JEMMME (Journal of Energy, Mechanical, Material, and Manufacturing Engineering)
Vol.6, No. 2, 2021

ISSN 2541-6332 | e-ISSN 2548-4281
Journal homepage: http://ejournal.umm.ac.id/index.php/JEMMME

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 (N_2) on the top ignition is 2233.33 mm/s at N_2 10% of the third frame and at lower ignition, the speed is 3550.03 mm/s at N_2 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% N_2 sample. Therefore, the highest improvement in combustion efficiency is obtained by using a 20% N_2 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 gas. 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 CH_4 remains stoichiometric [13]–[16] (9.5:1). Meanwhile, the dependent variable is the velocity of the flame propagation pattern in the midpoint.

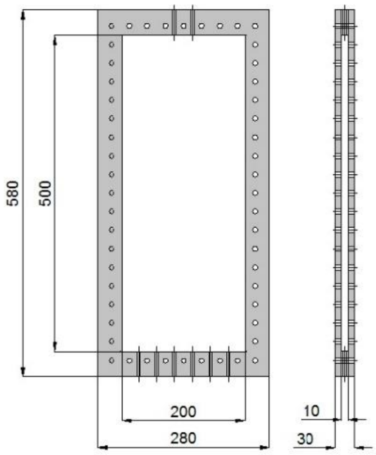

Figure 1. Dimensions of Helle Shaw Cell

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% N_2 mixture, the addition of 10% N_2 was taken from the percentage amount of CH_4. So that the percentage amount of CH_4 becomes 90%. The composition of CH_4 and air must remain stoichiometric, so it can be described as the reaction equation below.

$$N_2+9CNH_4+18(O_2+3.76N_2) \rightarrow CO_2+2H_2O+(1+7.52)N_2$$

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

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:

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

$$\begin{aligned} number\ of\ mole &= (moles\ of\ air) + (moles\ of\ CH_4) + (moles\ of\ N_2) \\ &= 85.68 + 9 + 1 \\ &= 95.68 \end{aligned}$$

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 N_2 10% - N_2 60% can be seen in table 1. After knowing the amount of composition in each mixing variation, CH_4, N_2, and air are fed alternately through the valve according to the scale in the combustion chamber to obtain the ratio of CH_4, N_2 and specific air to be tested. The entry of CH_4, N_2, 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 CH_4, N_2, 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 CH_4, N_2, 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 N_2 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 N_2) and a maximum speed of 2900 mm/s at 0.04 seconds. The number of flame propagation on stoichiometry-N_2 10% = 9 frames and a maximum speed of 2233.33 mm/s at 0.12 seconds. The number of flame propagation on stoichiometry-N_2 20% = 19 frames and a maximum speed of 1525.00 mm/s at 0.04 seconds. The number of flame propagation on stoichiometry-N_2 30% = 17 frames and the maximum speed is 1700.18 mm/s at 0.04 second. The number of flame propagation on stoichiometry-N_2 40% = 14 frames and a maximum speed of 2025.00 mm/s at 0.04 seconds. The number of flame propagation on stoichiometry-N_2 50% = 12 frames and a maximum speed of 950.00 mm/s at 0.04 seconds and the number of flame propagation on stoichiometry-N_2 60% = 8 frames and a maximum speed of 775.40 mm/s at 0.04 seconds.

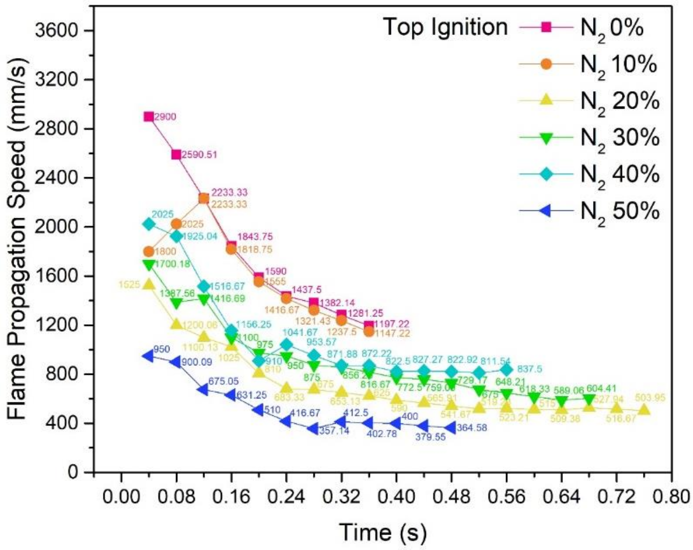

Figure 2. Flame Propagation Speed Graph of Stoichiometric Mixture - Nitrogen on Top Ignition Condition

The average velocity of flame propagation in the stoichiometric-N_2 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-N_2 10% = 2233.33 mm/s. In addition, Figure 2 shows the graph of N_2 10% top ignition has a similar speed in the stoichiometric N_2 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% N_2 samples, where the highest peak occurred in 40% N_2 samples. In this case, it indicates that the ignition of a mixture of CH_4 and N_2 40% is much more efficient than N_2 20, 30, and 50%.

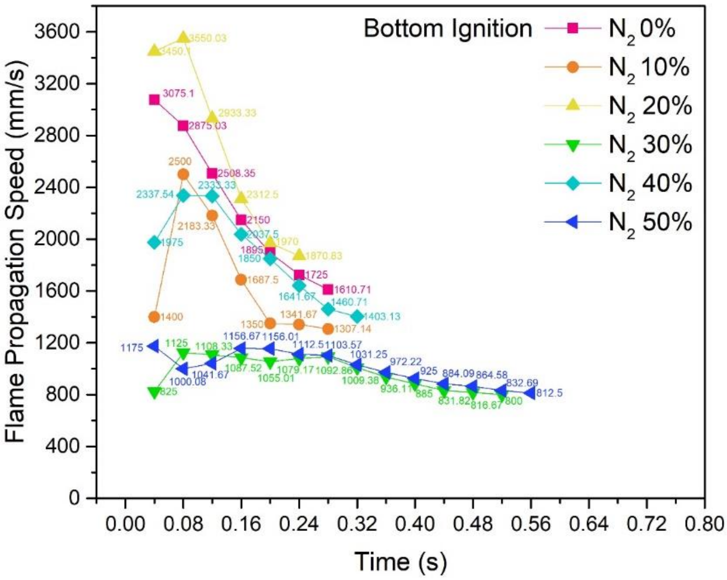

Figure 3. Flame Propagation Speed Graph of Stoichiometric Mixture - Nitrogen on Bottom Ignition Condition

Figure 3 shows the number of flame propagation on stoichiometry = 7 frames (not mixed with N_2) and a maximum speed of 3075 mm/s at 0.04 seconds. The number of flame propagation on stoichiometry-N_2 10% = 7 frames and a maximum speed of 2500.00 mm/s at 0.08 seconds. The number of flame propagation on stoichiometry-N_2 20% = 6 frames and a maximum speed of 3550.03 mm/s at 0.08 seconds. The number of flame propagation on stoichiometry-N_2 30% = 13 frames and a maximum speed of 1125.00 mm/s at 0.08 seconds. The number of flame propagation on stoichiometry-N_2 40% = 8 frames and a maximum speed of 2337.54 mm/s at 0.08 seconds. The number of flame propagation on stoichiometry-N_2 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-N_2 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-N_2 mixing 20% = 3550.03 mm/s. In addition, in Figure 3 the graph N_2 20% lower ignition shows great results. Where N_2 20% has a flame propagation speed that is much greater than the stoichiometric sample condition N_2 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.

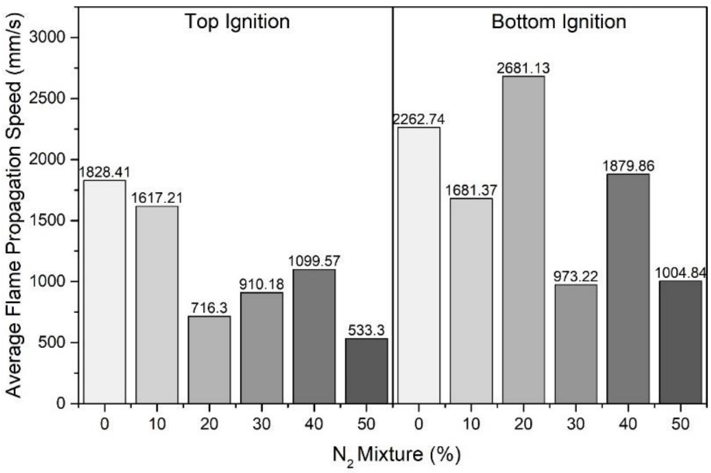

Figure 4. Average Flame Propagation Speed Graph of Stoichiometric Mixture - Nitrogen on Top dan Bottom Ignition Condition

This indicates that at bottom ignition the 20% CH_4 and N_2 mixture is much more efficient than the whole sample. While the 40% N_2 sample almost matches the condition of the 0% stoichiometric sample N_2 and can exceed the 10% N_2 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 N_2 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% N_2 sample with susceptibility 1964.83 mm/s. Then followed by a sample of N_2 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 (N_2) at the top ignition is 2233.33 mm/s at N_2 10% of the third frame and at lower ignition, the speed is 3550.03 mm/s at N_2 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% N_2 sample. Therefore, in this study, the highest improvement in combustion efficiency is obtained by using a 20% N_2 mixture and at the bottom ignition condition.

REFERENCES

1. K. Hu, J. Wu, and M. Liu, 2018. Exploring the Energy Efficiency of Electric Vehicles with Driving Behavioral Data from a Field Test and Questionnaire, *Journal of Advanced Transportation*, vol. 2018, pp. 1–14, 2018, doi: https://doi.org/10.1155/2018/1074817.
2. A. E. Pg Abas, J. Yong, T. M. I. Mahlia, and M. A. Hannan, 2019.Techno-economic analysis and environmental impact of electric vehicle, *IEEE Access*, vol. 7, pp. 98565–98578, 2019, doi: https://doi.org/10.1109/ACCESS.2019.2929530.
3. K. Hu, J. Wu, and T. Schwanen, 2017.Differences in energy consumption in electric vehicles: An exploratory real-world study in Beijing, *Journal of Advanced Transportation*, vol. 2017, p. 17, 2017, doi: https://doi.org/10.1155/2017/4695975.
4. J. Morgan, 2020.Electric vehicles: The future we made and the problem of unmaking it, *Cambridge Journal of Economics*, vol. 44, no. 4, pp. 953–977, 2020, doi: https://doi.org/10.1093/cje/beaa022.
5. P. Puspitasari, A. A. Permanasari, M. S. Shaharun, and A. Muhammad, 2020.High saturation superparamagnetic properties of low-temperature sintering of nickel oxide, *AIP Conference Proceedings*, vol. 2228, no. April, 2020, doi: https://doi.org/10.1063/5.0000884.
6. D. Kustono, P. Puspitasari, and A. Muhammad, 2019.Time Dependence on Magnetic Properties of Nanomaterial, pp. 361–370, 2019.
7. A. Muhammad, P. Puspitasari, and Andoko, 2019.Properties of soft magnetic material SmCo5 synthesized using low-temperature sol-gel method, *AIP Conference Proceedings*, vol. 2120, no. 1, p. 50008, Jul. 2019, doi: https://doi.org/10.1063/1.5115684.
8. P. Puspitasari, A. Muhammad, H. Suryanto, and A. Andoko, 2018.Determination of The Magnetic Properties of Manganese Ferrite by The Coprecipitation Method at Different Ph Concentrations, *High Temperature Material Processes: An International Quarterly of High-Technology Plasma Processes*, vol. 22, pp. 239–248, 2018.
9. W. Anggono, F. D. Suprianto, K. Purnomo, T. I. Hartanto, and T. P. Wijaya, 2016.The Effect of Nitrogen on Flame Characteristics in Biogas External Premixed Combustion, *Applied Mechanics and Materials*, vol. 836, pp. 265–270, 2016, doi: https://doi.org/10.4028/www.scientific.net/AMM.836.265.
10. S. Sukarni, A. E. Widiono, R. Wulandari, A. Prasetiyo, and P. Puspitasari, 2020.Thermogravimetric Study on the Thermal Characteristics of Tetraselmis chuii Microalgae Pyrolysis in the Presence of Titanium dioxide, *Key Engineering Materials*, vol. 851, pp. 156–163, 2020, doi: https://doi.org/10.4028/www.scientific.net/KEM.851.156.
11. D. Kurniawati and I. S. Aisyah, 2020.The Potent of Carrier Oil on Pretreatment of Crude Jatropha Curcas Oil, *Journal of Energy, Mechanical, Material, and Manufacturing Engineering*, vol. 5, no. 1, p. 45, 2020, doi: https://doi.org/10.22219/jemmme.v5i1.12336.
12. W. Anggono, F. D. Suprianto, T. I. Hartanto, K. Purnomo, and T. P. Wijaya, 2016.The effect of nitrogen on biogas flame propagation characteristic in premix combustion, *AIP Conference Proceedings*, vol. 1718, no. 2006, pp. 3–8, 2016, doi: https://doi.org/10.1063/1.4943345.
13. S. Minhang, Z. Lingyan, L. Xiaoguang, C. Zhichao, and L. Zhengqi, 2017.Effect of Stoichiometric Ratio of Fuel-Rich Flow on Combustion Characteristics in a Down-Fired Boiler, *Journal of Energy Engineering*, vol. 143, no. 3, p. 4016058, Jun. 2017, doi: https://doi.org/10.1061/(ASCE)EY.1943-7897.0000415.
14. A. P. W. and Y. T. Noor, M. M., M. M. M. Noor, A. P. Wandel, and T. Yusaf, 2013. The Air Fuel Ratio Study for the Mixture of Biogas and, *International Journal of Automotive and Mechanical Engineering*, vol. 10, no. July, pp. 61–72, 2013, doi: : http://dx.doi.org/10.15282/ijame.10.2014.29.0180.
15. S. E. Shcheklein and A. M. Dubinin, 2018.Stoichiometric analysis of air oxygen consumption in modern vehicles using natural and synthetic fuels, *IOP Conference Series: Earth and Environmental Science*, vol. 177, no. 1, 2018, doi: https://doi.org/10.1088/1755-1315/177/1/012020.
16. C. Mokrane, B. Adouane, and A. Benzaoui, 2018.Composition and stoichiometry effects of biogas as fuel in spark ignition engine, *International Journal of Automotive and Mechanical Engineering*, vol. 15, no. 1, pp. 5036–5052, 2018, doi: https://doi.org/10.15282/ijame.15.1.2018.11.0390.
17. H. Saroso, I. N. G. Wardana, R. Soenoko, and N. Hamidi, 2014.Premixed combustion of coconut oil in a hele-shaw cell, *International Journal of Renewable Energy Development*, vol. 3, no. 3, pp. 155–160, 2014, doi: 10.14710/ijred.3.3.155-160.
18. N. Kamiuchi and K. Eguchi, 2012.Catalytic combustion of methane, *Catalysis for Alternative Energy Generation*, vol. 9781461403, pp. 305–327, 2012, doi: https://doi.org/10.1007/978-1-4614-0344-9_8.