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The Influence of Heat Recirculation Segment of Meso-Scale Combustor o Gas and Liquid Fuel Inside Microscale Combustor

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ABSTRACT

This study aims to determine the effect of heat recirculation segments configuration on the stability of the flame. Mesoscale combustor used is made from duralumin-quart glass tube, and Ø 3.5 mm diameter combustion chamber. The heat recirculation segments part is made of duralumin as a segment of evaporation and air-fuel mixing. Combustor A has heat recirculation segments length of 7 mm, while combustor B has a heat recirculation segments length of 10 mm. The fuel used is liquid hexane and butane gas fuel. The results showed, the stability of hexane flame in combustor A between the equivalent ratio of ϕ 0.73-1.28 temperature can reach 803.8°C. Combustor B is stable at an equivalent ratio of ϕ 0.76-0.98 to a temperature of 580.9°C. Furthermore, for butane flames; combustor A, stable in the range of ϕ 0.68-1.31 temperature to 931.3°C. Combustor B has a stability range of ϕ 0.79-1.41 temperature reaches 857.2°C. Combustor A with a 7 mm heat recirculation segments length is proven to produce wider flame stability, using both liquid fuel and gas. So, combustor A can be recommended to be applied to micro power generators. It should be noted that butane flames appear to have more flame stability than hexane flames. This is because gaseous fuels are more homogeneous (gaseous) so they are more quickly mixed with air.

1. Introduction

Advances in technology have implications for the increasing use of equipment. The need for electricity itself is generally supplied from generators whose energy is supplied from water turbines, wind turbines, or diesel, steam turbines, photovoltaic [1-4]. Diesel can be operated with diesel oil or biodiesel [5]. In general, the generated electricity is channelled through an electrical power network. In certain needs, it takes supply for only one device. Like one battery for one laptop, one battery for robots, one cellular phone battery. To meet the needs of one device and one source of electricity, in addition to batteries, a micro power electric generator, or portable power generator or micro power generators (MPG) has been developed.

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Portable power generator, such as micro power generators (MPG) have been created and developed as battery replacements for power suppliers [6,7]. One of the important components of a micro power generator is the mesoscale combustor, which plays a role in generating heat through the combustion of hydrocarbons in it. The heat produced by the mesoscale combustor is then converted into electrical energy through thermoelectric/thermos photo voltaic [8].

Creating a flame or stabilizing the flame in the mesoscale combustor is difficult, due to the short resident time of the reactant and the magnitude of the heat loss [9,10]. High heat losses due to the high of the area to volume ratio of combustion chamber. This high heat loss causes the cooling of the flame. The smallness of the combustion chamber also causes a short resident time of fuel and oxidizers in it, affecting the flame instability [11-16].

One of the efforts to stabilize the flame is by the method of heat recirculation. The heat recirculation method can also be applied to the combustion of liquid fuels in the mesoscale combustor for its evaporation and preheating process. Heat recirculation segments is an effective component to improve combustion performance in the mesoscale combustor to anticipate heat loss. There is a fuel chamber in the heat recirculation segments, as a space for evaporation and mixing of reactants. Heat comes from a flame or an external reaction [17-19]. The energy from this flame is used as a preheating energy of evaporation energy and also the activation energy of new reactants. There is a fuel chamber in the heat recirculation segments, as a space for evaporation and mixing of reactants. Heat comes from a flame or an external reaction. The energy from this flame is used as a preheating energy of evaporation energy and also the activation energy of new reactants.

The selection of heat recirculation segments materials is important, related to their heat capacity, or heat conductivity [20]. Low conductivity (stainless steel) causes slow heating, while excessive conductivity causes heat to be transferred rapidly, impacting the cooling of the flame. The use of copper as a heat recirculation segment can stabilize the flame of liquid fuel in the mesoscale combustor [21]. Soft copper, causing easily deformed plastic due to high temperatures, resulting in the easily damaged heat recirculation segments [22]. Stainless steel heat recirculation segments have good firmness but have low thermal conductivity. Stainless steel is more resistant at high temperatures, but its conductivity is much lower than copper, affecting its flame stability. Stainless steel heat recirculation segments have good firmness but have low thermal conductivity. Stainless steel is more resistant at high temperatures, but its conductivity is much lower than copper, affecting its flame stability. Stainless steel heat recirculation segments have good firmness but have low thermal conductivity. Stainless steel is more resistant at high temperatures, but its conductivity is much lower than copper, affecting its flame stability [21].

In addition to the type of material, the effectiveness of heat circulation will also be influenced by the geometric factor of the heat recirculation segments. The wider or longer the heat recirculation segments, the greater the heat sent to the new reactant in the fuel chamber. On the other hand, if it is too wide or too long then also more and more flame heat is absorbed to heat the body heat recirculation segments. Heat uptake into the body of the heat recirculation segments can cause cooling resulting in a extinguished flame. Therefore, it takes the right length of heat recirculation segments to produce wide flame stability with higher temperatures. This study, intended to find out the influence or prove the effect of the size and material of the heat recirculation segments on the stability of the flame of liquid fuel (hexane) and gas fuel (butane) in the mesoscale combustor with a diameter of Ø 3.5 mm combustion chamber in addition to the type of material, the effectiveness of heat circulation will also be influenced by the geometric factor of the heat recirculation segments. The wider or longer the heat recirculation segments, the greater the heat sent to the new reactant in the fuel chamber. On the other hand, if it is too wide or too long then also more and more flame heat is absorbed to heat the body heat recirculation segments. Heat uptake into the body of the heat recirculation segments can cause cooling resulting in an extinguished flame. Therefore, it takes the right length of heat recirculation segments to produce wide flame stability with higher temperatures. This study, intended to find out the influence or prove the effect of the size and material of the heat recirculation segments on the stability of the flame of liquid fuel (hexane) and gas fuel (butane) in the mesoscale combustor with a diameter of Ø 3.5 mm combustion chamber.

2. Methodology

The study used two mesoscale combustor duralumin-quart glass tubes with a combustion chamber diameter of Ø 3.5 mm. Inserted flame holder duralumin type perforated plate lines 8 with a thickness of 1 mm between the separator and the exhaust section, as shown in Figure 1 and Figure 2. The two combustors used are the same, differing only on the short length of the heat recirculation segments. Mesoscale combustor has the main parts, as follows: Heat recirculation segments made of the duralumin heat with an annulus chamber inside; inserts of quart glass tube separator segment; duralumin flame holder; downstream section of quart glass tube exhaust section.

Heat recirculation segments are used for the initial heating of reactants, which are air-fuel mixtures that enter through the inlet channel in the annulus chamber. The reactant heat flows into the combustion chamber through a small hole in the wall of the annulus chamber. At the upstream the reactant heat flows through a gap in the flame holder which is then reacted to the downstream (reaction zone) close to the flame holder.

To facilitate the research, each meso scale combutor is named; combustor A has heat recirculation segments length of 7 mm and combustor B has heat recirculation segments 10 mm. Each combustor is alternately assembled and observed at the research installation as shown in Figure 3 and Figure 4.

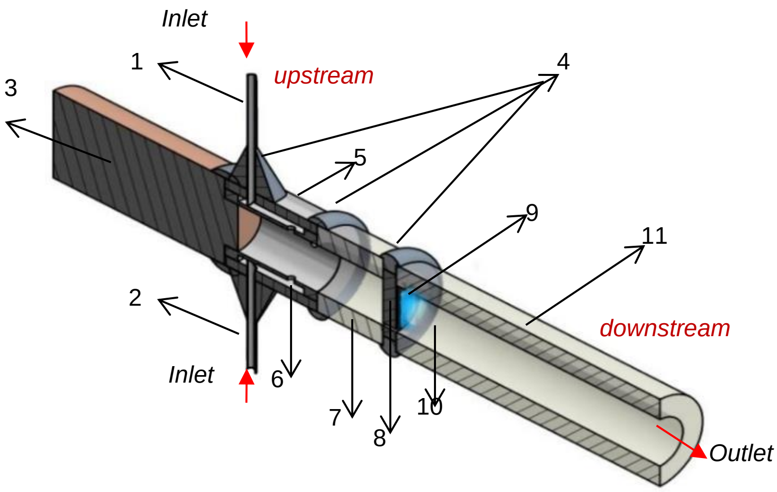

Fig. 1. Mesoscale Combustor parts: 1) Air Inlet, 2) Fuel Inlet, 3) Ceramics, 4) Ceramic Adhesives, 5) heat recirculation segments, 6) Annulus Room, 7) Quart-Glass Tube divider, 8) Flame Holder, 9) Flame, 10) Reaction Zone, 11) Quart Glass Tube disposal section

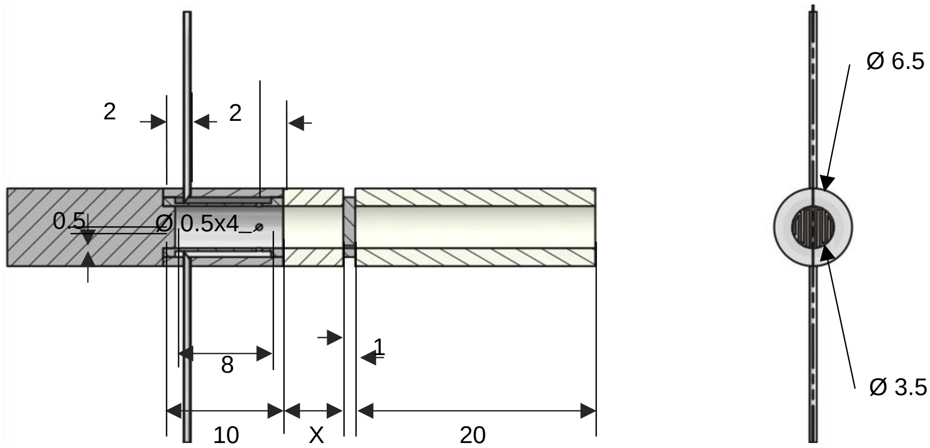

Fig. 2. Combustor B (unit: mm)

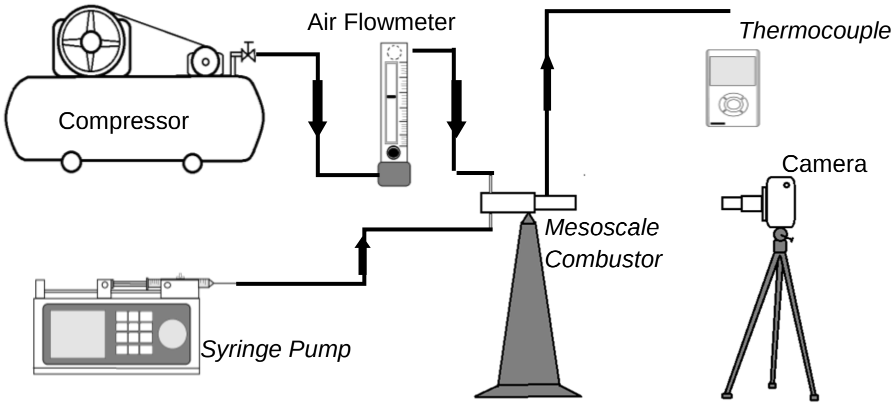

Fig. 3. Research installations for liquid fuel

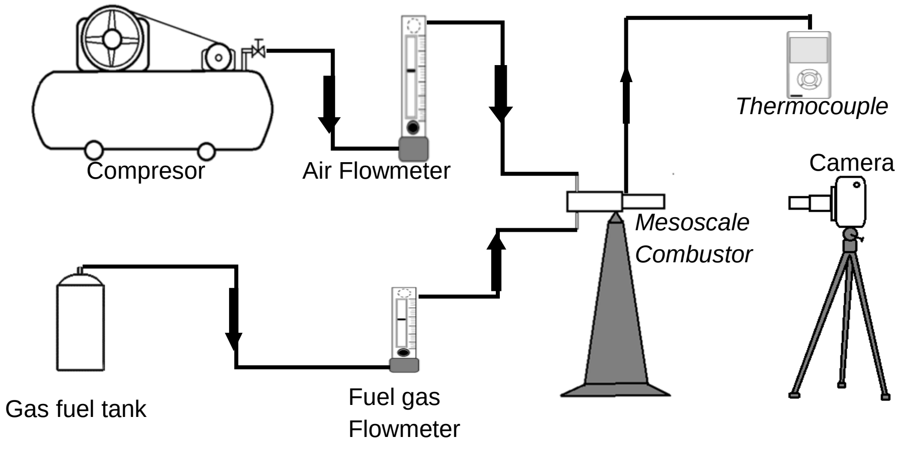

Fig. 4. Research installations for gas fuel

Liquid fuel hexane (C6H14), injected and discharge is set to mesoscale combustor using a syringe pump. As for butane gas fuel (C4H10) is expanded from gas fuel tubes and discharge is regulated using a fuel flowmeter. Air is supplied from the air tank (compressor), and the discharge is controlled by an air flowmeter. Connected wire probe or cable 0.2 mm diameter to thermocouple to measure temperature. Placed a camera complete with a macro lens on the front side of the mesoscale combustor to observe and visualize the flame inside. Liquid fuel hexane (C6H14), injected and discharge is set to mesoscale combustor using a syringe pump. As for butane gas fuel (C4H10) is expanded from gas fuel tubes and discharge is regulated using a fuel flowmeter. Air is supplied from the air tank (compressor), and the discharge is controlled by an air flowmeter. Connected wire probe or cable 0.2 mm diameter to thermocouple to measure temperature. Placed a camera complete with a macro lens on the front side of the mesoscale combustor to observe and document the flame inside.

Data retrieval begins by providing external heating to the combustor body from upstream to downstream and combining air and fuel discharge until the flame is stable in it. Flame observation is observed for more than 3 minutes to ensure that the flame is completely stable. It then varies the air discharge to get the minimum and maximum values and then it is recorded. Continued on the next fuel discharge is to increase/decrease the discharge constantly to the minimum-maximum discharge value. Done again by looking for air discharge values ranging from minimum to maximum value where the flame is extinguished/carried out away from the flame holder.

3. Results

Figure 5 shows the limit of the stability of combustor flames A and B using liquid fuel and gas. The area between the minimum curve line (on the left) and the maximum curve line (on the right) is the limit of the stability of the flame that is successfully stabilized. This means that the flame can burn close to the flame holder for more than 3 minutes. The higher the value of the equivalent ratio, the richer the reactant mixture, the richer the fuel. While the smaller the equivalent ratio, the more fuel-poor the reactant mixture. There will be no flame if the equivalent ratio exceeds the minimum limit, because the mixture is too poor. Likewise, on the right side there is also no flame if the equivalent ratio exceeds the maximum limit, because the mixture is too rich.

Combustor A hexane flame managed to stabilize with a range ratio of ϕ 0.73-1.28 with a flow speed of U reactants 22.8 - 33.23 cm/s. Combustor B can be stable at an equivalent ratio of ϕ 0.76-0.98 with a speed of U 26.3 - 32.03 cm/s. While in the use of fuel gas butane flame managed to be stable at a ratio of ϕ 0.68-1.31 to the flow speed of U reactants 24.17 - 53.83 cm/s in combustor A, for combustor B stable flame between ϕ 0.79-1.41 with a speed of U 24.8 - 45.03 cm/ s. This means combustor A with a shorter heat recirculation segments, the range of flame stability is wider using both liquid and gaseous fuels.

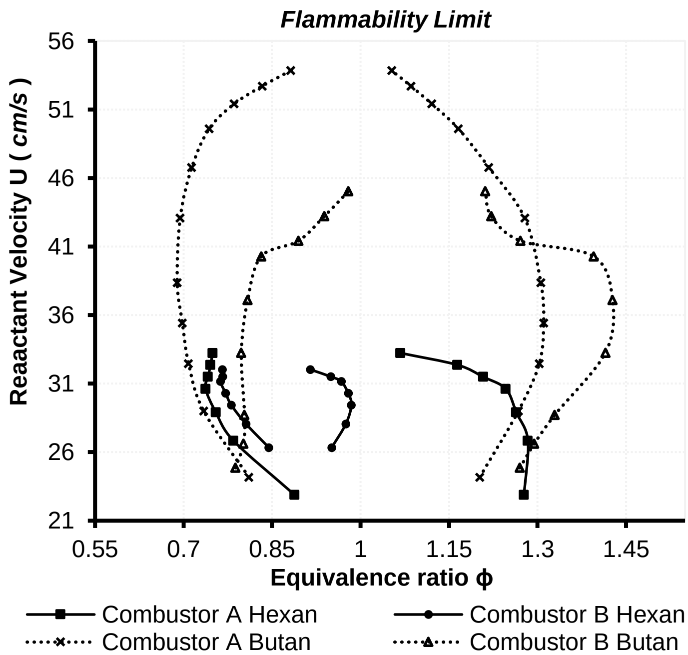

Fig. 5. Combustor flame stability A and B

In Figure 6 and Figure 8, it is a visualization of hexane and butane flames that are successfully stabilized on combustor A and B. At low speeds the flame is dark blue. While at high speeds the flame is getting bright blue (thick) and widening closer to the wall of the combustion chamber. This indicates the higher the speed of the reactant flow, the more air-fuel mixture. As a result, more and more reactants are reacted. Therefore, the flame at a high speed is brighter and wider than the low flow speed of the reactants.

Figure 7 and Figure 9, visualization of hexane and butane flames also thicken at each increase in the equivalent ratio but the flames appear to be getting smaller. The higher the equivalent ratio (ϕ) of the reactant mixture the richer the fuel (fuel rich mixture). Judging from the ratio of the lowest equivalent of the flame almost fills the combustion chamber and shrinks away from the combustor wall at a higher equivalent ratio. This is because more and more reactants contained a lot of fuel to conditions where the amount of air is not enough for combustion reactions. This causes the flame to become bright and shrink.

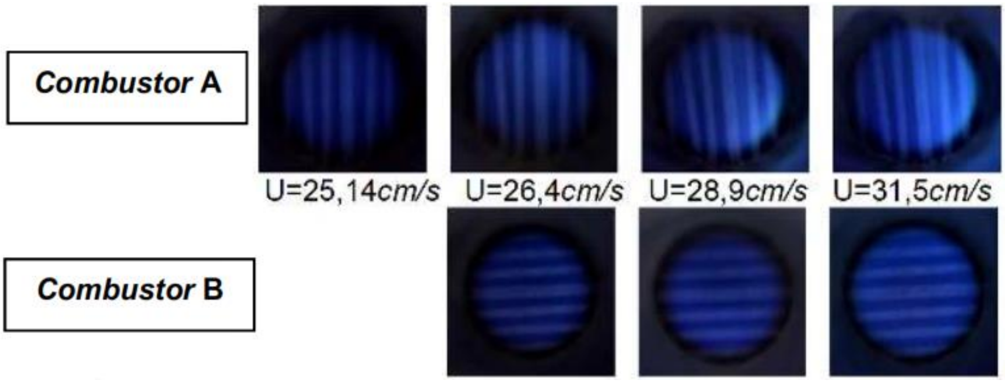

Fig. 6. Visualization of combustor hexane flames A and B, at ϕ = 0.87

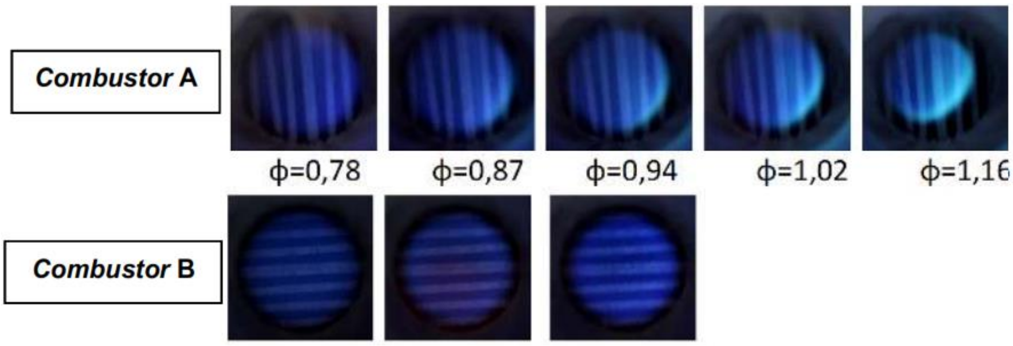

Fig. 7. Visualization of combustor hexane flames A and B, at U=29.83 cm/s

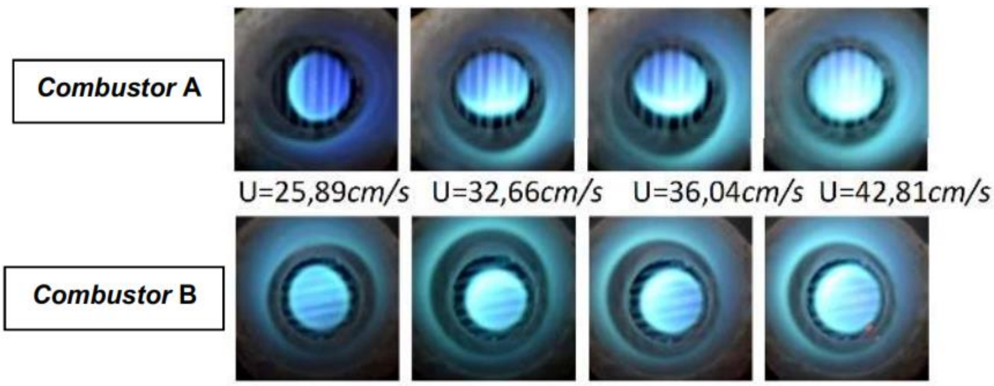

Fig. 8. Visualization of butane combustor flames A and B, at ϕ = 1.03

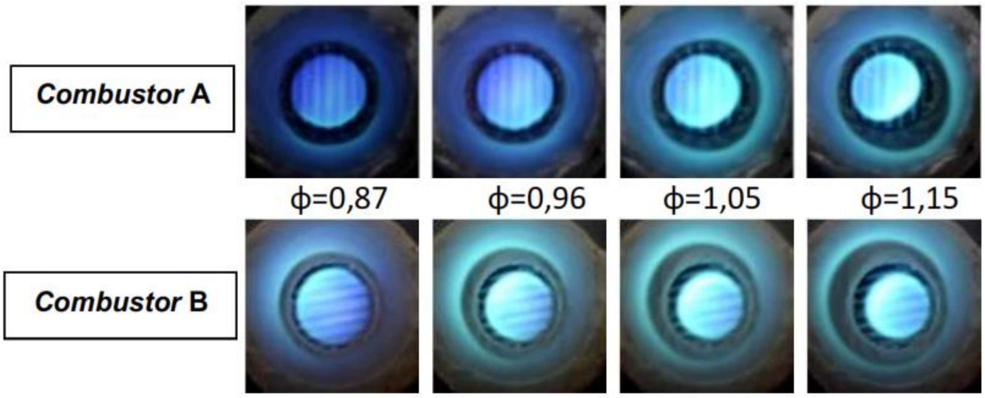

Fig. 9. Visualization of butane combustor flames A and B, at U=38.57 cm/s

Figure 10 and Figure 12 are the distribution of hexane and butane combustion temperatures at varying reactant (U) speeds. There is an increase in temperature of each increase in the rate of reactant flow (U) at a constant equivalent ratio. This is because at a higher speed, air-fuel discharge is increasingly abundant. Many air-fuel mixtures cause reactants to react more and more so that the temperature at a top speed of U = 31.5 cm/s hexane temperature, U = 42.81 cm/s butane increases.

Figure 11 and Figure 13 saw a change in temperature that increased and then decreased as the ratio of equivalents increased. At a higher equivalent ratio, the amount of fuel in the combustor is increasingly abundant and not offset by an increase in air discharge. So the reactant mixture is rich in fuel. As a result, many unburned reactants (unburned gas) will increase. The increase in unberned gas flame temperature decreases because the unburned gas temperature is much lower than the temperature of the flame. Combustion like this can be said to be wasteful combustion of fuel, because a lot of fuel that cannot be reacted.

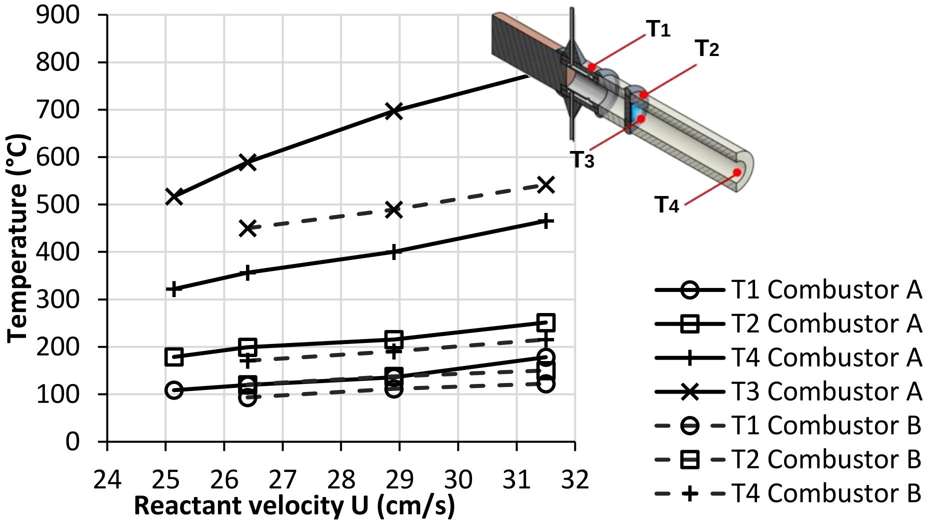

Fig. 10. Combustor temperature distribution A and B liquid hexane, ϕ = 0.87

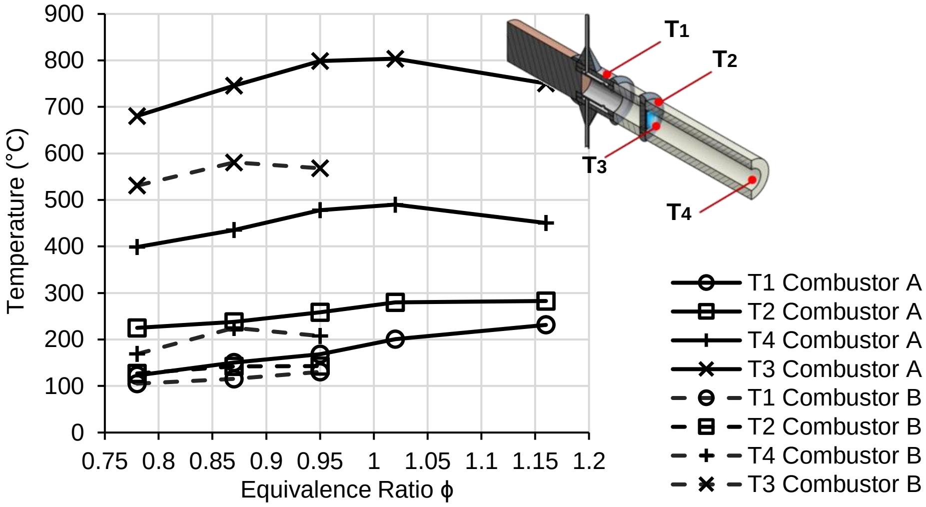

Fig. 11. Combustor temperature distribution A and B liquid hexane, U=29.83 cm/s

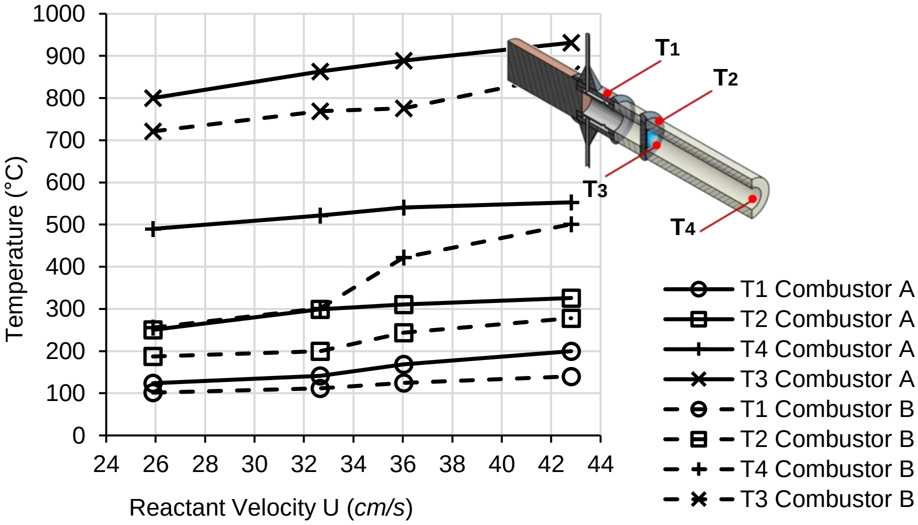

Fig. 12. Combustor temperature distribution A and B butane gas, ϕ = 1.03

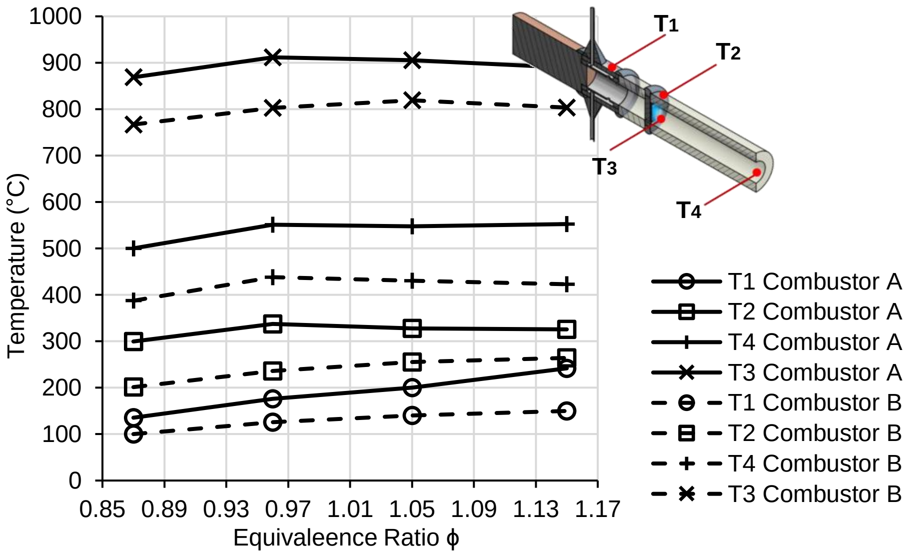

Fig. 13. Distribution of combustor temperature A and B butane gas, U=38.57 cm/s

Seen at the equivalent ratios ϕ=0.94 - 1.02 (Figure 12), and ϕ=0.96 - 1.05 (Figure 14) the flashpoint temperature is at its highest peak then decreases at a higher equivalent ratio. This means showing that the reactant mixture is/close to stoichiometric conditions, considering that the air-fuel mixture at ϕ=1 is the ideal mixture [23].

The stability of the flame in combustor A is wider, the temperature is also higher than combustor B. As shown in (Figure 5) the stability of the flame and (Figure 10 to Figure 13) the distribution of temperature, this is due to the amount of heat capacity sent to the annulus chamber or flame heat absorbed in the reaction zone. More details, you can see the illustration of heat flow on Figure 14 and Figure 15.

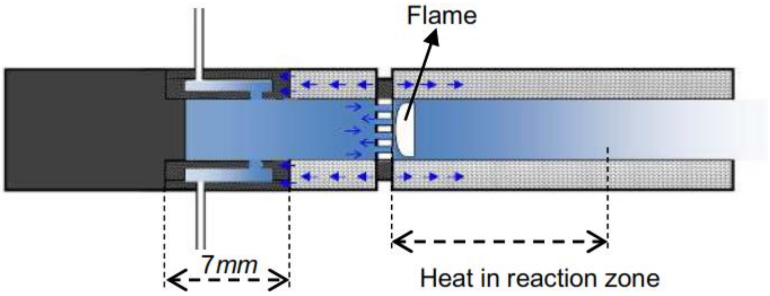

Fig. 14. Illustration of reactant heat flow on combustor A

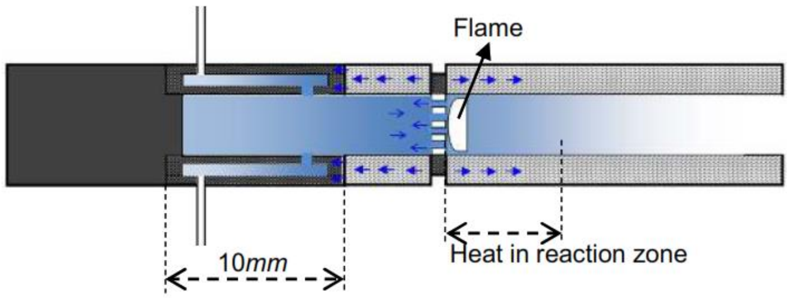

Fig. 15. Illustration of reactant heat flow on combustor B

Combustor B has a longer heat recirculation segments meaning the annulus space is also wider. The heat recirculation segments are getting longer, so the heat from the flame is also absorbed larger. While in combustor A does not absorb too much heat because the capacity or area in the annulus space is smaller or shorter. This causes the distribution of temperatures ranging from T1 to T4 at combustor A higher and more able to keep the heat at the flash point. Therefore, combustor A has a wider flame stability. When observed again, the stability of the butane flame is wider than the hexane flame, the visualization of the flame is also brighter evenly and thickened than the hexane flame. This is because butane gas fuel is more homogeneous meaning it is the same as air, so it is easier or faster to mix it with air.

The stability of the hexane flame is narrower than the butane flame, the flame visualization is also uneven compared to the visualization of the butane flame. This is because the use of hexane liquid fuel still requires the process of evaporation before mixing with air. The mixing process is slower than the use of gas fuels that are faster evenly distributed. In addition, the dripping of hexane fuel with conditions that are still cold in the annulus chamber, also affects the decrease in temperature in the combustor.

4. Conclusions

Hexane flame on combustor A, successfully stabilized at an equivalent ratio of ϕ 0.73-1.28 with a speed of U 22.8 - 33.23 cm/s. While in combustor B between ϕ 0.76-0.98 with a reactant speed of U 26.3 - 32.03 cm/s.

Butane flame on combustor A, can be stable at an equivalent ratio of ϕ 0.68-1.31 with a U reactant speed of 24.17 - 53.83 cm/s. In combustor B between ϕ 0.79-1.41 with a speed of U 24.8 - 45.03 cm/s.

The Combustor A with a 7 mm heat recirculation segments is the right choice, proven to produce wider flame stability, using both liquid and gaseous fuels. The flame temperature can reach 803.8°C in hexane liquid fuel and 931.3°C for butane gas fuel. So, combustor A can be recommended to be applied to micro power generators.

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