INTERNATIONAL JOURNAL OF ADVANCE RESEARCH AND DEVELOPMENT

*(Volume3, Issue4)*
Available online at: www.ijarnd.com

# Study and prototype of the thermoacoustic refrigerator

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## ABSTRACT

***A thermo acoustic refrigerator (TAR) includes an acoustic wave generation device arranged directed to the channel of a hollow tube, and a stack provided at a pre-determined position in the channel of the tube. A temperature difference is obtained across the stack by an acoustic wave emitted from the acoustic wave generation device. The working fluid used is air. This work examined the performance of thermo acoustic refrigeration, which is the theory of using sound waves to cool the air. The main aim of this work is to design and construct a small thermo acoustic refrigerator from inexpensive and readily available parts and analyzed the results. The design includes dimension of stack, selection of acoustic driver, and acoustic resonator. The experiments showed that while thermo acoustic cooling was possible, high efficiency was beyond our reach due to materials restrictions. We obtained the temperature difference of 7℃ for constructing this simple device. However, from these limitations devised several proposals for increasing the performance of thermo acoustic refrigerators. Experiments show the performance can improve by using a better material such as high heat carrying capacity materials and the working fluids like inert gases.***

**Keywords:** *TAR, Acoustic wave generation, Inert gases.*

## 1. INTRODUCTION

In 19$^{th}$ century, modern refrigeration technologies were introduced to world. In the last few decades the use of them has increased significantly. Today mostly cooling is achieved by vapour compression systems that use a significant refrigerant. In recent year, it has been discovered that traditional refrigerators affects the environment adversely and are expansive too. So to avoid the use of hazardous materials the idea of thermo acoustic refrigerator was developed **[1].** 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 hotter substance to colder one. The model constructed for this project employed inexpensive, easily available materials. Although the model did not achieve the original goal of refrigeration, the experiment suggests that thermo acoustic refrigerators could one day be viable replacements for conventional refrigerators. Thermo acoustic is based on the principle that sound waves are pressure waves.

## 2. THERMO ACOUSTICS

Thermo-acoustic is a branch of acoustics and thermodynamics, which studies the movement of heat by sound waves. Acoustics deals with the study of effect sound transfer, like pressure changes and motion oscillations, whereas thermo-acoustic deals with temperature oscillations **[2].** And thermo acoustic refrigerator is a refrigerator that uses sound waves in order to provide the cooling so in this refrigerator the mechanical work is done by sound waves.

So the compression and expansion of molecule is taking place with the help of the pressure waves of the sound. One of the important fundamental sciences behind thermo acoustic refrigerator is thermodynamics, in specific the study of heat transfer. The ideal gas law states that, $PV = \rho RT$

Where $P$, $\rho$, and $T$ are the pressure, density, and temperature of the gas, respectively, and the $R$ is the gas constant (for air $R$=287 J/kg·K).This law states that changes in gas pressure is directly proportional to changes in temperature, as the pressure of gas increases, the gas temperature also increases**. [5]**

## 3. DESIGNING

In designing a standing-wave TAR, there are many parameters to consider, including the stack length and its position, resonator dimensions, working gas properties, and operating conditions. In this prototype the working gas is air.

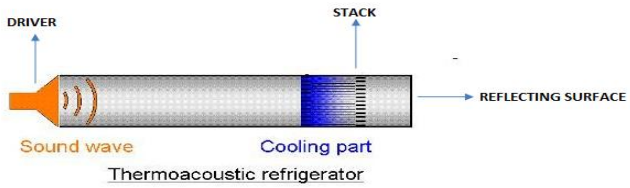



**Chart 1: Thermo acoustic refrigerator**

The main components used in thermo acoustic refrigerator prototype are:-

- **AMPLIFIER: -** An amplifier is an electronic device that can increase the power of a signal. An amplifier is a circuit that can give a power gain greater than one.
- **LOUDSPEAKER (driver):-** The total acoustic power used by the refrigerator is provided by an acoustic driver (speaker). A significant portion of this power is used to pump heat in the stack and the rest is dissipated in different part of the refrigerator. A Loudspeaker with the maximum power of 50W at the operating frequency of 288 Hz was selected as the acoustic driver for this project.
- **WORKING GAS: -** The working gas should be chosen to have a large thermal penetration depth, $\delta k$, and a small viscous penetration depth, $\delta v$. Thermal penetration depth is a measure of how well a fluid can transfer heat through its boundary. A large thermal penetration depth allows for more heat transfer between the stack walls and the gas, increasing the overall efficiency of the TAR.
- **STACK: -** A stack is the heart of a thermo acoustic refrigeration system. The stack provides increased gas solid interface and makes it possible to generate adequate temperature difference. It is desirable for the stack material to have a low thermal conductivity and greater heat capacity than the working gas. Furthermore, the geometry of the pores must be designed by balancing the thermal efficiency and viscous losses within the stack via the thermal and viscous penetration depths. Due to the necessary thermal properties, ceramic and plastic materials are often chosen as stack materials. In this project the stack material is a strip or sheet of transparent plastic film (photographic film). The stack consists of a large number of closely spaced surfaces that are aligned parallel to the to the resonator tube. In a usual resonator tube, heat transfer occurs between the walls of cylinder and the gas. Here shows the phenomenon that is happening inside the stack and its walls.

**WHAT IS HAPPENNING INSIDE STACK [9]**

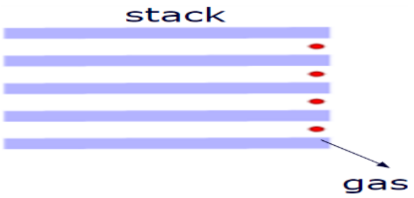



**Chart 2 Hot compressed gas at the right end of stack.**

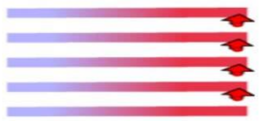


**Chart 3 Heat loss to stack. Stack temperature rises**

**Chart 4 Gas expands while moving to left and cools.**

**Chart 5 Cold gas takes heat from stack. Stack becomes colder.**


**Chart 6 Temp gradient across the stack is established.**

**Penetration depth: -** Thermal penetration depth is one of the critical variables in designing thermo-acoustic refrigerator in particularly the stack design. Thermal penetration depth is the spacing between stack walls. This variable helps to design the space between stack walls in a way that the spaces are not too close or too far, According to G.W. Swift, the ideal spacing in a stack is 4 thermal penetration depths. The Thermal penetration depth $\delta k$ is given by the formula shown below: $\delta k = \sqrt{(2k/\rho C p \omega)}$

where *k*, *ρ*, C*p* are the thermal conductivity, density and constant pressure(isobaric) of the working fluid within the pore, respectively, and *ω* is the angular acoustic frequency.**[4]** We have taken the camera roll which is length of 35cm. and the spacing is provided between them with the help of fishing line because it is economical and easily available.

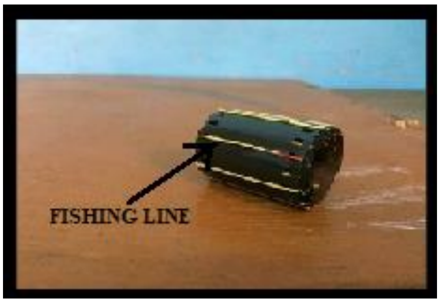




**Chart 7 Front and side view of stack**

- **RESONATOR TUBE:-** The resonator should be made of an acoustically reflective material that is sufficiently strong for the desired operating pressure. The purpose of the resonator in a TAR is to contain the working fluid and to cause it to have a desired natural frequency. The shape, length, weight and the losses are important parameters for designing the resonator. Length of resonator is determined by the resonance frequency and minimal losses at the wall of the resonator. Resonators are generally either half or quarter wavelength resonators. Quarter wavelength resonators are made with tubes by sealing one end and making the length approximately one quarter of the desired resonant frequency wavelength. The length of resonator tube corresponding to quarter wave length of the standing wave;

$L = \lambda/4$

$\lambda = a/f$

$L = 29cm = 0.29m$

So, $\lambda = 4L = 1.16m$

Now, $f = a/\lambda = 298.7$ Hz

Where, a is the speed of sound =346.5m/s, λ is the wavelength, L is the length of tube and f is the resonance frequency.

The viscous and thermal relaxation dissipation losses take place within the distance equal to the thermal penetration depth, from the surface of the resonator. For the resonance frequency 298 Hz, the length of resonant tube was set equal to 290 mm that corresponds to the quarter wavelength of the acoustic standing wave, the diameter of the resonator tube was set equal to 22mm.

- **TEMPERATURE SENSOR:-** We have used LM-35 temperature sensor as temperature measuring device. The LM35 is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature (in $^{o}$C)

Why Use LM-35 to Measure Temperature?

1. To measure temperature more accurately than a using a thermostat.
2. The LM35 generates a higher output voltage than thermocouples and may not require that the output voltage be amplified.

## 4. EXPERIMENTAL SETUP

Based on the design and selection, some standard components of the thermo acoustic refrigerator were purchased and fabricated. A thermo acoustic cooling device requires an acoustic driver attached to one end of the resonator, in order to create an acoustic standing wave in the gas. The acoustic driver converts electric power to the acoustic power. In this study, a loudspeaker with the maximum power of 50 watts and impedance of 8Ω at the operating frequency of 298Hz is used as the acoustic driver. The loudspeaker is driven by a function generator and a power amplifier to provide the required frequency and power to excite the working fluid inside the resonator. The loudspeaker has been enclosed in a wooden box in order to reduce the sound leakage from the speaker. The acoustic resonator is a PVC tube of length 29 cm. The diameter of the tube is 22mm and the wall thickness is 6 mm. One end of the tube has a wooden cover attached to connect it to the speaker frame. A wooden plug was made to fit snugly into the end of the tube forming the closed end. Many parameters such as power, efficiency etc. are involved in the selection of the working fluid, and it depends on the application and objective of the device.

Thermo acoustic power increases with an increasing the mean pressure inside the resonator. It also increases with an increase in the velocity of sound in the working fluid. The lighter gases such as $H_2$, He, Ne have the higher sound velocity. Lighter gases are necessary for the refrigeration application because heavier gases condense or freeze at low temperatures, or exhibit non ideal behavior. Air at atmospheric pressure is chosen as a working fluid for the present study.The stack is inserted in the resonant tube so as to obtain the temperature gradient across the stack. The stack was positioned in the tube approximately 4 cm from the closed end so as to be close to the pressure maximum, but away from the particle displacement minimum.

Two LM35 temperature sensors were used in order to measure the temperature of the cold end and the hot end of the stack and were placed at the two ends of the stack through a hole made in the wooden plug at the closed end of the tube. Leads for sensors were passed through a small hole drilled in the wooden plug at the end of the tube. An ARDUINO was used in order to display the sensor readings and to convert them into temperature readings in degree Celsius using ARDUINO software and the difference between the sensor readings at the two ends of the stack was displayed on the computer screen. The pressure amplitude inside the resonator tube was not measured, but the power to the speaker was increased until a second harmonic became barely audible, indicating that the system was becoming nonlinear.

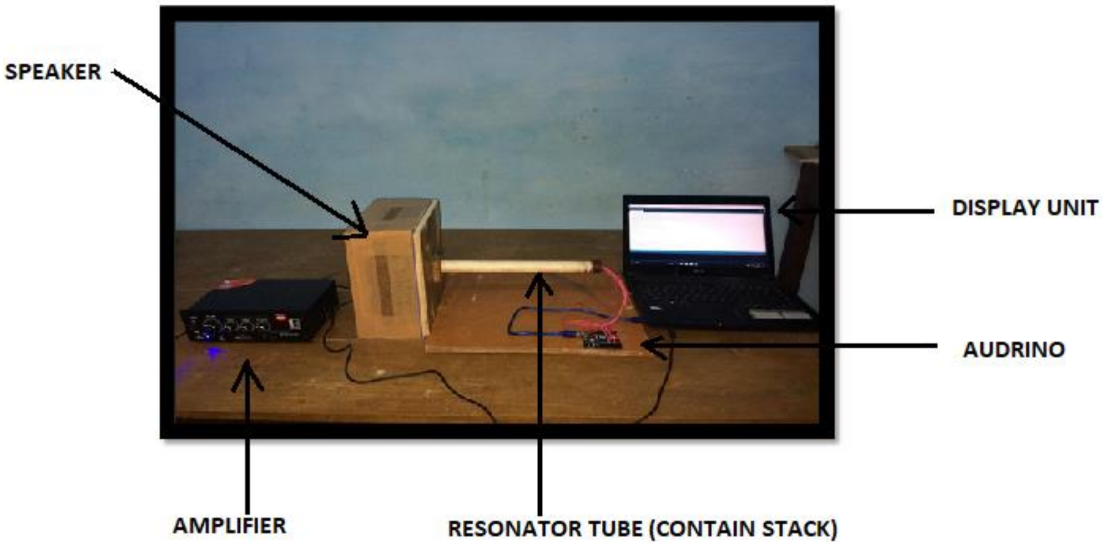



**Chart 3.1 Thermo acoustic refrigerator**

## 5. EXPERIMENTAL RESULT

**Effect of Stack Position**

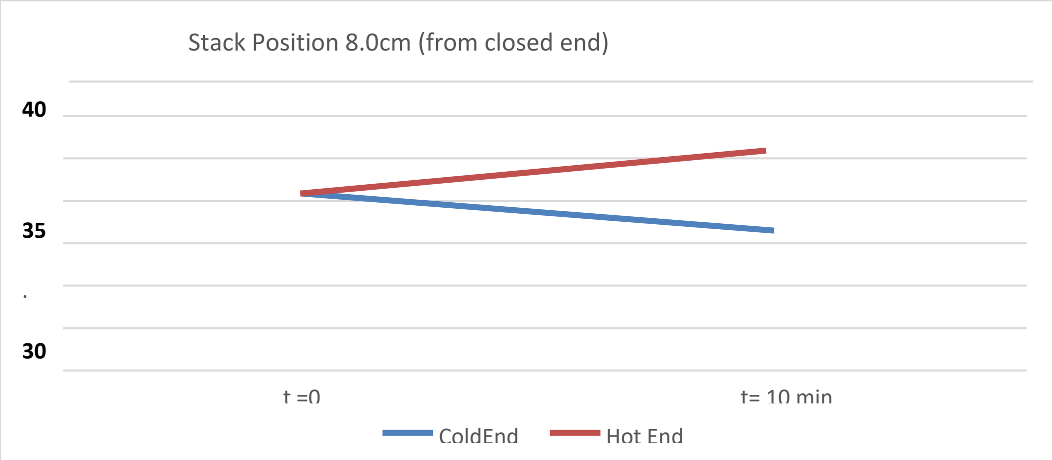
**Experiment No.1**

| Stack Position | Cold End Temp (in C) | Hot End Temp (in C) |
|---|---|---|
| **4.0 cm (from closed end)** | 30.2 | 30.2 |
| After 10 min | 26.84 | 34.18 |


**Experiment No.2**

| Stack Position | Cold End Temp (in C) | Hot End Temp (in C) |
|---|---|---|
| **12 cm (from closed end)** | 30.2 | 30.2 |

| | | |
|---|---|---|
| After 10 min | 27.84 | 33.18 |




## 6. RECOMMENDATION FOR FUTURE SCOPE

- Stacks made of ceramic can be used.
- Different Resonator shapes to maximize power could also be investigated.
- Helium can be used instead of air.
- The fluid may be filled under pressure.
- Resonator material may be chosen to optimize efficiency.
- Different waveforms can be used with the help of wave form generator.
- General improvements on the Seals could also improve the system.

## 7. CONCLUSION

The Thermo acoustic Refrigeration System consists of no moving parts. Hence the maintenance cost is also low. The system is not bulky. It doesn't use any refrigerant and hence has no polluting effects. It doesn't use any refrigerant and hence has no polluting effects. In this model our main motive was to construct the demonstrative model with readily available materials. This experiment proved that thermo-acoustic refrigerators indeed work. The efficiency of this model is very low we get temperature difference of 7 degree Celsius but the efficiency can increase by using other materials like ceramics for stack and good resonating material for resonator tube etc. This device is concept device proving the possibility of thermo acoustic device, to cool the air only for short period of time. By developing TARs we can get to control on the alarming situation of global warming.

## 8. REFERENCES

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