COMBUSTION IN MICRO COMBUSTORS WITH REDUCED CHEMICAL KINETIC MECHANISM

LUQMAN HAKIM BIN ZAINUDIN
B041310285
BMCL
Email: luqmanhakim.zainudin@gmail.com

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Supervisor: DR. FUDHAIL BIN ABDUL MUNIR
2nd Examiner: DR. MIZAH BINTI RAMLI

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

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This report is submitted
in fulfilment of the requirement for the degree of
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2017

DECLARATION

I declare that this project report entitled “Combustion In Micro Combustors With Reduced Chemical Kinetic Mechanism ” is the result of my own work except as cited in the references

Signature	:	....
Name	:	Luqman Hakim bin Zainudin
Date	:	15 JUNE 2017

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and quality for the award of degree of Bachelor of Mechanical Engineering (Plant & Maintenace).

Signature :. ....

Name of Supervisor: Dr. Fudhail bin Abdul Munir

Date : 15 JUNE 2017

DEDICATION

I would like to dedicate to

My father,

ZAINUDIN BIN AB AZIZ

My mother,

KAMSIAH BINTI TAN KOFLI

My supervisor,

DR. FUDHAIL BIN ADUL MUNIR

And

All my friend,

For their assistance & supportive efforts.

ABSTARCT

A micro combustor is an alternative device to the conventional lithium-ion batteries. Miniaturized product development such as micro robots, notebook computers and other small scale devices are critical in need of powerful energy resources. Nonetheless, stabilizing flame inside narrow channel combustor is the greatest challenge for the researchers. This research can be categorized as fundamental research where the flame stabilization in micro combustors is investigated. In this project, two dimensional (2-D) numerical simulations that focus on the effect of thickness on combustion of micro combustor with reduced chemical kinetics mechanism were performed. By using ANSYS-Fluent 17.1 as the Computational Fluid Dynamics (CFD) tool, the blowout limits for micro combustors with different size of thickness is determined. The thickness use for each micro combustor design are 0.3 mm, 0.5 mm, 1.0 mm and 1.2 mm, respectively. The chemical reaction employed is global one-step and two-step propane-air mixture. The blowout limits for the different thickness micro combustor had been determined. Thus, trend pattern of the effect of combustor thickness on the flame stabilization are also deduced. From the results, it can be concluded that the thickness of the micro combustors significantly affect the blowout limits. Meanwhile, two types combustion reaction mechanism for propane-air mixtures were employed to investigate the effect reaction mechanism on flame stabilization limits. It is suggested that the reaction mechanism for one-step and two-step combustion of propane-air mixture does not significantly affect the flame stabilization limits of the combustors.

ABSTRAK

. *Peranti pembakar mikro adalah alternatif kepada bateri lithium-ion konvensional. Kemajuan produk bersaiz kecil seperti robot mikro, komputer riba dan peranti kecil adalah kritikal yang memerlukan sumber tenaga yang kuat. Namun begitu, menstabilkan api di dalam saluran pembakar sempit adalah cabaran terbesar bagi para penyelidik. Kajian ini boleh dikategorikan sebagai penyelidikan asas di mana penstabilan api dalam pembakar mikro disiasat. Dalam projek ini, dua dimensi (2-D) simulasi berangka yang memberi tumpuan kepada kesan ketebalan pada pembakaran pembakar mikro dengan mengurangkan mekanisme kinetik kimia telah dijalankan. Dengan menggunakan ANSYS-Fluent 17.1 sebagai alat dinamik bendalir sebagai pengiraan (CFD), had pembakaran terpadam untuk pembakar mikro dengan saiz yang berbeza ketebalan ditentukan. Penggunaan ketebalan bagi setiap reka bentuk pembakar mikro adalah 0.3 mm, 0.5 mm, 1.0 mm dan 1.2 mm, masing-masing. Tindak balas kimia yang digunakan adalah satu langkah dan dua langkah campuran propana udara global. Had semburan keluar untuk ketebalan yang berbeza pembakar mikro telah ditentukan. Oleh itu, trend corak kesan ketebalan pada penstabilan pembakar api juga disimpulkan. Daripada keputusan, ia boleh disimpulkan bahawa ketebalan pembakar mikro ketara memberi kesan kepada had semburan keluar. Sementara itu, dua jenis mekanisme tindak balas pembakaran untuk campuran propana-air telah digunakan untuk menyiasat kesan ke atas mekanisme tindak balas had penstabilan api. Adalah dicadangkan bahawa mekanisme tindak balas untuk satu langkah dan dua langkah pembakaran campuran propana-udara tidak ketara memberi kesan kepada had penstabilan api daripada pembakar.*

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LIST OF ABBEREVATIONS

MEMS	Micro-Elctromechanical System
2-D	Two-Dimensional
CFD	Computational Fluid Dynamics

CHAPTER 1

1. INTRODUCTION

1.1 BACKGROUND OF STUDY

A micro combustor is an alternative device to the conventional lithium-ion batteries. Miniaturized product development such as micro robots, notebook computers and other small scale devices needed in developing small scale of combustion. Nonetheless, stabilizing flame inside narrow channel combustor is the greatest challenge to the researchers. This research is considered as a fundamental study. Due to supply power to these devices, higher energy density, higher heat and mass transfer coefficient are needed in developing these devices. Micro combustor are the medium of the study and to achieve the objective of the study is to stabilizing the flame inside the micro combustor with reduce chemical kinetic mechanism (Hua et al, 2005). Understanding of the flow dynamics, chemical kinetics and heat transfer mechanism within micro-combustors is essential for the development of combustion-based power MEMS devices. In this study, only numerical simulations using the commercial software are performed.

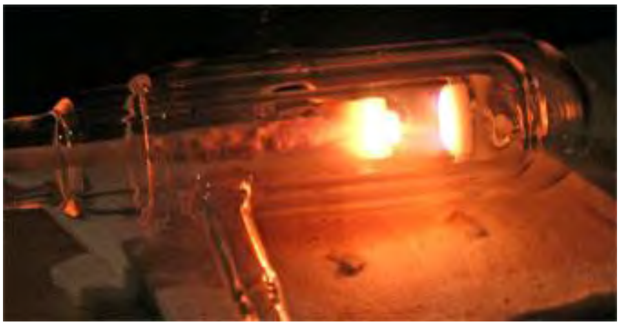

Figure 1-1 Micro combustor (micro thruster) (Fan et al, 2012)

Combustion in micro combustor is a chemical reaction of exothermic between oxidant and chemical substance which in this study are using propane-air mixture. Air act as oxidant and propane is the chemical use in this study. In experiments, the result is the heat released in product of light which is flame or glowing form. To stabilize the flame is the major problem in this study, which is mainly due to high surface to volume ratio. The surface to volume to ratio is increase, heat loss to wall of combustor is also increasing.

Chemical kinetic mechanisms is determine in the reaction order and rate of equation of reactant. By using hydrocarbon propane as chemical reactant which is C_3H_8 combining with air [1]For these mechanism, it must satisfy two requirement which is the elementary steps must add up to give the overall balanced equation for the reaction and the rate law for the rate-determining step must agree with the experimentally determined rate law. Rate law equation is $r = k[A]^x[B]^y$, by applying these two requirement will stabilize the chemical reaction equation and needed to design the flow to simplified the chemical kinetics reaction modelling which retained the essential features of full system inside the tube channel of the micro combustor.

By using software of ANSYS-Fluent to solve the governing equations, the flow is shown inside the tube combustor channel. Determine the flow steady-state, the flame inside are need to stabilize. Parameter is set in this software are from the equation of reaction of propane-air mixture in this area of study. The figure shown below is the example of flow that simulation ANSYS-Fluent produce after simulation is running.

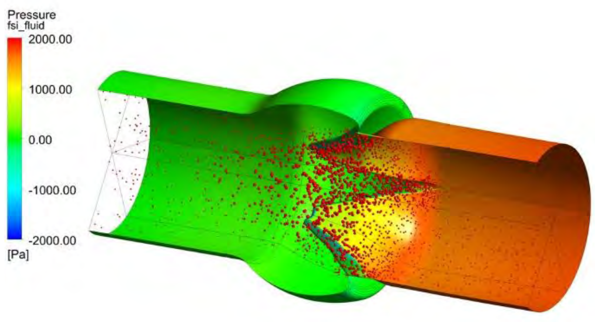

Figure 1-2 Simulation ANSYS-Fluent flow

In this research, the area of the study is limited to numerical simulations using ANSYS-Fluent with reduced chemical kinetic mechanisms of propane-air mixture. The aim of this study is to investigate the effect of combustion reaction mechanism on the flame stabilization in micro combustors with stainless steel wire mesh.

1.2 PROBLEM STATEMENT

Micro combustor is a small combustion devices. Stabilizing the flame inside such narrow channel combustors poses a great challenge to researchers. Despite such difficulties, flame stabilization in sub millimetres combustors is feasible. Numerical simulations using one step global reaction has greatly over predicted the flame temperature, which is not realistic. Hence, a reduced kinetic mechanism simulations are preferred for results with better accuracy. Apart from that, the emission of the micro combustor with C can also be studied with the reduced kinetic mechanism.

1.3 OBJECTIVE

1) To establish a two dimensional (2-D) numerical model of micro combustors with concentric rings.
2) To utilize a reduced kinetics mechanism to stimulate combustion in micro combustion in micro combustor with concentric rings.
3) To investigate the effect of thickness of the micro combustor using reduced kinetics mechanism

1.4 SCOPE

1) To utilize ANSYS-Fluent as CFD tools.
2) The reduced kinetics mechanism is limited to propane-air mixture only which is 1-step propane-air mixture and 2-step propane air mixture
3) To investigate the blowout limit of combustion phenomena in micro combustor with concentric rings.

CHAPTER 2

2. LITERATURE REVIEW

2.0 Overview

This chapter summarizes the previous related well-known work which in area of experimental and numerical that have been performed in micro power generation field. In this chapter, the related work that have been review is only using hydrocarbon fuel as experimental or medium source. The objective of the most study is to stabilize the flame in micro combustion. Several of research or journal have been proposed by using various method and mechanism to stabilize flame in narrow channel of micro combustor. It is also will explained the terminologies of micro combustion field area.

2.1 Flames Stabilization in Micro Combustor

Many paper proposed the method or mechanism use to form combustion in micro combustion, but it is challenging task to able to form stabilize flame in narrow tube channel of micro combustor. Fudhail et al. stated that it is essential to fully understand the underlying factors that affect the combustion stability in meso and micro-scale combustors (Fudhail et al, 2015). Fudhail et al. in their other paper also said that flame stabilization in such narrow channel combustors is a considerably challenging task and requires a proper thermal management due to larger heat loss ratio (Fudhail et al, 2015).

In general, flame can be stabilize within the certain limit that called flammability limits. The definition of flammability limit is range of mixture strength of which particular flame propagate within these limit (Turn S.R, 2000). Majority of micro combustor field of study use hydrocarbon fuel air mixture as the medium of the study. Each of these fuel-air mixture have their own propagate speed. The flame started to propagate when it is been ignited to the fresh unburned mixture area with their own velocity approximately near to the propagation speed theoretically. To get stationary flame or stable flame, it is need to adjust the mean flow velocity of the unburned mixture. In the real life, it is difficult to able stabilize the flame due to complexity interaction between flame and the wall of micro combustor. Feng et al. say in their paper that at the gas-wall interfaced, a highly intensified heat loss from the combustor wall and radial destruction occur (Feng et al, 2010).

Many method have been proposed to stabilize the flame in micro combustors. One of them is to overcome flame quenching. It is needed to utilize the heat recirculation mechanism can significantly enhance the flame stabilization limits (Fan et al, 2012). From combustion product, there is an excess enthalpy is utilized to pre-heat the fuel and air mixtures. There is various example of micro combustion model in figure 2.1. Categorize the flow of heat in micro combustor is laminar, the mixing process between fuel and air are relatively slow. Caused of that, the mixing process is performed by the molecular diffusion and chaotic advection (Stroock et al, 2002). To enhance the blending procedure that can conceivably upgrade fire adjustment, a blender can be presented (Hessel et al, 2005). The mixer can be introduced.

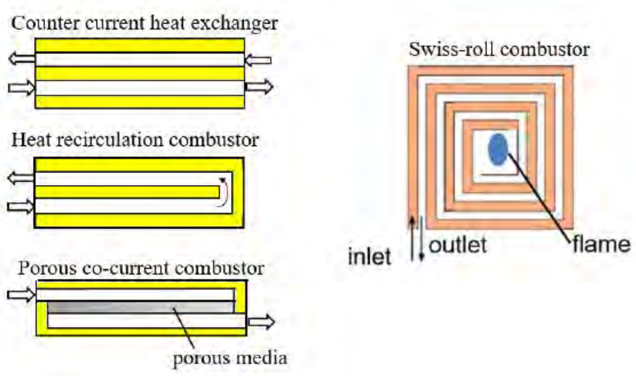

Figure 2-1 Various geometry of heat recirculation micro combustor (Kaisare et al, 2012)

Other than that, Lei et al. proposed that an annular tube of micro combustors with recirculation of exhaust heat is one of the method to get stabilize flame in micro combustor narrow tube channel (Lei et al, 2016). It is to understanding the mechanism of sustaining combustion within quenching distance of fuel. Another work that use to performed micro combustor flame stabilization from experimental method is analyse the difference in flame stabilization, temperature distribution at external wall and flammable channel-height (Tang et al., 2015) As the result, the difference between equivalent ratios of mix hydrogen/air has much wider and stable flammable range.

The alternative method that to improve stabilization of flame in micro combustor tube is the utilization of the catalyst. The use of catalyst enhances the flame stabilization limits inside the micro combustor by boosting the mass transfer (Maruta et al, 2002). Lower flame temperature are generate by the combustion of reactant in catalytic combustor than non-catalytic combustors. This low ignition temperature prompts to the decrease of warm anxiety related issues (Maruta et al, 2002). There is three major components in catalytic material which are catalyst, support and substrate. There are many techniques to deposit catalyst in micro burner. From Kikas et al. , they recommended that by using catalytic wires in micro combustors the likely the most effortless approach to deposit the catalyst into micro burner (Kikas et al, 2003). From figure 2.2 shows that the thin film is coated with catalyst. There also disadvantages using catalyst. Such as in paper Li et al., there is very complex interaction of combustion between heterogeneous and homogenous combustion (Li et al, 2012). As consequences is it is difficult to perform an experiment since there are too many variables needed to be controlled.

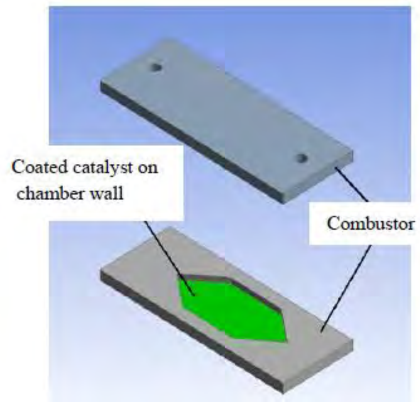

Figure 2-2 Schematics of micro-catalytic combustor with thin-film coated

2.2 Flame Quenching

Phenomenon of incomplete combustion due to the flame quenching is the task challenged in order to designing a reliable micro combustor (Hua et al, 2005). The definition of the flame quenching is a condition of flame extinguish upon entering small channel. The two types of mechanism of flame quenching it is thermal quenching and radial quenching. For thermal quenching, it is occurs when the heat is generated by the combustion process is not sustainable not feasible because of the heat misfortunes to the surrounding. Fernandez-Pello in his paper, in micro scale combustors, the heat losses in not only due to radiation, it is to a great extent contributed by the convection and conduction of heat (Fernandez-Pello, 2002). Radial quenching happens when radicals from the fire are diffused to the dividers, coming about to radical species exhaustion (Kim et al, 2006). The recombination of radical prompts to the loss of active combustion of bearers that in the long run outcomes to a to a flame quenching.

Quenching distance it is the critical distance of a channel in which the flame extinguish. For determine this distance, the two type of flame quenching mechanism which is thermal quenching and radial quenching plays an important role. It is depend on the reaction rate, temperature, species and radial concentration. For designing fire-resistance devices, the quenching distance is essential part that should have been consider. To achieve a better and safe design for micro combustor tube, the flame must not flashback to the upstream of the circular tube when the reactant is disconnected and the diameter of the tube is larger than the quenching distance.

Many studies investigate the effect of flame quenching. For example, in figure 2.3 Miesse et al. performed an experimental work that show the possibility of combustion of gaseous hydrocarbon fuels in their designed micro scale combustor (Miesse et al, 2004). On the other journal, Saiki et al. posted that the effect of thermal and radical quenching on flame propagation is dominant in meso and micro-scale combustion (Saiki et al, 2013). Selection of proper operating conditions and optimization of combustor design are required in order to reduce or eliminate the flame quenching problem (Shirsat et al, 2011).