An experimental study into the effect of fuel on step micro-combustor to the flame stability characterization

H Saputro¹, E D Ariyanto¹, D S Wijayanto¹, R Muslim¹, L Fitriana², F A Munir³

¹Department of Mechanical Engineering Education, Universitas Sebelas Maret, Jl. Ahmad Yani No.200, Pabelan, Surakarta, Indonesia.
²Department of Mathematic Education, Universitas Sebelas Maret, Jl. Ir. Sutami 36A, Surakarta, Indonesia
³Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, 76100 Hang Tuah Jaya, Durian Tunggal Melaka Malaysia

hermansaputro@staff.uns.ac.id

Abstract. Energy demand in the form of portable devices to supply electronic equipment increases every year. Micropower Generator is an alternative solution for portable energy generation. The most crucial component in micropower generation is micro-combustion. The problem faced in micro-combustion is the presence of a stable flame in the combustor. This study aims to produce flame stability on the combustor by using several fuels such as acetylene gas and propane gas. The micro combustor used in this study is a cylinder type with an inlet diameter of 3.5 mm, an outlet diameter of 4.5 mm, and a wall thickness of 0.5 mm. The micro-combustor is made of stainless steel with a burned region of 10 mm and an unburned region of 40 mm. The results showed that the combustor wall's temperature with propane fuel reached the highest average temperature at 182.45°C, while 113.20°C for acetylene fuel.

1. Introduction

In recent years, electronic devices have become an essential part for everyone to have. This development encourages the development of micro-scale power plants to support energy needs. The challenges faced in developing micro-scale power plants are fluid flow in the micro-channel, heat transfer at micro-scale, small-scale combustion, design, and fabrication. Other factors that need to be considered are selecting materials with high heat resistance, and fabrication precision work is needed [1].

A Micropower generator is a solution to produce micro-scale electricity more than lithium-ion batteries. One of the efforts to develop a power plant uses a Micro Scale Combustion for Micropower Generator (MPG). Mesoscale combustion can be used as a micro-scale electricity source through the combustion heat produced [2]. The heat generated from combustion is converted into electrical energy. The fuel used in the combustor can be either liquid or gas. The combustion of fuel in the combustor converts the fuel's chemical energy into heat energy, generating electricity. Micropower generators can generate electricity on a small scale and have a small form, making it portable and easy to carry.

Micro-combustion is different from conventional combustion. The factors that distinguish between the size of the combustion chamber are smaller than macro combustion. Several types of research related to stable flames have been conducted, such as [2] [3][4]. The combustor that is used in micropower
generation can be different, using two types of burners with heat recirculation and without using heat recirculation [5].

Micro or meso combustion is expected to obtain the combustion flame's stability, according to Munir et al., 2013 [6] that the flame stability is the limit when the flame is stable near the mesh. The steps that can be used to obtain flame stability are to reduce the quenching effect of combustion in three ways, namely, the use of catalysts, homogeneous combustion, and initial combustion of reactants. Heat recirculation in the combustor can generate heat for the initial combustion of the reactants. According to [7], the combusted and unburned gases' recirculation occurs conduction heat transfer on the combustor wall and mesh (flame holder). This study focuses on observations about the effect of fuel on the stable flame in the micro-combustor.

2. Research Method
This research method uses an experimental method with a focus on a stable flame. Stable flames were observed by measuring temperature data using a type K thermocouple and collecting visual data on the flame and combustor walls' stability using the EOS 70 D cannon camera. This research uses acetylene and propane gas as fuel. The combustion oxidizer uses the air produced by the compressor. The experimental setup is shown in Fig. 1.

![Figure 1. Experimental Setup](image1)

![Figure 2. Step micro-combustor](image2)
The experimental setup consists of several components, including a pressure regulator, mass flow controller as a measurement tool when air and fuel are supplied to the combustor. This study's micro combustor is a cylinder type with an inlet diameter of 3.5 mm, an outlet diameter of 4.5 mm, and a wall thickness of 0.5 mm. The micro-combustor is made of stainless steel with a burned region of 10 mm and an unburned region of 40 mm (Fig. 2). Experiments were carried out at the equivalent ratio of fuel and air = 1 and a flow velocity of 0.2 m/s. The micro-combustor wall temperature measurement uses a type K thermocouple. The measuring instrument is placed in two places in the burned region, i.e., the end of the burned region and the burned region's base (Fig. 3). The camera is placed in the front position in the burned region and next to the combustor position.

![Figure 3. Position of measurement temperature](image)

### 3. Result and Discussion

#### 3.1 Comparison of stable flame temperature between micro-combustor with acetylene and propane fuels

Figure 3 shows the results of the combustion experiment on a micro-combustor with acetylene fuel. Based on Figure 3, the temperature difference between the measured position I (end of the burned region) and position II (base burned region) is not significant. The micro-combustor with acetylene fuel had the highest temperature at the end of the burned region. At the end of the combustor (measurement position I), the burned region experienced a rapid increase in the initial 20 seconds. The maximum temperature occurs in the first 50 seconds, reaching 125.63 °C. After that, the flame is stable at an average temperature of 116 °C. The micro-combustor temperature at the combustor base (measurement position II) reaches a maximum temperature of 120.75 °C in the initial 50 seconds after a stable flame is formed on the micro-combustor. After that, the flame is stable at an average temperature of 108.7°C.

Meanwhile, Fig. 4 shows the results of the combustion experiment on a micro-combustor with propane fuel. The results of research on the micro-combustor with propane fuel showed different results from acetylene fuel. Based on Figure 4, the difference in temperature between the position of measurement I (end of the burned region) and position of measurement II (base of the burned region) is very significant. The propane-fueled micro-combustor had the highest temperature at the base of the burned region. This result is in reverse with acetylene fuel. In the burned region at the combustor base (measurement position II), there was a rapid increase in the initial 50 seconds. The maximum temperature occurred in the first 50 seconds, reaching 162.6 °C. After that, the flame is stable at an average temperature of 149.7 °C. The micro-combustor temperature at the end of the combustor (measurement position I) reaches a maximum temperature of 120.87 °C, and the flame is stable at an average temperature of 112.53 °C.
Figure 4. The difference in temperature between the measured position I (end of the burned region) and position II (base of the burned region) with acetylene fuel

Figure 5. The difference in temperature between the measured position I (end of the burned region) and the measured position II (base of the burned region) with propane fuel.

3.2 Comparison of stable flame visualization between micro-combustor with acetylene and propane fuels

Visualization of a stable flame between the micro-combustor with acetylene and propane fuels is shown in Fig. 5 and 6. The stable flame on the micro-combustor with propane fuel looks bluer than the micro-combustor flame with acetylene fuel. A stable flame condition in the micro-combustor with propane fuel occurs in the combustor close to the mesh (flame holder), and the flame is bluish. Meanwhile, in the micro-combustor with acetylene fuel, it occurs in the micro combustor but still leaves a yellowish flame. This result also informs that acetylene fuel with an unburned region length of 10 mm is still visible outside the micro-combustor. Thus, the length of the micro-combustor unburned region for acetylene fuel must be made even longer. This flame's presence causes the micro-combustor with acetylene fuel to lower stable flame temperature than the propane-fueled micro-combustor (Fig. 7). The presence of flames makes the stable flame unable to focus on the micro-combustor.
4. Conclusion
This study focuses on observing acetylene and propane fuels' effect on the stable flame in the micro-combustor. This study's micro combustor is a cylinder type with an inlet diameter of 3.5 mm, an outlet diameter of 4.5 mm, and a wall thickness of 0.5 mm. The micro-combustor is made of stainless steel with a burned region of 10 mm in length and an unburned region of 40 mm. The experiment was carried out at the equivalent ratio of fuel and air = 1 and flow velocity = 0.2 m/s. The results showed differences, and the effect of temperature results between acetylene and propane fuels. This effect is shown by the temperature results obtained by each fuel. A stable flame condition in the micro-combustor with propane fuel occurs in the combustor close to the mesh (flame holder), and the flame is bluish. Meanwhile, in the micro-combustor with acetylene fuel, it occurs in the micro combustor but still leaves a yellowish flame. This flame's presence causes the acetylene-fueled micro-combustor to have a lower stable flame temperature than the propane-fueled micro-combustor.

Acknowledgments
This research was partly subsidized by the Grant of research PNPB Universitas Sebelas Maret 2020. The researchers gratefully acknowledge financial support from the LPPM Universitas Sebelas Maret Surakarta, Indonesia.

References
[1] Fernandez-Pello AC 2002 Micropower generation using combustion: Issues and approaches.
[2] Saputro H, Juwantono H, Bugis H, Susilo Wijayanto D, Fitriana L, Perdana V 2018 Numerical simulation of flame stabilization in meso-scale vortex combustion MATEC Web Conf. 197:8005

[3] Saputro H, Purwanto A, Fitriana L, Wijayanto DS, Sutrisno VLP, Ariyanto ED 2018 Analysis of flame stabilization limit in a cylindrical of step micro-combustor with different material through the numerical simulation MATEC Web Conf. 197: 8003

[4] Abdul Munir F, Ikhwan Muazzam M, Gader A, Mikami M, Saputro H, Fitriana L 2018 Effects of Wall Thickness on Flame Stabilization Limits for Combustors with Wire Mesh. J. Adv. Res. Fluid Mech. Therm. Sci. J. 49:11–7

[5] Tang A, Cai T, Deng J, Xu Y, Pan J 2017 Experimental investigation on combustion characteristics of premixed propane/air in a micro-planar heat recirculation combustor Energy Convers. Manag. 152:65–71.

[6] Munir FA, Hatakeda N, Mikami M, Seo T 2013 Improvement of Combustion Stability in Narrow Tubes with Wire Mesh. 24th Int. Symp. Transp. Phenom

[7] Mikami M, Maeda Y, Matsui K, Seo T, Yuliati L 2012 Combustion of gaseous and liquid fuels in meso-scale tubes with wire mesh. Proc. Combust. Inst. 34:3387–94.