# THE STUDY OF WAVE DISTORTION IN A 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**

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**DECLARATION**

I declare that this project report entitled “The Study of Wave Distortion in The Thermoacoustic System” is the result of my own except as cited references.

Signature: ....................................

Author: MOHD FIRDAUS BIN ROSLI

Date: ...............................

**APPROVAL**

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

Signature: ...................................

Name of Supervisor: TS. DR ASRIANA BINTI IBRAHIM

Date: ...................................

## DEDICATION

To my beloved family.

Thanks to the non-stop encouragement and guide given by my honourable supervisor, Ts. Dr. Asriana Binti Ibrahim, I can complete the task successfully.

# ABSTARACT

A thermoacoustic system gives a lot of benefit to the environment and the ecosystem. A thermoacoustic system helps us to reduce pollution and fully make use of the sound energy that been wasted before. Even though the thermoacoustic system is a good technology but without fully understanding how it works and the elements that affect the thermoacoustic system's efficiency, it just a waste for us. Therefore, a study of wave distortion allows us to understand the wave behaviour of the wave that been used in thermoacoustic. Besides, additional knowledge on other elements may help increase the efficiency of the thermoacoustic system. In this study, two mini test rigs of the thermoacoustic system have been made to measure wave velocity experimentally. The mini test rigs are differed by diameter and length of the resonator. We could understand the relationship between the wave velocity, diameter, and the length of the resonator from the findings. It is found that wave distortion has existed in the design of a small diameter but long resonator.

ABSTRAK

*Sistem termoakustik memberi banyak manfaat kepada persekitaran dan ekosistem. Sistem termoakustik membantu kita mengurangkan pencemaran dan memanfaatkan sepenuhnya tenaga bunyi yang telah dibazirkan sebelumnya. Walaupun sistem termoakustik adalah teknologi yang baik tetapi tanpa memahami sepenuhnya cara kerjanya dan unsur-unsur yang mempengaruhi kecekapan sistem termoakustik, ia hanya sia-sia. Oleh itu, kajian penyimpangan gelombang membolehkan kita memahami tingkah laku gelombang gelombang yang telah digunakan dalam termoakustik. Selain itu, pengetahuan tambahan mengenai elemen lain dapat membantu meningkatkan kecekapan sistem termoakustik. Dalam kajian ini, dua rig ujian mini sistem termoakustik telah dibuat untuk mengukur halaju gelombang secara eksperimen. Rig ujian mini dibezakan berdasarkan diameter dan panjang resonator. Kami dapat memahami hubungan antara halaju gelombang, diameter, dan panjang resonator dari penemuan tersebut. Didapati bahawa penyimpangan gelombang telah wujud dalam reka bentuk resonator berdiameter kecil tetapi panjang.*

# ACKNOWLEDGEMENT

I would like to acknowledge the contribution of several people who have been influential during completing this study. I would like to thank my supervisor, Ts. Dr. Asriana binti Ibrahim for providing me tremendous support on completing this study. Her technical suggestions and eye for finer details have always been of immense help in completing this project. Ts. Dr Asriana has been a wonderful advisor in that she always encourages one to think and work independently.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Technology gives a lot of advantages for human needs. But we forgot that technology also causes pollution to the environment and require a new type of technology that is more eco-friendly with the environment, especially in the refrigeration system. Now adays, refrigeration system used harmful gasses such as Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs). These gasses can damage our earth ozone layer and can cause global warming. A thermoacoustic refrigeration system is suitable for replacing the old system because the thermoacoustic system used inert gas as the working fluid to operate the system. The usage of inert gas is cheaper than the old refrigeration system. In the thermoacoustic system, they only used simple mechanical technology, which is easy to assemble, and maintenance compared to the old system that used complex mechanical technology (Zolpakar,2016).

The thermoacoustic refrigeration system used the acoustic energy that been provided by the thermoacoustic engine, or the acoustic driver usually loudspeaker had been used. With the support of the acoustic driver, the fundamental resonance frequency for the resonator, the working fluid usually use inert gas, had been compressed (heat up) and expanded (cool off) adiabatically by an acoustic standing wave. Then the working fluid is oscillating within the stacks. Next, the thermal interaction between the acoustic wave with the plate changed the original temperature (one-part become hot, and the other parts become cold). The temperature difference will occur between the stacks, and the heat exchanger needs to be attached at both end stacks so that the heat pump process will occur. Once the process of heat in and heat out occurred at the ends of the plates, the refrigeration system occurs (Tiwatane,2014).

The importance of studying wave characteristics in the thermoacoustic system is to improve efficiency and performance and to understand more about the wave that is suitable for use in the system. Some of the waves are not suitable to be used especially if we want to gain the high efficiency of the refrigerator in the thermoacoustic system. According to Ke, et. al, (2010) the performance of the thermoacoustic system in a practical application can be improved by increasing the amplitude of the sound wave. Other than that, another factor can help improve the performance of the thermoacoustic system. According to Poignand, et. al, (2007) optimizing the pressure velocity field in the thermoacoustic system can be improved and the efficiency of the refrigerator.

## 1.2 Problem Statement

Thermoacoustic is the interaction between thermal and acoustic waves that provide many eco-friendly benefits to the environment and sustainable for a cooler or generator. But, unfortunately, a lack of understanding of acoustic wave behaviour, how it works and its efficiency determination, the thermoacoustic system has not yet been used as a commercial system. Therefore, wave characteristic needs to be studied such as distortion behaviour that can affect the system performance and efficiency when the thermoacoustic refrigerators are driven at small and large amplitudes.



## 1.3 Objective

The Objectives of this project are as follows:

1. To evaluate the acoustic wave distortion in a mini thermoacoustic system.
2. To determine the parameters that affect acoustic wave distortion in the thermoacoustic system.

## 1.4 Scope of Project

The scopes of this project are:

1. The study of wave characteristic is focusing on distortion behaviour.
2. The application of a large-scale thermoacoustic test rig is for a cooling system.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

In this chapter, a literature review based on previous works is done to understand the basic principle and application of the thermoacoustic system. In addition, studies on the acoustic wave are also conducted to understand its characteristics that may affect the performance of the thermoacoustic system.

## 2.2 Thermoacoustic

In general, thermoacoustic is the reaction between acoustic wave and temperature with a variation of density and pressure. The thermoacoustic system is a system that utilizes the phenomenon of the thermoacoustic, which is mutual energy conversion phenomenon between heat and sound (Kurata,2020). The cold energy and electrical energy can be pulled out from the reconversion once the thermal energy had been converting into sound energy. Based on the thermoacoustic system, the cooling facilities, air conditioner, and electrical generator can be powered by the unused thermal energy that been wasted before, such as factory exhaust heat and solar light.

A study claimed that the thermoacoustic phenomena are the solid-fluid interaction which involves the capability of the heat pumping mechanism of working fluid usually used inert gas of either generating acoustical work or inducing a cooling effect Zolpakar, et. al, (2016). Thus, acoustic work involves the process of heat movement from a lower temperature reservoir to a high-temperature reservoir.

## 2.3 Thermoacoustic Application

A thermoacoustic system can be applied to high temperature (generator) or low temperature (cooler) applications. According to a study stated there are two applications for the thermoacoustic system, which are the thermoacoustic engine and the thermoacoustic refrigerator (Kujerak, 2018). The thermoacoustic engine is the system that utilizing the heat flowing from high-temperature sources to low-temperature sources to generate acoustic power. In contrast, the thermoacoustic refrigerator is the system that transfers heat from low-temperature sources to high-temperature sources by absorbing acoustic power.

Biwa (2012) stated the thermoacoustic engine is the system that supplied heat from acoustic power generates from the prime mover based on the thermoacoustic oscillation. Biwa (2012) and Tijani (2011) claimed standing wave thermoacoustic engine is unsuitable for a thermoacoustic engine because it has a lower thermal efficiency of converting heat supplied into acoustic power than a travelling wave thermoacoustic engine. The situation can be seen through the data that shown travelling wave has 32% of thermal efficiency while 49% Carnot efficiency.

They also stated that the main component for the thermoacoustic engine is the stack for the standing wave and regenerator for the travelling wave. Both are the same material which is the porous material that consists of narrow flow channels in which energy conversion from Q (heat flow) to I (workflow) occurs. The usage of this porous material is to enhance the thermal contact of the gas with solid walls. The interaction between the acoustic wave with the solid walls is the elements for the thermoacoustic engines. As shown in Figure 2.1, the Stirling engine is the same as the travelling wave thermoacoustic engine.

According to Tijani (2002), the thermoacoustic refrigeration system is the system that produces cooling power by using the sound wave. As shown in Figure 2.2, the thermoacoustic refrigeration system consists of several main components that help the system undergoes the cooling process very well. The components consist of an acoustic driver, resonator, a stack, the heat exchanger and working fluid usually used air as the working fluid in the system. The heat pump process had been generated at the stack which is occurred due to thermal interaction between sound and the surface of the stack. Tiwatane (2014) explained that the refrigerator occurred once the presence of many stacks which a part is heated and another part been cooled had been atop each other, placed of an optimal length in the optimal area of the tube and then been attach heat exchangers to get the heat in and heat out at the end of the plates. To increase the efficiency of the refrigerator system for the thermoacoustic system, we must increase the number of stacks that been used in the system based on Tiwatane's (2014) explanation.

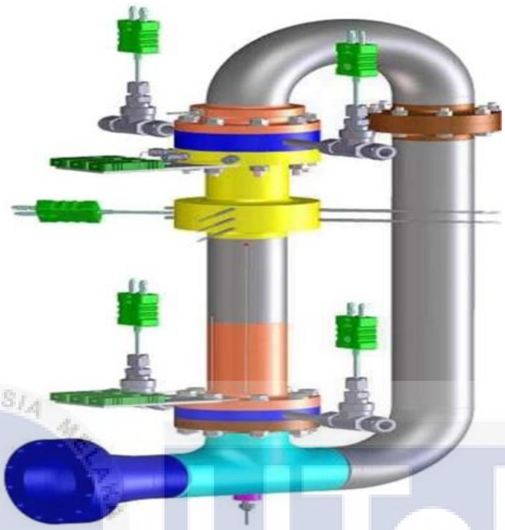

Figure 2.1: The Stirling engine (Tijani,2011)



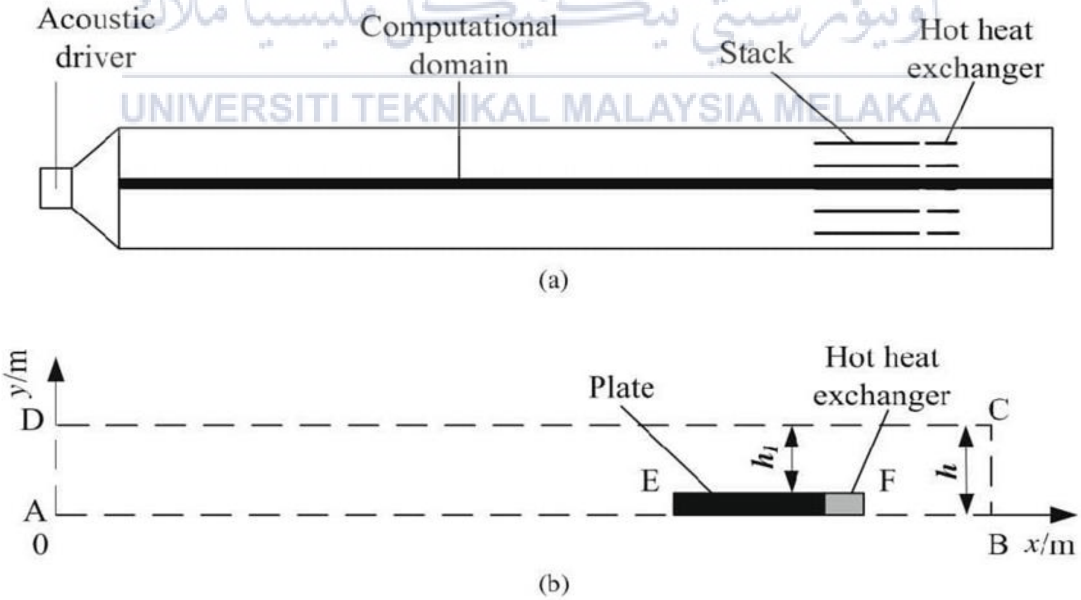


Figure 2. 2: The schematic diagram for the model of the thermoacoustic system. The dark domain is the computation domain shown in magnified in (b). (Ke et al, 2010)

## 2.4 Thermoacoustic System

This chapter explains the components that involve in the thermoacoustic system. There are a few main components that need in the thermoacoustic system, especially in the refrigerator. These main components may affect the efficiency of the thermoacoustic system, especially the results during running the experiment. According to Zolpakar et. al, (2016), the main components that are essential in the thermoacoustic system are the stack that been used in the system, working fluid, resonator, frequency, and average pressure. When the working fluid in the system hit the stack, the stack will act as the temporary storage for the heat inside the working fluid during the final stage of the compression (pressure antinode) or expansion (pressure node). So that the temperature of the system will decrease during the experiment due to heat transfer from the working fluid to the stack. The more the number of stacks in the system, the more the heat transfer occurred, and the temperature of the system will decrease.

Figure 2.4 show the geometries of the stack that had been used in the thermoacoustic system. The geometry of the stack may affect the efficiency of the heat transfer. When the separate gap between the solid wall decreases, the thermal boundary layer will increase and the efficiency of the thermoacoustic system will increase.



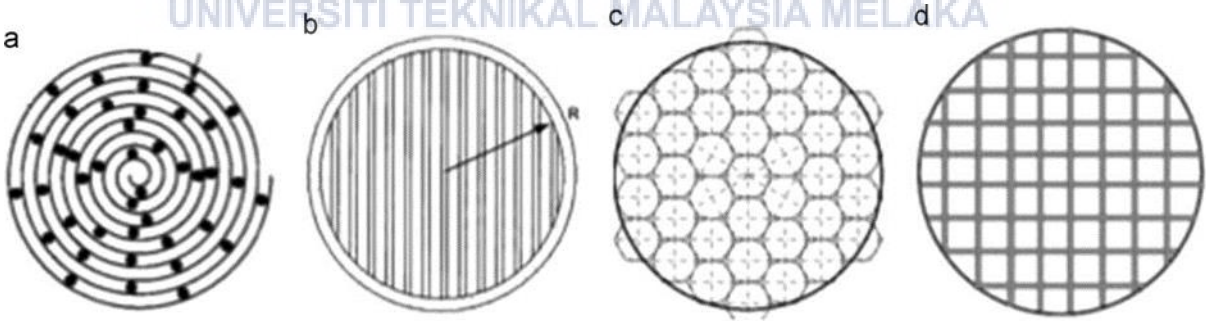


Figure 2.3: Different stack geometries utilized in the previous studies (a) spiral (b) parallel plate (c) honeycomb and (d) corning celcor. (Zolpakar et al. 2016)

According to Babu, et. al, (2017), the amount of heat produced is predominantly dependent on the material properties of the stack, such as the thermal conductivity, heat carrying capacity, the porosity, and the length of the stack. The position of the stack in the resonator also decides the amount of refrigerant that can be obtained for the thermoacoustic system. Other than that, the design of the stack also decides the amount of refrigerant that can be obtained for the thermoacoustic system. The honeycomb ceramic stack as shown in Figure 2.4, is the recommended design for the stack according to Babu, et. al, (2017) compared to the other design of the stack. This is because the material that been used is ceramic which is a good heat insulator and the shape of the honeycomb allow the wave to travel through smoothly. But according to Alamir, et. al (2019), the best material that can be used in a thermoacoustic system is steel wool. This is because the steel wool stacks had the best performance and the maximum cooling power compared to the honeycomb ceramic stack, as shown in Figure 2.4.

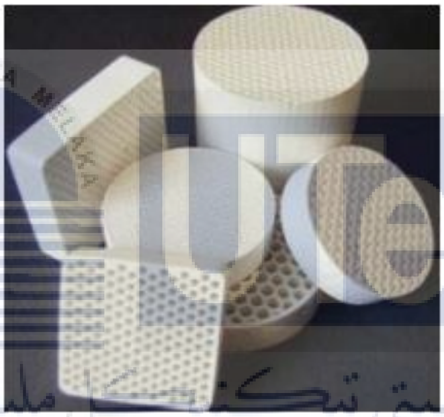

Figure 2.4: The honeycomb ceramic stack. (Babu, et. al, 2017)



Working fluid is the components that been produce inside the thermoacoustic system by the acoustic driver. There are a few types of working fluid that can be used in the thermoacoustic system. According to Kajurek, et. al, (2018), the working fluid that suitable to be used in the thermoacoustic system is the standing wave and air. Other than that, travelling wave also had been used as the working fluid in the thermoacoustic system. According to Sharify, et. al, (2017), the travelling wave also can be used as the working fluid in the thermoacoustic system. According to Tasnim, et. al, (2012), helium and xenon also can be used as the working fluid for the thermoacoustic system because they also part of inert gas. We know that all the inert gasses can be used as the working fluid for the thermoacoustic refrigeration system. Alamir, et. al (2019) also agreed with a study Tasnim, et. al (2012) about the usage of helium gas as the working fluid for the thermoacoustic system.

The next component that been used in the thermoacoustic system is the resonator. According to Babu, et. al (2017), the resonator may be of a half-wavelength type and quarter-wavelength type and with or without buffer volume of various geometries. The resonator is placed in the system where the high intensity of sound wave from the loudspeaker travels inside it.  The cooling and heating process are happened at the end of the resonator due to the interaction between the stack and the waves in the resonator. Figure 2.5 shows the type of resonator that had been used in the thermoacoustic system. In the experiment that had been conducted by Johari, et. al (2019), a quarter wavelength resonator has been used and the been attached to a loudspeaker that acts as the acoustic driver. The frequency and pressure in the thermoacoustic system are affected by the acoustic driver of the system.

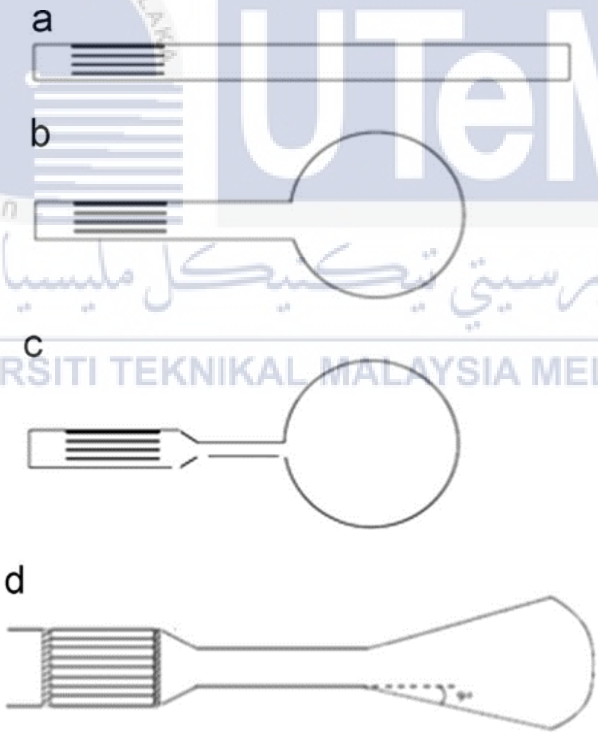




Figure 2.5: Types of resonators:(a) half wavelength (b) quarter wavelength with sphere buffer volume (c) two diameter of a resonator with sphere buffer volume and (d) two diameters of a resonator with conical buffer volume. (Zolpakar, et. al, 2016)

According to Agarwal, et. al, (2016), other components need to be used in the thermoacoustic system to increase the efficiency and performance of the system. The components that need to be used are the heat exchanger and the alternator. The function of using the heat exchanger is to keep the temperature gradient along with the stack higher than the critical temperature gradient needed to maintain the thermoacoustic effect. According to Babu, et. al (2017), the heat exchanger needs to be placed on the stack at either end of the stack. This is because the position of the heat at the end of the stack enables the heat transfer to occur from the stack ends. Even the optimal design of the stack is essential to get a maximum difference in temperature, but the presence of heat exchanger will help to increase the efficiency of the thermoacoustic system.  Figure 2.5 show the heat exchanger that been used in the thermoacoustic system. The linear alternator is to increase the complexity of the design, but it also increases the cost to fabricate the thermoacoustic system. There still no cost-efficient linear alternator for the low acoustic impedance that available in the market.



Figure 2.6: The heat exchanger that been used in the thermoacoustic system. (Agarwal, et. al, 2016)

According to Avent, et. al (2015), thermoacoustic can be used as the energy harvesting system for the application of the thermoacoustic system. The critical temperature gradient that been produced in the system can be used to produce powerful acoustic pressure waves if it been fully utilized, and it can be the main key to help the thermoacoustic in energy harvesting system. The temperature gradient that occurred between the stacks or regenerator can be improved by using the mechanism for coupling a thermoacoustic prime mover with electromagnetic harvester and the piezoelectric transducer materials, as shown in Figure

2.7(a). We know that the piezoelectric transducer materials can offer the potential to enhance the energy density attained beyond that possible with linear alternators. The critical temperature gradient is the gradient through the length of the stack in the direction of acoustic wave propagation. The above part will function as a prime mover or engine, and for the below part, it will function as a refrigerator or heat pump has been shown in Figure 2.7(a).

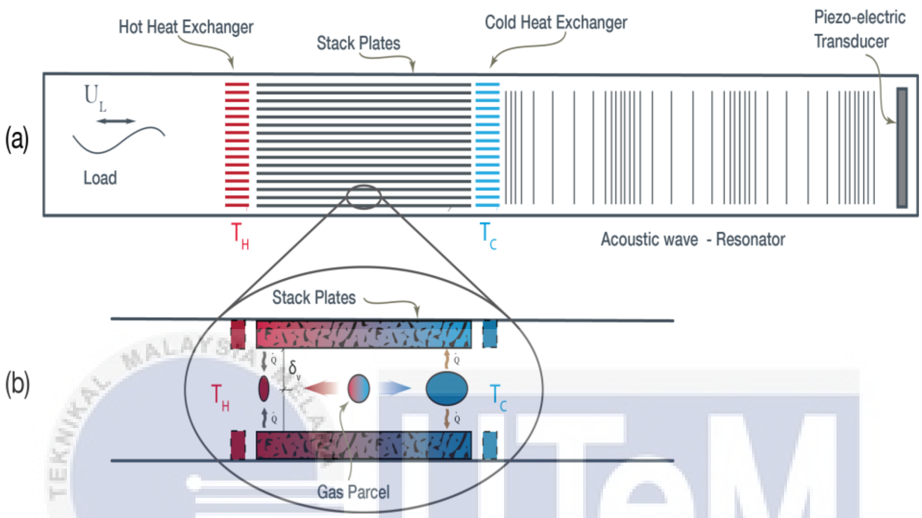


Figure 2.7: (a) The schematic diagram of a thermoacoustic energy harvester and (b) the expended view of the stack plates. (Avent, et. al, 2015)



## 2.5 Standing Wave in Thermoacoustic System

According to Babu, et. al (2017), the standing wave has been created due to the interaction between the reflected wave with the original wave in the constructive interference in which both waves are in the same phase, and the incident occurs in the closed medium. The reflected wave occurs due to the sound wave of pre-set frequency that been sent into the resonator has been reflected due to the closed on the other side. Kurata (2020) stated that the standing wave is the wave that undergoes the self-excited vibration at the same mode.

While for the thermoacoustic system, Kurata (2020) stated the standing wave is the sound wave that undergoes the self-excited vibration at the same mode and the heat exchange in the prime mover (PM) inside the thermoacoustic system. At the higher mode, the superposing of the sound wave had been changed from the fundamental mode to the system