STUDY OF FLOW INSIDE THERMOACOUSTIC SYSTEM

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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STUDY OF FLOW INSIDE THERMOACOUSTIC SYSTEM

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This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

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DECLARATION

I decleare that this project report entitled "Study Of The Flow Inside Thermoacoustic System" is the result of my own work except as cited in the references.

Signature : ……………………………………………

Name : LEE WEE TECK

Date : ……………………………………………

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is enough in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ……………………………………………

Supervisor Name : DR. FATIMAH AL-ZAHRAH BINTI MOHD SA'AT

Date : …………………………………………....

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DEDICATION

To my beloved father and mother.

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ABSTRACT

The study of flow in thermoacoustic system is important in order to find out ways to increase the efficiency of thermoacoustic engine. However, the study of thermoacoustic principle is difficult to be understood without the working experimental apparatus and simulation model. The objectives of this project is to design a small scale thermoacoustic prototype for experimentation, to test the small scale thermoacoustic system using suitable measurement methods, and to model a simple thermoacoustic flow field by using computational fluid dynamics (CFD) software. In experimentation, a small thermoacoustic refrigerator (TAR) rig that is operating under 133.45 Hz is built with two different type of stacks; acrylonitrile butadiene styrene (ABS) and stainless-steel scrubber. In CFD simulation, a simple CFD model is designed based on the actual operating parameters of the experiment rig with ABS stack only. Experimental result shows that a temperature drops of approximately 1 ^{o}C is achieved for both type of stacks and the same result is also obtained from the CFD simulation with ABS as the stack. The results are discussed and the recommendations for further research on the study of flow inside thermacoustic system are suggested at the end of the report.

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ABSTRAK

Kajian aliran dalam sistem termoakustik adalah penting untuk mengetahui cara meningkatkan kecekapan enjin termoakustik. Walau bagaimanapun, kajian prinsip termoakustik sukar difahami tanpa peralatan uji kaji dan model simulasi. Objektif projek ini adalah untuk merekabentuk prototaip termoakustik berskala kecil untuk eksperimen, untuk menguji sistem termoakustik berskala kecil dengan menggunakan kaedah pengukuran yang sesuai, dan memodelkan medan aliran termoakustik dengan menggunakan perisian dinamik bendalir komputasi (CFD). Dalam eksperimen, sebuah penyejuk termoakustik kecil (TAR) yang beroperasi di bawah 133.45 Hz dibina dengan menggunakan dua jenis timbunan yang berbeza yang diperbuat daripada acrylonitrile butadiene styrene (ABS) dan span keluli tahan karat dan diuji dengan menggunakan instrumen ukuran yang sesuai. Dalam simulasi CFD, satu model CFD yang mudah telah direka berdasarkan parameter operasi sebenar dalam rig uji kaji yang menggunakan timbunan ABS sahaja. Hasilnya, kejatuhan suhu adalah kira-kira 1 ^{o}C untuk kedua-dua jenis timbunan dapat dihasilkan dan keputusannya adalah sama dengan apa yang didapatkan daripada simulasi CFD untuk ABS sahaja. Semua dapatan dalam projek ini dibincangkan dan cadangan untuk penyelidikan lanjut tentang kajian aliran di dalam sistem termoakustik dicadangkan di bahagian hujung laporan.

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ACKNOWLEDGEMENT

First and foremost, I would like to say thank you to Universiti Teknikal Malaysia Melaka (UTeM) for providing me a golden opportunity to study the Bachelor of Mechanical Engineering course and providing facilities, equipment, and resources to me in order to complete my final year project (FYP).

Next, I would like to give my deepest appreciation to my FYP supervisor, DR. Fatimah Al-Zahrah binti Mohd Sa'at for supervising and guiding me so that I could complete my FYP along this year. Thanks for her patience, kindness, and guidance on sharing her knowledge regarding my FYP field.

After that, I want to say thank you to my second examiner, DR. Mohamad Shukri bin Zakaria and Prof. Madya DR. Tee Boon Tuan for providing me suggestions and advices for my FYP. I would also like to thank Miss Dahlia binti Johari for her kindness to share her knowledge and experience on thermoacoustic and measurement instrumentation.

Lastly, I want to thank my coursemates, friends, and family for their encouragement and mental support throughout my study in UTeM.

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LIST OF ABBREVIATION

ABS	Acrylonitrile Butadiene Styrene
ANSYS	Analysis System
COP	Coefficient of Performance
CFD	Computational Fluid Dynamics
FYP	Final Year Project
GA	Genetic Algorithm
MOGA	Multi-Objective Genetic Algorithm
Ph. D.	Doctor of Philsophy
PISO	Pressure-Implicit with Splitting of Operators
PLA	Polylactic Acid
PSM	Projek Sarjana Muda
SOGA	Single-Objective Genetic Algorithm
STL	Stereolithography
TA	Thermoacoustic
3D	Three Dimensions
UTeM	Universiti Teknikal Malaysia Melaka

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LIST OF SYMBOLS

λ	=	Wavelength of sound
α	=	Speed of sound
f	=	Oscillation frequency
ρ	=	Density of air
k	=	Thermal conductivity
ω	=	Angular frequency
π	=	Pi (Mathematical constant for circle)
C_p	=	Specific heat per unit mass
κ	=	Diffusivity of gas
μ	=	Dynamic viscosity
υ	=	Kinematic viscosity
σ	=	Prandtl number
δ_y	=	Viscous penetration depth
δ_k	=	Thermal penetration depth
Q_c	=	Cooling Power
W	=	Acoustic Power
Q_{cn}	=	Normalized cooling power
W	=	Normalized acoustic power
δ_{kn}	=	Normalized thermal penetration depth
COP	=	Coefficient of performance
L_s	=	Stack length
L_{sn}	=	Normalized stack length
p_o	=	Dynamic pressure
p_m	=	Mean pressure
x_n	=	Normalized stack position

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x_s	=	Stack center position
γ	=	Ratio of specific heat (Gamma)
y_o	=	Half spacing of the stack
J	=	Acoustic wave number
T_m	=	Mean Temperature
ΔT_m	=	Temperature difference across the stack
ΔT_{mn}	=	Normalized temperature difference
B	=	Blockage ratio (Porosity)
ΔT_{crit}	=	Critical longitudinal temperature gradient
η	=	Thermal efficiency
T_c	=	Cold end temperature
T_h	=	Hot end temperature
Q	=	Conservative variable sector
t	=	Time
E	=	Inviscidflux vector along the x-axis
x	=	Horizontal Cartesian coordinate
F	=	Inviscid flux vector along y-axis
y	=	Vertical Cartesian coordinate
E_v	=	Viscous flux vector along the x-axis
F_v	=	Viscous flux vector along the y-axis
e	=	Total energy per unit mass
T	=	Temperature
τ	=	Stress tensor
τ_{xx}	=	Stress tensor along x-axis
τ_{yy}	=	Stress tensor along y-axis
τ_{xy}	=	Stress tensor along xy-axis
v	=	Vertical velocity component
u	=	Horizontal velocity component
g	=	Gravitational acceleration, 9.81 m s^{-2}
P_1	=	Inlet oscillating pressure

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m_1	=	Inlet mass flux
θ	=	Phase difference

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CHAPTER 1

INTRODUCTION

1.1 Background

Thermoacoustic (TA) system is a system that is able to produce either heating effect or cooling effect based on thermoacoustic principle. Thermoacoustic principles allow gas particles to expand, compress and exchange heat with adjacent surfaces to complete a thermodynamic cycle so that heating or cooling effect can be produced.

These processes take place inside a resonator without the use of any moving mechanism, except for the acoustic driver. Hence, it is greener technology than the conventional refrigerator or engine.

The meaning of "Thermoacoustic" (TA) is a field from combination of thermodynamic and acoustic fields which is self-explanatorily defined by Nikolaus Rott in1980 (Rott, 1980). According to Swift (2001), the early stage of thermoacoustic was begun with Stirling engines since a century ago and the early concept of the Stirling engine was to produce work with the combination of crankshaft, piston, connecting rods, displacer, and et cetera while the structure of a Stirling engine is shown in Figure 1.1(a) and Figure 1.1(b) as in below.

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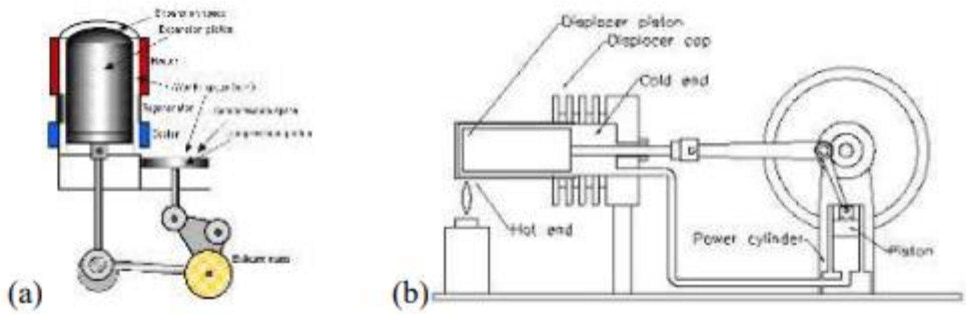

Figure 1.1: (a)Alpha Type Stirling Engine

(Retrieved from: https://www.ohio.edu/mechanical/stirling/engines/engines.html) and (b)Beta Type Stirling Engine

(Retrieved from: https://www.webcomsknkwrks.com/schmstirl.jpg)

Based on the analysis that was done in nineteenth century ago, powerful computational tools during that time had been used to analyze the four discrete steps of Stirling cycle, that is compression, displacement to and fro (two steps), and expansion in order to study the relation between the pressure change and velocity in the Stirling engine.

The studied analysis was based on extreme approximation in order to simplify the analysis or in another word, the analyzed Stirling cycle could be said as idealized cycle. Figure 1.2 below shows schematic diagram of how does a thermoacoustic engine work.

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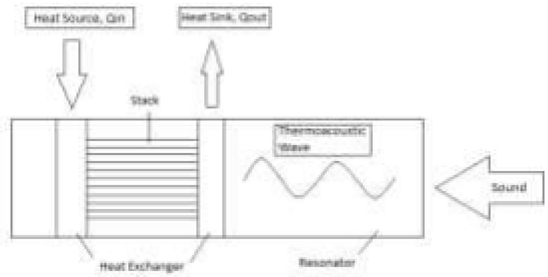

Figure 1.2: Schematic Diagram of Thermoacoustic Refrigerator

However, the study of Stirling cycle gave a sparking idea to Peter Ceperly that the phasing between pressure and velocity in the thermodynamic elements of Stirling machine is the same as the phasing between pressure and velocity in a traveling acoustic wave. As long as there is a phasing between pressure and velocity, there will be a temperature change and this concept leads to invention of thermoacoustic engine where the engine is used as heat exchanger or sub-cooler in both heat engine and refrigerator.

The components of a simple thermoacoustic engine is basically built from resonator, stack, and sound source. The two ends of the stack in the engine experience temperature increase and temperature decrease when a sound wave is passing through the stack. Due to this phenomenon, the thermoacoustic engine can be used as heat exchanger or sub-cooler in both heat engine and refrigerator.

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1.2 Problem Statement

If the thermoacoustic engine is used as a heat exchanger or sub-cooler in power plant industry, the heat exchanger structure is much simpler than the commercial heat exchanger in power plant system and of course the cost is relatively cheaper than commercial heat exchanger. However, the work generated due to temperature change in thermoacoustic engine may be insufficient for huge electric energy generation. In order to obtain a higher efficiency or a more stable thermoacoustic system, the study of flow characteristic and heat transfer performance of the acoustic wave inside the thermoacoustic engine is very important to help us to understand the behavior of the acoustic wave.

Thermoacoustic has been studied by many researchers around the world but there are very few thermoacoustic laboratories available in Malaysia. Building a big and complicated thermoacoustic system may be costly especially for beginners. However, few researchers such as Zolpakar et al. (2017), Yap and Cruz (2015), and Russell and Weibull (2002) reputed on research activities on the thermoacoustic system just by building a small simple thermoacoustic engine or thermoacoustic refrigerator. Understanding thermoacoustic system is difficult without the help of working apparatus. Hence, there is a need to conduct feasibility study for a laboratory scale thermoacoustic apparatus. Moreover, most earliest experimental investigations of thermoacoustic system were not accompanied by appropriate Computational Fluid Dynamics (CFD) simulations. This makes it difficult to understand the fluid dynamics and thermodynamics properties of the system. Hence, a simple CFD model of the laboratory scare thermoacoustic system is also needed.

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1.3 Objectives

The objectives of this study or project are:

i. To design a small scale thermoacoustic prototype for experimentation.

ii. To test the small scale thermoacoustic system using suitable measurement method.

iii. To model a simple thermoacoustic flow field by using Computational Fluid Dynamics (CFD) software.

1.4 Scope of Project

This project is carried out experimentally and numerically. A simple thermoacoustic prototype will be developed using available cheap materials. A simple Computational Fluid Dynamics (CFD) model is also built by using ANSYS Fluent to provide additional details of flow behavior inside the system. This project is not covering details such as efficiency or stability of thermoacoustic engine, the fitness value and so on. This study is mainly focused on the study of flow of a thermoacoustic system. Therefore, the study concerns only the temperature at both ends of stack, pressure and velocity in thermoacoustic refrigeration system. Since this study is only focused on the resonator part of thermoacoustic system, either thermoacoustic refrigerator or thermoacoustic engine can be selected to be studied and hence, flow inside of thermoacoustic refrigerator system is chosen to be studied in this project.

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