate the oil with fuel at 3%, the following procedure was followed:

1. Convert 18 liters into milliliters (mL).
   18 L × 1000 = 18000 mL
2. Calculate the volume of diesel oil to be withdrawn from the 18-L container according to the target level of fuel contamination—3% in this case.
   18000 mL × 3/100 = 540 mL

3. Use a graduated needle to remove 540 mL of oil from the 18-L container, thus leaving 17460 mL of oil.
   18000 – 540 = 17460 mL
4. Add 540 mL of diesel fuel to the mixture.
   17460 + 540 = 18000 mL

We thus contaminated the oil with diesel fuel at a rate of 3%. The same procedure was followed to contaminate the oil at 1%. Note that a graduated container and graduated cylinders of German origin were used to measure the samples accurately.

Table 3. Results of oil and Fuel analysis

Oil analysis			**Gas Oil analysis**				
No.	**Lab. Insp. Data.**	**Results**	**No.**	**Properties**	**Unit**	**Results**	**method**
1	Density @15 C°	0.885	**1**	API @ 15.6 C°	-	40.5	ASTM D 4052
2	Vis. C.st. @ 40 C°	177.08	**2**	Specific gravity @ 1506 C°	-	0.8226	
3	Vis. C.st. @ 100 C°	17.04	**3**	Density @ 15.0 C°	g/cm^3	0.8222	
4	VI	102	**4**	Flash point	C°	67.0	ASTM D 93(A)
5	COC Flash point C°	256	**5**	Viscosity @ 40 C°	cSt	2.08	ASTM D 445
6	H_2O % VOl.	Nil	**6**	Calorific value Gross Net	Kcal/Kg	10979 10291	Calculated
7	Sul. Ash % Wt.	0.746					
8	T.B.N. mg KOH/g Oil	6052					

Figure 1 shows that the test platform used in the experiment consisted of an internal combustion engine with an attached generator. Additionally, the test platform included a panel for measuring fuel consumption, electrical power, voltage and current, indoor temperature, atmospheric pressure, humidity ratio, engine water temperature, and exhaust gas temperature. Figure (1) shows the experimental setup.

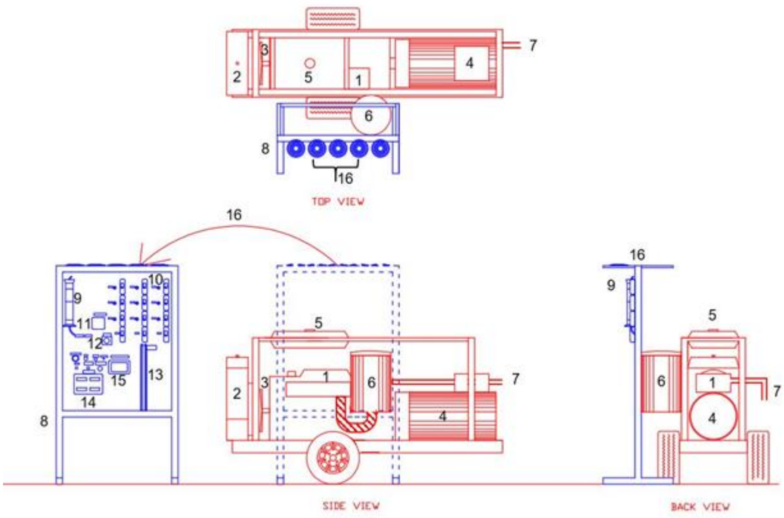

Figure 1. Illustrated diagram of test platform, where 1-Engine. 2- Radiator. 3- fan. 4-Electric generator. 5-Fuel tank. 6-Air box. 7-Exhaust pipe. 8-Board. 9-burette. 10-Load switches. 11-Electric meter. 12-Cycles counter. 13-Manometer. 14-Sensors panel. 15-An electronic platform for the weather. 16-loads.

The braking power was measured using an electric generator, and the braking power was calculated using Eq. [26]:

$$\mathrm{BP} = \frac{Tp}{1000 \times \eta_g} \tag{1}$$

Where BP is brake power (kw) , Tp total power (w), and η_g the efficiency of generator (80%).

The total power was calculated according to the following equation [27]:

$$T_p \text{ (3 Phases)} = P_1 + P_2 + P_3 \quad (2)$$

Where Tp is a total power (w) and P the wattage of each line (w).

$$P = V \times I \times PF \quad (3)$$

Where V: potential difference (v), I is current (amps), and PF: power factor (%).

The fuel consumption was calculated through the formula proposed by [28] [29]:

$$\dot{M}_f = \frac{\rho \times V \times 0.001}{t} \times 3600 \quad (4)$$

As $\dot{M}_f$: Average fuel consumption (kg/h), ρ: fuel density (kg / cm^3), V: The volume of fuel descending through the burette and the amount (50 cm^3), and t: time to consume a certain amount of fuel (sec).

The specific brake consumption of the fuel was calculated using the following equation [30]:

$$BSFC = \frac{\dot{M}_f}{BP} \quad (5)$$

Where BSFC: specific brake fuel consumption (kg / kw.hr), $\dot{M}_f$: Fuel consumption (kg/h), and BP: brake power (kw).

The brake thermal efficiency is calculated from the following equation [31]:

$$\eta_{bth} = \frac{BP}{\dot{M}_f * CV} \quad (6)$$

As: η_{bth}: brake thermal efficiency (%), BP: brake power (kw), $\dot{M}_f$: Average fuel consumption (kg/h), CV: the calorific value of the fuel (kJ/kg).

The total Indicated power of the engine (kw) was calculated based on the Morse test, which is used to multi-cylinder engines, In order to conduct this test, two important parts must be provided, first is a device to find the total brake power and second a tachometer to measure the rotation speed of the engine [18] [19].
The frictional power was calculated from the following equation [18] [25]:

$$FP = TIP - TBP \quad (7)$$

whereas : FP: frictional power (kw), TIP: total indicated power (kw), TBP: total brake power (kw).

The temperature was measured using a Max6675 thermocouple probe with a K-type thermocouple connected to an Arduino Mega 2560 controller board, As this sensor is placed in the exhaust pipe and near the engine cylinder block, this sensor has the ability to measure temperatures in the 0–1024°C range. The SAE 50 engine oil was contaminated with diesel fuel at three different levels (0%, 1%, and 3%). The engine speed was 1500 rpm and the load was 5240 W. Prior to each run, the fuel level in the tank, the amount of water in the water tank, and the oil level in the engine were checked. The engine was first supplied with uncontaminated SAE 50 oil and then run with cruise control at 1500 rpm without load for 10 minutes.

The load was gradually increased by operating the load switches, which were nine heaters, while maintaining the engine speed at 1500 rpm until reaching the required load of 5240 W. The following readings were taken: fuel consumption, indoor temperature, indoor humidity ratio, and temperature of the exhaust gas. A Morse test was then performed to obtain the indicated power at a speed of 1500 rpm. This procedure was repeated three times, collecting the same readings each time for increased accuracy. After the data were collected, the engine was turned off and the engine oil was changed. Fresh oil (SAE 50) was poured into the engine, this time with the second contamination level (1%). The previous procedure was then repeated to obtain data. Finally, the procedure was repeated for the 3% contamination level.

RESULTS AND DISCUSSION

Figure 2 illustrates the effect of the fuel contaminant on the brake-specific fuel consumption. Increased contamination levels produced significant differences in performance. The 0% contamination level resulted in the lowest brake-specific fuel consumption (0.37665 kg/kW·h). The 1% contamination level resulted in the second-highest brake-specific fuel consumption (0.3964 kg/kW·h), and the 3% contamination level yielded the highest average brake-specific fuel consumption (0.40592 kg/kW·h). Brake-specific fuel consumption increased as the contamination level increased due to the deterioration of the quality of the oil. The rate of fuel consumption therefore increased while the load remained constant. These results are consistent with those obtained by [13] [14] and [5].

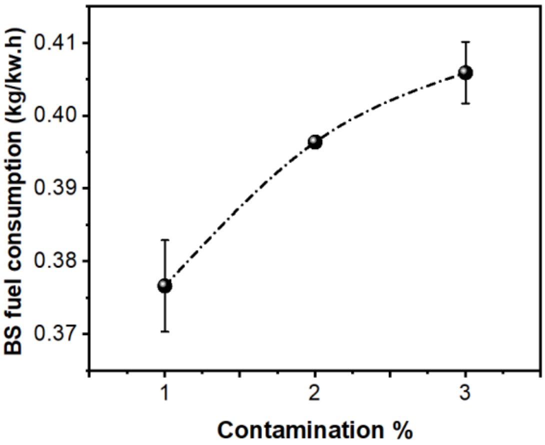

Figure 2. The effect of contamination levels on the braking specific (BS) fuel consumption rate

Figure 3 shows the fuel contaminant's effect on brake thermal efficiency. There are significant differences at the 5% probability level when increasing the contamination levels from 0% to 1% and then to 3%. As the contamination level increased, the brake thermal efficiency gradually decreased. It was found that the 0% and 1% contamination levels had the highest thermal efficiencies (20.68% and 19.75%, respectively). The 3% level yielded the lowest value for brake thermal efficiency at 19.3%. The decrease in brake thermal efficiency may be due to more fuel entering the engine as the engine oil is increasingly more contaminated. The resulting increases in friction force and engine temperature at a constant brake power reduce the brake thermal efficiency. These results are consistent with the results obtained by [13] [14]. Furthermore, brake thermal efficiency is inversely proportional to specific fuel consumption. When the specific fuel consumption increases, the brake thermal efficiency decreases [16].

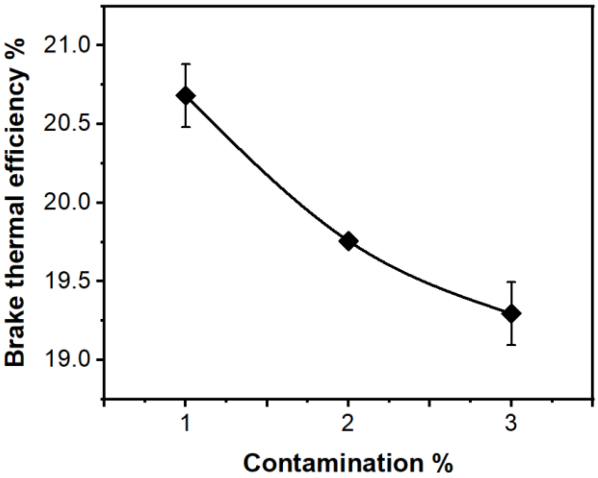

Figure 3. The effect of contamination levels on the rate of thermal brake efficiency

Figure 4 shows that the 0% contamination level yielded the lowest friction power (8.47667 kW). The friction power increased as the contamination level increased. The 1% contamination level yielded 9.125 kW while the 3% contamination level yielded the highest friction power (10.1325 kW). The one-way ANOVA confirmed statistically that the different results between the three contamination levels were significant. The high frictional power may be due to the degradation of the oil's properties and its oxidation causing an increase in engine temperature. These results were consistent with those obtained by [13] [14]. Oil contamination affects the friction in the engine. Contaminants diminish oil's capacity to reduce friction and thus increase friction power, as found by [21].

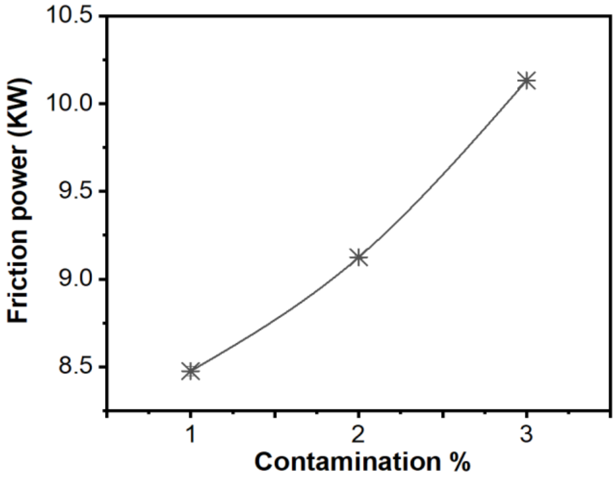

Figure 4. The effect of contamination percentage on frictional power

Figure 5 shows oil contamination's effect on the exhaust gas temperature. It was found that the 0% and 1% contamination levels had the lowest exhaust temperatures (163.7°C and 168.5°C, respectively) while the 3% contamination level resulted in an exhaust temperature of 174.5°C. The ANOVA results confirmed that these differences are statistically significant. The increase in exhaust temperature as oil contamination increased may be due to the fuel oxidizing the oil, which results in an increase in the force of friction and heat inside the engine and thus increases the exhaust temperature. These results were consistent with those obtained by [13] [14] and [21].

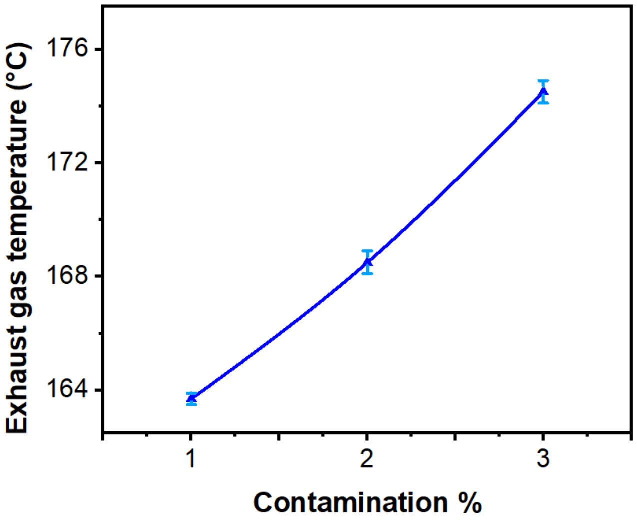

Figure 5. The effect of contamination percentage on exhaust gas temperature

CONCLUSIONS

This study contaminated SAE 50 diesel engine oil with fuel at three different levels (0%, 1%, and 3%) to determine how this would affect the performance of a four-stroke diesel engine. The results showed statistically significant differences between the three fuel contamination treatments at the 5% probability level. It was found that by increasing the oil contamination level from 0% to 1% and then to 3%, the brake-specific fuel consumption increased by 5.24% and 2.4%, respectively; the friction power increased by 7.64% and 11.04%, respectively; the exhaust gas temperature increased by 2.93% and 3.56%, respectively; and the brake thermal efficiency decreased by 4.49% and 2.27%, respectively.

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CONFLICTS OF INTEREST

Researchers declare that there is no conflict of interest.

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