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Fabrication and Experimental Analysis of Thermo Acoustic Refrigerator

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Abstract—*The Thermoacoustic deals with the conversion of sound energy to heat energy and vice-versa. In this study, fabrication of thermoacoustic system for refrigeration application was considered. This study comprises of two parts, in first part different components of thermoacoustic refrigerator are fabricated based on numerical design. Later performance of the device is then analyzed. The drop of 15.4°C was observed from the room temperature at the cold end of the stack within 330 seconds. It was also observed that, replacing the hot and cold heat exchangers, made the system more effective, reduced the complexity of the fabricated structure. Finally concluding the Performance of the Refrigerator,*
Coefficient of performance was calculated, and it came out be 0.69.

Keywords*: Thermoacoustic; refrigeration; Coefficient of performance.*

1. INTRODUCTION

The meaning of the term thermoacoustic is, in the words of Nicholas Rott who laid much of the theoretical foundation for the field, fairly self-explanatory. Thermoacoustic deals with the conversion of the heat energy to sound energy. Acoustic waves experience displacement oscillations and temperature oscillations in association with the pressure variations.

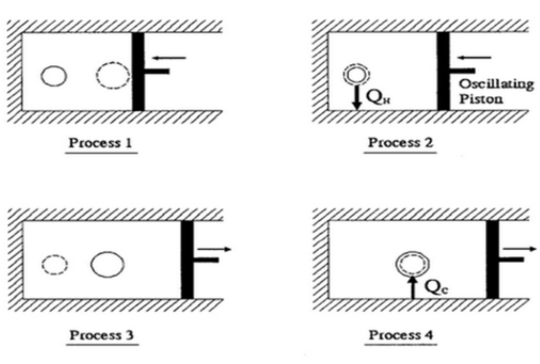

Fig. 1. Thermoacoustic cycle. [1]

In order to produce thermoacoustic effect, these oscillations in a gas should occur close to a solid surface, so that heat can be transferred to or from the surface. To understand the thermoacoustic cycle in a thermoacoustic refrigerator, consider a gas parcel inside the tube with a piston attached to one end of tube as shown in Fig. 1. The studies on thermoacoustics have continued seriously for more than two hundred years. Sondhauss worked on the dimensions of this cylindrical glass and the frequency of the sound emitted [1]. Sondhauss tube in Fig. 2 was investigated as a thermoacoustic engine in 1850 and Rijke tube in 1859 [2]. Lord Rayleigh explained Sondhauss tube correctly in 1896 [3]. But a theoretical definition would be missing half a century more.

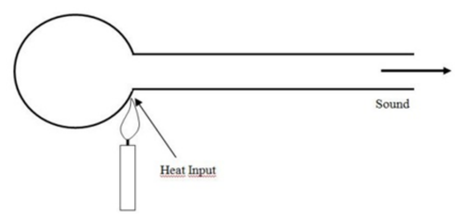

Fig. 2. Sondhauss Tube [1]

In 1962, Carter et al. [4] found out that the performance of Sondhauss tube increased when appropriate parallel plates were placed inside the tube. It was a great discovery in thermoacoustics, because the heat transfer between the gas and the plate would be accomplished by many parallel plates and a great deal of work would be produced from small systems. Feldman completed his Ph.D. thesis on Carter's work [5] and produced 27 W of acoustical work using 600 W of heat. Theoretical studies on thermoacoustics were commenced with Kirchoff who calculated the acoustical vibration from a heat source in 1868. Rott et al. [6] introduced the equations correctly for the first time which expressed the displacement, pressure distribution and energy transfer in a channel that included a temperature gradient and sinusoidal oscillations [7]. The theory of Rott was verified by Yazaki with helium [8], Müller and Lang with air [9], and Hofler with high pressurized helium [10] as the working gases. The comparison of the results to Rott's theory was very good. Transferring heat by using acoustical oscillations is much newer compared to producing sound by using heat. Gifford and Longsworth produced a great deal of cooling by applying high-amplitude low-frequency pressure oscillations to a gas in a tube [11].

They called the invented machine "Pulse Tube Cooler". Swift et al. [12] In 1992 another thermoacoustic cooler (SETAC) that was supported by US Navy was mounted on USS Deyo for cooling Radar circuit elements in 1995. The efficiency had been diminished because of the ineffectiveness of heat exchangers [13].

No environmentally hazardous refrigerants are needed and only inert gasses that are environmentally safe and suitable are used. Bailliet et al. [14] measured the acoustic power flow in the resonator of thermoacoustic refrigerator by using Laser Doppler Anemometry (L.D.A) together with microphone acoustic pressure measurement. They found good agreement between the experimental and theoretical results. Jin et al. [15] studied thermoacoustic phenomenon in a pulse tube refrigerator. They used a thermoacoustic prime mover to create an acoustic wave to drive the refrigerator. They studied the characteristics of thermoacoustic prime mover and the effect of working fluid i.e. helium and different percentage of helium-argon mixture, on the thermoacoustic refrigerator. They achieved a cryogenic temperature of 120 K in their experiments. Fig. 3 shows the circuit diagram.

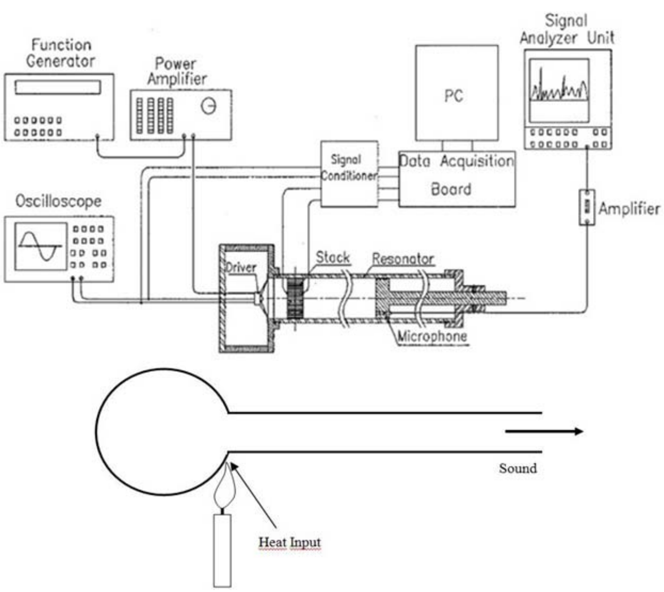

Fig. 3 Circuit diagram of electronic Circuit [16]

2. DESIGN CONSIDERATION

The compression of the gas corresponds to the crest 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 Fig. 4. In a longitudinal wave the particle displacement is parallel to the direction of propagation of wave i.e. they simply oscillate back and forth about their respective equilibrium positions. The compression and expansion of a longitudinal wave results in variation of pressure along its longitudinal axis of oscillation. A longitudinal wave requires a material medium air or water to travel. This pressure variation is the key process that causes the thermoacoustic phenomenon. This pressure variation is the key process that causes the thermoacoustic effect. The wavelength is defined as horizontal distance from the beginning of wave to the end of wave.

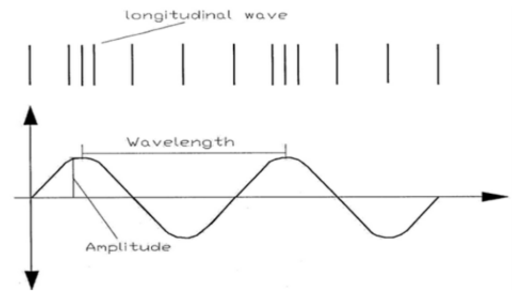

Fig. 4: Comparison of longitudinal wave with the sine wave. [17]

3. THERMODYNAMIC CONSIDERATIONS

In this section we will discuss the thermoacoustic phenomenon based on acoustics and thermodynamics. To understand the phenomenon, consider a thermoacoustic cooling device such as refrigerator. This device consists of an acoustic driver attached to tube filled with working fluid. Inside the tube a stack of thin parallel plates and two heat exchangers are installed for the heat transfer. The schematic of a typical thermoacoustic device is shown in Fig. 5

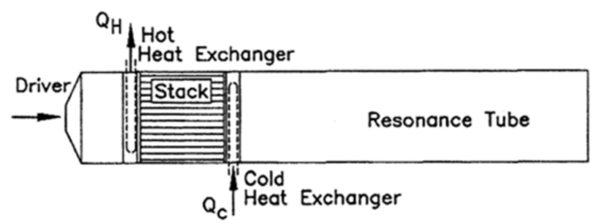

Fig. 5 Schematic of thermoacoustic refrigerator[17]

The acoustic driver connected to one end of resonator tube excites the working fluid (typically gas with low prandtl number), and creates a standing acoustic wave inside the tube. Hence the gas oscillations inside the resonator with expansions and compressions. The total Acoustic power used by refrigerator is provided by an acoustic driver. A significant portion of this power is used to pump heat in the stack and rest is dissipated in different parts of refrigerator. A higher performance of the driver leads to a higher performance of whole refrigerator system. The acoustic driver converts electric power input to acoustic power. A loudspeaker with the maximum power of 30 watts and 10Ω at the operating frequency of 630 hertz was selected as driver for this study. Generally a most common electrodynamics type loudspeaker is used which consists of copper wires and permanent magnets

4. ACOUSTIC RESONATOR

The shape, length and losses are important parameters for designing the resonator. Length of resonator is determined by the resonance frequency and minimal losses at the wall of the resonator. The length of resonator tube corresponds to half the wavelength of standing wave;

L= λ/2

and

λ = c/ν

Where c is speed of sound in air, λ is the wavelength and ν is the frequency of acoustic wave. As discussed in section 3.5 an acoustic driver with the frequency of 630hertz was selected for present design. For this frequency the length of resonant tube was set equal to 275 mm that corresponds to half the wavelength of acoustic standing wave, diameter of resonator tube was set equal to 150 mm to accommodate the size of acoustic driver

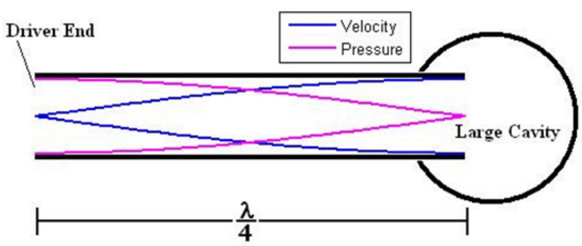

Fig. 6 A Quarter wavelength inside Resonator

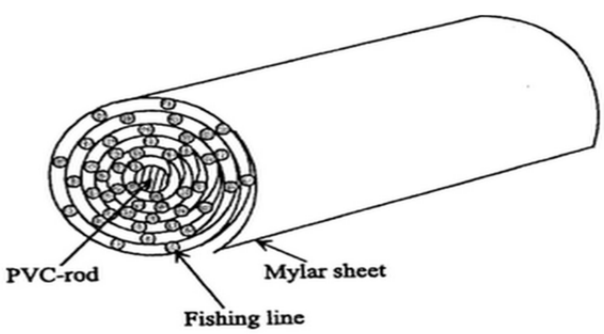

Fig. 7 - Illustration of Spiral Stack [18]

5. ASSEMBLY

A schematic representation of the refrigerator parts is shown in **Fig.** 6,7 and 8. It consists of an acoustic driver housing, an acoustic driver, stack and resonator filled with air at atmospheric pressure. Four holes were drilled in the resonator tube to attach heat sink at the closed bottom end of resonator tube. For battery chamber a second door is cut out again from the resonator surface and properly filled.

Now in the battery chamber a 12V DC battery and the circuit for generating function required by the loudspeaker is implanted. At the end of the Battery Chamber, housing of loudspeaker begins and for that a loudspeaker of 6 inches diameter with 10Ω impedance is fixed. A groove is cut on the surface of Acoustic Driver housing where a rubber O-ring is placed to seal the resonator tube. Two thermocouples were attached to measure the temperature across the stack.

Fig. 8 Complete final assembly of Thermoacoustic Refrigerator

6. RESULTS AND DISCUSSION

In this set of experiments, the effect of stack on the temperature field inside the resonator was investigated. The stack was mounted in the resonator at a distance of 206.25 millimeters from the driver end and the acoustic standing wave was generated inside the resonator. The temperature was measured at every interval of 30 seconds, as shown in Table 5.2. This data is acquired for 330 seconds. The table shows both the thermocouples on either side of stack were at the same room temperature, i.e. 32.2°C. Within 330 seconds temperature drop of 15.4°C was observed. Initially the temperature difference across the stack was 0°C and after 5 minutes and 30 seconds, we observed the temperature difference across the stack be 23.7°C. Temperature across the hot side of the stack rises from 32.2°C to 40.5°C and the temperature across the cold side of the stack drops from 32.2°C to 16.8°C.

Coefficient of Performance

= (Heat extracted out from the thermoacoustic refrigerator)/(Work Input)

$$\text{C.O.P} = \frac{\dot{Q}}{W} = \frac{0.0207}{0.03} = 0.69$$

Hence Coefficient of Performance of refrigerator comes out to be 0.69

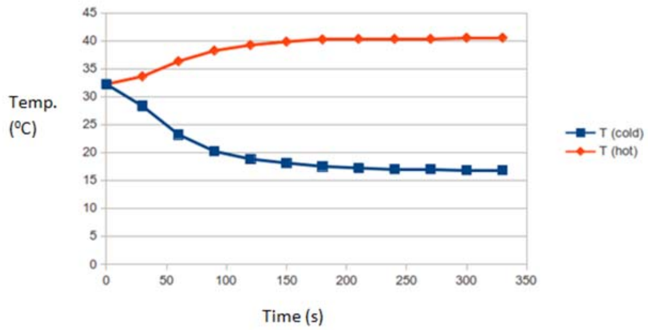

Fig. 9 Variation of temperature with time for hot and cold junction

The two major outcomes based on the results are

1) There was no temperature gradient along the resonator centre line without stack. However, a temperature drop, of 15.4°C is established at the cold end of the stack, by adding stack inside the resonator tube.
2) Once the heat sink was incorporated, temperature rise of 8.3 °C was established at the hot end of stack.

7. CONCLUSIONS

Based on the results of present investigation following conclusions can be drawn:

1) Without stack temperature in the resonator almost remains constant.
2) Temperature distribution along the resonator is significantly affected by the presence of stack. After 330 seconds of operation, a temperature gradient of 23.7°C was established across the stack.
3) Position of the stack is important, in order to get maximum temperature gradient. For the resonator of length 27.5 centimeters, the position of centre of stack from the driver came out to be 20.625 centimeters
4) Stack with homogenous material is important to get maximum temperature gradient across the stack.
5) The Coefficient of Performance of the refrigerator is approximately 0.69

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