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THERMOACOUSTIC REFRIGERATION

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ABSTRACT

In an early 19th century, modern refrigeration technologies were introduced to the world. In the last few decades, the use of refrigeration systems has significantly increased. Currently, Cooling is achieved with vapour 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 acoustic Refrigeration System. In this type of refrigeration all sorts of conventional refrigerants hazardous refrigerants by developing new alternative refrigeration technologies such as Thermo are eliminated and sound waves take their place. All we need is a loud speaker and an acoustically insulated tube. Also this system completely eliminates the need for lubricants and results in 40% less energy consumption. Thermo acoustic heat engines have the advantage of operating with inert gases and with little or no moving parts, making them highly efficient ideal candidate for environmentally-safe refrigeration with almost zero maintenance cost. Now we will look into a thermo acoustic refrigerator, its principle and functions.

Keywords:- ***Refrigeration, Vapor Compression System, Refrigerants, Thermoacoustic Refrigeration System., stack.***

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1. INTRODUCTION

From creating comfortable home environment to manufacturing fast and efficient electronic devices, air conditioning and refrigeration remain essential services for both homes and industries.

It is becoming increasingly important in the design and development of refrigerating systems to consider environmental impacts. To eliminate the use of environmentally hazardous refrigerants, research efforts are focusing more on the development of alternative refrigerants and alternative refrigeration technologies. An approach in the category of alternative technologies is thermoacoustic refrigeration which produces cooling from sound.

The thermoacoustic effect was first discovered in the 19th century when heat driven acoustic oscillations were observed in open-ended glass tubes.

These devices were the first thermoacoustic engines, consisting of a bulb attached to a long narrow tube. It was in the 1980's that thermoacoustic refrigerator was first developed, when a research group at the Los Alamos National Laboratory showed that the effect could be used to pump heat. The technology has seen rapid growth since then, developing it to a promising asset as a clean and environmentally friendly refrigeration method.

2. LITERATURE REVIEW

Emmanuel c. Nsofor and Azrai Ali (2009) studied on the performance of the thermoacoustic refrigerating system with respect to some critical operating parameters. Experiments were performed on the system under various operating conditions. The experimental setup consists of the thermoacoustic refrigerating system with appropriate valves for the desired controls, instrumentation and the electronic data acquisition system. The resonator was constructed from aluminum tubing but it had plastic tube lining on the inside to reduce heat loss by conduction.

Significant factors that influence the performance of the system were identified. The cooling produced increases with the temperature difference between the two ends of the stack. High pressure in the system does not necessarily results in a higher cooling load. There exists an optimum pressure and an optimum frequency for which the system should be operated in order to obtain maximum cooling load. Consequently, for the thermoacoustic refrigeration system, there should be a related compromise between cooling load, pressure and frequency for best performance. Ramesh Nayak.B. et al. (2011) proposed the design of a thermoacoustic Refrigerator (TAR) stack.

3. WORKING PRINCIPLE

Thermoacoustics is based on the principle that sound waves are pressure waves. These sound waves propagate through air via molecular collisions. The molecular collision causes a disturbance in the air, which in turn creates constructive and destructive interference. The constructive interference makes the molecules compress, and the destructive interference makes the molecules expand.

This principle is the basis behind the thermoacoustic refrigerator. Refrigeration based 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. Here are two types of thermoacoustic devices namely thermoacoustic engine and thermoacoustic refrigerator.

In a thermoacoustic engine, heat is converted into sound energy and this energy is available for the useful work. In a thermoacoustic refrigerator the reverse process occurs, i.e. it utilizes work in the form of acoustic power to absorb heat from a low temperature medium and reject it to a high temperature medium.

4. THERMOACOUSTIC EFFECT

Acoustic waves experience displacement oscillations, and temperature oscillations in association with the pressure variations. In order to produce thermoacoustic effect these oscillations in the gas should occur close to a solid surface so that heat can be transferred to or from the surface. A stack of closely spaced parallel plates is placed inside the thermoacoustic device in order to provide such a solid surface. The thermoacoustic phenomenon occurs by the interaction of the gas particles and the stack plate. When large temperature gradients are created across the stack, sound waves are generated i.e. work is produced in the form of acoustic power (forming a thermoacoustic engine). In the reverse case, the acoustic work is used in order to create temperature gradients across the stack, which is used to transfer heat from a low temperature medium to a high temperature medium (as the case of thermoacoustic refrigerator). A thermoacoustic refrigerator consists of a tube filled with a gas.

This tube is closed at one end and an oscillating device (a loud speaker) is placed at the other end to create an acoustic standing wave inside the tube. Standing waves are natural phenomena exhibited by sound waves. In a closed tube, columns of air demonstrate these patterns as sound waves reflect back on themselves after colliding with the end of the tube. When the incident and reflected waves overlap, they interfere constructively, producing a single waveform. This wave cause the medium to vibrate in isolated sections as the travelling waves are masked by the interference.

Therefore these standing waves seem to vibrate in constant position and orientation around stationary nodes. These nodes are located where the two component sound waves interfere to create areas of zero net displacement. The areas of maximum net displacement are located halfway between two nodes and are called antinodes. The maximum compression of the air also occurs at the antinodes. Due to these node and antinodes properties, standing waves are useful because only a small input of power is needed to create a large amplitude wave to cause thermoacoustic effect.

5. BASIC CONSIDERATIONS

5.1 THERMODYNAMIC CONSIDERATION

A thermoacoustic device consists of an acoustic driver attached to an acoustic resonator tube filled with the working fluid. Inside the resonator tube, a stack of thin parallel plates and two heat exchangers (hot and cold) are installed for the heat transfer. The schematic of a typical thermoacoustic device is shown in fig.

The acoustic driver, connected to one end of the resonator tube, excites the working fluid and creates a standing wave inside the tube. Hence the gas oscillates inside the resonator with expansions and compressions. The length of the resonator tube is typically set equal to one-half of the wavelength of the standing wave, i.e. The standing wave creates velocity nodes at the two ends of the tube and a pressure node at the middle of the tube as in the fig. if a stack of parallel plates is placed inside the tube, the gas will be at a higher pressure at the end of the stack, which is closer to the end of the tube(i.e. left side of the stack in fig), than the other end of the stack. This high pressure results in an increase in the temperature of the gas and the excess heat is transferred to the stack, causing an increase in the temperature of the stack at that end and an average longitudinal temperature gradient along the stack is established.

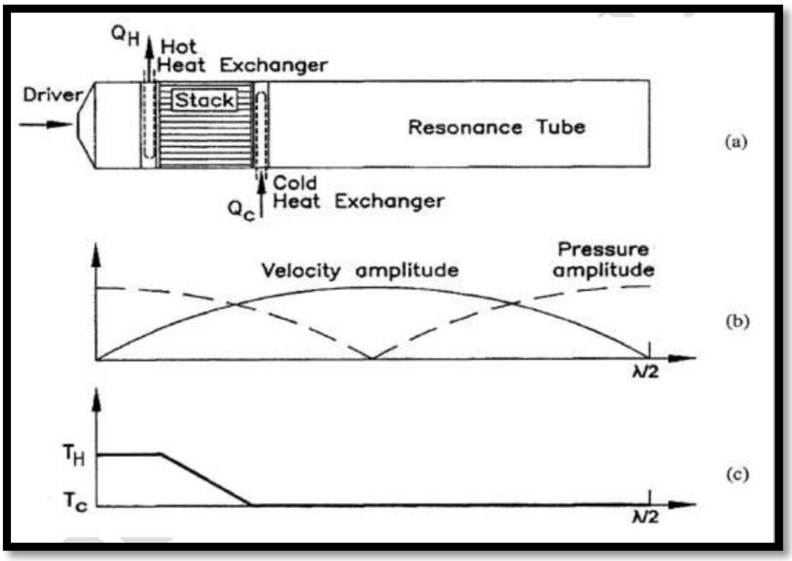

Fig.5.1. (a) Schematic of a thermoacoustic refrigerator,(b)velocity and pressure variation across the resonance tube, (c)temperature variation across the resonance tube

5.2 ACOUSTIC THEORY

The understanding of acoustic wave dynamics, i.e. the pressure and velocity fields created by an acoustic wave, is necessary to understand the working of a thermoacoustic device. The acoustical theory deals with the study of the longitudinal acoustic waves. The longitudinal acoustic waves are generated as a result of the compression, and expansion of the gas medium. The compression of a gas corresponds to the crust of a sine wave, and the expansion corresponds to the trough of a sine wave. An example of how these two relate to each other is shown in the figure. In a longitudinal wave, the particle displacement is parallel to the direction of wave propagation i.e. they simply oscillate back and forth about their respective equilibrium position. The compression and expansion of a longitudinal wave result in the variation of pressure along its longitudinal axis of oscillation. A longitudinal wave requires a material medium such as air or water to travel. That is, they cannot be generated and/or transmitted in a vacuum. All sound (acoustic) waves are longitudinal waves and therefore, hold all the properties of the longitudinal waves discussed above. Three characteristics of the acoustic waves are necessary for the understanding of the thermoacoustic process. These properties are amplitude, frequency and wavelength.

The displacement of a wave from its equilibrium position is called the wave amplitude. It is also a measure of the wave energy. Larger the amplitude, higher will be the wave energy. Thus, the energy of an acoustic wave can be estimated by measuring its amplitude. The energy or intensity of an acoustic wave is measured in terms of decibel. If the given acoustic wave is comprised of the superposition of different sine waves, then the amplitude and hence the energy of the given wave can be estimated by integrating the energy in all the frequency components of the given wave. The time period of a wave is the time required for the complete passage of a wave at a given point. The fundamental wave frequency is the inverse of the time period. In other words, it is the number of waves that pass a given point in a unit time.

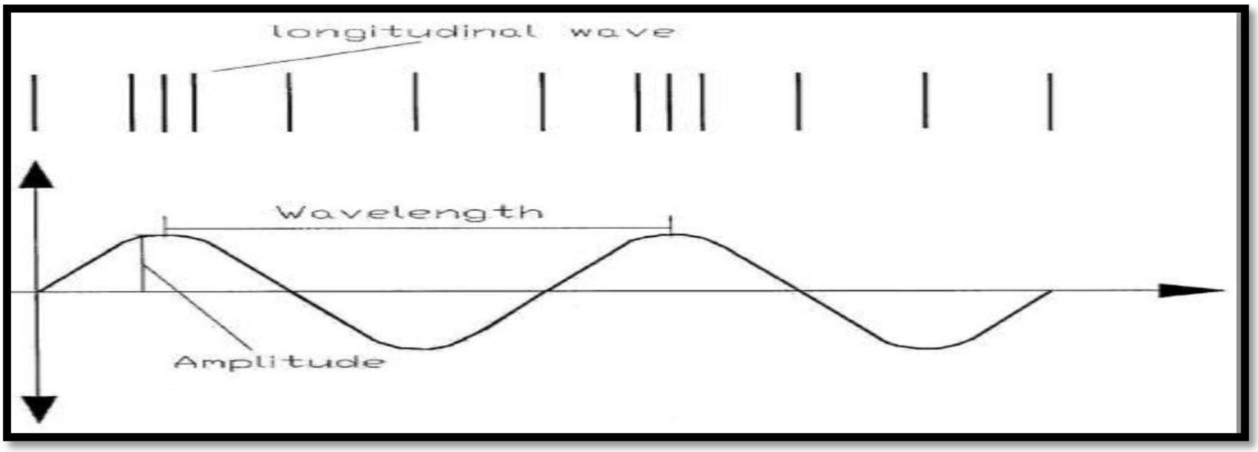

Fig5.2. Comparison of a longitudinal acoustic wave with a sine wave

It is measured in hertz (Hz), i.e. the number of waves that pass a given point in one second. The wavelength is defined as the horizontal distance from the beginning of the wave to the end of the wave. It can also be measured as the distance from one wave crest to the next wave crust, or one wave trough to the next wave trough. In acoustics, we can define wavelength as the distance between the two successive compressions or expansions. The compression and expansion of an acoustic wave result in pressure variations along the waveform. This pressure variation is the key process that causes the thermoacoustic phenomenon. These pressure variations can also be used to estimate the sound intensity. From the ideal gas equation of state,

$P/\mathbf{p} = RT$

Where P is the pressure, **p** is the density, T is the absolute temperature, and R is the universal gas constant. The above equation indicates that if the density variations are very small, the change in pressure causes a change in temperature. That is, an increase in pressure causes an increase in temperature and vice versa.

6. BASIC COMPONENTS

A thermoacoustic refrigeration system generally consists of:-

1. Acoustic driver
2. Stack
3. Heat exchanger
4. Resonator

6.1 ACOUSTIC DRIVER

A thermoacoustic cooling device requires an acoustic driver attached to one end of the resonator, in order to create an acoustic standing wave in the gas at the fundamental resonant frequency of the resonator. The acoustic driver converts electric power to the acoustic power. The loudspeaker is driven by a function generator and a power amplifier to provide the required power to excite the working fluid inside the resonator.

Fig. 6.1. Acoustic Driver

6.2. STACK

The most important component of a thermoacoustic device is the stack inside which, the thermoacoustic phenomenon occurs. Thus, the characteristics of the stack have a significant impact on the performance of the thermoacoustic device. The stack material should have good heat capacity but low thermal conductivity. The low thermal conductivity for the stack material is necessary to obtain high temperature gradient across the stack and a heat capacity larger than the heat capacity of the working fluid.

In addition, the stack material should minimize the effects of viscous dissipation of the acoustic power. The stack is made from Mylar sheet. The spacing between the layers is filled by fishing line spacers glued onto the surface of the sheet.

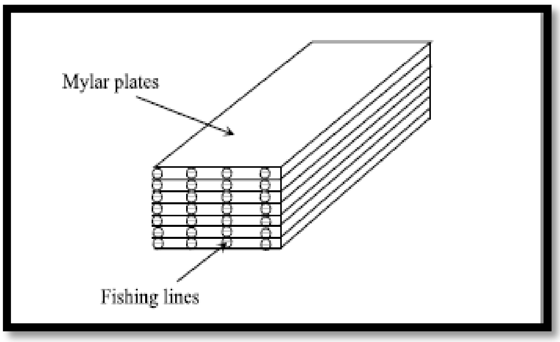

Fig.6.2.1. Parallel Stack

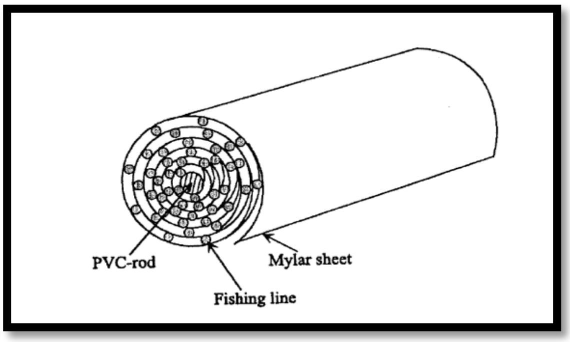

Fig.6.2.2. Spiral Stack

6.3 HEAT EXCHANGER

The heat exchangers employed in a thermoacoustic refrigerator influence the acoustic field created in the resonator. There are many design constraints such as porosity of the heat exchanger and high heat transfer coefficient for efficiency. Due to these constraints, special kinds of heat exchangers are used. One typical micro channel copper heat exchanger is shown below.

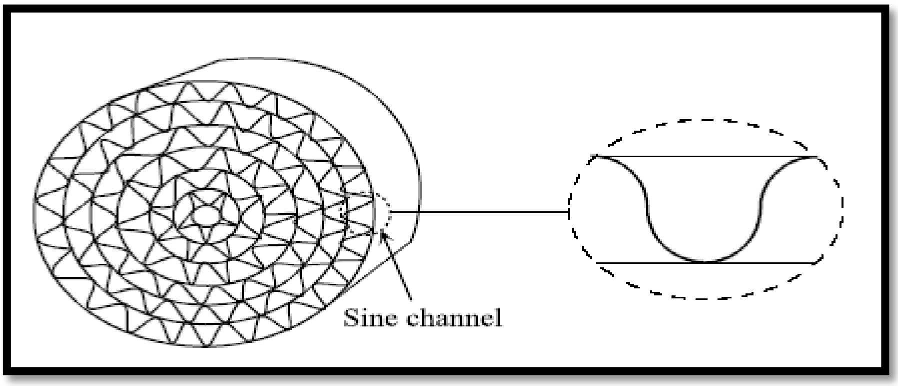

Fig.6.3. Heat Exchanger

This type of heat exchanger is made us from thin copper sheets. This type of heat exchanger is used as the hot and cold heat exchangers differ only in length. The heat exchangers have a sine channel structure which is chosen because of ease of construction. Two copper sheets are spirally wound together to provide this geometry. One sheet is flat and the other sheet has a sine shape, as shown in Fig. 6.3.1. The sine shape is achieved by passing a flat sheet between toothed wheel systems.

6.4 RESONATOR

This part of refrigerator which is only there for maintaining the acoustic wave. Resonator is nothing but a hallow tube which is heat insulated. The acoustic resonator is built from acrylic. One end of the tube has a plate attached to install the speaker frame. At the other end, it is sealed with a lid made up of aluminium or other material which reflects the sound waves.

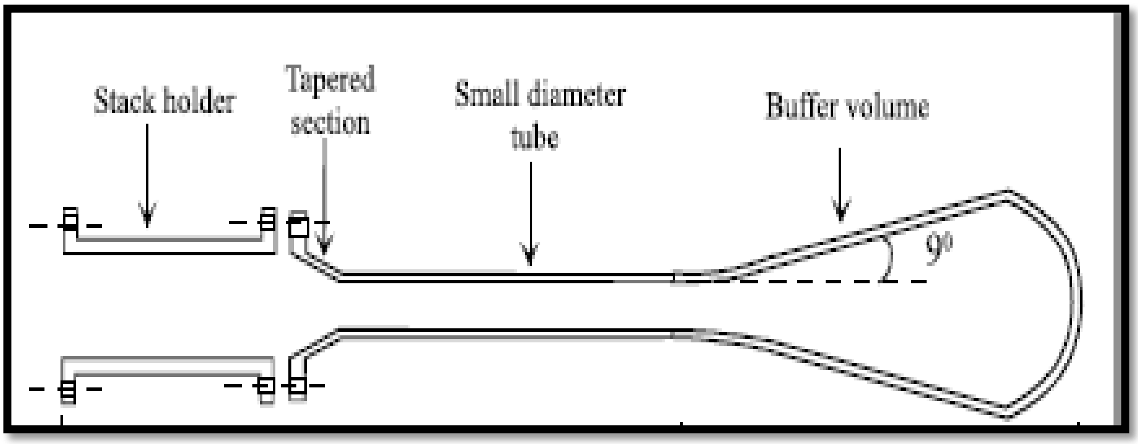

Fig.6.4. Resonator

7. CONSTRUCTION AND WORKING

Thermoacoustic Refrigeration System mainly consist of a loudspeaker attached to an acoustic resonator (tube) filled with a gas. In the resonator, a stack consisting of a number of parallel plates and two heat exchangers are installed. The loudspeaker, which acts as the driver, sustains acoustic standing waves in the gas at the fundamental resonance frequency of the resonator. The acoustic standing wave displaces the gas in the channels of the stack while compressing and expanding respectively leading to heating and cooling of the gas. The gas, which is cooled due to expansion absorbs heat from the cold side of the stack and as it subsequently heats up due to compression while moving to the hot side, rejects the heat to the stack.

Thus the thermal interaction between the oscillating gas and the surface of the stack generates an acoustic heat pumping action from the cold side to the hot side. The heat exchangers exchange heat with the surroundings, at the cold and hot sides of the stack.

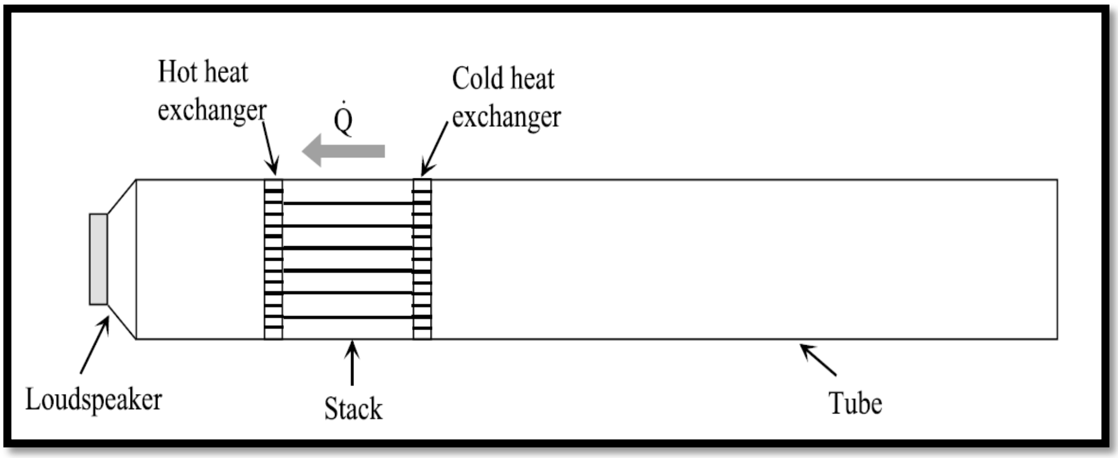

Fig. 7.1 Schematic representation of construction of thermoacoustic refrigerator.

Fig. 7.1 shows the schematic representation of the construction of thermoacoustic refrigerator where the loudspeaker is used as a driver, the resonance tube sustains the standing wave.

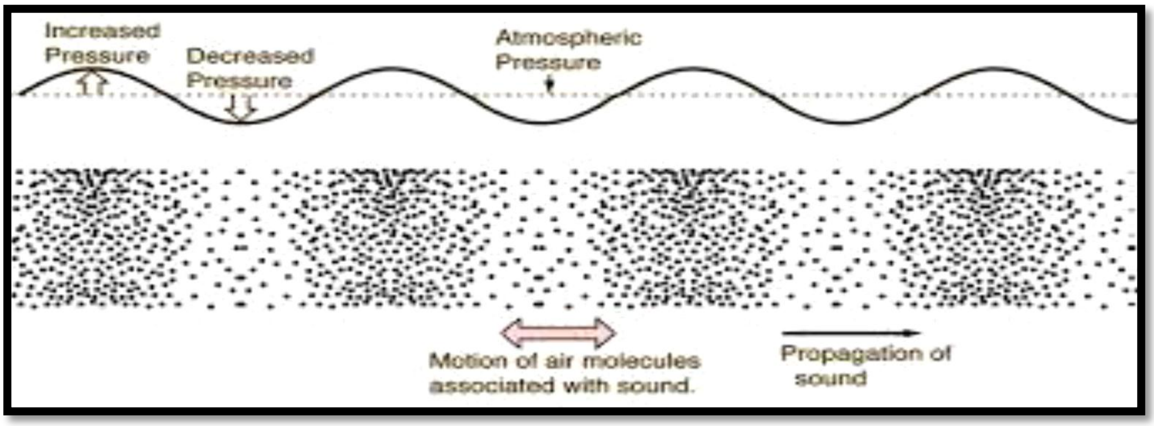

Fig.7.2 Pressure variation and displacement of sound waves.

The heat exchangers are used so that heat interaction with the surrounding takes place. Heat is pumped from the cold end heat exchanger to the hot end heat exchanger. Fig.7.2 shows the pressure variation and displacement of sound waves in thermoacoustic refrigeration system. It is known that sound waves are longitudinal waves. They produce compression and rarefaction in the medium they travel. Maximum pressure occurs at the point of zero velocity and minimum pressure at maximum velocity.

8. COMPARISON OF THERMOACOUSTIC REFRIGERATION OTHER REFRIGERATION SYSTEMS

Apart from vapor compression devices, there are several other ways to provide cooling and refrigeration. Although none of these are currently as versatile as a Vapor Compression Systems but some of these systems hold a high possibility of replacing the pollution causing Vapor Compression Systems. Comparison with various systems is as Follows.

A. Type of Refrigerant:-

The Absorption Refrigeration uses a binary mixture of refrigerant and absorbent like Water/ammonia or LiBr / water. The Absorption system uses natural refrigerants like water, ammonia or alcohol. Thermo-electric and Thermoacoustic Refrigeration Systems do not use any refrigerant.

B. Working Cycle:-

Vapor Absorption Refrigeration is a two stage process. The vapor refrigerant is absorbed in a binary solution which then regenerates the refrigerant on heating externally. It is cooled in the condenser to the required pressure level and the cycle repeats. Much like the Vapor Compression Refrigeration Systems the Absorption Systems are also based on Withdrawing heat from surroundings during an evaporation process. Thermo-electric System is based on the Peltier Effect wherein an electric current passing through a junction of two materials will cause a change in temperature. The Thermoacoustic Refrigeration System is powered by either a heat engine running on waste heat or an electric source. Due to compression and expansion of air packets heat transfer across two mediums is made possible.

9. ADVANTAGES

1) Inert working fluid. Helium, being an inert gas, cannot participate in chemical reactions and hence no toxicity, flammability, or negative environmental effects.

2) No sliding seals or lubrication. Due to the high frequency operation, high powers can be achieved with small displacements so no sliding seals or gas bearings are required. This also means that no "tight tolerance" machined parts are required thereby reducing manufacturing costs.

3) Very few simple components. Electrically driven systems require only one moving part and thermally driven systems have no moving parts. The "stack" can be fabricated from cheap plastics.

4) Large range of working temperatures. Depending upon the position and length of the stack in the acoustic standing wave field, one can trade off the temperature span and the heat pumping power. Different working fluids are therefore not required for different temperature ranges.

5) Easy to control. - Just as one is able to control the volume of a stereo system.

6) Noise less technology:- All the process happens in the sealed resonator so there is no noise outside the resonator.

7) Low Energy Consumption.

8) Long Life:- Because of no moving part, life of the system is long.

10. DISADVANTAGES

1) **Low Efficiency:-** The downside of the TAR is that these failed to achieve efficiencies as high as those of standard refrigerator units.
2) **Low COP:-** The coefficient of performance of most advanced TAR is only 1 when compared to 3-4 of modern refrigerators.
3) **Short term cooling effect:**-These refrigerators were able to cool the air for a short amount of time before the cooled air started raising its temperature.

11. APPLICATIONS

1] Existing

A} NASA: - Preserve blood and urine sample.
B} U.S. Navy: - cool radar electronic onboard warships.

2] Potential

A} Marine Vehicles: - Replace Noisy Generator
B} Satellite Sensors
C} Super-Fast Computers

12. CONCLUSION

The Thermoacoustic Refrigeration system uses acoustic driver which is electrical part instead of compressor which have no maintenance or very low maintenance. The Thermoacoustic 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 on the environment like other refrigerants which depletes the ozone layer. The main motivation for presenting this topic to take attention of people towards the eco-friendly refrigeration system.

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