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***Abstract*— Liquefied petroleum gas or better known as LPG is a fuel and flammable gas commonly used by Indonesians for household consumption such as cooking. The combustion process of LPG has negative effects on ecological life if accumulated for a long period of time as it contributes to CO_2 accumulation and climate change. Ammonia can be used in the substitution of fuels such as LPG and as an alternative energy source for the future because of carbon-free fuel and environmentally friendly combustion. The current study investigates the effects of ammonia as the carbon-free fuel in the LPG using an external premixed combustor under stoichiometric fuel mixtures. Volumetric ratios of 0%-50% between LPG and NH_3 were investigated to understand the effect of replacing LPG with NH_3 on flame characteristics. Oxygen was used as the oxidizer to exclude nitrogen, which is an inhibitor of flame reactivity. A high-speed camera was employed to capture the flame propagation, and the recording was processed to determine the flame characteristics of the mixtures. The experimental results show that ammonia influence on the flame height, flame angle, and dimensionless flame height normalized by the nozzle diameter. A larger replacement of ammonia resulted in a shorter flame height and larger flame angle.**

Keywords-Liquefied petroleum gas; Ammonia; carbon-free fuel; External premixed combustion; Flame characteristics

I. Introduction

Indonesia's population continues to increase over the years and had an effect on many aspects of human life. One aspect that is greatly affected by the increase in population is energy use. Energy is used to support the various needs of human civilization such as various industries, transportation, household electricity, and so on. Therefore, the bigger the population of a country is, energy use will also be increased to meet the needs of its people.

Fossil fuels, such as liquified petroleum gas or LPG, are commonly used to meet the increasing energy demand. However, it is a main contributor to CO_2 accumulation, which is a large contributor to climate change. As such, new technologies aimed at reducing energy consumption have become necessary, due to increasingly strict government regulations on energy and CO_2 emissions. Such developments lead to the search for carbon-free fuels, and the growing importance of renewable energy sources [1]. Due to the limitations of LPG fuel and the impact of its combustion on the environment, it is necessary to find and develop renewable fuels to replace LPG fuel.

Ammonia is a promising carbon-free fuel as an alternative to hydrocarbon fuels [2]. With the high use of non-renewable LPG, it is only a matter of time before the supply of LPG completely runs out. However, ammonia has a poor combustion characteristics and to design a good combustor for ammonia, its flame characteristics need to be investigated. These characteristics include the flame angle, flame height, and dimensionless flame height which can be measured using an external premixed combustor [3].

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Ammonia is a gas that can be used in the substitution of fuels such as LPG and as an alternative energy source for the future, ammonia gas is obtained/produced from microbial activity, ammonia industry, waste treatment, and coal. Ammonia has good density for gas and is usable for combustion without needing additional processes [4]. The properties of ammonia gas are as follows: colorless, pungent, and no carbon content. With the nature of ammonia gas, which is free of carbon elements, ammonia gas is very important in the selective catalytic reduction (SCR) of NOx. Thus, making ammonia gas a suitable candidate to replace fossil-based fuels [4]. Another advantage of ammonia also includes the ease of storing it, and possible renewable production [5].

In a combustion process that is carried out in open air, it will not produce a good combustion rate. There are impurities both in the air and in the fuel that make the combustion rate decrease, such as the nitrogen component in the air (N_2) [6]. The research carried out investigates the effect of ammonia addition. The output of this study investigates provides the flame characteristics of an external combustor, which previous works have highlighted their importance in combustion applications [7-9]. Furthermore, previous studies employed different combustors which include a porous radiant burner that is often used to burn LPG. Other studies have also found flame propagated using McKenna burner, is flatter and causes an even temperature profile compared to other burners [10-11].

The main objective of this research is to analyze, observe, and determine the effect of adding ammonia gas to LPG, which is the most widely used energy source in the community and has pollutant effects on LPG combustion residues. By conducting research by burning a stoichiometric mixture of Ammonia-LPG-Oxygen on a test burner with a nozzle diameter of 5mm. The gas mixture will flow through a hose from a fuel tank and an oxygen tank. Flowmeters with regulators were installed on the tank in order to observe the amount of flow to the burner and gas valves to regulate the flow of gases. A High-speed camera was used to record the flame shape and afterward post-processed.

II. Experimental Methods

In this study, the experimental variable was the amount of ammonia added to the fuel mixture, namely 0%, 10%, 20%, 30%, 40%, and 50% by flow rate respectively. Figure 1 shows the schematic of the current experiment. The gases, which are LPG, ammonia, and oxygen, were passed through a pipe under a flow rate of 0.5 L/min to the furnace and the pressure of each gas was set at 1 bar. Pressure-reducing regulators, high-pressure regulators, and a flowmeter were equipped on the tank to monitor the gas flow, and valves on each tube were regulated to control the opening and closing of the gas supply. The flowed gas underwent a mixing process on the fuel inlet hose before going to the burner through a nozzle with a tip diameter of 5 mm. The hose then will carry the gases with a check valve attached to the inlet of the hose and a stop valve to prevent further fuel contamination. While the gases were flowing, the pressure of each gas was set to 1 bar so that every gas had the same pressure and would not clog the gas mixture passage.

The flowmeter on the fuel tank was also checked periodically during the experiment to ensure that the required flow rate was appropriate. The flowmeter has a good accuracy of 96%. Checks were performed to ensure the valves were not leaking and the other apparatus works properly, to prevent gas leakage which can damage the surrounding environment. Due to the toxic nature of ammonia gas and the risk of burning, it is necessary to prepare protective glasses, gas masks, and light fire extinguishers.

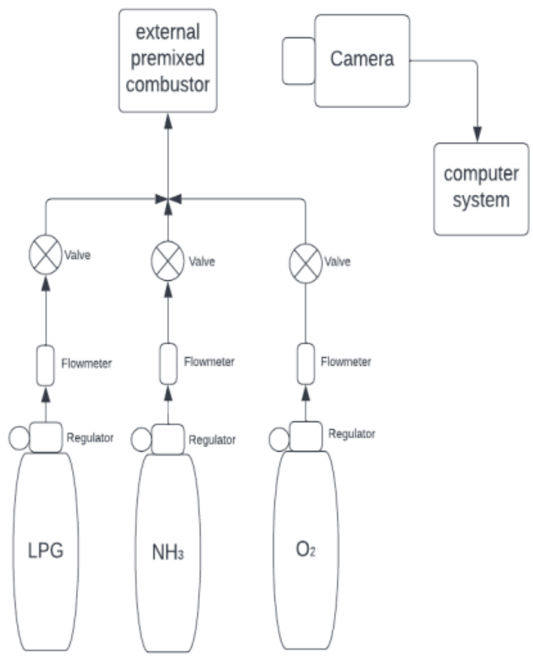

Figure. 1. Schematic diagram of an experimental system

After flowing the gases, the combustion furnace was ignited until the flame reached a stable condition and changes in flame characteristics could be seen. Afterward, a high-speed camera was employed to capture the flame propagation through the nozzle. The recordings were post-processed to determine the flame characteristics including the flame angle, flame height, and the dimensionless flame height, which was determined by normalizing it with the nozzle tip diameter. It should be noted that all experiments conducted in this study were carried out at atmospheric pressure and temperature. The flame characteristics obtained in this study correspond to those standard conditions.

III. Results and Discussion

In the study of the effect of the addition of ammonia (NH_3) on the flame characteristics of liquefied petroleum gas (LPG) fuel and oxygen mixtures, experimental results were obtained in the form of flame height, flame angle, and dimensionless flame height of various ammonia contents ranging from 0% to 50% experimental combustion compositions. The captured image of the flame at various ammonia-LPG-oxygen mixtures is shown in Figure 2. The figure shows the flame propagation images for 0% ammonia content on the leftmost and 50% ammonia content on the rightmost, and a 10% increment in the ammonia content as it moves from the left image to the right. It also shows the post-processing results to capture the flame height and the flame angle.

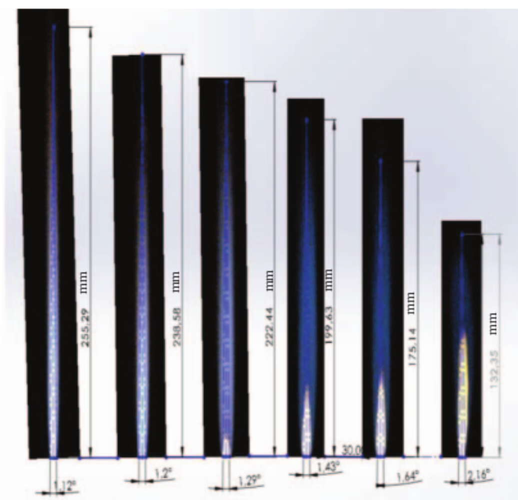

Figure. 2. Images of the flame under ammonia addition conditions (0% to 50% from left to right, with 10% increments, respectively)

In the relationship between ammonia gas content and flame angle as shown in Figure 3, the greater the concentration of ammonia in ammonia-LPG-oxygen mixtures, the flame angle is greater. The largest difference appears between 50% and 40% ammonia concentration. The 40% ammonia mixture produces a flame angle of 1.64 degrees, and the 50% ammonia mixture produces a flame angle of 2.16 degrees. The difference is 0.52 degrees, followed by 0.21 degrees, 0.14 degrees, 0.09 degrees, and 0.08 degrees, which are respectively produced by 40%-30%, 30%-20%, 20%-10%, and 10%-0% ammonia concentrations. The smallest difference (0.08 degrees) is observed between 10% and 0% ammonia concentrations. The increased flame angle with higher ammonia concentration can be attributed to the reduced reactivity from replacing LPG with ammonia since ammonia has a lower heating value and laminar flame speed compared to LPG. Based on the review work by Kobayashi et al. [4], they reported that the maximum laminar flame speed of NH_3 under standard conditions reached 7 cm/s while propane, which is the main composition of LPG, has a maximum laminar flame speed of 43 cm/s under similar condition. In addition, the lower heating value of NH_3 is 18.6 MJ/kg, which is about 2.5 times less than the lower heating value of propane with a value of 46.4 MJ/kg.

In the relationship between the ammonia gas content and the flame height, as shown in Figure 4, the greater the ammonia concentration in the ammonia-LPG-oxygen mixture, the smaller the flame height since ammonia has a lower heating value and laminar flame speed than LPG. The greatest difference appeared between the 50% and 40% ammonia concentrations. The 40% ammonia mixture produces a flame height of 175.14 mm, and the 50% ammonia mixture produces a flame height of 132.35 mm. The difference is 42.79 mm, followed by 24.49 mm, 22.81 mm, 16.14 mm, and 16.71 mm, each of which produces 40%-30%, 30%-20%, 20%-10%, and ammonia concentration of 10%-0%. The smallest difference (16,14 mm) was observed between 20% and 10% ammonia concentrations.

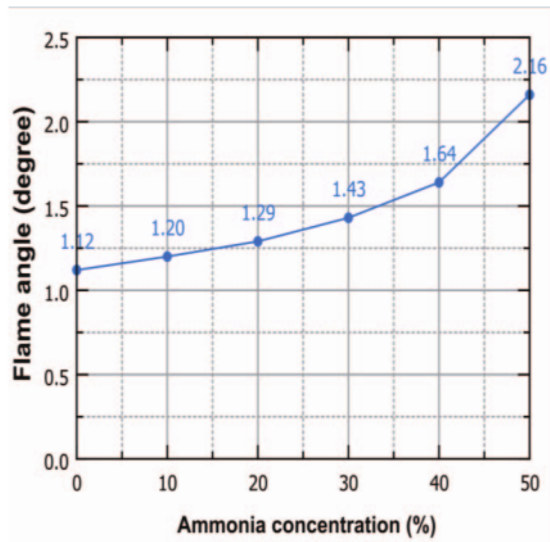

Figure. 3. Relationship between ammonia gas content and flame angle.

In the relationship between the ammonia gas content and the dimensionless flame height, as shown in Figure 5, the greater the ammonia concentration in the ammonia-LPG-oxygen mixture, the lower the dimensionless flame height. The greatest difference appeared between the 50% and 40% ammonia concentrations. The 40% ammonia mixture produces a dimensionless flame height of 35.028, and the 50% ammonia mixture produces a dimensionless flame height of 26.47. The difference was 8.558, followed by 4.898, 4.562, 3.228, 3.342 which respectively produced

40%-30%, 30%-20%, 20%-10%, and 10%-0% ammonia concentration. The smallest difference (3.228) was observed between 20% and 10% ammonia concentrations.

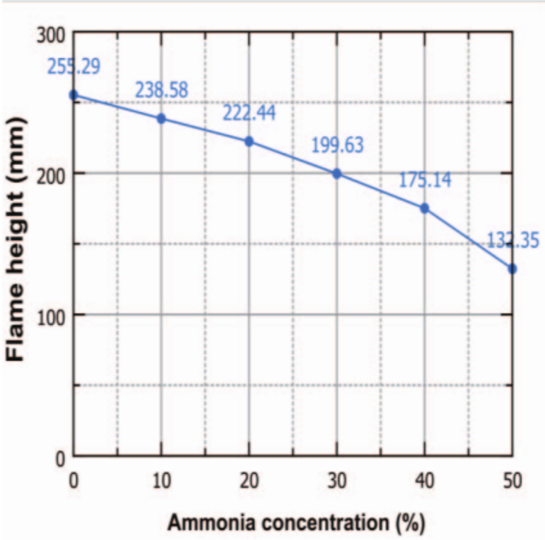

Figure. 4. Relationship between ammonia gas content and flame height

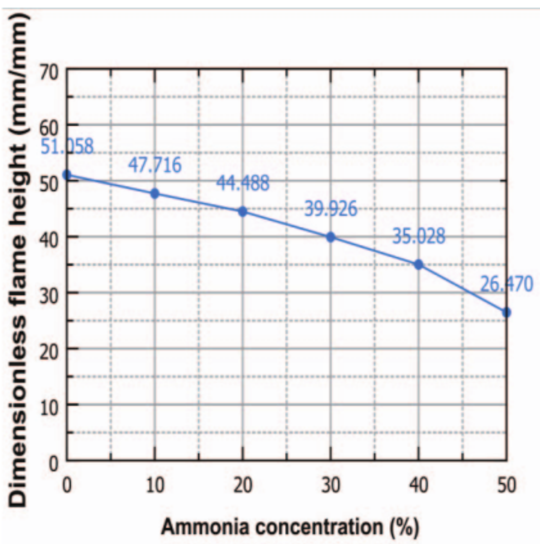

Figure. 5. Relationship between ammonia gas content and dimensionless flame height

IV. Conclusion

The addition of ammonia gas affected the flame characteristics of the LPG external premixed combustion. The higher the concentration of ammonia in the LPG combustion mixture, the lower height of the flame. This is shown in the experiment where 0% of ammonia added to the fuel mixture corresponds to a flame height of 255.29 mm whilst the experiment with 50% of added ammonia corresponds to a flame height of 132.35 mm. Accordingly, the dimensionless flame height also follows a decreasing trend as the concentration of ammonia increases. Moreover, with the addition of ammonia gas concentration, the flame angle of the combustion flame will increase. Higher replacement of ammonia on the mixture resulted in a greater flame angle, with 0% ammonia having an angle of 1.12°, and the addition of 50% ammonia gas with a flame angle of 2.16°. The increased flame angle and the reduced flame height and dimensionless flame height with increased ammonia concentrations can be attributed to the lower heating value and laminar flame speed of ammonia as compared to LPG.

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