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Thermoacoustic Refrigeration System

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ABSTRACT
This project examines the effectiveness of thermo acoustic refrigeration, which is the theory of using sound waves as a coolant. The work reported here deals with the design and optimization of a thermo acoustic-refrigerator (TAR) as an attempt to address the future generation environment-friendly energy systems. The literature survey gives a complete picture of the history of thermo acoustics and the work carried out in the field of thermo acoustics till today. The motivation of the design of thermo acoustic refrigerator explains the reasons for carrying out the work illustrating its benefits and how the performance of the TAR in future can be made efficient in comparison with the performance of a conventional refrigerator.

Keywords: Acoustical Theory, VCR System.

1. INTRODUCTION

Recent developments in the field of thermo acoustics promise to revolutionize the way that many machines currently operate.By manipulating the temperature-changes along the acoustic longitudinal waves, a machine can be created that can replace current refrigeration and air conditioning devices. These machines can be integrated into refrigerators, hot water heaters, or space heaters and coolers. The thermo acoustic devices contain no adverse chemicals or environmentally unsafe elements that are characteristics of current refrigeration systems. Thermo acoustics deals with the conversion of heat energy to sound energy and vice versa. There are two types of thermo acoustic devices: thermo acoustic engine (or prime mover) and thermo acoustic refrigerator.

In thermo acoustic engine, heat is converted into sound energy and this energy is available for useful work. In this device, heat flows from a source at a higher temperature to a sink at a lower temperature. In a thermo acoustic refrigerator, the reverse of the above 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.

1.1. THERMOACOUSTIC PHENOMENON

Acoustic waves experience displacement oscillations and temperature oscillations in association with the pressure variations. In order to produce thermo acoustic effect, these oscillations in a 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 thermo acoustic device in order to provide such a solid surface. The thermo acoustic 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 thermo acoustic engine). The gradient at the wall is very small or zero, this process is called heat pumping (or refrigeration).

During the first process, the piston moves a thermo acoustic refrigerator consists of a tube filled with a gas. This tube is closed at one end and an oscillating device (e.g. a piston or loudspeaker) is placed at another end to create an acoustic standing wave inside the tube. To understand the thermo acoustic cycle in a thermo acoustic refrigerator, consider a parcel of gas inside the tube with a piston attached to one end of the tube (as shown in fig.1.1).If the temperature toward the closed end and compresses the parcel of gas, and hence the gas parcel warms up. During the second process, heat flows irreversibly from the parcel to the wall due to compression. During the third step, the piston moves back (i.e. towards the right side), and the gas parcel expands and cools.

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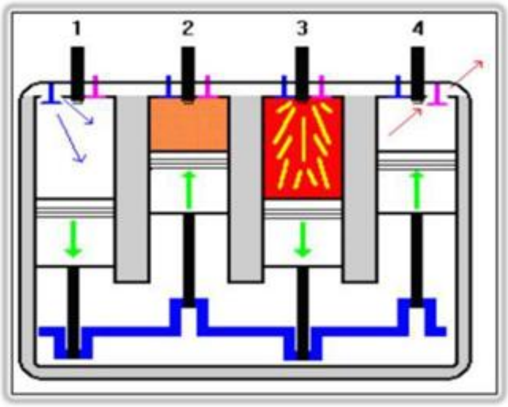

Fig-1.1: Thermo acoustic Cycle

At the end of the third process, the temperature of the gas parcel is less than the wall temperature.

1.2. PROBLEM DESCRIPTION

In today’s world refrigerator has become the need of common society. Basically, modern refrigerators operate on VCR system which is quite efficient but utilizes harmful refrigerants [once chlorofluorocarbons (CFCs), now hydro fluorocarbons (HFCs)] which are ozone depleting chemicals which are a major cause of concern. Also, it possesses moving parts which reduces its service life & undoubtedly increases its maintenance life. So here we have made an attempt to not only replace the existing refrigeration system but also to make it suitable w.r.t environment affability and provide efficient means of refrigeration which would be not only cost efficient but also maintenance free at its most suitable level.

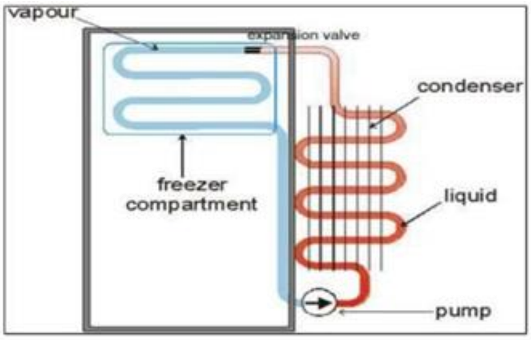

Fig.1.2 Conventional VCR System

1.3. ENVIRONMENTAL AFFABILITY

No environmentally hazardous refrigerants are needed and only inert gases that are environmentally safe and suitable are used. The international restriction on the use of CFC (chlorofluorocarbon) and skepticism over the replacements of CFC, gives thermo acoustic devices a considerable advantage over traditional refrigerators. The gases used in these devices are (e.g. helium, xenon, air) harmless to the ozone and have no greenhouse effect. It is expected that in the near future, regulations will be tougher on the greenhouse gases. The awareness about the destructive effects of CFC on the depletion and the banning of the CFCs production, lead the researchers to find an alternative solution to this problem. In this scenario, thermo acoustic refrigerator could be the most suitable candidate to replace the conventional vapour-compression refrigeration systems. In addition, the thermal acoustic cycle also lends itself well to a more efficient proportional control rather than the primitive binary control that conventional refrigerators currently employ. All of these reasons make thermo acoustic refrigerator potentially attractive for widespread use.

1.4. OBJECTIVES

Even though thermo acoustic devices have been known for 30 years, there are several aspects which are not well understood. The gas behaviour inside the resonator tube, its interaction with the solid surface (e.g. stack plate, Heat exchanger) and its effect on the heat transfer are not known. A better understanding of the fundamental process is necessary to improve the design of these devices. As a first step, which is the objective of this thesis project; analysing, designing and fabricating a simple and fundamental prototype thermo acoustic refrigerator and test it to study the performance? As far as we know, the work presented in this thesis is the first research on thermo acoustic devices done at any Canadian University.

2. DESIGN METHODOLOGY AND IMPLEMENTATION STRATEGY

2.1. BASIC REFRIGERATION THEORY

The refrigerator is a device that transfers heat from a low –temperature medium to a higher temperature using external work input. The working fluid used in the refrigerator is called the refrigerant. The refrigeration process is based on the first and second law of thermodynamics, and its operation is based on the thermodynamic refrigeration cycles. The most commonly used refrigeration cycles are the vapour-compression type.

2.2. VAPOUR-COMPRESSION REFRIGERATION CYCLE

The vapor-compression refrigeration cycle is the most widely used cycle for refrigerator, air-conditioning systems, and heat pumps. It consists of four thermodynamic processes and involves four main components: compressor, condenser, expansion valve, and evaporator, as shown in Fig.2.1. The refrigerant enters the compressor as a saturated vapour at a very low temperature and pressure (state 1). The compression process takes place inside the compressor. Both the refrigerant becomes a superheated vapour at the exit of the compressor (state 2). The heat transfer process takes place in the condenser at a constant pressure, where heat is transferred from the refrigerant to the high-temperature medium. As a result is a small decrease in the temperature of the refrigerant as it exits the condenser (state 3). The four processes of ideal vapor-compression refrigeration cycle are plotted on the T-S diagram in Fig. 2.1.

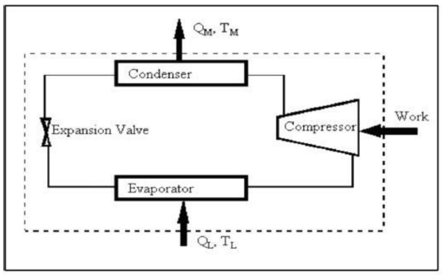

Fig.2.1 Basic Component of a Refrigeration System Working on the VCR Cycle.

2.3. ACOUSTICAL 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 thermo acoustic 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 troughs of a sine wave. An example of how these two relate to each other is shown in a Fig. 2.3. 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 positions. 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.

2.4. THERMODYNAMIC DESIGN CONSIDERATION & ACTUAL WORKING

The configuration of standing-wave thermo acoustic refrigerators is simple. A standing-wave TAR comprises a driver, a resonator, and a stack. The practical device also utilizes two heat exchangers; however, they are not necessary for creating a temperature difference across the stack. The parts are assembled as shown in **Fig** 2.4

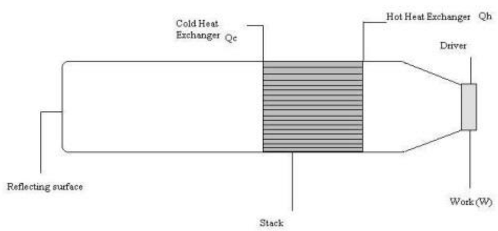

Fig 2.4 Schematic Diagram

The driver, which is often a modified electro dynamic loudspeaker, is sealed to a resonator. Assuming the driver is supplied with the proper frequency input, the resonator will respond with a standing pressure wave, amplifying the input from the driver. The standing wave drives a thermo acoustic process within the stack. The stack is so called because it was first conceived as a stack of parallel plates; however, the term stack now refers to the thermo acoustic core of a standing-wave TAR no matter the core's geometry. The stack is placed within the resonator such that it is between a pressure antinode and a velocity antinode in the sound wave. Via the thermo acoustic process, heat is pumped toward the pressure antinode. The overall device is then a refrigerator or heat pump depending on the attachment of heat exchangers for practical application. A temperature gradient can be created along the stack with or without heat exchangers. The exchanges merely allow a useful flow of heat. If the hot end is thermally anchored to the environment and the cold end connected to a heat load, the device is then a refrigerator. If the cold side is anchored to the environment and the load applied at the hot end, the device operates as a heat pump. In any case, a few simple parts make up the thermo acoustic device, and no sliding seals are necessary.

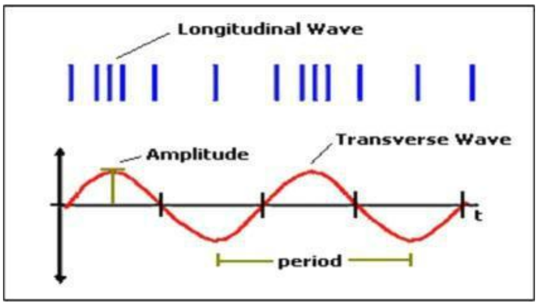

Fig 2.5 Behaviour of Gas Molecules

First, the gas parcel undergoes adiabatic compression and travels up the channel due to the acoustic wave. The pressure increases by twice the acoustic pressure amplitude, so the temperature of the parcel increases accordingly. At the same time, the parcel travels a distance that is twice the acoustic displacement amplitude. Then the second step takes place. When the parcel reaches maximum displacement, it is has a higher temperature than the adjacent walls, assuming the imposed temperature gradient is sufficiently small. Therefore, the parcel undergoes an isobaric process by which it rejects heat to the wall, resulting in a decrease in the size and temperature of the gas parcel. In the third step, the second half-cycle of the acoustic oscillation moves the parcel back down the temperature gradient. The parcel adiabatically expands as the pressure becomes a minimum, reducing the temperature of the gas. The gas reaches its maximum excursion in the opposite direction with a larger volume and its lowest temperature.

3. IMPLEMENTATION

3.1. EXPERIMENTAL SETUP

The components of the thermo acoustic refrigerator are designed, and the many design parameters are selected in the current chapter. In this chapter fabrication of the thermo acoustic refrigerator is described, which is followed by the description of the experimental setup, instrumentation, and methods for the measurements in the fabricated refrigerator.

Fig 3.1 Schematic of the Thermo acoustic Refrigerator

3.2. ACOUSTIC DRIVER

A thermo acoustic cooling device requires an acoustic driver attached to one end of the resonator, in order to create 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. In this study, a loudspeaker with the maximum power of 15 watts and impedance of 8Ω at the operating frequency (450 Hz) is used as the acoustic driver (G

50 FFL, VISATON). 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. The efficiency of this type of loudspeaker is relatively low, and their impedances are

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poorly matched to gas when the pressure inside the resonator is high. Consequently, the range of pressure amplitudes inside the resonator is limited

3.3. STACK
The most important component of a thermo acoustic device is the stack inside which, the thermo acoustic phenomenon occurs. Thus, the characteristics of the stack have a significant impact on the performance of the thermo acoustic device. The stacked material should have good heat capacity but low thermal conductivity. The low thermal conductivity for the stack line spacers (0.36 mm thick) glued onto the surface of the sheet. The Mylar sheet is wound around a 4 mm PVC-rod to obtain a spiral stack as shown in above **Fig**.

3.4. WORKING FLUID
Many parameters such as power, efficiency, and convenience are involved in the selection of the working fluid, and it depends on the application and objective of the device.

Thermo acoustic power increases with an increase in the velocity of sound in the working fluid. The lighter gases such as $_2$, He, Ne have the higher sound velocity. Lighter gases are necessary for refrigeration application because heavier gases condense or freeze at a lower temperature, or exhibit not ideal behaviour.

3.5. ACOUSTIC RESONATOR
The acoustic resonator is built from a straight acrylic tube of length 70 cm. The internal diameter of the tube is 6.3 cm and the wall thickness is 6 mm. One end of the tube has a plate attached to install the speaker frame. At the other end, a movable piston is placed inside the resonator. The reason for having a movable piston is to adjust the length of the resonator so as to change the fundamental frequency of the resonator.

3.6. ELECTRONIC DEVICES
An amplifier (MPA-25, Realistic) with the maximum power output of 20 watts is used to amplify the power input to the loudspeaker to increase power input.

3.7. THERMOCOUPLE
J-type thermocouples are used for the temperature measurements in this study. They are used to measure the temperature at different locations inside the resonator and the temperature of heat exchanger fluids. The specifications of the thermocouple are given below:

- Thermocouple grade :- 0 to 150 ℃
- Limits of Error:-1.0 ℃ or 0.75% above 0℃.

3.7. TEMPERATURE INDICATOR
50 Hz, 200-240V temperature indicator

3.9. PVC CAP SEALINGS & ALUMINIUM END PLUG
PVC pipes are made to contain the speakers, along with threads to make air tight zones. Aluminum end plug is placed at the end of the resonator tube to dissipate the Heat generated**.**

3.10. DESIGN STRATEGY
The stack is considered as the heart of any thermo acoustic system. It can be seen that these systems have very complicated expressions which cannot be solved, which necessitates the use of approximations. The coefficient of performance of the stack for example which can be defined as the ratio of heat pumped by the stack to the acoustic power dissipated in the stack. A simplified expression is derived from the short stack and boundary–layer approximation [1]. However, even after the approximation, the 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 of thickness 0.13 mm. The Mylar sheet was cut into pieces each of 3 cm wide. The spacing between the layers is filled by fishing expression looks complicated. They contain a large number of parameters such as working gas, material and geometrical parameters of the stack. It is difficult to deal with so many parameters in engineering. However, one can reduce the number of parameters by choosing a group of dimensionless independent variables. Some dimensionless parameters can be deduced directly. Others can be defined from the boundary layer and short stack assumptions [1, 2]

Table 3.2 Operating and Working Gas Variables.

Operational variables	Working gas properties
Operating frequency f	Dynamic viscosity μ
Average pressure P_M	Thermal conductivity K
Dynamic pressure amplitude P_O	Sound velocity a
Mean temperature T_M	Ratio of isobaric to isochoric specific heat γ
Temperature gradient ΔT_M	Specific heat C_P
Mach number M	Gas density ρ_m
Drive ratio D	Prandtl number σ
Cooling power Q_C	

The goal in the design of a thermo acoustic refrigerator is to meet the requirements of a given cooling power QC and a given low-temperature TC. These requirements are added to the operating parameters. The low-temperature TC is shown indirectly in the form of Temperature gradient ΔTm.

Table 3.3 Normalized Design Parameters.

Non-Dimensional Parameters
Normalised thermal penetration Depth δ_{kn}
Normalised Stack center position x_{sn}
Normalised Stack Length L_{sn}
Normalised Acoustic power loss in Small Diameter resonator tube $\frac{W_2}{N}$
Normalised Cold heat exchanger position from the driver end x_{chn}
Normalised Hot heat exchanger position from the driver end x_{hhn}
Normalised Length of Cold heat exchanger L_{chn}
Normalised Cold heat exchanger position from the driver end L_{hhn}
Acoustic Mach Number M

3.11. DESIGN ASSUMPTION

1. The thermal conduction (i.e. heat leak from the cold side to hot side) along both the stack material and the gas in the stack is neglected.
2. The stack is short compared to the wavelength of the acoustic standing wave.
3. The temperature difference across the stack is a small fraction of the mean temperature of the stack and gas.
4. The heat and work flow are steady states.
5. The viscosity of the boundary layer is assumed to be zero.
6. The pressure inside the resonator remains almost constant.

3.12. DESIGN PROCEDURE

A total of 5 basic components has to be designed of which stack is the most important. It is not only the most critical component when it comes to the functioning of the thermal acoustic refrigerator, but also has a determining effect on the design and dimensioning of all remaining components. In order to begin with the design of the stack, first, the values of all parameters are obtained and finalized. Sometimes direct values are not available. Values at particular temperatures are accurately available and using appropriate formulae, the values at operating temperatures can be calculated. The temperature gradient ΔTM is indicative of

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the range of temperatures within which the system is going to be operating. Given the lowest temperature TC and the highest TH one can obtain the operating temperature range which is nothing but ΔTM.
$\Delta TM = TH - TC$

Assuming that the maximum operating temperature is 45℃; and minimum -15℃, a temperature difference of 60 ℃ was obtained. In an effort to simplify calculations a concentrated effort has been put into converting all parameters into dimensionless form so that computations are simpler. This is achieved by normalizing them. Hence

ΔTM is converted into ΔTMN, the normalized mean temperature difference by dividing with mean temperature TM. Assuming mean temperature to be 300 K, a value of 0.2 is obtained.

$\Delta TMN = {}^{\Delta TM}/_{TM}$

3.13. DYNAMIC PRESSURE

The dynamic pressure amplitude Po is limited by the following three factors:

1. The maximum force of the driver
2. Non-linearity's
3. Drive ratio

The acoustic Mach number' can be defined as,

$M = PO/\ _{Pm\ a}2$

The acoustic Mach number for noble gases has to be limited to 0.1 in order to avoid any nonlinear effects [1]. Correspondingly, the drive ratio has to be less than 3%. The value of 2% is chosen.

3.14. AVERAGE PRESSURE AND DRIVE RATIO

After fixing the temperatures, the average pressure was calculated. Since the power density in the thermo acoustic device is proportional to the average mean pressure PM and drive ratio [${}^{PO}/_{Pm}$]. Hence it is preferable to choose PM and drive ratio D as large as possible. This is determined by the mechanical strength of the resonator. On the other hand K, the thermal penetration depth is inversely proportional to the square root of PM. So a high pressure results in a small K and small stack plate spacing. This makes the construction difficult. Taking into account these effects and also making the preliminary choice for Air as the working gas, the maximal pressure is 12 bars and drive ratio should be D < 3% [2]. An average means pressure of 10 bars and drive ratio

2% was chosen**.**

Drive ratio D = 2% D= [${}^{PO}/_{Pm}$] = 2%= 0.02
Hence PO = 0.2 bar

Hence the maximum dynamic pressure amplitude is limited to Po = 0.2 bar.

3.15. SOUND SPEED

Speed of sound is given by the expression

$$a = \sqrt{\frac{C \times \gamma \times V}{v^{\gamma} \times n \times M}}$$

When a sound wave travels through an ideal gas, the longitudinal wave is expected to be polytropic or adiabatic and therefore the pressure and volume obey the relationship

$$pv^{\gamma} = c$$

The association with the sound wave happens so quickly that there is no opportunity for heat to flow in or out of the volume of air. This is the adiabatic assumption. Density of gas is

$$\rho = {}^{nM}/_{V}$$

Now,

$$P = {}^{C}/_{V^{\gamma}}$$

Therefore speed of sound:

$$a = \sqrt{\frac{p \times \gamma \times V}{n \times M}}$$

$$PV = n \times R \times T$$

$$RT = {}^{PV}/_{n}$$

The ideal gas relationship:

Hence,

$$a = \sqrt{\frac{R \times \gamma \times T}{M}}$$

It can be also written as,

$$a^2 = \gamma \times R_{gas} \times T_M$$

The conditions for these relationships are that the sound propagation process is adiabatic and the gas obeys the ideal gas laws.

R = 8.314 J/ mol-K and M = 0.004002602 kg/ mol

Hence, for a mean absolute temperature of 300 K the sound speed is found to be a = 1019.1047 m/s.

3.16. FREQUENCY

As the power in the thermo acoustic device is a linear function of the acoustic resonance frequency an obvious choice is thus a high resonance frequency. On the other hand, ΔK is inversely proportional to the square root of the frequency which again implies a stack with very small plate spacing. Making a compromise between these two effects and the fact that the driver resonance has to be maintained to the resonator resonance for high efficiency of the driver, the frequency of 238Hz was chosen [2].

3.17. WORKING GAS

After fixing the above values, it's time to choose the working gas. It should not be chemically reactive and should also have a high thermal conductivity. Owing to these reasons, helium is chosen. It is a noble gas and hence not reactive and has a high thermal conductivity [3]. It also has the highest sound velocity of all inert gases. Furthermore, helium is cheap in comparison with other noble gases. A gas with a high thermal conductivity is used since Δk is proportional to the square root of the thermal coefficient k. Having chosen Helium, its properties have to be noted down. Sometimes, accurate values at desired temperatures are not available necessitating the use of formulae to extrapolate those values to arrive at the values at the required temperature. Hence the following formulae are used to arrive at accurate values. The thermal conductivity of helium at required temperature is given by [3].

$$k = k_o \times [{}^{T}/_{TO}]^{bk}$$

The value of bk is 0.72 for Helium. At 300K the thermal conductivity is 0.1513 W/m K. The specific heat ratio of a mono-atomic gas like helium is 5/3. Specific heat is found to be 5192.872 and gas density of helium is 1.626 kg/m3 calculated using the formula

$$C_P = \frac{\gamma R}{(\gamma - 1)}$$

$$P = \rho RT$$

Prandtl number is a dimensionless parameter characterizing the ratio of kinematic viscosity to thermal diffusivity, which is a very important parameter to study the behaviour of gases in thermo acoustic devices.

Prandtl number is given by [3]

$\sigma = \mu \times Cp/_{K}$ The Prandtl number written in terms of thermal and viscous penetration depth is [3].

$$\sigma = (\delta v/_{\delta K})^2$$

Viscous friction has a negative effect on the performance of a thermo acoustic system. Decreasing the Prandtl number generally, increases the performance of a thermo acoustic device. Kinetic gas theory [4] has shown that the Prandtl number for monatomic gases is about 0.2. Lower Prandtl number can be realized using noble gases like Helium and coefficient of performance of refrigerator can be maximized. The value of can is obtained from either equation. They yield the same answer. Prandtl number of 0.6835 is obtained for pure Helium gas.

$$\delta_v = \sqrt{\frac{2\mu}{\rho\, m\, \omega}}$$

$$\delta_v = \sqrt{\frac{2K}{\rho\, m\, c_p\, \omega}}$$

A value of δv = 0.0987 mm and δv = 0.11941 mm was got by calculations.

3.18. STACK MATERIAL

The formulae of Qcn and Wcn can vary depending on parameters, initial assumptions, etc. Formulae are subject to an improvement over time. All formulae were noted, analysed and the best ones were chosen. Some formulae were obtained by theoretical calculations alone and which may not be validated through experiments/ working models. Taking these factors into consideration, a comparison of the chosen parameters with the initial assumptions was made.

The stack forms the heart of the refrigerator where the process of heat pumping takes place and it is thus an important element which determines the performance of the refrigerator.

3.19. STACK DESIGN

The stack was designed and normalization of parameters is carried out to aid simplification. The length and position of the stack can be normalized by /2. The thermal and viscous penetration depths can be normalized by the half spacing in the stack y0. The cold temperature or the temperature difference can be normalized by TM. Since k and v are related by Prandtl number ‘’, this will further simplify the number of parameters. The acoustic power W and the cooling power QC can be normalized by the product of the mean pressure PM, the sound velocity ‘an’ and the cross-sectional area of the stack A[3].PM × A × a

$$B = {}^{yo}/_{l + y0}$$

It is also used as a dimensionless parameter for the geometry of the stack. It is taken as 0.75. The thermal and viscous penetration depths are given by [5]

$$\delta_k = \sqrt{\frac{2k}{\rho\, m\, Cp\, \omega}}$$

Where, $\omega = 2\pi f$

$$\delta_v = \sqrt{\frac{2\mu}{\rho\, m\, \omega}}$$

Where k is the thermal conductivity, μ is the viscosity, ρ is the density, Cp is the isobaric specific heat of the gas, and ω is the angular frequency of the sound wave.

These resultant normalized parameters are given an extra index n. The number of parameters can once more be reduced by making a choice of some operation parameters and the working gas. Values for δk and δv were found to be 0.11941 mm and 0.0987 mm respectively.

3.20. RESULT

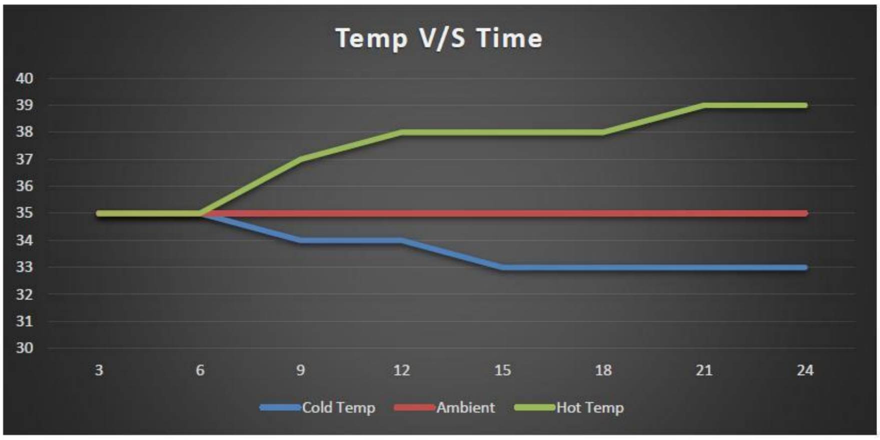
The results have shown that the performance of the refrigerator depends on the working gas, the pressure inside the resonator tube, shape of the resonator tube, material, position and length of the stack. Another merit of this device is that it could provide cooling and heating simultaneously, that is cooling from the cold-end and heating from the hot-end. Based on the results of the present investigation the following conclusions may be drawn:

1. Without the stack, the temperature along the resonator tube is almost constant the variation is within 0.5°C.

2. Temperature distribution along the resonator is significantly affected by the presence of stack. After nearly 18 minutes of operation, a temperature gradient of 7 °C was established across the stack.

3. The position of the stack is important in order to get maximum temperature gradient across the stack.

4. The power input is important to get the maximum temperature gradient across the stack; therefore an efficient acoustic driver is very important to get better COP



4. FUTURE SCOPE & CONCLUSION

4.1 CONCLUSION

We set out upon this project with the simple goal of constructing a cheap, demonstrative model of a thermoacoustic refrigerator. To this end we succeeded: this experiment proved that thermo-acoustic refrigerators indeed work. Additionally, this experiment did yield some discoveries regarding the efficiency of thermo-acoustic

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Refrigeration. It was revealed that finding the optimal frequency is essential for the maximization of efficiency. This optimal frequency was found using trial-and-error because the equation used to calculate frequency was ineffective. Another factor that increased efficiency was the proper sealing of the apparatus. If the parts are not properly sealed, heat escapes from the refrigerator, and it does not function as well. However, the overall efficiency of such an apparatus is debatable. Our research shows that thermo-acoustic refrigeration has the potential to replace conventional refrigeration.

4.2 FUTURE SCOPE

The use of inexpensive, household items to construct the refrigerators could explain such low efficiency. If other materials were used, it is possible that the factor that could be adjusted for optimization. The stack works best when it is centered on a region in the tube where the standing wave produces the highest pressure (and thermal) forces. Experimenting with different frequencies and stack placements could yield greater efficiency. We also concluded that the shape and length of the resonator tube was a major factor in the efficiency of the device. Improvements to the resonator tube would involve further research into the effects that differently shaped tubes would have on the thermo-acoustic effect. Perhaps a resonator tube which was tapered to focus the intensity of the wave and therefore increases both the pressure and temperature maximum would increase effectiveness. However, as stated above further research is required to ascertain the resonator tube shape of maximum efficiency. Other tube factors that should be explored include tube diameter and length. Due to the correlation between the resonator tube and the frequency used these two factors would have to be experimented with simultaneously. If peak efficiency was to be achieved, the most optimal solution would be to model the acoustic properties by computer simulation and predict efficient tube-frequency combinations in that manner.

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