Effects of Ammonia (NH_3) on Flame Characteristics of Methane (CH_4) External Premixed Combustion

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Abstract. Methane has long been proposed as an alternative to heavy hydrocarbon fuels due to its low carbon content. However, considering the effect of climate change and the need to transition to zero-carbon, ammonia has recently gained popularity as a sustainable fuel. Nevertheless, previous studies have highlighted the poor combustion of ammonia and the need to blend it with other fuels like methane. As such, this study looks for parameters from the results of the fire of external combustion of premixed methane-ammonia gas. The study was conducted by burning stoichiometry first and then using a volume ratio as the content of the methane-ammonia mixture (ammonia concentration used 0-50%). The gas that comes out of the gas cylinder was adjusted in pressure and flow before mixing and then flowed into the burner to be combusted. The flame propagating from the burner was recorded in a high-speed camera and was used to define the combustion characteristics such as the flame height, flame angle, and dimensionless flame height. The higher concentration of ammonia in the fuel mixture was found to shorten the flame height and dimensionless flame height, while the flame angle became wider.

1. Introduction

The large use of fossil fuels in meeting daily needs has led to the depletion of fossil fuels and causes air pollution which is damaging to nature. It encourages more combustion studies to focus on environmentally friendly alternative fuels. The purpose of this study is to use ammonia gas mixed with methane gas to become a fuel [1-5]. One such fuel is biogas, which is an alternative renewable fuel source from animal wastes and is comprised of mostly methane (35% - 65%). Biogas also contains various contaminants such as carbon dioxide and nitrogen, followed by trace amounts of hydrogen gas, oxygen, and H_2S. Methane is an organic component that is easily combustible, while carbon dioxide and nitrogen are considered inert gases, meaning they won't play a role in combustion. Furthermore, the heat value of biogases depends on the amount of methane present in the biogas. [6-8]. Ammonia (NH_3) is another alternative energy source to replace fossil fuels. They can be easily produced

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and it does not have any carbon content which leads to less pollution [9]. However, some study has noted the poor combustion characteristics of ammonia, such as low laminar flame speed, high ignition temperature, and NO_x by-products [10-12].

A previous study was done by Xia et al. The study is about the co-combustion of coal/ammonia, in which they investigated the underlying mechanism of the difference in flame propagation speeds between co-combustion and ammonia-only combustion under different ammonia compositions [12]. This study used a burner to study the laminar flame of ammonia/N_2/O_2 in the presence of extra air. This study showed that the laminar burning velocity of ammonia got as high as 36.1 cm/s when the oxygen concentration was at 35% with the stoichiometric ratio at 1:1 [13]. A study conducted by Vinod et al. uses an ammonia gas combined with gasoline and methane. This study uses a single-cylinder engine with a carburetor [14]. A numerical study about the combination of ammonia, hydrogen, and methane fuels was done by Bayramoğlu et al. The study shows that the results can reduce combustion emissions [15].

The purpose of this study is to analyze the effect of NH_3 blended with methane, by burning the stoichiometric mixture of CH_4 and NH_3 (0 to 50% of fuel), and oxygen on the burner with a nozzle diameter of 5 mm. The burner is then connected to a tube from the oxygen tank and another tube from the fuel tank. A regulator and flowmeter are attached to each of the gas tanks to measure the flow rate of gases to the burner. A valve is used to control the flow rate of the gases. Then, the flame propagation generated from the combustion will be recorded. The recording will use a high-speed camera. The data from a high-speed camera will be processed through a computer.

2. Experimental method

The experimental variable was the concentration of NH_3 in the fuel (CH_4 – NH_3), in which the mixture of ammonia was tested at 0% up to 50% in increments of 10%. The experimental schematic is shown in Figure 1.

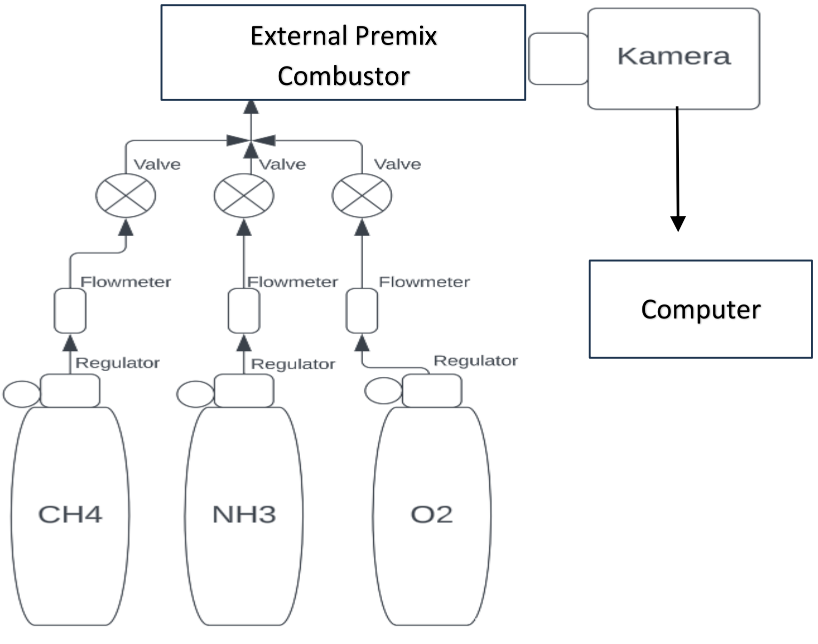

Fig. 1. Experimental schematic.

The purpose of this experiment is to assess the effects of ammonia as an additive in the external combustion of premixed biogas. The experiment is carried out by burning the stoichiometric mixture of CH_4-NH_3 (mixture ranging from 0-50%) and oxygen in which the gases were passed through the nozzle with a diameter of 5 mm. The tube from the oxygen tank, biogas tank, and ammonia gas tank will be connected to the burner. There are three regulators and three flowmeters to monitor the flow rate of the gas in each tank. Valves were used to control the flow rate of the gases.

In each of the trials, every mixture of fuel and oxygen flowed simultaneously to the burner which they will be sparked by the spark plug after they flowed for 10 seconds. Every flowmeter was checked in order to ensure that the volumetric flow rate of the gases corresponds to the stoichiometric volumetric flow rate. After that, high-speed cameras were used to take a picture of the flames from the combustion. The procedures were repeated again for different nitrogen concentrations. The experiment was carried atmospheric pressure and room temperature (20^0C).

After performing the experiments, the flame recording was post-processed in the computer to determine the flame angle, flame height, and dimensionless flame height. In calculating the dimensionless flame height, the measured flame height was normalized with the nozzle diameter of 5 mm.

3. Results

In studies of the effects of ammonia addition on the external combustion characteristics of methane and oxygen, the results that can be seen from experiments are flame angle, flame height, and dimensional flame height marks of 0% to 50% combustion of ammonia addition to the mixture of methane and oxygen fuel. The image of the experimental flame can be seen in Figure 2.

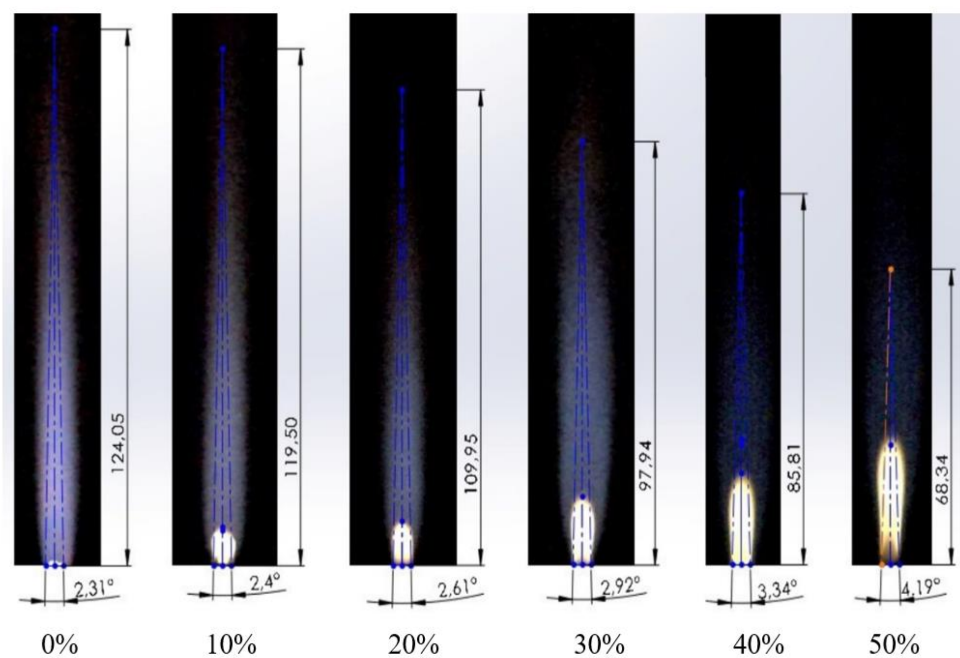

Fig. 2. Images of the combustion flames with different concentrations of ammonia (0-50% with 10% increments from left to right, respectively).

From the experimental results (Table 1), it can be concluded that the higher concentration of ammonia in the fuel mixture will make the flame height and dimensionless flame height shorter. Furthermore, the flame angle will also be bigger as the amount of NH_3 in the fuel mixture increases. These results can be seen in Figure 3 which shows the plot of the flame angle with different concentrations of NH_3 in the mixture from 0% to 50%.

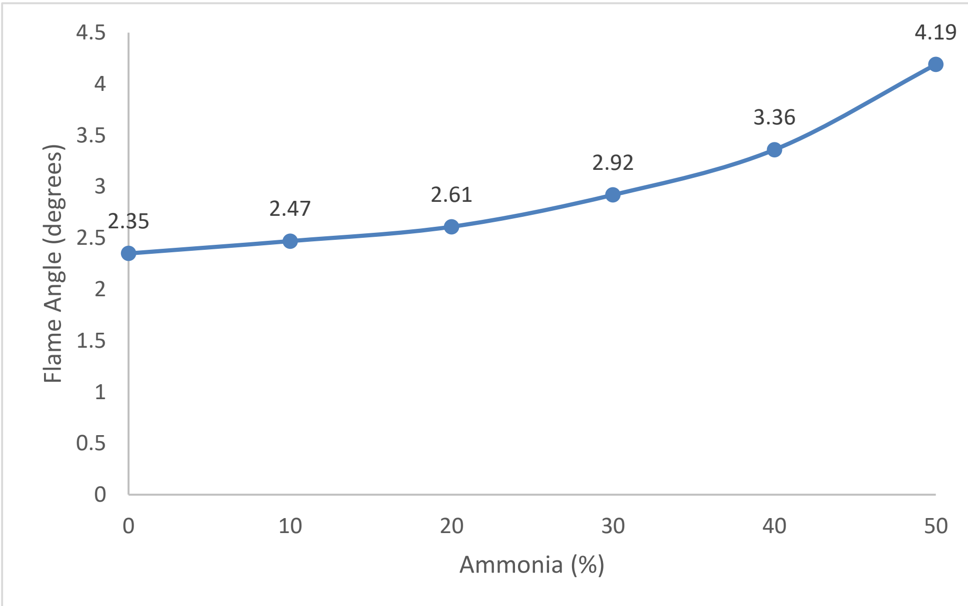

Fig. 3. The flame angle at various concentration of NH_3 (0-50%).

The flame angle graph in Figure 3 tends to increase with increasing ammonia gas concentration, the largest difference appears in ammonia concentration 40%-50% with the largest difference of 0.83 degrees, followed by concentrations 0-10%, 10-20%, 20-30%, 30-40% 40-50% with results of 0.12 degrees, 0.14 degrees, 0.31 degrees, 0.44 degrees, 0.83 degrees. The smallest difference appears (0.12 degrees) between 0-10% ammonia concentrations.

Table 1. Combustion results table

Concentration		Flowrate			Flame		Dimensionless *flame height* (H/d)
NH_3 (%)	CH_4 (%)	NH_3 (L/min)	CH_4 (L/min)	O_2 (L/min)	*angle* (°)	*Height* (mm)	
0	100	0	0.5	1	2.31	124.05	24.81
10	90	0.05	0.45	0.9375	2.4	119.50	23.9
20	80	0.1	0.4	0.875	2.61	109.95	21.99
30	70	0.15	0.35	0.8125	2.92	97.94	19.086
40	60	0.2	0.3	0.75	3.34	85.71	17.142
50	50	0.25	0.25	0.6875	4.19	68.34	13.668

The trend of the flame height graph in Figure 4 decreases with increasing ammonia concentration, the biggest difference appears in ammonia concentration of 40%-50% The largest difference is 17.37 mm, followed by concentrations 0-10%, 10-20%, 20-30%, 30-40% 40-50% with results of 4.55 mm, 9.55 mm, 14.52 mm, 9.72 mm, 17.37 mm. The smallest difference (4.55 mm) arises between the concentration of 0-10% ammonia concentrations.

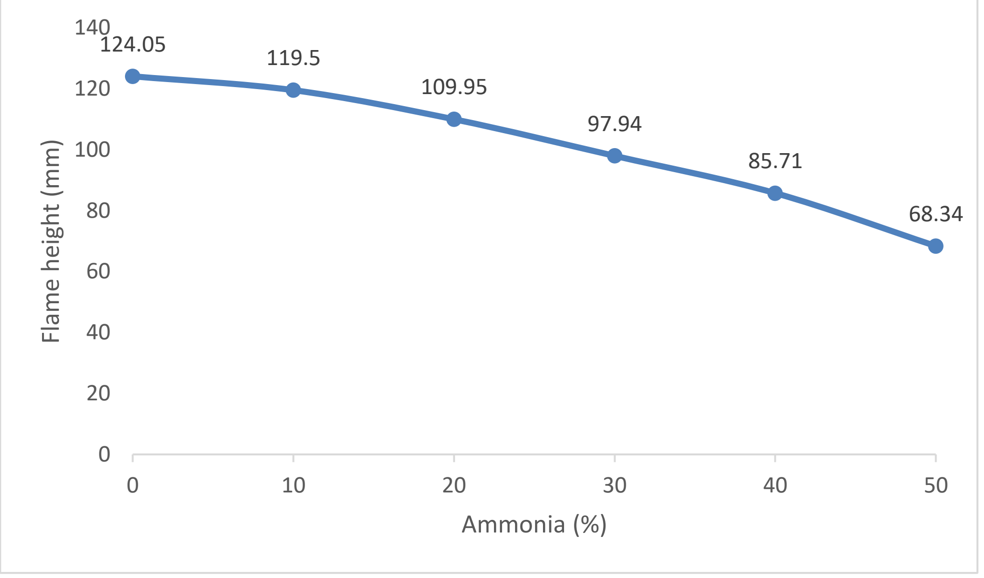

Fig. 4. Flame height plotted against NH_3 concentration (0-50%).

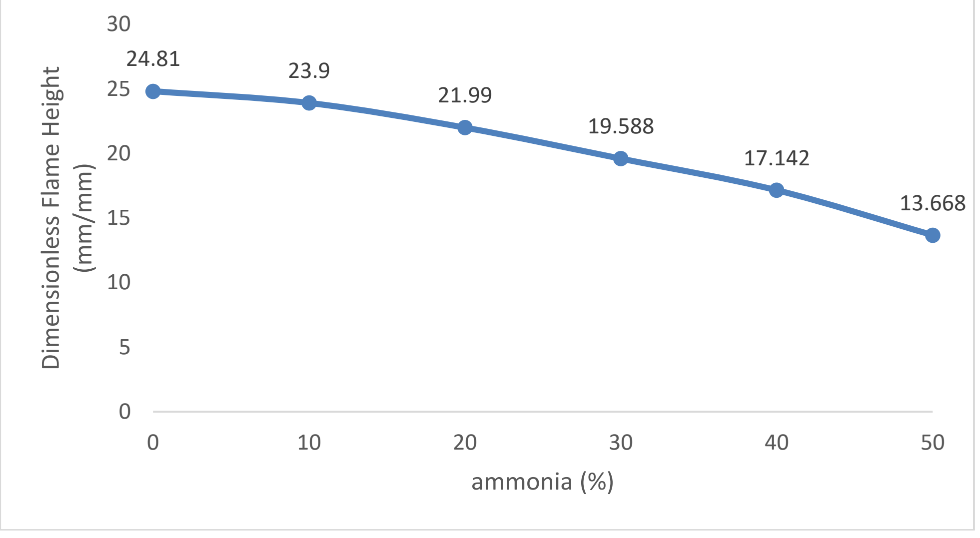

Fig. 5. Dimensionless flame height plotted against NH_3 concentration (0-50%).

The dimensionless flame height value was obtained by using the equation (H/d) that is shown in Table 1. H refers to the flame height and d refers to the nozzle diameter. The graph of dimensionless flame height in Figure 5 tends to decrease with increasing ammonia concentration, the largest difference appears in ammonia concentration 40%-50% difference of 3.474 mm, followed by concentrations 0-10%, 10-20%, 20-30%, 30-40% 40-50% with results of 0.91 mm, 1.91 mm, 2.904 mm, 1.944 mm, 3.474 mm. The smallest difference (0.91 mm) arises between the concentration of 0-10% ammonia concentrations.

The trends observed in this study can be associated with the different combustion properties of ammonia and methane. Under similar conditions, ammonia has a lower laminar flame speed than methane. In addition, ammonia also has less lower heating value [11]. The partial replacement of methane by ammonia resulted in overall less fuel energy content, and therefore less height in the flame propagation, and wider flame angle.

4. Conclusion

The addition of ammonia gas in combustion affects methane's external combustion flame characteristics were experimentally investigated. A greater concentration of ammonia results in shorter flame propagation, as shown in the flame height results when the 0% ammonia gas content produced is 124.05 mm, while the flame height when the 50% ammonia gas content reaches 68.34 mm. Accordingly, the dimensionless flame height has the same trend as the flame height. On the other hand, the greater concentration of ammonia causes the flame angle to be larger as seen from the combustion results when 0% ammonia content produces a flame angle of 2.45 degrees while ammonia content of 50% produces a flame angle of 4.19 degrees.

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