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MANIPULATING EXHAUST GAS RECIRCULATION TECHNOLOGY RATIOS OF AN INDUSTRIAL BURNER ON PERFORMANCE AND EMISSIONS CHARACTERISTICS THROUGH HEAVY OIL DIESEL BLEND FUEL

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Abstract

Among the many dangerous gases released by industrial diesel burners are nitrogen oxides (NOx) and carbon monoxide (CO). Flue gases can be reused by industrial burners to lessen their adverse environmental effects. The effect of flue gas recirculation on burner emissions and performance metrics is the focus of this study. This experiment tested different of air-to-fuel (A/F) ratios (20%, 25%, 30%, 35%, 40%, and 45%) and various ratios of exaust gas recirculation (EGR) by (0%, 5%, 10%, and 15%). The A/F is the ratio in the external combustion chamber in an industrial burner. The results showed that A/F(30) is the ideal ratio for attaining balanced performance with lowering pollutant emissions. The best balance between performance and pollutant emissions was found at a 30% air-to-fuel ratio and a 10% flue gas recirculation (FGR) ratio, according to the results. In comparison to the 0% EGR, the the blend of 100% D fuel's thermal efficiency decreased by 4.5%, and its NOx content dropped by 53.33%. Furthermore, NOx declined by 6.52% and thermal efficiency reduced by 6.1% for 50% HD/D fuel when compared to the 0% EGR. The significance effect of EGR system in lowering NOx emissions and its effect on the efficiency are clearly noticed in the results. Thermal efficiency is significantly reduced by the lower temperatures brought on by FGR, and small amounts of FGR can balance emissions control and combustion efficiency. This study's technology could lead to new burner designs or EGR system that optimize efficiency and lower emissions of pollutants from industrial oil burners.

Keywords: Heavy Diesel, Exhaust gas recirculation, Emissions, Thermal efficiency

1.1 Introduction

Heavy fuel oil is one of the most widely used fuels in the industrial sector. This fuel is characterized by its high viscosity, which requires additional measures, low volatility, and low aromatic components, due to its composition from the heaviest residues of crude oil refining [1–4]. In recent years, concern about atmospheric pollution has grown, with industry developing various strategies to reduce pollutant emissions. This concern is driven by requirements to reduce emissions of nitrogen oxide (NOx), sulfur dioxide (SO_2), and carbon dioxide (CO_2) to meet increasingly stringent environmental regulations [5–10]. Addressing the environmental impacts of industrial emissions from heavy diesel fuel is critical. Numerous

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research findings have been conducted to address this issue. Some of these studies have investigated the contribution of nitrogen oxide emissions in an oscillating system, with the goal of developing advanced, low-emission heavy oil burners [11–13]. One emission control technology that has attracted attention is exhaust gas recirculation (EGR). EGR is the process of controlling the boiler furnace temperature by reusing a portion of the flue gases. When provided in moderate quantities, EGR combines some of the flue gases with the combustion air before entering the burner system, diluting the oxygen in the functional volume [14–19].

A literature review was conducted to evaluate the most recent and significant research studies available that investigated the effect of FGR on the emission characteristics and performance of an industrial heavy diesel burner. Emission characteristics focused on the results for each of the pollutants (NOx, soot, and CO_2), while burner performance focused on efficiency, which refers to the conversion of fuel to useful work generated in the burner [20–24].

The study by Hao Zhou et al. [25] studied how separation plates affect the amount of NOx released by burners and the stability of the combustion process. They finding that adding more separation plates lower NOx. Both the 1D and 3D FEM methods show areas with a negative growth rate. It was found that adding burner separation plates lowers the amount of NOx that is released. Masoud [26] recorded that the dispersion and dispersion of HFO spray droplets are influenced by flow and spray parameters. Understanding the relationship between droplets and cross flow is essential for industrial applications such as gas turbine combustors. The behavior of droplets and their interactions with turbulence are simulated numerically using the Eulerian-Lagrangian method. The study examines various test cases and contrasts data from earlier studies with computational approaches. The findings demonstrated that the spray's characteristics are significantly influenced by both the flow rate and the droplets' inertia. Droplets break up between 170 and 150 µm, but not less than 150 µm, according to the study. Finer sprays and less deep droplet penetration are the results of higher axial velocity. More swirling produces better droplet spreading and finer sprays. Larger, colder droplets in spray deflect and pass through less. The residence time of SMD and cross flow droplets is shortened at high injection speeds. The study focuses on the effects of droplet inertia and flow velocity on spray characteristics. The interaction between droplets and cross flow is crucial for numerous industrial applications. Based on earlier research, Darbandi [27] in order to compare data from the lab and the boiler itself with the simulation of HFO burning in a large boiler, a mathematical framework was developed. According to the initial research, NO emissions could be reduced by altering the airflow and the intensity of the swirls. Conversely, larger droplet sizes and faster injection rates reduced NO emissions but reduced combustion efficiency. According to the study, the best burner modifications improved air distribution and fuel injection. A numerical framework for simulating HFO combustion in a large boiler and accurately predicting combustion flow fields was developed in this study. NO emissions were reduced by 49% and 30%, respectively, by the first and second burner modifications. As droplet size and injection velocity increased, NO emissions decreased, but combustion efficiency decreased. The maintaining high combustion efficiency, optimizing the burner settings reduced NO emissions, indicating that the technique might be applied to other boilers of the same kind.

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Zhu [28] recorded that the goal of the study is to increase combustion efficiency by utilizing HiTAC to examine a 9 MW heavy fuel-oil boiler. The Euler-Lagrange and Eddy Dissipation models in the simulations were used to perform the combustion analysis. Reusing flue gas improves temperature uniformity and lowers thermal NOx emissions. Because of soot radiation, the peak temperature is expected to be 140 K lower when hot combustion air is used. The study found that the temperature of the combustion air caused the peak temperature to rise from 2240 K to 2390 K. As the oxygen concentration decreased, the temperature distribution became more consistent and the peak temperature decreased to 1510 K. Fuel NOx took center stage as recirculating flue gas dramatically reduced thermal NOx emissions. Radiation and soot in hot combustion air resulted in a 140 K decrease in peak temperature. Heavy fuel-oil boiler experiments showed that HiTAC reduced emissions while increasing combustion efficiency. This is what Abdelaal [8] discovered while researching EGR's effects on oxygen and recycled flue gas-based non-premixed combustion systems for CO_2 capture and NOx reduction are examined. In particular, it emphasizes the necessity of reducing emissions of pollutants such as CO_2 and NOx. Experimental results show that using up to 40% recycled flue gas in stable flames can lower NOx levels from 90 to 5 ppm. The study emphasizes how FGR may lead to cleaner combustion. According to the study, exhaust gas recirculation (EGR) can reduce NO emissions by over 90% in certain situations. EGR enhances heating performance by 5–10% due to the CO_2 concentration. A stable flame is made possible by using 40% recycled flue gas. The ability of EGR to lower flame temperature by 25% affects combustion. Results show that even without specialized combustion chambers, FGR is capable of storing CO_2. Higher EGR ratios result in higher CO and UHC emissions. Prior studies conducted by Bazooyar [29] et al. examined are biodiesels made from vegetable oil and petroleum that are burned using alkali-based transesterification. It uses a water-cooled, non-pressurized chamber to test combustion performance and gas emissions. In the study, fuel pressure had an impact on emissions and boiler performance. At different fuel pressures, biodiesels emit fewer emissions than petrodiesel. At low fuel pressures, biodiesels release more NOx and CO than petrodiesel. It examined the reduced NOx emissions from belgrade's district heating boilers that use flue gas recirculation (EGR) systems, according to research by Tanasi´c [30]. For steam boilers and hot water boilers, we test a 10% recirculation system with and without FGR fans. EGR systems can reduce NOx emissions by 20–50% to comply with regulations. High flue gas temperatures resulted in more severe emissions from steam boilers. The study found that raising the EGR rate can further reduce emissions from hot water boilers. The effectiveness of flue gas recirculation (EGR) systems in reducing NOx emissions from utility boilers is examined in this study. High flue gas temperatures were associated with higher nox emissions from steam boilers. One way to improve hot water boilers is to increase the recirculation of flue gas. According to the study's findings, NOx emissions from steam and hot water boilers ranged from 85.3 to 108.4 mg/m³. Based on Ng's [31] research Palm oil methyl ester (POME) exhaust species and their blends with No. 2 diesel are evaluated in a combustion chamber. In a combustion chamber, exhaust species from diesel blends and palm oil methyl ester (POME) were examined. Low CO levels in the equivalency ratio (ER) range of 0.75 to 0.85 suggested good combustion. A trade-off was that while increasing the POME proportion improved

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combustion, it also increased NO. The study verified that CO and NO emissions from combustion systems can be accurately measured. ElKelawy [32] An experimental burner is used to study the emissions and flame characteristics of diesel and biodiesel blends. It examines flame parameters and combustion emissions. Blends of biodiesel have lower flame temperatures and emissions than diesel. While oxygen lowers flame parameters, a higher percentage of biodiesel improves them. According to the study, biodiesel is a practical and sustainable substitute for diesel. Emissions and flame characteristics of diesel and diesel-biodiesel fuel blends were investigated at oxygen concentrations of 22, 24, 26, and 28% by volume. Because of higher oxygen rates result in higher combustion temperatures, NOx emissions also increased. The study also demonstrated how oxygen levels and fuel blend impact the characteristics, brightness, and shape of flames. The study also emphasized the necessity of industrial biofuels because of environmental and energy-related issues.

A Few studies have compared pure diesel with a 50% heavy and 50% light diesel mixture in the external combustion chamber, with or without EGR. Finding the connection between EGR rates, emissions, and combustion efficiency in industrial burners was the main goal of this study. We examined the effects of varying FGR rates on NOx , CO and HC emissions as well as combustion efficiency. By experimenting with a variety of air-to-fuel ratios (20, 25, 30, 35, 40, and 45) and three distinct volumetric ratios (5%, 10%, and 15%), the ideal fuel-to-gas ratio was found for EGR ratio. This study evaluates an industrial burner using a cutting-edge technique and examined how various EGR ratios affected thermal efficiency and emission reduction. Using an industrial burner (Figure 1) that burned both pure diesel and a mixture of 50% heavy diesel and 50% light diesel to assess the burner's performance and measured NOx emissions before and after FGR. Also, this study focus on choose the ideal EGR ratio to achieve a balance between harmful emissions and efficient combustion.

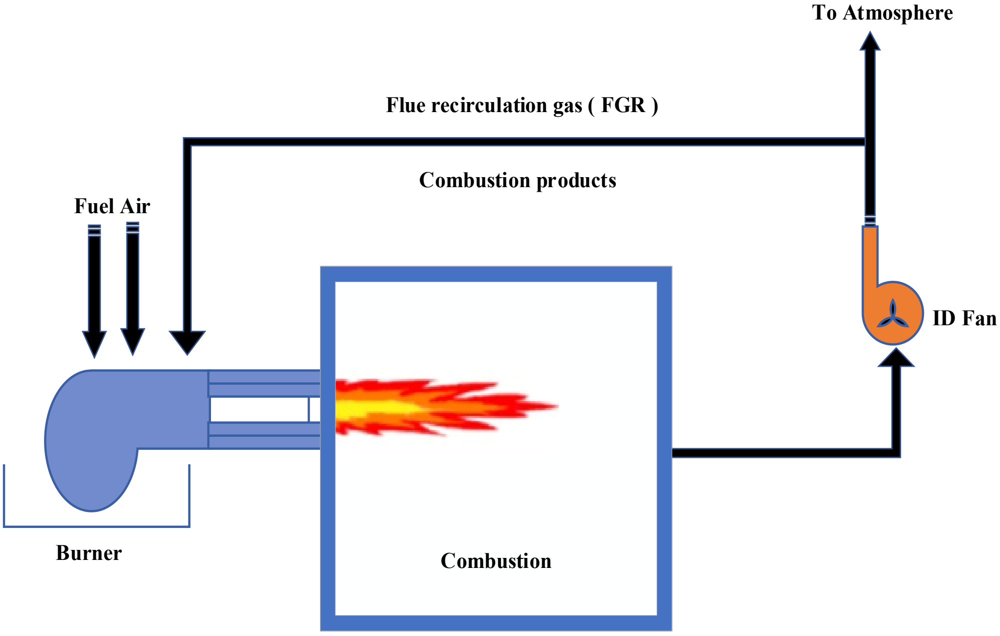

Figure 1: Schematic diagram of EGR system with burner

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2. Research Design and Methodology

The research conducted extensive experiments in an outside combustion chamber and a non-premixed mixing type to determine how heavy diesel blend and pure diesel powered by EGR technology affects combustion efficiency and emissions from a commercial oil burner. This is accomplished by running the oil burner with diesel fuel under normal combustion conditions using intake air.

2.1. Experimental Setup

The burner characteristics system, measuring instruments, and exhaust gas recirculation system are the most parts of the experimental setup (Figure 2 and Figure 3). Many domestic laboratories and factories, including those producing bricks, asphalt, and cement, have used pressure spray burners for their simplicity. With a fuel pump atomization pressure of 21 bar, a nozzle diameter of 0.2 mm, a 45° atomization angle, and air circulation, this burner can generate 20 to 80 kW. The horizontal combustion chamber is 130 cm long and 60 cm in diameter. A horn-shaped thermal mass (30 cm from the burner side) surrounds the flame. This type has two jackets, separated by a water-cooled coolant. Emissions of carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NOx) from the flue gases were tracked in real time. During measurements under normal operation without EGR and with 5%, 10%, and 15% EGR, the air mass flow in the burner was regulated to maintain the same excess air ratio.

Figure 2: Aphoto of the experimental rig

1-Burner	7- Flame	13- Water pump	19- Bypass Valves
2-Fuel pump	8- Insulation block	14- Chimney	20- Control

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			valves EGR
3-Fuel suction	9- Digital Thermometer	15- Copper pipe for EGR	21- Air supply pipe for industrial burner
4-Bypass fuel	10- Thermocouples	16- EGR cooling system	22- Air quantity control
5- Burette (measurement of fuel flow)	11- Cooling water	17- Silica gel cylinder	23- Air flow meter
6- Nozzle	12- Water flow meter	18- blower	24- Gas analyzer

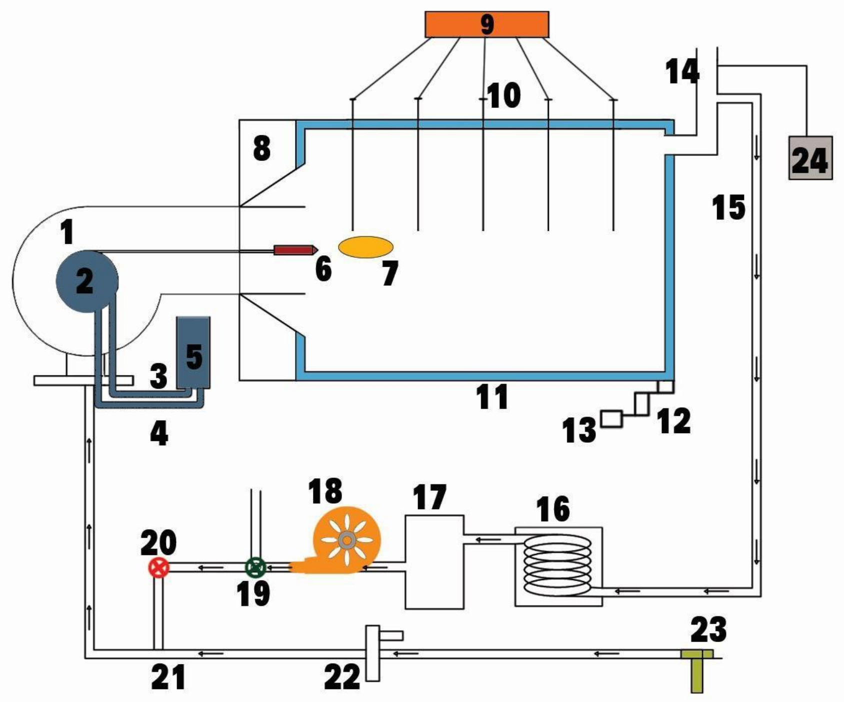

Figure 3: Schematic diagram of experimental rig

2.2. Fuel and equipment measurement

The characteristics of light and heavy diesel burning in an industrial oil burner are displayed in Table 1. The effects of exhaust gas recirculation (EGR) on the emissions of pollutants and the burning characteristics of an industrial oil burner were evaluated in this experiment using a variety of measurement techniques. Thermal measurements, optical emissions, and gas emissions were among the methods employed in the study. To guarantee the accuracy of the measured data and to avoid the measurement equipment tainting the results or being negatively

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impacted by the burning process, each technique was honed through a number of tests. The temperature of the flame and hot gases in the combustion chamber, as well as the temperatures of the fuel, air, and cooling water in the combustion chamber, were all measured using a K-type thermocouple with a range of 0–1300 degrees Celsius. The Van anemometr testo 417 device was used to measure the air volume flow, and the HG-550 device was used to analyze the exhaust gases as shown in Figure (4) and Figure (5)

Table 1: Light diesel and Heavy Diesel properties used in the experiment

Properties	**Unit**	**Light diesel**	**Heavy Diesel**
Density @ 15 C°	g/cm	0.819	0.92
Viscosity @ 40C°	Cst	1.96	33.8
Flash point	°C	60.5	>100
Pour point	°C	<-21	0
Calorific value (high)	Kcal/Kg	10989	10626.8

Figure 4: Digital reader thermocouple

Figure 5: Exhaust gas analyzer

2.2.1 Analysis of uncertainty

During tests, a number of variables may affect the experimental measurements, leading to uncertainty. The results of measurements or equipment calibration may give rise to the error analysis. As a result, the following formula was used to calculate the results' uncertainty.

$$e_R = \left[\left(\frac{\partial R}{\partial V_1} e_1\right)^2 + \left(\frac{\partial R}{\partial V_2} e_2\right)^2 + \cdots + \left(\frac{\partial R}{\partial V_n} e_n\right)^2 \right]^{0.5}$$

The partial derivative ($\frac{\partial R}{\partial V_1}$) represents a measure of sensitivity for a single variable in relation to the result. er and ei stand for the uncertainty in the results and the uncertainty interval in the nth variable, respectively. Table 2 lists the experimental measuring devices and the uncertainty associated with them.

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Table 2: Measured properties of diesel

Measured variable	Device	Uncertainty %
CO, CO_2, NO_X gases	Exhaust gas analyzer (type- HG-550)	±3.76
Temperature	Thermocouples	±0.36
Air flow meter	Van anemometer testo 417	±0.25
Fuel consumption measurement	Burette	±0.1

2.2.2 Calculations for experimental work

Burette was used to measure the burner's fuel usage. Its surface is marked to show that it holds 1000 milliliters. The fuel consumption was measured using a stopwatch. Equation (1) was used to calculate the fuel consumption rate.

$$m_f = \frac{\rho_f \times v_f}{t} \qquad (1)$$

It is well-known that emissions and thermal efficiency are metrics for evaluating the performance of external combustion (burners). Consequently, the following equations were used to compute the thermal efficiency:

$$\eta_{th} = \frac{Qwater}{Qin} \qquad (2)$$

3. Results and Discussion

3.1 Performance characteristics

3.1.1 The thermal efficiency (η_{th})

Figure 6 shows how the thermal efficiency gradually drops as the EGR percentage rises from 0% to 15%. Because there is less oxygen present and more inert gas (N_2 and CO_2) present, the thermal efficiency decreases as the FGR percentage rises. A cooler flame results from these molecules absorbing some of the heat produced during combustion. The ultimate conclusion is that, for the different air/fuel and FGR ratios, there is a trade-off between emission levels and combustion efficiency, as demonstrated by the findings of recent studies [33–34]. The excess air ratio and the Flue Gas Recirculation (EGR) system have opposing effects on thermal efficiency. Heat recovery is impacted by both excess air and EGR; the former dilutes the combustion zone, lowering the flame temperature and resulting in heat losses. Additionally, EGR lowers the flame's oxygen content, which affects heat recovery [36].

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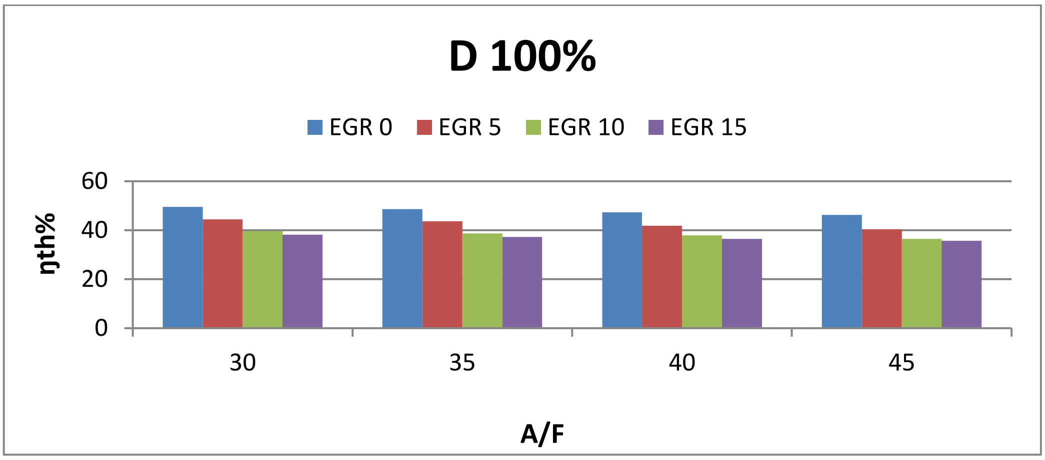

Figure 6: Variations in the thermal efficiency trend column with respect to the air-to-fuel ratio

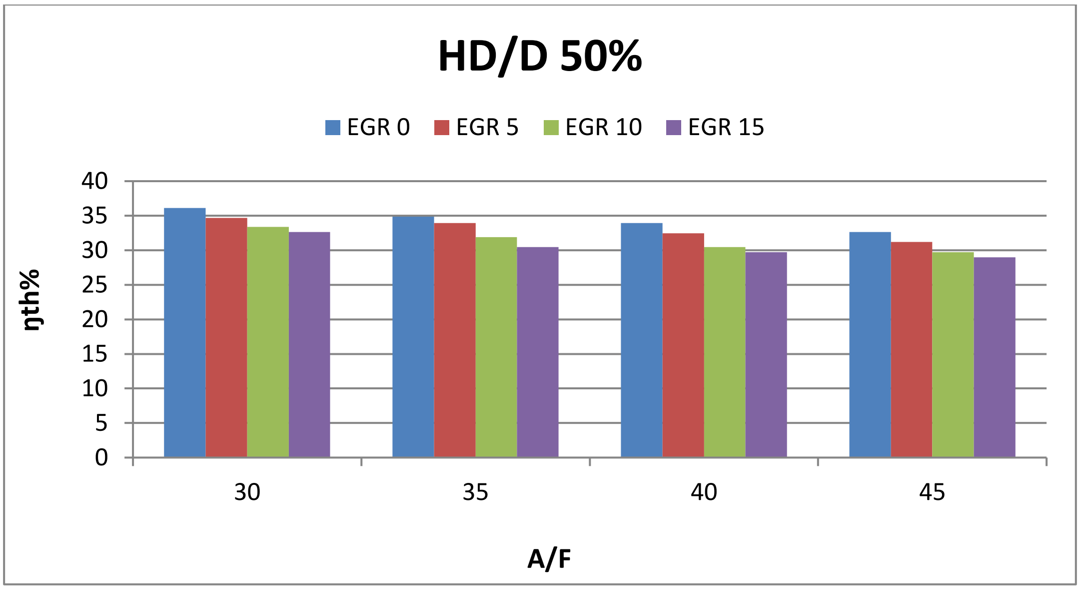

Figure 7: Variations in the thermal efficiency trend column with respect to the air-to-fuel ratio

3.1.2 Maximum temperatures in the centerline (Tmc)

Figure 8 and 9 illustrates the decline in flame temperature, which progressively decreases from FGR 0% to FGR 15%. Specifically, as the percentage of FGR increases, the flame temperature diminishes due to the reduction in oxygen concentration and the augmentation of inert gases (N_2 and CO_2), which subsequently absorb a portion of the energy generated during combustion, thereby lowering the flame temperature also in agreement[36]. The flame temperature rises with an increasing air-to-fuel ratio up to a specific threshold, after which it declines due to excessive oxygen, which cools the flame (quenching flame). This results are also in agreement with previous study [32].

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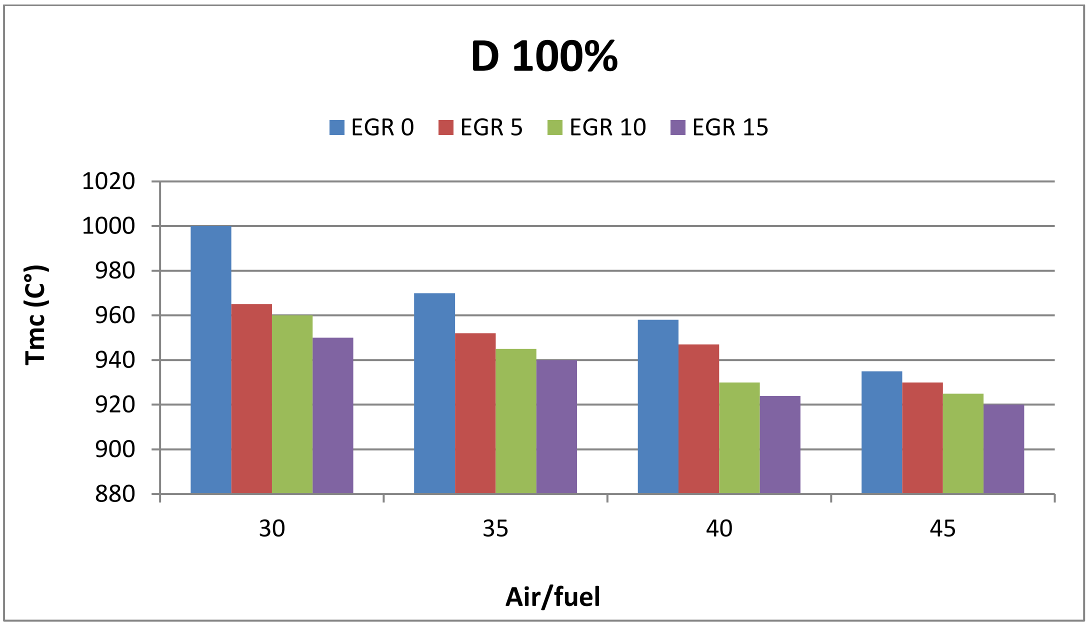

Figure 8: Changes in (Tmc) trend column for D 100% as a function of air-to-fuel ratio

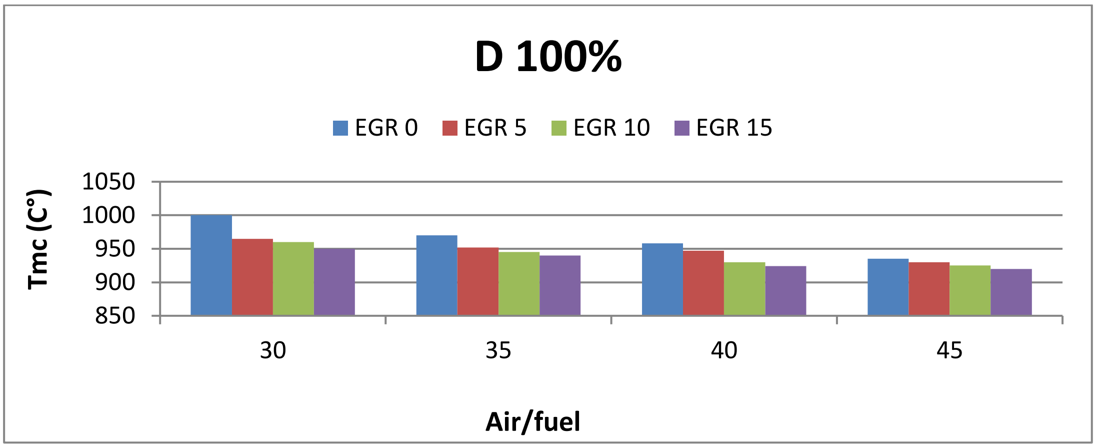

Figure 9: Changes in (Tmc) trend column for HD/D 50% as a function of air-to-fuel ratio

3.2 Pollutant Emissions

3.2.1 Nitrogen oxide (NOx)

Figure 10 and 11 showed how the A/F ratio and various EGR rate proportions affected NOx emissions. As illustrated in Figure 3, as the percentage of EGR rises, the production of NOx gradually decreases because EGR lowers the peak flame temperature and flame radical temperature, which also lowers thermal NOx production [30]. Exhaust NOx levels varied in tandem with changes in air-fuel (A/F) ratios; the proportion of NOx decreases as the proportion of A/F ratios increases. However, by lowering the flame temperature and producing emissions, this reduction has a negative impact on the combustion process and ultimately reduces combustion efficiency. Previous research demonstrates that the results obtained align with the

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current investigation. The maximum EGR that the burner can operate at is 5% when A/f =20 and 10% when A/f =25. The device will shut off if the amount of flue gas recirculation surpasses these limits because the recalculated gases combined with air will extinguish the flame [30].

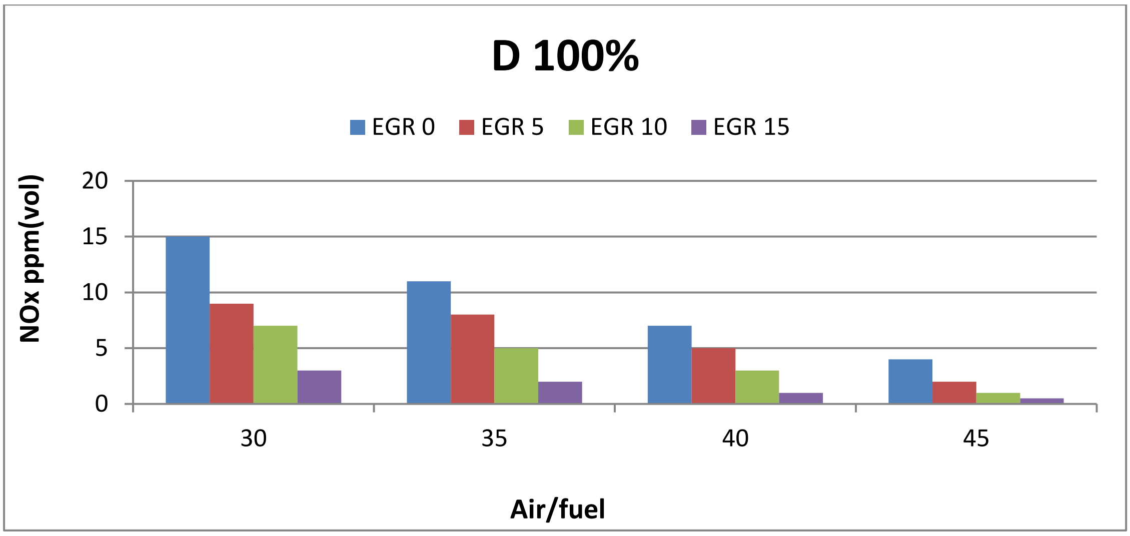

Figure 10: Variations in the trend column for nitrogen oxides as a function of the air-to-fuel ratio

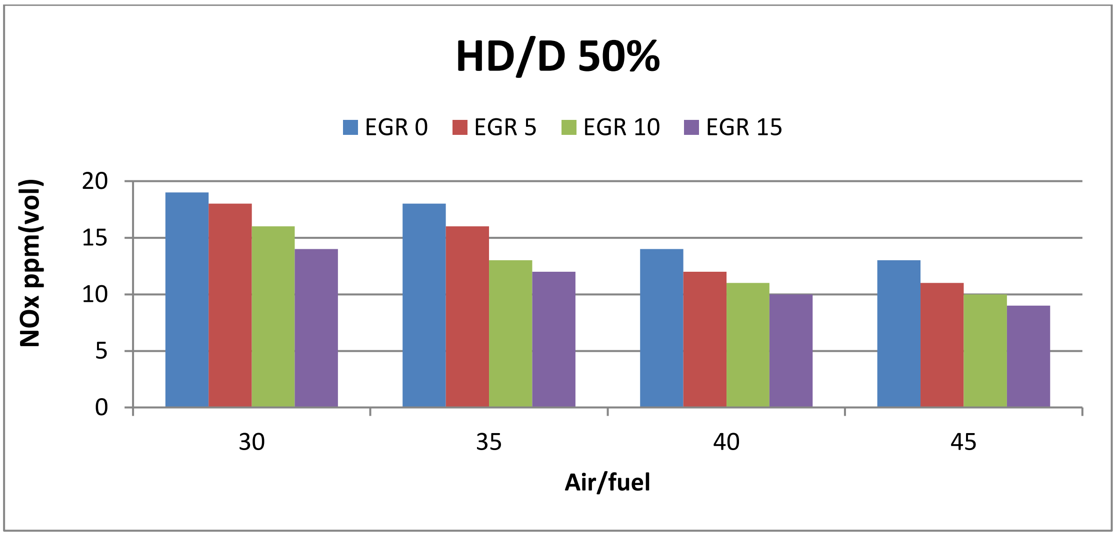

Figure 11: Variations in the trend column for nitrogen oxides as a function of the air-to-fuel ratio

3.2.2 Carbon monoxide (CO)

Because an air/fuel ratio below the stoichiometric condition results in increased CO production, Figure 12 and 13 illustrates how the amount of excess air affects the amount of carbon monoxide (CO) produced. However, as the fraction of flue gas recirculation (EGR) increases, CO emissions rise because a lower flame temperature from more recycled flue gases results in raised CO being produced at the same air-to-fuel ratio. In line with the current study's findings, Ng et al. [31] also discovered. The EGR system has less of an effect on CO generation overall,

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even though it can lower NOx emissions. However, the lower oxygen concentration brought on by EGR can promote CO decomposition if the excess air is not utilized to fully oxidize the fuel. Adding more air does not always reduce CO emissions further when the oxygen content is high enough to oxidize the carbon; in fact, it reduces device efficiency and increases heat loss [32].

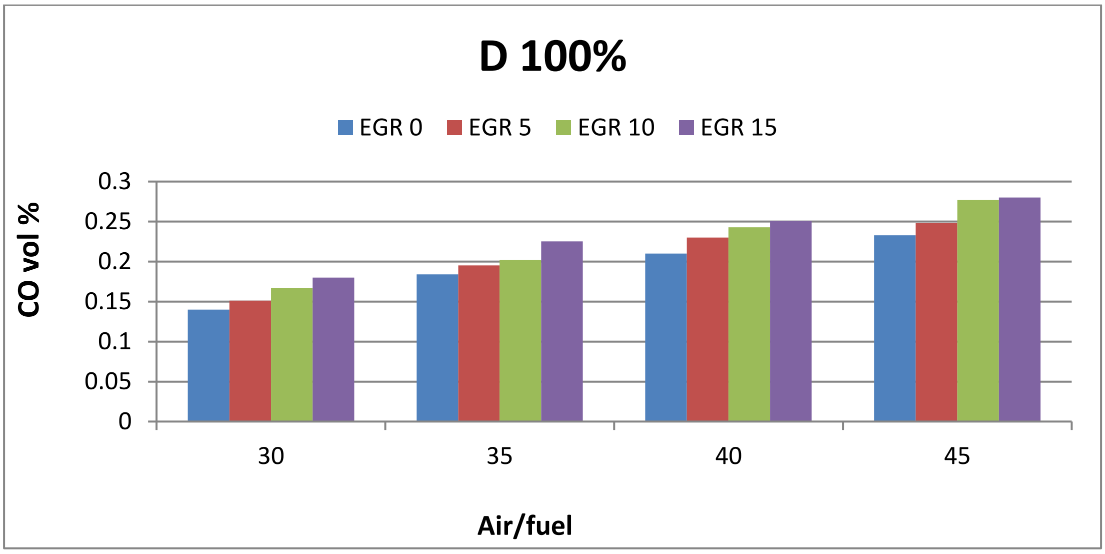

Figure 12: Variations in the trend column for carbon monoxide as a function of the air-to-fuel ratio

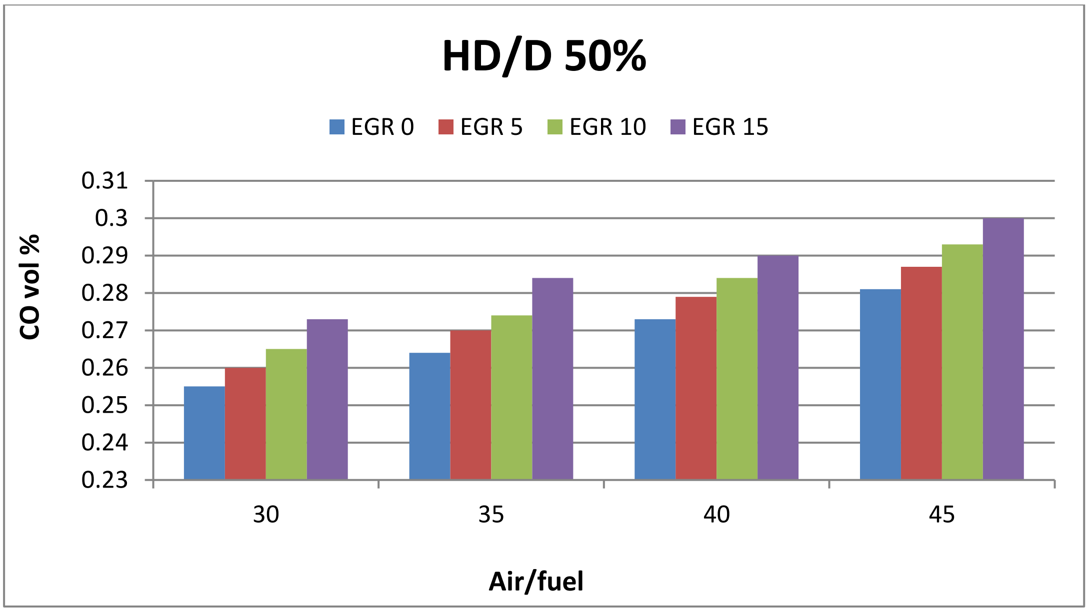

Figure 13: Variations in the trend column for carbon monoxide as a function of the air-to-fuel ratio

3.2.3 Unburned hydrocarbons (UHC)

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Figure 14 and 15 illustrates the relationship between the amount of excess air and the quantity of unburned hydrocarbons (HC) produced. This is because increased HC production occurs when the air/fuel ratio is below the stoichiometric condition. To increase HC production at a given air-to-fuel ratio, the combustion process lowers the flame temperature using recycled flue gases. Therefore, the proportion of flue gas recirculation (EGR) is directly proportional to the increase in HC emissions. According to the results of this investigation [31,32].

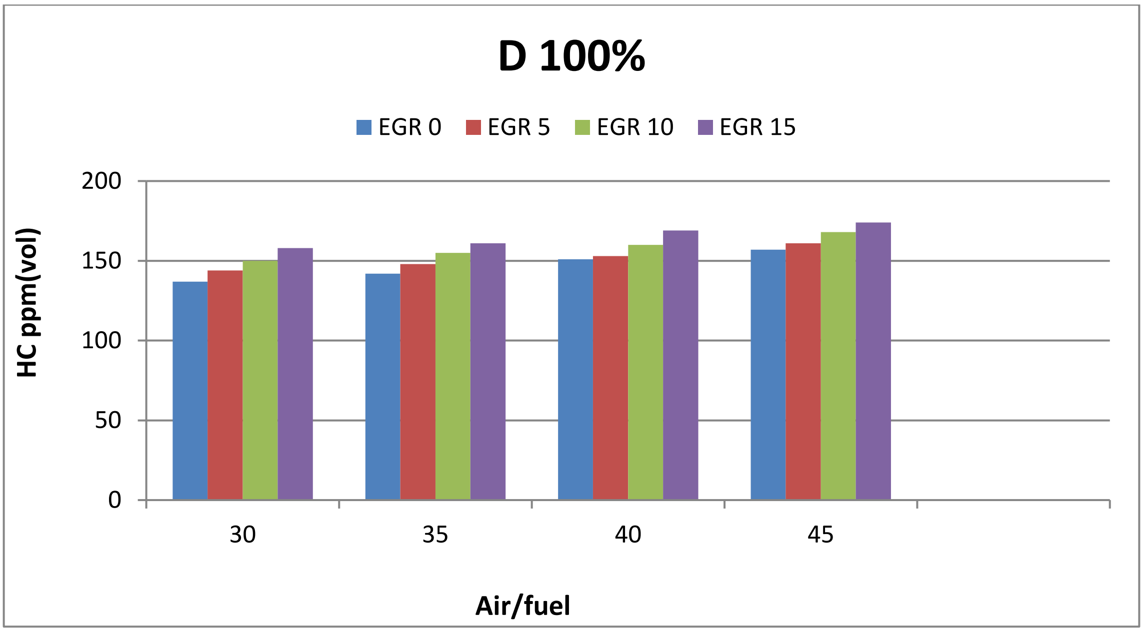

Figure 14: Variations in the trend column for unburned hydrocarbons as a function of the air-to-fuel ratio

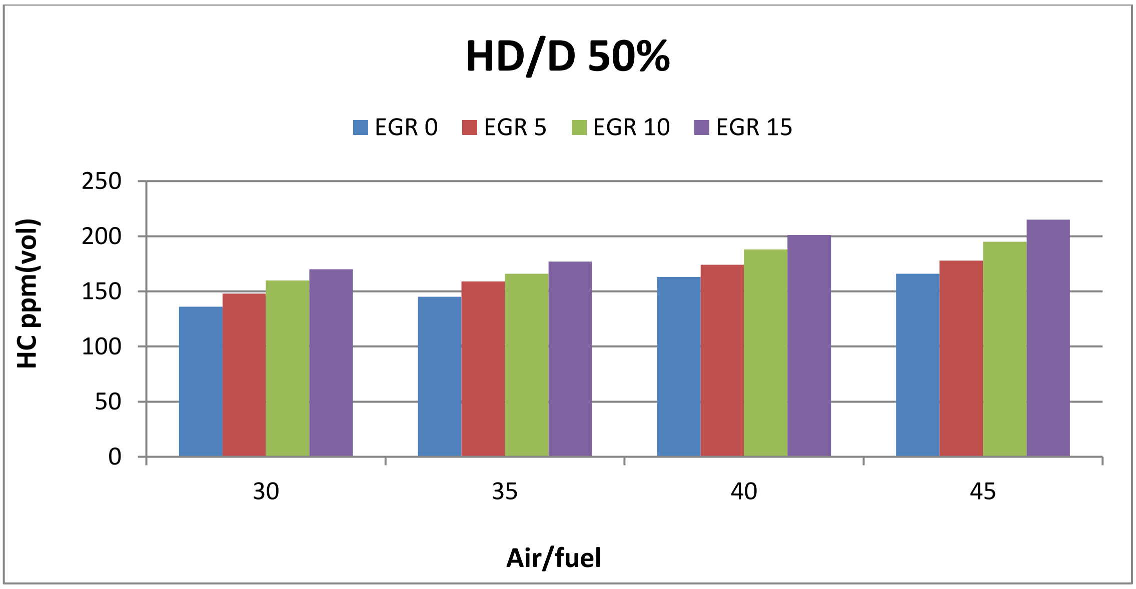

Figure 15: Variations in the trend column for unburned hydrocarbons as a function of the air-to-fuel ratio

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4. Conclusions

The performance and emission characteristics of a diesel-fueled industrial burner are examined in this study in relation to two parameters: the air-fuel ratio (A/F) and the flue gas recirculation ratio (EGR). To improve combustion characteristics and decrease pollutant emissions, the researchers found that the burners should use a flue gas recirculation ratio. Here are the findings:

- Through the use of various fuel types in our experiment, we came to the conclusion that the EGR system is a technology that effectively reduces nitrogen oxide (NOx) emissions by lowering the temperature of the combustion chamber at varying rates.
- Even though the Exhaust Gas Recirculation (EGR) system reduced nitrogen oxides, the lower temperature resulted in a decrease in heat transfer efficiency.

The optimal combination for minimizing pollution-inducing emissions was identified as a 30% air-fuel ratio with 10% fuel gas recirculation. The subsequent information is provided:

- The peak temperature in the combustion chamber for D 100% fuels diminished by 3.5%, 4%, and 5% at the optimal air-fuel ratio of 30 and EGR levels (5%, 10%, and 15%) relative to D 100% fuel at 0% EGR. The maximum temperature for HD/D 50% fuel diminished by 3.6%, 5.16%, and 6.38% relative to 0% EGR.
- Nitrogen oxide (NOx) emissions for D 100% fuels diminished by 40%, 53.33%, and 80% at the optimal air-fuel (A/F) ratio of 30 and exhaust gas recirculation (EGR) levels of 5%, 10%, and 15%, respectively, in comparison to D 100% fuel at 0% EGR. Nitrogen oxide (NOx) emissions for HD/D 50% fuel diminished by 5.26%, 15%, and 26.3% relative to 0% EGR.
- The carbon monoxide (CO) emissions for D 100% fuels rose by 7.85%, 19.28%, and 28.5% at the optimal air-fuel (A/F) ratio of 30 and exhaust gas recirculation (EGR) levels of 5%, 10%, and 15%, respectively, in comparison to D 100% fuel at 0% EGR. Carbon monoxide (CO) emissions for HD/D 50% fuel increased by 1.96%, 3.92%, and 7.05% in comparison to 0% EGR.
- The unburned hydrocarbon (HC) emissions for D 100% fuels rose by 3.64%, 10.21%, and 14.59% at the optimal air-fuel (A/F) ratio of 30 and exhaust gas recirculation (EGR) levels of 5%, 10%, and 15%, respectively, compared to D 100% fuel at 0% EGR. Unburned hydrocarbon (HC) emissions for HD/D 50% fuel increased by 8.82%, 17.64%, and 25% in comparison to 0% EGR.

This discovery has demonstrated the significance of the system for recirculating recycled flue gas. Subsequent research may expand upon the advantageous foundation established by this study by examining flue gas recirculation within a more comprehensive framework. Fuel blends that vary from diesel fuel in volatility and viscosity can influence combustion characteristics and the potential effects of flue gas recirculation. The combustion characteristics and exhaust gas composition can be substantially modified when gaseous fuels like biogas or natural gas are utilized in an industrial burner, presenting a compelling avenue for future research.

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Nomenclature

FGR	flue Gas Recirculation
NO_X	Nitrogen oxide
O_2	Oxygen
CO	Carbon monoxide
UHC	unburned hydrocarbons
D	Light diesel
HD	Heavy diesel
D 100%	Pure diesel
HD/D 50%	50% blend light diesel and heave
T	Temperature

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