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Thermoacoustic Refrigeration System

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ABSTRACT

Thermo acoustic have been known for over years but the use of this phenomenon to develop engines and pumps is fairly recent. Thermo acoustic refrigeration is one such phenomenon that uses high intensity sound waves in a pressurized gas tube to pump heat from one place to other to produce refrigeration effect. In this type of refrigeration all sorts of conventional refrigerants are eliminated and sound waves take their place. All we need is a loud speaker and an acoustically insulated tube. Also this system completely eliminates the need for lubricants and results in 40% less energy consumption. Thermo acoustic heat engines have the advantage of operating with inert gases and with little or no moving parts, making them highly efficient ideal candidate for environmentally-safe refrigeration with almost zero maintenance cost. Now we will look into a thermo acoustic refrigerator, its principle and functions.

Keywords: **Thermoacoustic refrigerator, resonator tube, stack, stack spacing, stack geometry.**

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I. INTRODUCTION

Creating comfortable home environments to manufacturing fast and efficient electronic devices, air conditioning and refrigeration remain expensive, yet essential, services for both homes and industries. However, in an age of impending energy and environmental crises, current cooling technologies continue to generate greenhouse gases with high energy costs. Thermoacoustic refrigeration is an innovative alternative for cooling that is both clean and inexpensive. Through the construction of a functional model, we will demonstrate the effectiveness of thermoacoustics for modern cooling. Refrigeration relies on two major thermodynamic principles. First, a fluid's temperature rises when compressed and falls when expanded. Second, when two substances are placed indirect contact, heat will flow from the hotter substance to the cooler one. While conventional refrigerators use pumps to transfer heat on macroscopic scale, thermoacoustic refrigerators rely on sound to generate waves of pressure that alternately compress and relax the gas particles within the tube. The model constructed for this research project employed inexpensive, household materials. Although the model did not achieve the original goal of refrigeration, the experiment suggests that thermoacoustic refrigerators could one day be viable replacements for conventional refrigerators.

The entire features mentioned above is possible only because sound waves in thermo acoustic engines and refrigerators can replace the piston and cranks that are typically built into any machinery. These thermo acoustic devices produce or absorb sound power, rather than the shaft power characteristic of rotating machinery making it mechanically simple

II. PROBLEM STATEMENT

In today's world we are much more conscious toward reason for global warming. One of the crucial reason for global warming is depletion of ozone layer. Use of refrigerant in refrigeration system causes leakage CFC's & ammonia gases which are responsible for ozone depletion layer. So there is need of alternatives of refrigerant and study of THERMOACOUSTIC REFRIGERATION is introduced.

OBJECTIVE

Thermoacoustic refrigeration is an innovative alternative for cooling that is both clean and inexpensive. Through the construction of a functional model, we will demonstrate the effectiveness of thermo acoustics for modern cooling.

FUTURE SCOPE

Thermoacoustic refrigeration also has a broad range of applications, including computers and nanotechnology. It will likely be employed by the military and space program, due to its low-maintenance, toxin free, high-reliability cooling methods.

III. STANDING-WAVE THERMOACOUSTIC REFRIGERATOR

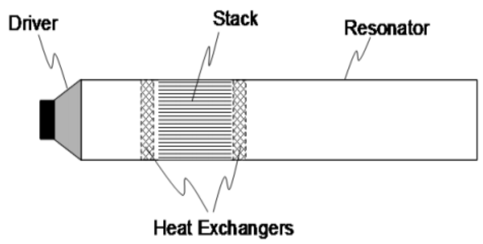


Figure1. Configuration of TAR

The configuration of standing-wave thermoacoustic refrigerators is simple. A standing-wave TAR comprises a driver, a resonator, and a stack. To make the device practical, it must also utilize two heat exchangers; however, they are not necessary for creating a temperature difference across the stack. The parts are assembled as shown in the driver, which is often a modified electrodynamic 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 thermoacoustic proceed 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 thermoacoustic core of a standing-wave TAR no matter the core's geometry.

Thermo acoustic Refrigeration System mainly consist of a loudspeaker attached to an acoustic resonator (tube) filled with a gas. In the resonator, a stack consisting of a number of parallel plates and two heat exchangers are installed. The loudspeaker, which acts as the driver, sustains acoustic standing waves in the gas at the fundamental resonance frequency of the resonator. The acoustic standing wave displaces the gas in the channels of the stack while compressing and expanding respectively leading to heating and cooling of the gas. The gas, which is cooled due to expansion absorbs heat from the cold side of the stack and as it subsequently heats up due to compression while moving to the hot side, rejects the heat to the stack. Thus the thermal interaction between the oscillating gas and the surface of the stack generates an acoustic heat pumping The heat exchangers are used so that heat interaction with the surrounding takes place. Heat is pumped from the cold end heat exchanger to the hot end heat exchanger.[2] the pressure variation and displacement of sound waves in thermo acoustic refrigeration system [5].

It is known that sound waves are longitudinal waves. They produce compression and rarefaction in the medium they travel. Maximum pressure occurs at the point of zero velocity and minimum pressure at maximum velocity. action from the cold side to the hot side. The heat exchangers exchange heat with the surroundings, at the cold and hot sides of the stack.

IV. WORKING

Linear acoustic theory, first developed by Rott [13-17], is applicable to both thermoacoustic refrigerators and engines; the only difference is the size of the temperature gradient along the stack. Before deriving the general theory, a few assumptions should be noted. Consider a single stack pore of arbitrary cross-section. The pore is taken to be long and narrow (of infinite length).

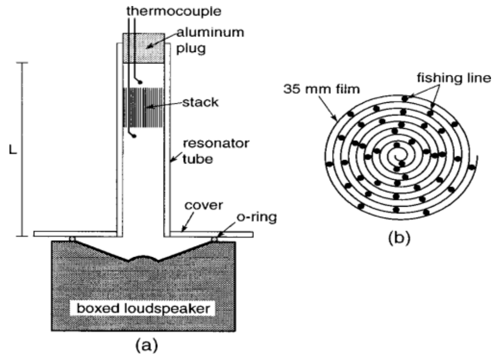


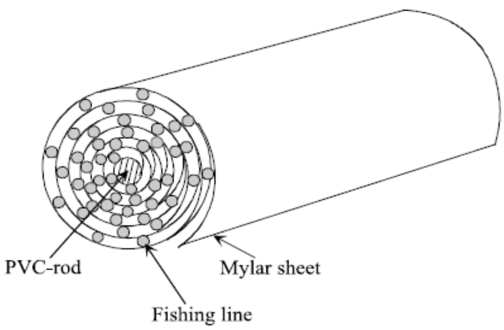
Figure 2. working diagram

A coordinate system is applied such that y and z are transverse coordinates and the x-axis lies in the longitudinal direction.

The pore walls are considered rigid and their temperature a function of x alone. Furthermore, it is assumed that the walls have a sufficiently high heat capacity that their temperature is not locally affected by the temperature fluctuations in the gas. Note that all temperature-dependent physical parameters are implicitly dependent on x due to the temperature gradient in that direction. Finally, all acoustic variables are taken to be harmonic in time with radian frequency, ω. Following Arnott et al. , expressions for pressure, particle velocity, and heat and work flows will be derived. The fluid's acoustic variables .

STACK MATERIAL

A stack material should be selected first so that its properties can be taken into account while choosing other parameters. The material chosen should have a low thermal conductance. As a TAR's main purpose is to move heat from one end of the stack to the other, heat conduction in the opposite direction (from the hot end to the cold end) results in a reduction of efficiency.



I

Figure -stack

the thermal conductivity is too high, the situation is analogous to carrying water uphill with a leaky bucket. The material should also have a larger specific heat capacity than the gas. A stack with a larger heat capacity is less affected by the temperature oscillations of the nearby gas, which is desirable because it allows the temperature gradient along the stack walls to remain steady, increasing the effectiveness of the gas in transporting thermal energy from the cold end to the hot end of the stack. Due to the necessary thermal properties, ceramic and plastic materials are often chosen as stack materials.

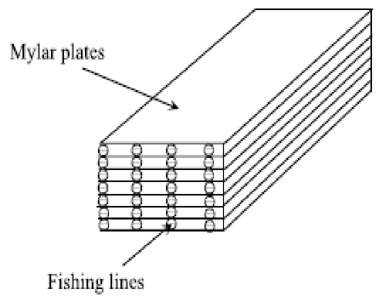


Figure- flat plate stack

ACOUSTIC DRIVER

A thermo acoustic cooling device requires 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 the electric power to the acoustic power. In this study a loudspeaker with an operating frequency of 178 *Hz* was used as the acoustic driver.

Figure-speaker

ACOUSTIC RESONATOR

The acoustic resonator was built from a straight CPVC pipe of length 385 mm and diameter 28mm. One end of the tube was open to attach the speaker and the other end is also open. In this design the resonant frequency of the resonator is 178 *Hz*. Thus the length of the tube was set equal to 385 mm that corresponds to the quarter wavelength of the acoustic wave generated at this frequency.

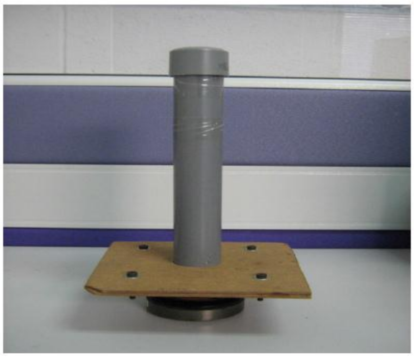


Figure- resonator

STACK SPACING, LENGTH AND POSITION

Using equations we have computed the thermal and viscous penetration depths for our system, i.e. $\delta k = 0.199215$ mm and $\delta v = 0.1675$ mm. The distance between the two plates is set in way that the gas between the two plates remains in thermal contact with the surface of either of the two plates, with the minimum possible viscous effect. The Optimal value for spacing between the stack layers is $2^* \delta k$ to $4^* \delta k$.

With a known frequency of operation, dimensionless heat and work flow equations were used to calculate and plot performance curves for various stack lengths and positions relative to the speaker. These equations were derived from the exact partial differential equations by making some simplifying assumptions The dimensionless forms of these equations, as derived by Tijani et al. [11], further simplify the design process. Although the dimensionless forms were not absolutely necessary, they are included here to allow future design endeavors to follow a different path.

The main assumptions made in the derivation from the exact equations are the short-stack and boundary-layer approximations [12]. The short-stack approximation states that the length of the stack is much less than the acoustic wavelength at the TAR's operating frequency. The boundary-layer approximation is used to greatly simplify the coupled equations governing the fluid motion and heat transfer. These assumptions have a few implications. First, the velocity and pressure of the gas can be considered constant over the length of the stack [15]. Although no Thermoacoustic effect would take place if pressure was constant; this approximation is acceptable because, if the stack is sufficiently short, the variation in pressure from one end to the other is small in comparison to the full acoustic pressure amplitude , p0 . Next, under the approximations it is assumed that the temperature difference across the stack ΔTm, is much less than the, average absolute temperature, Tm. This assumption allows the thermophysical properties of the, working gas and stack to be taken as constants within the stack [8]. Away from the stack, temperature should only vary by the acoustic temperature amplitude, which is even smaller than the temperature difference across the stack. It follows that the thermophysical material properties can be considered constant everywhere, simplifying the general equations.

Operating parameters
Drive ratio : D = p0 / pm
Norm. cooling power : Qcn=Qc/ pm aA
Norm. acoustic power : Wn = Wn /pm aA
Norm. temperature difference : $\Delta T_{mn} = \frac{\Delta T_m}{T_m}$

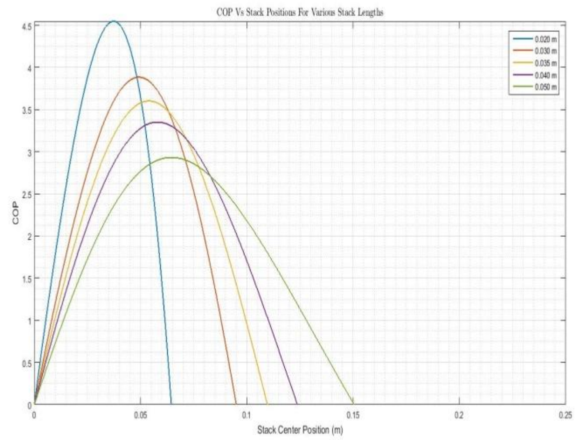
Gas parameters

Norm. Thermal penetration depth : $\delta_{kn} = \frac{\delta_k}{y_o}$

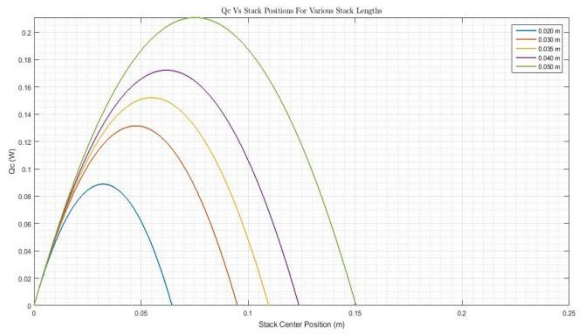
Stack geometry

Norm. stack length : $Lsn = \frac{2\pi f}{a} Ls,$

Norm. Stack position : $Xsn = \frac{2\pi f}{a} Xs,$



Graph-1 COP Vs Stack Centre Position For Various Stack Lengths (For 2* δ_k)



Graph-2 Cooling Power Vs Stack Center Position For Various Stack Lengths (For 2* δ_k)

RESULTS AND DISCUSSIONS

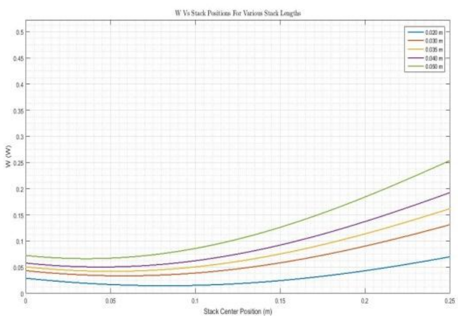
We performed the two trials.1st trial has stack of length 3 cm and second trial has stack length. During first trial we placed the stack at 6 cm from sound face and for second trial we placed stack on 7 cm from face.

We took readings of hot side and cold side of stack using digital thermometer at interval of 5 min for total 25 min. Four sets of data tabulated below for each stack.

We analyze the performance of thermo acoustic refrigeration system and we get a temperature difference of 10-15 degree Celsius between the two ends of the stack. Also we achieved lower side temperature decreasing by 1 to 2 degree Celsius with respect to atmospheric temperature.

This simple and inexpensive thermoacoustic refrigerator effectively demonstrates the basic physical principles behind its operation. As shown, however, it is rather inefficient as a heat transfer device. If both ends of the stack were connected to heat exchangers, thus coupling the stack to a heat source or heat sink, the transfer of heat would be more efficient.Other improvements could be made by modifying the shape of the resonator4 or increasing the stack layer separation to an optimal four thermal penetration depths.1 One could also study the performance as a function of sound level inside the resonator. Such studies might make for an interesting senior research project.

A method for improving the heat transfer within the tube would be to use helium as the sound medium. Of all gases, helium behaves the most like an ideal gas in that diatomic helium molecules exhibit weak electrostatic attractions upon each other. Due to low dispersion forces and a low atomic mass, helium molecules have a greater thermal conductivity than any other gas except for hydrogen. Hydrogen gas, however, is reactive, whereas helium is relatively inert. Using helium as a sound medium, though beyond the reach of this study, would only require an evacuated airtight tube that would then be pressurized with the helium gas. This process is used in many professional-grade thermoacoustic refrigerators where helium gas has led to increased efficiency and heat transfer across the stack. Unfortunately we could not try this modification because of a lack of materials.



Graph3 –Acoutic power vs stack length

MEAN PRESSURE

Mean Pressure, is proportional to the power density of a thermoacoustic refrigerator. For this reason, it is desirable to choose a large average pressure; however, other factors limit the pressure, including the mechanical strength of the resonator and the effect of pressure on the thermal penetration depth.

Higher pressures require a stronger pressure vessel. Designing a stronger resonator often
leads to more expensive materials and a heavier, bulkier overall TAR. In addition to these drawbacks, a higher internal pressure makes it more difficult to seal the working gas inside. Sealing the TAR can be especially problematic when working with helium due to its small molecular size. Another consideration is the effect of pressure on the thermal penetration depth. The thermal penetration depth is inversely proportional to the square root of the mean pressure, so as pressure increases, the thermal penetration depth shrinks. The mean pressure was chosen to be 1 atmosphere, or 101 kPa. Although the resonator could certainly have held higher pressures, other effects needed to be considered.

V. 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 increase 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.

APPLICATIONS

Thermal management has always been a concern for computer systems and other electronics. Computational speeds will always be limited by the amount of noise produced by computer chips. Since most noise is generated by waster heat, computer components and other semiconductor devices operate faster and more efficiently at lower temperatures.8 If thermoacoustic cooling devices could be scaled for computer applications, the electronic industry would realize longer lifetimes for microchips, increased speed and capacity for telecommunications, as well as reduced energy costs Although this project was specifically designed to test the effectiveness of thermoacoustic refrigeration for electronic devices, low-cost, high efficiency cooling devices have broad applications in commercial industries and households. Research conducted by Professor Steven Garrett at Pennsylvania State University has yielded reliable air conditioning devices used in submarines and space shuttles[10].However; future applications of thermoacoustic air conditioners would not be restricted to industrial uses but could offer inexpensive heating and cooling for homes. Additionally, since current air conditioners use HFCs and other potentially harmful chemicals, thermoacoustic cooling systems that employ inert gases would have long-term benefits on the environment [10]. One thermoacoustic device could potentially operate an entire household's air conditioner, water heater, and furnace, eliminating the need for natural gases and oils.

VI. CONCLUSION

Thermo acoustics is a promising area, which if properly explored, could serve as a good refrigeration system. However, the performance of these device is currently very low. The main motivation for the present work was to develop a simple thermo acoustic refrigerator that is completely functional. This project reports on the design and fabrication of a simple thermoacoustic refrigeration system with inexpensive and readily available material. The characteristic of the fabricated refrigerator and its performance were analyzed experimentally and the results are discussed. The results have shown that without a stack, no temperature gradient is established inside the resonator. Once the stack is placed the temperature gradient is established across the stack. For the given operating condition a temperature gradient of 10-15 degree Celsius could be established across the stack. Our device worked as a proof of concept device showing that a thermo acoustic device is possible and is able to cool air, for only a short period of time. If we were able to build the device with better materials, such has a more insulating tube, we might have been able to get better results. In order to create a working refrigerator we probably would have to attach a heat sink to the top of the device, thus, allowing the excess heat to dissipate to the surroundings.

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