DESIGN AND FABRICATION OF THERMO ACOUSTIC REFRIGERATOR

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Abstract - *A thermo acoustic refrigeration system is one of the harmless types of refrigeration system, which which offers a wide range of scope for further research. Some key advantages include no emission of harmful ozone depleting gases like cfcs and Freon and the presence of no moving parts. This field is gathering the attention of many researchers as it combines both the disciplines of thermal and acoustics. Researchers have found the influence of various parameters of the components, the working fluid, and the geometry of the resonator on the performance of the device. Simulations using software also being developed from time to time. The main objective of the paper is to present a detailed overview on the arrangement and functioning of the refrigeration system using high intensity sound waves. This work experimentally investigates the performance of ceramic substrates used as stacks in standing wave thermo acoustic coolers.*

***Key Words*: Thermoacoustics, standing wave, ceramic substrates, air as working medium**

1. INTRODUCTION

From creating comfortable home environments to manufacturing fast and efficient electronic devices, air conditioning and refrigeration remain expensive yet essential, services for both homes and industries. However, in an age of impending energy and environmental crises, current cooling technologies continue to generate greenhouse gases with high energy costs.

2. WORKING

Thermo acoustic refrigeration is an innovative alternative for cooling that is both clean and inexpensive. Through the construction of a functional model, we will demonstrate the effectiveness of thermo acoustics for modern cooling. Refrigeration relies on two major thermodynamic principles. First, a fluid's temperature rises when compressed and falls when expanded. Second, when two substances are placed in direct contact, heat will flow from the hotter substance to the cooler one.

While conventional refrigerators rely on pumps to transfer heat on a macroscopic scale, thermo acoustic refrigerators depends on sound to generate waves of pressure that alternately compress and relax the gas particles within the tube. Although the model constructed for this research project does not achieve the original goal of refrigeration, the experiment suggests that thermo acoustic refrigerators could one day be viable replacements for conventional refrigerators.

3. PRINCIPLE

Thermo acoustics is based on the principle that sound waves are pressure waves. These sound waves propagate through the air via molecular collisions which causes a disturbance in the air thereby creating constructive and destructive interference. The constructive interference compresses the air molecules while the destructive interference expands them. This principle is the basis of thermo acoustic refrigerator.

One method to control these pressure disturbances is with standing waves. These waves are natural phenomena exhibited by any wave in a closed tube. When the incident and reflected waves overlap they interfere constructively producing a single wave form. This wave causes vibration in the isolated sections. These waves form nodes and antinodes. The maximum compression of air occurs at antinodes. Due to this antinode property standing waves are useful as only a small input power is required to produce a large amplitude wave which has enough energy to cause a visible thermo acoustic effect.

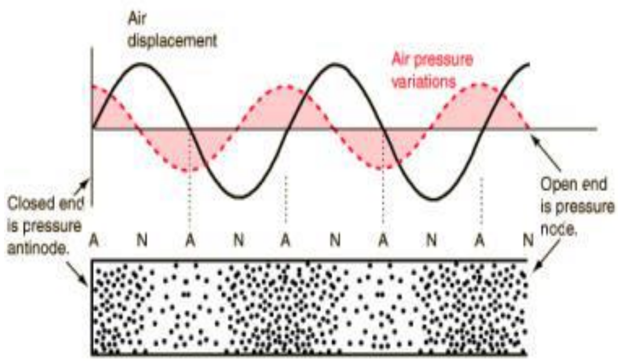


Fig -1: Sound waves

4. THERMO ACOUSTICS

Thermo acoustics combines the branches of acoustics and thermodynamics together to move heat by using sound. While acoustics is primarily concerned with the macroscopic effects of sound transfer like coupled pressure and motion oscillation, thermos acoustics focuses on the microscopic temperature oscillations that accompany these pressure changes. Thermos acoustics take advantage of these pressure oscillations to move heat on microscopic level. This results in a large temperature difference between the hot and cold sides of the device and causes refrigeration.

4.1 Thermo acoustic cycle

The cycle by which heat transfer occurs is similar to the Stirling cycle. The figure traces the basic thermos acoustic cycle for a packet of gas, a collection of gas molecules that act and move together. Starting from point 1, the packet of gas compressed and moves to the left. As the packet is compressed, the sound wave does work on the packet of gas, providing the power for the refrigerator. When the gas packet is at the maximum compression, the gas ejects the heat back into the stack since the temperature of the gas is now higher than the temperature of the stack. This phase is the refrigeration part of the cycle, moving the heat farther from the bottom of the tube.

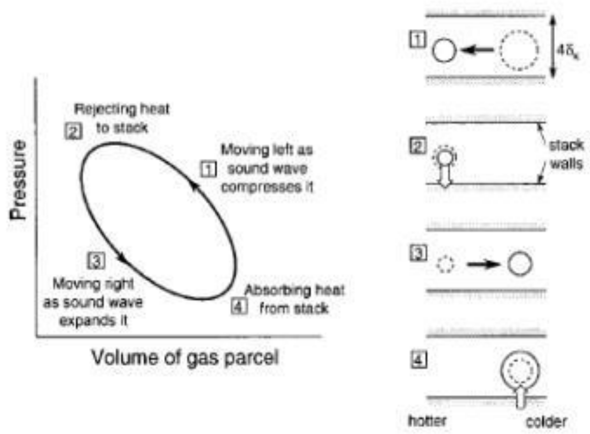


Fig- 2: Thermo acoustic cycle

The most important part of this device is the stack. The stack consists of a large number of closely spaced surfaces that are aligned parallel to the resonator tube. The purpose of the stack is to provide a medium for heat transfer as the sound wave oscillates through the resonator tube. The purpose of the stack is to provide a medium where the walls are close enough so that each time as a packet of gas move, the temperature differential is transferred to the wall of stack. Stack is greater than the work expended to return the gas to the initial state. This process results in a net transfer of heat to the left side of the stack. Finally, in the 4th step the gas packets of gas reabsorb heat from the cold reservoir to repeat the heat transfer process.

4.2 Penetration Depth

The ideal spacing in a stack is thermal penetration depth. The thermal penetration depth is the distance heat can diffuse in a gas over a certain amount of time. For example, if a block of aluminium is at a constant low temperature and suddenly one side is exposed to a high temperature, the distance that the heat penetrates the metal in one second is the heat penetration. As the time passes, the heat penetrates farther into the material, increasing the temperature of the interior section. The thermal penetration depth for an oscillating heat source is a function of the frequency of the standing wave ƒ, the thermal conductivity κ, and density ρ, of the gas, as well as the isobaric specific heat per unit mass of the gas *cp*, according to the equation.

$$\delta = (\kappa/\pi f \rho cp)^{0.5}$$

4.3 Critical Temperature

The critical temperature is the temperature at which heat will be transferred through the stack. If the temperature difference induced by the sound wave is greater than this critical temperature, the stack will function as a refrigerator, transferring heat from the cold end of the tube to the warm end. if the temperature is less than the critical temperature then the stack will function as an acoustic engine, moving heat from the warm region to the colder region and creating sound waves. This temperature is important in determining the properties of a thermos acoustic device, since efficiency depends on a temperature differential caused by the sound waves that is larger than the critical temperature so that a large cooling effect is created.

5. COMPONENTS AND 2D DRAWING

The components of experimental setup of a thermo acoustic refrigerators are as shown below.

Table -1: Components

Component	Material	Quantity
Resonator	Plexi glass tube	1
Stack	Steel scrap, Aluminium foil	-
Speaker	-	1
Amplifier	-	1
Temperature sensor	-	3

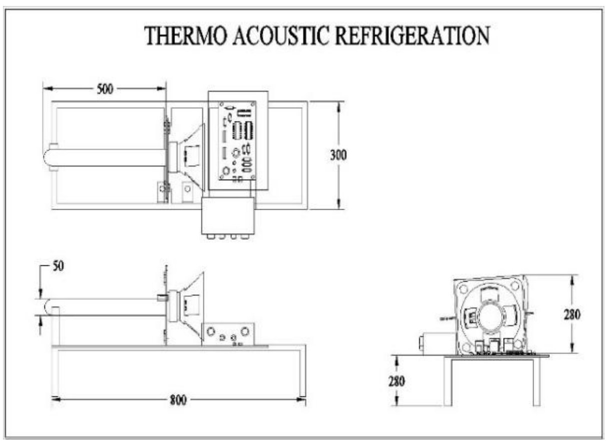


Fig- 3: 2D Drawing

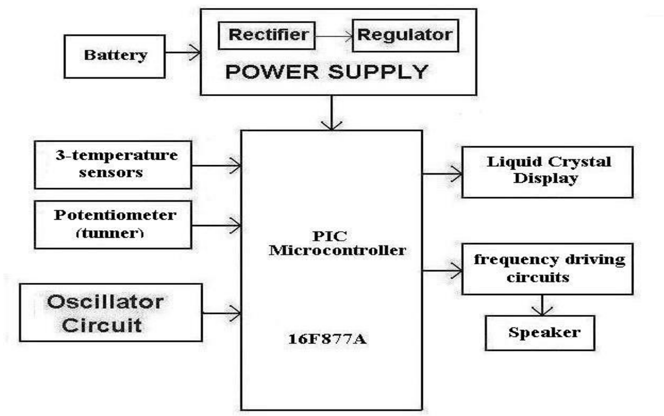


Fig- 4: Components of control unit

The 2D drawing of the thermo acoustic refrigerator is shown in the figure 4 and the components of the control unit is shown in the figure above.

6. EXPERIMENTAL INVESTIGATION

In this experiment the geometrical parameters of the stack have been extensively researched. However, a common methodology has been adopted. The frequency is generally considered the independent variable, kept constant, and individual geometrical configurations are considered the dependent variable. The aim of this work is to investigate the geometrical aspects of the stack and study the performance of a thermo acoustic cooler system. The paper consists of the use of frequency and coupled geometry parameters as non-independent variables and investigation of possible interdependent relationship. Results and conclusions increase the feasibility of this technology being introduce as an alternative refrigerator.

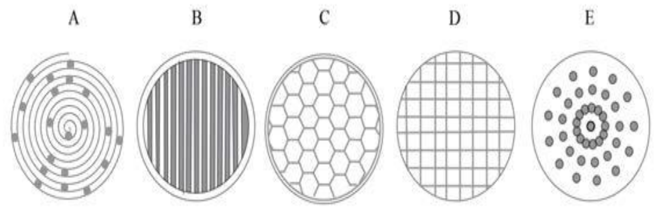


Fig- 5: Stack geometries A. spiral stack, B. parallel plate, C. honeycomb, D.corning celcor, E. pin array

Fig.-6: Stack materials A. aluminium foil, B. steel scrap

In this experiment, no heat exchangers are used as the aim is to study is to investigate the performance of the geometrical stack parameters, as well as focus on the material choice. An electronic board was programmed to produce continuous sound wave input to the speaker. The square wave function was used in the experiment. An amplifier was used to increase the magnitude of sound pressure. A multimeter was used to measure the input voltage and to obtain the input power. The input power to the loud speaker was evaluated to be 12 W.

Time (minutes)	Temperature °C (Aluminium)	Temperature °C (Steel srap)
0	30	30
4	29	30
8	28	29
12	27	28
16	25	27
20	23	25
24	21	24
28	20	23
32	18	21
36	17	20

Table 2. Time temperature readings

The stack was fixed at a constant position and the experiment was conducted. We found that Aluminium foil rolled with plastic fish net is giving more cooling effect than steel scrap at same working conditions.

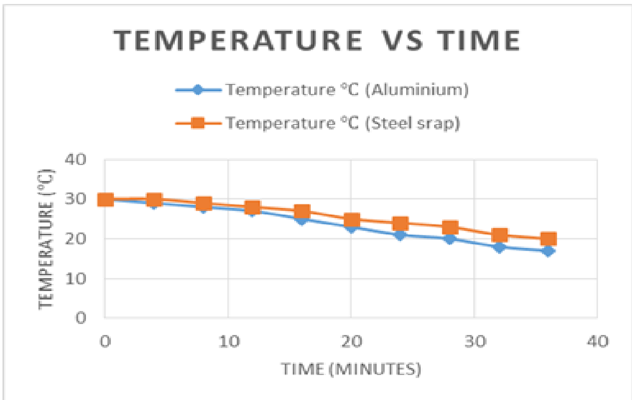
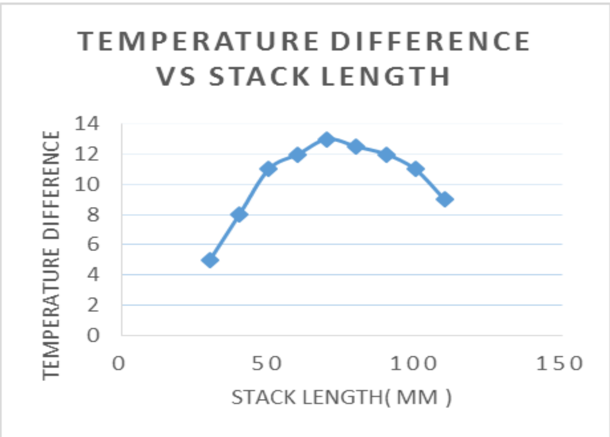


CHART -1: Temperaturs vs Time graph

Our next objective was to find the optimum stack length and stack position. Firstly we created a stack of length 100 mm. We conducted the test with the stack for 30 minutes and then reduced the stack length by 10 mm. Again the test is conducted. After conducting the test we found that 70 mm stack length is giving a maximum temperature difference of 13 °C. Then the objective was to find the optimum stack position from the fixed end. It was found that as the stack move towards the fixed end cooling effect increases. The results and the graphs are plotted below.

Table -3: Stack length optimization

Stack length(mm)	Stack position from the fixed end(mm)	Maximum temperature difference(°C)
100	200,150,100,50	8
90	200,150,100,50	9
80	200,150,100,50	11
70	200,150,100,50	13
60	200,150,100,50	12
50	200,150,100,50	11
60	200,150,100,50	9
50	200,150,100,50	7
0	200,150,100,50	6
30	**200,150,100,50**	3



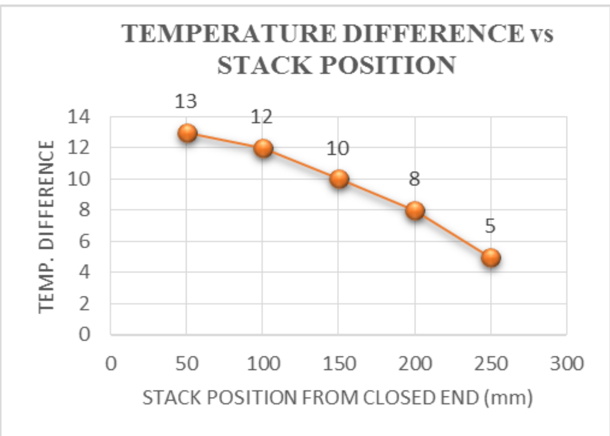


CHART -2, 3: Temperature difference vs Stack length & Temperature difference vs Stack position

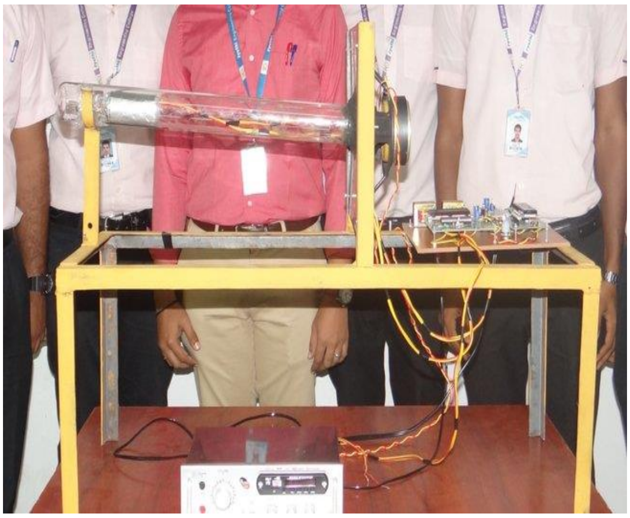


Fig- 9: Fabricated model

7. CONCLUSION

In this paper an experimental set up was used to investigate the performance of the thermo acoustic refrigerator consisting of a loud speaker driven thermo acoustic refrigerator. Material choice and manufacturing of the stack are important factors affecting the performance or the efficiency of thermo acoustic refrigerator (TAR). One of the main attributes of the TAR, is the sustainability it offers. It is for these reasons that ceramic substrates were used as the stack choice for these experiments. Geometrical configurations such as porosity, stack length and stack position were used to study the performance of TAR. The results show that there is a maximum temperature difference when the stack is located closer to closed end of resonator tube. The relationship between the geometrical parameters describing the ceramic substrates, and the measured temperature difference related to the TAR performance were nonlinear. This suggests that further studies on the interdependence between the geometrical parameters and the corresponding frequencies are necessary. We strongly believe that further researches in this field will open up opportunities to cool an auditorium or a stadium by the sound energy produced in it. Also it will be green idea in this era of increase global warming and energy scarcity.

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