Design of a Sustainable Refrigeration System Using Thermo-Acoustics

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***Abstract* - Traditional refrigeration methods use vapor compression of a refrigerant to create heat transfer and cool a chamber. An alternative to that method is thermo-acoustic's, which is an area of physics that investigates how heat can be transferred through the expansion and compression of longitudinal sound waves. The motivation for this project is to provide a more eco-friendly and sustainable method to possibly replace the traditional method of refrigeration. By manipulating soundwaves to trap heat in high pressure zones, a hot and cold chamber could be created. The purpose of this project was to design a thermo-acoustic refrigeration system or a temperature difference between the cold chamber and the hot chamber.**

I. Introduction

Thermo-acoustics began by noting pressure and temperature differences created by the compression or expansion of sound waves. By the expansion of a medium through a wave propagation heat can be observed to be absorbed, and by a compression of a given medium heat can be released. Just by having a conversation with someone the sound waves produced create a local temperature and pressure difference albeit an insignificant and unnoticeable one. However, by increasing the volume, along with other operating parameters, a significant pressure difference can be created and large amplitudes of pressure lead to more heat transfer [1].

Much work has been done in the field of thermo-acoustics because of its applicability to any system which requires a temperature or pressure difference. Notably, In the year 2000 Ben and Jerry's effectively harnessed the cooling powers of sound to create a travelling wave thermo-acoustic ice cream cabinet. This refrigeration system had a coefficient of performance of 19% of a theoretical Carnot coefficient of performance [2]. Because this used a travelling wave it is not exactly what was desired for the senior design team, but it is just a different way of creating a sound disturbance in the resonance tube for refrigeration.

The purpose of this project was to design and optimize a working thermo-acoustic refrigeration system. The proposed design requires fewer moving parts and eliminates the need of coolants, when compared to traditional systems. By designing an efficient and sustainable thermo-acoustic refrigeration system, companies could then build on this technology to produce greener systems to help play a part in sustainable production and reducing global warming.

II. Methods and Materials

To effectively create a thermo-acoustic system the parameters would need to be optimized to obtain the desired temperature difference. Thermo-acoustic refrigeration systems may only have about five or six major components. A loudspeaker is the driver of the system and propagates the soundwave to create expansions and compressions of the working medium. The loudspeaker is connected to a signal generator to produce a consistent longitudinal wave. The frequency chosen would be near or equal to the natural frequency of the resonance tube to create a standing wave in the system. Inside the resonance tube is the working medium which is chosen to have a relatively high specific heat and a low Prandtl number to maximize the temperature and pressure differences. The heart of the system, the stack, is strategically placed in the resonance tube sustaining and creating a temperature difference on either side of it. On either end of the stack is a thermocouple to detect the temperature difference and ensure the system is cooling at one end. Finally, some sort of heat sink is used to help dissipate energy from the hot end of the tube [3].

The team would design a straight tubed system to create their desired pressure gradient as seen below in figure 1. This system would have a 3.25-inch acrylic resonance tube of one meter in length, corresponding to an operating frequency of ~ 150 Hz. The ideal working fluid of the system was helium due to its excellent thermal and viscous properties. The system stack was then optimized during testing, utilizing a fine spacing of low thermal conductivity plastic material at a high-pressure zone. Heat exchangers were added at the end of either side of the stack to help dissipate heat on the hot side and draw heat in on the cold side.

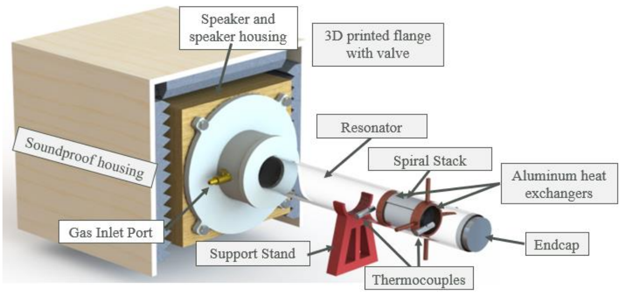

Figure 1: Thermo-acoustic system schematic

III. Results and Discussion

Prior to assembly the team made efforts to simulate the heat exchanger process and pressure differnece across a stack. To do this they would employ the computational fluid dynamics software Ansys and visualize the heat transfer process. Through these simulations the team felt comfortable in their designs and new they would achieve the results they wanted. After assembly of the system, the team tested multiple parameters to physically validate their designs. The main parameters that were altered were the stack spacing, position in the resonance tube, frequency, and heat exchanger design. Through testing the team was able to determine parameters for an effective refrigeration cycle. By creating a stack of about an eighth of an inch thickness and placing at a centered position of six inches from the reflective end cap, the team was able to get the results seen in figure 2.

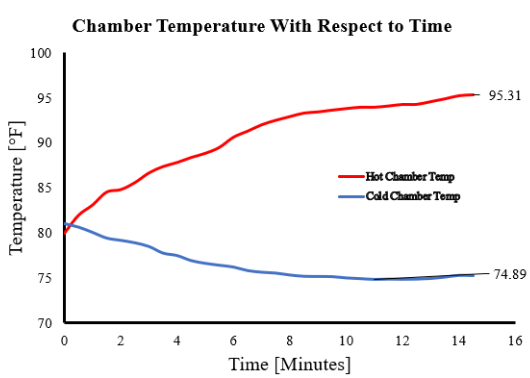

Figure 2: twenty-degree temperature difference between chambers

As seen in figure 2 there was a twenty-degree temperature difference recorded between the hot and cold chambers, as well as about a six degrees Fahrenheit difference between the cold side of the stack and the initial temperature reading.

The results of this system are comparable to other tabletop systems to demonstrate the physics of thermo-acoustics. If future iterations wanted to take the project to the next level, they could potentially have higher quality systems comparable to that which Tijani, et al created and achieved a -85 degrees Fahrenheit cold chamber temperature [4].

IV. Conclustion

The designed and manufactured thermo-acoustic system without moving parts and coolant would provide a more sustainable alternative to traditional refrigeration systems. By running the system at 150 Hz with a stack spacing of about an eighth of an inch at 6 inches from the end cap, the team effectively displayed the refrigeration cycle that this subset of physics can provide. Future design teams can build on this design to try and optimize its subsystems and obtain an even greater refrigeration effect.

Acknowledgments

The team would like to thank Northern Illinois University for funding this design project. Additionally, the team is very thankful for its advisor Dr. Tariq Shamim for proposing the project and supporting them along the way. Thanks to the helpful folks in the NIU machine shop as well for assisting on manufacturing methods. Finally, the team would like to thank Dr. David Schroeder for his additional guidance as well as the NIU machine shop for their expertise to manufacture parts for a successful project.

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