



**Faculty of Mechanical Engineering**

**INVESTIGATION OF EFFECTS OF COMBUSTOR WALL  
THICKNESS ON THE FLAME STABILIZATION LIMITS  
FOR MICRO COMBUSTORS WITH WIRE MESH**

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**MASTER OF MECHANICAL ENGINEERING**

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THICKNESS ON THE FLAME STABILIZATION LIMITS  
FOR MICRO COMBUSTORS WITH WIRE MESH**

**ABDELGADER AGILAH SALEH GHEIDAN**

**A thesis submitted  
in fulfilment of the requirements for the degree of Master of Science in Mechanical  
Engineering**

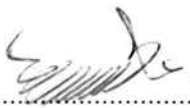
**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2017**

## DECLARATION

I declare that this dissertation entitled “Investigation of effect of combustor wall thickness on the flame stabilization limits for micro combustors with wire mesh” is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : .....3. July. 2017.....

## APPROVAL

I hereby declare that I have read this project and in my opinion this dissertation is sufficient in terms of scope and quality for the award of Master of Engineering  
(Mechanical)

Signature

:  .....

Supervisor Name

: Dr. Fudhail Bin Abdul Munir

Date

: 31/07/17 .

## **DEDICATION**

To my beloved mother and father who gives me a hand to be grown and devotes whole life for me. To my loved wife who stands and supports me to complete this potential work successfully. To my loved kids, Shahed, Abdel Rahman and Namark and the whole family who are waiting for me to share this success.

## ABSTRACT

The scarcity of energy has led to the invention of alternative solutions to the conventional power generation system. Micro-power generation system is one of the potential sustainable solutions that provide better energy resource for small electronic devices as compared to conventional lithium-ion batteries. The difficulty to stabilize the flame in micro-combustors is the main obstacle faced by researchers, which is hugely caused from heat loss. Nevertheless, huge efforts towards attaining flame stabilization have been made within this few years back. In this research, the effect of combustor wall thickness on the flame stabilization limits of micro combustors with stainless steel wire mesh has been investigated. Numerical simulations were performed using a two-dimensional (2-D) and three dimensional (3-D) steady-state model. The wall thickness was varied from 0.3 mm to 1.2 mm. The governing equations were solved using ANSYS Release 16.2 with fluent capability. The blowout limits for each of wall thickness were determined. From the results, it is suggested that the flame stabilization limits for the combustors made of quartz tube has a direct relationship with the wall thickness flame stabilization limits. The results observed in the graph of combustor (quartz-quartz) (2-D) whenever increase thickness combustor from 0.3 mm to 1.2 mm this leads to more the flame stability that means the velocity blowout occurs at high value. But, in three dimension (quartz-quartz) (3-D) at velocity 0.47 m/s when increase thickness more than 1mm it is not effective as results the better thickness of flame stability thickness 1mm. Nevertheless, the strategy of improving flame stabilization limits by increasing the wall thickness has a limited range of effectiveness. The benefits of this project is to provide an alternative solution for saving more power energy consumption and to serve small scale of electronic device.

## ABSTRAK

Sumber tenaga pada masa kini adalah sangat terhad dan kritikal. Justeru itu, pelbagai penyelesaian alternatif kepada permasalahan ini telah dicadangkan oleh para penyelidik dan jurutera. Salah satu penyelesaian yang boleh dikira sebagai solusi terbaik adalah penjana tenaga mikro. Penjana tenaga alternative ini boleh dikategorikan sebagai solusi terbaik untuk sumber tenaga bagi alat elektronik bagi menggantikan bateri konvensional yang ada iaitu lithium-ion. Namun begitu, masalah utama yang dihadapi oleh para penyelidik dalam menyediakan sebuah sistem penjana tenaga mikro yang mampan adalah masalah pembakaran yang tidak stabil. Api yang terbentuk dalam kebuk pembakaran yang bersaiz mikro adalah amat tidak stabil. Ini merupakan masalah utama yang perlu diatasi oleh para penyelidik untuk menghasilkan sebuah sistem yang stabil dan mampan. Walau bagaimanapun, penyelidik telah berusaha mengatasi masalah tersebut dengan mencadangkan pelbagai penyelesaian yang baik. Dalam penyelidikan yang diutarakan ini, kesan ketebalan pembakar terhadap kestabilan api telah dikaji secara model simulasi. Ketebalan pembakar divariasikan daripada 0.3 mm kepada 1.2 mm. Had atas kestabilan api ditentukan bagi setiap ketebalan dinding pembakar. Hasil dapatan mendapati bahawa terdapat faktor berkadar terus antara ketebalan dan had atas kestabilan api. Kendatipun begitu, faktor berkadar terus ini mempunyai had tertentu. Misalnya, kestabilan api hanya dapat dipertahan pada had maksimum 0.47 m/s sahaja walaupun ketebalan dinding pembakar dinaikkan dari 1.0 mm kepada 1.2 mm. Dengan erti kata yang lain, strategi untuk meningkatkan tahap kestabilan pembakaran dengan meningkatkan ketebalan dinding pembakar hanya berkesan bagi sesetengah ketebalan sahaja.

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**In the name of Allah, the most beneficent, the most merciful**

All praises and thanks be to Allah, who has guided us to this, never could we have found guidance, were it not that Allah had guided us. First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr. Fudhail Bin Abdul Munir from the Faculty of Mechanical Engineering University Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this dissertation. Secondly, special thanks to all my peers, my mother, beloved father and siblings parents in-law who have been constantly giving support and prayers during my studies. For their moral support in completing this degree. Lastly, thank you to everyone who had been to the crucial parts of realization of this project.



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## LIST OF ABBREVIATION AND SYMBOLS

1-D	One-dimensional
2-D	Two-dimensional
3-D	Three-dimensional
CFD	Computational Fluid Dynamics
TPV	micro thermo-photovoltaic
$d$	Inner diameter of combustor
$D_{ah}$	Damkohler number
$E_a$	Activation energy
$F_x$	External force in x-direction
$F_r$	External force in r-direction
$H$	Convective heat transfer coefficient
$k$	Wall thermal conductivity
$k_b$	Wall thermal conductivity in the burned gas region
$k_u$	Wall thermal conductivity in the unburned gas region
$L$	Heater length

$L_{in}$	Insertion length
$L_b$	Length of the burned gas region
$L_u$	Length of the unburned gas region
$\dot{m}$	Mass flow rate
mm	Millimeter
$p$	Pressure
$q''$	Heat flux
$R$	Gas constant
$T$	Temperature
$T_{amb}$	Ambient temperature
$T_h$	Setting temperature of heater
$T_w$	Temperature of wall combustor
$U$	Flow velocity
$U_x$	Flow velocity in x-direction
$u_r$	Flow velocity in r-direction
$\mu$	Fluid viscosity
$\phi$	Equivalence ratio
$\rho$	Density

## CHAPTER 1

### INTRODUCTION

#### 1.1 Background

In recent years, electronic equipment have become one of the most important facilities that a person can have. Although the dramatic increasing for electronic equipment, the attention raised of the continued and increased electric power consumption. Consequently, unlike the lithium ion batteries in recent years, micro power generation systems have been seen as a potential source due to high-energy storage per unit mass and power generation per unit volume. Micro- power generation system means the small-scale generation of heat and electric power. However, recently micro-power generation system is one of the potential solution that provides better energy requirement for small device as compared to conventional lithium-ion batteries (Fernandez, 2002). In addition, meso and micro-combustor are considered as the most key components used in micro-power generation. Moreover, during the past few years, successful attempts have been done to develop numerous of micro-combustor such a rotary meso-scale engine, gas turbine engine, micro thermo-photovoltaic (TPV), heat recirculating combustor with different fuels such as Diesel, gasoline, Propane, Hydrogen, and natural gas. Fig 1.1 shows the idea of a micro-thermo photovoltaic unit (Ju and Maruta, 2011).



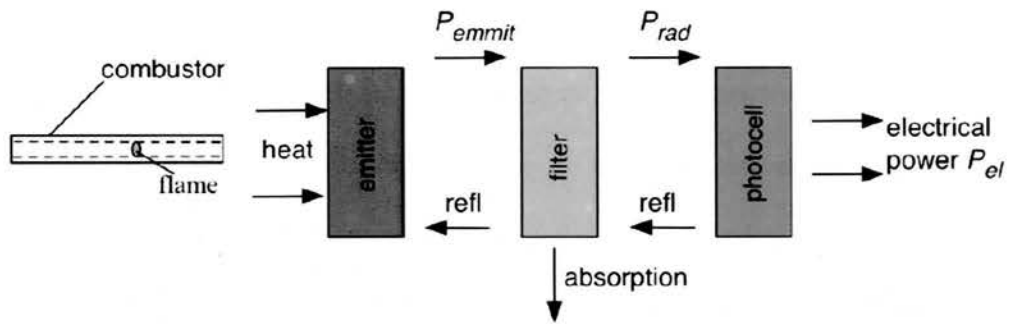


Figure 1.1 Schematic of a micro-thermo photovoltaic unit (Ju and Maruta, 2011)

Moreover, an integrated biogas (60%CH<sub>4</sub> + 40%CO<sub>2</sub>) micro-power generation was introduced by (Seyed et al, 2016) for electricity generation.

The difficulty of sustaining a stable flame for a micro combustor due to its high surface to volume ratio is a major issue in micro combustion. This high ratio causes a large portion of heat loss from the flame to the wall, which leads to thermal quenching. As early as in 2000s, Computational Fluid Dynamics (CFD) has been utilized to numerically investigate the flame propagation in micro-burners. In order to provide a better understanding to the underlying fundamentals of the combustion of gaseous hydrocarbon fuels like propane (C<sub>3</sub>H<sub>8</sub>) and methane (CH<sub>4</sub>) in micro-burners, numerical simulations using commercial software were conducted. For instance, FLUENT software with one-step irreversible reaction mechanism was employed to investigate the effect of wall conductivity, burner dimensions and external heat losses on combustion characteristics in meso-scale burners. A more detailed reaction mechanism with 25 reversible reactions was utilized to model methane-air combustion in narrow cylindrical tubes. It is essentially important to have a stabilized flame in meso and micro tube combustors. In fact, it was also demonstrated that the flame could be even stabilized in a tube with a diameter below than the classical quenching distance. However, due to the scale of the combustor, vital parameters such as the

wire mesh surface temperature contours and combustor inner wall temperature could not be established. Thus, a numerical simulation is required (Ju and Maruta, 2011). A two-dimensional (2-D) model is not suitable as the conductive heat transfer from the center of the wire mesh to the outer wall of combustor could not be well represented. The gas, inner wall and wire mesh temperature were investigated. The flame stabilization limits were also determined. The surface reaction is excluded in the analysis since there are materials that can resist radical quenching. The main purpose of this study is to demonstrate the capability of the wire mesh and to investigate its effect on the flame stabilization in the tube as shown in Fig 1.2 and Fig 1.3 (Munir et al., 2013).

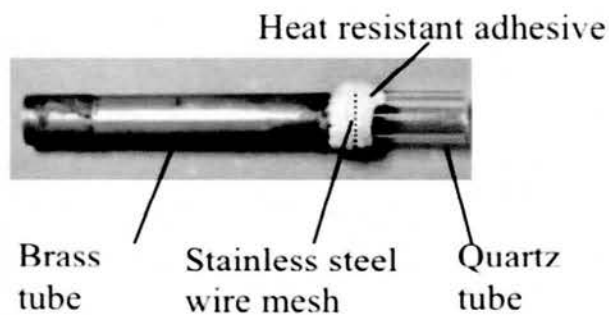


Figure 1.2 Image of Type B (brass) combustor (Robert, 2007).

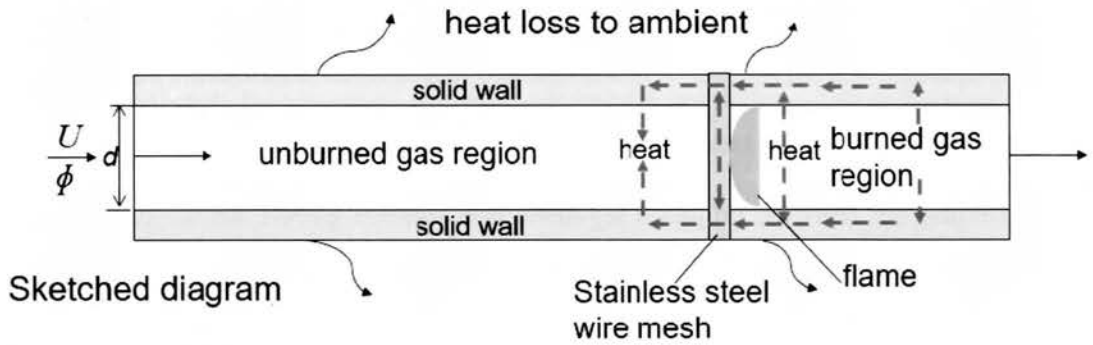


Figure 1.3 Diagram of a single channel combustor with wire mesh (Fudhail, 2015).

## 1.2 Research Background:

Basically, there are several factors that influence micro scale combustion, which generally can be divided into physical and chemical processes. However, convection, radiation, gas-phase and surface reactions, and molecular transport, thermal and mass diffusion are the significant examples of these factors (Ju and Maruta, 2011). There are several time and length scale involved during combustion process in narrow channel combustors. The characteristic size of combustor inner diameter and combustor structure scale is defined as the length scale. Commonly, the difficulty to sustain combustion in micro-scale devices is related to the substantial heat losses due to large surface area to volume ratio and physical time available for the combustion to occur. The combustion process to be taken place, the residence time should be larger than the combustion time, but, in micro-scale combustors, the length scale is tremendously reduced (Benedetto et. al., 2010). Therefore, the flow changed from turbulent to laminar due to the decrease of Reynolds number. (Wang et. al., 2001). The laminar flow generally causes the diffusion time to increase, which lowers the residence time. In such condition, combustion might cease to exist. The behaviour of fluids in micro scale devices can be assumed as the same as in macro scale (Maruta, 2011).

However, a few micro combustion features are distinctively different from macro scale combustion. On the other hand, combustion that occurs in a space with the characteristic length larger than 1 mm, but features the same features as Micro-scale combustion is defined as meso-scale combustion. Strong thermal and chemical coupling between the flame and combustor structure is also exhibited in micro combustor. In such combustor, the flame quenching is greatly depending on the flame-wall thermal coupling (Wang et. al., 2011). Therefore, it is essentially important to fully understand the underlying factors that contribute to the flame stabilization in micro combustors so that high-energy conversion can be achieved. Examples of these factors are thermal heat loss, excess enthalpy, wall-flame thermal and chemical coupling, fuel-air mixing, and liquid vaporization, flow field, burning rate and flame temperature. Since the combustion of hydrocarbon fuels in micro scale devices is not as efficient as in larger conventional devices, it is also vital to address the issue of fractional production of unburned species and high amount of carbon monoxide (CO). Overall, it is vital for an efficient micro combustor to have features as follows

- i. Wide flame stability limits
- ii. Versatility in terms of combustion modes for different use of application
- iii. Considerably good combustion efficiency
- iv. Minimum hazardous gas emission
- v. Simple in geometry for easier coupling with energy conversion module

A single channel combustor (SC) can also be considered as a heat recirculation Combustor since the heat from the burned gas region is distributed to the unburned gas region via the combustor wall (Dunn-Rankin et al., 2011).

### **1.3 Problem Statement:**

Instability of the flame in micro-combustor is a common dilemma faced by researchers, which is mainly caused by huge heat loss. However potential efforts towards enhancing the flame stabilization has been made in the past few years in order to attain and considerable high flame stabilization limits. Although several methods such as the use of flame holders, using catalysts and modification of combustor geometry were introduced by researches through opening literature review, complex and costly process is still needed to be considered again in small scale combustor. In addition, pre-heating the incoming recants is the effective and simple way to improve the flame stabilization limits. The combustor that achieve the preheating process is called heat recirculation combustor. Consequently, in order to achieve the preheating process, the current project is carry out to study the effect of selected and using the simple and more effective material such stainless steel wire mesh and two different types of fuel on flame stabilization limits. Stainless steel wire mesh is a connected strands of Stainless steel which is used in current project for improvement of flam stabilization limits. Propane and Methane are the two types of the most important fuels used in the current project.

### **1.4 Objectives:**

- i. To establish numerical model of two dimensional and three dimensional of combustors with different wall thickness
- ii. To numerically simulate the effect of combustor wall thickness on the flame stabilization limits for combustors with stainless steel wire mesh

## 1.5 Project Scopes:

The scopes of this project are as follows:

- i. The wall thickness of the combustors is varied between 0.3 mm to 1.2 mm
- ii. The numerical models utilized are in two dimensional and three dimensional
- iii. The governing equations are solved using the commercial CFD software, which in this case is ANSYS Release 16.2.
- iv. The blowout limits are determined for each of the numerical model

## **CHAPTER 2**

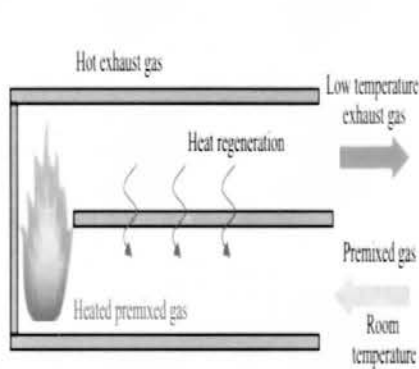
### **LITERATURE REVIEW**

The literature review for the current project is summarized and compiled from large open sources relevant to the topic of this study and to survey the previous works that has been published to attain more experience about what had been discussed and done by the previous research. In the literature review some important subtopics are presented such as general background of the idea as development of the micro combustor as a micro-power generation source, flame stabilization in micro combustors, methods of flame stabilization for micro combustors and effect of the combustor fuels.

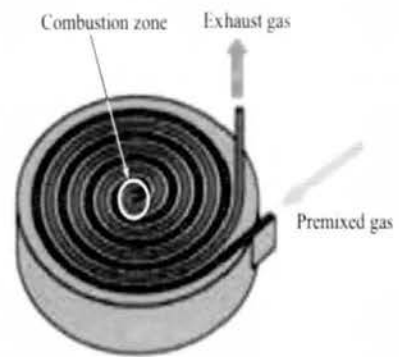
#### **2.1 General background**

Although reduction of fossil fuel consumption and CO<sub>2</sub> emissions in the building sector, industrial and public areas become global concerns towards depletion of fossil fuel and the ozone layer protection, the dramatically demand of energy use is in increasing in term of thermal energy and power generation. Extensive researches effort have been made over the past 20 years, in order to bring alternative and effective solutions to save the environment, energy consumption and provide the necessary thermal power. The most areas were considered as the main sources lead to break down the ozone layer and lost more fuel to generate a heat and electricity is combustion process (Irena et.al., 2016). In addition, for small scale power generation and heat without losing more heat and save the environment, micro-combustor is the most significant approach and effective tool was considered as a simple and an alternative solution to some conventional source (Fudhail, 2015).

In general the heat produced from electricity results in a larger amount of CO<sub>2</sub> emissions generated than if the heat were directly produced by combustion[(Takahashi et al., 2009) However when combustors are scaled down, it is well known that the heat loss from the flame to its surroundings increases. Incomplete combustion results higher in CO (carbon monoxide). In the past decade several technologies were introduced in order to minimize excessive CO (carbon monoxide) and to stabilize the flame by utilizing such new type of combustors such as excess enthalpy combustion technology, Swiss-roll type micro combustor, disk-type micro combustor and tube-type micro combustor. Fig 2.1 shows the schematic drawing of these technologies.



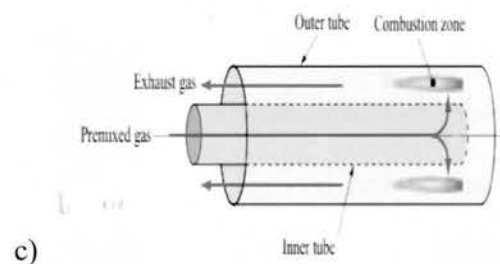
a) Excess enthalpy combustion



b) Swiss-roll type micro combustor



Disk-type micro combustor



d) Tube-type micro combustor

Figure 2.1 Schematic drawing of micro-combustor technology (Takahashi et al.,

2009)