

2021_Paper_Nitrogen_Methane _Gas_-_Sinta_3

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The Effect of Nitrogen on Methane Gas Flame Propagation Characteristic in Premix Combustion

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Abstract

The electric engine is a serious opponent of the fuel engine. However, this does not mean that fossil fuels should be abandoned, but rather makes it a great challenge and a strong reason to develop fossil fuels to be even more efficient. Increasing the combustion efficiency of the current fuel engine can be done in various ways and methods. One of the many ways to increase combustion efficiency in terms of fuel is by mixing the fuel with other compounds. This article examines the effect of mixing variations of methane gas with nitrogen gas. The flame propagation speed in the midpoint of the mixture of stoichiometry (methane-air) and Nitrogen (N₂) on the top ignition is 2233.33 mm/s at N₂ 10% of the third frame and at lower ignition, the speed is 3550.03 mm/s at N₂ 20% of the second frame. In addition, the bottom ignition experiment has a very large effect on maximizing the speed of flame propagation, especially in the 20% N₂ sample. Therefore, the highest improvement in combustion efficiency is obtained by using a 20% N₂ mixture and at the bottom ignition condition.

Keywords: Premix Combustion, Flame Propagation, and Sustainable Energy

1. INTRODUCTION

The development of electric vehicles has reached an advanced stage and is spread in various parts of the world even in developing countries [1]. Until now, many well-known vehicle manufacturers have officially issued electric vehicle products. This development certainly has a huge impact on the world economy [2] and other types of energy sources [3]. It's already becoming no secret again, that the electric engine is a serious opponent of the fuel engine [4]. However, this does not mean that fossil fuels should be abandoned, but rather makes it a great challenge and a strong reason to develop fossil fuels to be even more efficient.

Increasing the combustion efficiency of the current fuel engine can be done in various ways and methods. Starting from increasing the quantity and quality of fuel, to the use of nano catalysts such as metal oxides [5] and magnetic nanoparticles [6]–[8] to reduce the value of the activation energy. In terms of improving the quality of fuel, of course, it costs quite a lot in terms of materials and processes. However, what remains the main focus of this increase is the level of efficiency.

One of the many ways to increase combustion efficiency in terms of fuel is by mixing the fuel with other compounds [9]. As far as current developments, hydrocarbon compounds can exist in three forms of matter, namely solid [10], liquid [11], and gas [9]. Hydrocarbons in the form of gases can be sourced from natural gas which can be depleted in the future or produced with waste materials such as biogas [12]. If it is concluded from a sustainability point of view, hydrocarbon gas still has great and abundant potential in the future.

Based on the demands of the development of the current types of energy and increasing the efficiency of fuel use, this article examines the effect of mixing variations of methane gas with nitrogen [5]. Nitrogen acts as a good inhibitor in the combustion process in the methane-air mixture. The magnitude of the flame propagation velocity in the midpoint of the combustion process by igniting the upper and lower flames of the methane-air mixture and nitrogen is the objective of this study.

2. METHODS

The method used is by conducting experimental combustion research, namely making direct observations to determine the cause-effect relationship by using one or more treatment groups in the combustion process. The research was conducted at the Mechanical Engineering Laboratory of Brawijaya University. In this study, the independent variable is the percentage of nitrogen mixture 10%-50% and the ignition point from above and below. The percentage of nitrogen is taken from the percentage of methane gas, for example, 10% nitrogen then 90% methane gas. The mixture of air and CH₄ remains stoichiometric [13]–[16] (9.5:1). Meanwhile, the dependent variable is the velocity of the flame propagation pattern in the midpoint.

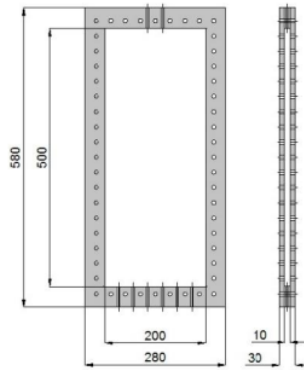
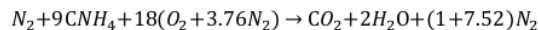


Figure 1. Dimensions of Helle Shaw Cell

Testing in the combustion chamber uses a Helle Shaw Cell model [17] with dimensions of 580 mm in length and 280 mm in width. The combustion chamber has a volume size of 500 x 200 x 10 mm. Acrylic is composed of three layers with a thickness of 10 mm each so that the overall thickness is 30 mm. On the sidewalls, there are several holes (places for bolts and nuts) for acrylic binders, besides that, to avoid leakage when methane, nitrogen, and air were mixed. Therefore, the pressure in the combustion chamber remains constant. The two vertical holes above act as a place to enter gas and air. Six holes below as overflow holes.

In obtaining nitrogen in the stoichiometric mixture without nitrogen mixture are by calculating the total volume of Helle Shaw Cell, then determining the percentage of nitrogen that entered the combustion chamber according to the variation in the percentage of nitrogen. The way to calculate the ratio of the stoichiometric mixture and the percentage of nitrogen is to pay attention to the combustion process equation, as follows.

In the stoichiometric mixture without nitrogen and 10% N₂ mixture, the addition of 10% N₂ was taken from the percentage amount of CH₄. So that the percentage amount of CH₄ becomes 90%. The composition of CH₄ and air must remain stoichiometric, so it can be described as the reaction equation below.



$$AFR = \frac{18(1 + 3.76)}{9} = \frac{85.68}{9} \rightarrow \frac{\text{moles of air}}{\text{moles of methane gas}}$$

In this study, it is known that the length of the combustion chamber is 50 cm. By using a comparison, the volume of the mixture for each composition in the combustion process can be found:

$$\frac{\text{number of mole}}{1} = \frac{\text{the length of combustion chamber}}{x}$$

$$\begin{aligned} \text{number of mole} &= (\text{moles of air}) + (\text{moles of CH}_4) + (\text{moles of N}_2) \\ &= 85.68 + 9 + 1 \\ &= 95.68 \end{aligned}$$

Then, the comparative value is,

$$\frac{95.68}{1} = \frac{50}{x}$$

$$x = \frac{50}{95.68} = 0.5226$$

$$N_2 = 1 \times 0.5226 = 0.5226$$

$$CH_4 = 9 \times 0.5226 = 4.7$$

$$Air = 85.68 \times 0.5226 = 44.775$$

Table 1. Methane-Air Volume and Nitrogen Percentage in each Combustion Process

Volume	Nitrogen Percentage (N ₂)				
	10%	20%	30%	40%	50%
N ₂	0.5226	1.16	1.96	2.98	4.34
CH ₄	4.7	4.64	4.564	4.47	4.34
Air	44.775	44.17	43.38	42.55	41.317

The percentage of the stoichiometric mixture without nitrogen and N₂ 10% - N₂ 60% can be seen in table 1. After knowing the amount of composition in each mixing variation, CH₄, N₂ and air are fed alternately through the valve according to the scale in the combustion chamber to obtain the ratio of CH₄, N₂ and specific air to be tested. The entry of CH₄, N₂ and compressed air will push the water in the combustion chamber down to the set scale limit and the water will come out through the hose to fill the overflow tube which is on the side. After the combustion chamber is filled with a mixture of CH₄, N₂ and air, the camera is turned on. The lighter button is pressed until the fire ignites. Image of combustion chamber flame propagation was taken. After the image of the flame propagation is recorded, the camera is then turned off and the remaining combustion gas in the combustion chamber is removed by opening the top valve. Then the steps as above were carried out for each variation in the ratio of the mixture of CH₄, N₂ and air.

The recordings from the MOV file video camera are transferred to the computer and converted into AVI files. Then edit the recording to take a video of only the combustion process, so that the burning time of each explosion can be known. From a moving image, it is extracted into a still image in several frames that are arranged sequentially from the first light up until it turns off.

Each variation of the Stoichiometric N₂ mixture comparison will display an image of different shapes and propagation patterns in each frame. From the results of this image, measurements of the distance of each frame flame using ImageJ software. The camera speed used is 25 frames/second, therefore the time required for one frame is 1/25 second. Thus, the speed of flame propagation can be obtained by dividing the distance of the flame in each frame by time. By using Excel software, the overall rate of flame propagation pattern is obtained.

3. RESULT AND DISCUSSION

In Figure 2 shows the number of flame propagation on stoichiometry = 9 frames (not mixed with N₂) and a maximum speed of 2900 mm/s at 0.04 seconds. The number of flame propagation on stoichiometry-N₂ 10% = 9 frames and a maximum speed of 2233.33 mm/s at 0.12 seconds. The number of flame propagation on stoichiometry-N₂ 20% = 19 frames and a maximum speed of 1525.00 mm/s at 0.04 seconds. The number of flame propagation on stoichiometry-N₂ 30% = 17 frames and the maximum speed is 1700.18 mm/s at 0.04 second. The number of flame propagation on stoichiometry-N₂ 40% = 14 frames and a maximum speed of 2025.00 mm/s at 0.04 seconds. The number of flame propagation on stoichiometry-N₂ 50% = 12 frames and a maximum speed of 950.00 mm/s at 0.04 seconds and the number of flame propagation on stoichiometry-N₂ 60% = 8 frames and a maximum speed of 775.40 mm/s at 0.04 seconds.

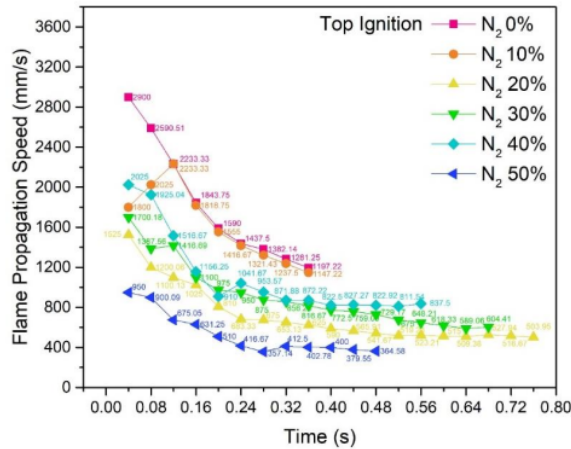


Figure 2. Flame Propagation Speed Graph of Stoichiometric Mixture - Nitrogen on Top Ignition Condition

The average velocity of flame propagation in the stoichiometric-N₂ mixture occurs at 0.04 seconds or in the first frame, this is due to the maximum heat from the reaction of the combustion process. The highest velocity of midpoint flame propagation on top ignition at stoichiometric mixing-N₂ 10% = 2233.33 mm/s. In addition, Figure 2 shows the graph of N₂ 10% top ignition has a similar speed in the stoichiometric N₂ 0% sample condition even though at the initial 0.04 seconds it has a susceptibility of 1100 mm/s which is quite far. A unique thing happened between 20-50% N₂ samples, where the highest peak occurred in 40% N₂ samples. In this case, it indicates that the ignition of a mixture of CH₄ and N₂ 40% is much more efficient than N₂ 20, 30, and 50%.

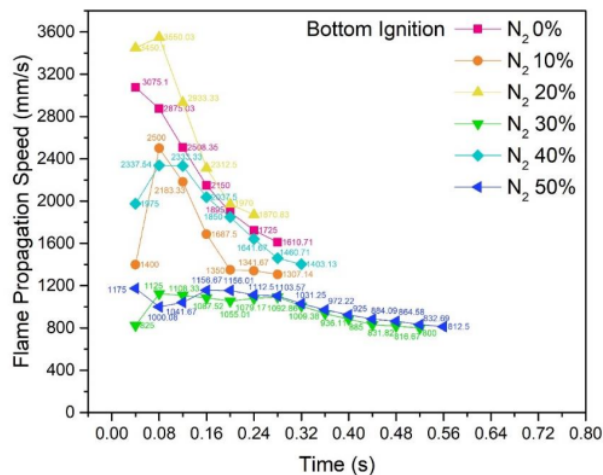


Figure 3. Flame Propagation Speed Graph of Stoichiometric Mixture - Nitrogen on Bottom Ignition Condition

Figure 3 shows the number of flame propagation on stoichiometry = 7 frames (not mixed with N₂) and a maximum speed of 3075 mm/s at 0.04 seconds. The number of flame propagation on stoichiometry-N₂ 10% = 7 frames and a maximum speed of 2500.00 mm/s at 0.08 seconds. The number of flame propagation on stoichiometry-N₂ 20% = 6 frames and a maximum speed of 3550.03 mm/s at 0.08 seconds. The number of flame propagation on stoichiometry-N₂ 30% = 13 frames and a maximum speed of 1125.00 mm/s at 0.08 seconds. The number of flame propagation on stoichiometry-N₂ 40% = 8 frames and a

maximum speed of 2337.54 mm/s at 0.08 seconds. The number of flame propagation on stoichiometry-N₂ 50% = 14 frames and a maximum speed of 1175.00 mm/s at 0.04 seconds.

The average velocity of flame propagation in the stoichiometric-N₂ mixture occurs at 0.08 seconds or in the second frame, this is due to the maximum heat and buoyancy from the reaction of the combustion process. The greatest velocity of propagation of flame at the midpoint on Stoichiometric-N₂ mixing 20% = 3550.03 mm/s. In addition, in Figure 3 the graph N₂ 20% lower ignition shows great results. Where N₂ 20% has a flame propagation speed that is much greater than the stoichiometric sample condition N₂ 0% with susceptibility of 370 mm/s. This uniqueness occurs because Nitrogen, which should act as an inhibitor, turns into Nitrogen Oxides, which has the opposite role of inhibitors, namely activators. The creation of Nitrogen Oxide occurs in certain conditions depending on the design of the combustion chamber, the amount of nitrogen content in the fuel, and the operating conditions in the combustion chamber [18]. Whereas the mechanism for the formation of NO_x can occur in 4 ways, namely thermal NO_x formation, prompt NO_x, Nitrous Oxide, and Fuel NO_x.

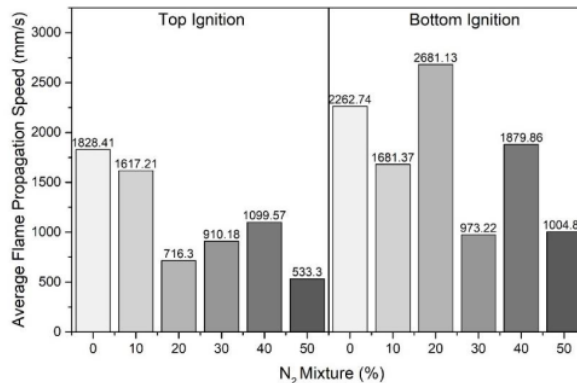


Figure 4. Average Flame Propagation Speed Graph of Stoichiometric Mixture - Nitrogen on Top dan Bottom Ignition Condition

This indicates that at bottom ignition the 20% CH₄ and N₂ mixture is much more efficient than the whole sample. While the 40% N₂ sample almost matches the condition of the 0% stoichiometric sample N₂ and can exceed the 10% N₂ sample which previously in the under-ignition experiment the speed was below it. Based on these data, the bottom ignition experiment was able to maximize the propagation speed of the flame in the N₂ sample by 20%.

The overall mean when compared between the top ignition and the bottom ignition is shown in Figure 4, all samples have an increase in the bottom ignition compared to the top ignition. The largest increase occurred in the 20% N₂ sample with susceptibility 1964.83 mm/s. Then followed by a sample of N₂ 40% which experienced an increase of 780.29 mm/s at the bottom ignition. Thus, it can be concluded that the bottom ignition can maximize the rate of propagation of the flame in all samples.

4. CONCLUSION

The velocity of flame propagation in the midpoint of the mixture of stoichiometry (methane-air) and Nitrogen (N₂) at the top ignition is 2233.33 mm/s at N₂ 10% of the third frame and at lower ignition, the speed is 3550.03 mm/s at N₂ 20% of the second frame. Thus, in this study, it can be concluded that, not always the higher the percentage of nitrogen will reduce the speed of propagation of the flame. In addition, the bottom ignition experiment has a very large effect on maximizing the speed of flame propagation, especially in the 20% N₂ sample. Therefore, in this study, the highest improvement in combustion efficiency is obtained by using a 20% N₂ mixture and at the bottom ignition condition.

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