Micro-channel combustor with bluff body

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ABSTRACT – Effects of the bluff body with slit in the micro-channel combustor have been numerically studied. Two-dimensional computational domain with the height and length of the channel is H = 1 mm and L=16 mm is used. The slit gap percentage utilized in this study is 0% to 70%. Results shows that the combustion characteristic is significantly influenced by the slit gap percentage. Flame is moving downstream and result in blow-off at the slit percentage 10% to 25%. At the slit percentage 30%, the flame zone moves towards the upstream result in stable flame. These observation is suggested due to the secondary vortex exist behind the bluff body as slit gap increases and pull or push the flame to the upstream or downstream.

1. INTRODUCTION

The main problem in small-scale electronic devices such as smartphones, unmanned aerial vehicles (UAV), and MEMS is the capability to sustain long operation hours. Conventional batteries and even the latest technology of common alkaline batteries (lithium-ion) can only provide an energy storage of 0.6 MJ/kg whereby sustainability is about three to six hours for non-stop operation. Thus, requirement for new method of energy-generated system is highly demanded.

Currently, every user demanded for most reliable system to ease their workload. With that concern, electronic devices such as smartphones are required to be operated in longer hours to avoid communication break down or any unwanted incident. Epstein and Senturia (1997) proposed new method of power generated system for small electronics devices by creating micro combustor for supplying heat energy to be converted to electrical power [1]. Every new finding has its own challenges; major issue in micro combustor is how to stabilize the combustion in small volume area. Several methods have been proposed to overcome the issue in micro combustor such as adjusting the geometry of the combustor, making cavities, wire insertion and adding bluff body at the inlet of combustor. To the author's knowledge, bluff body with a slit has never been studied previously. Thus, this topic builds an author's interest. One of the contributions of this study is the improvement the combustion stability on supplying heat towards achieving higher energy density for micro-scale system. In conjunction with higher energy density, the service ability of electronic components or system can be prolonged.

2. RESEARCH METHODOLOGY

A computational domain and the boundary conditions of the system are shown in Figure 2.1. The height and length of the channel is H = 1 mm and L = 16 [1] respectively. The bluff body height is H_{bluff} = 0.5 mm height and located at x = 2 mm from the inlet. Slit gap percentages of 0% to 70% have been selected in this study. Percentage of the slit gap is defined by the ratio between height of slit, H_{slit} and height of the bluff body, H_{bluff}.

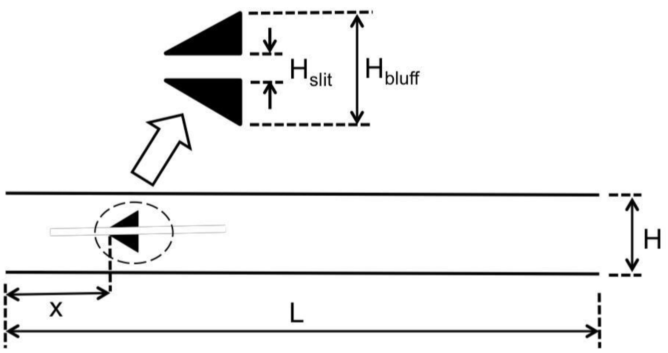


Figure 2.1 Micro-combustor with zero percentage slit gap of bluff body

The analysis was performed in a two dimensional configuration. CH_4/air mixture is issued from inlet at temperature 300 K. The selection of the CH4/air is because of the simple reaction mechanism compare to propane. Moreover, the CH_4/air is easy to stored compare to hydrogen. Outlet of the combustor is assumed to be a fully developed flow. In the present study, air is assumed to be a mixture of O_2 and N_2 with 21 mol% and 79 mol% respectively. One-step reaction mechanism of CH_4/air was used in this study.

Ansys Fluent 14.5 was applied to solve a set of the conservation equations using a segregated solver with an under relaxation method. A uniform size of grid with a size of 1×10-5 m × 1×10-5 m was used. Laminar model was used following the suggestion from Kuo and Ronney [2] since the Reynolds number, Re < 500.

A non-slip and impermeable wall surfaces boundary condition are applied at the combustor walls. Both natural convection and thermal radiation heat transfer have been assigned at the outer surface of the combustor walls. Initially an isothermal flow was solved. Artificial ignition was setting by the higher temperature zone at 2500 K. After the reaction was started and the flame exists, the artificial ignition temperature was off. The convergence criterion was set for energy residual less than 10-6. .

3. RESULTS AND DISCUSSION

3.1 Effects of Equivalent Ratio and Inlet Velocity

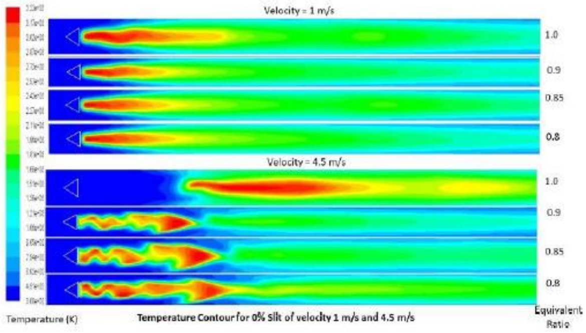


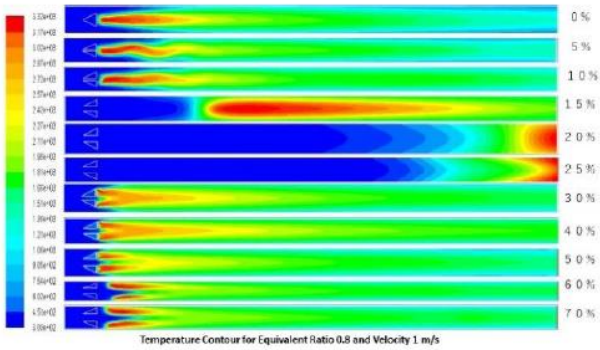
Figure 3.1 Temperature contour for 0% slit of velocity 1 m/s and 4.5 m/s for Various Equivalent Ratios

Figure 3.1 shows a temperature contour for slit gap 0% with various equivalence ratio at inlet velocity 1 m/s and 4.5 m/s. At the inlet velocity 1 m/s, as the equivalence ratio increases from 0.8 until 1.0, the temperature contour becomes wavy. At inlet velocity 4.5 m/s, as the equivalence ratio increases from 0.8 to 1.0, the temperature contours severely wavy and the flame zone is pushed downstream towards blow-off. At higher inlet velocity size of vortex behind the bluff body decreases, thus this vortex cannot hold the flame and results in blow-off.

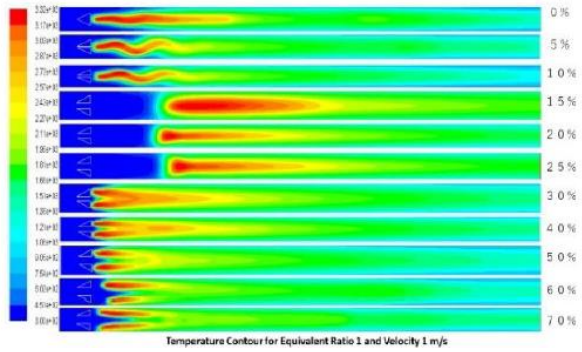
3.2 Effect of Slit Gap Percentage and Equivalence

In low equivalence ratio of 0.8, the maximum wall temperature is 1439.05 K, takes place when slit gap is opened until 60% and inlet velocity is applied in velocity of 4.5 m/s. It was clarified that when the equivalence ratio increases to 0.85, the wall temperature intensifies up to 1634.07 K (slit gap 60% and inlet velocity 4.5 m/s) in all cases except for 10% until 25% due to blow-off. As the equivalence ratio raises for 0.9 and 1.0, the maximum wall temperature gets lower to 1521.37 K (equivalence ratio 0.9, slit 70%, inlet velocity 5.0 m/s) and 1441.47 K (equivalence ratio 1.0, slit 50%, inlet velocity 4.5 m/s).

The maximum micro combustor wall temperature was recorded at inlet velocity of 4.5 m/s and it can be concluded that to get maximum wall temperature and stabilized flame, the slit gap must be opened 50% or higher. This result is similar with Bagheri et al. (2014)[5] who found that wall-blade bluff body is more stable than other cases (circle, ellipse, diamond, semicircle, half ellipse, triangle, crescent, and arrowhead bluff body). The higher the slit gap percentage, the more parts of bluff body are close to micro combustor inner wall whereby same configuration occurred with wall-blade bluff body. Figure 3.2 shows a figure of temperature contour inside the combustor of inlet velocity 1.0 m/s for equivalent ratio 0.8 and 1.0 respectively.



(a)



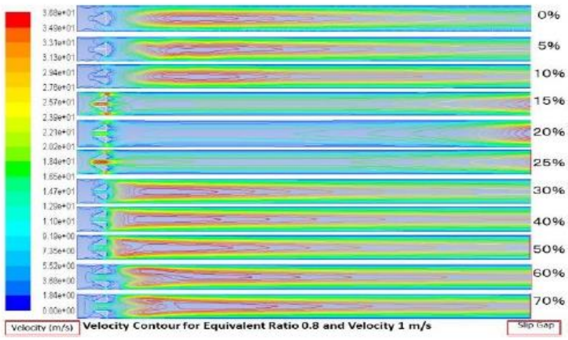
(a)

Figure 3.2 Temperature Contour of Inlet Velocity 1 m/s in Various Slit Gap Percentage for (a) Equivalent Ratio 0.8 and (b) Equivalent Ratio 1.0

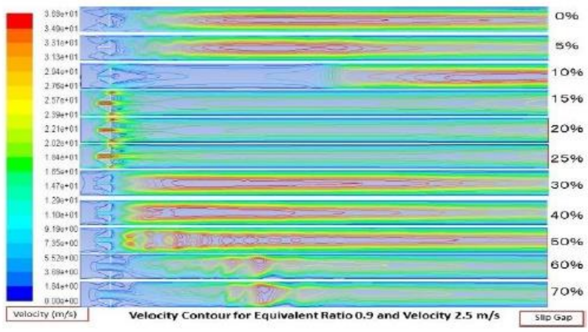
3.2 Effect of Flame Velocity Magnitude

Figure 3.3 which shows a figure of velocity contour along the combustor length for (a) equivalent ratio 0.8 and velocity 1 m/s and (b) equivalent ratio 0.9 and velocity 2.5 m/s. It is seen that the flow fields are wavy but prolonged for the 0%, 5% and 10% (except for Figure 3.3 (b)) of slit gap. With the increase in inlet speed, the range of recirculation zone is expanding. Recirculation zone contributes a positive part in the burning of methane, which assembles the ignition reaction intermediate segment. When the speed of fresh reactants in recirculation zone is slower, it is helpful for delaying the residence time of the reactants. Interestingly, as the slit percentage increased to 30%, the flow field returned. It was due to flame anchored behind the bluff body. At relatively higher blockage ratio, large recirculation zone existed and flame attached to the bluff body.

Moreover, it can be seen that if there is an increase in the slit percentage, recirculation zone is avoiding the bluff body and wavy especially starting at 50% slit gap and beyond. This is due to higher blockage ratio that contributed to the existence of vortex behind bluff body and thus pushed the recirculation zone downstream. However, for Figure 4 (a), the flame was able to sustain due to low inlet velocity and low equivalence ratio, which contributed to hot products that were able to ignite the unburned gases and provided a region where the local flames speed can match the local flow velocity.



(a)



(b)

Figure 3.3 Velocity Contour for (a) Equivalent Ratio 0.8 and Velocity 1 m/s and (b) Equivalent Ratio 0.9 and Velocity 2.5 m/s

4. SUMMARY

Generally, combustion characteristics are influenced by slit gap percentage, inlet velocity and equivalence ratio. At 0% and 5% slit percentage, the temperature contour is stable for velocity 2.0 m/s and below. Beyond velocity 2.0 m/s, the temperature zone is unstable except for some cases, for instance inlet velocity 4 m/s for slit gap 5%. By increasing the inlet velocity to 2.5 m/s, the flow fields are wavy but prolonged for 0% and 5% of slit gap. With the expansion of inlet speed, the range of recirculation zone is expanding. Unfortunately, with the increment of slit gap from 10% until 25%, the flow fields move downstream and then blow-off. The four slip gaps percentage blow-off due to high local flow velocity produces vortex that pushes recirculation zone downstream and thus blow-off happens. Interestingly, as the slit percentage increases to 30%, the flow field returns due to flame root that can be anchored at relatively higher blockage ratio because of large recirculation zone that is attached to the bluff body.

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