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The Role of Flue Gas Inhibitor on Stabilizing Heptane Flame in Mesoscale Combustor

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Abstract

A mesoscale combustor is one of the components that serve to generate heat on a micropower generator. As one of the components of a micropower generator, a meso scale combustor serves to supply heat through the combustion process. The stability of the flame in the combustion chamber mesoscale combustor is influenced by the temperature of the combustion chamber. One way to maintain a high temperature in the combustion chamber is to insert a flue gas stainless steel mesh resistor. This research aims to prove the role of flue gas mesh resistors in stabilizing the flame on the mesoscale combustor... The heptane liquid fuel flame was successfully stabilized at an equivalence ratio of ϕ 0.81 – 1.29 and a reactant flow velocity of 26.12 – 36.83 cm/s. The higher the rate of reactant flow, the higher the flame temperature until it reaches 502ºC. The combustor with a flue gas mesh resistor is 10 mm away has a flammability limit that is not wider than a combustor without a flue gas mesh resistor.

Keywords: *flue gas resistor mesh; heptane; mesoscale combustor; wire mesh*

1. INTRODUCTION

Micropower generators are micro-scale power plants designed to replace batteries. One of the components of a micropower generator is a mesoscale combustor that serves to supply heat by burning hydrocarbons in it. Combustion on the micro or mesoscale must be stable to ensure the sustainability of the electrical energy generated. The mesoscale combustor has a characteristic diameter between 1 mm to 10 mm [1]–[5]. Stabilizing the flame in the mesoscale combustor is difficult due to its small size, which causes large heat losses, and a short reactant resident time. In increasing the stability of the flame, the fuel resident time needs to be increased, while the heat loss needs to be reduced [6], [7]. Various ways are done to stabilize the flame in the micro/mesoscale combustor such as insertion of stainless steel mesh, multi-step tube combustor [8]–[10][11], [12], use of various type flame holder, Use of double mesh [13], use of variations in wall thickness on combustors [14]–[17].

Stabilizing the flame of liquid fuel in the mesoscale combustor is more challenging than the combustion of gas fuel. This is due to the evaporation phase of liquid fuel. Liquid fuel flame successfully stabilized in mesoscale combustor tube type in various ways [18][10][19][17][20]. The stable flame attaches to the flame holder where the flame holder increases the recirculation of the heat to the reactant so that the reactant is more flammable, and ultimately increases the stability of the flame. The stability of the flame in the micro/mesoscale combustor is better if combustion occurs at high temperatures [21]. The combustion gas directly exits through the mesoscale combustor outlet, in hot conditions. This means that some heat is wasted along with exhaust gases. If the combustion gas is inhibited out, then there will be an increase in the temperature of the combustion chamber, thus increasing the stability of the flame. Inhibition of exhaust gases means that it will also prolong the stay of reactants in the mesoscale combustor. Overall, this will increase the stability of the flame [22]. However, inhibition of exhaust gases causes the concentration of oxygen in the combustion chamber to decrease due to the presence of CO2. This decreases the stability of the flame. Making a flame or stabilizing the flame on the mesoscale combustor with exhaust gas inhibitors is more difficult than on a mesoscale combustor without flue gas inhibitor mesh, especially during ignition. In a tube-type mesoscale combustor, exhaust gas containment can be strengthened with stainless steel mesh inserts, the challenge is on how to trigger it. The challenge of fraying if burned there is a liquid fuel, because of the evaporation phase.

This research aims to stabilize the flame in the mesoscale combustor with the insert of the exhaust gas retaining mesh and find out the effect of exhaust gas retaining on the gas emissions of mesh resistors. This study used heptane liquid fuel with a duralumin flame holder with a tube diameter of 3.5 mm and added stainless steel mesh to the combustor. In this study, observations were made on the visualization of flames, flammability limits, and fire temperature.

2. METHODS

The study used a mesoscale combustor, composed of a quart glass tube flame holder, heat recirculation. All of these components have an inner diameter of 3.5 mm. Flame holders are made of duralumin with perforated plate lines and have 1 mm thick. In the gas discharge segment inserted in the exhaust gas inhibitor mesh, the distance of the flame holder with the mesh insert is 10 mm. The segment, which is bounded by flame holders and flue gas inhibitor mesh is a combustion chamber, has a length of 10 mm.

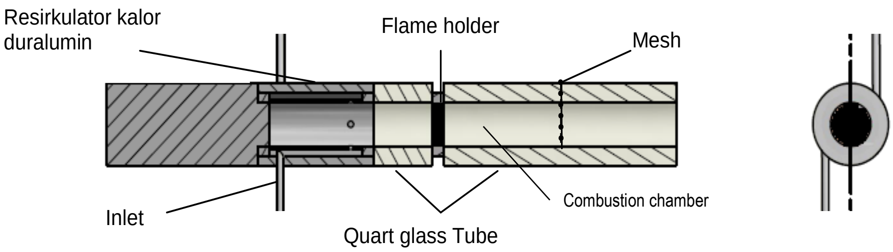


Figure 1. Structure of mesoscale combustor

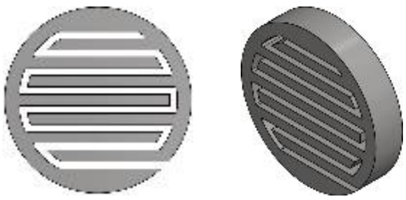


Figure 2. Lines Perforated Plate

Heptane liquid fuel, pumped into the combustor using a HE 1000 syringe pump. Air is supplied from the compressor, regulated discharge by an airflow meter, Koflock, and flowed to the mesoscale combustor. A lighter composed of a cathode is placed inside the combustion chamber, connected to a high voltage source of 13KV. Once the fire is lit, the lighter is turned off. If stable, the fire will remain burning due to the heat circulating from flue gas inhibitor mesh, flame holder, quart glass tube inserts, and heat recirculating. Visualization of the flame is documented with the camera. Thermocouple type K is connected to data acquisition to measure the temperature that occurs on the mesoscale combustor.

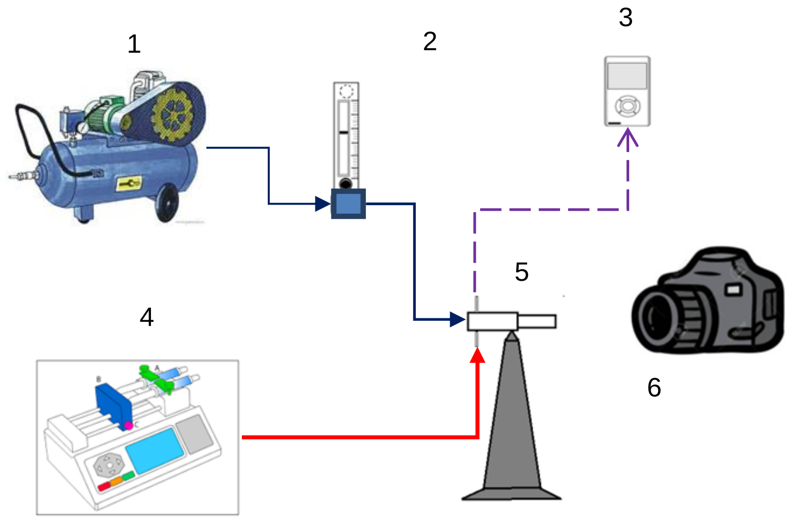


Figure 3. Research Installation
1). Compressor, 2). Air flow meter, 3). thermocouple, 4). Syringe pump 5). Meso combustor, 6). Camera

3. Result and Discussion

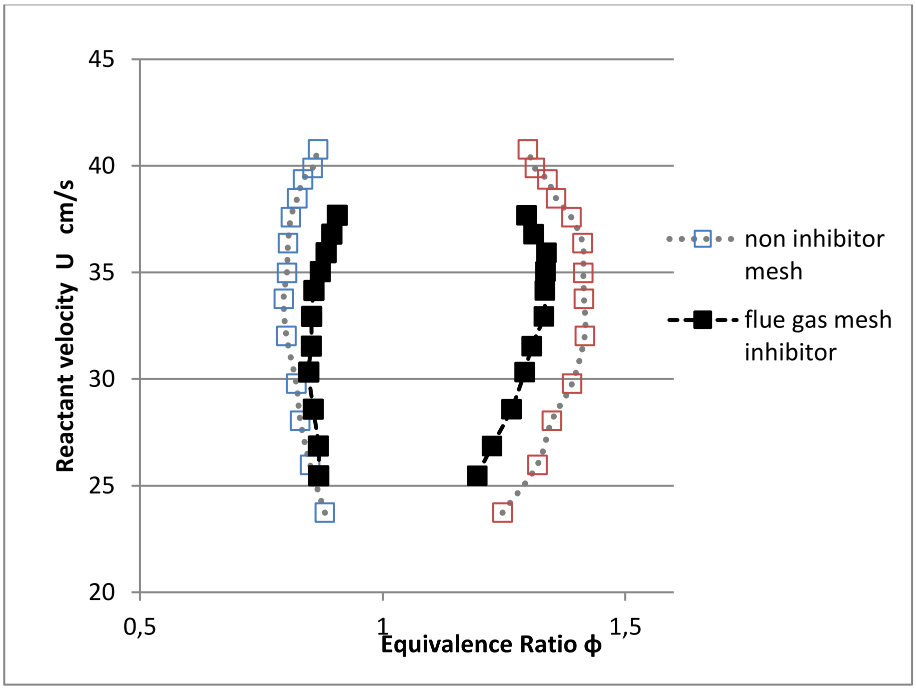


Figure 4. Flammability limits

Figure 4 is express the flammability limits of heptane combustion in mesoscale combustion. The area is irrigated by the minimal curve and the area to the right of the maximal curve is the area without the flame. The area is flanked by a minimal curve and the maximum curve is the area of flame. This means that if the equivalence ratio is ϕ = 1 and the reactant speed is 30 cm /s then there can be a flame. If the equivalence ratio is ϕ = 1.5 and the reactant speed is 30 cm/s then there cannot be a flame.

The design of mesoscale combustor tube type studied, which is composed of heat recirculation segment, flame holder, quartz tube and flue gas inhibitor proved to be used to stabilize hexane. From the graph, mesoscale combustor with flue gas inhibitor mesh has narrower flammability limits compared to mesoscale combustor without flue gas inhibitors.

One of the causes of the stability of a flame that is narrower than a mesoscale combustor without mesh is the diameter of the hole in the mesh that is too small, and the mesh is too tight to cause the flame to get stuck between the mesh and flame holder and cannot last long. The higher the equivalence ratio value, the richer the fuel contained in the reactant mixture, and vice versa the smaller the equivalence ratio value, the smaller the fuel contained in the reactant mixture.

In meso-combustor with flue gas inhibitors, the flame is successfully stabilized at an equivalence ratio of ϕ 0.87 to 1.13. Flue gas inhibitors play a role in keeping the temperature in the combustion chamber hot so that when the reactant arrives in the combustion chamber, at the self-ignition temperature. Heat in the retained combustion chamber is stored longer indirectly wasted out because it is held back by the presence of flue gas inhibitors mesh.

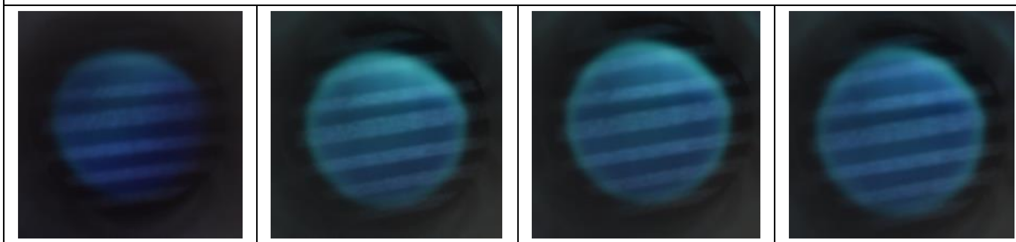
equivalence ratio **ϕ = 1,08**			
			
U = 26,12 cm/s	U = 29,93 cm/s	U = 34,24 cm/s	U = 36,83 cm/s

Figure 5. Flame visualization

Figure 5 presents a visualization of the heptane flame in the mesoscale combustor with flue gas inhibitors. In the constant equivalence ratio ϕ, it is seen that at U = 26.12 cm/s, the flame appears to shrink and thicken in color. At U = 29.93 cm/s the fire looks brighter when compared to the flow speed of U reactants = 26.12 cm/s. While at U = 34.24 cm / s the flame looks wider on the side of the combustor wall. For U = 36.83 cm/s the flame widens to fill the side of the combustor wall. This indicates that with a constant equivalence ratio and a higher flow speed, the flame gets bigger and fills the side of the combustion chamber wall.

This shows that the higher the speed of the reactant, the more fuel and air mixture. The mixture of fuel and air is mixed more slowly due to heat in the combustion chamber that is cooling because the heat is absorbed by the wire mesh. As a result of this, the color of the flame becomes widened to the side of the combustor wall. This is a fuel-poor flame because of the more air mixture when compared to fuel.

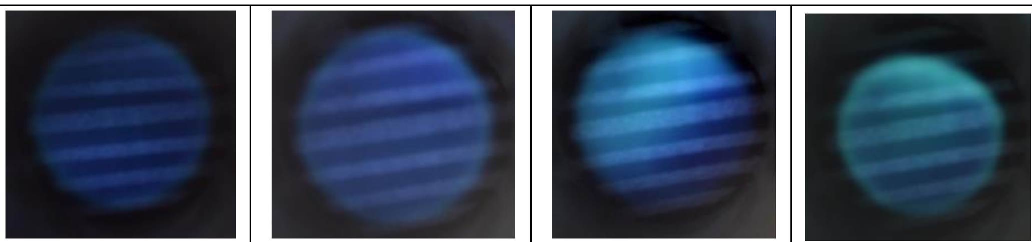
Reactant velocity* U = 32,29 *cm/s			
			
ϕ = 0,87	ϕ = 1,01	ϕ = 1,15	ϕ = 1,29

Figure 6. Flame visualization at constant reactant velocity

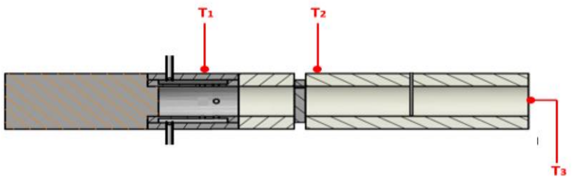


Figure 7. Temperature capture point

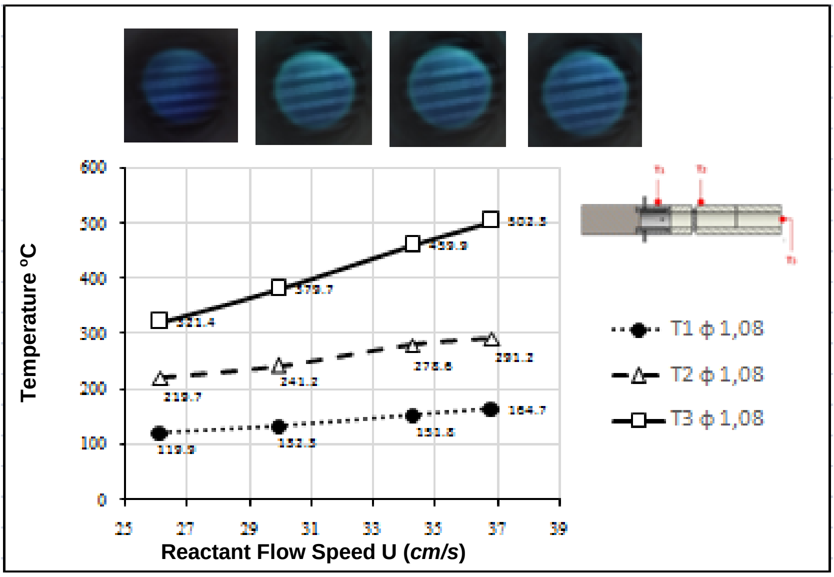


Figure 8. Flame temperature with a constant equivalent ratio

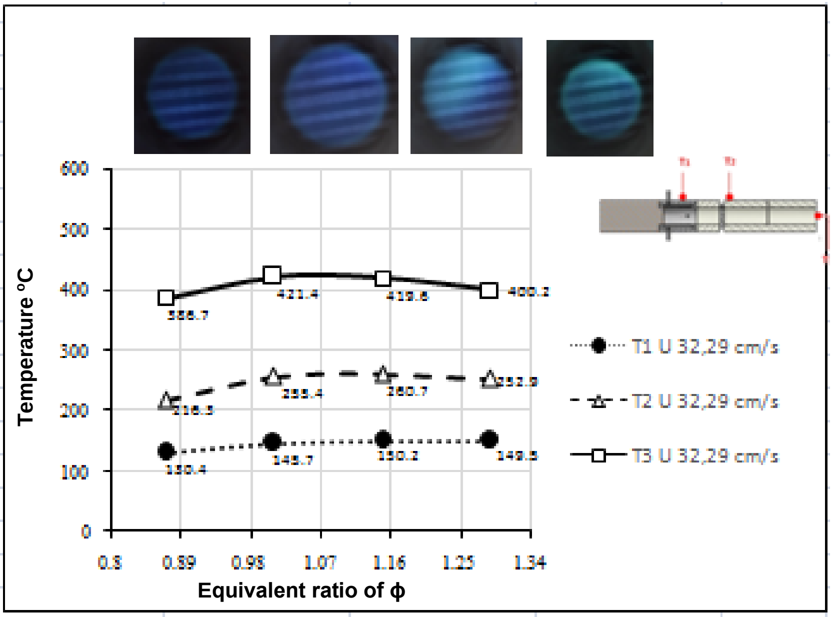


Figure 9. The flame temperature at a constant reactant flow velocity

Figure 6 is a visualization of the heptane flame in the mesoscale combustor with a flue gas mesh inhibitor insert at a constant reactant flow speed. At ϕ = 0.87 flames are dark blue and thickened. With ϕ = 1.01 the flame is still seen thickening and widening on the side of the combustor wall. As for ϕ = 1.15 flames look brighter and start to shrink. At ϕ = 1.29 the flame looks much smaller, and the flame is also brighter blue. The speed of constant reactant flow and the varying equivalent ratio indicates the higher the equivalent ratio, the brighter the flame, and the flame shrinks. This indicates that more and more reactants are contained in the fuel or are rich mixtures so that the amount of air is not fulfilled for combustion reactions.

Narrow flammability limits on mesoscale combustors with flue gas inhibitors can be caused by the magnitude of heat loss from the walls of the combustion chamber that is too long, for that it needs further investigation.

The temperature measurement point is as figure 7 shows. Temperature data is done to make it easier to analyze how the flame on the combustor.

Figure 8 is a temperature chart with a constant equivalent ratio and varying reactant flow speeds. At a constant equivalent ratio of ϕ = 1.08, there is an increase in temperature along with the speed of reactant flow. This happens because higher speeds have more air and fuel discharge. Therefore, the temperature at a speed of 36.83 cm / s has a high temperature caused by reactants that react more to produce more heat so that the temperature is higher. From the graph, the higher the flow speed of the reactants, the temperature also becomes higher. This can be seen from the flames that occurred. The greater the speed, the wider the flame fills the side of the wall on the combustor and the thickening the color of the flame.

Figure 9 is a temperature chart with a constant reactant flow speed and varying equivalent ratios. It is seen from the graph that at first the temperature increases but as the ratio of the temperature is increased it drops. This indicates that with the increasing value of the equivalent ratio, the more fuel reacts and the air entering the reactant cannot be met. The higher the equivalent ratio, the flame that was originally dark blue and filled the side of the combustor wall becomes smaller and brighter blue. More fuel than air causes cooling on the side of the combustor wall due to the heat of the reactant that does not burn and causes the temperature to decrease so that the flame is seen shrinking between the walls of the combustor.

4. Conclusion

Mesoscale combustor which has 3.5 mm inner diameter, flue gas inhibitor, 10 mm combustion chamber can be used for combustion of liquid fuel heptane. The flame can be stabilized at equivalence ratio of ϕ 0,81 – 1,29 and reactant velocity 26,12 – 36,83cm/s. The use of flue gas inhibitors does not automatically increase the flammability limits. It has been proven that flammability limits combustors with flue gas inhibitors are narrower, compared to similar mesoscale combustors that do not take flue gas inhibitors. The use of flue gas inhibitors does not automatically increase the flammability limits. It has been proven that flammability limits combustors with flue gas inhibitors are narrower, compared to similar mesoscale combustors that do not take flue gas inhibitors. There is a larger or wider flame, and brighter along with the higher equivalent ratio, to some extent. Narrow flammability limits on mesoscale combustors with flue gas inhibitors can be caused by the magnitude of heat loss from the walls of the combustion chamber that is too long, for that it needs further investigation.

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