

Characterization of Biogas as an Alternative Fuel in Micro-Scale Combustion Technology

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Abstract: This study observes the flame characteristics of the biogas in micro/meso-scale (MSC) combustion technology, namely in a cylindrical MSC. For comparison, the fuel and combustor variations were carried out with backward-facing step size (bfs) as the flame holder in the combustor. The bfs are varied by changing the combustor's length of the inlet diameter. However, the size of the outlet diameter of the combustor is always constant to obtain a continuous combustion reaction zone. Biogas/methane (CH₄), butane gas (C₄H₁₀), and a mixture of biogas-butane are used as fuel, with air as the oxidizing agent. The results showed that the type of fuel, reactant flow velocity, and equivalent ratio that occurred in the fuel variation and the bfs variation of the cylindrical msc influenced the flame characterization. Stable flame forms in the stoichiometric to rich equivalent ratio area and the medium to high reactant velocity area. The result shows that the equivalent ratio (ϕ) is 1.23 – 1.44, the flame stability limit at the combustor ratio of 0.7, and biogas fuel has low flame stability compared to butane and the biogas-butane mixture. Moreover, the flame can be stable on butane fuel in the equivalent ratio (ϕ) 0.85 – 1.43 and (ϕ) 0.86 – 1.19 for the biogas-butane fuel mixture. Furthermore, when the D1/D2 increases, the flame stability of biogas tends to be wider than when the combustor ratio is 0.7, where the equivalent ratio (ϕ) is 0.98 – 1.42. The result also shows that the flame can be stable on butane fuel in the equivalent ratio (ϕ) 0.71 – 1.43, and for the biogas-butane fuel mixture, the flame can be stable in the equivalent ratio (ϕ) 0.69 – 1.32. However, the best characterization of biogas combustion is formed in the variation of biogas treatment by mixing butane gas (biogas-butane). One of the methods used is called with a wider flame stability limit area. More varied flame visualization variations with a more widely distributed flame mode map, flame, and combustor wall temperature. The result shows that the combustor wall temperature of butane is around 225-250 °C, higher than the characterization of biogas combustion around 150 °C, where it's without mixing butane gas for the possible test ranges.

Keywords: Alternative fuels, biogas, butane, micro scale, cylindrical combustor, flame

1. Introduction

The dominance of the conversion process of fossil fuel energy into energy through the combustion process to meet the needs of human life is still not replaced [1]. The current fuel crisis has caused the price of fossil fuels to increase

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[2], so the need for reliable and renewable energy sources is expected to increase [3], [4] like crude vegetable oils [5], biogas [6], syngas [7], bioethanol [8], [9] and biodiesel are also clean and renewable energy [10]. Energy reserves derived from fossils continue to decline and are expected to be depleted in the next few decades, and therefore alternative energy is a very urgent choice for the sustainability of energy needs. Biogas fuel as an alternative energy source has great potential to be applied considering the abundant available resources. [11], [12].

At the same time, the miniaturization of energy-generating equipment based on small-scale combustion or known as Micro Power Generator (MPG) is being developed massively [13], [14]. This is because the energy density produced by the Micro Power Generator is greater than the energy density of the Lithium Ion Battery which is widely used today [15], [16]. Furthermore, converting fuels into thermal power in an MSC combustion chamber to get high efficiency of MPG [17] using the thermos-photovoltaic method. However, to improve combustion stability in an MSC, sudden expansion was carried out in the combustor channel [18]. The bfs enhance the mixing of fuel and air and extend the fuel residence time of reactants in the combustion reaction area. The bfs in a combustor duct is a sudden diameter enlargement from a smaller inlet to a larger outlet diameter. However, the MSC with a bfs is very effective in controlling the flame position and can circulate the mixed reactants in the combustor [19]. Biogas fuel has the potential to be developed as fuel in Micro Power Generator equipment related to the current need for alternative energy sources.

Many studies have been carried out through bio-gas combustion [20], but researchers rarely investigate premix combustion of biogas where the biogas fuel is mixed before combustion is carried out [21]. Related to the research that has been done, it is necessary to examine the characterization of biogas fuel combustion as information in its application. Efforts to optimize combustion with small-scale combustion technology (Micro-/Meso-Scale Combustion) to obtain a large energy density can be applied to the combustion of biogas fuel which has a small energy density. In this case, the review of fuel combustion characterization will focus on the characterization of the combustion flame to search for conditions/parameters where optimal combustion characterization can be produced.

In this study, research will be conducted on the characterization of biogas fuel combustion in applications in small-scale combustion technology (Micro-/Meso-Scale Combustion) as an alternative to obtain new and renewable fuel sources as a substitute for fossil fuels. The specific objective of this research is to obtain the results of the combustion characteristics of biogas fuel as a source of information on its use and application of it in the next stage in the search for alternative sources of new and renewable fuels to replace fossil fuels.

2. Material and Method

The fuel used in this experiment is biogas from cow dung and butane, with air as the oxidizing agent. Biogas from cow dung was used because it contains methane (CH_4) which can be converted and used as an alternative fuel. However, as a gas, methane is only flammable when its concentration reaches 5-15% in the air. Therefore, butane (C_4H_{10}) is added, which has flammable properties. On the other hand, measurements of flowrate biogas and butane are supplied from pressurized tubes using Kofloc, RK 1250, with a flow rate maximum, is 20 mL/min, along with measurements of the flow rate of air supplied from the air compressor tank with the speed of 500 mL/min). The research apparatus is shown in Figure 1. Furthermore, the fuel and air mixture is mixed in the combustion chamber and ignited using the lighter. However, taking a visualization of the flame using a digital camera (Canon EOS 1300D) and shooting from the side of the combustor makes it possible to determine.

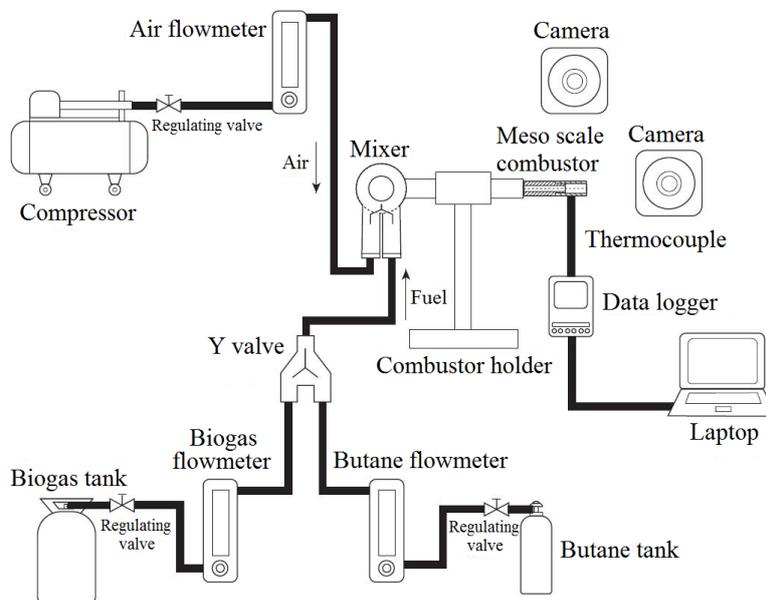


Fig. 1 - Schematic of the test equipment

The flame geometry was analyzed by several classifications to clarify the findings, when the first combustion occurs in the combustor rim, so the flame in the combustor rim must be identified. The flame continues to propagate in the combustion chamber until it reaches the backward-facing step area. Therefore, the flame mode that develops from the combustor rim to the bfc area must be classified. Furthermore, the flame mode formed is displayed in a graph of the equivalent ratio to the reactant flow velocity to obtain flame mode maps.

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Figure 2 presents the details of an MSC. The inlet material of the combustor is copper, and the outlet is made of a quartz glass tube. To understand the flame stability of the cylindrical MSC between the outlet diameter (D2) (reaction zone) and the inlet diameter (D1) was varied with the values of D1, D2, and D1/D2 ratios (see Table 1).

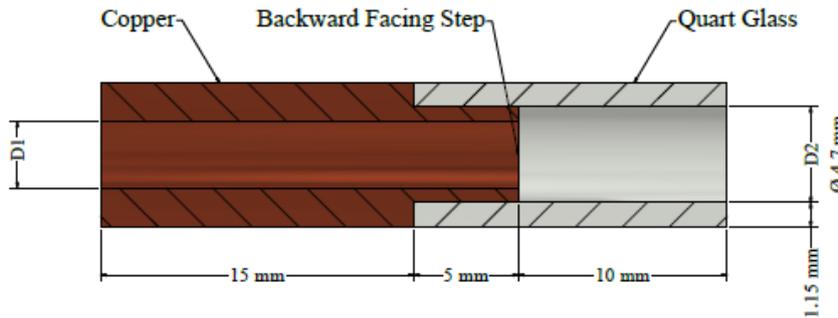


Fig. 2 - Combustor schematic with bfs

Table 1 - The various diameter of the combustor

D ₁ (mm)	D ₂ (mm)	D ₁ /D ₂ ratio
3.3	4.75	0.7
4.2	4.75	0.9

3. Result and Discussion

The investigated combustion characteristics of biogas-air fuel were experimental. A flame holder of BFS carries out the combustion of the premixed biogas-air mixture in a cylindrical MSC. As a comparison of the characterization of the biogas-air premixed combustion flame, the combustion flame characterization for butane gas fuel was used, and premixed combustion of the biogas-butane fuel mixture was used with an air oxidizer. The BFS is a flame holder on the cylindrical meso-scale combustor and consists of a D1 and D2 for the combustor. The inlet and outlet areas are conditioned to have different geometries by varying the size of the D1 and D2 is always constant so that the burner will have a steady combustion reaction space [18], [22]. Variations in the D1/D2 ratio of the backward-facing step on the cylindrical meso-scale combustor are 0.7 and 0.9. This method was carried out to determine the characteristics of the combustion flame of biogas and butane fuel. Moreover, with relatively constant combustor heat loss conditions without enlargement of the outlet diameter or without changing the surface to volume (S/V) area in the combustion reaction zone.

Figures 3 and 4 show the flame volatility and stability for a cylindrical MSC with biogas, butane, and biogas-butane mixtures for variations D1/D2 with backward-facing steps of 0.7 and 0.9. The flame stability limit is a condition where the flame can burn continuously without extinguishing at a location close to the BFS in the combustor. Figure 3 shows the flame stability limit at the combustor ratio of 0.7, and biogas fuel has low flame stability compared to butane and the biogas-butane mixture, where the equivalent ratio (ϕ) is 1.23 – 1.44. While the flame can be stable on butane fuel in the equivalent ratio (ϕ) 0.85 – 1.43, and for the biogas-butane fuel mixture, the flame can be stable in the equivalent ratio (ϕ) 0.86 – 1.19. Figure 4 shows that, when the D1/D2 increases, that biogas fuel has flame stability that tends to be wider than when the combustor ratio is 0.7, where the equivalent ratio (ϕ) is 0.98 – 1.42. While the flame can be stable on butane fuel in the equivalent ratio (ϕ) 0.71 – 1.43, and for the biogas-butane fuel mixture, the flame can be stable in the equivalent ratio (ϕ) 0.69 – 1.32.

Figures 3 and 4 on all variations of the combustor ratio show that the butane flame stability limit has a wider stable flame area, followed by a mixture of biogas-butane and biogas fuel. The variation of biogas fuel has a low calorific value of 20799 KJ/m³ with 50-70% CH₄ content, 30-40% CO₂ and other impurities [19]. The low calorific value in biogas is due to the low CH₄ content and the number of impurities that disrupt the combustion process. Butane has a

higher calorific value than biogas, with a calorific value of 49500 kJ/kg [19]. However, the high calorific value of butane (C_4H_{10}) is determined by the carbon and hydrogen content of the chemical structure [20]. In this case, the higher the calorific value, the wider the stable flame area. Mixing biogas fuel with butane increases calorific value and stability in biogas at large equivalence ratios and high reactant rates [21].

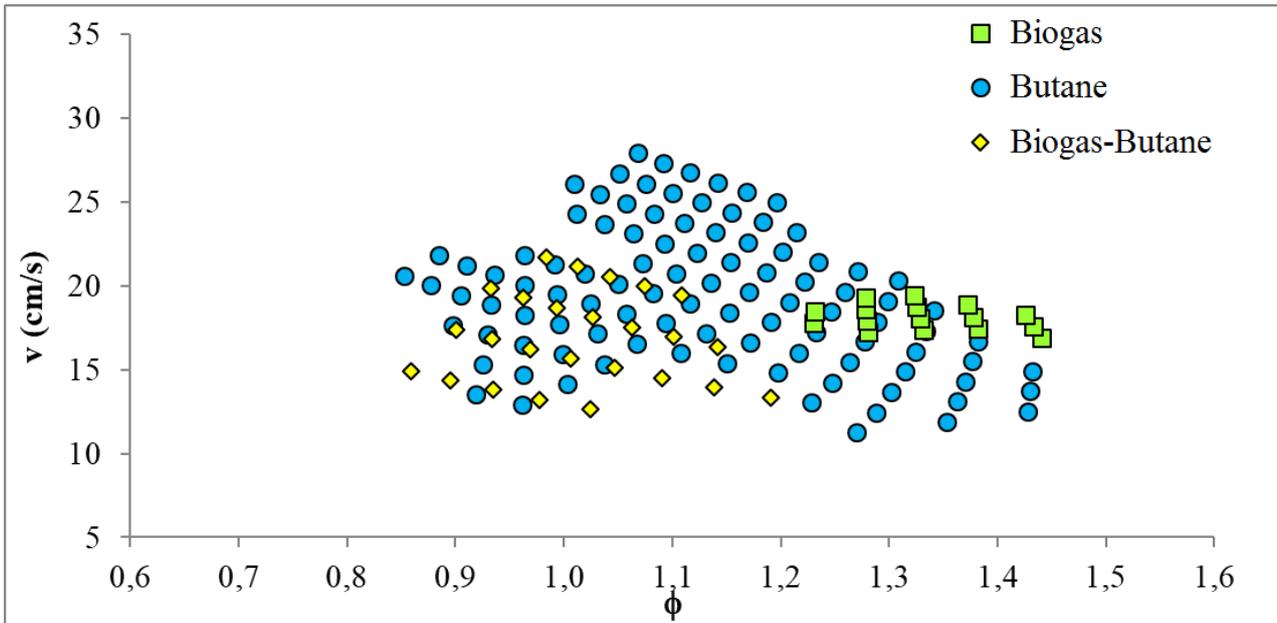


Fig. 3 - Flame stability limit for combustor $D1/D2 = 0.7$

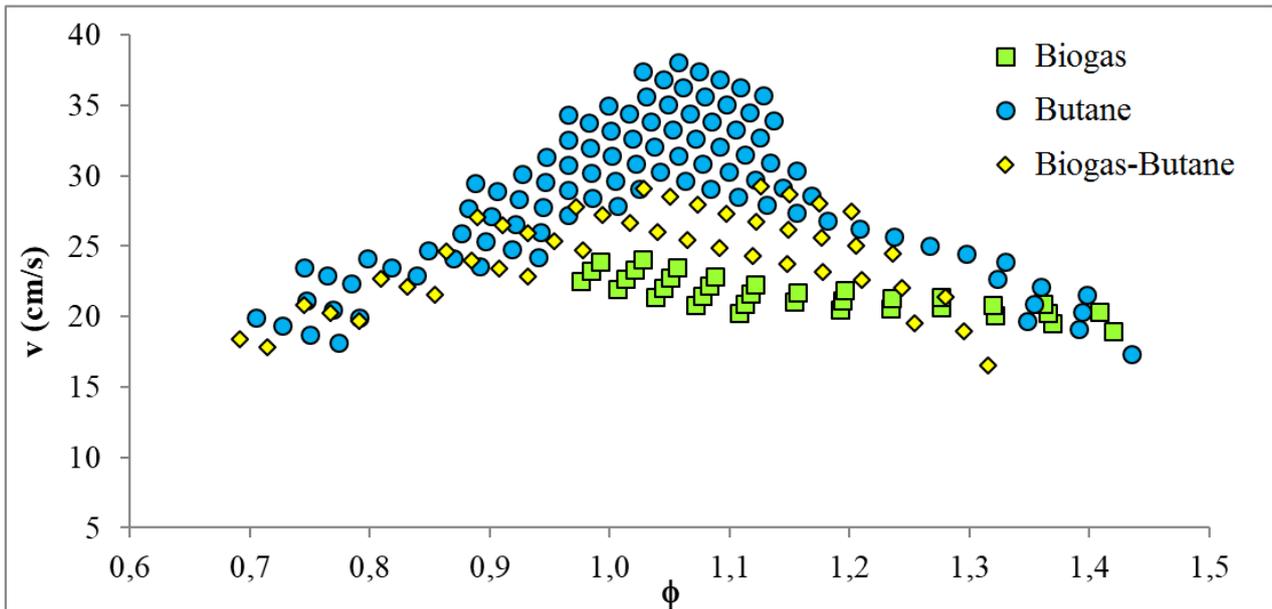


Fig. 4 - Flame stability limit for combustor $D1/D2 = 0.9$

However, variations in the size of the bfs potentially cause a shift in the flame stability space, as shown by Figures 3 and 4. A larger $D1/D2$ ratio will create a flame stability limit area leading to a lower equivalent ratio. In comparison, a $D1/D2$ ratio size smaller will create a flame stability limit area leading to a higher equivalent ratio. The shear stress also influences the shift in the flame stability limit graph on each combustor [22]. Minor shear stress is obtained as the size of the backwards-facing step decreases. On the other hand, Figure 5 shows the visualization of flame modes with various fuels and $D1/D2$ ratios in the range of possible reactant speeds (v) to equivalent ratios (ϕ). The result clearly shows that there are several flame structures: flame at the combustor rim, in the combustor, and the flame close to the step, oscillating and spinning flame. Moreover, the flame mode is formed due to reactant velocity and equivalent ratio variations.

Furthermore, Figure 5 shows that the different fuel and D1/D2 combustor ratios produce different flame shapes with the same equivalent ratio conditions. However, a low calorific value will make the flame unstable [23], [24], [25]. Variations in the ratio of D1/D2 combustor will result in differences in reactant flow velocity and recirculation area as well as the impact on flow shear stress, flow reattachment length, and recirculation region in the step area that occur in each combustor variation [26], so that it will produce a flame visualization different.

In the flame at the combustor rim for variations in biogas fuel, butane and a mixture of biogas-butane on a combustor D1/D2 ratio of 0.7, the flame geometry potentially to be more comprehensive and stretching slightly away from the combustor rim. The greater the D1/D2 ratio, the smaller the step size so that the reactant flow velocity, flow shear stress, flow reattachment length and recirculation region are smaller. Furthermore, flame mode at the burner occurs in the reaction area. The flame moves into the combustor as the reactant velocity (v) decreases. In the variation of biogas and butane fuel and a mixture of biogas-butane with a combustor with a D1/D2 ratio of 0.7, the position of the flame formed occurs in a part that tends to be far from the step in the combustor. With the increase in the D1/D2 ratio of the combustor to 0.9, the position of the flame indicates that it is getting closer to the backward-facing step area. This is in line with the decrease in reactant flow velocity, flow shear stress, flow reattachment length and smaller recirculation region.

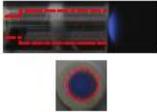
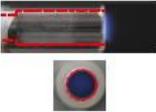
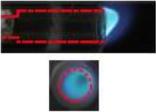
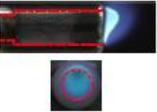
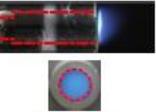
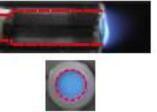
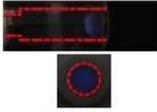
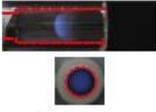
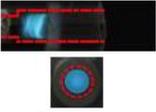
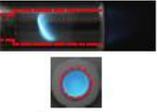
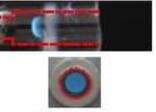
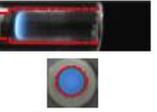
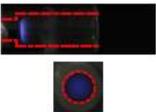
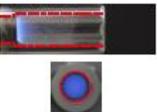
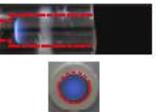
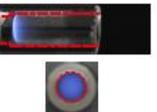
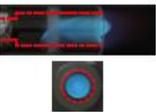
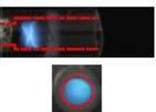
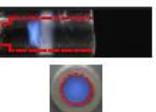
No.	Flame Mode	Biogas 0.7	Biogas 0.9	Butane 0.7	Butane 0.9	Biogas-Butane 0.7	Biogas-Butane 0.9
1.	Stable flame at combustor rim	 $\phi = 1.32$ $v = 20.12 \text{ cm/s}$	 $\phi = 1.32$ $v = 21.51 \text{ cm/s}$	 $\phi = 1.32$ $v = 28.12 \text{ cm/s}$	 $\phi = 1.32$ $v = 28.12 \text{ cm/s}$	 $\phi = 1.32$ $v = 25.18 \text{ cm/s}$	 $\phi = 1.32$ $v = 29.51 \text{ cm/s}$
2.	Stable flame in combustor	 $\phi = 1.23$ $v = 17.80 \text{ cm/s}$	 $\phi = 1.23$ $v = 20.58 \text{ cm/s}$	 $\phi = 1.23$ $v = 24.44 \text{ cm/s}$	 $\phi = 1.23$ $v = 32.84 \text{ cm/s}$	 $\phi = 1.23$ $v = 15.22 \text{ cm/s}$	 $\phi = 1.23$ $v = 26.91 \text{ cm/s}$
3.	Stable flame near the step			 $\phi = 0.99$ $v = 19.50 \text{ cm/s}$	 $\phi = 0.99$ $v = 28.43 \text{ cm/s}$	 $\phi = 0.99$ $v = 18.69 \text{ cm/s}$	 $\phi = 0.99$ $v = 27.20 \text{ cm/s}$
4.	Oscillating flame			 $\phi = 1.20$ $v = 32.21 \text{ cm/s}$			
5.	Spinning flame			 $\phi = 1.04$ $v = 30.27 \text{ cm/s}$		 $\phi = 1.04$ $v = 26.04 \text{ cm/s}$	

Fig. 5 - Flame mode visualization at 0.7 and 0.9 combustor ratios

Flame mode flame near the step is formed with the position in near zone of the bfs, therefore, the variation of biogas fuel with a D1/D2 ratio of 0.7 and 0.9 is not formed. This is due to the instability of the biogas fuel, which

causes a flame to only form in the flame in combustor. However, in the variation of butane fuel and biogas-butane mixture in the burner with a D1/D2 ratio of 0.7 and 0.9, the flame near the step formed is increasingly sticking to the step. The reactant velocity, shear stress, reattachment length, and recirculation region can hold the flame in the position attached to the step. In oscillating flame mode, the flame is formed in an oscillating state in the combustor. This mode of oscillating flame forms unstable, vibrates, and moves back and forth continuously. This flame mode is only formed on butane by combustor with D1/D2 ratio of 0.7. This flame shape condition occurs in the area around the equivalent ratio = 1.20, but the combustion cannot be stabilized.

The condition of the oscillating flame mode will last, and no blackout will occur, even though the flame is in a vibrating and unstable condition. The condition of the oscillating flame mode in which the flame is insulated occurs due to the flame moving back and forth towards the upstream and downstream of the combustor due to an equilibrium process between the flame speed and the reactant speed due to the influence of the heat interaction of the combustor wall. When the flame moves into the combustor upstream, because the flame velocity is greater than the reactant flow rate, it will result in heat loss to the combustor wall as the flame moves towards the combustor upstream. This will cause the speed of the flame to weaken when it reaches the upstream area of the combustor. Loss of heat to the walls of the combustor causes its energy to be weakened and the speed of the flame to decrease lower than the reactant flow rate. At a position where the flame velocity is lower than the reactant flow velocity, the flame will move in the opposite direction towards the downstream of the combustor. Reactants to move back toward the combustor upstream. Then when the flame reaches the downstream area of the combustor, the additional heat from the combustor wall results when the flame moves upstream to the combustor will result in additional energy that can increase the energy of the flame so that the flame speed will return to be greater than the flow velocity. The equilibrium condition between the flame speed, which is influenced by the interaction of energy from the heat of the combustor wall and the flow velocity of the reactants, causes the insulated condition to occur repeatedly, resulting in a flame that occurs in an insulated and vibrating condition.

The spinning flame mode is formed in the combustor with the spinning flame condition, as shown in Figure 5. This spinning flame mode can be formed stably at a specific position in the combustor. The spinning flame mode occurs in the transition phase after the oscillating flame mode in the flame's movement towards the upstream combustor, where the flame moves towards the bfs zone. After the spinning mode, the flame will move to the bfs area to form a stable flame near the step mode. This process due to the increase in reactant flow rate and decrease in the equivalent ratio to a specific position of reactant velocity and equivalent ratio. When the speed of the reactants increases and the equivalent ratio decreases, the stable flame near the step mode will again move away from the step towards the downstream of the combustor.

Furthermore, the flame mode changes sequentially into spinning due to a thermal wall interaction. This phenomenon follows previous research [27], which stated that this phenomenon is due to the flame stretching in the tangential and axial directions so that the flame is spun and resembles. Moreover, the other flame modes formed outside are flashbacks, and no ignition occurs when the flame moves toward extinction. The phenomenon is due to the flame propagation speed being more significant than the reactant flow velocity in the combustor channel.

Figure 6-11 shows a detailed flame shape on the reactant velocity (v) graph to the equivalent ratio (ϕ) of various fuels and combustor D1/D2 ratios. The flame mode map area consists of several flame modes, such as a steady fire in the combustor rim, stable fire in the combustor, stable fire near the step, oscillating fire, spinning fire, flashback, and no-ignition conditions.

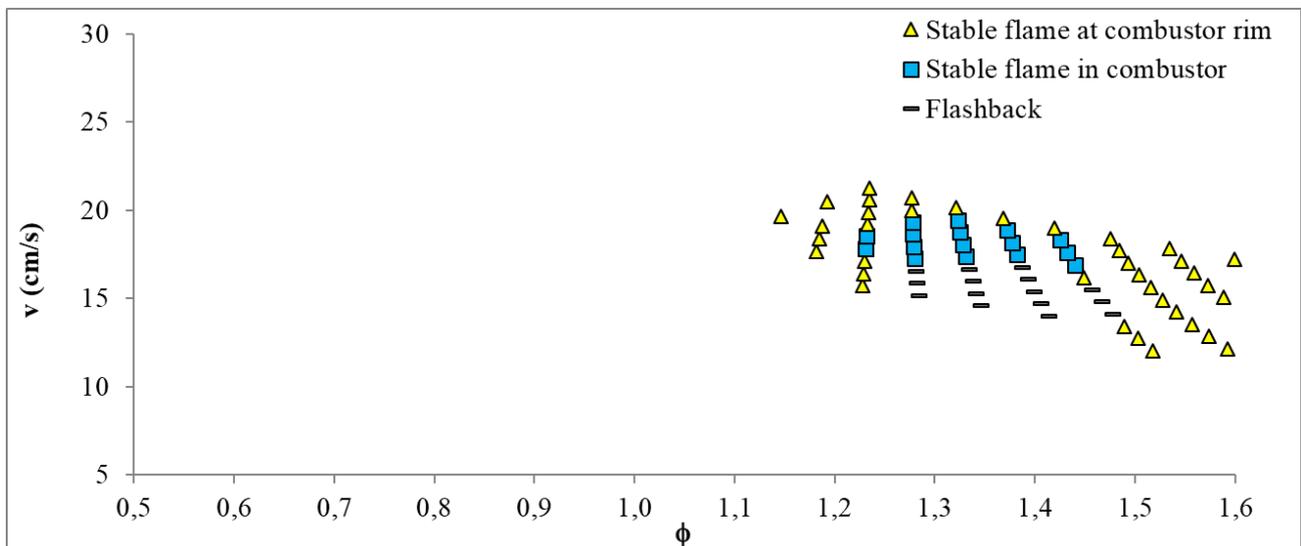


Fig. 6 - Biogas flame mode at 0.7 combustor ratio

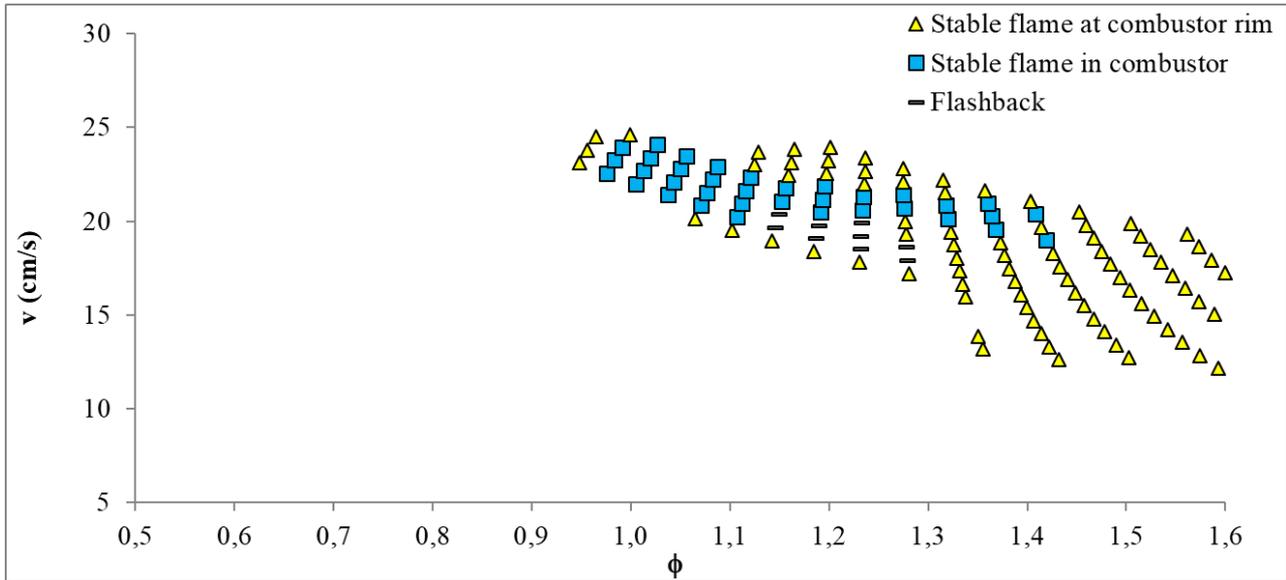


Fig. 7 - Biogas flame mode at 0.9 combustor ratio

As shown in Figure 6, biogas with a combustor ratio of 0.7, has a stability area of stable flame mode in a narrow combustor at high reactant rates. This shows that the biogas fuel in the combustor ratio of 0.7 does not have flame stability at low reactant speeds due to the need for large air and biogas fuel flow and large jet flow at the 0.7 ratio combustor. When the D1/D2 ratio increases to 0.9, as shown in Figure 7, the biogas fuel has a stability area of a stable flame mode within a wider combustor at high reactant velocities. This shows that biogas fuel at a high combustor ratio of 0.9 has reasonably good flame stability at high reactant speeds, which is influenced by a small jet flow at a high combustor ratio of 0.9. Furthermore, when the D1/D2 ratio increases to 0.9, as shown in Figure 7, the biogas fuel has a stability area of a stable flame mode within a wider combustor at high reactant velocities. This shows that biogas fuel at a high combustor ratio of 0.9 has reasonably good flame stability at high reactant speeds, which is influenced by a small jet flow at a high combustor ratio of 0.9.

Furthermore, the graph in Figure 7 shows a flame mode transition from a stable flame at the combustor rim to a steady flame in the combustor, then flashback and back to a stable flame at the combustor rim as the equivalence ratio increases, besides the reactant velocity decreases. This happens because there is a balance between the rate of the reactants and the flame propagation speed with changes in the equivalence ratio and the rate of the reactants. When the rate of the reactants is balanced with the flame propagation speed, the flame will form a stable flame in combustor flame mode, or a flame will start in the combustor. When the velocity of the reactants is greater than the flame propagation speed, the flame will form a stable flame at combustor rim flame mode, or if the rate of the reactants is excessive, a blow-off will occur. A flashback occurs when the reactant velocity is lower than the flame propagation speed in the combustor. As shown in Figure 8 on butane with a combustor ratio of 0.7, there is a wide range of flame modes from low to high reactant velocities. This shows that butane fuel has good flame stability at low and high reactant speeds at a combustor ratio of 0.7, and vortex flow dominates the flame stability. Butane fuel at a combustor ratio of 0.7 has a broader stability area in the flame mode, stable flame in combustor and near the step.

By increasing the D1/D2 ratio to 0.9, as shown in Figure 9, the area for the spinning flame mode disappears. However, replaced with flashback conditions. This shows that the tiny rear-facing stroke size causes a weak jet stream making the combustion speed beat the average flow and the flashback flame mode wider at a burner ratio of 0.9. Mixing biogas-butane fuel at a combustor ratio of 0.7, as shown in Figure 10, shows that the flame stability area becomes more expansive as the flame mode stabilizes near the step and spinning flame. This shows that mixing biogas-butane fuel improves different fire characteristics than using only biogas. Furthermore, by increasing the D1/D2 ratio to 0.9 by mixing biogas-butane fuel, as Figure 11 shows, the area for the spinning flame mode flame disappears. However, replaced with flashback conditions. This shows that mixing biogas-butane fuel will result in the dominant average flow regime regulating the flame stability of the biogas fuel that has been mixed with butane.

In addition, Figures 6 – 11 in all combustor ratios show that the butane flame mode map has a wider flame area, followed by a mixture of biogas-butane and biogas fuel. Variations of biogas fuel it has low flame stability compared to butane fuel or a mixture of biogas-butane fuel. This is because the calorific value of biogas is lower than the calorific value of butane or a mixture of biogas-butane. Moreover, variations in the D1/D2 ratio of the combustor cause shear stress, reattachment length, and recirculation region. The reactant flow velocity, which affects the shear stress, reattachment length, and recirculation region of the reactant flow due to variations in the D1/D2 ratio combustor, will form different flame mode maps at the exact ratio equivalent for each D1/D2 ratio combustor.

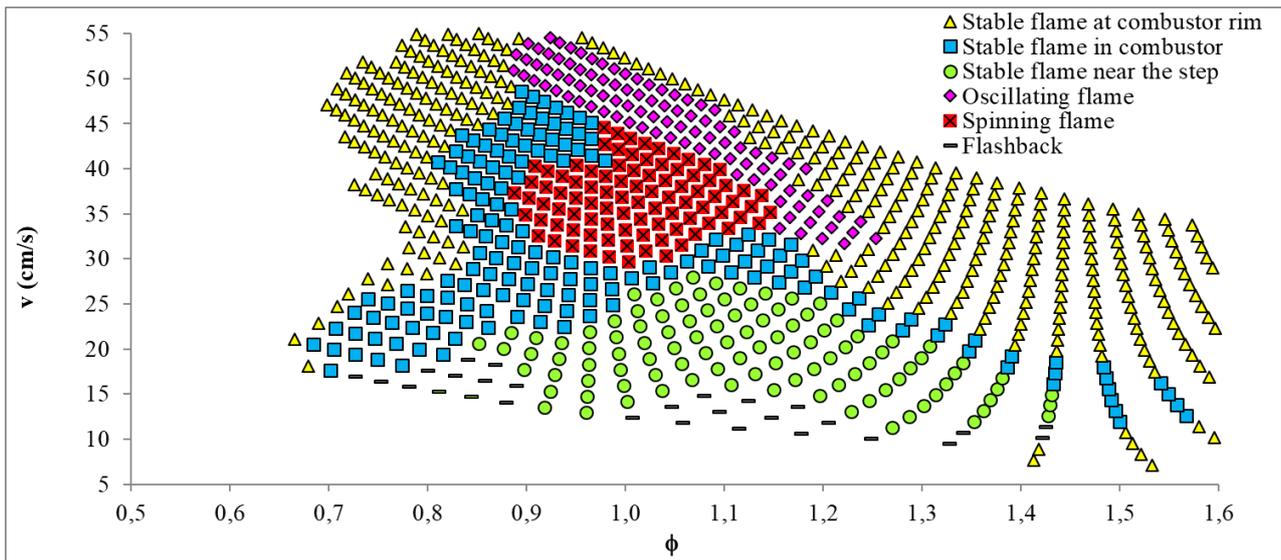


Fig. 8 - Butane flame mode at 0.7 combustor ratio

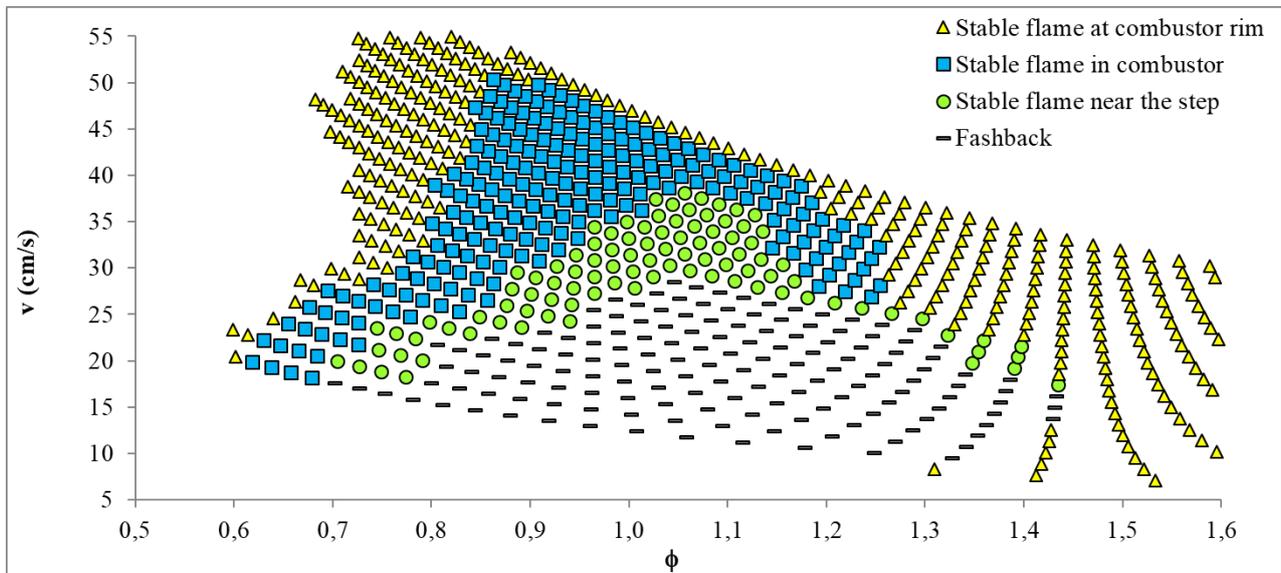


Fig. 9 - Butane flame map at 0.9 combustor ratio

Furthermore, in Figure 6 – 11, we can see that the larger ratio of $D1/D2$ in the burner gives a broader area, showing that it can achieve the flame's stability in the combustor channel. In $D1/D2$, the higher combustor ratio (from $D1/D2$ combustor ratio 0.7 to 0.9) causes the size of the backward-facing step to be smaller, which will provide a smaller reactant velocity, shear stress, reattachment length, and recirculation region so that the flame will burn to get the stable flame. Moreover, in variations of butane fuel and biogas-butane mixture with variations of $D1/D2$ ratio combustor 0.7 and 0.9, the flame near the step mode can occur stably. The flame near the step mode area is around the equivalent area = 0.69 to 1.43 with a reactant velocity that is not too high. $D1/D2$ ratio combustor 0.7 can form flame stability in step because the flame formed is in a flat area between reactant speed and flame stability. At the $D1/D2$ combustor 0.9, the flame shape area near the step can achieve stability at the equivalent ratio and a higher reactant velocity. Furthermore, this phenomenon indicates that the reactant velocity and the recirculation region can stabilize the flame.

The oscillating flame mode is formed at a $D1/D2$ ratio of 0.7 combustors with butane fuel. The oscillating flame mode area is around the equivalent ratio = 0.89 to 1.26. The flame formed oscillates from the end of the combustor to the step and continues to oscillate without experiencing extinction. The spinning flame mode is formed at $D1/D2$ combustor 0.7 with butane fuel and a biogas-butane mixture. The spinning flame mode area occurs at the equivalent ratio = 0.89 to 1.20 with medium to high reactant velocities. Flame mode spinning flame is formed crosswise and spins like an X shape with a flame that is stable for a long time without extinguishing.

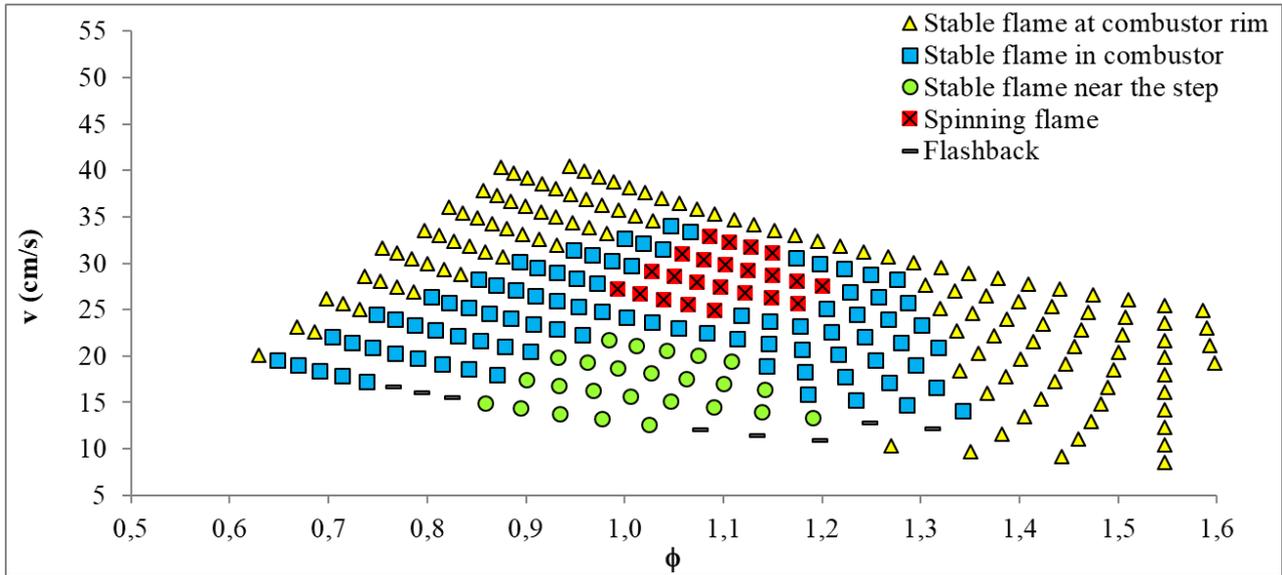


Fig. 10 - Biogas-butane mixture flame mode map at 0.7 combustor ratio

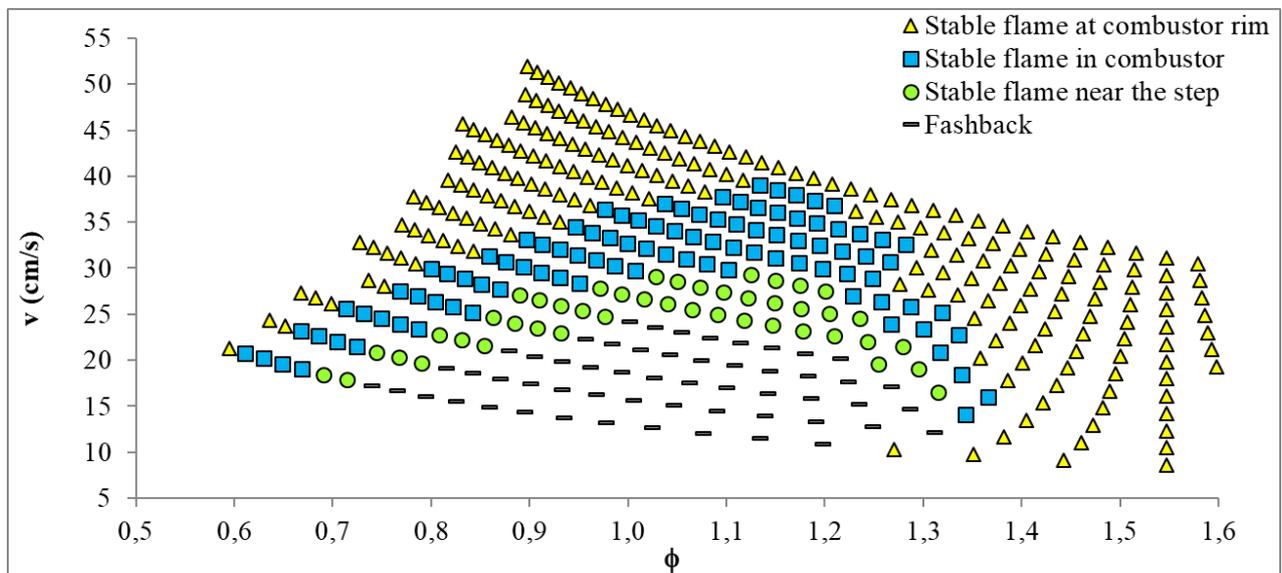


Fig. 11 - Biogas-butane mixture flame mode at 0.9 combustor ratio

Furthermore, figure 12–17 shows a bar graph of the flame and combustor wall temperatures for each fuel variation and the combustor D1/D2 ratio. This figure shows that the flame temperature is stable at the equivalence ratio (ϕ) 1.23. However, as shown in Figure 12, biogas fuel has a very low flame temperature, where the flame temperature produced is 681.98 °C, followed by a mixture of biogas-butane fuel with a flame temperature of 873.96 °C and butane fuel produces a flame temperature of 873.96 °C. Highest with a temperature of 950.02 °C. Furthermore, as shown in Figure 13, biogas fuel has a very low flame temperature, where the flame temperature produced is 733.94 °C, followed by a mixture of biogas-butane fuel with a flame temperature of 950.76 °C and butane fuel produces a high flame temperature. Highest with a temperature of 1103.96 °C.

On the other hand, as shown in Figure 14, each fuel in the 0.7 combustors has a lower flame temperature than the fuel in the 0.9 combustors. This shows that the small size of the bfs can affect the heat and mass recirculation at any ratio D1/D2 combustor. The graph of the average wall at a combustor ratio of 0.9, as shown in Figure 16, shows that biogas fuel has a very low average wall temperature, where the average wall temperature produced is 159.53 °C, followed by a mixture of biogas-butane fuel with an average temperature of 159.53 °C. The average wall temperature is 230.55 °C, and butane fuel produces the highest average wall temperature with a temperature of 279.46 °C. In addition, the graph of the average wall at the combustor ratio of 0.7 and 0.9, as shown in Figure 17, shows that each fuel in the 0.7 combustors has a lower average wall temperature than the fuel in the 0.9 combustors. This shows that the small size of the bfs can affect the heat and mass recirculation at each ratio D1/D2 combustor so that the temperature on the wall

also increases along with the increasing flame temperature. However, Figure 12 – 17 shows the flame temperature and the average wall temperature for the variation of fuel and combustor ratio at equivalence ratio (ϕ) 1.23. The combustor ratio of 0.7 and 0.9 indicates that the flame temperature and the average wall temperature of butane fuel have the highest temperature, followed by butane fuel and biogas fuel. For the variation of biogas fuel, it has a lower flame temperature and average wall temperature compared to butane fuel or a mixture of biogas-butane fuel. This is because the calorific value of biogas is lower than the calorific value of butane or a mixture of biogas-butane, so the flame temperature and the average wall temperature are lower. Mixing biogas fuel with butane results in an increase in the calorific value of biogas so that the temperature of the biogas-butane increases [28]. The various shape of the bfs will cause a temperature difference, as shown in Figures 14 and 17. A larger size of the D1/D2 ratio will result in sufficient heat and mass recirculation for the occurrence of a stable flame in the combustor so that the flame temperature will be obtained. Moreover, higher average wall temperature compared to the small D1/D2 ratio size.

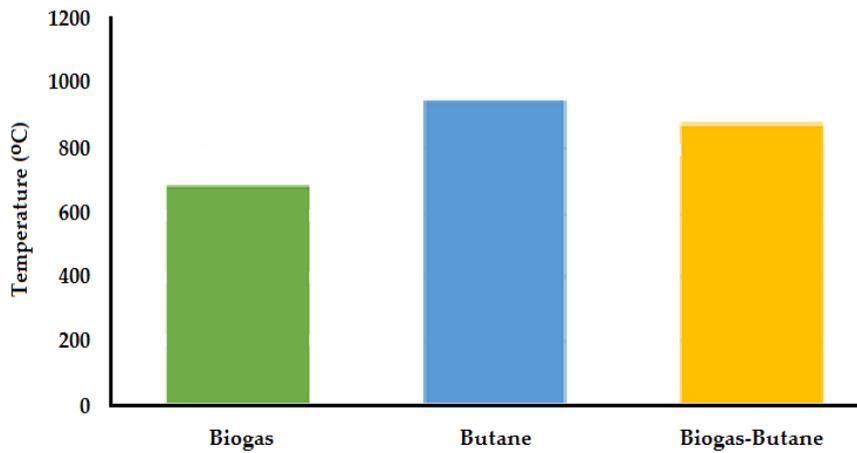


Fig. 12 - The flame temperature at 0.7 combustor ratio

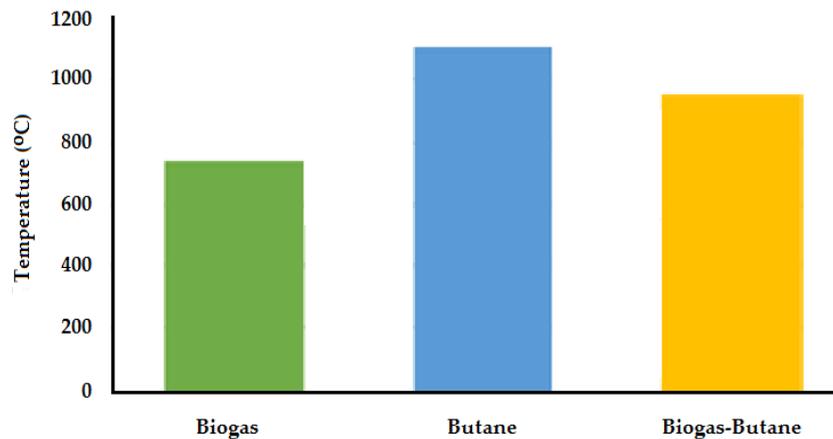


Fig. 13 - The flame temperature at 0.9 combustor ratio

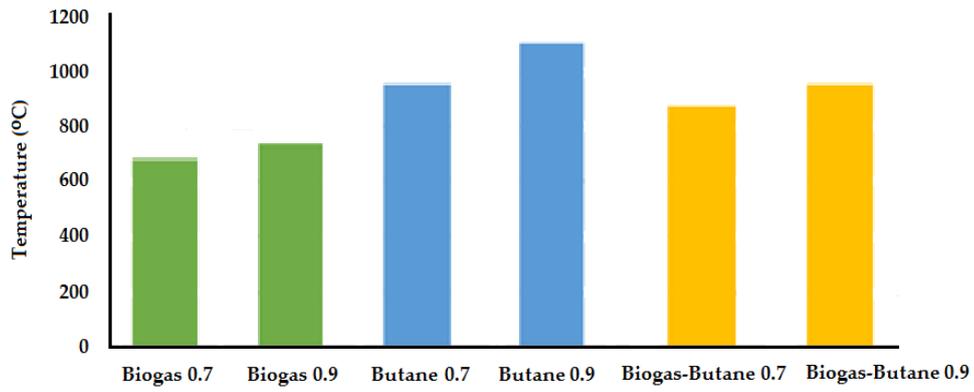


Fig. 14 - The flame temperature at 0.7 and 0.9 combustor ratio

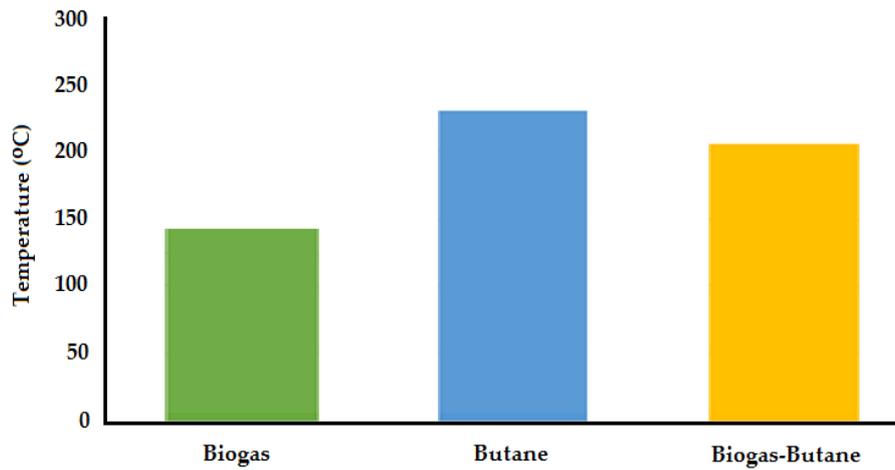


Fig. 15 - The temperature of the combustor at 0.7 combustor ratio

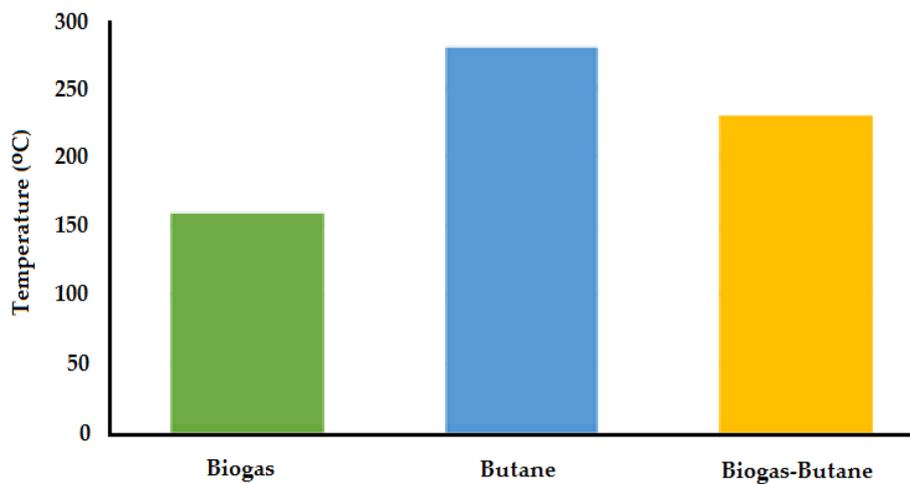


Fig. 16 - The average wall temperature of the combustor at 0.9 combustor ratio

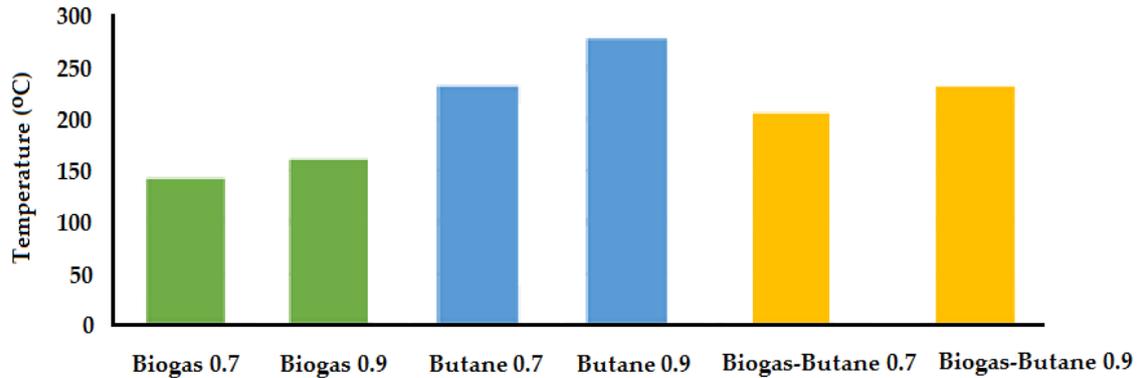


Fig. 17 - The average wall temperature of the combustor at 0.7 and 0.9 combustor ratio

4. Conclusion

Research on the characterization of biogas as an alternative fuel with a mixture of Butane in micro-scale combustion technology has been done. Several important findings were found, i.e.;

- The characterization of biogas fuel combustion gave lower yields than the treatment of variations of biogas-butane fuel and butane fuel due to the effect of the lower calorific value of biogas. It takes mixing biogas fuel with butane to improve biogas fuel properties.
- The combustion of biogas-butane fuel produces a wider flame stability limit area, a wider variety of flame mode visualization variations with a more widely distributed flame mode map, and higher flame and combustor wall temperatures than the characterization of biogas combustion without butane gas mixing for combustion possible test range.
- A smaller backward step size will provide a wider flame stability area. Moreover, a small backward-facing step improves reactant flow recirculation and heat recirculation in flame stabilization of biogas fuel combustion.
- The future development is crucial to explore further studies about the role and phenomena of biogas fuel from a molecular perspective so that it can reveal basic scientific information about the performance of biogas fuel at atomic and subatomic levels.

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