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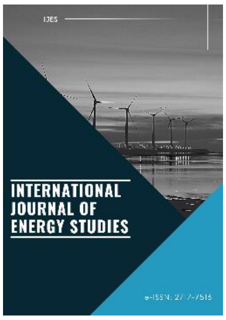

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Investigation of propane combustion at different equivalent ratios in a premixed model burner

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Highlights

- Experiments were conducted with increments of 0.1 from 0.6 to 1.4 equivalence ratio.
- The highest emission values were determined at an equivalence ratio of 0.8.
- As the equivalence ratio increased beyond 0.8, a decrease in emissions was observed.
- After the 0.8 equivalence ratio, a decrease in NOx emissions occurred.

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ABSTRACT

Combustion is a chemical process that causes a burning substance to emit heat and light as a result of its reaction with oxygen. Propane can combine with oxygen to perform a combustion reaction. Especially in homes and vehicles, propane combustion is frequently used and heat or light energy is released. In this study, premixed propane combustion was investigated. The thermal power (3 kW) and swirl number (1) were kept constant in all experiments. According to the findings, the O_2 emission value also increases with the increase in propane equivalent. It was observed that if the propane equivalent was up to 0.8, the carbon dioxide emission remained at the optimum level. These results are actually similar in terms of light and heat emission. In fact, it was observed that the heat and Luminous emission and the flame height increased to the highest level at less propane equivalent levels. In the study, it was seen that changing the equivalent ratio affects the ratios of various gases produced during combustion and the total heat output. These experiments help optimize the combustion properties of propane. It is also important for design and operating decisions regarding the use of propane in industrial processes.

Keywords: Energy efficiency, Equivalent ratio, Combustion, Propane, Premixed model

1. INTRODUCTION

Today, fossil fuels are used frequently, this situation leads to an increase in dependence on fossil fuels and inevitably results in a granül decrease in fossil fuel resources. It is thought that hydrogen-based fuels will shape the future as an alternative to fossil fuels [1]. In this study, the combustion characteristics of the flame that will be formed by the use of propane gas (C3H8) with high hydrogen content, which is likely to be used in the future, as fuel have been investigated.

In this study, the combustion characteristics of propane under the premixed combustion conditions for different equivalent ratios were investigated. Emission, temperature, Luminous intensity and dynamic pressure values have been measured at each equivalence stage. In order to shed Luminous on future studies, these values have been compared one by one and the characteristics of propane gas have been tried to be revealed.

Premix modeling can examine the effect of different equivalent ratios on propane combustion and provides information for estimating the amounts of products formed during combustion. This study is important in terms of revealing information that can be used in applications such as fuel design and optimization of the combustion process. Experiments of propane combustion at different equivalent ratios are important for understanding and optimizing the combustion properties of propane. Equivalent ratio refers to the ratio between hydrocarbon and oxygen in fuel molecules. During the combustion of propane, the equivalent ratio can be used as a way to control the ratio between fuel and oxygen.

It is possible to characterize combustion as a reaction of fuel and oxygen. In this context, combustion is the name given to a chemical event in which the properties of substances change. Most of the energy released during the reaction is heat energy [2]. However, heat is not the only output of the reaction. With a certain amount of energy, electromagnetic waves, namely light, emerge. The sound is also heard. In addition, although there is electrical energy in combustion reactions, it is often at a negligible level. Since it is a chemical reaction, various products are obtained after combustion. Therefore, there is a mass balance of the reactants and products [3].

In the study conducted by Moiseeva et al. [4] a physico-mathematical model of the combustion rate of the propane-air mixture was created and calculated. The problem formulation is supported by the oxidizer and fuel mass conservation equations for the gas, and the mass, momentum and energy conservation equations for the gas are also included in the model. Godunov's scheme was used to solve the equation system of the model. In the study, in which the results of the numerical simulation of the apparent and normal combustion rates of the paper, propane-air mixture were recorded, it was determined that the results obtained were compatible with those in the literature. The apparent and normal combustion velocity in a propane-air mixture is dependent on the excess fuel coefficient in the gas, the normal and apparent combustion velocity tends to be zero for mixtures with propane content close to the lower flammability limit, the combustion rate of lean propane-air mixtures is dependent on the normal and normal combustion velocity of a stoichiometric mixture. It has been determined that it is lower than the apparent burning rate.

A detailed kinetic model of propane ignition and combustion in air was developed in 2011 by Titova et al. [5] The model created includes both high temperature and low temperature oxidation mechanisms and 599 reactions. In addition, the model was tested against experimental data on ignition delay time, propane conversion during low temperature oxidation, changes in species concentrations during propane pyrolysis, and lainar flame propagation velocity. In addition, the initial temperature T0= 680–1900 K, pressure p0=0.17–30 atm, and fuel-air balance φ =0.13–2 were investigated and tested in wide ranges. The key advantage of the kinetic model developed in the study is its ability to accurately predict integral characteristics such as ignition delay time and laminar flame velocity for light hydrocarbon mixtures (CH4/C2H6/C3H8) and a propene mixture. In the research, based on the sensitivity analysis, it was found that the effect of different reactions on the laminar flame velocity in the propane-air mixture largely depends on the composition of the mixture.

In 2004, the combustion of SPG mixtures containing gasoline and propane was investigated by Sayın et al. In the study, it is aimed to understand the change of combustion products in relation to the level of using dual fuels (gasoline and SPG), especially in order to minimize close consumption and exhaust emissions. With the help of a computer program called Olikara/Borman, 4 different combustion equations were tested with different temperature and fuel excess coefficient variables. One of the most valuable findings of the study is that increasing the amount of SPG reduces the resulting CO2. However, it was observed that the amount of CO also changed depending on the temperature and the fuel excess coefficient. The study contains important information for air pollution control, especially in the world where the use of motors is increasing [5].

In the study conducted by Kayataş et al., in order to deal with the numerical simulation of the combustion of propane in a combustor with air containing 21% oxygen and 79% nitrogen, and the numerical solution of the local entropy production due to high temperature and velocity changes in the combustion chamber, Equivalence ratio (f) and combustion The effects of heat transfer to the chamber on combustion and entropy production were investigated for different values of f (from 0.5 to 1) and (from 5 to 10 kW). Numerical calculation of combustion for these conditions was made with the help of FLUENT CFD code, in addition, a computer program was developed that numerically calculates the volumetric entropy production distributions and other thermodynamic parameters by using the results of the calculations performed with the FLUENT code. According to the information obtained in the study, the maximum values of the reaction rates decreased with the increase of f. Calculations revealed that if f<1 complete combustion occurs and if f=1, combustion is very close to complete combustion [6].

A study was carried out by Şahino and Didari to detect spontaneous combustion. In the study, gas samples taken from Karadon (Tea, Sulu, Bitter veins) , Kozlu (Big, Bitter, Çay veins) and Amasra (Çınarlı vein) Establishments of Turkish Hard Coal Institution (TTK) and ignition temperature technique were used. In the 2002 study, which was prepared with the experiments carried out in the laboratory environment, gas analyzes were also carried out while performing the spontaneous combustion experiments. According to the results obtained, it was seen that the evaluation of carbon monoxide gas and Cr C6 alkane group gases, 2,2 dimethyl propane and 1-pentene gases would be beneficial in early detection studies [7]. Investigating the combustion of propane as a fuel is one of the topics that have been explored in the literature [8, 9, 10,11].

In conclusion, with the literature review on propane combustion, chemical process with example studies has been analyzed. The topics such as the kinetic modeling of combustion rates, the effects of equivalence ratios and mixture compositions, and the impact of temperature and fuel properties on combustion characteristics has been found to be important research areas. he study aimed to elucidate the combustion instability and emissions of propane at various equivalence ratios.

2. EXPERIMENTAL SETUP

2.1. Experimental Equipment

The experimental setup in the study consists of a combustion chamber of certain dimensions (32 cm inner diameter and 165 cm length). The thermal power (3 kW) and swirl number (1) were kept constant in all experiments. The combustion chamber is equipped with a fan cooling system to control the temperature. Besides, there are ten inputs on the combustion chamber in order to obtain emission values from different axial regions. There are also loudspeakers on the right and left sides of the combustion chamber in order to provide external acoustic forced conditions. The size of the burner, which will operate at a burning power of 10 kW and a pressure of 20 mbar, has been calculated based on the fuel and air flow rates to enter the system. Supported with with an ionization stick, the burner system operates with an automatic system. It is also secured against blowout and flashback. This system can automatically cuts off the gas in case of flame blowout. Using mass flow controllers, the flow of fuel and air entering the burner could be automatically adjusted. It has been observed that the output of the burner can also be used for changing the swirl generator. For this reason, swirl effect can also be examined. The diameters of the fuel and air supply pipes have been designed based on the mass flows which pass through the system. Furthermore, Fuels which comes out of the fuel tanks are reduced from 200 to 300 bar to 0–1.5 bar using a regulator which is connected to the head of the tank. With with flexible hoses, the fuel transmission process is carried out. The pressure gauge enables us to monitor the pressure on the system. Mass flow controllers (MFCs) have been utilized in fuel and air supply systems in order to achieve a constant flow into the system. While MFCs which is used for fuel systems operates in the range of 600–30000 sccm (cm3 / s), higher volumetric flows are needed for the air. For this reason, air MFC can increase to 300 slm (L/s) range. In all MFCs, the minimum flow input value is expected to be 2% of the maximum working flow. A vacuum system controlls all MFCs are controlled from a single centre. In order to get acoustic forces, two loudspeakers have been added to the arms of the combustion chamber. The operating range of these speakers is 20–125 Hz with a a diameter of 30.48 cm.

Furthermore measure temperature, ceramic coated thermocouples around the combustion chamber have been used.Two different pressure meters in the system exist. Piezoresistive pressure meter is one of them and by using it, pressure changes between 0 and 10 bars can be measured precisely. The other one is called dynamic pressure gauges and it can continuously record pressure fluctuations under acoustic force in the range (± 622 Pa). Luminous intensity is utilized in order to measure stability and is obtained with photodiodes. These photodiodes have been designed for signals with a wavelength of 350 to 1100 nm. Using ProfiSignal Go software, values can be monitored. During experiments, with a portable flue gas analyzer, emission measurements were carried out. All values are stored in a desktop computer with a 28-channel data logger. Geometric structure of the combustor is presented in Figure 1. The process used to conduct combustion experiments is depicted in Figure 1. At 20 mbar of pressure, the burner (7) at the system's outlet can generate up to 10 kW of thermal power for flame. The fuel supply lines are followed by the gases that exit the tanks. These lines' three mass flow controllers provide for instantaneous and adjustable control over the fuel flows that enter the system. By using the vacuum system controller (4), mass flow controllers can modify the amount of fuel that enters the system. The fuel mixture (6) meets air in the pre-mixer after all of the fuels (5) come together in the collector.The compressor (1) provides the air needed for combustion. To maintain a consistent air flow, the compressor has an extra 1000 L tank in addition to its 500 L internal tank. A MFC situated on the air line has a 300 slm flow capacity. To assess the instability characteristics of the same event in the burner (7), a combustion chamber (8) measuring 16.5 cm in diameter and 165 cm in length was built. Around this combustion chamber, thermocouples, piezoresistive pressure meters, and photodiodes are used. The apertures that surrounded the combustion chamber and chimney at axial intervals were used to measure emissions. A logger gathers and displays 28 channels of data that are fed in via ports on the computer.

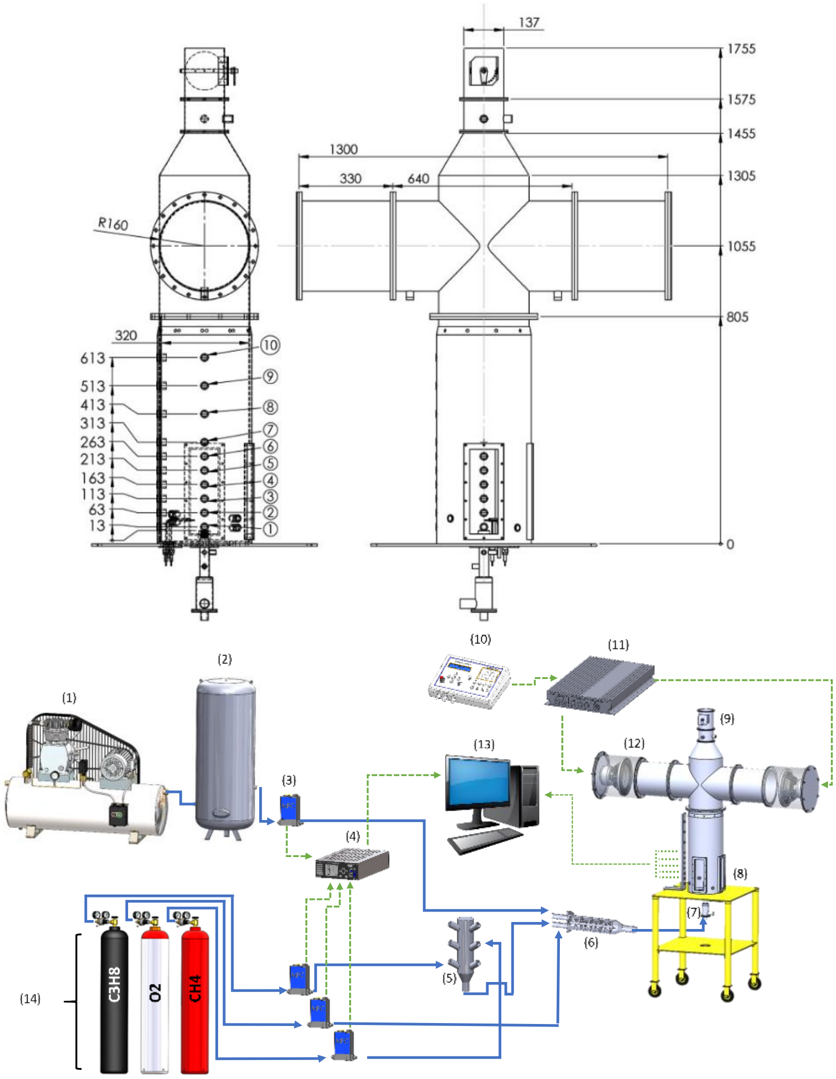

Figure 1. Experiment setup and geometric structure of the combustor (dimensions in millimeters).

1.Air Compressor (5.5 hp, 500 lt) 2. Air Vessel (1 m^3) 3. Mass Flowmeter Controller (MFC) 4. Vacuum System Controller 5. Gas Fuel Collector 6. Mixer 7. Premixed Burner 8. Combustion Chamber 9. Flue Signal 10. Generator 11. Amplifier 12. Loudspeaker 13. Computer Gas Cylinders

3. RESULTS AND DISCUSSIONS

An effective combustion process has a number of important components. Two of these are flame stability against blowoff and flashback mechanisms and fume gas emissions, which are critical to the environment and efficient use of energy resources. This study's experimental findings are divided into two categories: emissions and combustion instabilities.

3.1. Emission Values with Varying Propane Equivalent Ratio

In this study, emission measurements were conducted by varying the propane equivalent ratio from 0.6 to 1.4 during combustion. The measured emission values are presented in tabular form.

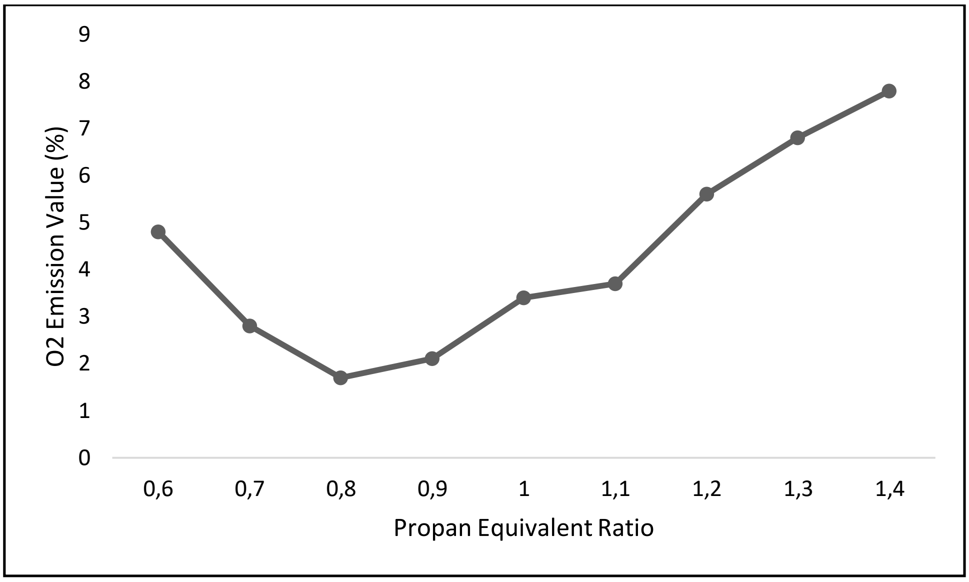

Figure 2. O_2 emission value at different propane equivalent ratio

As seen in Figure 2, it is understood that the O_2 emission value decreases until the propane equivalent ratio is 0.8, but then the O_2 emission value increases as the propane equivalent ratio increases. However, as can be seen in the figure, the O_2 emission value increases with the increase in propane equivalent ratio. In fact, this is a proof that the combustion reaction does not occur with the highest efficiency. The increase in O_2 emission can also be interpreted as the absence of the correct amount of O_2 in the environment for the complete combustion of propane. Because the oxygen taken into the system during combustion is expected to turn into CO_2 and/or CO. The increase in O_2 emission indicates that some oxygen leaves the system without entering the combustion reaction.

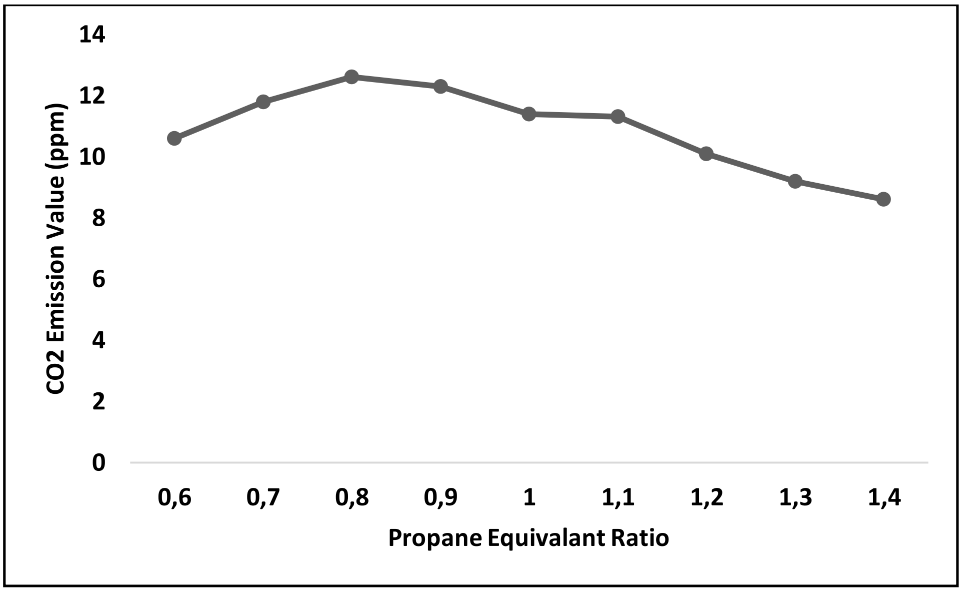

Figure 3. CO_2 emission value at different propane equivalent ratio

Figure 3 shows the measurement results of CO_2 emission values at different propane equivalent ratios. It is seen that CO_2 emission reaches the highest level at 0.8 propane equivalent ratio, and then there is a decrease in the CO_2 emission value. In case of complete combustion of the fuel, it is expected that CO_2 emissions will increase and O_2 emissions will decrease. The more the burn heals, the more pronounced this will be. Propane equivalence improves up to 0.8 and is optimum at 0.8. At values above 0.8, it is understood that complete combustion does not occur.

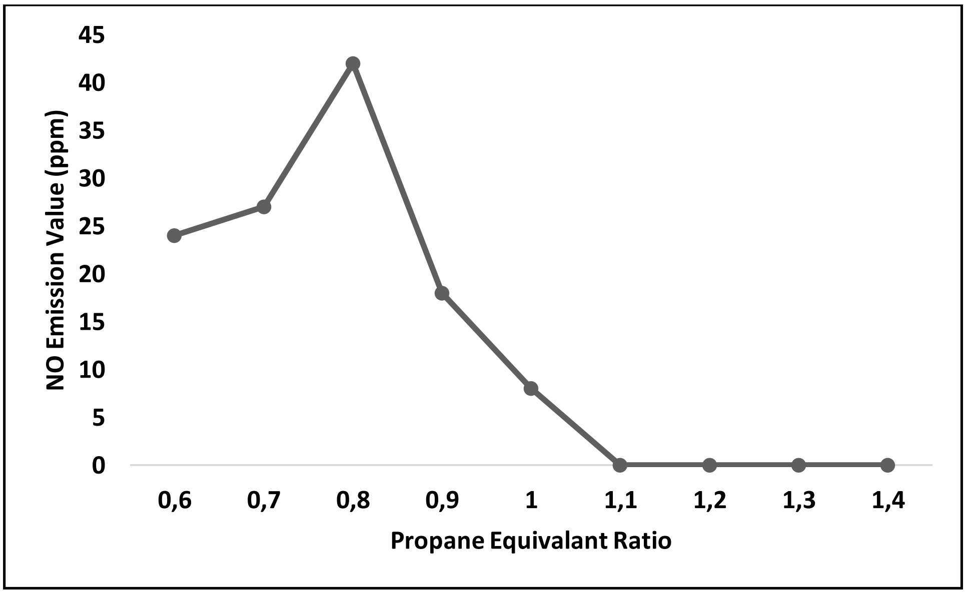

Figure 4. NO emission value at different propane equivalent ratio

In the study, it is seen in Figure 4 that the NO emission value increases up to 0.8 propane equivalent ratio and then decreases after 1.1 propane equivalent ratio and then becomes zero.

Nitrogen oxide emissions are emissions dependent on combustion temperatures. Nitrogen oxide emissions (NO_x) are expected to increase as the end-of-combustion temperatures increase. Combustion temperatures are directly related to how much of the fuel can be burned. In other words, as the combustion improves, the post-combustion temperatures will also increase. It is seen that the propane equivalent ratio improves up to 0.8, after which the combustion worsens. The NO emissions given in the graph are compatible with O_2 and CO_2 emissions, and as expected, the propane equivalent ratio increased up to 0.8, and the maximum value was observed at 0.8, where combustion is the best. When the values are higher than 0.8, complete combustion could not be realized and therefore the temperatures at the end of combustion decreased. When the propane equivalent ratio is made 1.1 and higher, it is understood that the temperatures cannot be reached to the extent that NO emission will occur.

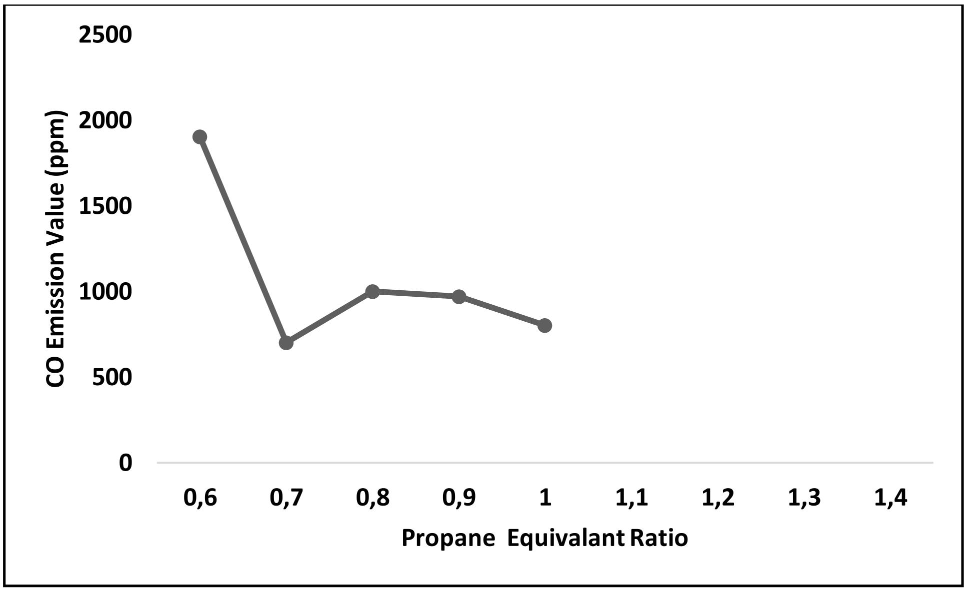

Figure 5. CO emission value at different propane equivalent ratio

It is seen that the propane equivalence of CO emission reaches the lowest value of 0.7, it is seen that it increases again and starts to decrease at 0.8 propane equivalent. After 1.0 propane equivalent ratio the meter appears to be out of range.

CO emissions are expected emissions when partial combustion or insufficient oxygen is present (such as in rich mixture situations). Minimum CO was observed when the propane equivalence was 0.7. However, when the propane equivalence is increased, it has been determined that some CO emissions increase because the combustion worsens.

3.2. The Effect of Changing Propane Equivalent Ratio on Temperature Values

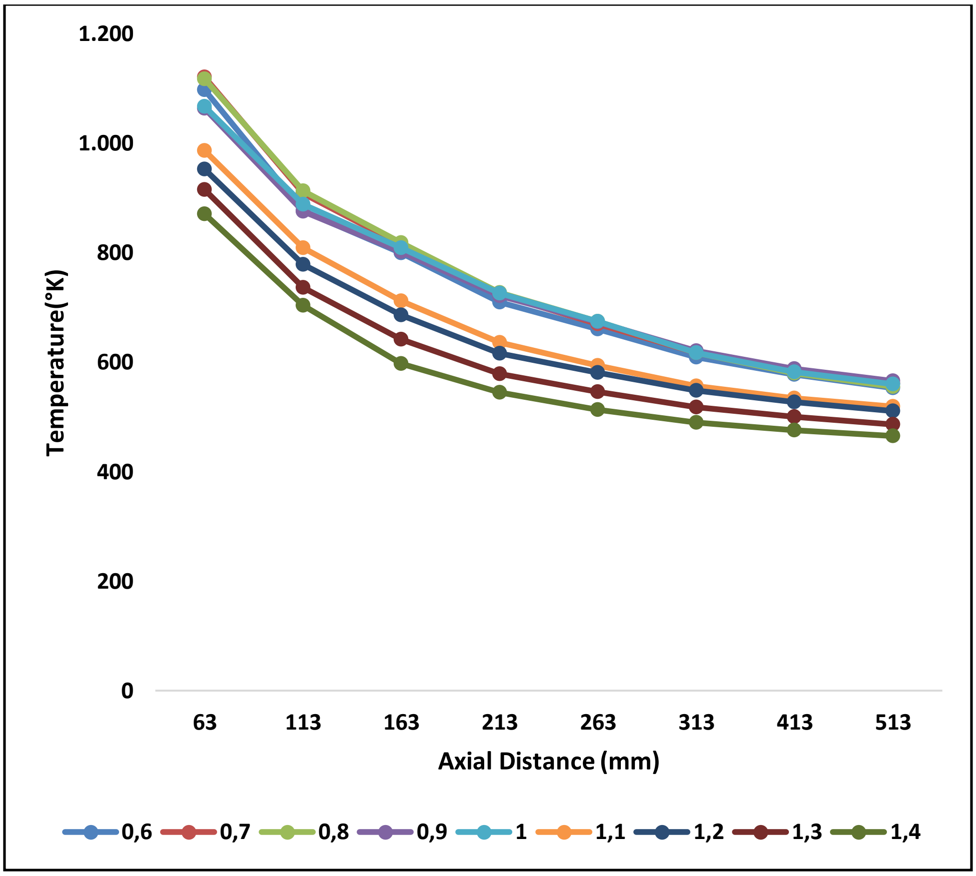

Figure 6. Axial temperature values at different propane equivalent ratios

In the chart above, the axial temperature values seen in 9 different propane equivalent ratios are given. The equivalence ratio affects the mean flow velocity, adiabatic flame temperature, and laminar flame speed. Therefore, it influences flame stability, temperature distribution, and pollutant emissions. Depending on the equivalence ratio, conditions such as mass flow rate and turbulence intensity are affected [12]. As the axial distance increases from the burner outlet, temperature values decrease. The effects of equivalence ratio are prominent in the flame region, diminishing as the distance increases. As can be seen from the graph, in all equivalences, the temperature value decreases as the axial distance increases. For example, for propane equivalent ratio of 1.4, if the distance is 63 mm, the temperature is approximately 850 K; the situation is similar in the case where the propane equivalent ratio is 1.3. Interestingly, the temperature decreases as the propane equivalent ratio increases. At a distance of 63 mm, propane with 0.6 and 0.8 equivalent ratios provides the highest temperature, while the lowest temperature is observed at 1.3 and 1.4 equivalent ratios. The situation is also valid for different distances. As a result, it can be interpreted that the temperature values in the flame region (maximum temperature value 1150 K) decrease depending on the decreasing flame length.

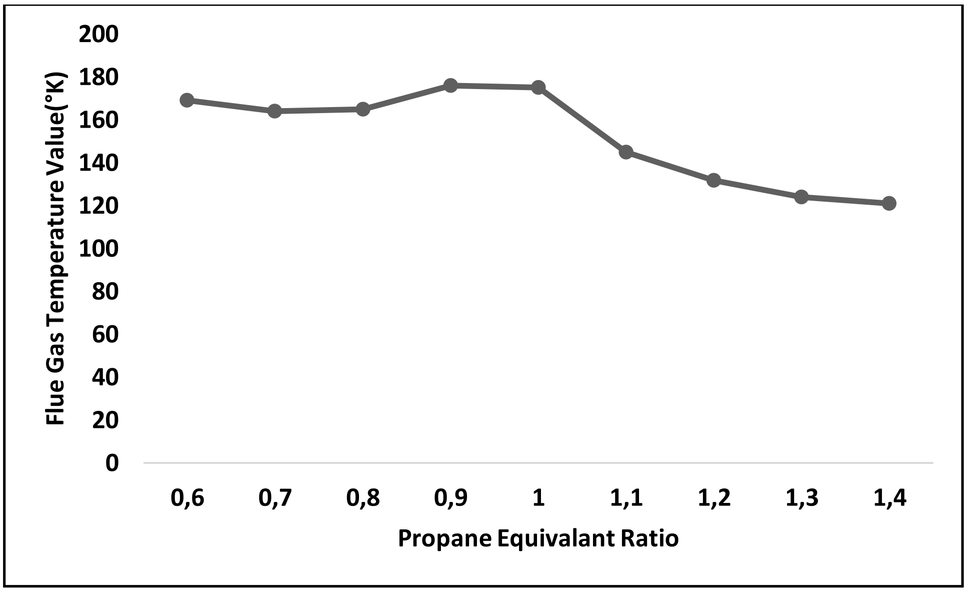

Figure 7. Flue gas temperature values at different propane equivalent ratios

As seen in the graph above, there is no linear relationship between the increase in propane equivalence and the flue gas temperature. For example, while the propane gas equivalent ratio ranged between 0.6 and 0.7, the flue gas temperature decreased, but when the propane gas equivalent ratio changed between 0.8 and 0.9, this temperature increased. It is difficult to say that the flue gas temperature increases with the increase of propane. Because when the propane gas equivalent ratio increases from 1 to 1.1, it is observed that there is a sharp decrease in the flue gas temperature. When the equivalent ratio changes from 1.1 to 1.2, it is seen that while the flue gas temperature continues to decrease, the falling rate decreases.

3.3. Effect of Propane Equivalent Ratio on Combustion Characteristics

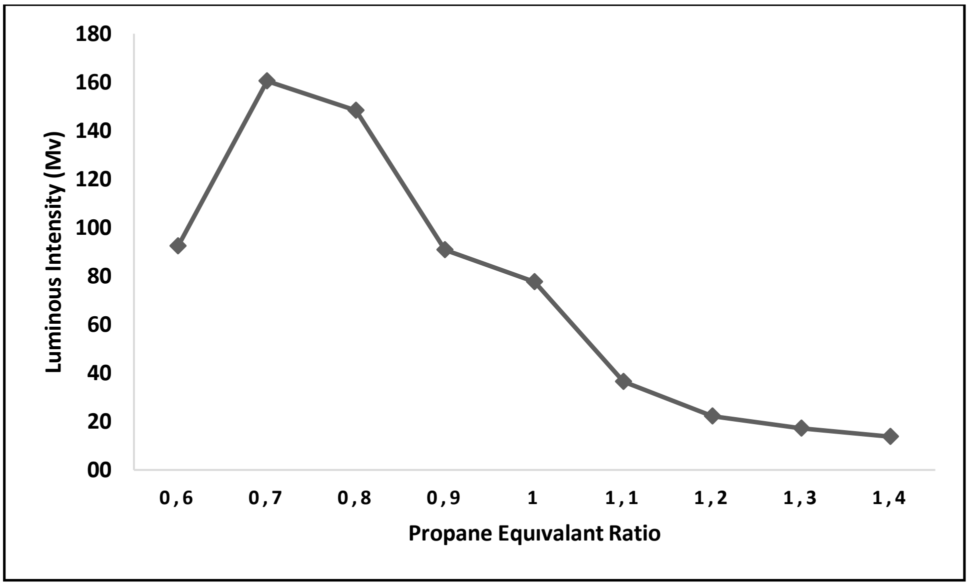

Figure 8. Luminous intensity values at different propane equivalent ratios

While the luminous intensity shows that the burning continues, sharp drops suggest extinction. The graph reveals that the maximum luminous intensity is 0.7 propane equivalent ratios. During the combustion of 0.9 and 0.6 equivalent ratios of propane, the luminous intensity values are the same. This shows that there is no linear relationship between propane equivalence and luminous intensity. While the highest luminous intensity was observed at 0.7 equivalent ratio, it was observed that the luminous intensity decreased as the equivalence increased. When going from 0.8 equivalent ratio to 0.9, the rapid luminous intensity decrease indicates that a fading condition may occur here. The same rapid luminous intensity decrease was observed at 1 and 1.1 propane equivalent ratios.

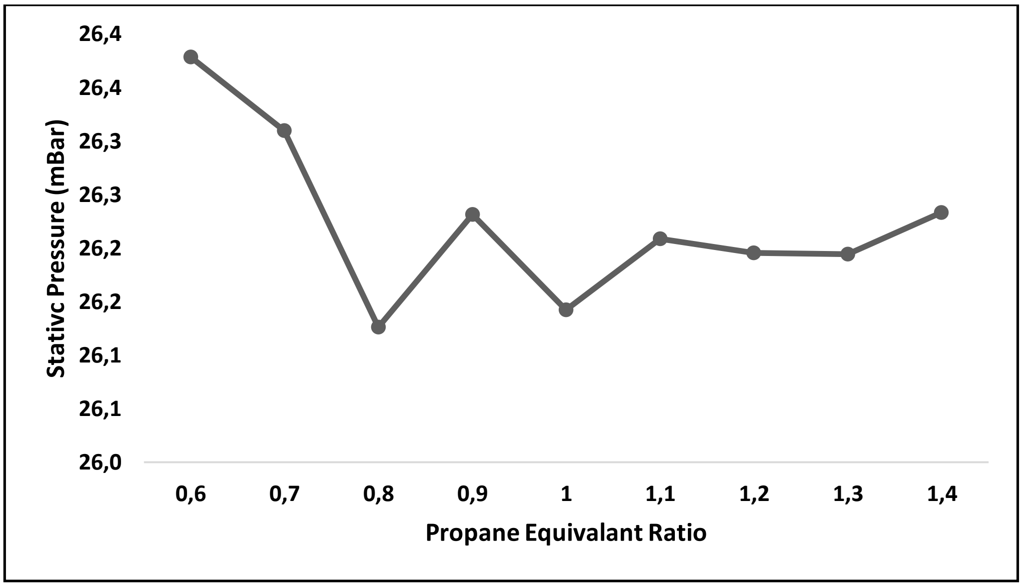

Figure 9. Static pressure values at different propane equivalent ratio

The graph above shows the variation of static pressure at different propane equivalent ratios. The pressure level of 0.6 was recorded as the highest level. At this point, it is seen that the static pressure value is 26.4, and at 0.7 equivalent ratio, the pressure value drops to 26.3. It was also found that when the propane equivalent ratio was increased from 0.7 to 0.8, the pressure showed a sudden decrease, but when it increased from 0.8 to 0.9, the pressure also increased rapidly. A similar decrease and increase, 0.9; It is also observed at the equivalent ratios of 1 and 1.1. The sudden change in propane equivalent ratio is also a factor that shapes the pressure.

Fluctuations in the flow rate or other thermodynamic state variables cause the rate of heat release to fluctuate. Fluctuations in heat release also induce acoustic oscillations, and acoustic oscillations cause fluctuations in velocity and thermodynamic state variables. Depending on the relative magnitude of the energy added or removed from the acoustic oscillations, the amplitude of the oscillations may decrease, remain constant, or increase over each cycle. Combustion instability occurs only when the energy supplied to the acoustic mode by the combustion process exceeds the energy losses of the combustion mode (eg, acoustic energy evacuation by radiation and convection, viscous loss and heat transfer).

4. CONCLUSIONS

The effect of propane fuel at different equivalence ratios on combustion stability and exhaust emissions was experimentally investigated in a laboratory-scale premixed combustion chamber. The results obtained from the research are as follows:

- The study demonstrates that emissions of NO increase up to an equivalence ratio of 0.8 propane and then decrease after 0.8. These findings elucidate the relationship between combustion temperatures and NOx emissions.
- High temperatures were achieved at low equivalence ratios. As the axial distance increased, the temperature difference between them decreased.
- The highest luminous intensity (160 mV) was observed at an equivalence ratio of 0.7. Beyond this value, an increase in the equivalence ratio led to a decrease in light intensity

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DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Murat Taştan: Bringing the idea, planning the method, evaluation and interpretation of the results, final check of the paper template, and proofreading.

Kağan Cenk Mızrak: Conducting the literature review, evaluation and interpretation of the results, final check of the paper template,

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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