Loud Speaker Driven Thermo Acoustic Refrigeration

Jithin George

Abstract— Thermo Acoustic refrigeration is a phenomenon in which sound waves having high intensity is utilized in order to produce a cooling effect. This cooling effect is produced with the help of heat transfer from one point to other with the help of sound waves. These sound waves are send inside a pressurized gas tube. The energy consumption is very less and cost of construction is low when compared to conventional methods. One of the most important advantage of thermo acoustic refrigerator is that it does not requires any refrigerants. The working fluid used in thermo acoustic refrigerator is air. We can also operate it with the help of Inert gases. Thermo Acoustic refrigerator does not requires any moving parts. In this paper we are dealing with the working and construction of a Loud Speaker Driven Thermo Acoustic Refrigerator.

Index Terms— C.F.C (Chloro fluoro carbon), H.F.C (Hydro fluoro carbon), Heat engine, Heat pump, Longitudinal temperature gradient, Pressure wave, Standing wave.

1 Introduction

Refrigerators have an important role in almost all states of life. All conventional refrigerators works based on a vapor compression cycle. In a vapor compression cycle, an interaction between vapor and a refrigerant is involved. The most commonly used refrigerants are Chloro fluoro Carbons (C.F.C) and Hydro fluoro Carbons (H.F.C). The main disadvantages of using Chloro fluoro Carbons and Hydro fluoro Carbons are, they are toxic chemicals and it results in the depletion of ozone layer. From this it is clear that this is the main problem of using conventional refrigerants. In this context there comes the importance of Thermo Acoustic refrigerators.

Scientists and Engineers have been working on refrigerators that does not requires any moving parts, refrigerants and lubricants. Then they introduced the process of thermo acoustic refrigeration. In thermo acoustic refrigerators, refrigeration takes place with the help of sound waves. Sound waves are introduced with the help of loudspeaker. This sound waves reverberates inside an acrylic tube and as a result a temperature difference is created. This temperature difference is converted into mechanical energy. Thermo acoustic refrigerators can replace piston, rotating units used in a conventional refrigerator.

Sound waves consists of combined pressure and displacement oscillations in a gas. It also consists of temperature oscillations. These temperature oscillations are produced because of the pressure variations occurring in the working medium. The pressure oscillations and displacement oscillations interacts together and as a result the temperature oscillations are generated. The temperature oscillations are generated in a gas close to the solid surface. That is the temperature oscillations are generated near the walls of the acrylic tube through which the sound waves propagates.

Because of these oscillations a temperature difference is created. Because of this temperature difference a heat transfer takes place between the hot and cold ends.

There are various parameters that effect the working of a thermo acoustic refrigerator. They are length of the tube, spacing between parallel plates in stack and the Prandtl number. These parameters are also considered in this paper. The working principle of thermo acoustic refrigeration is based on the fact that sound waves are pressure waves. In loud speaker driven thermo acoustic refrigeration the propagation of sound waves takes place through air. The propagation of sound waves takes place by molecular collisions. Because of these collisions a disturbance is created in the air. These disturbances results in constructive and destructive interference. Constructive interferences results in the formation of high pressure molecules. These molecules are of compressive in nature. Destructive interference results in the formation of low pressure molecules. These molecules are of expansive in nature and these molecules expands near the surface. This property of sound waves is the basis of thermo acoustic refrigeration.

2 Experimental Setup

The construction of thermo acoustic refrigerator is comparatively simple, when compared to conventional refrigerators. Thermo acoustic refrigerators consists of an acoustic driver, an amplifier, acrylic tube, stack and a heat exchanger. These are the important components of a loud speaker driven thermo acoustic refrigerator. Here loud speaker is used as the acoustic driver. Loud speaker is placed inside an acrylic box. The top of the acrylic box is constructed in such a way that there is a Housing for the installation of acrylic tube. Acrylic tube of a certain length is connected to the housing in the box. The acrylic tube may be empty or it may be filled with inert gases based on the working fluid used. There is a stack inside the acrylic tube which is used for the compression and expansion of pressure waves passing through it. A heat exchanger is also placed for improving the heat transfer rate.

- *Jithin George is currently pursuing masters degree program in Thermal Engineering in Excel Engineering College,Anna University, PH-+91-8129456795. E-mail: jithinukran@gmail.com*

Acoustic driver is used for the generation of acoustic waves in the resonator. The important part of the acoustic driver is a moving coil loud speaker. The driver is selected based on certain requirements. These requirements includes compactness, power, light weight and low amount of losses. Certain modifications are done at the loud speaker in order to meet certain requirements. Loudspeaker was placed inside the acrylic box. For this we machined an acrylic box of size 8*12 inches and at the center of box we made a hole of 32 mm diameter. Then selected a loud speaker of 6 inch size having an impedance of 4Ω and a power of 5W. With the help of MI bolts, loud speaker is the bolted to the acrylic box. Another important component of the thermo acoustic refrigerator is a resonator tube. The resonator tube is made up of acrylic material. Here we uses an acrylic tube of 32 mm diameter. This tube is connected to the hole at the top of the acrylic box. The resonator consists of a tube in which a stack and heat exchanger is placed. The acrylic tube has very low thermal conductivity. So an aluminum plug is used as a heat exchanger. Then the tube is glued into the acrylic box. In order to seal the connection silicon caulk was used.

The heart of the refrigerator is known as stack. Mylar material is used for the construction of stack. Mylar sheet is wound around a PVC rod in order to get a spiral shape. Between the gaps, fishing line spacers of 0.38 mm diameter is placed. The thickness of the sheet is 0.06 mm. The length of the sheet is 7 cm. Heat exchanger used in thermo acoustic refrigerator is aluminium plug. Heat exchanger is used for the transfer of heat from a region of high temperature to a region of lower temperature. For improving the heat transfer rate, circular fins are placed around the aluminium plug. This results in a high temperature reduction at the hot side. If the heat transfer rate is reduced heat flows towards the cold side and as a result, temperature at the cold side increase. When the temperature of the cold side increases, the effectiveness of the refrigerator is reduced. Using the aluminium plug, the temperature at the hot side is reduced to a minimum value of 42˚C.

In a thermo acoustic refrigerator an amplifier is used. Amplifier is used in order to increase the power of the signal. Here we are using a power amplifier. Power amplifiers are classified into audio power amplifier and RF power amplifier. An audio power amplifier amplifies the low-power audio signals. In this experiment we uses a computer for controlling the working. It is known as control unit. A special software named NTC tone generator is used for producing sounds of different frequencies. These frequencies are find out from the differential length of the resonator.

3 METHODOLOGY

In a thermo acoustic refrigerator, sound waves oscillates in an acrylic tube and as a result heat transfer takes place. Sound waves oscillates a specific amount of time in a second and it is known as wave frequency. Wave frequency is measured in Hertz. The length of the tube is determined by knowing the frequency of the wave. The frequency of the wave is given by,

$$F=V/4\,L \qquad (1)$$

Where F is the frequency of the wave, V is the velocity of the wave and L is the length of the tube. From (1) the length of the tube is determined. It is given as

$$L= V/4F \qquad (2)$$

The length, L is determined by knowing the velocity, V and Frequency, F. Consider the working operation of a heat engine and a heat pump. In a heat engine heat is transferred from a reservoir of high temperature to a reservoir of lower temperature by doing a work in the process. In a heat pump work is applied externally. This externally applied work transfers heat from a reservoir of lower temperature to a higher temperature reservoir. The working of thermo acoustic refrigerator is similar and the external work is supplied with the help of sound waves in the acrylic tube.

There are some longitudinal standing sound waves. These longitudinal standing sound waves results in the oscillation of the gas particles, back and forth parallel to the stack walls. This results in the alternate compression and rarefaction of the gas. As a result the temperature of the gas starts to oscillate. This oscillations takes place due to the adiabatic nature of sound waves. When the temperature of the gas becomes more than the temperature of the stack wall, heat transfer takes place from the gas to wall. If the temperature of the gas is lower than the stack wall temperature, heat transfer takes place from wall to the gas. One of the most important factor that affects the performance of a thermo acoustic refrigerator is the critical longitudinal temperature pressure gradient. It is given by

$$\Delta T = P/\rho\varepsilon C \qquad (3)$$

Where ΔT is the longitudinal temperature gradient, P is the acoustic pressure, ε is the displacement amplitude and C is the velocity gradient. Sound waves propagates through the acrylic tube. The motion of the sound waves results in the movement of gas particle in the stack towards the closed end of the tube. When it passes through the tube, the pressure increases and the gas get compressed. The temperature of the compressed gas parcel is hotter. After sometime the temperature of the gas parcel become more than the stack wall. As a result it transfers its heat to the cooler stack. As a result the volume shrinks. The standing waves continues through its cycle and the gas parcel is moved towards the region where the pressure is lower. Because of that the parcel become cooler than the stack wall and the parcel absorbs heat from the stack wall and the parcel expands.

High amplitude sound waves are usually generated inside the acrylic tube. A large amount of pressure fluctuations occurs inside the resonator. These pressure fluctuations can generate a huge temperature differences. These temperature differences occurs across the stack placed between the hot heat exchanger and cold heat exchanger. In a thermo acoustic refrigerator the temperature changes are utilized by the use of stack and heat metal sink. Refrigerator absorbs energy from input work in the form of sound waves and a cooling effect is produced between the two edges of the tube. Low voltage solar cells or batteries can be used for charging the thermo acoustic systems.

4 CONCLUSIONS

The construction of in expensive and simple load speaker driven thermo acoustic refrigerator effectively demonstrates the basic principle behind its operation. In this paper the influence of resonator tube length is also investigated. From the experiment we concluded that increasing the length of the tube will increase the hot end temperature. The use of aluminium plug instead of plastic plug resulted in improving the performance. The attachment of heat exchanger at both ends of the stack improved the performance of thermo acoustic refrigerator. The hot end of the heat exchanger acts as the heat sink and cold end of the heat exchanger acts as the heat source. After reaching the lowest temperature, cold end temperature showed an increasing tendency. The temperature increases because of the heat diffusion from the hot side to cold side through the stack. Stack material used here ha very less thermal conductivity. This helps to prevent the diffusion of heat through the stack. Another factor influencing the thermo acoustic refrigerator is the plate spacing of the stack. Here we used a plate spacing of 0.34 mm. If we increase the plate spacing, heat transfer rate decreases. Decreasing the plate spacing increases the viscous effects and air will not pass through the stack. This will adversely affect the performance. The performance can be improved by using Helium as the working fluid.

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