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DEVELOPMENT OF A THERMO-ACOUSTIC DEVICE FOR THE CONVERSION OF SOUND WAVES INTO COLD AIR

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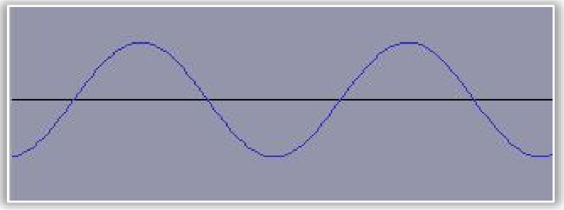
Abstract: Refrigerants play a decisive role in determining the cooling performance of household and commercial refrigerators. In addition to being toxic, flammable in nature, harmful to health and also possess the potential threat to environmental crisis like Global warming, Ozone Layer Depletion when released to atmosphere. Different approaches to establish a feasible alternate to conventional refrigeration system has been undertaken in recent times. Thermo acoustic refrigerator (TAR) can a practicable solution. This technology uses high intensity sound wave to convert mechanical energy to produce thermal gradient with the help of a speaker in a resonator. In order to further improve the performance of a TAR, optimization of the sound wave is important. Effect of sound waves of different levels of intensity, pitch and amplitude has been investigated in this study. Also use of Phonics as input to the system is also investigated. It was noticed that maximum thermal gradient was achieved while using sinusoidal waves as input signal.
Keywords: thermo acoustics, refrigerator, cooling performance, sound waves, thermo acoustic refrigerator (TAR), intensity, pitch and amplitude

INTRODUCTION

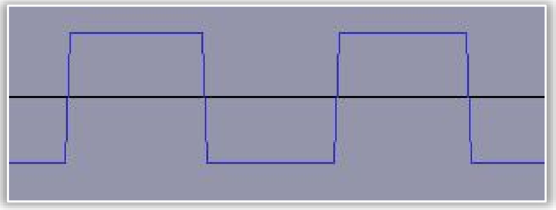
Thermo acoustics is an emergent technology that uses the phenomenon of interaction of sound fields with solids to develop heat pumps or heat. Sound waves in air are longitudinal waves. The medium in which they move undergoes vibrations, thus experiences compression and rarefaction. This is associated with change in temperature and pressure. When the gas carrying a wave is brought in contact with a solid surface, it absorbs the heat as the gas gets compressed [1]. Acoustic waves cause oscillation while propagating through a medium. This oscillation can be used as pressure waves on neighboring media. To produce the thermo acoustic effect, these oscillations in a gas should occur close to a solid surface so that heat can be transferred to and from the surface. A stack of closely spaced parallel plates is placed inside the thermo acoustic device to provide such a solid surface. The thermo acoustic phenomenon occurs by the interaction of the gas particles and the stack plates. The discovery of the thermos-acoustic phenomenon goes back to more than a century ago. It was discovered that acoustic oscillations in a pipe might be excited by suitable placement of a hydrogen flame inside in the late 18th century [2]. The oscillation was also found by glass blowers when a hot glass bulb was attached to a cool glass tube, i.e. the tube tip sometimes emitted sound [3]. The investigation on thermo acoustics began with these occasional findings. But the significant work in this area was started about two decades ago at the Los Alamos National Laboratory by the research group of researchers led by Greg Swift. They have developed different types of thermos-acoustic refrigerators and heat engines [4]. Garret et al. developed a Space Thermo-Acoustic Refrigerator (STAR). The cryocooler was flown on the Space Shuttle Discovery (STS-42) in January, 1992 [5]. Tijani et al. successfully achieved as low temperature -65°c which is one of the lowest reported temperature till date [6]. Wetzel et al. developed algorithm to optimize the design and performance of thermos-acoustic refrigerator. They proposed a systematic approach that provides fast engineering estimates for initial design calculations based on first law analysis [7]. Different studies to predict the impact of different parameters on the performance of thermos-acoustic refrigerator have been undertaken. Akhavanbazaz et al. investigated the impact of gas blockage on the cooling performance [8]. Anayet U Patwari et al. investigated the application of TAR in turning process and found effective in machining process [9]. In this study, the effect of some design parameters such as wave pattern, frequency, pitch & amplitude of input signal were investigated. In addition to that, use of some Phonics as input signal as alternate to pure sinusoidal waves were also the key objective of this study. The theme concept of the study is to use this technique for automotive refrigeration system that can convert any sorts of sound waves like music to cold wave for getting cooling effect inside the automobile cabin. From the study, it has been found that using sine wave at high level of amplitude and pitch enhances the performance of thermo-acoustic refrigerator.

ACOUSTICAL THEORY

Thermo acoustics waves cause oscillation while propagating through a medium. This oscillation can be used as pressure waves on neighboring media. To produce the thermos-acoustic effect, these oscillations in a gas should occur close to a solid surface so that heat can be transferred to and from the surface. A stack of closely spaced parallel plates is placed inside the thermos-acoustic device to provide such a solid surface. The thermos-acoustic phenomenon occurs by the interaction of the gas particles and the stack plates. There are three characteristics of the acoustic wave which are necessary to understand the thermos-acoustic process. These characteristics are Intensity, amplitude and pitch.



(a)



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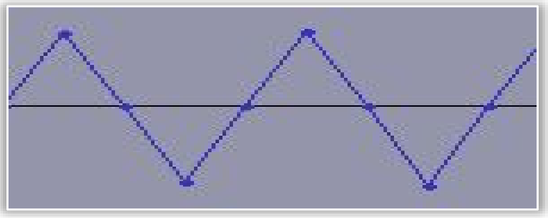

(c)

Figure 1. Different wave patterns used in the study
(a) Sinusoidal; (b) Square; (c) Triangular

The intensity of a wave is the rate of energy per unit time which is transferred per unit area of a surface that the wave impinges on. It's also gives a measurement of direction of the energy flow in some direction but not in others. The amplitude of a sound is the measure of its power and the unit is in decibels. It refers to the distance of the maximum vertical displacement of the wave from its mean position. In sound, it refers to the magnitude of compression as well as expansion experienced by the medium through which the sound wave is travelling. It is expressed either as instantaneous values or mostly as peak values. The frequency of a sound wave is what our ear understands as pitch. A higher frequency sound has a higher pitch, and a lower frequency sound has a lower pitch. Frequency in a sound wave refers to the rate of the vibration of the sound travelling through the medium. The wave pattern configuration is important to know because these effect the pressure amplitude inside the tube. Thermo acoustic refrigerator uses several waves pattern to generate pressure along the resonator tube. In this paper sine wave, square wave and triangle wave have been used for experimental purpose, which is shown in Fig 1.

EXPERIMENTAL DESIGN

Figure 2 shows the construction of a simple thermos-acoustic refrigerator. It contains a resonator tube made of PVC pipe and Copper tube and it contains the inert gas as working fluid. A loud speaker is used to produce the necessary acoustic power to drive the system. A stack, the heart of the TAR which is a porous medium is placed inside the resonator to increase the gas solid interaction and contact surface to exchange heat. Heat exchangers are used in both sides of the stack.

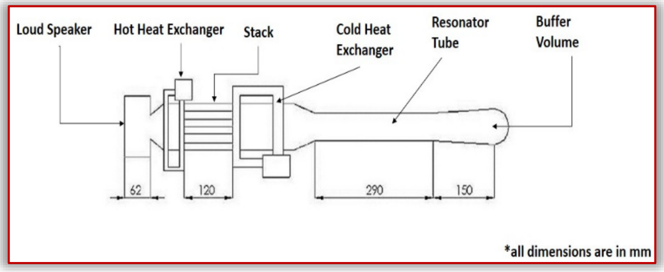

Figure 2. Schematic Diagram of TAR developed for this study

A thermocouple is used to determine the temperature difference between hot and cold air. The brief description of the different components developed in this study as shown in Figure 3 are given below:

- **Loud speaker**:

Loud speaker supplies the required acoustic power to drive the system. It should be compact, powerful and light weight. For these reasons an R-2430, 100 watt, 3.5 inch, 3 way speaker was used. The speaker was kept inside a PVC made speaker housing as PVC was readily available and thermally insulating.

- **Speaker Housing:**

It is made of PVC. Speaker is inserted inside it. Two holes were drilled at the back, one for electrical wiring of the speaker and another for charging the gas.

- **Stack:**

It is the heart of Thermo-acoustic refrigerator. It is a porous medium that increases the heat exchange surface area. To guarantee low thermal conductivity of the stack Mylar sheet was chosen. A spiral stack of Mylar sheet is constructed wounding around a PVC dowel of 1.5-inch diameter. A channel structure between the layers is realized with the help of 0.25 mm fishing lines. Fishing lines were attached to the Mylar sheet with the help of Glue gun and glue sticks. For the first 200 lines a distance of 1 cm was maintained and for the rest a distance of 3 cm up to the diameter of the stack became 3.5 inch. Then it was inserted inside the stack housing. Housing is made of 3.5 inch PVC pipe. PVC material is chosen for its low thermal conductivity and insulation.

- **Resonator Tube**:

Resonator tube is the body of the thermos-acoustic refrigerator in which the sound wave propagates. It consists of three major parts. First part consists of a large diameter PVC pipe called stack housing which contains the stack, followed by a smaller diameter Copper tube and the last part is the Buffer volume. Copper tube has relatively higher thermal conductivity and its diameter is 2 inch and 29 cm in length.

- **Buffer Volume**:

The buffer volume is to be used to simulate open-end resonator. It is a conical shaped copper tube with a taper angle of about 90 and a diameter of 2.35 inch and gradually increasing up to 2.85 inch. The total length of this buffer volume is 15 cm.

Heat Exchanger:

Two heat exchangers are made of 0.25-inch Copper coil. These are placed in both sides of the stack.

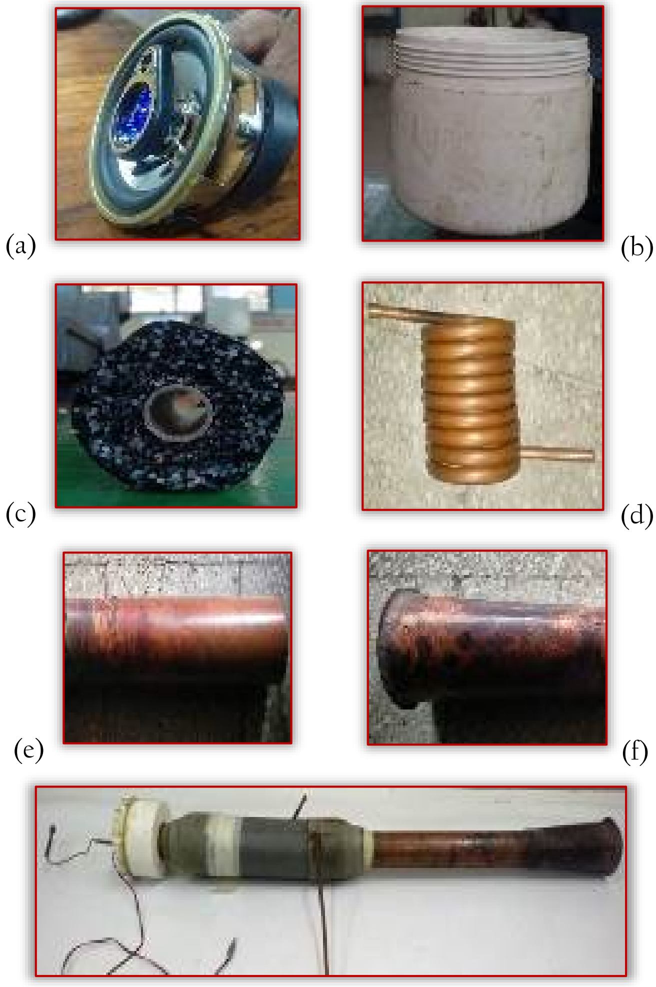

Figure 3. Different components of TAR; (a) Speaker, (b) Speaker Housing, (c) Stack, (d) Heat Exchanger, (e) Resonator Tube, (f) Buffer Volume, (g) Assembled view

— RESEARCH METHODOLOGY

Experiments have been performed by changing different parameters for Thermo acoustics. Different properties that characterize the sound wave are changed and its effects have been tested in the experiments. Two similar experiments have been performed in the study (a) Amplitude test of pure waves (b) Parametric study of phonics.

These experimental conditions were selected arbitrarily and kept constant throughout the study. Gas used in this study is Nitrogen as it was readily available in the laboratory and it is inert in nature and kept in atmospheric pressure inside the resonator tube. A CIE 305 Thermometer was used to measure the temperature at the inlet and outlet of the cold heat exchanger.

Amplitude Test of Pure Waves:

Effect of amplitude change of different wave form like Sinusoidal, Triangular and Square on temperature gradient have been studied. For the completion of this study a reference frequency of 750 Hz has been modified to generate different wave form using Audio Recorder.

Parametric Study of Bengali Phonics:

For the second part for the study, A Phonics has been used as input signal. This phonics was recorded and edited using Audio Recorder. Effect of different level of amplitude and pitch of the phonics on thermal gradient has been studied. Spectrum Analysis of the Phonics Used has been analyzed to generate spectrum graph. It depicts the graph of frequencies (the horizontal scale in Hz) against amplitudes (the vertical scale in dB). Plots are made using a mathematical algorithm known as a Fast Fourier Transform or FFT. This gives a value for each narrow band of frequencies that represents how much of those frequencies is present. All the values are then interpolated to create the graph. The spectrum analysis of this phonics is shown in Figure 4.

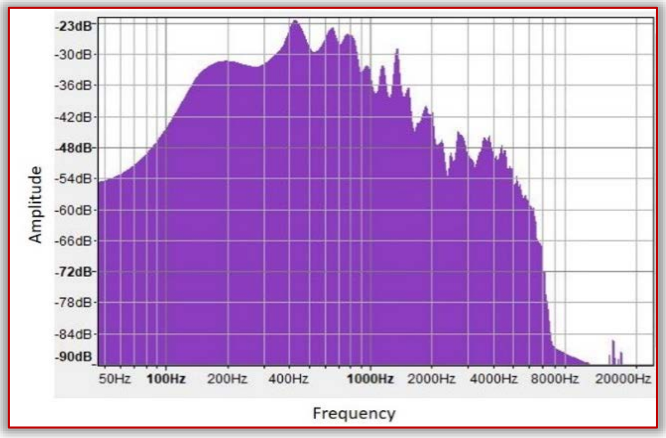

Figure 4. Spectrum analysis of Phonics

— RESULT & DISCUSSION

Amplitude Testing of Pure waves

For the first part of the study different modification have been made for a 750 Hz sound wave. Different frequencies of different wave form (Sinusoidal, Square & Triangular) have been studied. Figure 5 depicts the effect of amplitude change on temperature change for 750 Hz in different wave form.

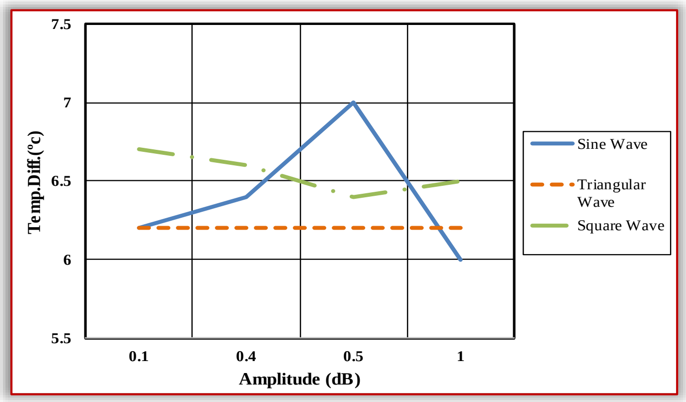

Figure 5. Effect of Amplitude change on Temperature Difference

From the graph, it is evident that Temperature difference is highest 7°c when operating at an amplitude of 0.5 dB for sinusoidal waveform. A steady temperature difference of 6.2°C while the system was tested with triangular wave. For square wave form the highest temperature gradient obtained is 6.7°c at 0.1 dB level. Use of sinusoidal waves at high level of amplitude results in enhanced performance of TAR.

- **Parametric Test of Phonics: Amplitude Test of Phonics**

The recorded phonics was modified at different levels from 7dB to 30 dB and tested. Figure 6 depicts the effect of amplitude change on temperature change for Bengali Phonics.

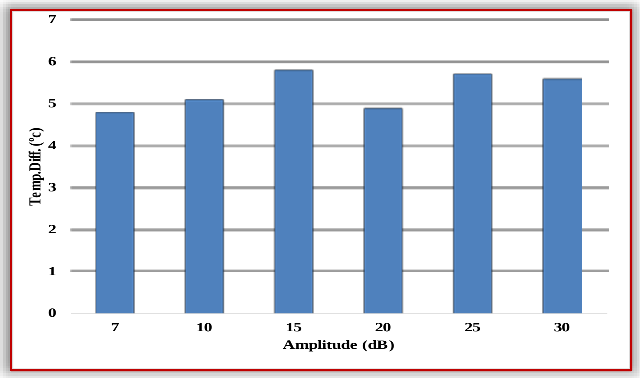

Figure 6. Effect of Amplitude change on Temperature Difference

The graph depicts that maximum temperature difference obtained is 5.8°c at 15 dB. Although the performance is not satisfactory but the lower thermal difference obtained in this process suggests that instead of pure waves the use of Phonics can be an alternative approach to achieve thermal gradient in thermo acoustic study.

- **Pitch Test of Phonics:**

The unedited Phonics is changed with the use of software. The change in pitch of a particular sound can be in percentage of the pitch of the unaltered sound. If the pitch is decreased the sound becomes deepened. Similarly increasing the pitch sharpens the sound. Figure 7 shows the effect of temperature change in percentage of the Phonics. It is evident that for increasing in the pitch increases the temperature difference. Maximum temperature difference of 6.2 °c at +25% pitch change whereas lowest temperature gradient is obtained at -25% pitch change. Temperature change increases with the increase of pitch.

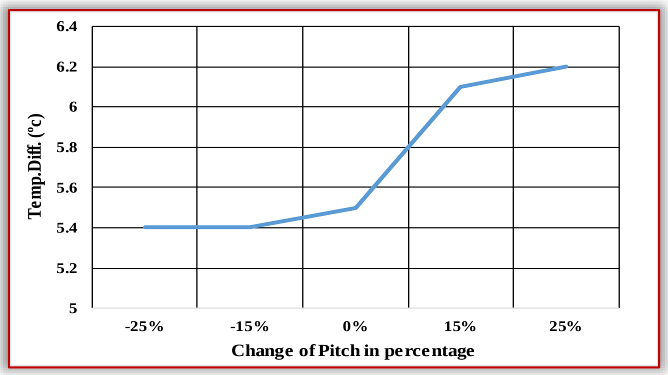

Figure 7. Effect of Pitch change on Temperature Difference

CONCLUSION

Selection of appropriate wave is crucial for the performance of the optimum performance of a TAR. It has found that sinusoidal waves with relatively higher amplitude and increased pitch can result in better performance for the thermo-acoustic performance. The use of Phonics instead of pure waves can be an alternative approach in thermo acoustic phenomenon. It may be a scope of using a recorded phonics instead of pure wave that has been used in TAR system. This study shows that thermal gradient can be achieved not only with the use of pure waves but also a customize phonics.

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