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THE EFFECT OF CO_2 FRACTION ON THE FLAME STABILITY OF BIOGAS PREMIXED FLAME

Mega Nur Sasongko and Widya Wijayanti
Mechanical Engineering, University of Brawijaya Jalan Mayjend Haryono Malang, East Java, Indonesia
E-Mail: megasasongko@ub.ac.id

ABSTRACT

This study aimed to determine the effect of CO_2 on flame structure and stability of premixed flames biogas using counterflow flame configuration. In this research, the CO_2 fraction in Biogas was varied from 0% to 50%. The total mass flow of gas flowed from both combustion nozzle was varied within 6 L / min and 8 L / min. The burning behavior of biogas counterflow flames were photographed by digital camera. Besides, the stability limit of counterflow diffusion flame was characterized by the minimum oxygen concentration at extinction. The results showed that the CO_2 content in the biogas affect the characteristics of premixed flame, especially the change of a blue flame to blue flame with lower luminosity when increasing CO_2 concentration. On the other hand, the variation in the oxygen concentration has more significant effect on the dimension of the premixed flame compared to the effects of the CO_2 content in the biogas. The flash back phenomena exist in the counterflow premixed flame when the equivalence ratio of reactant closes to 1. It means that the biogas combustion is recommended to be done in the equivalence ratio close to 1 in order to obtain the best combustion performance. The results also showed that the highest concentration of oxygen minimum to keep the biogas premixed flame remained stable occurred in the percentage of CO_2 in the biogas is 30%. This result could be explained based on the composition of unburned CH_4 and CO_2 gas in the combustion process.

Keywords: biogas, premixed flame, CO_2 fraction, counterflow configuration, flame stability.

INTRODUCTION

Nowadays, the utilization of Biogas as one of the potential fuel for fossil fuel replacement is gaining increased public attention. Biogas is cheap and renewable energy source because it is produced from organic waste like garbage, food scraps, manure and industrial waste. The main composition of Biogas is commonly methane (CH_4) and CO_2, with small amount of other substances such as hydrogen sulphide, moisture and siloxanes. The presence of CO_2 in the biogas (ranges from 30 % to 60 %) have many negative effect in combustion processes. For instance, it will significantly reduce the heating value of combustion. The present of CO_2 will be dropped the calorific value of fuel results in the lowering combustion energy generated from the combustion process [1-2]. Moreover, CO_2 has a high specific heat so that some of the heat of combustion will be absorbed by these substances. Negative effect due to the presence of CO_2 in the biogas cannot be avoided. Therefore, the application of biogas directly in energy conversion machines still need comprehensive review on the characteristics of the biogas combustion process in more detail. A next challenge is to find new methods in the combustion process that can minimize the effect of CO_2 on the performance of combustion.

Porpathan [3] investigated performance of spark combustion engine using biogas as a fuel. His research showed that CO_2 on the Biogas affected the engine performance. The engine will significantly improve its performance when the CO_2 content reduced 41% to 20%. Besides, the level of emissions of hydrocarbons HC and NO reduced with decreasing the CO_2 content. The application of Biogas as a fuel on the diesel engine also have the same tendency. The thermal efficiency of diesel engine reduced with increasing the concentration CO_2 in the Biogas [4]. However, the application of biogas in diesel engine operating on HCCI mode showed more promising results. The thermal efficiency of diesel engines in HCCI mode using biogas fuel approached the same value with the efficiency of fossil fuel diesel engines.

This study presents an experimental investigation of the premixed combustion of Biogas. Counterflow premixed flame configuration is used as a method to investigate more detail the effect of CO_2 on the burning behaviour and the flame stability limit of Biogas. Counterflow configuration technique is one of a convenience configuration to study the combustion model. The phenomenon of one-dimensional counterflow flame configuration is very suitable for studying the structure of the flame due to the influence of the type of content of the fuel, the mass flow (AFR) and the characteristics of the fuel reactant fuel and oxidizer [5,6,7]. This study is expected to provide a new improvement of biogas combustion model in practical application

EXPERIMENTAL METHOD

Figure-1 shows the counterflow burner configuration used in this research. The burner consists of two concentric double cylinders were mounted opposite each other. In the premixed flame experiment, the fuel and oxidizer have been mixed before it reaches the flame front. Accordingly, CH_4 and CO_2 gases as a main component of

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Biogas were mixed with oxygen and flowed together from the lower inner duct while the nitrogen stream was supplied from the upper inner duct to keep the fuel flow momentum and inert gas is in balanced conditions. Counterflow premixed flame was established in the stagnation region between the two streams. In conformity, Co flows of nitrogen were supplied from both outer ducts to suppress the shear between the gas from the inner duct and the ambient gas. Both of the inner cylinders had an inner diameter of 23 mm and a length of 700 mm. The inner diameter and length of the outer cylinder were 40 and 300 mm. The separation distance between the two duct exits was set at 2 cm.

In this research, the concentration of CO_2 in Biogas was varied from 0% to 50%. The total mass flow of gas flowed from both combustion nozzle was varied within 6 L / min and 8 L / min. The flow rate of all supplied gases to the counterflow burner was controlled by 8 pieces of flowmeter where configured as research scheme in Figure-1.

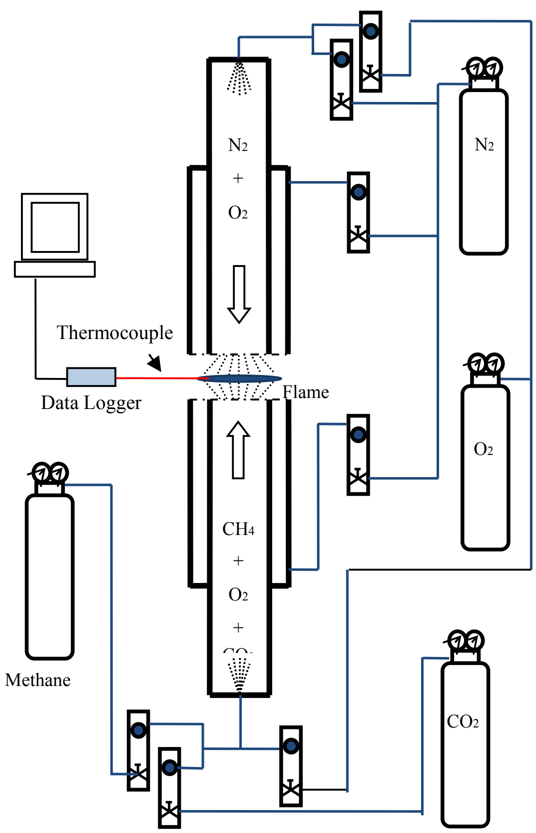

Figure-1. Experimental apparatus.

K type of thermocouple was used to measure the temperature of the flame and surrounding. Thermocouples were connected to a data logger and the position of the thermocouple could be controlled automatically by a stepping motor system. The burning behavior of biogas counterflow flames were photographed by digital camera (NIKON D5000). The camera was placed 20 cm from the center of the flame in horizontal position with flame. Besides, the stability limit of counterflow premixed flame was characterized by the minimum oxygen concentration at extinction. Using the data of the minimum oxygen concentration for all variation of CO_2 concentration, it will describe the stability limit of biogas combustion with variation of CO_2 contents in the fuel.

RESULT AND DISCUSSIONS

Burning Behaviour

Figure-2 shows a typical photographs of biogas premixed flame without CO_2 mixture at oxygen concentrations of 20% and 40%. The shape of biogas premixed was very stable and closer to the flat condition or envelope flame, which is represent the characteristic of counterflow flame. At different oxygen concentrations, the premixed flame was seen to be wider at higher oxygen concentrations. More details about the premixed flame characteristics for different CO_2 fraction can be explained in Figures-3.

Figure-2. Visualization of counterflow premixed flame.

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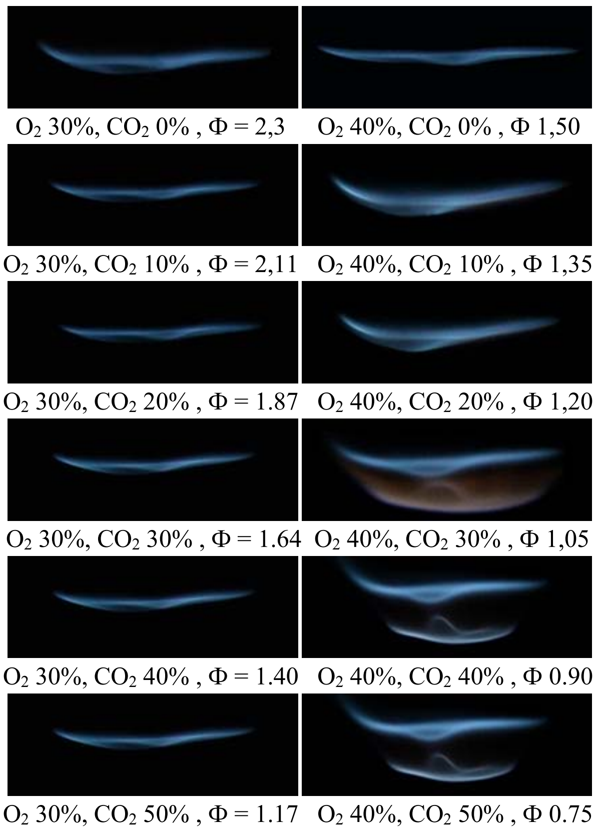

Figure-3. Photographs of premixed flame for oxygen concentration 30 % and 40 %.

Figure-3 displays a photograph of burning behaviour of biogas premixed flame for the oxygen concentration of 30% and 40 % and the total reactant flow rate of 6 L/min. The concentration of CO_2 was varied from 0 % to 40 %. For oxygen concentration of 30%, it appears that the increasing of CO_2 did not show a significant difference in the colour of flame. However, the flame colour tends to fade from blue to blue with weaker intensity when increasing the CO_2 content. The same trend is also observable in the oxygen concentration of 40%, where the flame colour is also dominated by a blue flame with weaker intensity. The oxygen concentration in the fuel did not much effect on the flame colour, but more effected on the width of the counter flow premix flame. The flame width becomes wider along with the additional oxygen percentage. This is because with a higher supply of oxygen, more fuel will be able to burn out completely and widen the premixed flame area. On the other hand, when the oxygen is reduced, the reactants mixture will occur on the condition of rich fuel. So, the more unburned fuel will become an obstacle to the combustion process.

CO_2 in the fuel mixture also showed a significant effect on the width of premixed flame. The formation of flame width decreases along with the increasing of CO_2 fraction. The nature properties of CO_2 as an inhibitor in the combustion process will absorb some heat from the combustion results in the decreasing flame temperature. Low flame temperature flame will lead to the lowering the rate of combustion reaction.

The Interesting phenomenon on the burning behaviour of counterflow premixed flame is seen in the Figure for the oxygen concentration of 40%. The flash back occurred when the concentration of CO_2 more than 30%. In this phenomenon, the counterflow premixed flame moves down towards the end of the burner. The flash back occurs because the combustion speed is greater than the reactants flow rate, so that this imbalance condition causes a fire to be moving towards the reactant stream. In this study, the flash back only occurs in the oxygen concentration variation of 40% to the reactant mass flow of 6 L/min or 8 L/min. When examined further, the oxygen concentration of 40% and the CO_2 concentration of more than 30%, the ratio equivalence between fuel and oxygen is approaching 1 (Φ = 1). Equivalence ratio around unity, the biogas combustion speed takes place very quickly despite the biogas is also contains the mixture of CO_2 concentration. It can be concluded that in order to get the best biogas combustion, a mixture of fuel and oxygen should be conditioned on the mixture with equivalence ratio around 1, without considering the concentration of CO_2 contained in the biogas. This statement can be proved further on the measurement about the temperature distribution of premixed flame.

Flame Temperature

Figure-4 shows the temperature distribution of counterflow premixed flame and the area around the flame. The different colour indicates the different flame temperature, the red colour represent the higher flame temperature. From this Figure, it can be seen clearly the boundary of flame area, which is indicated by the gradation of colour from red to yellow and blue. The plotting temperature clarifies the discussion about the oxygen and CO_2 content effect to the burning behaviour of premixed flame described in the previous section. For higher the oxygen concentration, the area of the flame is dominated by red colour which means that the flame has the high temperature. On the other hand, the CO_2 content effect shows the opposite tendency. Increasing the CO_2 fraction in the biogas, the flame temperature tends to decrease and the flame area is increasingly narrow. This result suggests that the CO_2 concentration in Biogas has undesirable effects in the combustion process. The flame will tend to weaken with the addition of CO_2 concentration in the fuel.

Figure-5 depict the maximum temperature of the premixed flame for different CO_2 and O2. The additional CO_2 concentrations will generally lower the maximum flame temperature. However if we look more closely for the oxygen concentration variation of 40%, a decrease in the flame temperature due to the CO_2 effect show a

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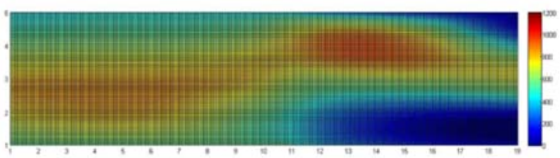
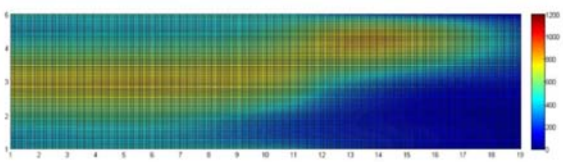
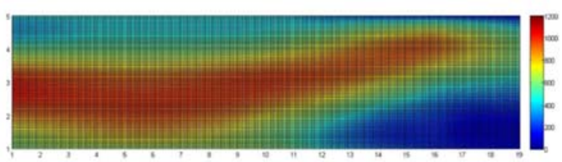
different trend. The maximum flame temperature tends to increase in CO_2 concentration approaching 30% and then decrease if the CO_2 concentration is increased. If it is reviewed in the flame visualization in the previous section, with equivalence ratio approaching 1, the flame showed the flash back phenomenon. It appears that in the equivalence approaching 1, the flame temperature is always at the maximum condition even without taking into account the amount of CO_2 content in the fuel.



O_2 20%, CO_2 0% (Φ = 4.01)



O_2 20%, CO_2 40% (Φ = 2.81)



O_2 30%, CO_2 40% (Φ = 1.40)

Figure-4. Temperature distribution of counterflow premixed flame.

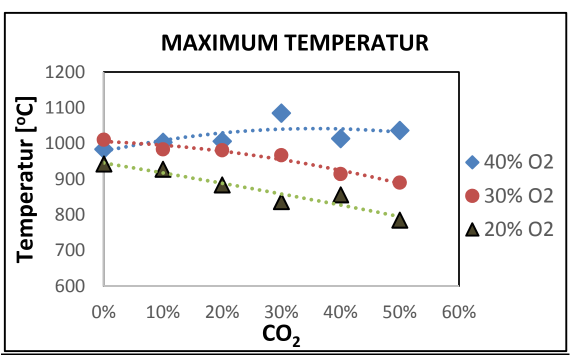


Figure-5. Maximum temperature of premixed flame for different CO_2 and O_2 concentration.

Flame Stability

Figure-6 shows the extinction condition of counterflow premixed flame of Biogas. The extinction was characterized by the oxygen concentration of the oxidizer stream at extinction (YO_{2ext}). In order to determine the extinction of the flame, the oxygen concentration of the fuel mixture stream was decreased gradually until the flame was extinguished. Every point in the graph shows the critical value of oxygen concentration which is required to establish the flame. Below this point, the combustion process was not able to be maintained due to insufficient of oxygen.

As can be seen in Figure-6, YO_{2ext}, initially tends to increase with the increase in the percentage of CO2 in the biogas and then decreased in the CO_2 concentration above 30%. The same trend of extinction condition existed even we change the flow rate of reactant from 6 L/min to 8 L/min. This tendency shows that increasing the CO_2 fraction in Biogas is not always require a greater oxygen supply for premixed flame combustion. Extinction experiment were performed on the fuel-rich conditions, so that, a lot of fuel did not be burned in the combustion process. As a result, the unburned fuel will absorb some heat from the combustion and will significantly lower the flame temperature and the reaction rate of combustion. Methane as a fuel in the Biogas has a very high specific heat capacity and almost four times higher than CO_2. In the mixture reactant with 30% of CO_2 fraction, combination of unburned methane and CO_2 contents have a higher capability to absorb heat combustion.

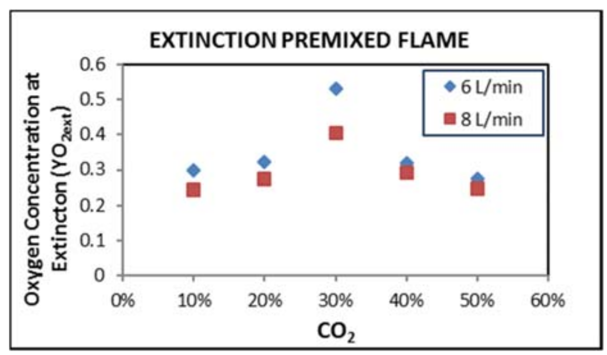


Figure-6. Extinction premixed flame.

CONCLUSIONS

This research determines the effect of the CO_2 fraction in the biogas to the characteristic of counterflow premixed flame. Some conclusions can be explained as follows:

1. Flach Back phenomena occurred in the counterflow premixed flame when the equivalence ration between fuel and oxidizer close to unity. The maximum temperature and maximum combustion rate of Biogas existed in the equivalence ratio around unity regardless of the amount of CO_2 fraction in fuel.
2. Oxygen concentration at extinction has the maximum value at the CO_2 fraction around 30 %. Differences in the composition of methane and CO_2 affect the minimum oxygen required to remain the stable flame.

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