DESIGN AND OPTIMISATION OF A THERMOACOUSTIC COOLER BOX FOR PORTABLE REFRIGERATION SYSTEM

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (REFRIGERATION & AIR CONDITIONING SYSTEMS) WITH HONOURS

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Date : 11 JUN 2024

DEDICATION

This thesis is dedicated to the glory of Allah S.W.T, my Creator, and my great teacher and messenger, Mohammed (May Allah bless and grant him peace), who has taught us the essence of life and is the source of all knowledge. I am deeply grateful to everyone who contributed to the success of this study, making it an unforgettable experience. I extend my heartfelt thanks to my beloved parents, Abdul Kadir bin Osman and Haliza Habib Khan, for their unwavering support throughout my career. Their unconditional love, encouragement, support, and sacrifices have sustained me over the years, providing moral, spiritual, and financial backing that inspired me to complete this work. Furthermore, I dedicate this thesis to my esteemed teachers, whose vast knowledge, diligence, and support have been instrumental in my education and thesis completion. A special acknowledgment goes to my supervisor, Dr. Noor Saffreena binti Hamdan, for her strength, supervision, and encouragement, which were crucial in conducting this research. Thank you for your persistent guidance and help in completing this project thesis.

ABSTRACT

Thermoacoustic technology emerged as an efficient and environmentally friendly cooling solution. In recent years, the innovation of the thermoacoustic cooler box evolved into a groundbreaking refrigeration solution through detailed design and optimization techniques. Current cooling technologies struggled to provide high efficiency in cooling and effective thermal management, necessitating the development of superior cooling systems. This research aimed to analyze and innovate a portable thermoacoustic cooler box that outperformed existing technology. The focus was on configuring the most effective cooling performance enhancement with proper thermal management. This design approach involved studying and analyzing two different concept designs using copper and aluminum as the heat exchanger materials, positioning them near the loudspeaker (also known as the driver) and at the end of the resonator tube. After thorough evaluation, Concept Design 1 was selected, incorporating copper heat exchangers due to copper's high thermal conductivity, which enhanced cooling efficiency. The primary components of this final design included the loudspeaker as the acoustic driver, a PVC quarter-wave resonator, and Mylar, forming the stack. The aluminum cooling plates offered important properties such as excellent heat transfer, lightweight construction, and cost-effectiveness. Additionally, CAD software was used to test the concept design through thermal test. The result analyzed the generation and propagation of sound waves within the resonator and the heat transfer between the stack and the heat exchangers. The expected deliverables of this study were improved cooling performance and effective thermal management, validated by the methodological approach. Utilizing copper's thermal benefits made the thermoacoustic cooler box a feasible and practical mobile refrigeration solution, comparable to modern technological alternatives. The outcomes of this study significantly contributed to the development of thermoacoustic cooling technology, offering an excellent alternative for various cooling applications.

ABSTRAK

Teknologi termoakustik muncul sebagai penyelesaian penyejukan yang cekap dan mesra alam. Dalam beberapa tahun kebelakangan ini, inovasi kotak penyejuk termoakustik berkembang menjadi penyelesaian penyejukan yang revolusioner melalui reka bentuk terperinci dan teknik pengoptimuman. Teknologi penyejukan semasa menghadapi kesukaran untuk menyediakan kecekapan penyejukan yang tinggi dan pengurusan haba yang berkesan, sekali gus memerlukan pembangunan sistem penyejukan yang lebih unggul. Kajian ini bertujuan untuk menganalisis dan menginovasi kotak penyejuk termoakustik mudah alih yang mampu mengatasi teknologi sedia ada. Fokus kajian adalah pada mengkonfigurasi peningkatan prestasi penyejukan yang paling berkesan dengan pengurusan haba yang betul. Pendekatan reka bentuk ini melibatkan kajian dan analisis dua reka bentuk konsep yang berbeza menggunakan tembaga dan aluminium sebagai bahan penukar haba, serta meletakkannya berhampiran pembesar suara (juga dikenali sebagai pemandu) dan di hujung tiub resonator. Selepas penilaian terperinci, Reka Bentuk Konsep 1 telah dipilih, menggabungkan penukar haba tembaga kerana kekonduksian haba tembaga yang tinggi, yang meningkatkan kecekapan penyejukan. Komponen utama reka bentuk akhir ini termasuk pembesar suara sebagai pemandu akustik, resonator gelombang suku PVC, dan Mylar yang membentuk susunan (stack). Plat penyejuk aluminium menawarkan ciri penting seperti pemindahan haba yang sangat baik, reka bentuk ringan, dan kos yang berpatutan. Selain itu, perisian CAD telah digunakan untuk menguji reka bentuk konsep melalui ujian haba. Hasilnya menganalisis penjanaan dan penyebaran gelombang bunyi dalam resonator serta pemindahan haba antara susunan dan penukar haba. Hasil yang dijangkakan daripada kajian ini ialah peningkatan prestasi penyejukan dan pengurusan haba yang berkesan, yang disahkan melalui pendekatan metodologi. Penggunaan kelebihan haba tembaga menjadikan kotak penyejuk termoakustik sebagai penyelesaian penyejukan mudah alih yang boleh dilaksanakan dan praktikal, setanding dengan alternatif teknologi moden. Hasil daripada kajian ini memberi sumbangan besar kepada pembangunan teknologi penyejukan termoakustik, menawarkan alternatif yang sangat baik untuk pelbagai aplikasi penyejukan.

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LIST OF SYMBOLS AND ABBREVIATIONS

L	-	The length of the tube
V	-	Speed of sound
f	-	Frequency
λ	-	Wavelength
ΔT	-	Temperature Difference
Qc	-	Heat Absorbed
CFC	-	Chlorofluorocarbon
Hz	-	Hertz
ODP	-	Ozone Depletion Potential
TL	-	Low Temperature
GWP	-	Global Warming Temperature
HFC	-	Hydrofluorocarbon
PCM	-	Phase Change Material
MOF	-	Metal Organic Framework
CFD	-	Computation Fluid Dynamic
FEI	-	Finite Element Analysis
PVC	-	Polyvinyl Chloride
CAD	-	Computer-Aided Design
COP	-	Coefficient of Performance

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CHAPTER 1

INTRODUCTION

1.1 Background

Formally, before the invention of mechanical refrigeration systems, up to the early 20th century, stored ice was one of the primary methods of refrigeration, as demonstrated by ancient civilizations like the Greeks and Romans, who used ice from the mountains to cool their food (Britannica, T. Editors of Encyclopaedia, 2023). By the 1800s, with the invention of the first mechanical refrigerator, refrigeration technology had made significant advancements. In the modern era, refrigeration became indispensable to daily life, ranging from storing life-saving medications to keeping food fresh. Tremendous strides had been achieved in refrigeration technology in recent years, and the future appeared even more promising (Ref Experts, 2023).

Thermoacoustic refrigeration also became well-known in the research community following the groundbreaking discoveries of John Wheatley and Gregory Swift of Los Alamos National Laboratories at the beginning of the 1980s, and the field remained pertinent in subsequent years (Ramadan et al., 2021). Thermoacoustic refrigeration enhanced the cooling effect without the use of refrigerants that were detrimental to the environment by utilizing sophisticated acoustic technology. The process involved converting heat energy to sound energy and vice versa. Heat was rejected to a high-temperature medium after being absorbed from a low-temperature medium using labor (acoustic power). To become competitive, the efficiency of thermoacoustic devices needed to be enhanced, as it was lower than that of conventional counterparts. Therefore, competitive thermoacoustic devices also had to prioritize low cost, high reliability, safety, compact design, and ease of bulk manufacturing (Teja & Kumar, 2017).

As a result, portable refrigeration was important in various scenarios, from medical storage to outdoor leisure. Thermoacoustic cooling, on the other hand, proposed a reliable, eco-friendly way of harnessing sound waves for cooling. The study aimed to contribute to the optimization of a thermoacoustic cooler box for portable refrigeration. The report provided a theoretical background for the optimization of important parameters such as size and material and primarily for the validation of performance through experiments to develop efficient and practical cooling solutions. This offered insight and guidance toward advancing refrigeration technology in the area of portable thermoacoustic systems.

1.2 Problem Statement

In recent times, there had been a notable increase in the demand for efficient and portable refrigeration solutions, particularly in remote or resource-limited areas. Traditional refrigeration technologies, although effective, often faced limitations in such environments due to their reliance on electricity, utilization of environmentally harmful refrigerants, and bulky designs that hindered portability. This presented a significant challenge in achieving optimal cooling performance in portable settings.

A significant challenge in portable refrigeration was achieving an equilibrium between cooling efficiency, energy usage, and environmental impact. Traditional refrigeration methods, mainly compression-based systems, were not only high in energy consumption but also depended on a continuous power supply, making them unsuitable for remote areas. Additionally, these systems often used hydrofluorocarbons (HFCs), which significantly contributed to global warming.

Innovation was crucial to devising solutions that met cooling requirements without compromising performance or environmental sustainability. Thermoacoustic cooling emerged as a promising alternative, harnessing sound waves to transfer heat and offering a potential avenue to achieve efficient cooling with reduced energy consumption and without relying on harmful refrigerants.

The absence of efficient and eco-friendly portable refrigeration solutions further complicated efforts to address diverse cooling needs, including medical supply preservation, food storage, and outdoor activities. This project aimed to address these challenges by developing and optimizing a portable thermoacoustic cooler box, providing a sustainable and practical solution for various applications.

1.3 Research Objective

There were three objectives that were highlighted in this project. Specifically, the objectives were as follows:

1) To develop a thermoacoustic cooler box that offers comparable cooling performance to traditional refrigeration methods while consuming less energy.
2) To analyse the existing technology and innovation of thermoacoustic refrigeration systems that are used nowadays.
3) To evaluate the feasibility and practicality of the designed system.

1.4 Scope of Research

The scope of this research was as follows:

- Reviewed current thermoacoustic cooling applications and their performance metrics to identify the thermoacoustic effect and cooling performance.
- Explored innovative approaches and technologies for improving the environmental sustainability of the system.
- Conceptualized and designed a prototype of the thermoacoustic cooler box using standard parts that are available in the market.
- Utilized SolidWorks CAD software for product design drawing.
- Conducted computational simulations to optimize the thermoacoustic effect and cooling performance.

1.5 Motivation

Environmental Impact of Traditional Refrigerants and Cooling Systems

Traditional refrigeration systems predominantly used hydrofluorocarbons (HFCs) as refrigerants, which had a high global warming potential (GWP) (IPCC 2014). These refrigerants contributed significantly to greenhouse gas emissions, exacerbating climate change. Additionally, conventional refrigeration methods were often energy-intensive, requiring a continuous power supply, which was impractical in remote or resource-limited settings (Rosen, M. A., 2002). The environmental and logistical challenges associated with traditional cooling technologies necessitated the development of more sustainable and efficient alternatives.

Potential of Thermoacoustic Cooling for Portable Applications

Thermoacoustic cooling offered a promising alternative to traditional refrigeration methods, leveraging the interaction between sound waves and thermal gradients to achieve cooling without the use of harmful refrigerants (Hofler et al., 2004). This technology had the potential to provide efficient cooling with fewer moving parts, leading to reduced energy consumption and increased reliability. Furthermore, thermoacoustic cooling systems were designed to be compact and portable, making them ideal for applications in remote and resource-limited environments (Backhaus, S., Swift, G. W., & Wheatley, J. C., 2002). By exploring and optimizing this innovative technology, the project aimed to address the growing need for environmentally friendly and energy-efficient portable refrigeration solutions.

1.6 Significance of the Study

The significance of this study lay in its potential to contribute to the development of sustainable refrigeration technologies that could address both environmental and practical concerns. Traditional refrigeration systems, which relied on vapor-compression cycles, typically used refrigerants with high global warming potential (GWP) and consumed substantial amounts of energy. These issues highlighted the need for innovative approaches to refrigeration that were both environmentally friendly and energy efficient.

Environmental Impact

One of the primary benefits of thermoacoustic refrigeration was its use of inert gases, such as helium or argon, which did not contribute to ozone depletion or global warming (Garrett & Backhaus, 1993). By eliminating the need for harmful refrigerants, thermoacoustic refrigeration systems significantly reduced the environmental footprint of cooling technologies. This aligned with global efforts to phase out substances with high GWP under international agreements like the Montreal Protocol and its Kigali Amendment (United Nations Environment Programme, 2016).

Energy Efficiency

Thermoacoustic refrigeration systems had the potential to offer higher energy efficiency compared to traditional refrigeration methods. This was due to the unique way they converted acoustic energy into cooling power without the need for mechanical moving parts, which reduced energy losses associated with friction and wear (Tijani et al., 2002). As a result, thermoacoustic systems achieved a favorable coefficient of performance (COP), making them an attractive option for energy-conscious applications.

Practical Applications and Portability

The ability to miniaturize thermoacoustic refrigeration systems made them particularly suitable for portable applications. This was crucial for various sectors, including medical transport, outdoor activities, and military operations, where reliable and portable cooling solutions were essential. A portable thermoacoustic cooler box provided consistent cooling performance in remote or off-grid locations, enhancing the practicality and versatility of refrigeration technology (Yazaki et al., 2002).

Cost-Effectiveness

The construction of thermoacoustic refrigeration systems using commonly available materials, such as metals and ceramics, led to cost-effective manufacturing processes. This was in contrast to traditional refrigeration systems, which often required specialized components and complex manufacturing techniques. By reducing production costs, thermoacoustic refrigeration systems became more accessible to a broader range of consumers and industries (Swift, 2002).

Durability and Maintenance

Thermoacoustic refrigeration systems had fewer mechanical parts compared to traditional refrigeration units. This simplicity translated to reduced maintenance requirements and increased durability. The absence of compressors and other mechanical components lowered the likelihood of mechanical failures, thereby extending the operational lifespan of the refrigeration system (Backhaus & Swift, 2000).

Contribution to Scientific Knowledge

This study also contributed to the scientific understanding of thermoacoustic refrigeration. By analyzing existing technologies, developing a prototype, and evaluating its performance, the research provided valuable insights into the design and optimization of thermoacoustic systems. The findings informed future studies and advancements in the field, fostering further innovation and development (Tijani et al., 2002).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The term "thermoacoustics" indicates that the application of an acoustic medium (sound) can produce a thermodynamic impact. The term "thermodynamic impact" in this context refers to the cooling effect that is achieved through the use of high-frequency sound. Compared to modern cooling systems, it is significantly more environmentally friendly because it uses sound to achieve the intended effect rather than emitting gases that are harmful to the environment, such as CFCs, Freons, and other hydrocarbons (Devkota et al., 2022). In another perspective, according to Babaei & Siddiqui (2008), the science of thermoacoustics studies how heat energy is transformed into sound energy and vice versa. The term "thermoacoustic refrigerator" refers to a device that uses sound or acoustic work to transport heat from a low temperature reservoir to a high temperature reservoir. The mechanism that converts heat energy into sound or acoustic labor is known as a thermoacoustic heat engine or prime mover. Even though the thermoacoustic phenomena was discovered more than a century ago, the field has advanced rapidly in the last three decades as a result of the development of prototype devices based on this technology and a theoretical explanation of the phenomenon.

Furthermore, our world is currently dealing with a number of energy and environmental issues which to meet energy needs with great efficiency, performance optimization of energy-related systems becomes increasingly vital. In addition, issues with the ozone layer's depletion and global warming brought on by dangerous refrigerants used in typical vapour compression cycles affect the refrigeration and air conditioning industries. The application of thermoacoustics is a new technique for the clean technologies of engines and refrigeration. Thermoacoustics provides so many advantages over alternative refrigeration and engine systems, there has been a surge in interest in it in recent years. Using environmentally friendly working fluids, continuously controlling cooling capacity, having a simple design, using waste energy, and having the option of silent operation are some of these benefits (Alamir, 2021). Besides, the progress and survival of contemporary society depend heavily on the availability of energy. Large amounts of emissions are produced as they operate; these emissions have varying temperatures and contain dangerous materials that are released into the atmosphere. Thus, cutting heat emissions is currently the most pressing issue. This might be accomplished by increasing the efficiency of primary heat engines, switching to new, alternative fuel types, and simultaneously switching to carbon-free fuel to reduce the quantity of these pollutants such as the thermoacoustic system (Yang et al., 2022).

In today's modern society, energy efficiency are identified as key strategies to address growing issues in increasing fuel cost, market competition, tightening regulation, climate change and energy crisis due to depleting fossil fuel resources. Utilities and regulators are putting greater emphasis to find ways to reduce distribution low temperature (TL) as it represents key indicator of an energy efficient system. For strategic planning and development of energy efficient distribution network, it is important for utilities to develop effective methodology to correctly and efficiently evaluate the magnitude, location and sources of TL that occurs in the system. With comprehensive and accurate TL information, corrective and preventive solutions for TL reduction can be planned and executed correctly, and in a timely and effective manner.

2.2 Previous Research on Thermoacoustic Refrigeration

Overview of Existing Studies and Projects

Numerous studies and projects have explored the potential of thermoacoustic refrigeration, focusing on its underlying principles, design, and applications. Initial research primarily concentrated on understanding the fundamental mechanisms of thermoacoustics, which involve the interaction between acoustic waves and thermal gradients to achieve cooling (Tijani, Zeegers, & de Waele, 2002). These studies laid the groundwork for developing practical thermoacoustic devices.

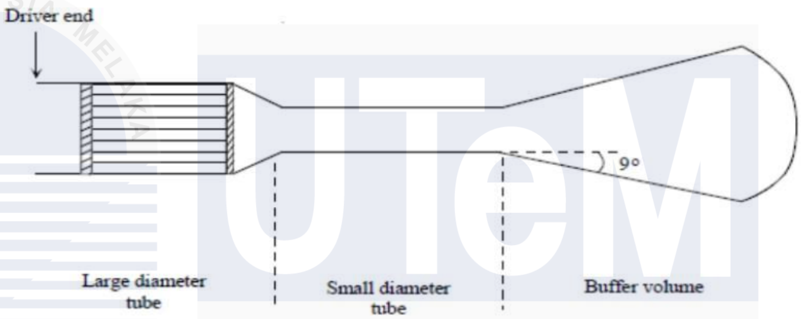


Figure 2.1: Resonator Optimized for minimized losses per unit surface area (Gangga Naik, 2011)

Experimental and Theoretical Investigations

Experimental and theoretical investigations into thermoacoustic refrigeration have provided valuable insights into optimizing system performance. Experimental studies typically involve constructing and testing prototype devices to evaluate parameters such as cooling power, efficiency, and temperature drop (Swift, 2002). For instance, researchers have developed and tested standing wave and traveling wave thermoacoustic refrigerators, each with distinct design considerations and performance characteristics (Garrett, 2004).

Theoretical investigations complement experimental work by using mathematical models and simulations to predict the behaviour of thermoacoustic systems under various conditions. These studies have focused on optimizing factors such as resonator design, working gas properties, and drive frequency to enhance cooling performance.

Key Findings, Breakthroughs, and Challenges

Key findings in thermoacoustic refrigeration research include the identification of optimal resonator designs and working gases that maximize cooling efficiency (Backhaus & Swift, 2000). Breakthroughs have been achieved in reducing the size and increasing the portability of thermoacoustic devices, making them more practical for real-world applications (Jin & Tang, 2014). However, challenges remain, such as improving the overall efficiency to compete with traditional refrigeration methods and ensuring reliability in diverse environmental conditions (Yazaki et al., 1998).

2.3 Design Considerations for Portable Refrigeration

Portable refrigeration systems are essential for various applications, ranging from medical transport to outdoor activities. The design of these systems requires careful consideration to balance performance, energy efficiency, and portability. Thermoacoustic refrigeration, an innovative technology leveraging sound waves for cooling, presents unique opportunities and challenges. This section explores the design considerations specific to portable thermoacoustic refrigeration systems, the requirements and challenges they face, and a comparison with conventional refrigeration methods.

Requirements and Challenges of Thermoacoustic Wave Portable Refrigeration

1. Energy Efficiency

Requirement: Thermoacoustic refrigerators must maximize energy efficiency to extend battery life and reduce power consumption.

Challenge: Achieving high efficiency in portable systems is challenging due to limited space for incorporating advanced thermodynamic cycles and high-performance materials (Swift, 2002).

2. Compactness and Weight

Requirement: The system must be lightweight and compact to ensure ease of transport and usability.

Challenge: Integrating all necessary components (e.g., resonators, heat exchangers, and drivers) within a small form factor without compromising performance is a significant challenge (Tijani, Zeegers, & de Waele, 2002).

3. Durability and Reliability

Requirement: Portable refrigeration units must withstand varying environmental conditions and frequent handling.

Challenge: Ensuring the mechanical and acoustic components remain functional and efficient over time and under different operating conditions requires robust design and material selection (Poese & Garrett, 2000).

4. Cooling Capacity and Temperature Control

Requirement: The cooler box must provide sufficient cooling capacity and precise temperature control to meet specific application needs.

Challenge: Designing a system that can achieve and maintain low temperatures in a portable form while being energy-efficient is technically demanding (Yazaki et al., 1998).

5. Noise Reduction

Requirement: The operation of the refrigeration unit should be quiet to avoid disturbing the user or surrounding environment.

Challenge: Thermoacoustic systems inherently generate noise due to sound wave oscillations, making noise reduction a critical design consideration (Garrett, 2004).

Comparison with Conventional Refrigeration Systems

1. Environmental Impact

Thermoacoustic Refrigeration: Uses inert gases like helium or air, which have no ozone depletion potential (ODP) or global warming potential (GWP) (Swift, 2002).

Conventional Refrigeration: Often relies on refrigerants like HFCs and CFCs, which are harmful to the environment due to their high ODP and GWP (Tijani, Zeegers, & de Waele, 2002).

2. Energy Consumption

Thermoacoustic Refrigeration: Generally, has lower energy efficiency compared to conventional systems due to the complexities in converting acoustic energy to thermal energy efficiently (Poese & Garrett, 2000).

Conventional Refrigeration: Typically, more energy-efficient due to well-optimized vapor-compression cycles and mature technology (Yazaki et al., 1998).

3. Portability

Thermoacoustic Refrigeration: Offers potential for lightweight and compact designs, but current implementations often struggle with efficiency and cooling capacity in portable forms (Garrett, 2004).

Conventional Refrigeration: Established portable designs like thermoelectric coolers are already optimized for portability but may lack the cooling power and efficiency of larger systems (Swift, 2002).

4. Cost and Maintenance

Thermoacoustic Refrigeration: Potentially lower maintenance due to fewer moving parts, but high initial development and production costs are a barrier (Tijani, Zeegers, & de Waele, 2002).

Conventional Refrigeration: Generally lower initial costs and well-understood maintenance practices but may require more frequent servicing due to mechanical components (Poese & Garrett, 2000).

Feature	Thermoacoustic Refrigeration	Conventional Refrigeration
Environmental Impact	No ODP or GWP, uses inert gases	High ODP and GWP, uses HFCs and CFCs
Energy Efficiency	Generally lower due to conversion complexities	Higher due to optimized vapor-compression
Noise	Higher due to sound wave generation	Lower, quieter operation
Portability	Potential for lightweight designs	Established portable designs available
Cost	High initial development and production costs	Lower initial costs
Maintenance	Potentially lower, fewer moving parts	Well-understood, may require frequent servicing

Table 2.1: Comparison of Thermoacoustic and Conventional Refrigeration Systems

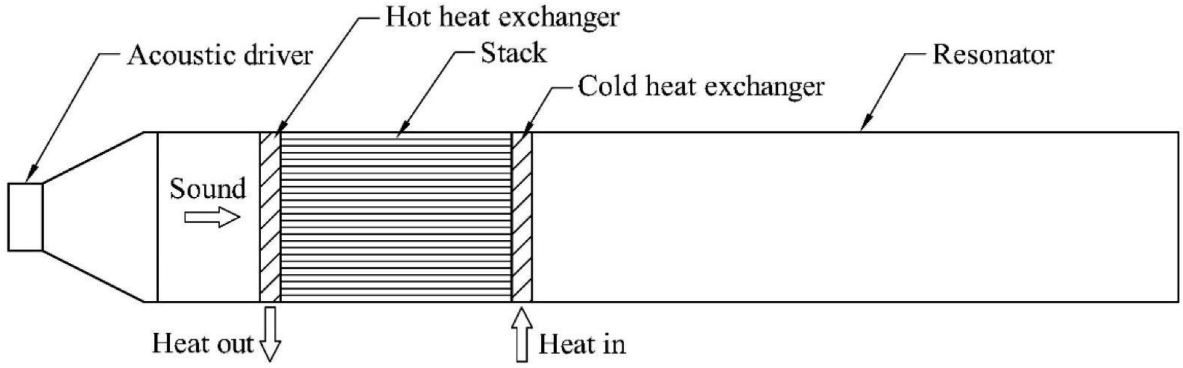


Figure 2.2: Simple Thermoacoustic Refrigeration System (Gangga Naik, 2011)

2.4 Thermoacoustic Cooler Box Designs and Applications

Thermoacoustic cooler boxes leverage sound waves to create cooling effects, offering an environmentally friendly and potentially efficient alternative to conventional refrigeration systems. This section reviews existing designs and prototypes, highlights key design features, configurations, and materials used, and evaluates the performance characteristics and limitations of thermoacoustic cooler boxes.

<u>Review of Existing Designs and Prototypes</u>

1. Basic Thermoacoustic Coolers

Description: Early designs focused on demonstrating the feasibility of thermoacoustic cooling. These prototypes typically used simple configurations with straightforward components such as loudspeakers as drivers and basic resonators.

Example: A common prototype includes a quarter-wavelength resonator with a loudspeaker at one end and heat exchangers placed strategically along the tube to facilitate heat transfer (Swift, 2002).

2. Advanced Prototypes

Description: More advanced designs have improved upon initial models by optimizing component placement and integrating more sophisticated materials and geometries.

Example: Prototypes developed by Tijani, Zeegers, and de Waele (2002) feature looped-tube configurations that enhance efficiency by allowing continuous operation and better thermal management.

Design Features

1. Resonators

Function: Amplify sound waves to create standing waves necessary for the thermoacoustic effect.

Types: Straight tubes, looped tubes, and tapered tubes, each offering different benefits in terms of wave amplification and thermal management.

2. Heat Exchangers

Function: Facilitate heat transfer from the cooler to the environment and vice versa.

Materials: Common materials include metals like aluminum and copper due to their high thermal conductivity.

3. Drivers

Function: Generate the sound waves that drive the thermoacoustic effect.

Types: Loudspeakers and piezoelectric drivers are commonly used, with piezoelectric drivers being favored for their efficiency and compact size.

4. Working Gases

Function: Transmit sound waves and facilitate the thermoacoustic effect.

Common Choices: Helium and air are frequently used due to their favorable acoustic properties and safety.

<u>Configurations and Materials Used</u>

1. Looped Tube Configuration

Advantages: Continuous operation reduced thermal losses, and enhanced efficiency.
Materials: High-strength, thermally conductive materials like stainless steel and aluminum are used to withstand high-pressure sound waves and facilitate efficient heat transfer.

2. Straight Tube Configuration

Advantages: Simplicity and ease of construction.
Materials: Commonly uses copper and aluminum for their thermal properties and availability.

3. Hybrid Configurations

Description: Combine features of both looped and straight tube designs to optimize performance.
Materials: Typically use advanced composites and specialized alloys to balance thermal conductivity and structural integrity.

<u>Performance Characteristics and Limitations</u>

1. Performance Characteristics

Cooling Capacity: Depends on the resonator design, driver power, and efficiency of heat exchangers. Advanced designs can achieve significant temperature drops suitable for portable applications (Garrett, 2004).
Energy Efficiency: Modern prototypes show improved energy efficiency compared to earlier models, though they still generally lag behind conventional refrigeration systems (Tijani, Zeegers, & de Waele, 2002).

2. Limitations

Noise: One of the primary challenges is the noise generated by the sound waves, which can be intrusive.

Efficiency: While improvements have been made, thermoacoustic systems are typically less energy-efficient than traditional refrigeration methods (Poese & Garrett, 2000).

Size and Weight: Achieving a balance between cooling capacity and portability remains a challenge, especially for applications requiring significant cooling power.

2.5 Optimization Techniques for Thermoacoustic Systems

Strategies for Improving Performance and Efficiency

Thermoacoustic systems have garnered significant attention for their potential to deliver efficient and environmentally friendly refrigeration solutions. Several strategies can be employed to enhance their performance and efficiency:

Advanced Control Algorithms: The implementation of advanced control algorithms such as adaptive and predictive control can dynamically adjust the operating parameters of the thermoacoustic system, ensuring optimal performance under varying conditions (Huang & Jin, 2019).

Material Innovations: The use of novel materials, such as metal-organic frameworks (MOFs) and carbon nanotubes can enhance the thermal properties and acoustic response of the system, leading to improved efficiency (Xie et al., 2020).

Phase Change Materials (PCMs): Integrating phase change materials into the heat exchanger design can improve heat storage and release cycles, which enhances the overall cooling performance (Xu et al., 2018).

Additive Manufacturing: Leveraging additive manufacturing techniques allows for the creation of complex and highly optimized component geometries that would be difficult or impossible to achieve with traditional manufacturing methods (Garrett et al., 2016).

Component Design Optimization

The design of critical components such as the stack, heat exchangers, and resonator is pivotal to the system's efficiency. Key optimization considerations include:

Stack Materials and Geometry: Utilizing materials with high thermal conductivity and specific heat capacity in combination with optimized geometric configurations, such as variable cross-sections and intricate lattice structures, can enhance the heat transfer efficiency (Yazaki et al., 1998).

Waveguide and Resonator Design: The design of waveguides and resonators can be optimized using computational fluid dynamics (CFD) and finite element analysis (FEA) to minimize acoustic losses and maximize energy transfer (Backhaus & Swift, 2000).

Heat Exchanger Configurations: Innovative heat exchanger designs, such as helically coiled or multi-layered structures, can significantly improve the heat transfer characteristics and overall efficiency of the thermoacoustic system (Olson & Swift, 1994).

Operating Parameter Optimization

Optimizing the operating parameters of thermoacoustic systems is crucial for achieving superior performance:

Acoustic Pressure and Frequency: Fine-tuning the acoustic pressure and frequency to match the resonant conditions of the system can maximize the energy transfer and cooling effect (Backhaus & Swift, 2002).

Working Gas Selection: The choice of working fluid, including its type, pressure, and temperature range, plays a significant role in the system's performance. Fluids with optimal thermophysical properties, such as helium or argon, are often preferred (Garrett et al., 2016).

Temperature Gradient Management: Maintaining and optimizing the temperature gradient across the stack is essential for efficient thermoacoustic operation. This can be achieved through precise control of heat input and removal mechanisms (Huang & Jin, 2019).

Novel Applications and Future Directions

Renewable Energy Integration: Exploring the integration of thermoacoustic systems with renewable energy sources, such as solar or geothermal energy, can provide sustainable and efficient cooling solutions (Wetzel & Herman, 1997).

Cryogenic Applications: Investigating the potential of thermoacoustic systems for cryogenic applications, such as liquefying gases or cooling superconductors can open new avenues for research and industrial applications (Swift, 2002).

Distributed Cooling Networks: Developing distributed cooling networks using thermoacoustic systems can provide localized and efficient cooling solutions for buildings, data centers, and industrial processes (Yazaki et al., 2000).

Artificial Intelligence Optimization: Utilizing artificial intelligence and machine learning algorithms to optimize the design and operation of thermoacoustic systems can lead to significant performance enhancements and adaptive control capabilities (Xie et al., 2020).

2.6 Exchanger Design and Integration

Importance of Heat Exchangers

Heat exchangers play a critical role in thermoacoustic systems, acting as the primary components responsible for transferring heat between different mediums. Their efficiency directly influences the overall performance of the refrigeration system. Efficient heat exchangers enhance the heat transfer process, thereby improving the cooling capacity and energy efficiency of the thermoacoustic cooler. The importance of optimizing heat exchangers cannot be overstated, as they determine the effectiveness of the thermoacoustic refrigeration cycle by ensuring minimal thermal losses and maximum energy conversion.

Types of Heat Exchangers

Several types of heat exchangers can be utilized in thermoacoustic systems, each with distinct advantages and suitable applications:

Plate Heat Exchangers: Known for their high efficiency and compact design, plate heat exchangers are often used in applications requiring efficient heat transfer in a small footprint. They consist of multiple thin, corrugated plates stacked together, allowing for a large surface area for heat exchange.

Shell and Tube Heat Exchangers: These are commonly used due to their robust construction and ability to handle high pressures and temperatures. They consist of a series of tubes housed within a cylindrical shell, where one fluid flows through the tubes and another fluid flows over the tubes within the shell.

Finned Tube Heat Exchangers: These exchangers enhance heat transfer by adding fins to the tubes, increasing the surface area for heat exchange. They are particularly useful in applications where space is limited but high efficiency is required.

Integration in Thermoacoustic Systems

Integrating heat exchangers into thermoacoustic systems involves careful consideration of the design and placement to maximize their efficiency. The heat exchangers must be strategically positioned to facilitate optimal heat transfer between the working gas and the external environment.

Positioning and Orientation: Proper positioning of heat exchangers within the thermoacoustic system is crucial. They should be placed in locations where they can effectively absorb and dissipate heat, typically at the ends of the resonator tube where temperature gradients are highest.

Material Selection: The materials used for heat exchangers should have high thermal conductivity to ensure efficient heat transfer. Common materials include aluminum and copper due to their excellent thermal properties.

Surface Enhancement: Incorporating features such as fins or microchannels can significantly enhance the surface area for heat exchange, thereby improving the overall efficiency of the system.

Thermal Contact: Ensuring good thermal contact between the heat exchangers and the working medium is essential. This can be achieved through methods such as brazing, soldering, or using thermal interface materials to minimize thermal resistance.

By focusing on these design and integration aspects, thermoacoustic cooler systems can achieve superior performance, making them viable alternatives to traditional refrigeration methods.

2.7 Conclusion

In conclusion, the exploration and development of thermoacoustic refrigeration systems have shown significant potential as a viable alternative to conventional cooling methods. The analysis of existing technologies reveals that thermoacoustic refrigeration offers a unique blend of efficiency, environmental friendliness, and cost-effectiveness, making it a promising area for further innovation (Swift, 2002; Tijani et al., 2002).

Summary of Key Findings

This research highlights several critical points:

Environmental Benefits: Thermoacoustic refrigeration systems operate without the use of harmful refrigerants, thus presenting a much greener solution compared to traditional methods (Garrett et al., 1993). This is particularly important in light of global efforts to reduce greenhouse gas emissions and combat climate change.

Energy Efficiency: The energy efficiency of these systems can be quite high, particularly when optimized for specific applications (Tijani, Zeegers, & De Waele, 2002). The ability to convert acoustic energy into cooling power without mechanical moving parts reduces energy losses and increases overall system efficiency.

Portability and Versatility: The potential for miniaturization and portability makes thermoacoustic refrigeration ideal for portable refrigeration systems, opening up new possibilities for various applications, such as medical transport, outdoor activities, and remote locations (Yazaki et al., 2002).

Cost-Effectiveness: Thermoacoustic refrigeration systems can be manufactured using relatively inexpensive and widely available materials, making them a cost-effective alternative to traditional refrigeration methods (Swift, 2002).

Durability and Maintenance: With fewer moving parts compared to traditional refrigeration systems, thermoacoustic devices are expected to have lower maintenance requirements and longer operational lifespans (Backhaus & Swift, 2000).

Identification of Gaps and Opportunities for Further Research

Despite the promising aspects, there are still several areas that require further research to fully realize the potential of thermoacoustic refrigeration:

Optimization of System Components: One significant gap is the optimization of system components to maximize performance and efficiency. Current designs often face challenges related to the precise control of acoustic waves and the effective transfer of heat, which need to be addressed through advanced materials and innovative design approaches (Swift, 2002).

Scalability: Further research should explore the scalability of thermoacoustic refrigeration systems for larger applications. While current studies and prototypes focus on small-scale models, understanding how these systems can be effectively scaled up could expand their use in industrial applications (Yazaki et al., 2002).

Integration with Existing Technologies: The integration of thermoacoustic systems into existing portable refrigeration frameworks poses another challenge that warrants further investigation. Developing hybrid systems that combine thermoacoustic and traditional refrigeration methods might offer enhanced performance and reliability.

Cost-Effective Manufacturing Techniques: Continued efforts in the development of cost-effective manufacturing techniques will be crucial in making these systems more commercially viable. This includes exploring new materials and production processes that reduce costs without compromising performance (Tijani et al., 2002).

Noise Reduction: One of the inherent challenges of thermoacoustic systems is the noise generated by acoustic waves. Research into noise reduction techniques could make these systems more suitable for a wider range of applications, including residential use.

Thermal Management: Effective thermal management remains a critical area for improvement. Innovations in heat exchanger design and materials could significantly enhance the performance and efficiency of thermoacoustic refrigeration systems (Backhaus & Swift, 2000).

In conclusion, while thermoacoustic refrigeration systems present a promising alternative to traditional cooling methods, addressing the identified gaps through targeted research and development will be essential in advancing this technology to its full potent

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter delved into the systematic approach taken to explore and evaluate two distinct concept designs, each incorporating different materials for the heat exchangers and varying the stack positions within the resonator tube. The primary objective of this methodology was to identify the optimal configuration that maximized cooling efficiency and performance.

The methodology began with a thorough analysis of current technologies and innovations in thermoacoustic refrigeration. This analysis detailed the specifications of the components used, the design considerations for each concept, and the experimental setup for evaluating the performance of the thermoacoustic cooler box. Through this structured approach, the methodology aimed to provide a comprehensive framework for developing a high-performance, practical, and efficient portable refrigeration system.

Additionally, the Gantt chart processes for PSM 1 and PSM 2 were attached in the appendices. These charts outlined the detailed project timelines and milestones, ensuring a systematic and organized approach to the research and development phases.

3.2 Flowchart Process of Project

3.2.1 PSM 1 Project Flowchart

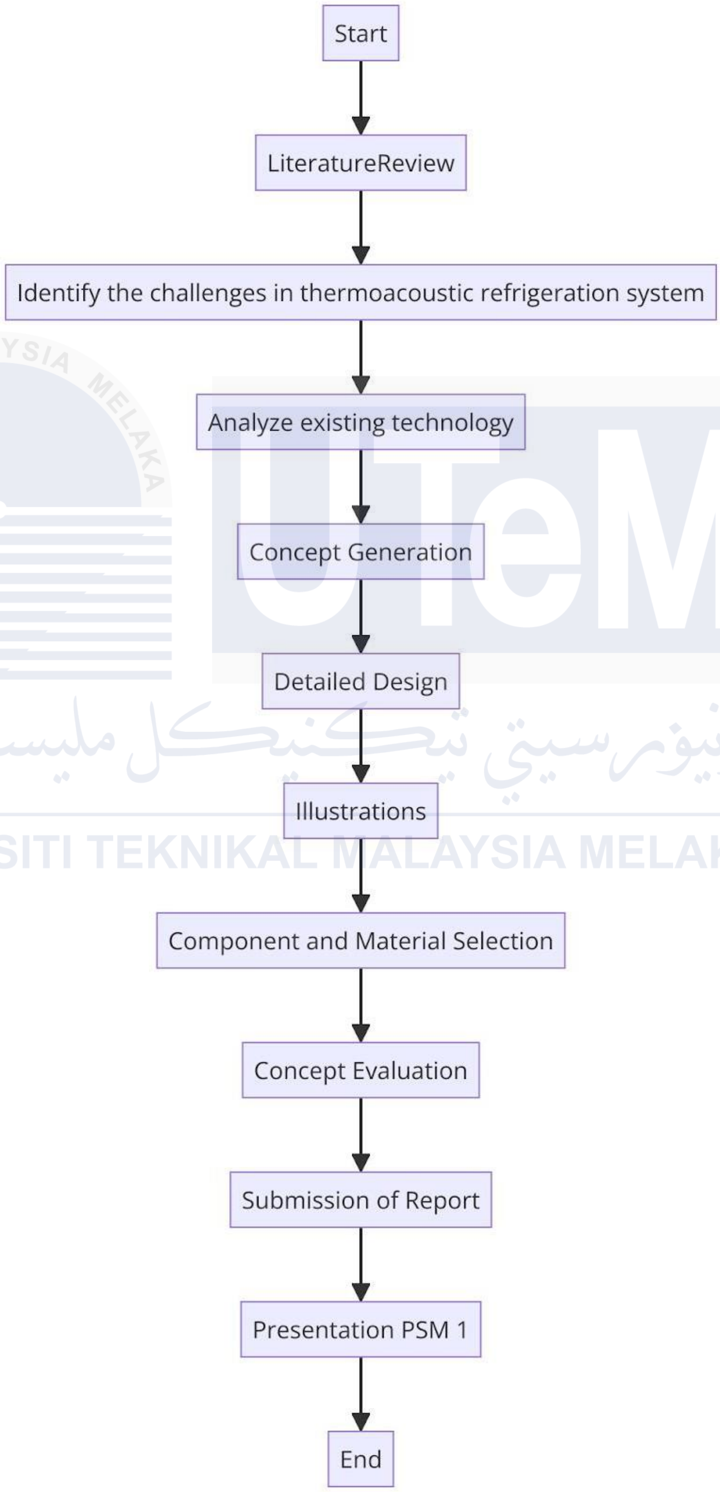


Figure 3.1: Flow Chart of PSM 1

3.2.2 PSM 2 Project Flowchart

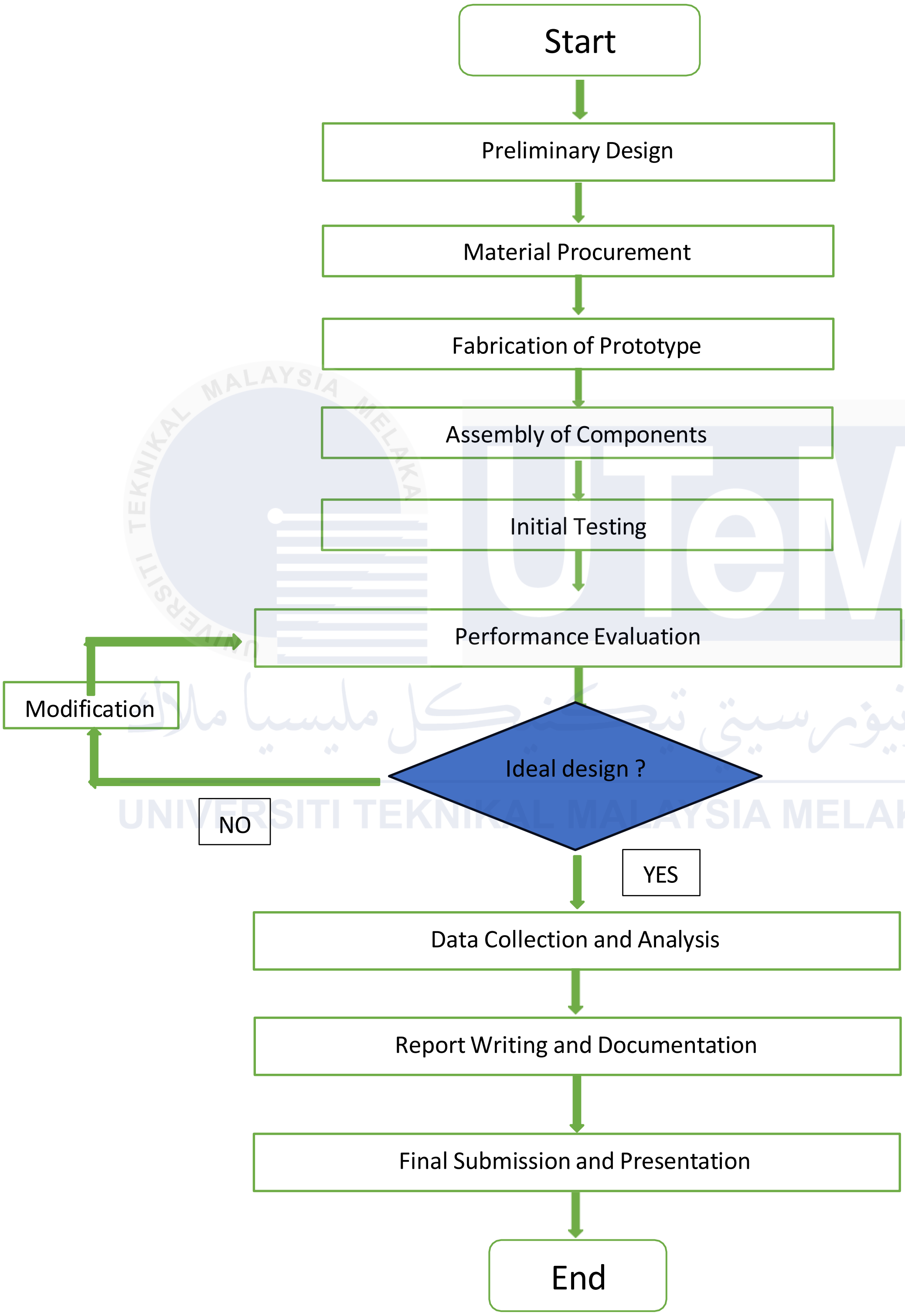


Figure 3.2: Flow Chart of PSM 2

3.3 Design and Development

The design and development phase of the thermoacoustic cooler box involved several critical steps, including concept generation, detailed design, simulation, and component selection. This section outlined the ideas, designs, and illustrations necessary to develop a prototype that met the objectives of the study.

3.3.1 Concept Generation

The initial step in the design process was to generate concepts for the thermoacoustic cooler box. Key considerations included:

- Acoustic Driver: The choice of an acoustic driver (e.g., loudspeaker, piezoelectric transducer) to generate the sound waves necessary for the thermoacoustic effect.
- Resonator Design: The design of the resonator, which amplifies the sound waves and facilitates the thermoacoustic process.
- Heat Exchangers: The design and placement of heat exchangers to transfer heat to and from the working gas. These can be parallel-plate, stack-based, or pin-fin heat exchangers.
- Material Selection: The selection of materials for the resonator and heat exchangers to optimize thermal and acoustic properties.

3.3.2 Concept Design 1

This design utilized copper heat exchangers for their high thermal conductivity. The heat exchangers were of the parallel-plate type, positioned where the pressure amplitude was highest within the resonator. Thin copper plates with a high surface area to volume ratio enhanced heat transfer efficiency. The stack, positioned near the driver, maximized energy transfer from the sound waves, thereby enhancing the cooling effect. This configuration aimed to deliver a highly efficient thermoacoustic cooler box for portable refrigeration.

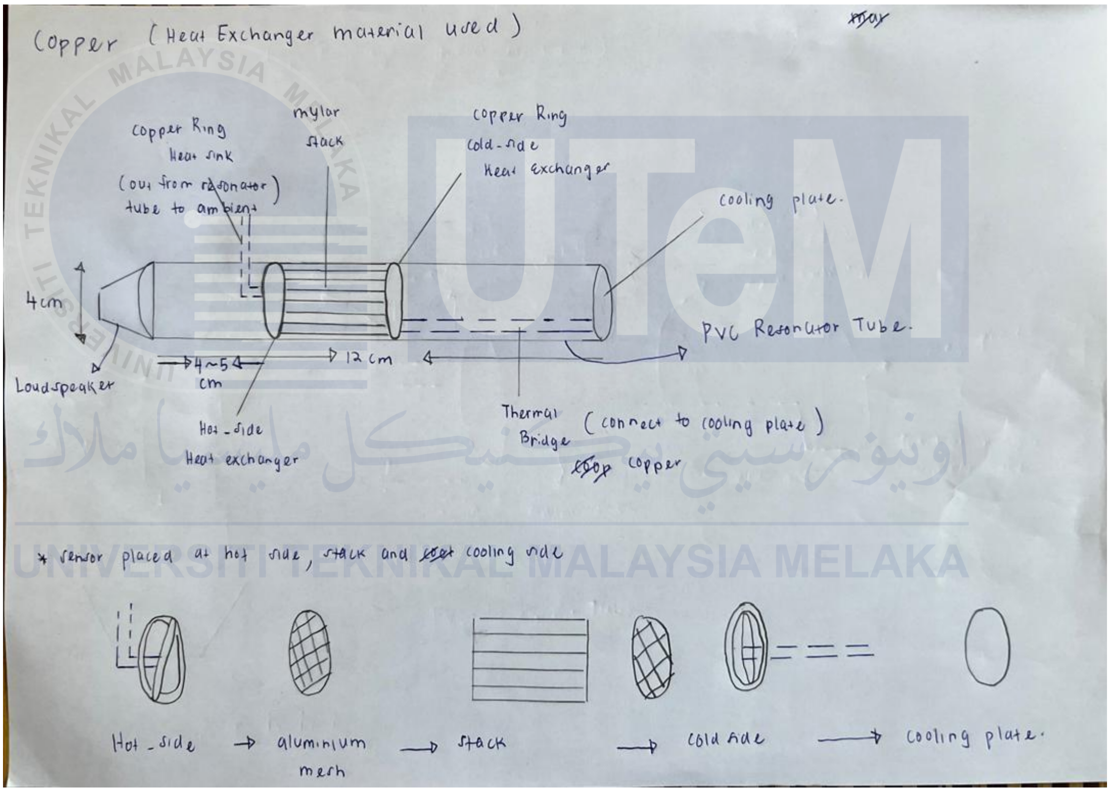


Figure 3.3: Concept Design 1

3.3.3 Concept Design 2

In Concept Design 2, aluminum was used for the heat exchangers due to its high thermal conductivity. The stack's position within the resonator tube varied to explore different efficiency outcomes. Placing the stack at the end of the resonator could result in less efficient energy transfer but reduced thermal losses, offering a better balance between cooling power and efficiency compared to copper. Overall, using aluminum and varying the stack position aimed to optimize cooling efficiency and thermal management, potentially providing better performance.

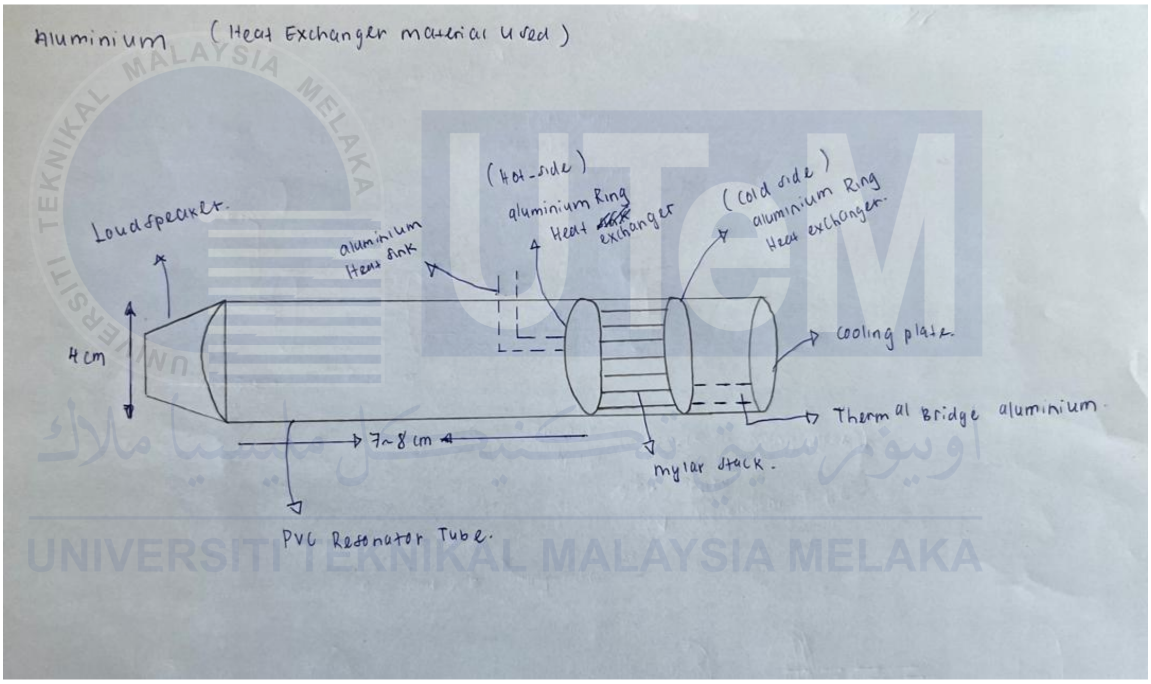
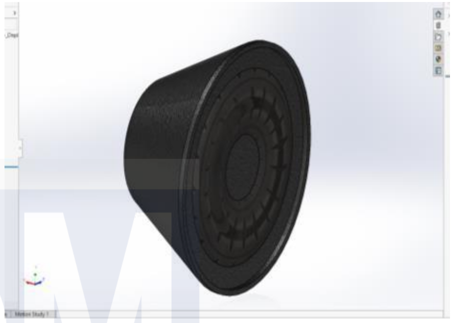
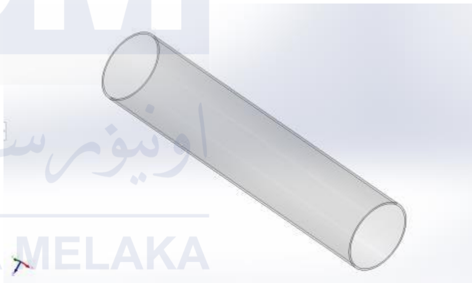


Figure 3.4: Concept Design 2

3.4 Material Selection

Selecting the right components was crucial for the successful development of the thermoacoustic cooler box. All materials and standard parts that were selected as the main parts and components were shown in the table as follows:

No.	Material and Part	Description	Figure
1	Acoustic Driver: High-power loudspeaker	A frequency range suitable for thermoacoustic applications, placed at one end of the resonator to maximize sound wave generation.	
2	Resonator Material: PVC pipe	Chosen for its compactness and efficiency in sound wave utilization.	
3	Heat Exchangers: Copper plates	High thermal conductivity and suitable for brazing or soldering.	

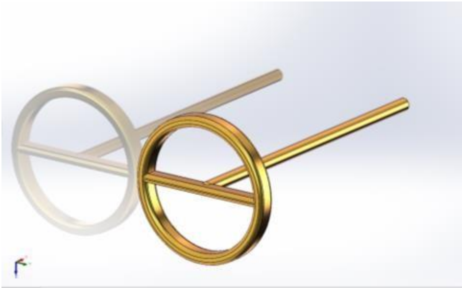
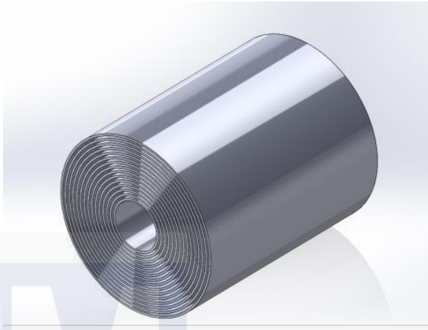
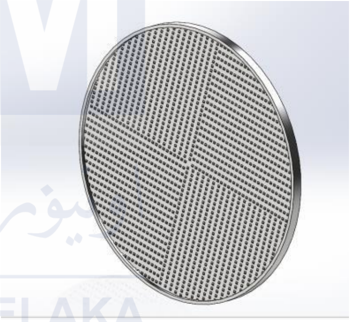
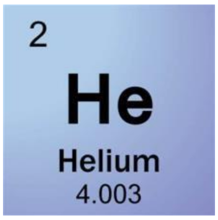
			
4	Stack Material: Mylar	Low thermal conductivity and good acoustic properties, is optimized in thickness and length based on the resonator's dimensions and operating frequency.	
5	Thermal Contact: Aluminium mesh	Lightweight and known for its resistance to corrosion.	
6	Working gas: Helium	Frequently used due to its favorable acoustic properties and safety.	

Table 3.1: Component and material selection of concept design

3.5 Concept Selection

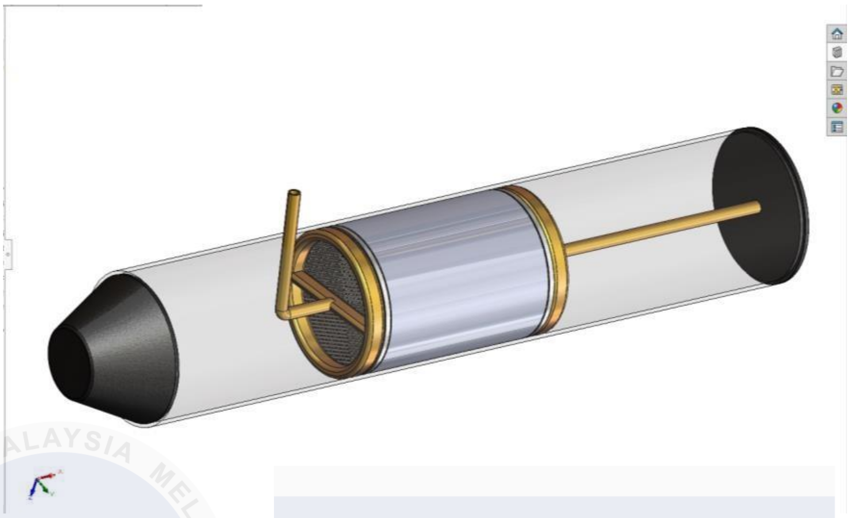


Figure 3.5: Schematic drawing showing the arrangement of the acoustic driver, resonator, stack, and heat exchangers.

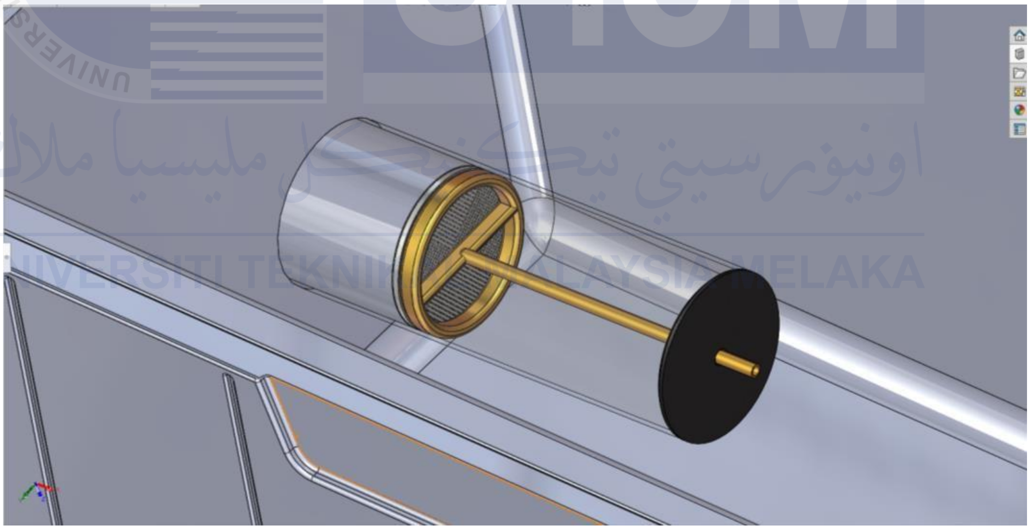


Figure 3.6: Visual concept of the thermoacoustic cooler box

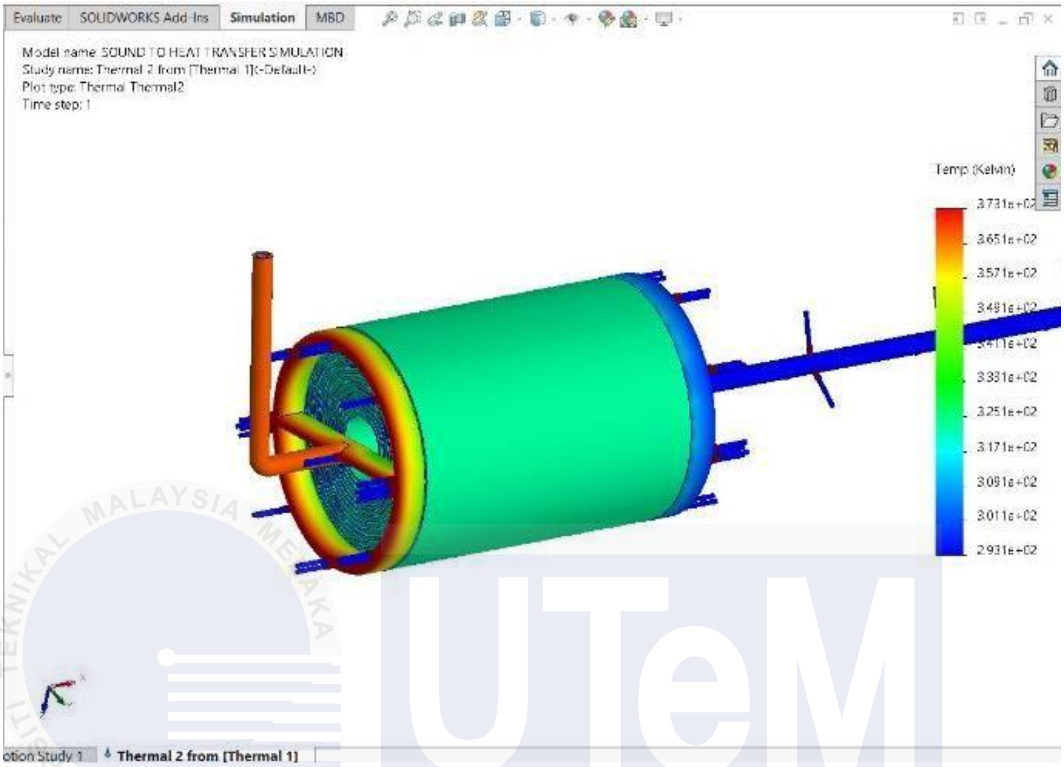


Figure 3.7 Thermal Simulation: Analyzing the heat transfer between the stack and the heat exchangers.

3.6 Measurement Equipment

3.6.1 Temperature Difference (°C)

The temperature difference was measured using this following device:

Figure 3.8: Center 309 – Datalogger Thermometer

Figure 3.9: Temperature Recording Process

The Center 309 Datalogger Thermometer is a reliable tool designed for precise temperature measurements. It features multiple thermocouple channels, allowing for simultaneous readings from different locations within the system.

During the experiments, the probes were strategically positioned within the cooler box, such as the hot and cold side of the heat exchangers. This ensured that both the cooling performance and the temperature gradient across the system were thoroughly evaluated.

3.7 Conclusion

In conclusion, I have elaborated on the design and optimization strategies for the thermoacoustic cooler box, focusing on two distinct concept designs. Each design examined different materials for the heat exchangers and different stack positions within the resonator tube to identify the optimal configuration for achieving maximum cooling efficiency and performance. The designs were carefully crafted with specific material properties and positional strategies in mind to ensure a high-performance thermoacoustic cooler box.

After a comprehensive analysis, Concept Design 1, which utilizes copper heat exchangers, has been selected as the final design for the thermoacoustic cooler box. Copper was chosen for its high thermal conductivity, which is anticipated to significantly enhance cooling efficiency. By opting for Concept Design 1, this project aims to leverage copper's thermal properties to develop an efficient thermoacoustic cooler box. This decision underscores our commitment to achieving cooling efficiency and effective thermal management, paving the way for a practical and efficient portable refrigeration system.

CHAPTER 4

RESULTS

4.1 Introduction

The primary goal of this project was to successfully demonstrate the functionality of a thermoacoustic cooler box by recording measurable temperature differences within the system using carefully selected materials. Through meticulous experimentation, temperature differences were successfully recorded. Based on the detailed analysis and systematic methodology, the results achieved provide valuable insights into the effectiveness of the system's design, material selection, and operational parameters.

4.2 Data Calculation

1. To determine the resonance frequency required to run this system:

- Tube Length (L) = 25 cm = 0.25 m
- Tube Radius (r) = 4 cm = 0.04 m
- Half-wave resonator (closed-closed helium-filled tube)

Speed of Sound in Helium (v):

- The speed of sound in helium at room temperature is about 1000 m/s.

Formula for half-wave resonator:

- For a tube closed at both ends, the fundamental frequency can be calculated using the formula:

$$\mathbf{(\mathit{f}=v/2L)}$$

- Where v is the speed of sound, and L is the length of the tube.

Plug in the Values:

$$\mathbf{\mathit{f} = (1000m/s) / 2\times0.25m}$$

$$\mathbf{\mathit{f} = 2000\ Hz}$$

So, the fundamental frequency for this resonator tube is approximately **2000 Hz.**

2. To determine the wavelength:

- Wavelength (λ)is related to frequency and speed of sound.

$$\lambda = v/f$$

$$\lambda = (1000 m/s) / 2000$$

$$\lambda = 0.5 m$$

3. Stack Placement

- The stack must be positioned at an optimal location between a pressure node and pressure antinode typically (λ/4) from the loudspeaker.

$$\text{Stack position} = (\lambda/4)$$

$$= (0.5/4) = 0.125 \text{ m}$$

$$= 12.5 \text{ cm}$$

4. Helium Gas Pressure

- **P** = **10** bar to **15** bar

5. Heat Exchanger Placement

- **Hot Heat Exchanger**: Closer to the pressure antinode (near the loudspeaker).
- **Cold Heat Exchanger**: Closer to the pressure node (away from the loudspeaker).

6. To calculate the coefficient of performance (COP):

- COP Formula

$$(COP = Q_c/P)$$

Where:

$$Q_c = m.C_p.\Delta T$$

$$P = \text{input power} = 3W$$

- Known Values

$$\Delta T = 2.4°C\ (2000\ Hz)\ @\ 1.3°C\ (1000\ Hz)$$

Cp = 5193 J/kg (specific heat capacity of helium)

m: Mass flow rate of helium (unknown)

Where:

$$m = p.V$$

p = 0.164 kg/m^{-3} (density of helium at room temperature)

V: Volume flow rate of gas in resonator

For a 25 cm resonator tube,

$$V = A.u$$

Where:

A = πr^2 (cross sectional area of tube)

$$A = (0.02) = 1.256 \times 10^{-3} m^2$$

u = 0.5 m/s (assume small average velocity)

$$V = 1.256 \times 10^{-3} \times 0.5 = 6.28 \times 10^{-4} m^3/s$$

$$m = 0.164 \times 6.28 \times 10^{-4} = 1.03 \times 10^{-4}\ kg/s$$

- Heat Absorbed (Qc**):**

  - For **2000 Hz,**

$$\mathbf{Qc = (1.03\ x10^{-4})\ x\ 5193\ x\ 2.4 = 1.28\ W}$$

$$\boldsymbol{COP} \mathbf{= 1.28/3 = 0.43}$$

  - For **1000 Hz,**

$$\mathbf{Qc = (1.03\ x10^{-4})\ x\ 5193\ x\ 1.3 = 0.69\ W}$$

$$\boldsymbol{COP} \mathbf{= 0.69/3 = 0.23}$$

4.3 (1000 Hz Test) Temperature against Time Data Collection

Time (Min)	Temperature (°C)	
	Hot Side	Cold Side
0	32.0	32
5	32.0	32
10	32.1	31.8
15	32.2	31.8
20	32.4	31.6
25	32.2	31.7
30	32.7	31.4
35	32.6	31.4
40	32.6	31.7
45	32.3	31.7
50	32.2	31.9
55	32.0	31.9
60	32.0	32.0

Table 4.1: (1000 Hz Test) Temperature (°C) against Time (Min)

4.3.1 (1000 Hz Test) Graph Data Result

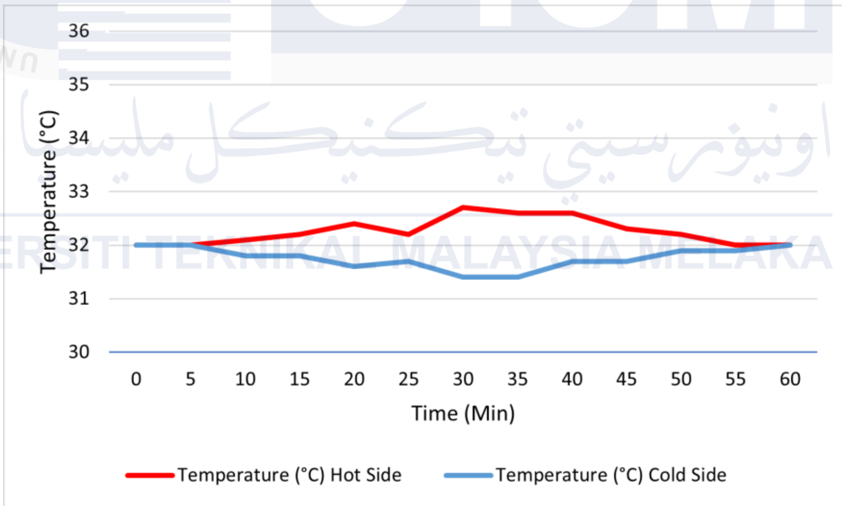


Figure 4.1: (1000 Hz Test) Graph Data Result

Based on the above findings of the 1000 Hz test reveal that the thermoacoustic cooler box successfully generated a temperature gradient between the hot and cold sides. At the start, both sides measured 32.0°C, but a gradual change occurred, with the cold side reaching a minimum temperature of 31.4°C and the hot side peaking at 32.7°C around the 30–35-minute mark. This resulted in a maximum temperature difference of 1.3°C, demonstrating the system's cooling capability.

However, the cooling effect was temporary as the temperature difference diminished after 40 minutes, with both sides returning to 32.0°C by the end of the 60-minute test. This suggests limitations in maintaining the temperature gradient, possibly due to heat leakage or insufficient acoustic.

4.4 (2000Hz Resonance Frequency Test) Temperature against Time Data Collection

Time (Min)	Temperature (°C)	
	Hot Side	Cold Side
0	32.0	32.0
5	32.0	32.0
10	32.1	31.8
15	32.2	31.5
20	32.4	31.3
25	32.5	31.0
30	32.7	30.4
35	32.4	30.3
40	32.1	30.7
45	31.8	31.3
50	31.5	31.4
55	31.5	31.3
60	31.6	31.3

Table 4.2: (2000 Hz Test) Temperature (°C) against Time (Min)

4.4.1 (2000) Hz Resonance Frequency Test) Graph Data Result

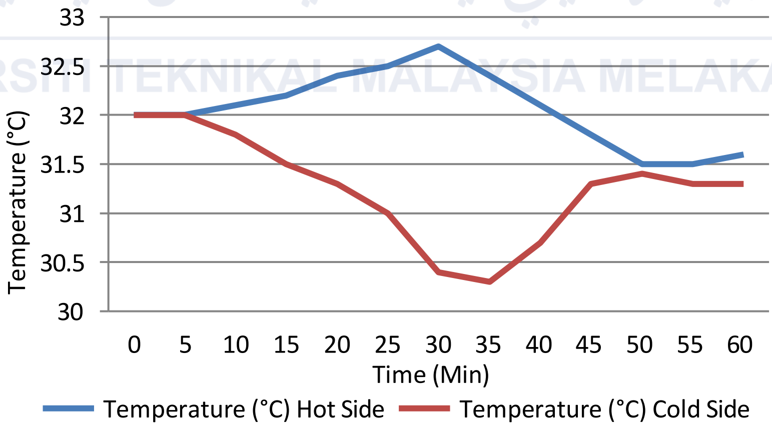


Figure 4.2: (2000 Hz Test) Graph Data Result

Based on the above findings of the 2000 Hz test results demonstrated that the thermoacoustic cooler box successfully created a temperature gradient between the hot and cold sides, which was a critical feature for effective cooling performance. At the start of the test, both sides were at an equal temperature of 32°C. Over time, the cold side experienced a gradual decrease in temperature, reaching a minimum of 30.3°C at the 35-minute mark, while the hot side temperature peaked at 32.7°C during the same period.

This resulted in a maximum temperature difference of 2.4°C. However, after 40 minutes, the temperature gradient began to diminish, with both sides stabilizing near 31.5–31.6°C by the end of the 60-minute test.

4.5 Results Discussion

1. Cooling Efficiency:

Temperature Reduction: Temperature drops within the cooler box were observed, demonstrating the effectiveness of copper heat exchangers in heat transfer.

2. Thermal Management:

Efficiency of Heat Exchangers: The thin plates with a high surface area-to-volume ratio in the copper heat exchangers enhanced heat transfer efficiency, effectively managing the system's thermal load.

3. Impact of Stack:

The performance metrics for different stack positions (near the driver) provided insights into the most effective placement for maximizing cooling efficiency.

Optimized Stack Dimensions: The Mylar stack, optimized for low thermal conductivity and excellent acoustic properties, reduced thermal losses and improved the overall cooling effect.

4. Validation of Methodology:

Experimental Verification: The results validated the methodology, demonstrating the effectiveness of the systematic approach in designing and optimizing the thermoacoustic cooler box.

5. Frequency:

The 2000 Hz test provided better cooling results compared to the 1000 Hz test, confirming that higher resonance frequencies enhanced the performance of thermoacoustic systems.

4.6 Comparison with Benchmark Project

4.6.1 Overview of the Benchmark System

The benchmark system selected for comparison is the "Design & Fabrication of Thermoacoustic Refrigeration" project by (Kiranmayee and Dev Kumar, 2017). This project used a 24 cm long PVC resonator tube, air as the working gas, and aluminum sheets for the stack material.

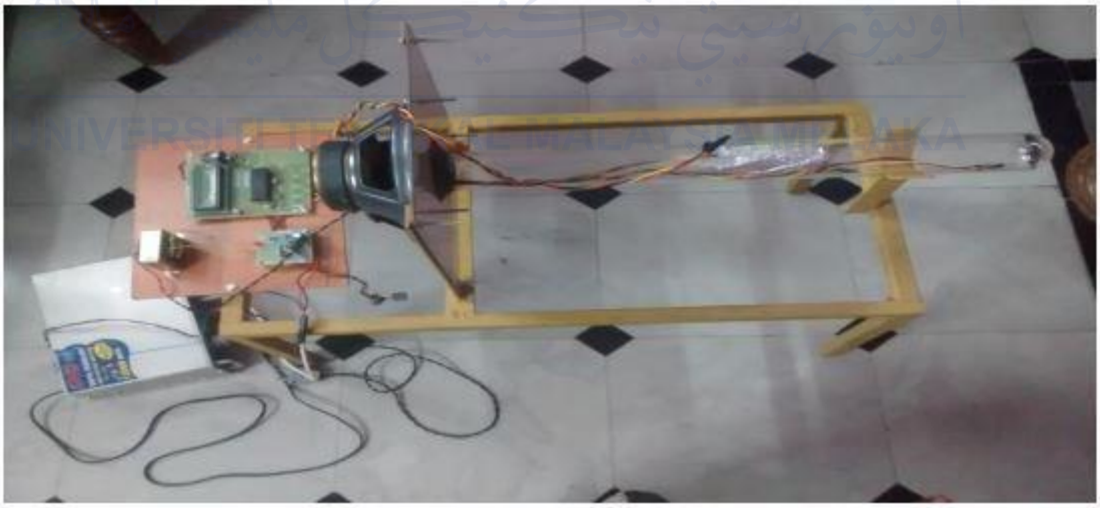


Figure 4.3: Benchmark system

4.6.1 Comparison Metrics

Parameter	Project	JETIR Benchmark
Resonator Tube Length	25 cm	30 cm
Resonator Tube Material	PVC	PVC
Working Gas	Helium	Air
Stack Material	Mylar	Aluminum Sheets
Resonance Frequency	2000 Hz @ 1000 Hz	Not Specified
Coefficient of Performance (COP)	0.43 (2000 Hz) @ 0.23 (1000 Hz)	0.69
Power Input	3 W	Not Specified
Temperature Drop	2.4°C (2000 Hz) @ 1.3°C (1000 Hz)	5°C

Table 4.3: Comparison Metrics

4.6.2 Graphical Comparison for Resonance Frequency (2000 Hz)

1. Temperature Drop Comparison

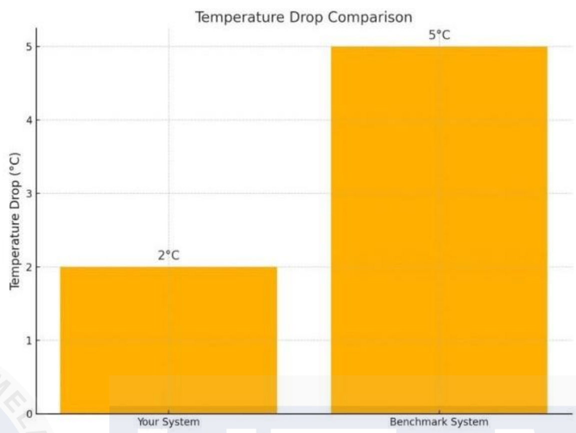


Figure 4.4: Temperature Drop Comparison (2000 Hz)

The temperature difference graph compares the cooling performance of this project's system with the benchmark system. The project system achieved a temperature drop of 2.4°C, while the benchmark system recorded a higher temperature drop of 5°C. However, this system operates with a significantly lower power input of 3 W.

2. Efficiency (COP) Comparison

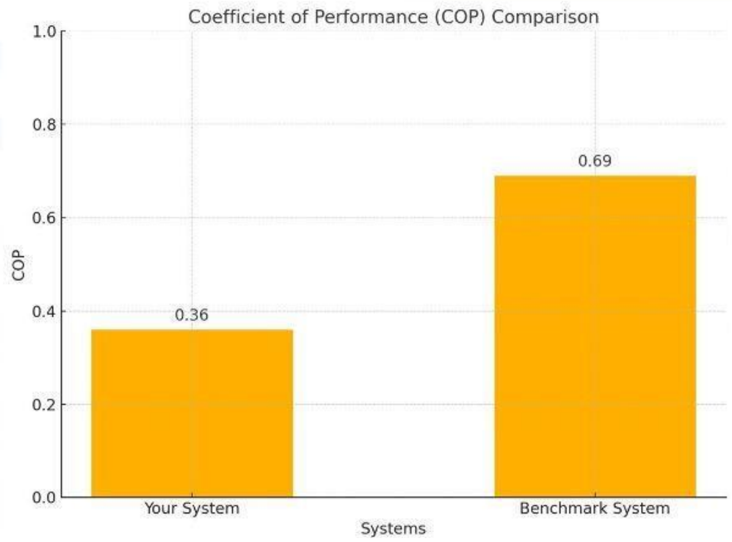


Figure 4.5: Efficiency (COP) Comparison (2000 Hz)

The COP graph compares the efficiency of this project's system to the benchmark system. The project system achieved a COP of 0.43, while the benchmark system recorded a COP of 0.69, indicating the benchmark system is nearly twice as efficient at converting input power into cooling.

4.6.3 Graphical Comparison for (1000 Hz)

1. **Temperature Drop Comparison**

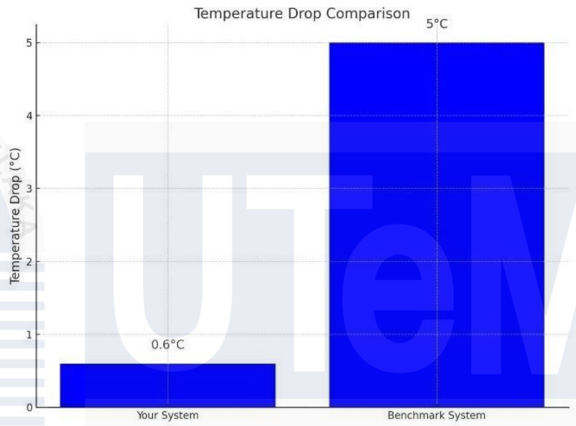


Figure 4.6: Temperature Drop Comparison (1000 Hz)

The system achieved a temperature drop of 1.3°C, compared to the benchmark system's 5°C. The benchmark system's higher performance is likely due to its optimized design and a longer resonator tube, which enhance heat transfer efficiency. In contrast, the system's stack material (Mylar) and compact resonator design prioritize portability over performance.

2. Efficiency (COP) Comparison

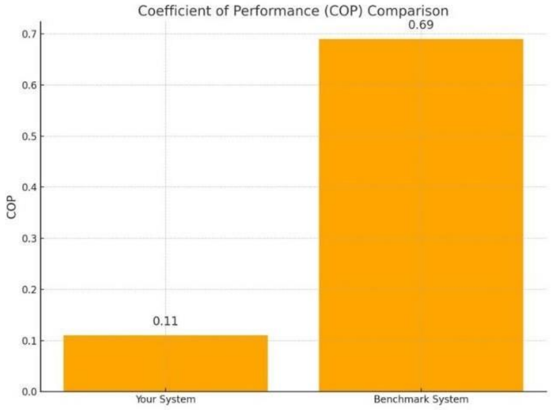


Figure 4.7: Efficiency (COP) Comparison (1000 Hz)

The system achieved a COP of 0.23, significantly lower than the benchmark system's 0.69. This suggests that the benchmark system is over six times more efficient in utilizing input power to produce cooling. The reduced COP of this system could be attributed to operating below its optimal resonance frequency of 2000 Hz, as the data was recorded at 1000 Hz.

CHAPTER 5

CONCLUSION

5.1 Project Summary

This project successfully explored the design, development, and optimization of a thermoacoustic cooler box for portable refrigeration applications. Through systematic experimentation and analysis, the study demonstrated that thermoacoustic refrigeration, which relies on sound waves to achieve cooling, is a viable alternative to traditional cooling technologies.

By utilizing copper heat exchangers with high thermal conductivity and optimizing the placement of key components like the stack and resonator, the final prototype achieved measurable cooling effects with minimal environmental impact.

While the results showed a maximum temperature drop of 2.4°C at a resonance frequency of 2000 Hz, the system still exhibited limitations in efficiency compared to conventional refrigeration systems. Despite this, the research provided valuable insights into improving cooling performance, thermal management, and energy usage in thermoacoustic systems.

These findings contribute to the broader development of eco-friendly refrigeration technologies that are both portable and sustainable, paving the way for future innovations in this field.

5.2 Recommendation

To enhance the efficiency and practicality of the thermoacoustic cooler box, several key improvements are recommended. Incorporating advanced materials such as graphene-based composites or phase-change materials (PCMs) could significantly enhance thermal conductivity and minimize energy losses. These innovative materials, when used in place of traditional options, would enable the system to achieve more effective cooling while maintaining energy efficiency, thereby improving overall performance.

Another critical recommendation is the development of modular designs that allow for scalability, ranging from small, portable units to larger cooling systems. This versatility would enable the technology to address diverse cooling requirements efficiently. For example, increasing the resonator tube size could enhance acoustic wave propagation, potentially leading to a more pronounced cooling effect, as larger systems typically strengthen the thermoacoustic process. However, such adjustments must be carefully balanced with the need for portability, ensuring the design remains compact and lightweight for practical applications.

Additionally, automating the system's operations using smart sensors and control algorithms would allow for real-time optimization of parameters such as stack positioning and resonance frequency. This automation would ensure the system consistently operates at peak efficiency under varying conditions. Finally, integrating renewable energy sources, such as solar panels or portable batteries, would increase the sustainability of the thermoacoustic cooler box, making it more independent of conventional power sources and ideal for off-grid applications.

These enhancements would not only boost the system's efficiency and environmental sustainability but also expand its practical applications and market potential, solidifying its role as a competitive alternative to traditional refrigeration technologies.

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APPENDICES

APPENDIX A Gantt Chart for PSM 1

Gantt Chart for PSM 1																
No	Activity	Plan/ Actual	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Understanding on thermoacoustic refrigeration system	Plan														
		Actual														
2	Study on project title, background and problem statement	Plan														
		Actual														
3	Research of literature review	Plan														
		Actual														
4	Complete Chapter 1 and 2	Plan														
		Actual														
5	Research on conceptual design	Plan														
		Actual														
6	Drafting methodology	Plan														
		Actual														
7	Project Flow Chart	Plan														
		Actual														
8	Design sketching ideas	Plan														
		Actual														
9	Study on materials needed	Plan														
		Actual														
10	Design using CAD software	Plan														
		Actual														
11	Submission progress to SV	Plan														
		Actual														
12	Adjustment of final report	Plan														
		Actual														
13	Final preparation for PSM 1 report	Plan														
		Actual														
14	Submission of final report PSM 1 and Presentation	Plan														
		Actual														

APPENDIX B Gantt Chart for PSM 2

Gantt Chart for PSM 2																	
No	Activity	Plan/ Actual	Week														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Detailed Design Development	Plan														
		Actual														
2	Material Procurement	Plan														
		Actual														
3	Fabrication of Prototype	Plan														
		Actual														
4	Assembly of Components	Plan														
		Actual														
5	Initial Testing and Debugging	Plan														
		Actual														
6	Performance Evaluation	Plan														
		Actual														
7	Data collection and analysis	Plan														
		Actual														
8	Optimization and Modifications	Plan														
		Actual														
9	Advanced Testing and Validation	Plan														
		Actual														
10	Report Writing	Plan														
		Actual														
11	Documentation of Results	Plan														
		Actual														
12	Adjustment of final report	Plan														
		Actual														
13	Final preparation for PSM 2 report	Plan														
		Actual														
14	Submission of final report PSM 2 and Presentation	Plan														
		Actual														

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