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The Effect of Nitrogen on Biogas Flame Propagation Characteristic in Premix Combustion

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Abstract Biogas is one of alternative energy and categorized as renewable energy. The main sources of biogas come from animal waste, garbage, and household waste that are organic waste. Primarily, over 50% of this energy contains methane (CH_4). The other substances or inhibitors are nitrogen and carbon dioxide. Previously, carbon dioxide effect on biogas combustion is already experimented. The result shows that carbon dioxide reduces the flame propagation speed of biogas combustion. Then, nitrogen as an inhibitor obviously also brings some effects to the biogas combustion, flame propagation speed, and flame characteristics. Spark ignited cylinder is used for the premixed biogas combustion research. An acrylic glass is used as the material of this transparent cylinder chamber. The cylinder is filled with methane (CH_4), oxygen (O_2), and nitrogen (N_2) with particular percentage. In this experiment, the nitrogen composition are set to 0%, 5%, 10%, 20%, 30%, 40%, and 50%. The result shows that the flame propagation speed is reduced in regard to the increased level of nitrogen. It can also be implied that nitrogen can decrease the biogas combustion rate.

Keywords: Biogas, flame propagation, nitrogen, premix combustion, sustainable energy.

INTRODUCTION

Biogas as a source of alternative energy is categorized as renewable energy. Biogas consists of several chemical substances such as flammable methane gas (CH_4), carbon dioxide (CO_2), and nitrogen (N_2) [1-8]. Nitrogen in this compound behaves as an inhibitor. Inhibitors are resulting in reducing the laminar burning velocity [1-5].

This research is conducted to see the effects of flame propagation speed, and flame characteristics of biogas combustion. Flame characteristics are useful to create several biogas combustion applications particularly for internal combustion. One of the flame characteristics is laminar burning velocity. The laminar burning velocity directly affects the pressure development. Hence, it is used to understand the combustion process in the internal combustion engine for reducing the emissions. The experiment is conducted in both room temperature and atmospheric condition using stoichiometric standards. Stoichiometric standard is a state where the fuel is ideally and completely burnt. This experiment is conducted at known rates of pressure, temperature, and volume so that ideal gas can be assumed to this experiment. Then, molar mass of each gas is used to calculate the mass ratio [9-13].

Flame propagation plays a crucial role in the success of combustion ignition. For example, the data of flame speed is used to determine the internal combustion chamber material and other parts that are connected to the chamber. Theoretically, during the methane explosion, the biogas combustion products compress the medium in front of the flame front surface also create a compression wave caused by the chemical reaction, the flame propagates very quick. As the result, the density, pressure and temperature sharply rises to form a detonation wave [14-15].

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EXPERIMENTAL SETUP AND METHODS

The combustion chamber from transparent acrylic cylinder with 300 mm of height and 70 mm of outer diameter was used in this experiment. The thickness of this acrylic cylinder is 5 mm thus the inner diameter is 60 mm. The schematic diagram of the combustion bomb system is shown in Figure 1.

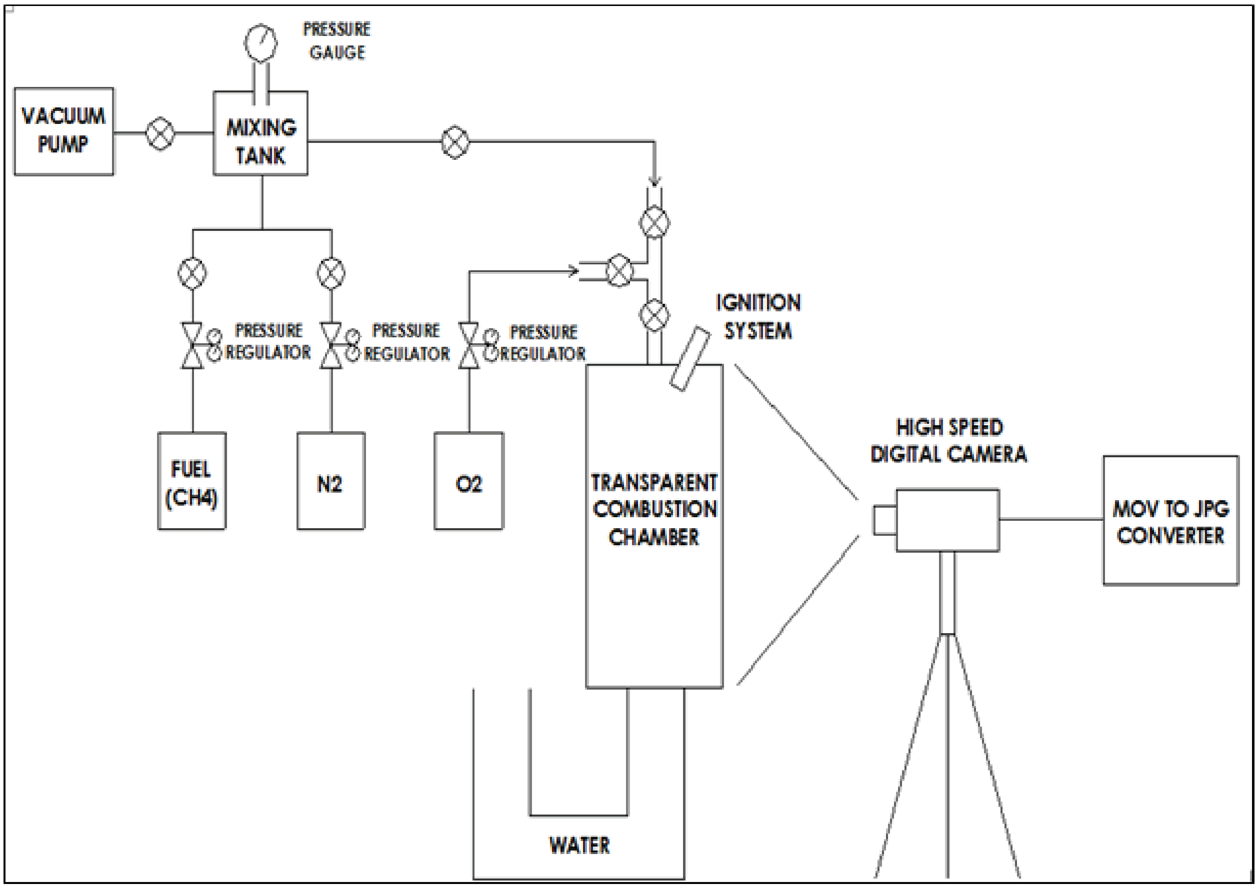

FIGURE 1. Experimental setup diagram

The combustion chamber is filled with premixed fuel-air with various nitrogen contents in biogas. This experiment is conducted in room temperature, atmospheric condition and stoichiometric standard (ϕ=1). High speed camera was used to record the all combustion process. Then, the video is converted to obtain the picture files so that the flame propagation speed differences can be measured.

RESULT AND DISCUSSION

The biogas combustion experiment had already been done by the presence of specific nitrogen inhibitor as stated before. These pictures have differences each other related to the nitrogen composition. In figure 2, there are 2 pictures for each nitrogen composition. Those 2 pictures show the first and second frame of the video which the combustion occurs.

From the pictures in figure 2, it can be seen that picture 1 is the pure methane combustion result without nitrogen inhibitor on it. Then, picture 7 is biogas combustion result that contains the most nitrogen inhibitor. Undoubtedly, it also showed that there is flame length different gradient from picture 1 to 7. Picture 1 have the biggest biogas flame length difference but on the other hand, picture 7 have the shortest biogas flame length difference which contains 50% of nitrogen inhibitor. The higher nitrogen (N2) inhibitor compositions in biogas combustion, the shorter biogas flame length difference result.

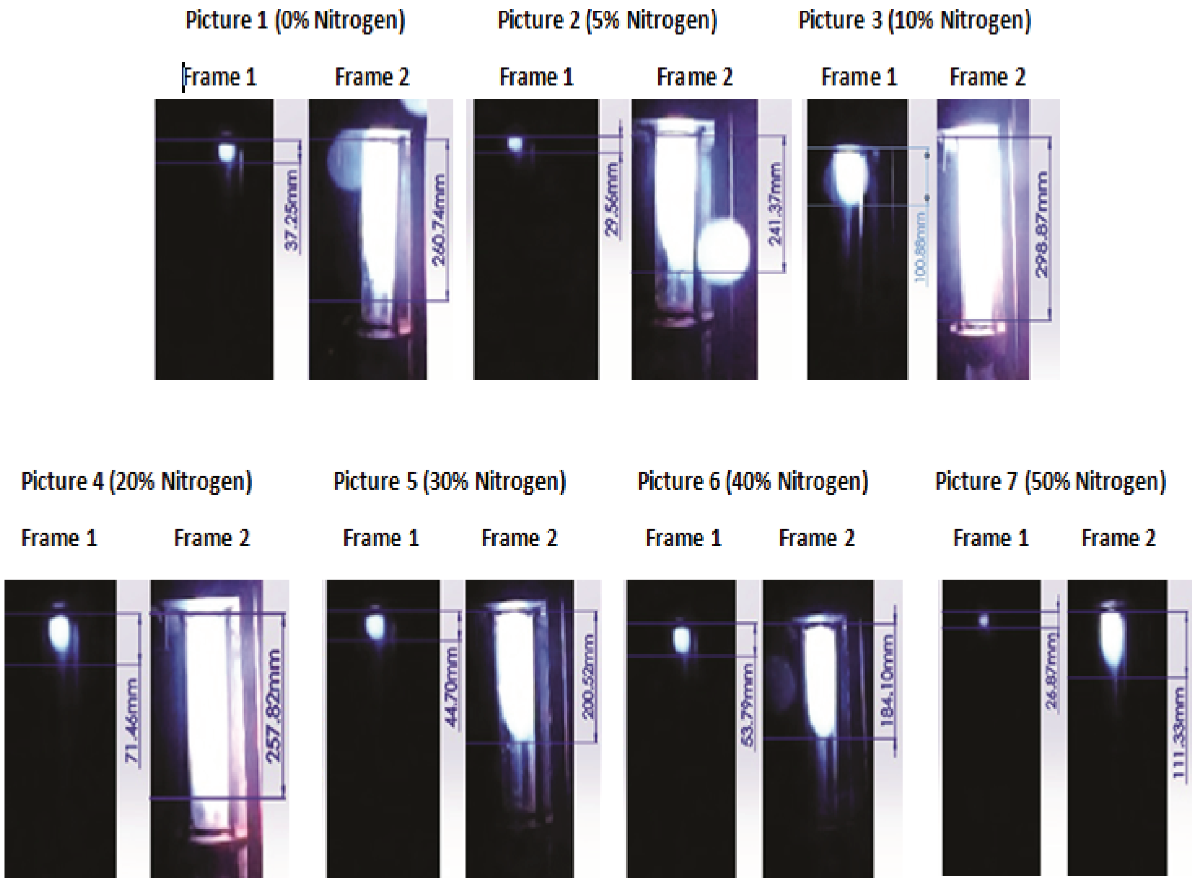

FIGURE 2. Biogas flame propagation

TABLE 1. Biogas flame propagation speed

Picture Number	N_2 (%)	Frame 1 (mm)	Frame 2 (mm)	Frame 2 – Frame 1 (mm)	Flame Diffusion Speed (m/s)
1	0	37.25	260.74	223.49	6.77
2	5	29.56	241.37	211.81	6.42
3	10	100.88	298.87	197.99	6.00
4	20	71.46	257.82	186.36	5.65
5	30	44.70	200.52	155.82	4.72
6	40	53.79	184.10	130.31	3.95
7	50	26.87	111.33	84.46	2.56

The results of biogas combustion flame are measured for every nitrogen (N_2) composition and the length of the biogas flame can be obtained. The flame recording time is also determined at the same time which is in the first and second frame after the flame appears in the video. The biogas flame propagation speed that had already been experimented is shown in Table 1. First, the 0% biogas addition delivers the fastest flame propagation speed which is 6.77 m/s. Then, flame propagation speed is reduced based on the nitrogen inhibitor enhancement to the biogas combustion. The flame propagation speed of 5%, 10%, 20%, 30%, and 40% nitrogen inhibitors are 6.42 m/s, 6.00 m/s, 5.65 m/s, 4.72 m/s, and 3.95 m/s respectively. Eventually, the latest flame propagation speed is 2.56 m/s which have 50% of nitrogen inhibitor in the reactant.

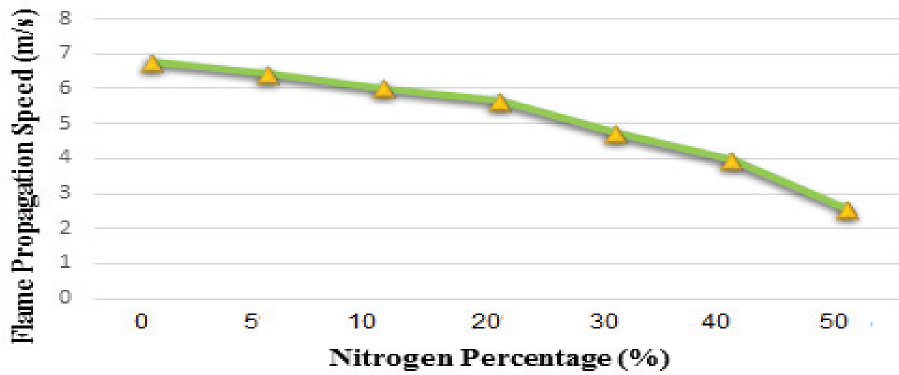

FIGURE 3. The effects of nitrogen inhibitor on flame propagation speed

Figure 3 shows that trend of flame propagation speed is declining corresponding to the addition of nitrogen inhibitor. Nitrogen as biogas inhibitor has the ability to reduce the oxidation chemical reaction during the combustion. The existence of nitrogen here also reduces the amount of methane as the primary fuel so that the flame propagation speed is hampered and becomes slower. Furthermore, the reactive compounds in this reaction are also reduced with the nitrogen addition.

CONCLUSION

The biogas combustion which contain specific methane (CH_4), oxygen (O_2), and nitrogen (N_2) had already been done in spark ignited combustion chamber. The transparent acrylic chamber is used to represent combustion process in internal combustion engine. The nitrogen inhibitor is ranged from 0% to 50% using stoichiometric standard (ϕ=1). The flame propagation speed with 0% of nitrogen inhibitor has 6.77 m/s of propagation speed. Contrarily, the flame propagation speed of the most nitrogen inhibitor (50%) is 2.56 m/s. The result indicates that nitrogen inhibitor in biogas reduces combustion rate. The more nitrogen concentration in the chemical reaction proportion also cuts down the methane (CH_4) fuel amount. If the combustion rate decreased, the thermodynamics efficiency of internal combustion engine application would decline as well. Hence, flame propagation speeds play a crucial role in the success of combustion ignition.

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