http://dx.doi.org/10.21172/ijiet.102.31

# Review on Thermoacoustic Refrigeration System

A.S.Futane[1], Prerana Hire[2], Rahul Mishra[3], Akshay Mali[4]
[1]*Assistant professor, Department of Mechanical Engineering, MGM's College of Engineering and Technology, Navi Mumbai, Maharashtra, India*
[2,3,4] *Department of Mechanical Engineering, MGM's College of Engineering and Technology, Navi Mumbai, Maharashtra, India*

**Abstract - Currently, cooling is achieved with vapor compression system that uses a specific refrigerant. In recent years, it has been discovered that conventional refrigerants affect the environment adversely. For the safety of the environment, it is necessary to avoid the use of environmentally hazardous refrigerants by developing new alternative refrigeration technologies such as Thermo acoustic Refrigeration System. Thermo acoustic principle has been known for over years but the use of this phenomenon to develop engines and pumps is recent and in research. Thermo acoustics refrigerators have no moving parts and an inert working medium, hence environment friendly. Designing, experimentation & comparison of different performance characteristics of thermo acoustic engines were reviewed from different research papers & conclusion were obtained for designing of project model.**
**Keywords: Thermo Acoustics, Stack, Stack Material, Thermal and Viscous Penetration Depths, Resonator**

## I. INTRODUCTION

Over the past two decades, heat engine or refrigerator with no moving pistons and oil seals has been area of research. These are called thermo acoustic devices. They take advantage of sound waves reverberating within them which converts temperature difference into mechanical energy and vice versa. Such systems thus can be used, to generate electricity or to provide refrigeration and air conditioning. Thermo acoustic devices perform best with inert gases as the working fluid hence they do not produce any harmful environmental effects such as global warming or stratospheric ozone depletion that have been associated with the engineered refrigerants such as CFCs and HFCs. When sound waves move through a medium by compression and rarefaction the medium undergoes vibration along with temperature and pressure change. When a gas carrying a wave is brought in contact with a solid surface, it absorbs the heat as the gas gets compressed. Since the specific heat capacity of solids is generally quite greater than that of fluids, the solid absorbs heat without much change in its temperature. Similarly, it rejects heat to the gas molecules nearby during expansion, thus maintaining stable temperature. If pressure of medium is high temperature difference obtained is higher between solid and gas. If continuous constant frequency vibration (by means of sound waves) is supplied to the gas in a tube with one end (reflector end) close, the reflected and the originally supplied sound waves will interfere with each other. If the length of the tube is selected equal to the resonating length, a standing wave is obtained. The pressure amplitude thus obtained is high and causes high temperature gradient. In the case of tube with one end open, length of tube required to sustain resonance should be equal to odd integrals of $\lambda/4$.[1]

## II. DESIGN PLAN

We begin by designing the stack which forms the most important part of the system and then try to optimize it. The basic motive is to maximize the coefficient of performance which is defined as the ratio of heat pumped to the acoustic power used by the stack. The design of thermo acoustic refrigerator aims at meeting the requirements of given cooling power $Q_c$ and a given low temperature $T_c$ .

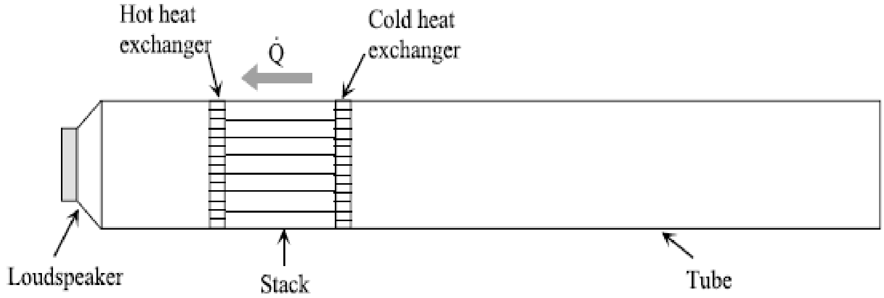


Figure1. 2D diagram of thermoacoustic refrigerator [2]

A simple diagrammatic representation can be shown as per the figure above [2]. The arrangement consist of an acoustically resonant tube which consists of a gas medium (air, helium or any inert gas etc), a stack designed by a foundation of layered parallel plates and two heat exchangers on either side of stack. A loud speaker is attached on one side of resonator tube as an acoustic source and the other end is closed. Heat generated by the stack is pumped up the tube in such a way that cold heat exchanger becomes colder and hot heat exchanger becomes hotter. This is the theoretical principle over which the concept of thermo acoustic refrigerator is based on following ahead we would try to study the mathematical aspect to give the concept a scientific and technical approach.

Table 1.Operation, working gas, and stack parameters that can be used

| Operation parameters | Working Gas Parameters |
|---|---|
| Operating frequency: $f$ | Dynamic viscosity: $\mu$ |
| Average pressure: $pm$ | Thermal conductivity: $K$ |
| Dynamic pressure amplitude: $p0$ | Sound velocity: $a$ |
| Mean temperature: $Tm$ | Ratio of isobaric to Isochoric specific heats: $\Upsilon$ |

``

STACK

| Material | Geometry |
|---|---|
| | Length: $L_s$ |
| Thermal conductivity: $K_s$ | Stack center position: $x_s$ |
| Density: $\rho_s$ | Plate thickness: $2l$ |
| Specific heat: $c_s$ | Plate spacing: $2y_0$ |
| | Cross-section: $A$ |

The boundary-layer and stack approximations Assumed [2]:

1. To keep the pressure and velocity approximately constant over the stack length reduced acoustic wavelength is greater than stack length: $\lambda/2\Pi >> L_s$.
2. To simplify Rott's functions by setting complex hyperbolic tangents equal to one we assume that thermal and viscous penetration depths are smaller than spacing in stack. [2]
3. The temperature difference is smaller than the average temperature: $\Delta T_m << T_m$, so that the thermo physical properties of the gas can be considered as constant within the stack.

To make calculations easier normalization of parameters is done. The length and position of the stack can be normalized by $\lambda/2\Pi$. The thermal and viscous penetration depths can be normalized by the half spacing in the stack y0. The cold temperature or the temperature difference can be normalized by $T_m$.

The performance of the stack is expressed in terms of the coefficient of performance [2]:

$$COP=\frac{Q}{W}$$

*2.1 Thermal and Viscous Penetration Depths–*

Thermal penetration depth is the distance in the gas from stack surface up to which the heat the heat can diffuse. It indicates the region in gas where the molecules take part in the thermo acoustic effect [1].

The thermal penetration depth is given by

$$\delta_k = \sqrt{\frac{2\kappa}{\rho C_p \omega}} \quad .... \quad (1)$$

This thermal penetration depth extends on both sides of the stack material.

However, there are some energy losses near the solid surface. This is because viscous stresses are produced during the oscillations of the fluid [5]. This generally occurs in the volume up to distance from the surface equal to the viscous penetration depth [4] given by

$$\delta_v = \sqrt{\frac{2\mu}{\rho\omega}} \quad .... \quad (2)$$

Where, $\kappa$ = thermal conductivity of the gas

http://dx.doi.org/10.21172/ijiet.102.31

$\rho$ = density of the gas
$C_p$ = specific heat at constant pressure
$\omega$ = angular frequency of the sound wave

*2.2 Resonator –*

The resonator is directly designed as per the stack measurements in such a way that the dimensions and the losses during heat pumping are optimal. The resonator is said to be optimal if it is compact, light and strong enough. Resonating frequency and losses at the wall of resonator are the parameters used to determine the shape and length of resonator. The sectional area A of the resonator at the stack location is determined in the preceding section. The acoustic resonator can have a length of λ/2 or a λ/4 [2].

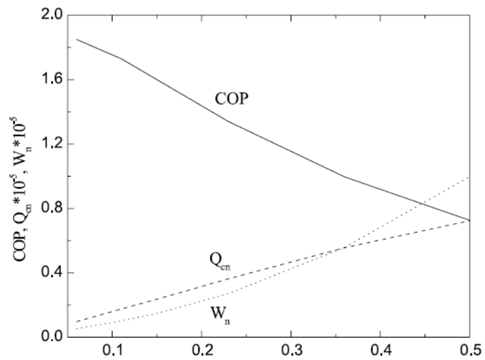


Figure 2. Graph for COP vs. Stack length [2]

The cooling power, acoustic power and performance are maximum of the stack at centre position as it is a function of normalized stack length.

The losses take place inside the thermal and viscous penetration depths due to thermal and viscous relaxation. In the boundary-layer approximation, the acoustic power lost per unit surface area of the resonator is given by

$$\frac{d\dot{W}_2}{dS} = \frac{1}{4}\rho_m |\langle u_1 \rangle|^2 \delta_\nu \omega + \frac{1}{4}\frac{|p_1|^2}{\rho_m a^2}(\gamma - 1)\delta_k \omega,$$

The kinetic energy lost due to viscous shear is represented by the first term on right hand side. Loss due thermal relaxation is represented by second term on right hand side. Since the total dissipated energy is proportional to the wall surface area of the resonator, a λ=4-resonator will dissipate only half the energy dissipated by a λ=2-resonator. Hence a λ=4-resonator is mostly used. Hofler [3] showed that instead of continuous diameter tube if the right hand side part diameter of resonator to stack is lowered compared to left hand side diameter the performance is optimized.

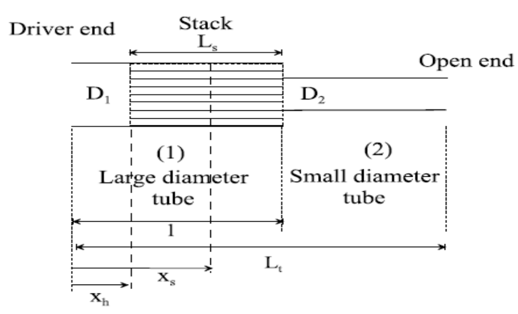


Figure 3. Change in diameter of Resonator [2]

*2.3 Heat Exchangers–*

The efficiency of thermo acoustic cooling process can be increased by using heat exchangers. Implementation of heat exchanger is a critical task in the design of heat exchanger. Very less research is available about heat transfer in oscillatory flow with zero mean velocity. Hence this steady flow design cannot be applied directly in the case of heat exchangers. Due to which some groups are using flow visualization techniques and simulations but the flow patterns obtained are also very complicated and difficult to read [2].

*2.4 Cold Heat Exchanger–*

As the right hand side of the stack cools down so a cold heat exchanger is essential for good thermal contact between cold side of stack and small tube resonator. An electric heater is used to measure the cooling power at the cold heat exchanger. The length of heat exchanger depends upon the distance over which heat is transferred by gas medium. The optimum length signifies peak-to-peak displacement of the gas at the location where cold heat exchanger is placed. The porosity of heat exchanger must match the porosity of stack so that the possible entrance of the gas from stack to cold heat exchanger or vice versa is avoided. This implies that the blockage ratio to be used in design of cold heat exchanger should be 0.75.Similarly as the heat is dissipated; acoustic power is also dissipated in cold heat exchanger.

*2.5 Hot Heat Exchanger–*

Hot heat exchanger proves an essential part as it as it removes the heat pumped by the stack and forwards it to the circulating cooling water. As discussed earlier the optimal length of the heat exchanger is equal to the peak to peak displacement amplitude of the gas at the location of the heat exchanger. But since the hot heat exchanger has to reject heat nearly twice the heat supplied by the cold heat exchanger, the length of the hot heat exchanger is suggested to be twice that of cold heat exchanger.

*2.6 Stack–*

Stack forms the integral part of the thermo acoustic refrigerator. Researchers have been keen in developing various designs to get improved performance simplicity of manufacturing and cost effectiveness. Also various geometries have been developed over the years such as parallel pate type, spiral type, pin array type etc. The parallel plate type of stack geometry using Mylar as a material is shown a below [1].

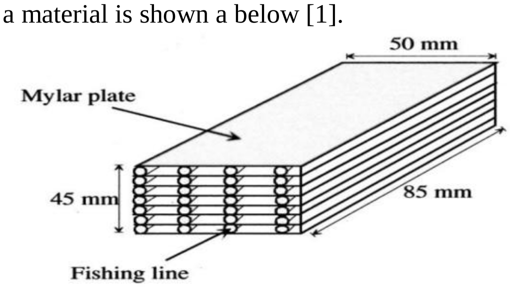


Figure 4. Parallel Plate Mylar Stack [1]

As the designs have been devised we try to implement results by changing the material of stack and try to implement them and determine their effectiveness. Following are some listed materials which could be used for experimentation depending on their thermal conductivity.

*2.7 Different Materials for Stack–*

Table -2 Material, their Thermal Conductivity and Specific Heat

| Material | Thermal conductivity (W/m-K) | Specific heat capacity(kJ/Kg-K) |
|---|---|---|
| Cork | 0.07 | 1.9 |
| Leather | 0.14 | 1.5 |
| Mylar | 0.16 | 1.2 |
| Plywood | 0.13 | 0.545 |
| Poly isoprene hard rubber | 0.16 | 1.19 |
| Tar | 0.19 | 1.47 |

The above materials were selected for experimentation purposes keeping in mind its environment friendliness, cost & availability.

*2.8 When Air Is Used As Working Medium*

As the design was changed, then the material was changed also other section was to find out what effects in COP was seen when the working medium was changed. The following are the effects over the COP when experimented under atmospheric air as the working medium (optimum results were obtained when the medium was helium gas).

*2.9 Effects on COP–*

COP of the refrigerator is found out to be directly proportional to the heating load and inversely proportional to the acoustic power which is supplied to the acoustic driver. COP of system increases when increase in heating load and decreases at higher acoustic power [6] as shown graphically below.

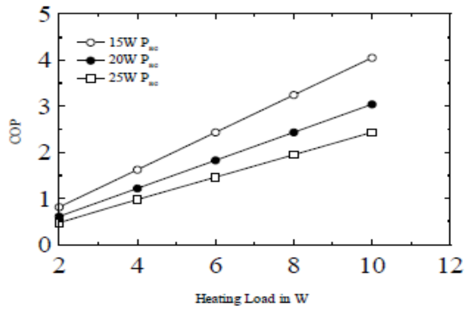


Figure 5. Variation of COP with Heating Load for Different acoustic power [6]

## III. CONCLUSION

The design strategy of thermo acoustic refrigerator was discussed briefly. The review on optimized design was elaborated. Different materials were suggested for the experimentation on thermo acoustic refrigerator stack. Effects of air as working medium on COP of refrigerator was shown. The objective to develop an environment friendly system with cheap cost and maximum efficiency were viewed.

## IV. REFERENCES

[1] Bhansali p. S, patunkar p. P, gorade s. V, adhav s. S, botre s. S. "*an overview of stack design for a thermo acoustic refrigerator*".ijret (2015): 04-06.
[2] M.e.h tijani,j.c.h.zeegers,and a.t.a.m.de waele "*design of thermo acoustic refrigerators*" .cryogenics 42 (2002) 49-57.
[3] Hofler tj." *Thermoacoustic refrigerator design and performance*". Ph.d. Dissertation, physics department, university of california at san diego, 1986.
[4] Tijani, m. E. H., j. C. H. Zeegers, and a. T. A. M. De waele. "*the optimal stack spacing for thermo acoustic refrigeration*." *the journal of the acoustical society of america* 112.1 (2002): 128-133.
[5] Keolian, robert m., and gregory w. Swift. "*pin stack array for thermoacoustic energy conversion*." u.s. patent no. 5,456,082. 10 oct. 1995.
[6] Ramesh nayak. B1. Bheemsha2, pundarika. G3, **"***performance evaluation of thermo acoustic refrigerator using air as working medium*". Ssrg international journal of thermal engineering (ssrg-ijte) volume 1 issue3 may to june 2015.
[7] B. L. Minner, j. E. Braun, l. Mongeau, *purdue university ,"optimizing the design of a thermo acoustic refrigerator*", international refrigeration and air conditioning conference,1996.
[8] Deniz filiz, mechanical engineering department, bogazici university, bebek, 34342, istanbul, turkey, "*convective heat transfer enhancement by ultrasound*",june,2016.
[9] Daniel george chinn, master of science, 2010, "*piezo electrically-driven thermo acoustic refrigerator*".
[10] Pranav mahamuni1*, pratik bhansali1, nishank shah1, yash parikh2, "*a study of thermo acoustic refrigeration system*" (ijirae) issn: 2349-2163 issue 2, volume 2 (february 2015).
[11] Luke zoontjens, carl q. Howard, anthony c. Zander and ben s. Cazzolato, university of adelaide, australia. "*development of a low-cost loudspeaker driven thermoacoustic refrigerator".* 9-11 november 2005, busselton, western australia.
[12] "*stack materials and design".* K. Kordesch and v. Hacker.volume 4, part 4, pp 765–773 in *handbook of fuel cells – fundamentals, technology and applications* (isbn: 0-471-49926-9).
[13] "*thermoacoustic refrigeration*".steven l.garrett and thomas j.hofler,physics department-code ph/gx,naval post graduate school,monterey,ca 93943. Issue n92-22720.
[14] Jay a. Adeff, thomas j. Hofler, and anthony a. Atchley physics department, naval postgraduate school, monterey, california 93943. "*measurements with reticulated vitreous carbon stack in thermoacoustic prime movers and refrigerators". © 1998 acoustical society of america.* [s0001-4966(98)05505-2].
[15] Viswa mohan pedagopu, khannaji pattapu. "*a novel approach to design and fabrication of thermo-acoustic refrigerator using high amplitude sound waves*". Iosr journal of mechanical and civil engineering (iosr-jmce) e-issn: 2278-1684,p-issn: 2320-334x, volume 8, issue 6 (sep. - oct. 2013), pp 15-24.
[16] David bartos, sonja kurzbach, zuzanna filipiak, maros petro. "*measuring the performance of different stack materials in thermoacoustic device".* Roskilde university 2015.
[17] Steven l. Garrett, jay a. Adeff,t and thomas j. Hofler. *"thermoacoustic refrigerator for space applications".* Journal of thermophysics and heat transfer vol.7, no. 4, oct.-dec. 1993.
[18] Kaushik s panara , amrat m patel , nikunj s patel , jigar d patel *"thermoacoustic refrigeration system setup".* Dept. Of mechanical engineering, laxmi institute of technology sarigam, valsad, india. Volume 6, issue 11, nov 2015, pp. 01-15, article id: ijmet_06_11_001.
[19] Shivaji h. Gaigole,sarang .v. Ugemuge ,amit d. Warbhe ,arshad rafe md."*thermo-acoustic refrigerator"* . Ijfeat, robonance-15, issn: 2321-8134.
[20] Ratish sawant, sandesh rasal, gaurav yadav, arunkumar yadav, darshan kadam, "*design and fabrication of thermoacoustic refrigerator*". International journal of research in advent technology, vol.3, no.4, april 2015 e-issn: 2321-9637.
[21] Gregory w. Swift, "*thermoacoustic natural gas liquefier***".** Us doe natural gas conference proceedings march 24-27, 1997 houston, texas doe/fetc-97/1043.