

Fabrication and Parametric Analysis of Thermo Acoustic Cooling System

Dr. Nishadevi n. Jadeja^a Dr. Sanjay H. Zala^b Dholariya Mayank^c

Assistant Professor, Department of Mechanical Engineering, Government Engineering College, Bhavnagar, Gujarat, 364002(India).

Assistant Professor, Department of Mechanical Engineering, Government Engineering College, Bhavnagar, Gujarat, 364002(India).

Department of Mechanical Engineering,
Government Engineering College, Bhavnagar, Gujarat, 364002(India).

Abstract-The conventional cooling system uses hazardous refrigerants and their results as bad impact on the environment. Harmful refrigerants did not use in Thermo acoustic cooling systems. Their thermo acoustic cooling system is environment-friendly. The phenomenon uses in a Thermo acoustic cooling system is high-intensity sound waves in a gas (pressurized) tube to flow heat from one place to another place to produce a cooling effect. A thermo acoustic cooling system eliminates the use of lubricant and thus less energy consumption. The main aim of this work is to fabricate a small thermo acoustic cooling system from inexpensive and readily available parts and analyzed performance at different Sound frequencies 50hz, 100hz, 400hz, 500hz, 1000hz and Working medium is air for this study. The thermo acoustic cooling system is both clean and inexpensive as well as environment-friendly.

Keywords: *Thermo acoustic cooling system, Thermo acoustic, Thermo acoustic refrigeration system;*

Introduction

During experiment, we are using air conditioning and refrigeration for our comfortable home environments. They are fast and efficient electronic devices but they produce greenhouse gases with high energy costs. Thermo acoustic cooling is both clean and inexpensive so it is an innovative alternative for the current cooling system. Thermo acoustic cooling systems use sound to produce pressure waves that alternately compress and expand the gas particles within the tube. The model fabricated for this project uses inexpensive and easily available materials. Although the model didn't achieve the goal of cooling, the experiment suggests that a thermo acoustic cooling system may sooner or later be a viable replacement for conventional refrigerators and it can be operated by various frequencies of sound. The Thermo acoustic cooling system considers that sound waves are based on the pressure waves principle. When pressure waves propagate in the air tube which causes molecular collisions which disturb the air as creates constructive and destructive interference. The constructive interference compresses the molecules while the destructive interference expands the molecules. This is the principle behind

thermo acoustic cooling. This study analyzes the performance of the Thermo acoustic cooling system with different sound frequencies like 50hz, 100hz, 400hz, 500hz and 1000hz.

When pressure waves propagate in the air tube, they cause molecular collisions which disturb the air as they create constructive and destructive interference. The constructive interference compresses the molecules while the destructive interference expands the molecules (as shown in Figure 1.1). The maximum compression of the air occurs at the antinodes and the maximum expansion of the air occurs at the nodes.

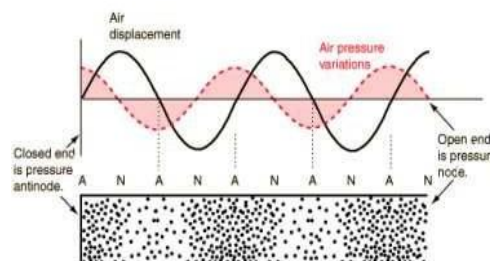


Figure 1.1: Pressure variation of air

1. Literature review

In this paper, the author uses ABS as a stack material, which gives a good temperature difference ($\pm 3^\circ\text{C}$) than nylon and wood stacks [1]. They give a review on

thermo acoustic cooling that Thermo acoustic refrigeration is both clean and inexpensive. They are currently still less efficient ($COP < 1$) than traditional vapor-compression refrigerators [2]. Use helium and air are working mediums in the Resonator tube. The disadvantage is low efficiency [3].

The author demonstrates a design using multi-stage thermo acoustic systems which can achieve higher efficiency than single-stage thermo acoustic systems [4]. Thermo acoustic refrigeration is eco-friendly. Use different stack locations in Resonator [5]. The approach to the design and manufacture of loudspeaker-driven thermo acoustic systems has been discussed with consideration of low-cost technologies and simple measurement systems [6]. Author used three different shapes of the resonator square tube, tapered tube, and cylindrical Resonator among all cylindrical resonator has the largest temperature difference of $7.5\text{ }^{\circ}\text{C}$ [7].

Author used a parallel plate stack that is made from PVC Rigid sheets to improve the efficiency of the thermo acoustic refrigeration system [8]. In this paper author used an iterative algorithm for the determination of the acoustic field and heat flow in a stack in Standing-Wave thermo acoustic refrigerators [9]. Researchers used a 3D printed stack in their study which gives more temperature difference than other stacks and a 3D printed stack minimizes errors of design [10].

In this paper, author used an adjustable geometric Resonator and stack, it is possible to alter its performance. A longer resonator was better than the shorter Resonator without a heat exchanger [11]. Although some researches shows a genetic Algorithm to optimize the thermo acoustic cooling system. The coefficient of performance is about 120.3 % higher than the previously published data [12]. Use a parallel plate stack to improve the performance of the thermo acoustic cooling system. The temperature difference and COP of the parallel plate stack are better compared with other stack geometries [13].

Use different parallel plate stack pipes 1, 2, and 4 mm, working medium as helium. Parallel plate stack with helium as working fluid with 10 bar mean pressure has better COP [14]. In this study author suggest different working mediums as

helium and hydrogen enable for the highest thermo acoustic coefficient of performance COP of 0.77 and 0.76 respectively, while the lowest COP values were 0.64 for xenon and 0.68 for argon [15]. some paper shows a study by varying spacing between stack plates 0.15 mm and 0.7 mm and the result shows that 2.5 to 3 gives optimum cooling effect [16].

Author develop an algorithm for Performance calculation and this predicts values of 40–50% of Carnot's efficiency for the thermo acoustic core, the heart of a thermo acoustic refrigerator [17]. Author analyze various parameters of the Thermo acoustic cooling system and give a review about that [18]. Some of the researchers used various stack geometry like spiral stack, circular pore stack, and pin array stack, and study shows that the cold end temperature of the pin array stack decreases more than that of the spiral stack and circular pore stack geometry by approximately 63% and 70%, respectively [19]. Author find out that three types of major heat losses are (a) Heat loss due to flue gas convection, (b) Heat loss due to radiation, and (c) Heat loss due to incomplete combustion. And they suggest heat-exchanger and insulated surfaces. May be In the future when thermo acoustic cooling systems use for refrigeration in their use proper insulation over resonator tube to reduce energy loss [20].

2. Design and Fabrication Of Thermo acoustic Cooling System

Thermo acoustic Theory

For understanding the working of the thermo acoustic device necessary to understand acoustic wave dynamics which create pressure and velocity field. The acoustic theory deals with the study of longitudinal waves. The longitudinal acoustic waves produce compression and expansion in the gas medium. The compression and expansion of gas corresponding to the crest and trough of the sine waves. In a longitudinal wave, particles displace along the direction of the wave. They oscillate about their equilibrium position back and forth. The compression and expansion of a longitudinal wave cause pressure variation in the air medium along its longitudinal axis of oscillation. A longitudinal wave cannot propagate in the vacuum they require a medium ie. Air. All

sound waves hold all the properties of the longitudinal waves. For the understanding of the thermo acoustic process Three properties amplitude, frequency and wavelength are necessary. Amplitude is the displacement of a wave from its equilibrium position. The time required for the complete passes of a wave at a given point is called time period of wave. A number of waves that passes through a given point in a unit of time are called frequency. The wavelength is defined as the horizontal distance of the wave from the beginning to the end of the wave. In other words, the wavelength is the distance between the two successive compression and expansions of the wave. These compression and expansion of waves cause pressure variation in the air medium and it is a key process for the thermo acoustic cooling phenomenon.

From the ideal gas equation of state, $P / \rho = RT$

Where P is the pressure, ρ is the density, T is the absolute temperature, and R is the gas constant.

From the above equation, it is clear that pressure is directly proportional to temperature. If the pressure increases that causes an increase in temperature and vice versa.

Thermodynamic Considerations

In this section, we will discuss the thermo acoustic phenomenon based on acoustics and thermodynamics. To understand the phenomenon, consider a thermo acoustic cooling device such as a refrigerator. The thermo acoustic cooling device requires a speaker as an acoustic driver which is attached to the resonator tube as an acoustic resonator filled with atmospheric air as a working fluid for this study and install stack in Resonator tube. The speaker connected to the resonator tube excites the air and produces a standing wave inside the resonator tube. And this causes working fluid to oscillate inside the resonator tube. The resonator tube length equal to one-half of the wavelength of the standing wave i.e. $\lambda/2$. The standing wave produces velocity nodes and a pressure node at the two ends of the resonator tube and the middle of the resonator tube respectively. If a stack is placed inside the tube, higher pressure produces at the end of the stack which is closer to the resonator tube end than the other end of the stack. This high-pressure

causes increase in the temperature of the gas and the excess heat is transferred to the stack, which creates a temperature gradient along with the stack in the longitudinal direction.

Design considerations

This study is about fabricating and parametric analysis of the thermo acoustic cooling system. For design consideration for the thermo acoustic cooling system linear thermo acoustic theory is used and due to the large number of parameters some parameters are independent variables will be used.

Acoustic Driver

The power required for a thermo acoustic cooling system is provided by a speaker which is called an acoustic driver. It converts electronic power to acoustic power. The major part of this power is used to run the thermo acoustic cooling system and the rest of it is dissipated in different parts of the thermo acoustic cooling system. The loudspeaker is of the electrodynamic type which uses copper wires and a permanent magnet. For this study Loudspeaker with the maximum power of 1000W at the operating frequency of 400hz, 500hz, 1000hz is selected.

Acoustic Resonator

For the design of resonator tube is important parameters are shape, length, weight, and losses. The length of the resonator tube is equal to half of the wavelength of the standing wave;

$$L = \lambda/2$$

$$\lambda = a/f$$

where a is the speed of sound = 346.5 m/s, λ is the wavelength and f is the resonance frequency.

As per the above discussion, an speaker with the resonance frequency of 400hz, 500hz, 1000hz was selected for the parametric analysis.

Stack

For a thermo acoustic cooling system, an important component is a stack. Therefore stack characteristics impact the performance of the thermo acoustic cooling system. This stack material should be high heat capacity and low thermal conductivity. For a higher temperature gradient require stack material should be low

thermal conductivity. And for minimizing the effects of viscous dissipation of acoustic power require high thermal capacity. There are different geometrical configurations of the stack such as; parallel plates, circular, hexagonal, and square pin arrays. These geometries are used to have efficient thermal contact between the working fluid and the solid surface across the cross-sectional area. The pin array and parallel plate stack are the best geometries. Numerical studies confirm that efficiency and power are almost 10% to 20% more with parallel-sided channels than honeycomb channels. The best location to put the stack inside the resonator is about $\lambda/20$ from the nearest velocity node.

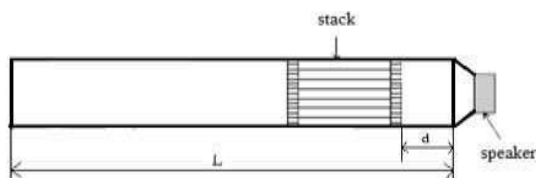


Figure 3.1: Stack position

Working Fluid

For a thermo acoustic cooling system selection of working fluid is important. Because it impacts parameters such as power, efficiency, etc. If required the mean pressure increase inside the resonator tube is requires more power. Also power increase with the increase in the velocity of sound. Lighter gases are necessary for higher sound velocity. For this study working fluid is air.

List of components

The list of components used for the fabrication of the thermo acoustic cooling system is shown in the table. The stack is made of aluminum foil.

SR. NO.	PART	QTY.	MATERIAL
1	THE RESONATOR	1	ACRYLIC
2	THE STACK	1	RUBBER
3	SPEAKER	1	
4	AMPLIFIER	1	
5	FRAME	1	GALVANISED STEEL
6	TEMPERATURE SENSOR	1	

Table 3.1: List of materials

3. Result and discussion

We analyze the performance of the thermo acoustic cooling system for sound frequency

50hz,100hz, 400hz, 500hz, 1000hz for the one-minute interval. and we get a maximum temperature difference of 2.1 degrees Celsius between the two ends of the stack.

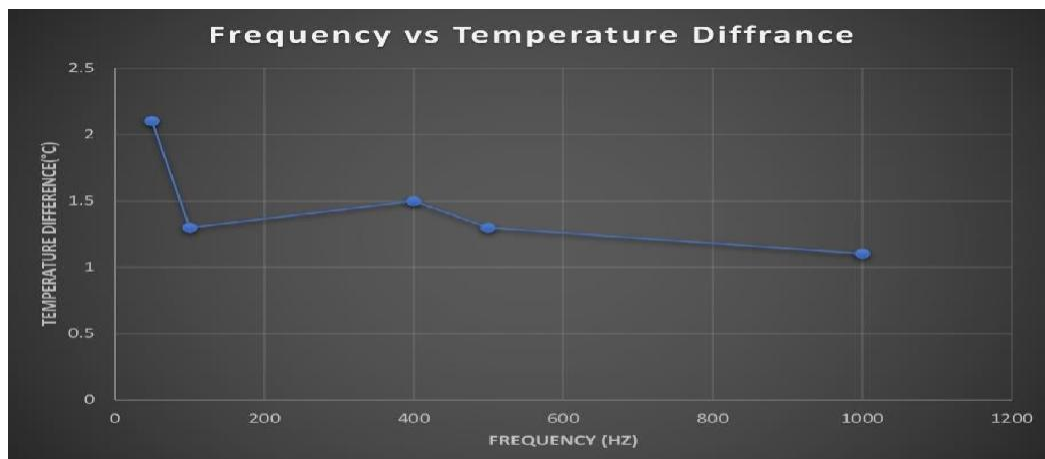
SR. NO.	FREQUENCY (HZ)	TEMPERATURE (CELSIUS)	DIFFERENCE STACK POSITION FROM DRIVER END (mm)
1	50	2.1	346.5
2	100	1.3	173.2
3	400	1.5	43.3
4	500	1.3	34.6
5	1000	1.1	17.3

Table 4.1: Result and discussion

The graph shows the temperature difference between the cold end and hot end of the stack at different Sound frequencies. And according to the different Sound frequencies different positions of the stack inside the resonator tube. The maximum temperature difference between the hot and cold ends of the stack is 2.1 degrees Celsius at sound parameters for thermo acoustic refrigeration or

cooling.frequency 50hz and the stack position 346.5 mm from the acoustic driver end. Graph temperature difference Vs frequency shows the relation between cooling effect and sound frequency. In the future may be thermo acoustic cooling system uses then sound frequency is used as one of the operating

Graph 4.1: Result and discussion



The graph shows the temperature difference between the cold end and hot end of the stack at different Sound frequencies. And according to the different Sound frequencies different positions of the stack inside the resonator tube. The maximum temperature difference between the hot and cold ends of the stack is 2.1 degrees Celsius at sound frequency 50hz and the stack position 346.5 mm from the acoustic driver end. Graph temperature difference vs frequency shows the relation between cooling effect and sound frequency. In the future may be thermo acoustic cooling system uses then sound frequency is used as one of the operating parameters for thermo acoustic refrigeration or cooling.

4. Conclusion

Thermo acoustics cooling is a promising area, which if properly explored, could serve as a good thermo acoustic cooling system. However, In the presence of the thermo acoustic cooling system performance is very low. The main motivation for the present work was to fabricate a simple thermo acoustic cooling system and Analysis performance of it for different Sound frequencies. This project

reports on the fabrication of a simple thermo acoustic cooling system with inexpensive and readily available materials. The characteristic of the fabricated cooling system and its performance were analyzed experimentally and the results are discussed. The maximum temperature difference between the hot and cold ends of the stack is 2.1 degrees Celsius in a one-minute time interval at a sound frequency of 50hz and a stack position of 346.5 mm from the acoustic driver end. If we are using the device with good materials, such as a more insulating tube, we might have been able to get better results.

5. Reference

- [1] Khan, M. I., Siddiqui, T. R., & Rahman, M. A. (2019, July). Combined experimental and numerical study on the performance of thermo acoustic refrigeration systems. In AIP Conference Proceedings (Vol. 2121, No. 1, p. 030022). AIP Publishing LLC.
- [2] Hemal pate, Sanket Vaniya, Neel Joshi,Ramesh Patel,Varma Dhaval,Vaghela Mahipalsinh,Saurav Mishra,Shah Dhairya. A Review on thermo acoustic Refrigeration

- System.
- [3] Dikshita Joshi. Design and modeling of thermo acoustic refrigeration.
- [4] Tartibu, L. K. (2019). Developing more efficient travelling-wave thermo-acoustic refrigerators: A review. *Sustainable Energy Technologies and Assessments*, 31, 102-114.
- [5] Karokar, S., Satpute, R., Parate, R., Giri, R., Chitare, R., & Sonwane, S. (2017). Design, Fabrication and Analysis of Thermo-Acoustic Refrigeration System—A Review.
- [6] Zoontjens, L., Howard, C. Q., Zander, A. C., & Cazzolato, B. S. (2005, November). Development of a low-cost loudspeaker-driven thermo acoustic refrigerator. In *Proceedings of ACOUSTICS* (pp. 9-11).
- [7] Agustina, D., & Purnama, S. (2019, June). Experimental investigation on the effect of resonator shapes on the temperature characteristic of thermo acoustic cooling device. In *IOP Conference Series: Materials Science and Engineering* (Vol. 539, No. 1, p. 012041). IOP Publishing.
- [8] Yulianto, M. (2019, June). Experimental study of thermo acoustic cooling with parallel-plate stack in different distances. In *IOP Conference Series: Materials Science and Engineering* (Vol. 539, No. 1, p. 012037). IOP Publishing.
- [9] Peng, Y., Feng, H., & Mao, X. (2018). Optimization of standing-wave thermo acoustic refrigerator stack using genetic algorithm. *International Journal of Refrigeration*, 92, 246-255.
- [10] Zolpakar, N. A., Mohd-Ghazali, N., Ahmad, R., & Maré, T. (2017). Performance of a 3D-printed stack in a standing wave thermo acoustic refrigerator. *Energy Procedia*, 105, 1382-1387.
- [11] Alcock, A. C., Tartibu, L. K., & Jen, T. C. (2018). Experimental investigation of an adjustable thermo acoustically-driven thermo acoustic refrigerator. *International Journal of Refrigeration*, 94, 71-86.
- [12] Ong, J. Y., King, Y. J., Saw, L. H., & Theng, K. K. (2019, June). Optimization of the Design Parameter for Standing Wave thermo acoustic Refrigerator using Genetic Algorithm. In *IOP Conference Series: Earth and Environmental Science* (Vol. 268, No. 1, p. 012021). IOP Publishing.
- [13] Nayak, B. R., Pundarika, G., & Arya, B. (2017). Influence of stack geometry on the performance of thermo acoustic refrigerator. *Sādhanā*, 42(2), 223-230.
- [14] Arya, B., Nayak, B. R., & Shivakumara, N. V. (2018, April). Effect of Dynamic Pressure on the Performance of thermo acoustic Refrigerator with Aluminium (Al) Resonator. In *IOP Conference Series: Materials Science and Engineering* (Vol. 346, No. 1, p. 012034). IOP Publishing.
- [15] Alshorman, A. A. Analysis of thermo acoustic Cooling and Refrigeration for Performance Enhancement.
- [16] Tijani, M. E. H., Zeegers, J. C. H., & De Waele, A. T. A. M. (2002). The optimal stack spacing for thermo acoustic refrigeration. *The Journal of the Acoustical Society of America*, 112(1), 128-133.
- [17] Wetzel, M., & Herman, C. (1997). Design optimization of thermo acoustic refrigerators. *International journal of refrigeration*, 20(1), 3-21.
- [18] Zolpakar, N. A., Mohd-Ghazali, N., & El-Fawal, M. H. (2016). Performance analysis of the standing wave thermo acoustic refrigerator: A review. *Renewable and Sustainable Energy Reviews*, 54, 626-634.
- [19] Wantha, C. (2018). The impact of stack geometry and mean pressure on cold end temperature of stack in thermo acoustic refrigeration systems. *Heat and Mass Transfer*, 54(7), 2153-2161.
- [20] Jadeja, N. N., & Ankit, C. Design of heat exchanger as heat recovery unit and improving insulation for efficient energy system.