A Review on Thermo acoustic Refrigeration

[1]Mr. Avishkar A Vadnere, [2] Prof. Vasant Jog
[1] Final year students of Mechanical Engineering, [5] Vice Principal
G V Acharya Institute of Engineering & Technology, Shelu, Raigad- 410201, India

---

***Abstract*— Nowadays most of the scientists are working on Acoustic waves and its application. One of the applications is Thermo acoustic Refrigeration. It is a technology in which it does not contain any harmful and moving parts. This system works on temperature gradient of sound waves. It has two subcategories one is forward effect which deals with pressure oscillations by generation of heat. This helps in producing thermo acoustic engine. Another one is reversed effect which deals with acoustic waves to heat pump. This effect is used to create thermo acoustic refrigerator.**

***Keywords*--- Thermo acoustic, temperature gradient**

I. Introduction

Refrigerator is essential device in almost every field, but the conventional refrigerators contain Ozone depleting substances (ODS) like Hydrofluorocarbons (HFCs), Chlorofluorocarbons (CFCs) as refrigerants which results into depletion of ozone layer. So Thermo acoustic is one of the alternatives to overcome this problem, which do not use any harmful refrigerant like Hydrocarbons (HFCs), Chloroflourocarbons (CFCs). It depends on power of sound that generates or creates oscillations within the gas molecules. The only disadvantage of this thermo acoustic system is that it has low efficiency & COP than vapour compression cycle (VCR).

Due to inherent reliability, absence of moving parts, use of working fluid which are not harmful for environment like Argon, Helium etc. Thermo acoustic technology has gained considerable attention in recent years. Such thermo acoustic systems have a more potential to replace conventional refrigeration systems to thermo acoustic refrigeration system. The basic principle on which thermo acoustic refrigerator runs is known as 'Thermo acoustic effect', this results in thermodynamic interaction of solid surface & compressible fluid.

A device which converts high amplitude sound waves can be converted into temperature gradient can be design by utilizing energy interaction. The system that converts heat energy into acoustic energy is called a thermo acoustic prime mover and a system which converts acoustic energy into temperature gradient is called a thermo acoustic refrigerator. Thermo acoustic device can also be classified standing waves and travelling waves system. Standing waves device uses stack. Stack is a heart of thermo acoustic refrigerator, it is a solid component with contains pores in it which allow the working fluid to oscillate while in contact with the solid walls.

II. Thermo acoustic Effect

Cooling can be produce by utilizing acoustic or sound waves. The pressure variations are directly proportional by temperature variations due to compressions and expansions of the gas. The average temperature for a single medium at certain location does not change. When the second medium is present in the resonator which is in the form of solid wall there takes place a heat transfer with the wall. The gas molecule which is in expanded form will take heat from the wall, while the compressed one will reject heat to the wall.

To fix the direction of the heat flow, a standing or sinusoidal pattern is generated in acoustic resonator. When a large temperature gradient is imposed on the wall, the net heat is absorbed and generation of acoustic waves takes place due to which heat is converted to work, this is called reverse effect.

This principle can be apply in practical refrigerators providing cooling, heat engines providing heat or power generators providing work.

III. Literature Review

Higgins [1]

In 1777, he conducted the first experiment based on acoustic oscillations generated by heat. In this experiment he observed that when the hydrogen flame was placed at correct position within the organ pipe acoustic oscillations would take place. From this he concluded that heat energy can be converted into sound waves.

Sondhauss [2]

He conducted the related experiment as the Higgins, He took a resonator with a glass ball attached to it and heating the junction of ball and the resonator. He observed that when the flame is kept near the junction the system first heat up or warm up and then the oscillation of the acoustic has been produce. But the solid review does not occur from this experiment. It was just an extension of Higgins setup.

Rott [3]

In 1969, He gave the mathematical equations on thermo acoustic. In his papers he derives and solved linear equations based on thermo acoustic theory. His theories are the foundation by which most of the parameters and calculations are considered while making thermo acoustic models. The model made by him was linear model.

Gifford and Longsworth [4]

They performed the experiment using low frequency pulse inside the resonator. They observed that cooling takes place inside the resonator. They named their model as pulse tube from which pulse tube refrigerator has derived.

Holfer [5]

The first known thermo acoustic refrigerator model was built by him, who was the member of Wheatley's group, the one who build thermo acoustic engine. He also notes that when the cross section area of the stack also require diameter tube on quarter wavelength resonator, the surface area of the resonator can be reduced past the stack by using small diameter tube, this helps to reduces the losses that are proportional to the surface area of the resonator. He observes that as the diameter of second tube is shrunk in the ratio to the diameter of first tube the thermal losses within resonator increases monotonically and the viscous losses have a steep drop and then remains steady.

Wetzel [6]

He makes an attempt in optimization of design of thermo acoustic refrigerators. He also developed algorithm for optimization. He noted that optimization of heat exchanger inside thermo acoustic refrigerator is an issue also optimizing of driver or speaker is another issue other than heat exchanger. His conclusion was theoretically efficient thermo acoustic refrigerators as compared to traditional refrigerators are possible if hang ups such better heat exchangers can be overcome.

Tijani [7]

He published a paper detail process used to design thermo acoustic refrigerators. He started from designing of stack in such a way as it must meet the cooling requirements. He made stack by making choices for average pressure, dynamic pressure, frequency, and working gas. After this the material geometry, position is considered. Resonator is designed by keep in mind the natural frequency and minimizing loss at the wall. The heat exchangers are designed in an oscillatory flow with zero mean displacement. He also performed a study on individual components of thermo acoustic refrigerator. On his results of researches he built a refrigerator, the COP he achieved relative to Carnot COP was 11% , this was done using helium gas. He also developed a method by which we can easily manipulate the mechanical impedance of the speaker.

Gardner and Swift [8]

They discussed use of entrance of medium in thermo acoustic refrigerators. They note that the maximum efficiency takes place when the impedance of the acoustic is purely real. They observed that many refrigerators have large compliance tank at the end of resonator due to which it causes negative imaginary component of impedance, to introduce positive imaginary part to impedance inertance can be used and make impedance purely real again.

IV. Design Overview

Thermo acoustic refrigerator mainly consists of a medium as a working gas, a speaker (sound generator), resonator, stack, heat exchangers.

1. Working Medium gas

To achieve high efficiency gas with low kinematic viscosity is preffered this viscosity is shown by inert gases like Xenon, Helium etc. Due to low kinematic viscosity the gas molecules are free to vibrate even in a small portion which results in high utilization of gas molecules to participate in heat transfer. Since inert gases has issue like cost, refilling, leakages etc. High pressure air can also use as working medium. Thermal penetration depths & the natural frequency of the resonator are also dependent on the choice of working fluid.

2. Speaker

Speaker is the source of acoustic waves which is also known as Acoustic driver. The acoustic driver produces high pressure sound waves. Just like a compressor in vapour compression cycle (VCR), acoustic driver is heart of thermo acoustic refrigerator. Sound waves are produce due to vibration of flexible cone or diaphragm. The diaphragm is made up of plastic, paper, metal etc. & narrow end of the coil is attached to the coil which produces sound name as voice coil. The voice coil contains two magnets namely permanent magnet & electromagnet. The audio signal transmits or travels in the form of waves it may be transverse & longitudinal. These waves are further travels through stack.

3. Resonator

The resonator is a device which contain working medium in it. There are two types of resonator half wavelength and quarter wavelength. Half wavelength resonators are the resonators which are open at one end and close at one end. Due to closed end the gas inside the resonator cannot move due to which velocity node and pressure anti-node is not form. The acoustic driver creates velocity node and pressure anti-node which causes the natural frequency to be half of acoustic wavelength.

Quarter wavelength resonator tubes are made by sealing one end and making the length approximately one quarter of the desired resonant frequency wavelength. A large volume is attached at the open end which creates boundary conditions of zero pressure at the end which cause velocity node and pressure anti-node at the end of the tube. This indicates that natural frequency of resonator will have wavelength four times the resonator length. Mainly thermo acoustic resonators used are half wavelength or quarter wavelength but they are not exact because ideal resonators are hard to build.

4. Stack

Stack is the element where thermo acoustic effect takes place. It is the most sensitive part of the design in thermo acoustic refrigerator because small change in dimensions of the stack can lead huge difference it the performance. The efficiency of the thermo acoustic refrigerator depends on the stack. This problem arises because there is point within the resonator where velocity and pressure oscillations work together to maximize thermo acoustic effect. Since this point is infinitesimally small whose cross section is also small which would produce no cooling effect if stack is operated at only this point. The cooling power and the efficiency of refrigerator is inversely proportional to each other, as the length of stack increases the cooling power of thermo acoustic refrigerator increases but the efficiency decreases, since the further cross sections of the stack are from optimal point. The stack materials used are of low thermal conductivity and have high heat capacity. Material used for stack is photographic flim or Mylar sheet. There are two types of stack formation parallel plate stack and spiral stack.

The another consideration while preparing stack is stack thickness, because it should provide sufficient heat capacity but the thickness must be reduce so that there must no blockage in the stack. If blockage would present then the acoustic wave would not pass through the stack and if the thickness is too thick then there would be formation of eddies near the stack.

5. Heat Exchanger

Heat exchanger is a component or a device which is use to transfer thermal energy between fluids, it may be two or more than two. There is no external heat or work interaction in heat exchanger. The working of heat exchanger is to remove the heat from high temperature source.

In thermo acoustic refrigerator the heat exchanger is used to remove the heat from the stack so that temperature is maintain as per requirement. In thermo acoustic refrigerator two heat exchangers are required one work as hot heat exchanger and other work as cold heat exchanger.

V. Scope Of Thesis

Most of the thermo acoustic refrigerators that are made, makes used of electromagnetic speakers. Good numerical models are present which makes a useful tool for engineers for design purposes. But the performance of electromagnetic speaker is not good at high frequencies so piezoelectric drivers or speakers can be used for high frequency applications of thermo acoustic refrigerators.

By using this type of refrigerator the biggest issue of global warming will decrease since there no use of harmful gases as refrigerant, which helps in depleting the ozone layer that results into global warming. We can also do optimization of the model compare to traditional refrigeration since the thermo acoustic model is smaller than traditional refrigerator. Since the COP of this refrigerators is 11%, as compare to Carnot COP by using helium gas which is good enough and further optimize which will give more efficiency. By changing the working medium efficiency can increase.

VI. Conclusion

As discussed in many papers most of parameters on behavior of thermo acoustic refrigerators is still lacking. Describing the coupling between the resonator and driver is helpful in maximizing the electro acoustic efficiency over a wider frequency range by matching mechanical resonance frequency of driver to the acoustic resonance frequency of the resonator tube. Gas spring system can be used to shift mechanical resonance frequency of the acoustic driver.

The transfer of heat in oscillatory flow of thermo acoustic refrigerators is not well explained, which is major limitation while modeling that can be done before designing. By using inert gases like helium the setup or model of thermo acoustic refrigerator, the cost is increase as compare to the traditional refrigerator.

References

[1] N. Rott, *Thermo acoustics*, Advances in Applied Mechanics, 20:135-175, 1980

[2] J. Wheatley, T. Hofler, G. W. Swift, and A. Migliori, *Understanding some simple phenomena in thermo acoustics with applications to acoustical heat engines* Am. J. Phys. 53 (2), February 1985

[3] M. E. H. Tijani, *Loudspeaker-driven thermo-acoustic refrigeration*, Ph.D. Thesis at Technische Universiteit Eindhoven, 2001

[4] B. Higgins, *Nicholson's Journal* **I**, 130 (1802)

[5] W.E. Gifford and R. C. Longsworth, *Surface heat pumping*, Adv. Cryog. Eng. 11, 171 (1966)

[6] Lord Rayleigh, .The theory of sound. 2nd edition, Vol.2, Sec.322 (Dover, New York, 1945).

[7] N. Rott, *Damped and thermally driven acoustic oscillations in wide and narrow tubes*, Z. Angew. Math. Phys. **20**, 230 (1969)

[8] T. J. Hofler, *Thermoacoustic refrigerator design and performance*, Ph.D. dissertation, Physics Department, University of California at San Diego, (1986)

[9] J. C. Wheatley, T. Hofler, G.W. Swift, and A. Milgliori, *An intrinsically irreversible thermoacoustic heat engine*, J. Acoust. Soc. Am. **74**, 153 (1983)

[10] G. W. Swift, *Thermoacoustic Engines*, J. Acoust. Soc. Am. **84** (4), 1145 (1988)

[11] G. W. Swift, *Thermoacoustics: A unifying perspective for some engines and refrigerators*, American Institute for Physics Press, New York, 2002