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Experimental investigation of the effects of diesel-bioethanol blends on combustion and emission characteristics in industrial burner

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Abstract. The increased rate of industrialization in various countries has increased the demand for fossil fuels, which are found in limited reserves and in specific countries. As a result, countries that lack these energy resources are experiencing an energy crisis. As a result, alternative fuels that are made locally within countries are needed, like alcohol.. Experiments were carried out in this research to examine the combustion and emission characteristics of diesel and bioethanol blends using an industrial 350 KW burner. Three different diesel/bioethanol ratios (DE-10, DE-15, and DE-25) were tested. Flame geometries, temperatures, and emissions for diesel/bioethanol blends were measured experimentally for each type of fuel to obtain a complete characterization of the combustion processes. The findings showed that an increase in the percentage of bioethanol in the fuel blends for DE-10, DE-15, and DE-25 reduced CO, UH, NOx, and soot emissions (by around 20%, 40%, and 45%), (by about 13%, 25%, and 43%), (by about 8%, 14%, and 22%), and (by about 16%, 33%, and 50%), respectively, compared to neat diesel combustion. However, because bioethanol has a lower heating value than diesel, As bioethanol percentages increased in the fuel mixture, exhaust temperature and maximum flame temperature decreased.

Keywords: Industrial burner; Diesel-Bioethanol blends; combustion characteristics; NOx Emissions; Open Flame

1. Introduction

Since fossil fuels are running out, have a lot of negative effects on the environment, and their prices are always changing, the industrial sector, which uses a lot of energy, needs fossil fuel alternatives right away. Because they come from a renewable source and are a sustainable fuel, biofuels are regarded as one of the best alternatives to conventional fuels [1, 2]. In the past few years on a global scale, the Interest in the use of alternative fuels, particularly those produced from biomass residue through fermentation techniques, has increased [3, 4]. Ethyl alcohol (ethanol) is one such fuel that can be produced from corn, sugarcane, beets, or biomass. Carbon, hydrogen, and oxygen make up ethanol. Ethanol is made up of two carbon atoms with the molecular formula CH_3CH_2OH. Bioethanol is derived from renewable sources, making them an attractive alternative to petroleum-based fuels, in addition to being low in emissions. Blends of ethanol and diesel have a high oxygenation capability. It reduces emissions of CO and NOx during combustion as well as particulate matter [5]. The ethanol industry has expanded in most countries over the past 30 years, which has resulted in new techniques for ethanol production on a large scale. The production of ethanol from sugars is one of the first biotechnological methods used by humans. This method of ethanol production relies on saccharomyces, which convert sucrose in sugars quickly and effectively into ethanol at high concentrations.[6].

By organically fermenting sugars generated from a variety of basic sources, bioethanol is created [7]. The three most prevalent categories of raw materials are as follows: Fruits, sugar cane, and other feedstocks containing sucrose fall into the first category. Wood, straw, and grasses are examples of lignocellulosic feedstocks in the second group; corn, wheat, rice, sweet potatoes, and other starch-based feedstocks fall into the third category. Sugar beets have a high sucrose focus, which is changed over into ethanol in modern cycles that utilization molasses, a side-effect of sugar beet creation [8]. In terms of worldwide cultivation, sugar beet ranks second behind sugar cane. Sugar beets contain a high amount of sucrose (16-20 percent by fresh weight) [9]. Molasses is the final byproduct produced during the sugar production process. It is a non-crystallizable residue and byproduct of sucrose purification. Molasses, the raw material, is widely available, reasonably priced, and easily fermented by yeast to produce ethanol [10]. One of the primary starting materials for the fermentation of industrial ethanol is molasses. Molasses, which isn't solidified, addresses up to half of the sugar delivered by handling sugar beets [6]. In 2018, approximately 110 billion liters (BL) of bioethanol were produced worldwide, and 140 BL are anticipated by 2022 [11]. In industrial burners, bioethanol and diesel can be combined without being altered. Furthermore, it has a ton of oxygen, which advances ignition [12]. One of the main disadvantages of ethanol as a fuel is its lower calorific value compared to diesel. Ethanol has a low heating value (LHV) of 24.6 MJ/kg, while diesel has a high heating value (LHV) of 42.5 MJ/kg [13] .

A few studies have been conducted on biofuel blends combined with diesel in industrial applications, such as industrial furnace burners. In a continuous-flow combustion chamber, Asfar and Hamed [14] studied the combustion and emission characteristics of traditional diesel and bioethanol fuel blends. Alcohol blends improve combustion quality, reduce soot mass concentrations and pollutant emissions in the exhaust, and increase NOx emissions slightly. More than 10% alcohol seems to have no effect on combustion or the reduction of pollutants and soot. Using water-cooled combustion furnaces fueled with different proportions of light diesel and ethanol blends, Prieto-Fernandez, Luengo-Garcia and Ponte-Gutierrez [15] investigated combustion and emission characteristics. Ethanol and light oil are found to reduce the amount of solid particles and unburned gaseous hydrocarbons in exhaust gases when combined. Nitrogen oxide emissions are reduced slightly by adding up to 15% ethanol to light oil; however, at higher ethanol percentages, nitrogen oxide emissions are greater than those of pure light oil. Barroso, Ballester and Pina [16] investigated the numerical and experimental performance and emission characteristics of bioethanol or bioethanol blends with gas oil in heating or industrial boilers. Bioethanol and gas oil combustion tests revealed significant differences. Although ethanol emits less soot, NOx, and SO_2 than gasoline, it does emit more CO. As a result, of the fuel change, the operation of the burner and boiler should be reset or modified, and the results indicated that switching to bioethanol fuel is technically feasible and reduces pollutants. Changing the boiler's fuel can disrupt heat transfer and reduce the amount of steam produced. Due to the low heating value of bioethanol, the blend must contain at least 50% gas oil to maintain acceptable levels of useful heat production. Breaux and Acharya [13] investigated the effect of hydrous ethanol with water content ranging from 0% to 40% on a swirl-stabilized combustor's combustion characteristics and emissions. According to the findings, increasing the water content of alcohol by up to 20% had no negative impact on the exhaust heat rate, combustion efficiency, or combustion thermal efficiency. The addition of water, on the other hand, reduced the overall temperature of the flame, resulting in lower NOx emissions, especially in the lower flame area. According to this study, hydrous ethanol with up to 20% water could be a viable fuel for continuous flame applications. Motamedifar and Shirneshan [17] studied biofuel blends with conventional diesel using radial air swirlers connected to cylindrical combustion chambers.. The results showed that at swirl numbers of 15°, 45°, and 60°, the CO, HC, and NOx emissions were created at the lowest levels. The swirl air vane angles of 35° and 90° were found to have the lowest CO2 emissions. According to the findings, the average temperature of the combustion gas rises when biodiesel is added to the fuel mixture, while the average temperature of the combustion gas decreases when ethanol is added. The findings demonstrate that the design of the air swirler has a significant impact on the mixing process, which in turn has an impact on combustion and pollutants.

This study aims to determine whether fermentation-derived alcohol, like other biofuels, could be utilized in the industrial sector. An industrial burner's performance and emissions has been the subject of experimental research into the effects of a diesel and alcohol mixture. It has been demonstrated that when compared to diesel, alcohol percentages in mixtures reduce temperature by up to 25% and improve emissions of pollutants.

2. Experimental Setup and Procedure

2.1 Experimental test setup.

Figure 1 is a schematic representation of the measuring setup. In a laboratory-scale furnace that was constructed, the chemical reactions of a multi-fuel industrial burner, as well as the performance characteristics of the flame and exhaust emissions, are being studied. For each test, a horizontal steel test chamber with refractory bricks inside was used. A swirl atomizer burner from the French manufacturer “CUENOD” with a maximum heat output of 350 kW was used. The furnace chamber had a diameter of 500 mm and a length of 1500 mm. R-type thermocouple with a wire width of 0.12 mm and treated steel sheath globule breadth of 6 mm, and a length of 70 cm was utilized to quantify the temperature of the fire as it went through the heater. Figure 2 depicts the mounting of four thermocouples on a multi-dimensional linear traversing mechanism. From the burner's inlet, they were 0, 30, 60, and 90 centimeters (cm) apart. The temperature of the exhaust was also recorded with the help of an R-type thermocouple that was inserted into the exhaust pipe [18]. The controller was used to obtain the temperature data. This thermocouple was positioned all the way along the flame's length with the help of a guided traverse mechanism. Temperature profiles were collected at various axial positions within the flame to provide an overall view of the temperature in the environment of the flame. The Gasboard—"5020 emission gas analyzer" can be used to measure the concentration of CO, HC, and NOx in emissions [19]. The "6010 Opacity Meter" from Gasboard offers a quick and precise way to identify and gauge the amount of smoke being released from the burner Figure 3 depicts a direct shot of the entire measuring system, complete with all required equipment.

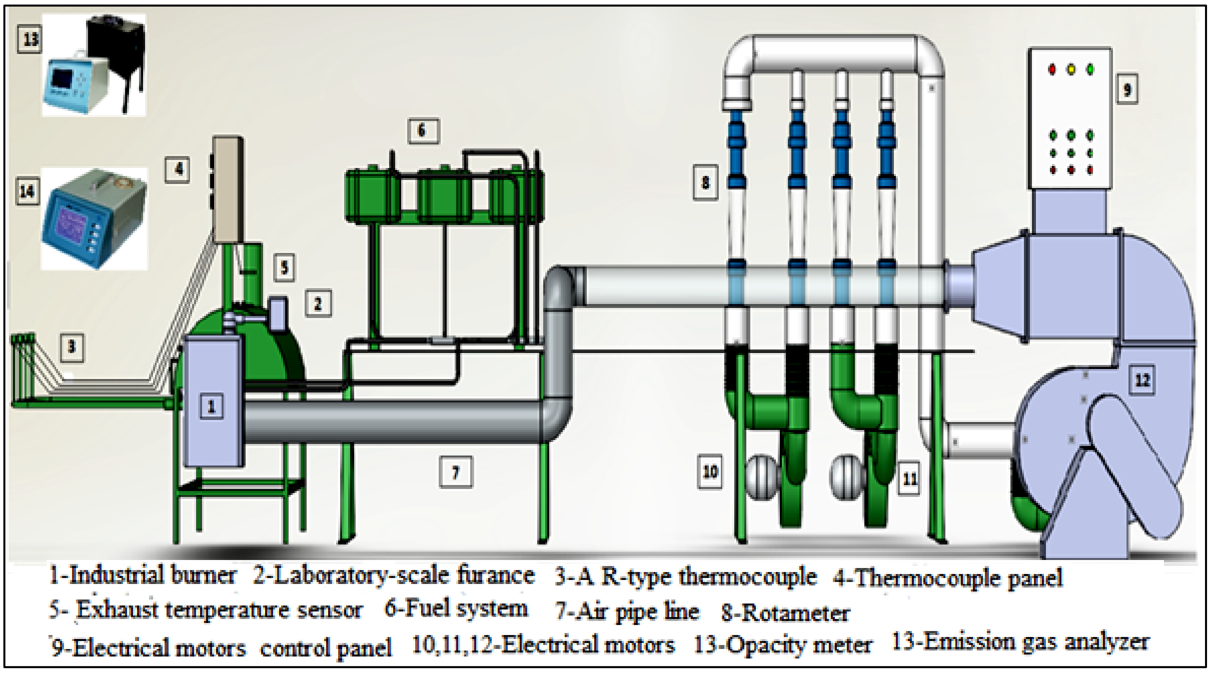

Figure 1. Test rig schematic diagram.

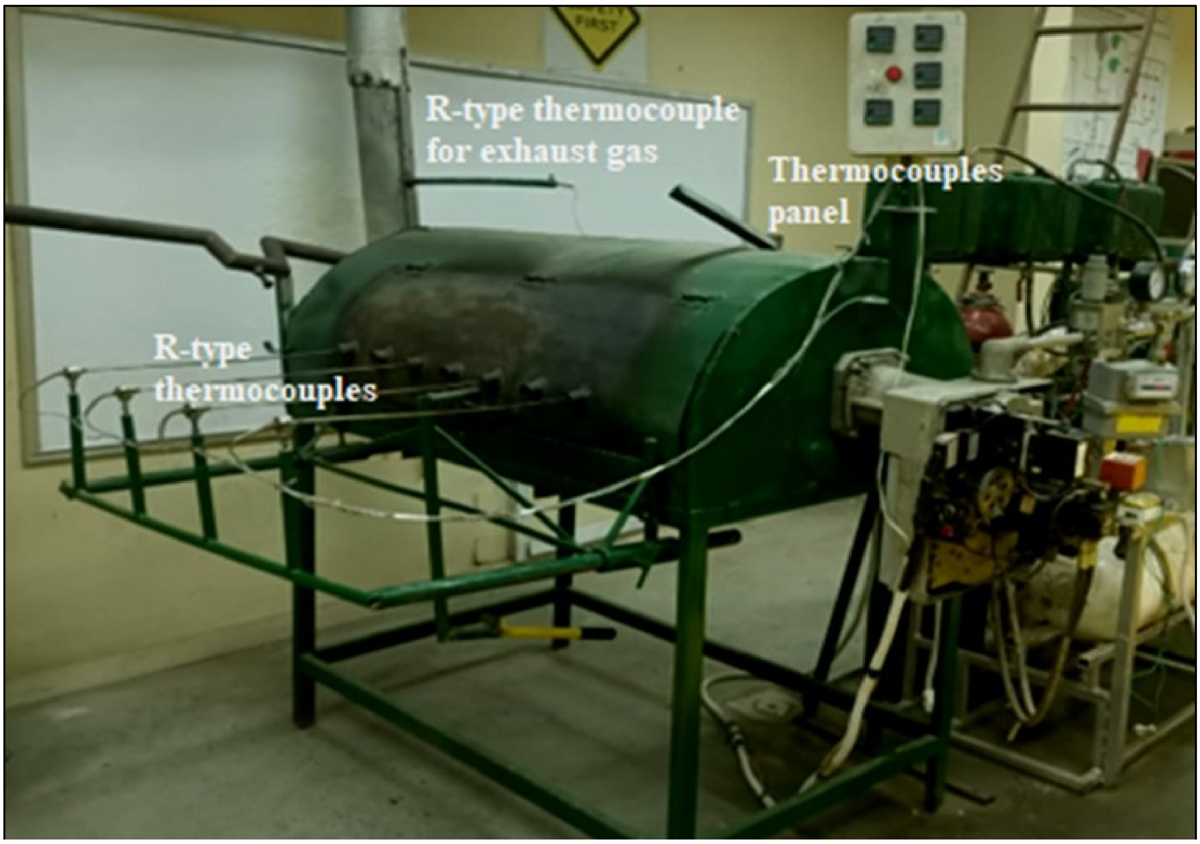

Figure 2. The R-type thermocouples mounted in the furnace.

Figure 3. A clear shot of the laboratory's testing equipment

2.2 Experiment procedures and properties of fuels.

Before each set of data was collected, the experiment began with diesel fuel, which required 15 minutes to warm up and reach a steady state. After that, a different kind of fuel was used without shutting down the burner. The burner was run for long enough to make sure that the fuel was taken out of the system and that the other fuel was in a steady state. All of the experiments were conducted in a steady state. Measurement instruments were used to measure temperature, fuel flow rate, air flow rate, emissions (CO, HC, and NOx), and soot opacity. After the mixtures' samples were prepared, they were placed in the experiment's designated fuel tank, where valves controlled how they got to the burner. The fuel siphon powers the fuel through the counter of fluid energizes, then, at that point, through spouts, where it is blended in with the air. It was touched off utilizing an electric cathode that makes starts and consumes the combination. A swirler made mixing easier. The experiment data were collected after about 15 minutes, and the same procedures were followed for each kind of liquid fuel.

A burner blower and three independent blowers make up the combustion air supply system. Each blower has an orifice meter for measuring airflow and an air intake pipe. Valves and an on/off switch on the electronic control panel controlled the air blower's flow rate. A fuel pump powered by the burner's motor and three tanks above the burner provided fuel. While the airflow rate was varied to produce various equivalent ratios, the fuel flow rate remained constant at 0.14 litters per minute. Due to its excellent burning qualities, diesel was chosen as the standard fuel. The diesel fuel utilized in the tests was bought locally at a business petrol station. For industrial burner applications, bioethanol is a viable fuel option. The chemical formula for normal bioethanol is C2H5OH. By fermenting cellulose-containing sugar industry byproduct molasses, bioethanol can be produced. It has been demonstrated that the mixtures of diesel and bioethanol are more stable. In this experiment, bioethanol with a purity of 90% was chosen, and bioethanol was added to diesel at various concentrations (on a volume basis, 10%, 15%, and 25%). At Egypt's National Research Centre (NRC-Dokki), ASTM standards were used to measure the diesel and bioethanol characteristics of the tested fuels, as shown in Table 1. The electrically mixed process was utilized to mix for over two hours prior to being utilized in the tried burner. Bioethanol was added volumetrically to commercial diesel fuel in order to create a mixture of diesel and bioethanol.

Table 1. The properties of fuels used in experiments.

Fuel type	Diesel	bioethanol	ASTM Standards
Density @ 15.56°C	0.837	0.8926	D-4052
Kinematic viscosity, cSt @ 40o C	4.38	2.24	D-445
Total sulfur, wt %	0.231	0.697	D-4294
Total acid number, mg KOH/g	0.056	1.868	D-664
Pour point, °C	0	<-42	D-97
Ash content, wt.%	Nil	0.073	D-482
Cetane index	50	-	4737
Copper corrosion	1a	1a	D-130
Calorific value KJ / Kg	44547	42500	D-240

2.3 Uncertainty analysis.

An uncertainty analysis was carried out to guarantee the results' accuracy. Various elements impact vulnerability. The reproducibility of the experiment and the precision of the equipment are two of the most crucial aspects. Tables 1 and 2 display the experimental value and instrument precision. In this research, the root-sum-squared (RSS) approach was utilized to calculate the uncertainty. [20]. Equation 1 is used to calculate the data's mean value [21] [22].

$$\bar{X}=\frac{1}{n}\sum_{i=1}^{n}X_i \quad ------(1)$$

$\bar{X}$ Mean value of measured data, n number of measured data (dimensionless). X measured data. The total uncertainty (U) of the quantity at each operational point was determined using formulas 2 and 3 below [23].

$$U=f\,(X_1,X_2,..........X_n)-----(2)$$

Where U represents the function uncertainty of Xn and X represents the number of readings

$$U_X=\left[\left(\frac{\partial x}{\partial x_1}U_{x_1}\right)^2+\left(\frac{\partial x}{\partial x_2}U_{x_2}\right)^2+.........+\left(\frac{\partial x}{\partial x_n}U_{x_n}\right)^2\right]^{1/2} \quad ----(3)$$

Where, Ux represents the dependent variable total of uncertainty. X_1 and X_n are the independent variables of measured data. Ux_1, Ux_2, and Ux_n are the uncertainties of the independent variables. The following equation 4 is used to compute the uncertainty due to the repeatability of the experiment for parameter x.

$$U_{x_n}=\frac{\left[\frac{1}{n-1}\sum_{i=1}^{n}(x_1-\bar{x})^2\right]^{1/2}}{n^{1/2}} \quad -------(4)$$

Where n is the repeatability of the experiment for parameter X.

Table 2. Equipment specifications for measurements.

	Range	Accuracy		Resolution
CO	0-10%	Rel	±3%	0.01%
HC	0-9999 ppm	Rel	±5%	1 ppm
NOx	0-5000 ppm	Rel	±5%	1 ppm
Specifications of Opacity Meter Gasboard-6010				
K-value	0-100%	±3%FS		0.01%
Specifications of R-type thermocouple				
R-type thermocouple.	0-1600 ˚C	0.25%		1.5 ˚C
Specifications of Rotameter				
Air flow sensors	18-180 m3/hr	±6%		

Table 3. Aquametro VZO 8 liquid fuel meter specifications.

Type		liquid fuel meter type aquametro VZO 8
Maximum Flow Rate Qmax	l/h	200
Nominal Flow Rate Qn	l/h	180
Minimal Flow Rate Qmin	l/h	4
Approx. Starting Flow Rate	l/h	1.6
Maximum Permissible Error		±1% of Actual Value
Repeatability		±0.2%
Smallest Readable Amount:	l	0.01
Registration Capacity	m^3	1 000

3. Results and Discussions

For laboratory tests, samples of bioethanol and diesel fuel are prepared, and the data, such as combustion and emission parameters, are collected. Three DE-10, DE-15, and DE-25 samples were used in all studies. The experiment used fuel samples and various equivalency ratios.

Table 4. Types of fuels tested in the experiments.

NO	fuels	Description
1	DE-10	90% diesel, 10% bioethanol
2	DE-15	85% diesel, 15% bioethanol
3	DE-25	75% diesel, 25% bioethanol

3. 1 Effect of Equivalence Ratio on Burner Emission

3.1.1 Carbone monoxide CO emission

The CO variation trend lines with equivalence ratios for all mixes are shown in figure 4. The levels of CO emissions are always influenced by the fuel mixture and equivalency ratio. CO emissions from diesel and bioethanol mixture fuels rise in the lean mixture zone because there is too much air and not enough fuel. This causes flames to die out because the mixture is too weak and the temperature is low, which makes combustion incomplete. Under stoichiometric conditions, the level of CO emissions decreases at the equivalence ratio of 1, but then rises in the rich fuel zone as a result of high fuel consumption and insufficient air supply, leading to increased CO yield during combustion. All different kinds of fuel exhibit this pattern. The fuel mixture of diesel and bioethanol for DE-10, DE-15, and DE-25 reduced CO emissions by approximately 20%, 40%, and 45% in comparison to diesel. Due to its high oxygen content, bioethanol influences blends to completely burn, extending the time it takes for CO generated in the combustion zone to fully convert into CO2 and lowering carbon monoxide levels.

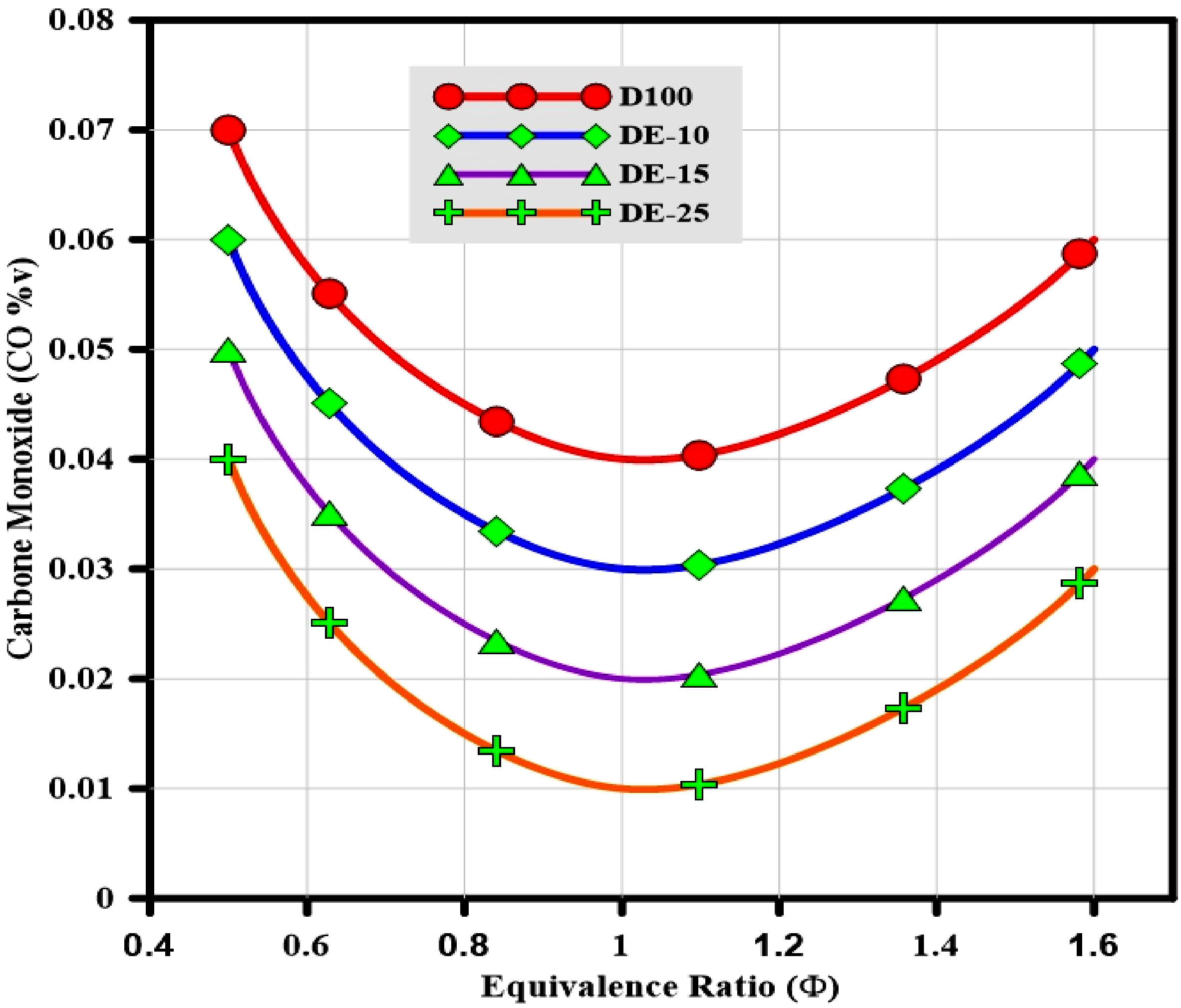

Figure 4. CO variation trend lines with an equivalence ratio.

3.1.2 Unburned hydrocarbons emission

Figure 5 depicts the unburned hydrocarbon emission for bioethanol-diesel mixtures at different equivalence ratios. Unburned hydrocarbon emissions rise in the lean fuel zone, then reduce until the equivalence ratio is 1.0, and then rise in the rich fuel zone. Unburned hydrocarbon emissions are the lowest of all fuels when the equivalence ratio is 1.0 due to complete combustion. Unburned hydrocarbon emissions increase in the lean mixture zone due to the effect of excess air on the flame temperature and causing incomplete combustion. A rich mixture zone also causes incomplete combustion and a high level of unburned hydrocarbons. All fuel blends exhibit the same pattern. According to the results of HC emissions, the ethanol-diesel mixture was lower than diesel fuel. Furthermore, as the percentage of ethanol in the fuel mixture increased, the HC emission was reduced. It is because bioethanol improves the reactivity of the mixture. This is because bioethanol fuels have more oxygen molecules and less carbon in their structure. Furthermore, air swirling promotes the complete combustion of a mixture of fuels, resulting in lower HC emissions. The HC decreases by around 13%, 25%, and 43% for DE-10, DE-15, and DE-25, respectively, compared to diesel.

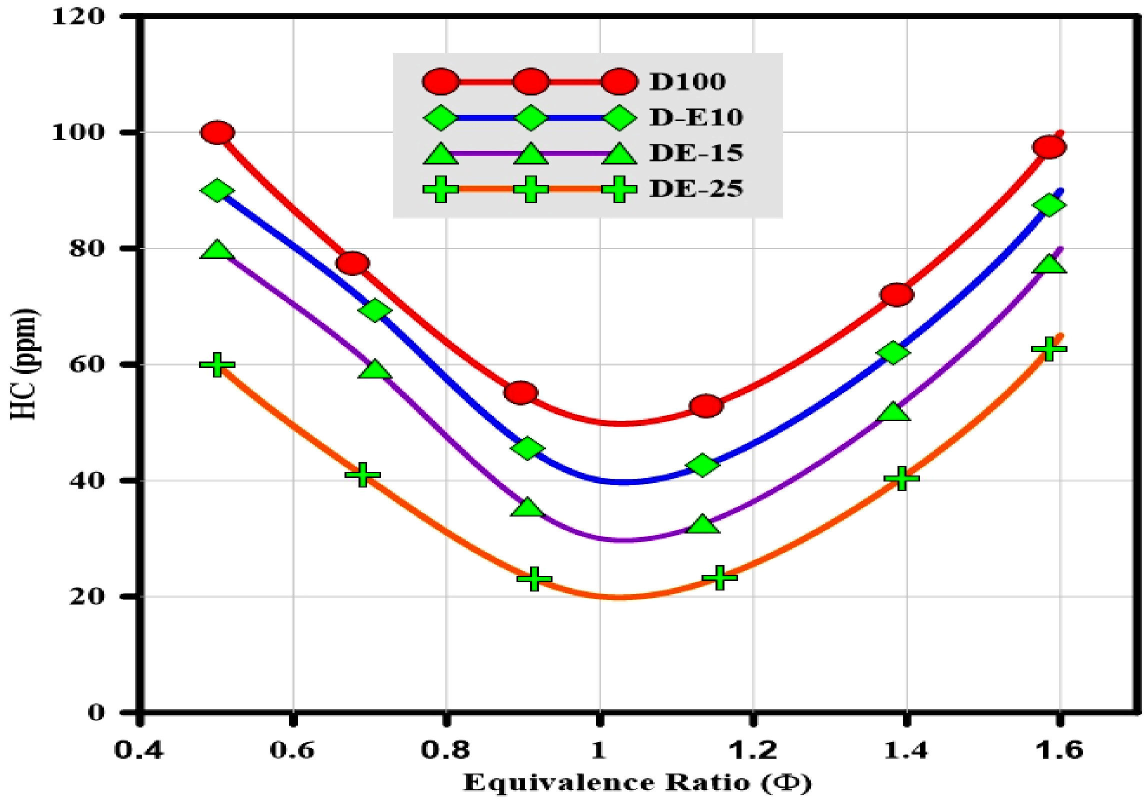

Figure 5. HC variation trend lines with an equivalence ratio.

3.1.3 Nitrogen Oxide NOx emission

Several factors influence NOx production, including the temperature of the furnace, the amount of oxygen present, the reaction time, the equivalency ratio, and the type of fuel used. A comparison of NOx emissions is shown in Figure 6 for D100, DE-10, DE-15, and DE-25 at various equivalence ratios. At an equivalence ratio of 1, the highest amount of NOx emissions was observed because of complete combustion and a high flame temperature. Additionally, a proportional decrease in air supply lowers the production of prompt and thermal NOx. Low and high equivalence ratios result in incomplete combustion, causing low NOx levels. Excess air diluted the flame and lowered the flame temperature in a lean mixture zone, preventing thermal NOx production.

At the rich mixture zone, incomplete combustion occurs due to excessive fuel and insufficient air. The higher equivalent ratio in the lean zone leads to a slight increase in the nitrogen oxide emissions. This accelerates the oxidation of ambient nitrogen into nitrogen monoxide, which results in the formation of NOx, due to the heating effect and the presence of too much air and oxygen from bioethanol fuel. The peak level of nitrogen oxide emissions is then reached in the stoichiometric zone, after which they begin to diminish as the amount of air is lowered, the interaction of air with nitrogen slows down, and less nitrogen oxide is formed in the rich mixture region. Figure 5 shows that a diesel-ethanol mixture produces lower nitrogen oxide emissions than conventional diesel. The flame's temperature is lowered as a result of the bioethanol's high latent heat, which slows the rate of thermal NOx reaction. The trend in NOx emissions indicates that bioethanol content has a significant impact on NOx emissions in all cases and at all equivalency ratios. The proportion of bioethanol in the fuel mixture decreases NOx emissions. NOx emanations are diminished by around 8%, 14%, and 22% for fuel combinations DE-10, DE-85, and DE-25 when contrasted with diesel D100, individually. This is because bioethanol has the effect of lowering the flame temperature to reduce nitrogen oxide emissions.

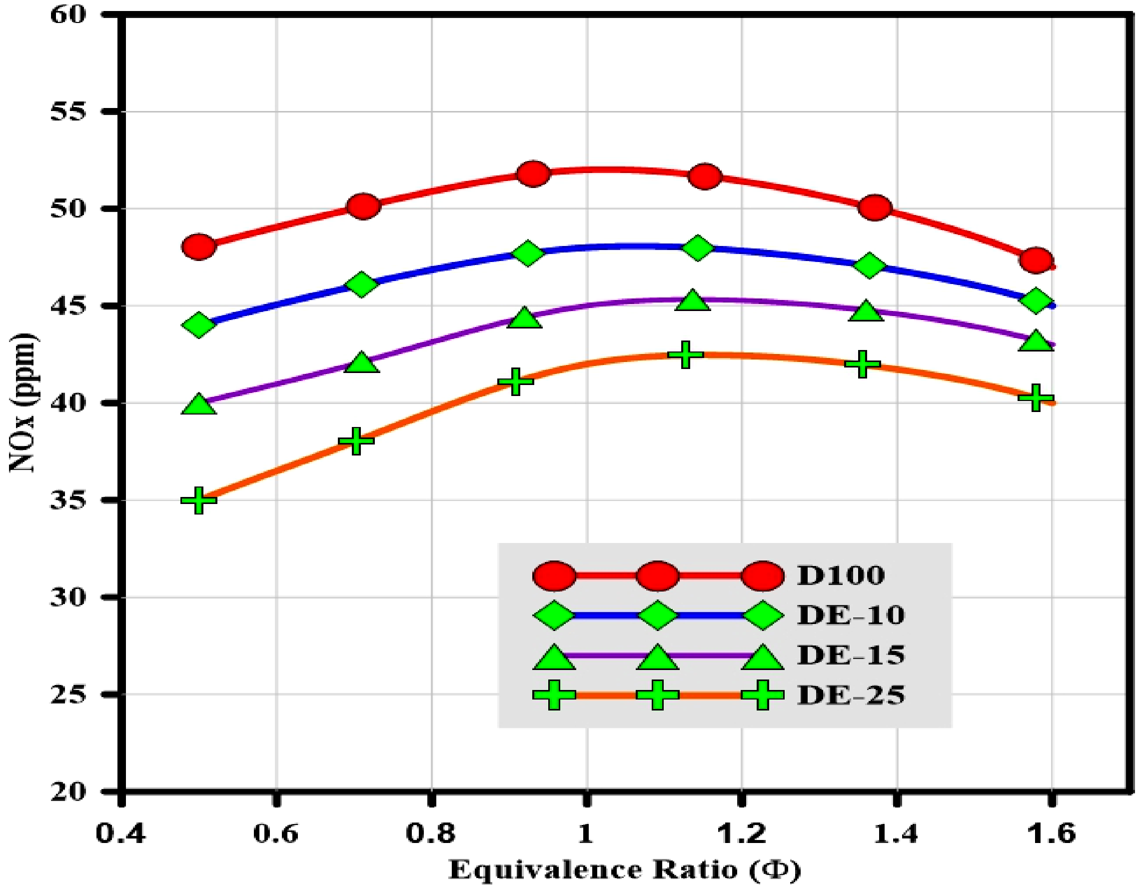

Figure 6. NOx variation trend lines with an equivalence ratio.

3.1.4 Smoke opacity emission

Figure 7 shows how soot emissions vary according to different fuels and equivalency ratios. Bioethanol's high H/C ratio reduces its ability to emit soot. This tendency is reduced when bioethanol and diesel are blended. As the bioethanol content is raised in the mixture, the soot emission level reduces. The amount of soot emitted by all fuels was increases with increasing the equivalence ratio. As the equivalence ratio increases in the lean mixture zone, the amount of soot emitted increases until it reaches its maximum value at 1.0 at stoichiometric conditions, after which it gradually decreases with an increase in the equivalence ratio at the lean mixture zone.

The emission of soot decreases due to the possibility that more sulfur in the fuel may react with oxygen to generate SO_2 and lower the tendency of content soot in exhaust [24] , while at the stochasticity zone, the emission of soot increases due to the high flame temperature, the richness of the fuel, and the abundance of air. However, because of less oxygen, more fuel in the mixture, and incomplete combustion, soot emissions are slightly lower in a rich fuel mixture. Due to improved combustion, Figure 6 demonstrates that soot emissions decreased as bioethanol content increased [14]. The diesel-bioethanol mixtures DE-10, DE-15, and DE-25 decrease soot emission by around 16%, 33%, and 50%, respectively, compared with diesel fuel. Due to the higher oxygen content in bioethanol, which keeps the average fuel spray droplet size small at the evaporation stage of bioethanol fuel, increases the air-fuel mixing process, and improves the combustion process, the fuel releases less soot.

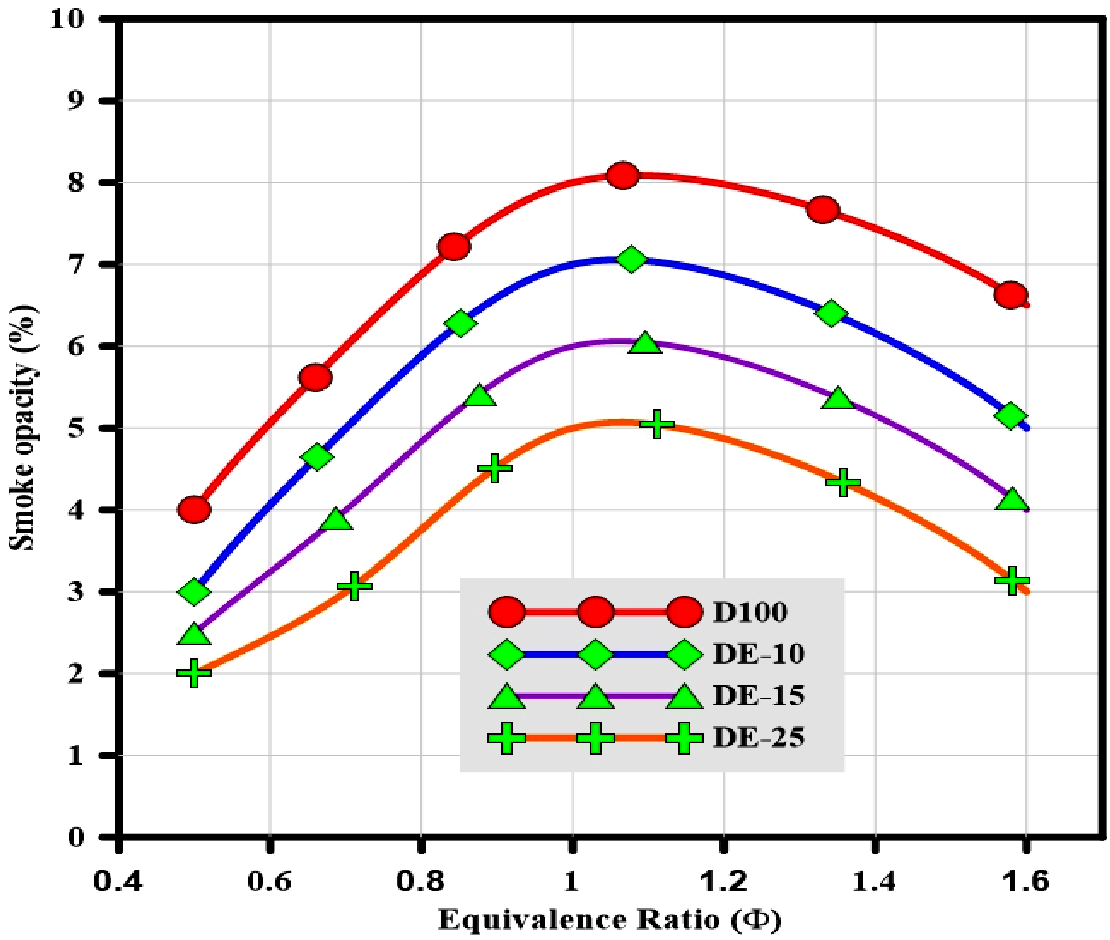

Figure 7. Smoke trend lines with an equivalent ratio of variation in opacity.

3.2. Effect of Equivalence Ratio on combustion performance.

3.2.1 The effect of various equivalence ratios on the temperature of the exhaust gas.

The equivalent ratio typically rises with rising combustion temperatures. At the furnace's end, 140 cm away from the burner nozzle is an R-type thermocouple. Figure 8 shows that the increased fuel-air mixture, which raises the temperature of the entire combustion process, causes all fuel types to raise the exhaust temperature with an increase in the equivalence ratio. As a result of the mixture's additional fuel.

As the proportion of bioethanol in the mixture rises, the exhaust temperature decreases. This is due to the lower flame temperature caused by bioethanol's high latent heat of vaporization. When compared to diesel, the combustion diesel-bioethanol mixtures DE-10, DE-15, and DE-25 had lower exhaust temperatures by approximately 8%, 11%, and 17%, respectively. Due to its high latent heat of vaporization and absorption of heat during combustion, bioethanol has a cooling effect that significantly affects fuel blends. Additionally, when compared to diesel, bioethanol has a lower cetane number, which lowers the temperature of the exhaust.

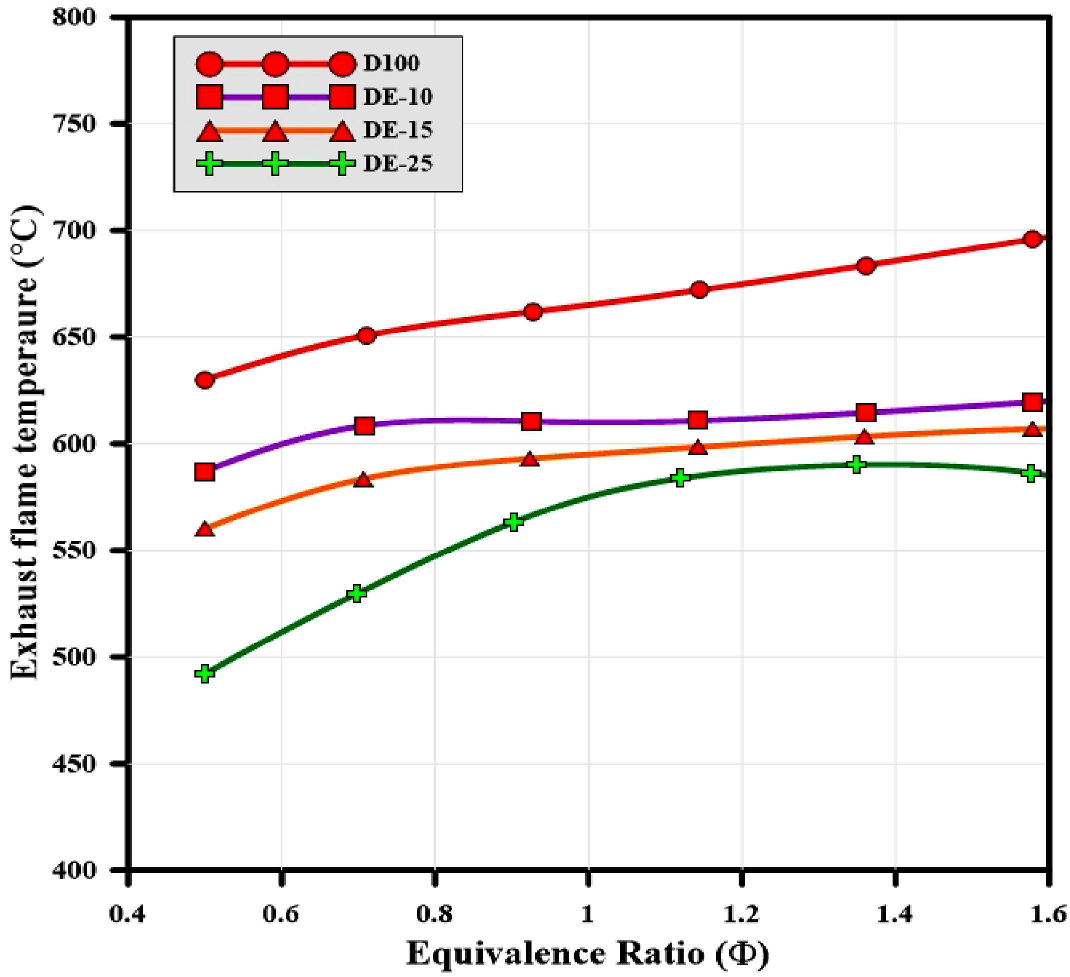

Figure 8. The effect of the equivalence ratio on the temperature of the exhaust gas.

3.2.2 The effect of various equivalence ratios on the furnace's maximum flame temperature.

The maximum flame temperature for variety of the tested fuels is depicted in Figure 9. According to the findings of the experiments, the maximum flame temperature rises in tandem with an increase in the equivalent ratio. All mixture fuels had the highest maximum temperature at an equivalence ratio of 1.6. This is because fuel-rich mixtures consume more fuel.

The maximum flame temperature decreases as the proportion of bioethanol in the mixture increases, as depicted in Figure 9. This is because bioethanol has a high latent heat of vaporization, making it capable of absorbing more heat from the reaction zone and exerting a greater cooling effect. This condition made the heater's temperature decline. As a result, the maximum flame temperature decreases in proportion to the percentage of bioethanol present. Due to the high latent heat of vaporization and low cetane number of bioethanol, which contribute to its lower maximum temperature in comparison to diesel, the maximum temperature inside the furnace at the ratios of bioethanol (10 percent, 15 percent, and 25 percent) in the mixture is lower than that of diesel by approximately 1%, 3%, and 6%, respectively.

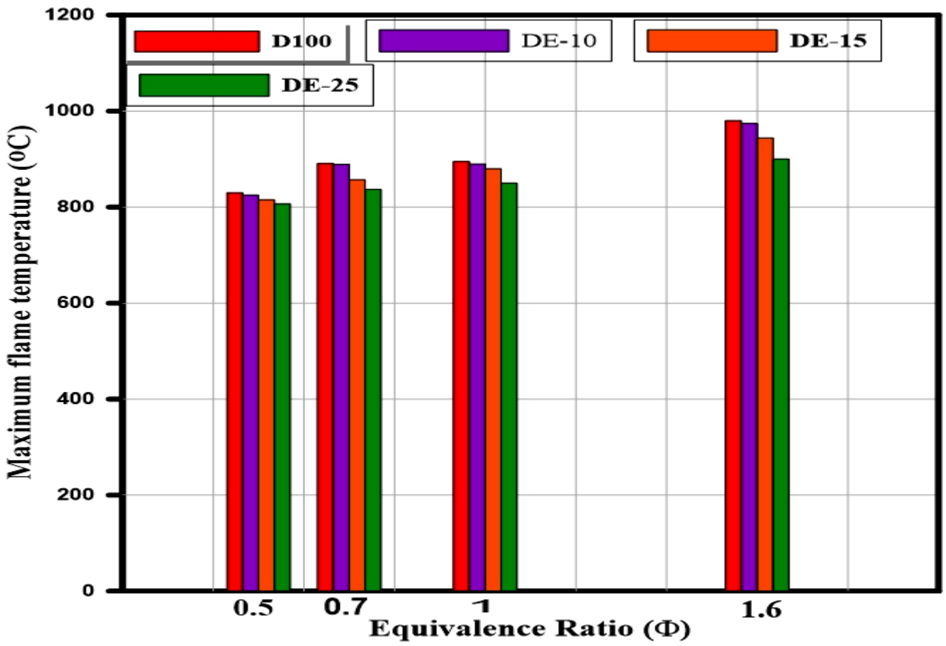

Figure 9. The effect of the equivalence ratio on maximum flame temperature.

3.2.3. The impact of various comparability proportions on the fire temperature in the centerline of the heater.

The most significant factor in determining the characteristics of a flame is its temperature. To understand and distinguish the fire conduct of various energizes, the temperature of the fire was estimated as it went through different regions. Four thermocouples were installed in a laboratory furnace for recording the temperature variation along the industrial burner's centerline during combustion experiments. Figures 10, 11, and 12 show the effects of various fuel mixtures and equivalence ratios on the flame temperature. The gas temperature decreases with distance from the burner to the end of the furnace in the figures due to convective and radiative heat transfer. The first thermocouple displays a rise in temperature from 0 cm away from the burner to 30 cm to 40 cm away, but it begins to decrease at 50 cm away. Ignition is most productive between 30 cm and 40 cm from the burner, which is the more sizzling area of the fire. At 30 centimeters from the burner's output, the flame reaches its maximum temperature. This is because complete combustion takes place here. As a result, the temperature of the flue gas goes up. The far-burner zone had lower temperatures than the other measured areas of the flame. The maximum temperature and the trend of the temperature distribution from the burner to the end of the furnace decrease as the amount of bioethanol increases because of its cooling effect. The figures show that as the equivalence ratio increases for each type of fuel, the temperature of the centerline of the flame rises. At higher equivalence ratios, more fuel is burned, leading to this. Figures 10, 11, and 12 were show a comparison between the temperature trends of the burner's centerline for the three equivalence ratios of 0.5, 1, and 1.6. On account of a 0.5 equivalency proportion, as the bioethanol content of the mixes builds, the typical fire temperature inside the heater decline by 35 ˚C and 55 ˚C, separately, for DE-15 and DE-25, contrasted with DE-10. As the equivalence ratio rises, so does the flame temperature. The diesel-bioethanol mixture DE-10's average flame temperature rises by 715 °C, 763 °C, and 812 °C, respectively; the diesel-bioethanol mixture DE-15's average flame temperature rises by 680 °C, 739 °C, and 762 °C; and the diesel-bioethanol mixture DE-25's average flame temperature rises by 660 °C, 701 °C, and 744 °C. This is because fuel has been added to the blends in some amount. In addition, the findings demonstrate that, in all cases of equivalence ratio, a bioethanol-to-fuel ratio of 25% significantly reduces flame temperature.

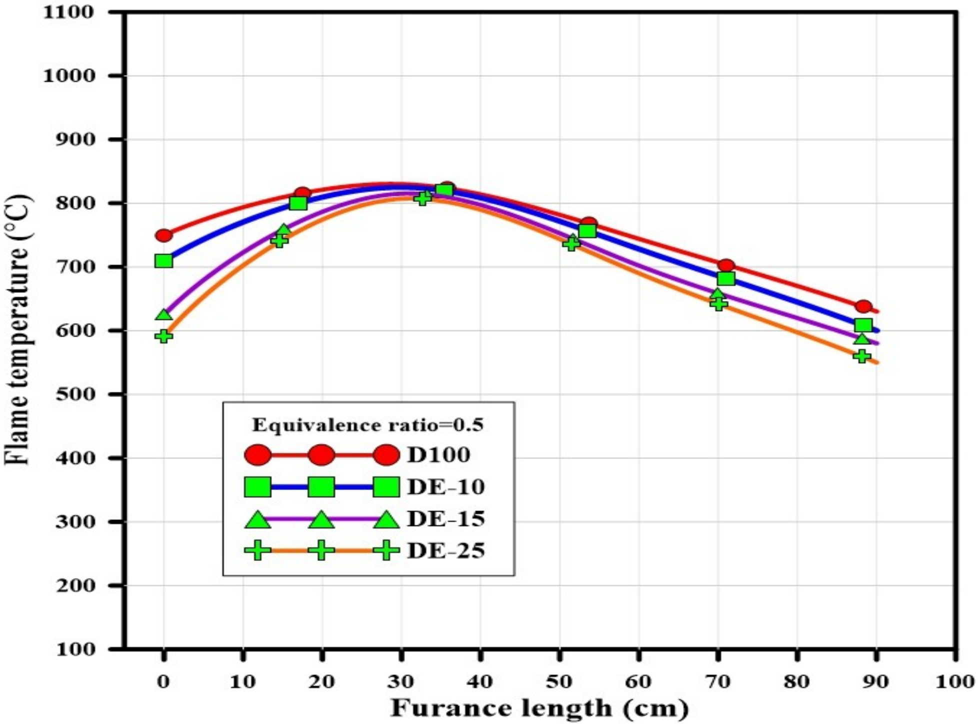

Figure 10. A furnace's centerline flame temperature at 0.5 equivalence ratio.

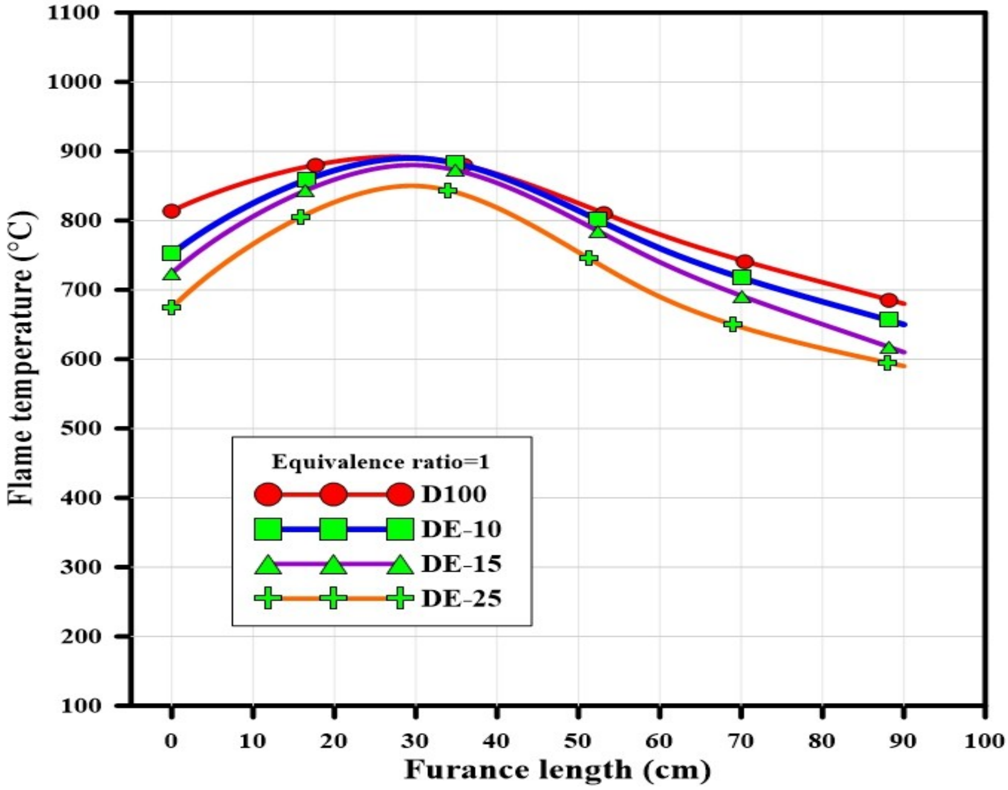

Figure 11. A furnace's centerline flame temperature at a 0.1 equivalence ratio.

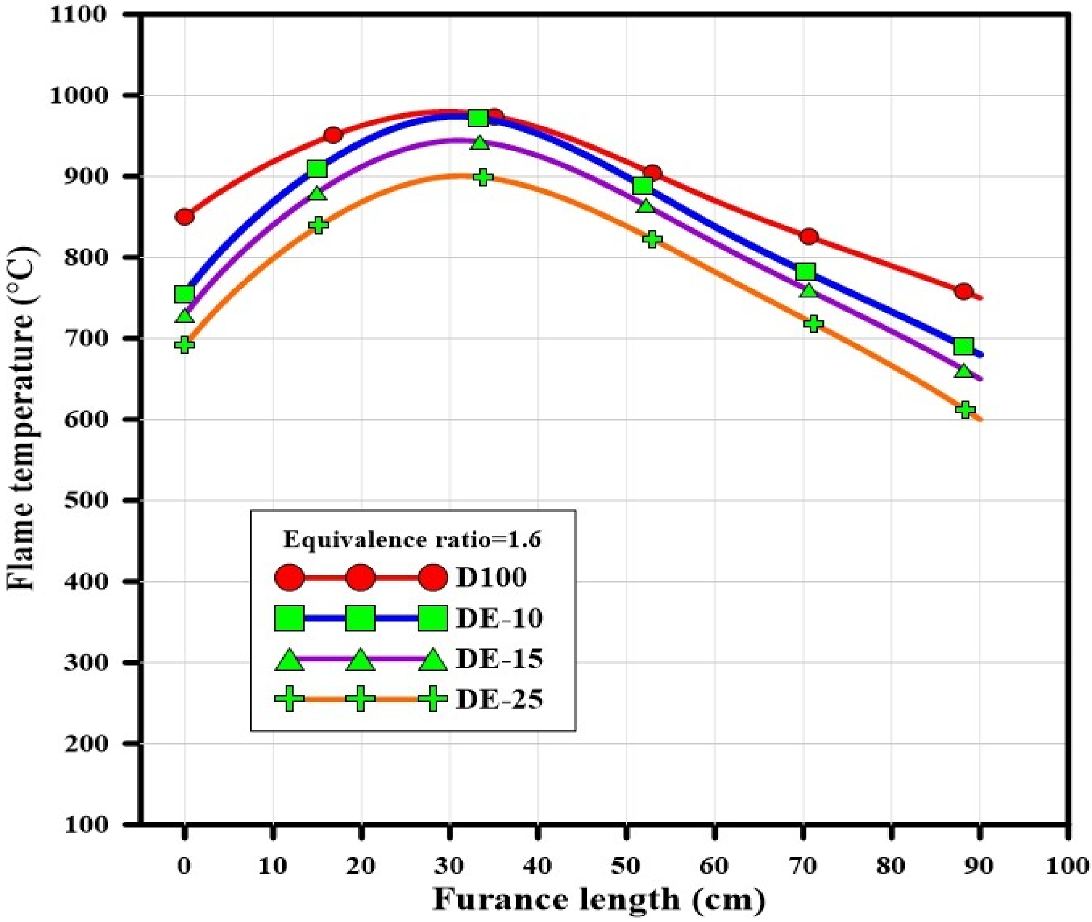

Figure 12. The temperature of the flame in a furnace's centerline at a 1.6 equivalence ratio.

3.2.4 The *influence that various equivalence ratios have on the flame pictures*.

Flame images for various test fuel equivalent ratios are shown in Figure 13. In all cases, the bioethanol impressively affected the splendor and design of the fire, showing a slower pace of ignition and oxidation, which would bring about a lower fire temperature due to the bioethanol impact. We observe a significant decrease in the temperature distribution inside the furnace because of the high percentage of bioethanol and its influence on the combustion processes and flame temperature. As per the outcomes, the most extreme fire temperatures of the fills DE-10, DE-15, and DE-25 were around 894˚C, 874 ˚C, and 848˚C separately.

All test fuels have a hotter reaction zone 30-40 cm away from the burner. In the case of DE-25, the flame inside the furnace has become unstable, and the yellow luminosity has visually decreased as the bioethanol ratio increased. The fire shows direct splendor altogether and straightforwardness on account of DE-10 and DE-15, attributable to add up to burning. With a higher equivalency ratio, the brightness of the flame rises rapidly. However, the structure of the flames in DE-25 shows a decrease in flame size and temperature as measured by temperature. As the amount of bioethanol in the mixture rises, a sluggish and unstable flame develops. There is also a zone with low heat. This is normal in flames with lower heating values. There is also a zone of low heat.

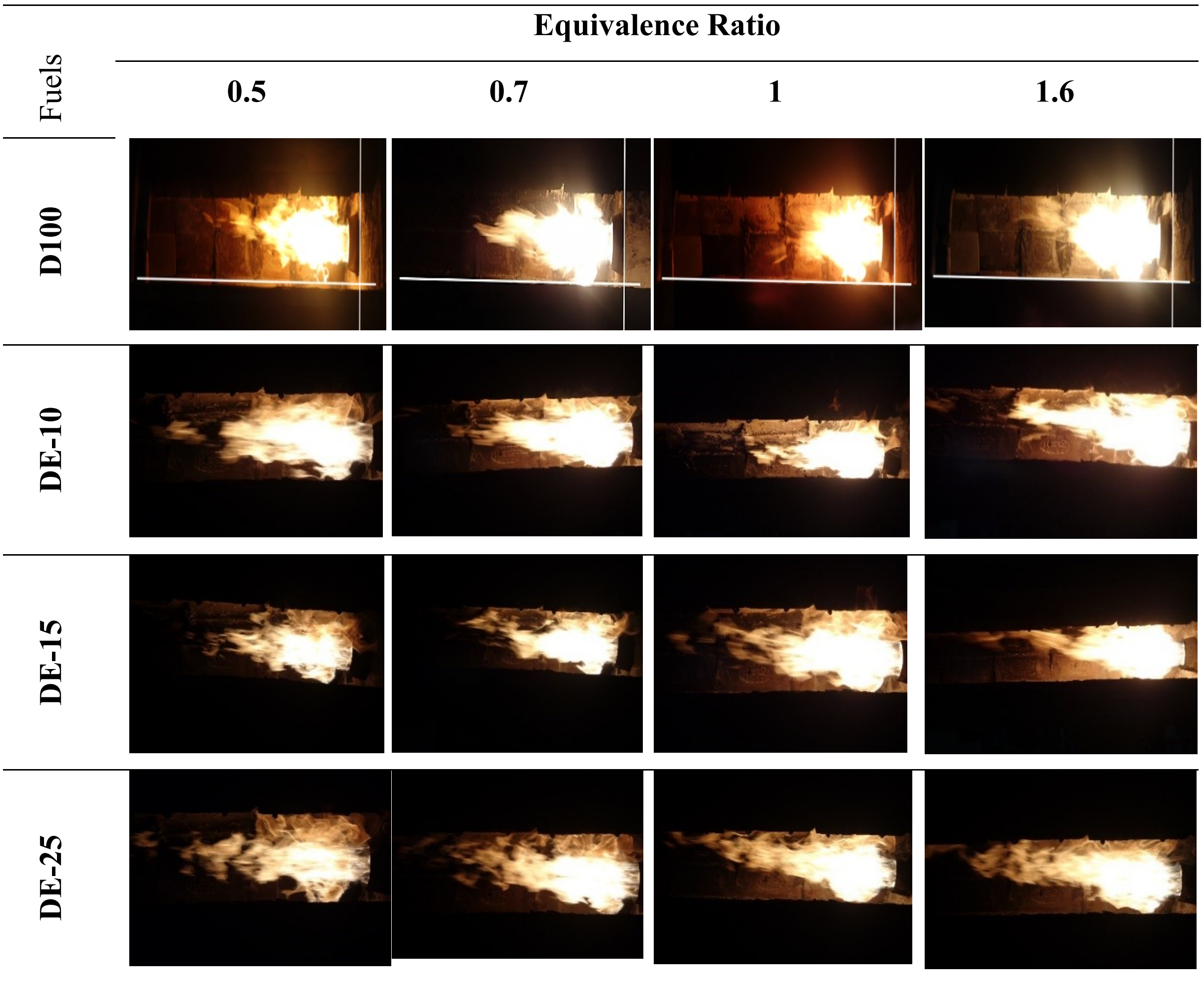

Figure 13. The images of flames from various fuels with varying ratios of equivalence.

4. Conclusion

The purpose of this study is to investigate the combustion performance and emission characteristics of a 350-kW industrial burner fuelled with various types of bioethanol and diesel blends without modifying the system combustion. In practical experiments, it was found that using bioethanol blends with diesel improves combustion performance and emissions in an industrial burner. It can also be blended with diesel fuel in any ratio to produce biofuel blends. All of the fuels were tested in an industrial burner at different equivalence ratios. Utilizing all fuel samples under similar operating conditions, all fuel comparative data were analyzed. The following is the conclusion drawn from practical experiments:

- In comparison to diesel fuel, the fuel mixture of diesel and bioethanol for DE-10, DE-15, and DE-25 decreased CO, UH, NOx, soot emissions (by around 20%, 40%, and 45%), (by around 13%, 25%, and 43%), (by around 8%, 14%, and 22%) and (by around 16%, 33%, and 50 %,) respectively.
- The exhaust temperature and maximum flame temperature of the combustion diesel-bioethanol mixtures DE-10, DE-15, and DE-25 decreased (by around 8%, 11%, and 17%) and (by around 1%, 3%, and 6%), respectively.
- In the case of DE-25, the flame structure shows a decrease in flame length and cone angle.

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