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Thermoacoustic Heat Extraction System-A Review

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Abstract- In the past few decades, refrigeration systems have gained immense importance. In today's world, it is nearly impossible to think of surviving without refrigeration. Currently, vapour compression system is made use of. The refrigerants utilized in this system affect the environment adversely. Due to this, there is a need to develop alternative refrigeration systems. Thermoacoustic refrigeration is one system of this kind. Thermoacoustic system is a clean energy technology. Thermo acoustics is a branch that deals with the transformation of sound energy into heat energy or vice versa. The literature survey helps to have a look at the history of thermoacoustics and the work carried out in this field. The thermoacoustic refrigeration system utilizes sound waves or sound energy which further causes the transfer of heat by introducing a temperature gradient and thus results in a refrigeration effect. It primarily relies on the pressure and temperature oscillations that are caused by the sound waves on the gas stored in the cylinder arrangement of the system.

Index Terms- Clean technology; Sound waves; Refrigeration effect.

1. INTRODUCTION

Thermo acoustics is a combination of thermal engineering and acoustics. It is a comparably new area of study in physics in which there is a combined study of thermodynamics, fluid dynamics along with acoustics. Thermo acoustics is a term usually used to illustrate the effect resulting from sound waves creating a temperature gradient. Theory of thermoacoustic as known today was first brought forward by Rott and later reviewed by Swift. Rott adopted the Navier Stoke's equation and mass continuity equation to make them effective in thermo acoustic devices. Acoustics is related to the production of sound, properties of sound, sound transmission and the effect of sound transfer. Thermodynamics deals with the study of heat and temperature and their effect on a system.

1.1. *Problem description*

The refrigerators currently in use are making use of Vapour Compression and Vapour Absorption System. Traditional refrigerators make use of Ozone Depleting Substances (ODS) like Chlorofluorocarbons (CFCs) and Hydro fluorocarbons (HFCs) which serve as refrigerants. These contents in the refrigerants prove harmful for the environment. Thus, there is an urge to develop and opt for an alternative method of refrigeration.

1.2 *Basics of refrigeration*

The process of refrigeration means cooling the space or maintaining the temperature of a substance below the ambient temperature. Refrigerators prove advantageous for preserving foods, maintaining things cold that are supposed to be kept cold. Thus, Refrigerators imply applications in almost every field. For the purpose of pumping of heat the heat is transferred from a low temperature body to a high temperature body with the assistance of external work. Fig. 1 illustrates the operating principle of a refrigerator.

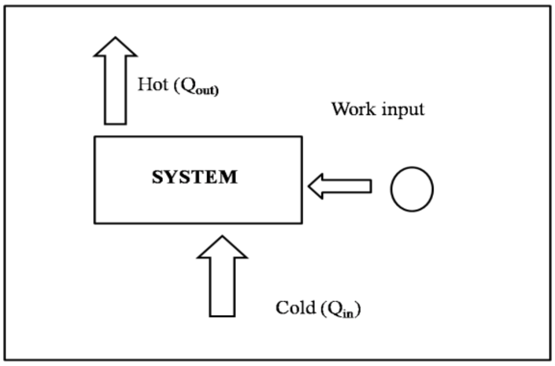

Fig.1 operating principle of refrigerator

1.3 *Thermoacoustic refrigeration*

To prevail over the problem of contribution of refrigerants in the depletion of ozone layer, an alternative method or system is required to carry out refrigeration. One of the alternatives is 'Thermoacoustic refrigerator'. Thermoacoustic refrigeration relies on the compression and expansion properties of sound waves and gas so as to attain the refrigeration effect. Different from conventional refrigeration system that is the vapour compression system this system does not make use of any harmful refrigerant. Instead, it uses the energy of the sound to generate oscillations required to compress and expand the working fluid. The work required for the refrigeration effect to take place is provided by the sound waves. Thermoacoustic refrigerator involves the transfer of heat energy from a body at lower temperature to a body at a higher temperature with the help of external work in the form of sound waves. Fig. 2 shows the operating principle of a thermoacoustic refrigerator.

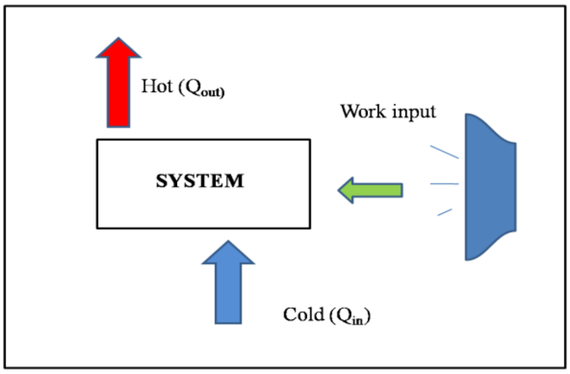

Fig. 2 operating principle of thermoacoustic refrigerator

2. LITERATURE REVIEW

Garette (1993) et. al. discussed that thermoacoustic refrigeration cycle was irreversible. They concluded that the curves for efficiency and heat pumping capacity were very steep.

Tijani (2002) et. al. described the main parts in thermoacoustic refrigeration namely vacuum cylinder, electronic apparatus and acquired the experimentation data. They also suggested designing thermoacoustic refrigeration system based on thermoacoustic theory.

Florian Zink (2010) et. al. studied the environmental motivation to opt for thermoacoustic refrigeration. They discussed about the various areas for applications of thermoacoustic refrigeration systems. In this paper their conclusion was that TAR's can reduce the global warming of refrigeration to a higher extent.

Bheemsha (2011) et. al. discussed the design modifications that could be made in resonator tube and the stack in order to enhance the efficiency of the TAR. They made use of various design softwares to design these parts. They solved the problem of turbulence occuring in the thermoacoustic refrigeration system by modifying the resonator design.

P.R.Ingole (2013) et. al. presented a complete review on thermoacoustic refrigeration system. They studied the various developments made in this area. They concluded that Thermoacoustic refrigeration can prove beneficial when applied in industrial fields.

Jinshah B. S. (2013) et. al. carried out a study on a standing wave thermoacoustic refrigerator made of readily available materials. They designed the entire system and fabricated it with readily available materials. They suggested the use of different materials and modification in the stack design in order to improve the coefficient of performance.

Jaydeep M. Bhatt (2013) et. al. Investigated a thermoacoustic refrigerator using a standing wave device. This paper involves a basic explanation of the thermoacoustic system and analysis of thermoacoustic refrigeration systems. This paper helps in the determination of practical applications where thermoacoustic refrigerators can prove to be a strong a strong rival for the conventional refrigeration methods.

Pranav Mahamuni (2015) et. al. discussed the effect of various parameters such as frequencies, stack position, mean pressures generated on the temperature gradient developed in the stack region. They carried out a case study on the system in order to identify the effect of the above mentioned characteristics on the performance of the thermoacoustic refrigerators. This paper concludes that the cooling power of the thermoacoustic refrigerator depends upon the developed load, working frequency and the pressures.

Research in this area has made it evident that these refrigerators can be as efficient as Vapour absorption and Vapour compression refrigeration technology, in a few situations. Competitive efficiencies for the refrigeration market, industrial applications are offered by the thermoacoustic refrigerators. Some external loop connecting the cold end to the space that is to be refrigerated is required to be added. Also a loop connecting the hot end to the environment is necessary to be added. These loops will add additional losses to the system.

3. THERMOACOUSTIC REFRIGERATION SYSTEM

3.1 *Construction of Thermoacoustic Refrigeration system:*

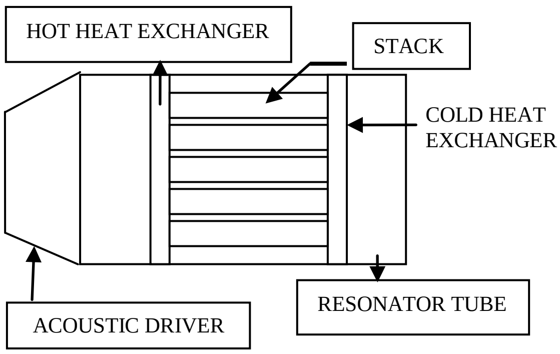

Fig. 3 Construction of thermoacoustic refrigeration system

Fig. 3 shows the construction of the thermoacoustic refrigeration system. The components of a thermoacoustic refrigerator are acoustic driver (loudspeaker), resonator tube, stack, working gas, heat exchangers.

3.1.1. *Acoustic driver:*
The sound waves that are necessary for refrigeration to occur are generated by the loudspeaker. The acoustic driver converts electric power to acoustic power. The driver is connected to a function generator so as to produce a sinusoidal waveform. Large amount of this acoustic power from this driver is utilized for the purpose of pumping of heat. The acoustic driver is utilized in order to give rise to an acoustic standing wave of a particular resonant frequency of the resonator tube. This driver usually is a moving coil type loud speaker. Fig. 4 shows the components of the moving coil type acoustic driver.
Working of an acoustic driver

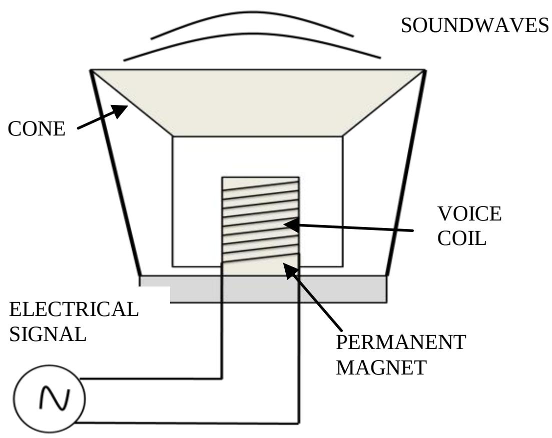

Fig. 4 Construction of acoustic driver

The electric signal is passed to the voice coil through electrical wires. The current induces a magnetic field that causes the diaphragm (cone) to be alternately forced. The resulting back and forth motion moves the air in the vicinity of the diaphragm, producing pressure differentials that further move away as soundwaves.

3.1.2. *Stack*
Stack is the vital component in the thermoacoustic refrigeration because it is the place where the temperature gradient is set up. Therefore, the dimensional characteristics and the properties of the stack play a crucial role in finding the performance of the thermoacoustic refrigeration system.
The stack must be made out of a material having high heat capacity and low thermal conductivity so that it does not interfere in the temperature gradient generation. The stack material should also reduce the effects of viscous dissipation of the sound power. Generally, the material used is Mylar whose thermal conductivity is 0.16 w/mk and heat capacity is 1.25KJ/KgK. Other materials that can be used are: Paper, Aluminium, and Foam.
The stacks are of different shapes namely; spiral, parallel, honeycomb stack.
In case of spiral stacks if the holes are not broad enough, it will be a tedious job to fabricate and the viscous properties of air lead to improper transmission of sound through the stack.
In case of parallel stack, the space present between the adjacent layers of the stack must be appropriate so that there is no interference of these layers in the thermal penetration depth of one another. Fig. 5 shows the parallel type of stack.

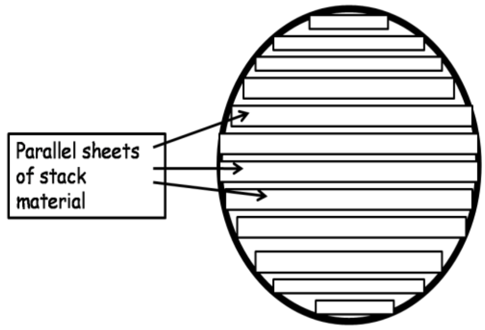

Fig. 5 Parallel stack

3.1.3. *Resonator tube*
It is a long hollow tube which houses the working gas as well as the stack within itself. The resonator tube must be compact, light in weight and should be strong enough to sustain the working pressures.
The length of the resonator tube depends on the resonance frequency. Also, it must not lead to minimal losses at the wall of the resonator. The length of the resonator tube is generally kept ¼ of the wavelength of the sound wave.
The shape, material and the length of a resonator tube is very important in improving the efficiency of the thermoacoustic refrigeration system. Generally the material used is acrylic.

3.1.4. *Heat Exchanger*
Heat exchangers are necessary to transfer the heat that is generated due to the thermoacoustic effect. They play an important role in keeping up the temperature gradient across the stack. The hot heat exchanger gives away the heat to the environment and the cold heat exchanger extracts the heat from the system to be cooled. The coefficient of heat transfer should be high so that it provides efficient heat transfer. The cold heat exchanger and the stack must have same porosity so as to avoid losses. Generally Parallel plate type copper heat exchangers having a porosity of 0.4 can be made use of for analysis purpose. The porosity of the cold heat exchanger is to be kept high nearly up to 0.6.

3.1.5. *Working fluid*
The performance of the thermoacoustic refrigerator is highly influenced by the properties of the working gas. Generally, gases with a low Prandtl number and

having a high ratio of specific heat are considered for thermoacoustic refrigeration so as to reduce the viscous losses. To attain higher efficiencies inert gases like helium, xenon, etc. are to be used. The kinematic viscocity of these gases is low as compared to other gases thus resulting in free vibrations even in a small space and participate in heat transfer process. Inert gases have certain drawbacks which namely are the cost, leakages, refilling. Hence, highly pressurized air can be used as a working medium.

3.2 *Working of Thermoacoustic Refrigeration system*

Thermoacoustic refrigerator uses the Thermoacoustic phenomenon. The thermodynamic principles used are: Temperature of fluid rises with increase in pressure. Fig.3 illustrates the above mentioned principle.

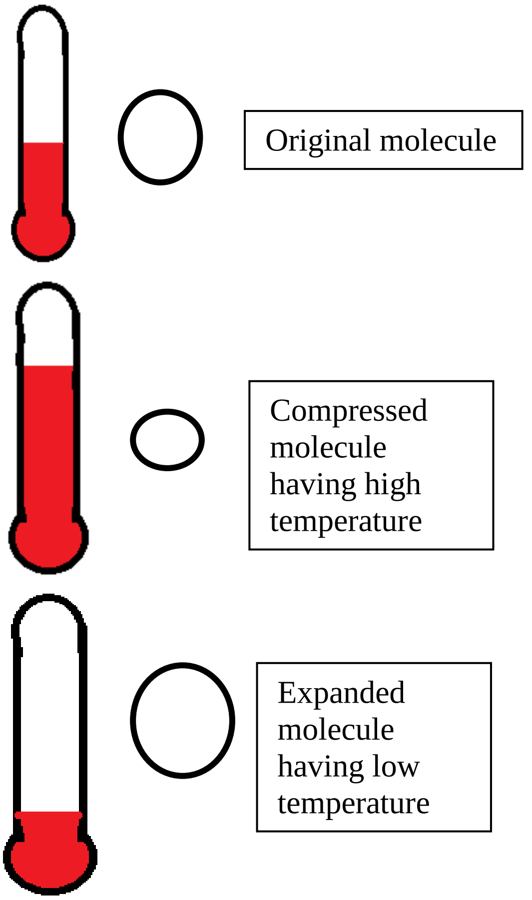

Fig. 3 Variation of temperature with pressure

The second phenomenon is that heat always moves from a higher temperature region to a lower temperature region.

The acoustic phenomenons used are: Sound waves travel through a medium via collision of the molecules of the medium. Constructive interference results in the compression of the medium and destructive interference causes the expansion of the medium. Fig. 4 shows the compression and rarefaction of a sound wave.

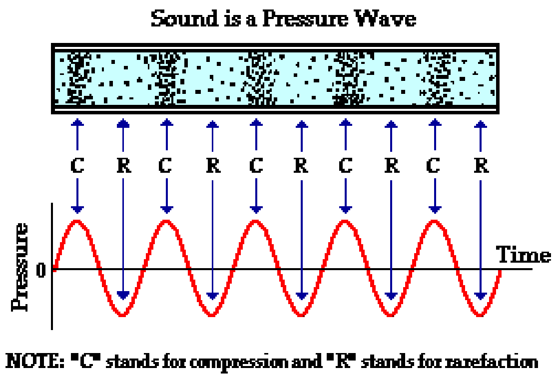

Fig. 4 Compression and rarefaction of sound wave.

The working of the system is as follows: The acoustic driver generates a sound wave having a suitable frequency. This sound wave travels up to the closed end, and then it is reflected back by the surface. This reflected wave interferes with the waves generated by the driver. Thus, leading to expansion and compression of the gas molecules. Due to this, there is continuous oscillation of the molecules in the region of the stack. After a certain time one side of the stack becomes hot and the other becomes cold as a result of this temperature gradient is set up.

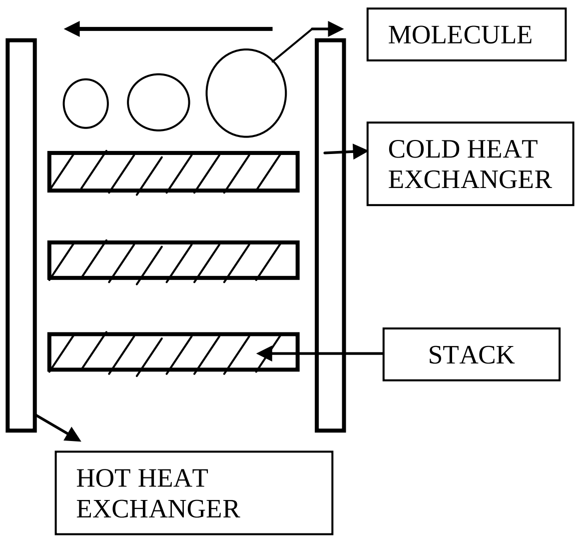

Fig. 5 Movement of the molecules

Fig. 5 shows the movement of a gas molecule in the stack region. As the gas molecule moves towards the hot side its temperature rises due to compression and at the extreme end the temperature of the molecule rises above the temperature of the heat exchanger thus leading to the liberation of heat to the exchanger.

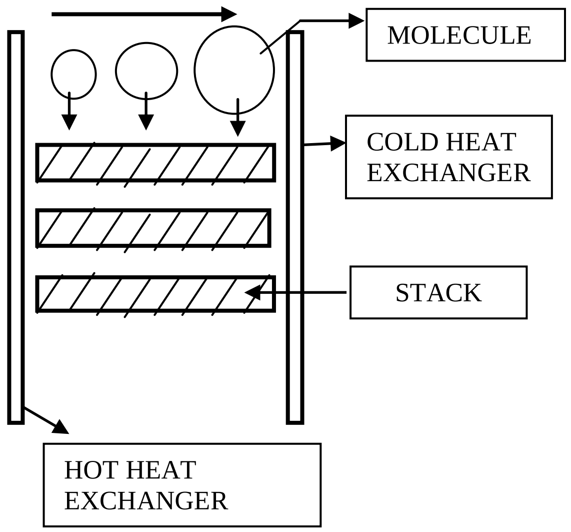

Fig.6 Molecules liberating heat to the stack and moving towards cold heat exchanger.

Fig. 6 shows the movement of molecules towards the cold side. When moving towards the cold side the molecule liberates heat to the stack surface by virtue of sound waves and thus starts expanding. At a instance the temperature of the molecules fall below the cold heat exchanger, due to which heat tranfer takes place from cold heat exchanger to gas molecule. Thus the refrigeration effect is achieved.

3.3 *Merits and demerits of the system*

3.3.1. *Merits*

- The working fluid is typically helium or other inert, benign gases such as air which are environment-friendly unlike common refrigerants.
- Simple in design, robust.
- It is light in weight.
- It has almost no moving parts, which further leads to a longer working life with fewer repairs. In turn, this makes the system less expensive.

3.3.2. *Demerits*

- Thermoacoustic Refrigeration system cannot achieve higher efficiencies.
- As compared to conventional refrigerators, the coefficient of performance of most advanced thermoacoustic refrigerator is only 1.
- It leaks a considerable amount of sound that causes ear pain but in return produces only a small temperature gradient.
- Lack of producers producing customized components.

4. FUTURE SCOPE

- In order to improve the efficiency of the existing systems, insulate the leakage of sound by isolating the system.
- Replace the closed end with a speaker so as to increase the efficiency by co-generation.
- The resonator can be widened so as to reduce the losses due to rapid area change.
- The composition of stack material may also be changed.

5. CONCLUSION

The thermoacoustic refrigeration systems are a good alternative for the conventional refrigeration systems presently in use. The efficiency of the Thermoacoustic refrigeration system can be improved by changing the governing factors like, position of stack, working medium, shape and size of the stack. Cooling power is dependent on the working frequencies. The thermoacoustic refrigeration system has less number of moving parts thus its maintenance cost is low. It does not make use of any harmful refrigerants thus has no adverse effects on the environment.

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