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Experimental Study of the Effect of Heating Diesel Fuel on Burner Performance and Emissions

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ABSTRACT

Heavy-fuel oil (HFO) is primarily used as fuel to generate electricity in marine engines and boilers. Because of its high energy density, accessibility, and low cost, is a desirable commodity from an economic standpoint. These characteristics of HFO include its high viscosity, high molecular weight, high asphaltene content, and complex compositional diversity. It leads to a non-uniform spray pattern and inaccurate injection viscosity. Furthermore, incomplete combustion caused by large fuel particles will result in incomplete vaporization and high exhaust gas particulates, mostly unburned hydrocarbons; it also produces toxic gases like NOx. To address this problem and for the purpose of using heavy fuel oil, this study improved diesel fuel properties and the combustion system. The high viscosity of heavy diesel fuel (before inserting it into the burner) is reduced by adding a suitable heating device to the fuel line. Light fuel (LD) is also mixed with heavy diesel fuel (HD) to reduce the fuel viscosity. A mixture called LHD (50% LD and 50% HD) was prepared and tested in a burner and combustion chamber. Burner performance and exhaust emissions are evaluated when heating the fuel at three degrees (50, 70, and 90 °C). The results showed that the thermal efficiency (ηth) of LHD fuel has its highest value at 90, followed by 70 and 50 °C, respectively, and also (2.2%) the highest percentage increase in thermal efficiency when heating at 90 °C compared to heating at 50 °C. and the percentage increase (1.9%) was at 70 °C compared to 50 °C as well. The results also show the behavior of NOx with changing fuel temperature, and 50°C is the best because it gives the lowest NOx levels, followed by 70 °C and then 90 °C, respectively. The percentage increases in NOx emissions at 70 and 90 °C compared to heating at 50°C are 46 and 69%, respectively. The temperature of 50 °C will be the best due to the good behavior of NOX compared to its behavior at 70 °C and 90 °C, as well as the chances of its formation being greater as the temperature of the flame increases.

Keywords:
Heavy-fuel oil (HFO); exhaust emission; thermal efficiency

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1. Introduction

Various types of factories, including those that produce road asphalt, gypsum, cement, and other materials, are dependent on fossil fuels because they burn a lot of fuel and release a lot of emissions, including carbon monoxide and nitrogen oxides. The industry is therefore pressured to come up with better ways to cut these emissions. Mokthsim *et al.,* [1] The extensive study of heavy fuel oil (HFO) is becoming more and more popular as a result of its expanding use in gas turbines, boilers, furnaces, and ships. Elbaz *et al.,* [2] the main purpose of heavy-fuel oil (HFO) is to power boilers and marine engines that produce electricity. Abdul Jameel *et al.,* [3] during the refining process, lighter gases and

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fuels for distillation are extracted from crude oil. They are more expensive, produce more energy, and have higher hydrogen-to-carbon ratios. Heavy fuel oil (HFO) is the leftover residue oil from refining that has high carbon content and low hydrogen content.

El-Gendy *et al.,* [4] from an economic perspective, heavy-fuel oil (HFO) is a desirable commodity due to its low-cost, high-energy density, and ease of access. Asphaltene produces a non-homogenous fuel mixture by unevenly mixing thousands of separate molecules and functional groups into the fuel. High viscosity, high molecular weight, high asphaltene content, and complex compositional diversity are some of HFO's distinguishing qualities. Atomizer fouling follows, causing an uneven spray pattern and erroneous injection viscosity. Moreover, incomplete vaporization and high exhaust gas particulates—mostly unburned hydrocarbons with variable amounts of ash from metals like sodium, vanadium, and other metals—will be the result of incomplete combustion brought on by large fuel particles.

Additionally, it releases harmful gases like NOx and Sox [5,6]. Manufacturers and researchers are keen to use various suggestions and alternatives to lower fuel costs and pollution emissions [7]. Researchers and designers looked into the use of water-diesel emulsion [8], oxidized fuel (alternative) [9], and biological diesel fuel as viable replacements for fossil diesel [10,11]. Researchers have added the nanoparticles to water, diesel emulsion, biomed mixtures, and diesel [12-15]. Sulfur emission limits have recently been added to the environmental protection standards that the international community has set, and these standards are becoming increasingly stringent. As of January 1, 2020, the International Maritime Organization (IMO) has established a 0.5% global limit for sulfur emissions [16]. Controlling and lowering air pollution emissions, including those of nitrogen oxides, particulate matter, sulfur oxides, and volatile organic compounds, is the aim by Yue and Yirong [17].

In Iraq, Heavy diesel fuel is used to power the engines of river and marine vessels, heavy machinery, water pumps, and large power generators that range in size from 0.5 to several megawatts. This is because of the economic blockade that was placed on the country from 1990 until 2003. The effects of this fuel are growing even though it is still in use. Nevertheless, the Iraqi citizen still favors using this inexpensive fuel because of his financial situation (a liter of it costs less than a quarter of a liter of light diesel). Iraqi fuel is known for having high sulfur content—up to 3% in heavy diesel and 2.5% in light diesel. In Iraq, the highest levels of environmental pollution risk and reduced air quality are caused by heavy diesel fuel use [18,19].

However, due to its status as an oil-producing nation and its large stockpile of inexpensive HFO relative to LFO prices, Iraq is included in this study. The purpose of this study is to supply low-income individuals with fuel that is both affordable and of appropriate quality. To this end, fuel known as LHD which is made up of 50% heavy and 50% light diesel is prepared by heating it before being injected into the burner in order to decrease its viscosity and density (Table 1).

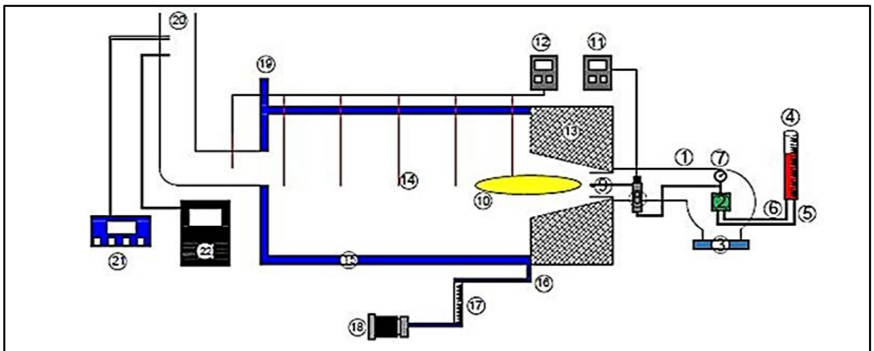
Table 1
Abbreviations

Symbol	Definition	SI units
HFO	Heavy fuel oil	---
HD	Heavy diesel	---
LD	Light diesel	---
LHD	50% heavy diesel and 50% light diesel	
Φ	Equivalence ratio	---
ρ	Density	kg/m^3
η_{th}	Thermal efficiency	%
A/F	Air to fuel ratio	---

Additionally, the process's impact on the burner's performance and the pollutants it emits are assessed. The purpose of the study is to present a new fuel blend that can replace heavy diesel fuel and prove to be economically viable by cutting costs by up to 50%.

2. Methodology

In this part, the devices and procedures needed to accomplish this experiment are explained. It provides a description of the fuel used, the testing samples prepared in this experimental work, procedures for measuring operational parameters, and measuring exhaust gas emissions. For different mixing ratios (air ratio to fuel), 20, 25, 30, 35, and 40, in experimental work. This work device was clarified in Figure 1. To check the performance of the burning and its emissions, experiments were made using a mixture of light and heavy diesel fuel.



(1) Burner; (2) Fuel pump; (3) Air flow meter; (4) Fuel tank; (5) Fuel suction; (6) Bypass fuel; (7) Pressure gauge; (8) Fuel Heater; (9) Nozzle; (10) Flame; (11) Fuel heater control; (12) Thermometer; (13) Insulation block; (14) Thermocouple; (15) Cooling water; (16) Inlet water; (17) Water flow meter; (18) Water pump; (19) Outlet water; (20) Chimney; (21) Gas analyser; (22) Smoke meter

Fig. 1. The schematic diagram of the test rig

2.1 Test Rig

The cylindrical tube depicted in Figure 2 represents the combustion chamber in this rig. The 316 stainless steel tube measures 100 cm in length, 44 cm in internal diameter, and 1.5 mm in thickness. In addition, the burner has a 30-cm side that forms a heat insulator, or thermal block, around the flame. It looks like a cone. And an industrial burner outfitted with atomization technology. This is a model with a 25-90 kW capacity and a 2.5-8 kg/h consumption rate. It has an electric motor that runs on 220 volts at 50 Hz.

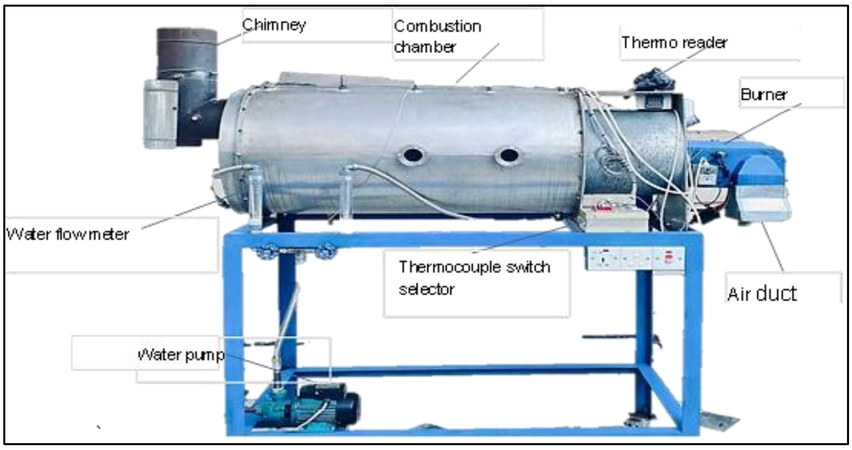


Fig. 2. The experimental rig

2.2 Fuel Heater

The heater as shown in Figure 3 is made up of two main components. A cylindrical tank measuring 16 cm in length and 6 cm in diameter makes up the first component. It has two holes: one at the bottom where fuel can enter and another at the top where fuel can exit. The heater, the second component, is an industrial steel heater with three rods, two of which are connected and shaped like the letter U. Each rod has a capacity of one kilowatt. The third rod has a hole at the top, is straight, and is rather short. It is equipped with an internal type a thermocouple (K Type; Nickel-Chromium / Nickel-Alumel) sensor for temperature monitoring and control.

Fig. 3. Fuel heater system

2.3 Measurement Device
2.3.1 Air flow rate

The velocity of the air used in the combustion process was measured using a digital turbine air sensor, and the mass of the air flowing was computed using the sensor's speed reading, air density, and known air duct area.

2.3.2 Water flow rate

Using an analog sensor to measure the amount of heat released during the cooling process, the amount of water effluent used in the combustion chamber cooling process was determined.

2.3.3 Fuel consumption

A burette and a timer were utilized as a small tank to represent the fuel consumption. By measuring the burette's decrease over a unit of time, fuel consumption is computed.

2.3.4 Temperature

Along with the other components of the system, such as the fuel, air, and cooling water temperatures in the combustion chamber, the temperature of the flame and hot gases was measured using a K-type thermocouple, which has a temperature range of 0 to 1300 degrees Celsius.

2.3.5 Emission

Gases analyzer: Figure 4 describes the device (HG-550), whose specifications are displayed in Table 2, which was used to analyse the exhaust gases.

Fig. 4. Gases analyser

Table 2
Gases analyzer properties [20]

	HG-550			
Measuring item	HC, CO, CO_2, O_2, Nox, λ (Lambda)			
Measuring method	HC, CO, CO_2 - NDIR (Non-Dispersive Infrared)			
	O_2, Nox – Electro chemical			
Measuring range	HC	0-10000 ppm	CO	0,000-9,999%
Resolution		1 ppm		0,001%
Display		5-digit FND		4-digit FND
Measuring range	CO_2	0-20%	O2	0-25%
Resolution		0.01%		0.01%
Display		4-digit FND		4-digit FND
Measuring range	NOx	0-5000 PPM	λ	0.5-3.00
Resolution		1 ppm		0.01%
Display		4-digit FND		4-digit FND
Repeatability	Less than ± 2% FS			
Response time	Within 10 seconds (more than 90%), O_2 Nox ≤ 20 sec			

Smoke opacity meter: The amount of light obstructed by the smoke that diesel engines emit can be found and measured using a capacity meter. As seen in Figure 5, diesel smoke's optical characteristics are computed by smoke opacity meters.

Fig. 5. Smoke opacity meter

2.4 LHD Fuel Preparation

The fuel used in the experiment is called LHD, which stands for fuel made by combining 50% heavy diesel and 50% light diesel. The ratios mentioned above are volumetric. A test experiment was conducted for the combustion process using the diesel fuel feature, where the cost of fuel consumption can decrease in half when mixing 50% of heavy and light diesel, which is only in the case of using light diesel, but one of its heavy diesel disadvantages, is its high viscosity. Therefore, the heater was used to heat the fuel, reduce viscosity, and improve the combustion process, as the fuel was heated at three degrees, which are 50, 70, and 90 °C at each temperature. Five A/F ratios are used, which are 20, 25, 30, 35, and 40. Table 3 show the properties of fuel.

Table 3
Properties of fuel from the Iraqi Ministry of Oil's Doura refinery laboratories in Baghdad

Properties	Unit	Light diesel	Heavy diesel
Density @ 15 C°	Kg/l	0.85	0.92
Viscosity @ 40C°	Cst	2.2	33.8
Flash point	C°	68	>100
Pour point	C°	<-21	0
Sulfur	Wt.%	1	3.2
Calorific value (high)	Kcal/Kg	10950	10626.8

3. Results and Discussion

The findings of this investigation are presented here in this section.

3.1 Flam Temperature

We notice from the Figure 6 that the flame temperature is higher when the fuel temperature is 90°C, then at 70°C and 50°C, respectively, and that the temperature at each case of the different fuel grades decreases with the increase of excessive air A/F because the excess air works on cooling. When the A/F is 20, 25, 30, 35, and 40 for heating the fuel at 70 and 90 °C, the percentage increases in flame temperature compared to heating at 50 °C by (3 and 3.8%), (3.4 and 4.2%), (3 and 4.9%), (3.3 and 3.9%), and (1.5 and 2.5%), respectively.

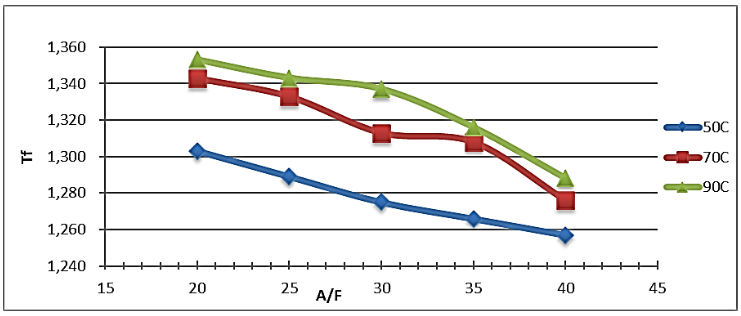


Fig. 6. The variation of flame temp with LHD and its heating at different A/F

3.2 Carbon Monoxide (CO)

Figure 7 shows that at 50°C temperature, the more excessive air percentage leads to an increase in CO emissions, and see the Table 4 contains A/F and Φ ratios. And the same behavior at a temperature of 70 and 90 °C. When comparing the three temperatures, we find that the highest CO emissions at 50 °C, then 70 and 90 °C, respectively. When the Φ: Φ1, Φ2, Φ3, Φ4 and Φ5 for heating the fuel at 70 and 90 °C, the percentage decreases in CO emissions compared to heating at 50 °C by (25 and 70%), (26 and 58.6%), (33.7 and 54.7%), (31 and 58.6%), and (21 and 58%), respectively. Table 4 show the values of Φ each case.

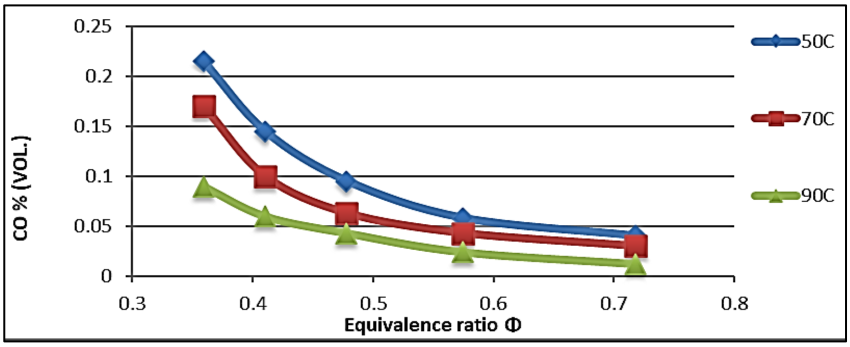


Fig. 7. The change in CO emissions at various Φ when using LHD and its heating

Table 4
Show the values of each A/F and Φ ratios

$(A/F)_{act}$	Φ	Formula
A/F = 20	Φ1 = 0.718	$\Phi = \dfrac{(A/F)stoichiometric}{(\mathrm{A/F})\mathrm{actual}}$
A/F = 25	Φ2 = 0.574	
A/F = 30	Φ3 = 0.478	
A/F = 35	Φ4 = 0.41	
A/F = 40	Φ5 = 0.359	

3.3 Oxides of Nitrogen (NOx)

Figure 8 shows the behavior of nitrogen oxides with a change of fuel temperature, and 50 °C is the best because it gives the lowest levels of nitrogen oxides, followed by 70 degrees and then 90 °C, respectively. Also, we conclude from Figure 8 that there is a decrease in nitrogen oxides with an increase in excessive air because it works to cool and thus reduce the flame temperature, which is an explanation for the decrease in the Nox values. When the Φ: Φ1, Φ2, Φ3, Φ4 and Φ5 for heating the fuel at 70 and 90 °C, the percentage increases in NOX emissions compared to heating at 50 °C by (13 and 25%), (25 and 45%), (46 and 69%), (33 and 56%), and (33 and 67%), respectively.

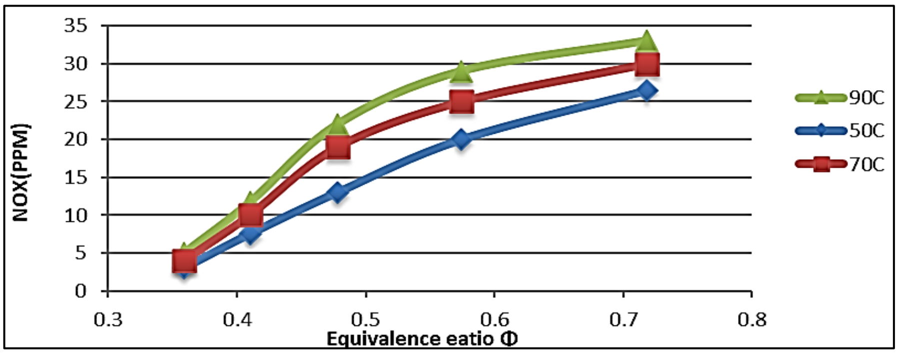


Fig. 8. The change in NOx emissions at various Φ when using LHD and its heating

3.4 Unburned Hydrocarbon (UHC)

The molecules that originate from heterogeneous combustion in the combustion chamber and are either fully unburned or partially burned are known as HC emissions. HC can have an impact on ozone-producing smog formation in the atmosphere as well as human mucous membranes such as those in the eyes and throat. When the fuel-air mixtures are either too rich or too lean to ignite automatically, HC emissions result. Figure 9 explains that when the percentage of excessive air increases A/F, it leads to a decrease in HC emissions. We also notice that when the heating increases, the mentioned emissions have decreased, and this is considered logical because the increased temperature decreases the density, and thus the fuel burns better, which means that fuel molecules burn better.

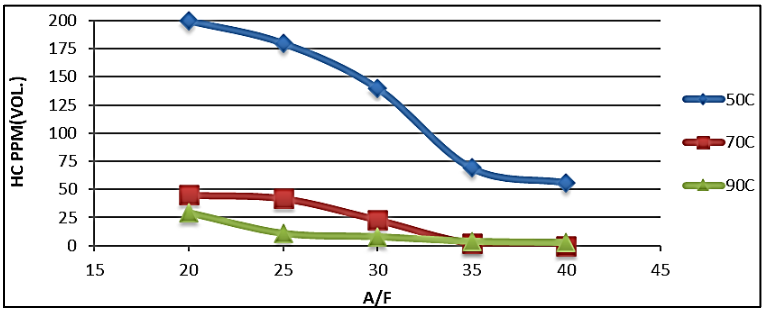


Fig. 9. The change in UHC emissions at various A/F when using LHD and its heating

3.5 Smoke Opacity

Smoke is a particle of liquid or solid that sticks in the exhaust gases and obstructs, reflects, or refracts light. Grey or black smoke is produced if the fuel is rich or if the air intake is low. Its formation decreases the better the atomization of the fuel, as Figure 10 shows that when the ratio of excessive air A/F increased, the percentage of smoke formation decreased, and the percentage also decreased as the temperature of the fuel increased. The reason is that with heating, the viscosity and density decrease, and thus the atomization is better. When the A/F: 20, 25, 30, 35 and 40 for heating the fuel at 70 and 90 °C, the percentage decreases in smoke compared to heating at 50 °C by (23 and 55%), (29 and 71%), (53 %), (67 and 0 %), and (33 and 67%), respectively.

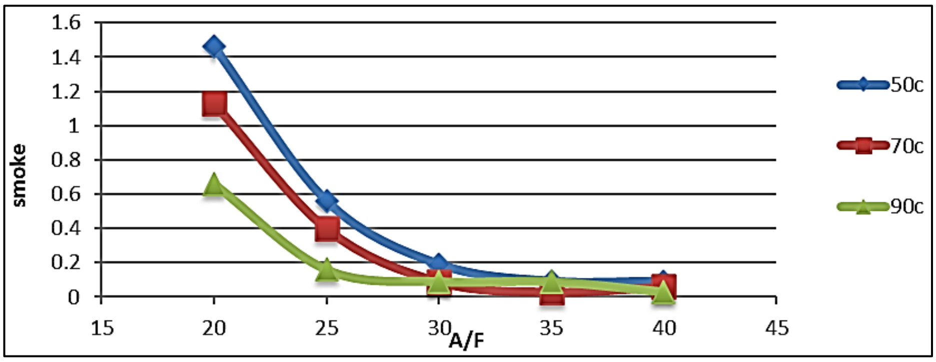


Fig. 10. The change in smoke emissions at various A/F when using LHD and its heating.

3.6 Efficiency

Figure 11 shows thermal efficiency, as we notice its height with the increase in excessive air A/F per case and then decreases in the end, and we also note that the highest efficiency is at a temperature of 90, then 70 and 50 C, respectively, because the more the fuel temperature increases, the greater the temperature of the gas, the higher the gas temperature. The outside, as well as the external water temperature, which are two effective factors in efficiency, and the fact that there is decrease in it at the last points, is due to the low temperature of the gases due to the increase in the air that cools the combustion chamber. When the A/F is 20, 25, 30, 35, and 40 for heating the fuel at 70 and 90 °C, the percentage increases in thermal efficiency compared to heating at 50 °C by (0.6 and 2%), (0.8 and 2.2%), (1 and 1.9%), (1 and 1.7%), and (1.9 and 1.8%), respectively. The maximum thermal efficiency values attained at each temperature are displayed in Figure 12. The above figure leads us to the conclusion that fuel operates most efficiently at a temperature of 90 °C.

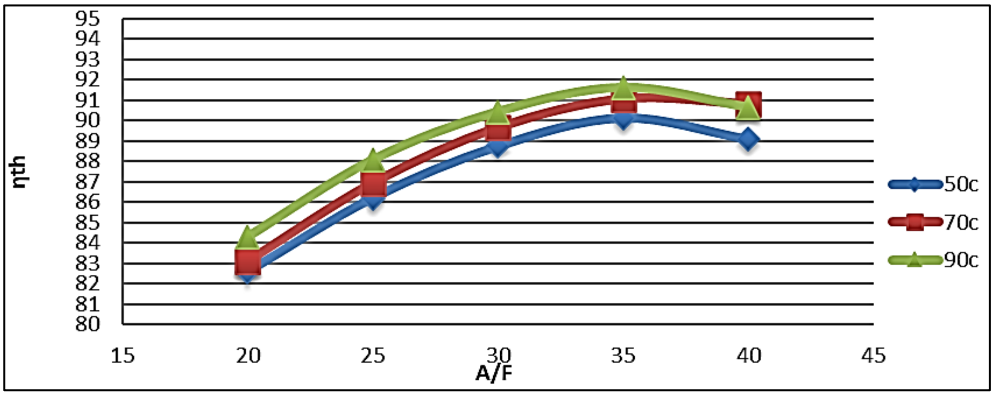


Fig. 11. The variation of thermal efficiency with LHD and heating at different A/F

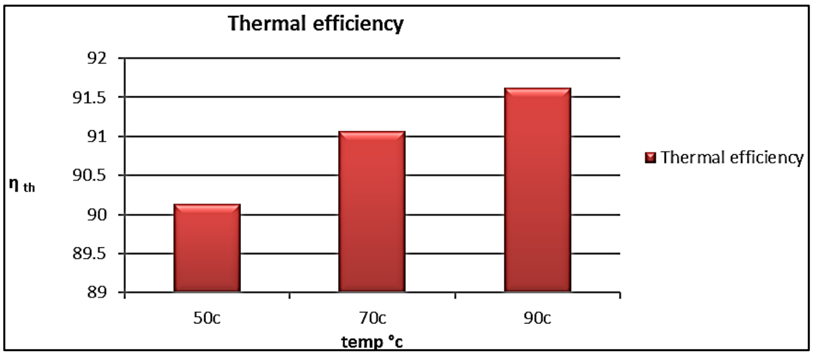


Fig. 12. thermal efficiency of LHD with heating

3.7 Comparison with Researches from Literature

The results of some studies are shown in Table 5. The aim of this comparison was to clarify a specific idea, which is the use of the same fuel, but with a change in fuel properties. It gave good results [21,22] and the use of different types of fuel as well as effective results [23], but all of these studies it was not given economic feasibility, but the fuel prepared in this study will undoubtedly be a more economical option. Since heavy diesel fuel is available at much lower prices than light diesel.

Table 5
Comparison with researches from literature

References	Year	Used fuel	Used engine specifications	Findings
[21]	2022	Emulsions for two types of domestic fuel, light diesel and heavy diesel with water.	Industrial burner and combustion chamber.	Increasing the η_{th} and reduced Nox, CO.
[22]	2014	Heavy oil emulsion.	Boiler furnace.	Increasing the η_{th} and reduced Nox, CO.
[23]	2010	Jet A, soy methyl ester, canola methyl ester.	Gas turbine engine.	Increasing the η_{th} and reduced Nox, CO.
The current study	2024	Light diesel and heavy diesel.	Industrial burner and combustion chamber.	Increasing the η_{th} and reduced Nox, CO.

4. Conclusions

We conducted an experimental study on the effect of fuel heating on burner performance and harmful emissions resulting from the use of LHD fuel, where the high viscosity of heavy diesel fuel (before introducing it into the burner) was reduced by adding a suitable heating device to the fuel line. Light fuel (LD) is also mixed with heavy diesel fuel (HD) to reduce the viscosity of the fuel. A mixture called LHD (50% LD and 50% HD) was prepared and tested in the burner and combustion chamber. When the fuel is heated at three degrees (50, 70, and 90 °C), The results showed that:

i. Mixing heavy diesel fuel, which has a low cost and poor characteristic, with light diesel fuel, which has a high cost and good characteristics, at a rate of 50% for each, is considered a cost reduction, meaning it gives us economic feasibility.
ii. The fuel used has a lower viscosity than heavy diesel, thus improving atomization and combustion.
iii. The fuel heating at 50 °C is better than at 70 and 90 °C because NOX emissions at 50 °C have good behavior and are low compared to 70 and 90 °C.
iv. Smoke emissions were higher at 50 °C, and then decreased at 70 and 90 °C. The reason is that increasing the temperature reduces the viscosity, and thus the dissolution and combustion are better. When comparing the results with the temperature of 50 °C, the highest percentage of decrease at the temperature of 70 °C was 67%, and at 90 °C it was 71%.
v. LHD fuel's thermal efficiency (η_{th}) reaches its maximum at 90 °C, then reaches 70 and 50 °C, in that order. It also exhibits the highest percentage increase in thermal efficiency (2.2%) when heated at 90 °C as compared to 50 °C. and at 70 °C, as compared to 50° C; there was a 1.9% percentage increase.
vi. The behavior of NOx with changing fuel temperature and 50 °C is the best because it gives the lowest NOx levels, followed by 70 °C and then 90 °C, respectively. The percentage increases in NOx emissions at 70 and 90 °C compared to heating at 50 °C are 46 and 69%, respectively. The temperature of 50°C will be the best due to the good behavior of NOX compared to its behavior at 70 °C and 90 °C, as well as the chances of its formation being greater as the temperature of the flame increases.

The current study has proven that heating is effective in reducing emissions, especially NOx, because it is considered one of the most harmful gases, and that a temperature of 50℃ is the best because of the good behavior of NOx compared to its behavior at 70 ℃ and 90 ℃, and also because the chances of its formation are greater with NOx. Increased flame temperature.

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