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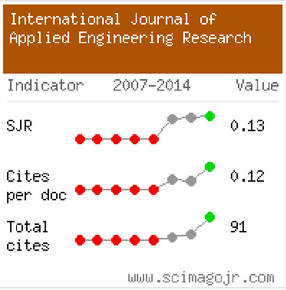

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Effect of Carbon Dioxide on Flame Characteristics in Biogas External Premix Combustion

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Abstract
Biogas is a renewable and environmentally friendly alternative fuels. Biogas is produced from the fermentation process which consists of mostly CH_4 (50-75%) and CO_2 (up to 50%) and a smaller amount of H_2, N_2, O_2, and H_2S, in which it varies from source. There are several related studies about the characteristics of biogas combustion and external combustion. This research focus on effects of CO_2 as the most abundant inhibitors in biogas towards its effects on external combustion process. This research was conducted by burning a stoichiometric mixture of fuel (CH_4 and CO_2% range 0-50%) and oxygen in the external test equipment premixed methane combustion with a 5 mm nozzle diameter. The results showed that the level of CO_2 affects the formation of flame angle and flame height. The increase in CO_2 content within the fuel mixture will decrease the flame height and moreover, more CO_2 content also creates larger flame angle.

Keywords: carbon dioxide, premixed combustion, external combustion.

Introduction

In combustion engineering, combustion success as is shown in the theoretical calculation in accordance with aspects of thermodynamics combustion is influenced directly by how the combustion process ongoing. In the process of gas fuel combustion, the flame properties and the flame propagation characteristics are the fundamental information, and the flammability limits of a compound or mixture of gases can be used to determine whether a compound gas mixture is flammable. The success of the practical utilization of a combustion system influenced directly by the combustion process that occurs and the characteristics of the flame.

In the field of combustion engineering, there are various categories of flame, and some of them have not been fully defined. But basically the flame can be grouped into two major categories based on the mixing method of the reactants, namely premixed flame and diffusion flame. In the premixed combustion, fuel gas and oxygen are perfectly mixed before the ignition. Ignition is required to give a certain amount of energy in the appropriate form, so as to trigger a combustion process. Furthermore, the reaction will be spreading to the mixture as a flame or which is known as deflagration. In the non-premixed combustion, the fuel and air are often initially not mixed. The fuel and oxidizer are kept on either side of the reaction zone and moved to the reaction zone. The resultant flame is termed as the diffusion or non-premixed flame. In some cases, the gas and air are injected in a coaxial parallel tube and ignited. The flow behavior of the non-premixed flame is laminar type. Molecular or turbulent diffusion is responsible for the mixing of the gases in non-premixed flames. The turbulent pre-mixed flame plays an important role in the various practical applications because it increases the ignition of fuel with the reduction in the emission of gases. Both the laminar premixed or laminar non-premixed flames (diffusion flame) are slow processes and not economic but however, the laminar flame characteristics are fundamental to the analysis of turbulent flames.

Biogas is a renewable alternative fuel that is derived from the secretion of living things such as plants, animals, and even humans. The composition of biogas varies from source in which the biogas is derived. Mainly, biogas is composed of methane (50-75%) and carbon dioxide (up to 50%) Biogas obtained by reaction of anaerobic bacteria within manure which produced Methane and Carbon dioxide. Methane (CH_4) is combustible organic compound belonging to the group of paraffin. Carbon dioxide (CO_2) is an inert substance that is difficult to react. In addition, there are several other impurities within biogas composition such as, Hydrogen sulfide, Hydrogen, Nitrogen, Oxygen, and some other substances depend on the biogas sources. The calorific value of biogas is highly dependent on the content of methane within. Biogas containing 60% Methane has a calorific value of 30 MJ / kg and several previous related studies conducted biogas combustion fundamental characteristics, those are laminar burning velocities and flammability limit (Anggono et al. and Ullman) [1-6]. One study conducted on the effect of carbon dioxide (CO_2) in methane (CH_4) combustion by utilizing a burner comprises of a stainless mesh to stabilize the flame and the perforated plate to create turbulence in the flow of premixed. The experiment used nozzle burner to generate a combustion reaction, in which later the flame characteristic is analyzed with a formula closer to the laminar burning velocity [7-9]. This is a good discovery, given that turbulent premixed flames exhibit an area that is challenging to study.

Several studies have been conducted regarding of combustion properties of alternative fuels [10-12]. In addition, there are several other studies that examine the effect of Air Fuel Ratio on combustion characteristics of both on LPG and in some studies on Methane/ Natural Gas [10,13]. These previous studies of gas fuel biogas focus mainly on Carbon dioxide as a compound "impurity" of the main flame instability burning a mixture of biogas which includes various characteristics, structure, properties and mechanisms in the combustion process. These studies aimed to understands the characteristic of Carbon dioxide on combustion process better as research on Carbon dioxide influence on combustion has not been widely studied.

There are also other previous studies involving different burner, with a wide variety of burner and the results obtained [13-17]. One of the studies [16] was using porous radiant burners commonly used on LPG burner to observe flame characteristics, emissions released, and thermal efficiency. In the case of McKenna burner, the flame produced by the burner is a flat flame with a more uniform temperature distribution than other burner [15]. Aside from the variation of the burner, there is also research on the effect of test equipment used. Studied the influence is on the length and width of the flame nozzle size variations are used, which ultimately affects the resulting flame heights [17].

The focus of the present study is on the effects of CO_2 as the most abundant inhibitor in biogas towards its effects on external premixed combustion process, and the main goal of the present study is to investigate the influence of CO_2 level on the formation of flame angles and flame heights.

Experimental Apparatus and Procedure

The research is conducted at the Thermofluid Laboratory of Mechanical Engineering Department, Petra Christian University. The variables of this experiment are percentage of CO_2 mixture at 0, 10, 20, 30, 40 and 50%. Fuel mixture consists of CH_4 and CO_2 was initially mixed in accordance with the desired ratio. Once the desired composition of fuel mixture is achieved, whether pure CH_4 or CH_4-CO_2 mixture with varying percentages, it is then supplied into the experimental apparatus along with the supply of O_2. The experiment apparatus are used with output of 5 mm in diameter. Details of experiment and test equipment used can be seen as follows:

The experiment was first done by preparing all the necessary modules and arranging them in accordance with the planned experimental scheme. The corresponding modules were then installed in accordance to Fig. 1. The next step was to set the Camera on a Tripod. Once the camera had been ready, the igniter was prepared. After all equipment was installed correctly, let the O_2 flow through the flowmeter and into the experimental apparatus. The flowmeter was checked accordingly. The procedure used to flow O_2 into the mixing chamber was also applied to flow CH_4/CH_4-CO_2 into the mixing chamber. Once the flowrates of both streams were set to stoichiometric ratio, the burner tip is ignited. To ensure a steady combustion, then a delay is introduced for about 10 to 15 seconds between the moment of ignition and when the flame is recorded. After the desired images are captured, the burner was turned off. The same steps were repeated for various compositions of CH_4-CO_2 mixtures.

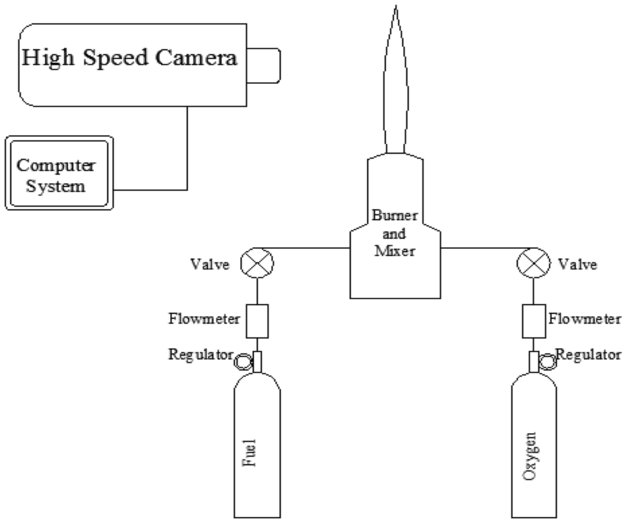


Figure 1: Experimental apparatus scheme

Results and Discussion

Data are obtained from experiment at RTP (Room Temperature Pressure) condition with various CO_2% content. Images of CH_4-CO_2 premixed flames with varying CO_2 content (0-50%) were captured using a high speed camera. These images were analyzed with the help of image processing software. Flame angle is the magnitude of the flame tip angle, and flame height is the distance from the base to the tip of the flame. Figure 2 shows how both parameters are measured.

Figure 2: Measurement of Flame angle (θ) and flame height

Flame angles and flame heights for each composition were measured by uploading pictures of the flame onto computer and using image processing software to measure the angle and the height. Dimensionless flame height is obtained by dividing flame height (H) to the diameter of nozzle (d = 5 mm). Dimensionless flame height is a parameter that shows flame height which are unaffected by nozzle diameter. The measurement results are given below:

Table 1: Experimental Results

CO_2 content (%)	Flame Angle (deg)	Flame Height (mm)	Dimensionless Flame Height (H/d)
0	2.81	102.016	20.403
10	3.27	87.557	17.511
20	3.73	76.835	15.367
30	4.71	60.820	12.164
40	6.50	44.053	8.811
50	7.96	35.911	7.182

Flame angle increases as the CO_2 level increases while flame Height decreases as the CO_2 level increases. This means that CO_2 affects the physical properties of flame, which in this case, flame angle and flame height. The differences in flame height for each CO_2 contents can be observed in Fig. 3. The flame image shows gradual decrease of flame height and gradual increase in flame angle with the gradual increase in CO_2 content. From experimental observations, no sudden changes of flame properties are present.

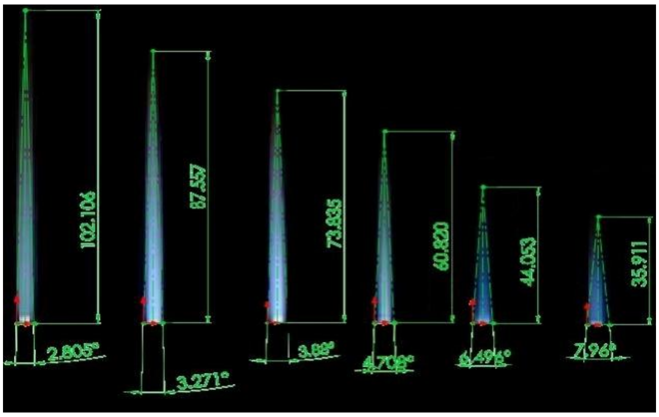
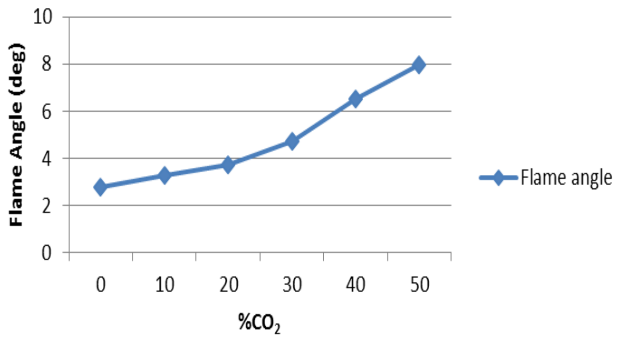
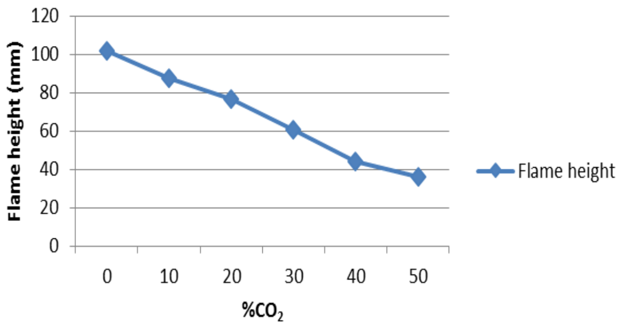


Figure 3: Differences in flame angle and height with varying CO_2 content (0-50%)

In order to ease the observation and to find the tendency of the magnitude of flame height and flame angle at various levels of CO_2, then the data above is presented in the form of simple charts. Fig. 4(a) shows the relationship between various CO_2 contents to the magnitude of flame angle, and Fig. 4(b) & 4(c) show the relation between various CO_2 contents to the flame height and the dimensionless flame height respectively. Below, there are graphs representing the Effect of CO_2 content on flame angle flame height, and dimensionless flame height.



(a)



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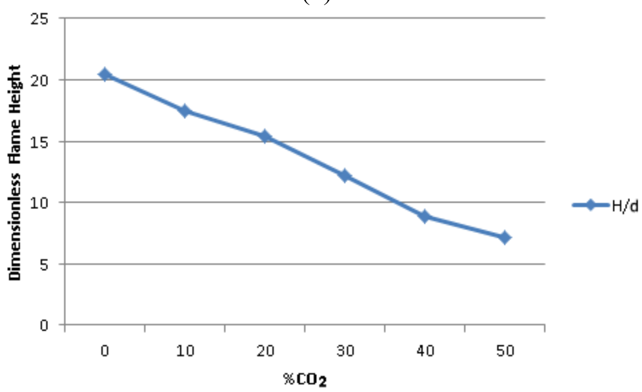

(c)

Figure 4: (a) Effects of CO_2 content on flame angle development; (b) Effects of CO_2 content on flame height development; (c) Effects of CO_2 content on dimensionless flame height development

Data obtained from the graphs indicates gradual decrease of flame height and gradual increase of flame angle with the gradual increase in CO_2 content. Based on the data obtained, there are no sudden changes in flame properties. Moreover, it can be concluded from this study that carbon dioxide acts as an inhibitor in the combustion process. Inhibitory effect of Carbon dioxide increased with increasing levels of CO_2 in methane that caused changes in the characteristics of the fire burning. Flame angle appears to increase with increasing CO_2 levels while the flame height decreases nearly in linear manner. This can be seen in the formation of flame angle which tends to be wider at high CO_2 concentrations, but lower the flame height obtained.

Conclusion

The experimental apparatus consists of a burner with a mixing chamber and a high speed camera is adequate to capture the flame produced by an external premixed combustion. Flame height and flame angle can be obtained with the help of an image processing software.

From the data analysis that has been discussed above, it can be concluded that carbon dioxide acts as an inhibitor at combustion process. The study has successfully shown the effect of various CO_2 content on the formation of flame angle and flame height in biogas premixed combustion.

Fuels with 0% content of carbon dioxide results in a narrow flame angle. Increasing levels of CO_2 will increase the flame angle. Decrease in flame height is proportional to the increase of CO_2 levels. The greater the concentration of CO_2 in biogas, the lower the flame height is achieved.

Acknowledgments

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