DESIGN AND FABRICATION OF THERMO ACOUSTIC REFRIGERATOR

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ABSTRACT

In an age of impending energy and environmental crises, current cooling technologies continue to generate greenhouse gases with high energy costs. Thermo acoustic refrigeration is an innovative alternative for cooling that is both clean and inexpensive.

Thermo acoustic refrigerators are systems which use sound waves and a non-flammable mixture of inert gases to generate refrigeration effect. The main components are a closed cylinder, an acoustic driver, a porous component called a stack, and two heat-exchangers. Application of acoustic waves through the driver makes the gas resonant. As the gas oscillates back and forth, it creates a temperature difference along the length of the stack. This temperature change is due to compression and expansion of the gas by the sound pressure and the rest is a consequence of heat transfer between the gas and the stack. The temperature difference is used to remove heat from the cold side and reject it at the hot side of the system, producing cooling.

KEYWORDS: *Thermo Acoustic Refrigeration, Sound Waves, Inert Gases, Stack, Heat Exchangers.*

I. INTRODUCTION

Thermo acoustic refrigeration is a recent technology that has been proposed to obtain cooling energy from high amplitude sound waves. Thermo acoustic refrigeration uses advanced acoustic technology to improve cooling capacity without the need for environmentally destructive refrigerants. The subject of Thermo acoustic refrigerator (TAR) is a test-bed for thermo acoustic theory and a major step toward achieving a practical thermo acoustic cry cooler. Thermo acoustics deals with the conversion of heat energy to sound energy and vice versa. 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. The efficiency or the thermo acoustic devices is currently lower than that of their conventional counterparts, which need to be improved to make them competitive. In addition, other considerations for a competitive thermo acoustic device are its low cost, high reliability, safety, compactness, and ease for mass production.

There are, however, noteworthy technical challenges related to the design and construction of efficient, robust, economical thermo acoustic cooling system. Furthermore, thermo acoustic system performance is very sensitive to the choice of design parameters and should be optimized to achieve a reasonable efficiency.

Efforts have been made to optimize the design of thermo acoustic coolers by improving stack geometry, gas mixture, thermal insulation, duct and other parameters.

II. LITERATURE REVIEW

Steady heat transfer enhancement has been studied in helically coiled-tube heat exchangers. The outer side of the wall of the heat exchanger contains a helical corrugation which makes a helical rib on the inner side of the tube wall to induce additional swirling motion of fluid particles. Numerical calculations have been carried out to examine different geometrical parameters and the impact of flow and thermal boundary conditions for the heat transfer rate in laminar and transitional flow regimes.

Comparison of the flow and temperature fields in case of common helical tube and the coil with spirally corrugated wall configuration are discussed [1].

The fuzzy logic expert system (FLES) for heat transfer performance investigation in helically coiled heat exchanger with spirally corrugated wall operated with water and CuO/water nanofluids. Compared with traditional logic model, fuzzy logic is more efficient in connecting the multiple units to a single output and is invaluable supplements to classical hard computing techniques. Hence, the main objective of this analysis is to investigate the relationship between heat exchanger working parameters and performance characteristics, and to determine how fuzzy logic expert system plays a significant role in prediction of heat transfer performance. Analytical values are taken in helically coiled heat exchanger with spirally corrugated wall operated with water and CuO/water nanofluids for investigation of heat transfer performance [2-5].

The inner tube of the concentric-tube heat exchanger has a sinusoidal, wavy surface in the longitudinal direction, which enables heat-transfer enhancement. The tube can be stretched to a certain extent and thus change the corrugation of the heat-transfer surface area. We designed an experiment in which we used the Wilson-plot method to separately determine the convective heat-transfer coefficient on the inside and outside of the inner tube of the concentric-tube heat exchanger with different corrugation ratios. Based on the measurements correlation equations were developed to calculate the convective heat-transfer coefficient for any corrugation ratio, which allows us to simplify the design of local ventilation devices [6-9].

Heat transfer coefficient and entropy generation rate of helical coil heat exchanger were analytically investigated considering the nanofluids volume fractions and volume flow rates in the range of 1–4% and 3–6 L/min, respectively. During the analyses, the entropy generation rate was expressed in terms of four parameters: particle volume concentration, heat exchanger duty parameter, coil to tube diameter ratio and Dean Number [10-15].

III. MOTIVATION FOR THERMO ACOUSTIC REFRIGERATION

The development of thermo acoustic refrigeration is driven by the possibility that it may replace current refrigeration technology. Thermo acoustic refrigerator, which can be made with no moving parts, are mechanically simpler than traditional vapor compression refrigerators and do not require the use of harmful chemicals.

Because of its simplicity, TARs should be much cheaper to produce than our own conventional technology. The parts are not inherently expensive, so the initial manufacturing costs are low. Furthermore, mechanical simplicity leads to reliability as well as cheaper and less frequent maintenance.

Besides reduced financial cost, environmental cost should be considered. Traditional vapour compression systems achieve their efficiencies through the use of specialized fluids that when released into the atmosphere, accidentally or otherwise cause threat to the environment by ozone depletion. Even most of the alternative fluids being developed have a possibility to cause harm in one way or another. For example, propane and butane don’t destroy the ozone, but are highly flammable and pose a threat when leaked. On the other hand, TARs easily accommodate the use of inert fluids, such as helium, that cause no harm to the environment. Also, normal operating pressures for TARs are about the same as for vapour compression systems, so thermo acoustic refrigeration is just as safe in that respect. Overall, thermo acoustic refrigeration is much more benign than conventional refrigeration methods in terms of environmental and personal safety.

One drawback, however, is lack of efficiency in current TARs when compared to vapour compression. Traditional refrigeration techniques have had the benefit of generations of research and application whereas thermo acoustic refrigeration is a new technology, so it is no wonder that vapour compression refrigerators are currently more efficient. There is reason to believe that thermo acoustic refrigeration will overtake vapour compression in the long run. The major reason is that a TAR can be driven with proportional control, but vapour compression schemes are binary (on/off). A normal refrigerator must switch off and on to maintain a given temperature; so the compressor is working its hardest whenever it is on, and the temperature actually oscillates around the desired value. In contrast, a refrigerator capable of proportional control, such as a TAR, can tune its power output to match the requirements of the load; so if the load increases a small amount, the refrigerator can slightly increase its power for a short time rather than running full tilt. This is especially advantageous in applications where thermal shocks can cause damage, such as cooling electronics.

IV. DESIGN CONSIDERATIONS

A Thermo acoustic refrigerator basically consists of an acoustic power source, a resonator, a stack.

4.1. Acoustic Driver

The sound waves required by the refrigerator are produced by an acoustic driver fitted at one end of resonator tube. Large amount of power from acoustic driver is consumed to pump heat across the stack and rest is dissipated to various parts of refrigerator. Basically it converts electrical power into acoustic power. High performance is essential for better results of system.

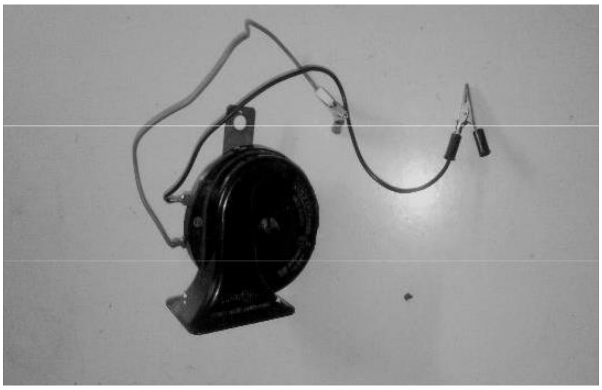

Fig.1 Acoustic Driver

4.2. Stack

Stack is the main component of Thermo acoustic refrigerator across which temperature gradient is obtained. The amount acoustic power that can be used pump heat depends on several aspects of stack like, stack positioning, its material and dimensions. It should have high heat capacity and low thermal conductivity as compared to working medium. Low thermal conductivity is essential to minimize the losses through conduction from hot side of stack to cold side of stack. Length and shape of stack determines how much the sound waves propagate through it.

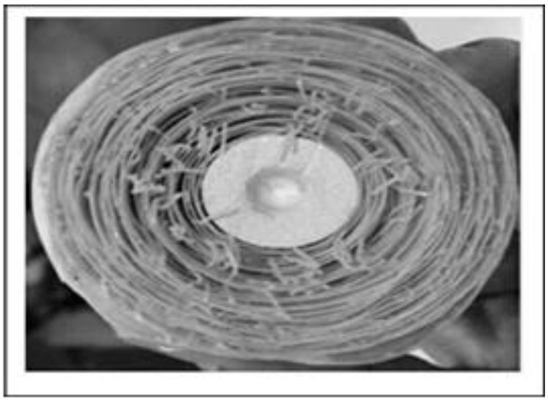

Fig.2 Stack

4.3. Resonator Tube

A resonator tube is a long hollow pipe which is a cylindrical tube having an air column. Resonator should be compact, lightweight and strong enough to sustain the working pressure. Consideration of shape, length, weight and the losses are important parameters to focus on while designing the resonator. The length of total resonator tube is equal to quarter of the wavelength of the standing wave is: L= λ /4 and λ =a/f, where, “a” is the speed of sound, “ λ” is the wavelength and “f” is the resonance frequency.

4.4. Digital Temperature Indicator

An electronic digital temperature indicator is used to display the temperature readings.

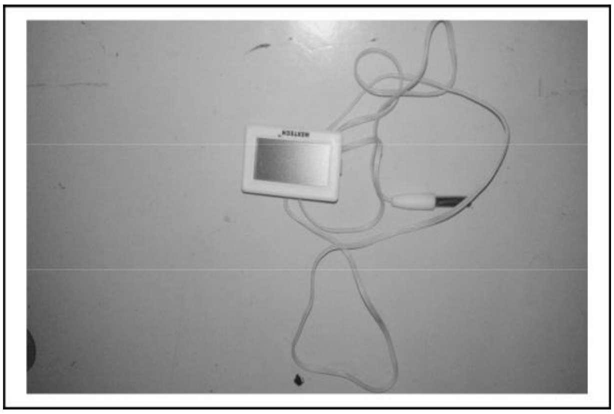

Fig.3 Digital Temperature Indicator

4.5. Working Gas

To achieve high efficiency inert gases like Helium, Xenon, etc. are preferred. They possess low kinematic viscosity as compared to other gases which makes it possible for molecules to vibrate freely even in a small portion resulting in high utilization of gas molecules to participate in heat transfer. It has the characteristics like high velocity of sound and high mean pressure required to generate high acoustic power. Inert gases have certain issues like leakages; cost, refilling, etc. therefore air with high pressure can also be used as a working medium.

4.5.1. Properties Of Helium Gas

Thermal conductivity, (K)	0.138W/ (m*K)
Ratio of specific heats, (γ)	5/3
Isobaric specific heat, (C_p)	5193.2 J/ (kg*K)
Prandtl number, (σ)	0.68
Specific ideal gas constant, (R_s)	2077
Density at NTP, (ρ)	0.1664 kg/m^3

V. HEAT EXCHANGERS

In this project, we use two types of heat exchangers, one is a cold heat exchanger and the other is hot heat exchangers made up of copper sheet and are fixed on either side of the stack which differ only in there width. The heat exchangers have a sine channel structure which is chosen because of ease of construction. Two copper sheets are wound together to provide this geometry. The sheets are 0.15 mm thick and 3 mm width for the cold heat exchanger and 5mm width for the hot heat exchanger. One sheet is flat and the other sheet has a sine shape. The sine shape is achieved by passing a flat sheet between toothed wheel systems. The top-to-top height of the sine structure is controlled by the spacing between the wheels and the tooth size. This height is chosen to be 0.1mm so that the needed porosity of 0.63 is obtained.

VI. EXPERIMENTATION

The thermo acoustic refrigerator consists of an acoustic driver housing, an acoustic driver, two heat exchangers, stack, and a resonator. Four holes are made on the stack holder to place the heat exchangers inside the tube. Firstly, we mount the hot and cold heat exchangers inside the stack holder. Two thermocouples are attached to both sides of the stack, touching the hot and cold heat exchangers, to measure the inlet and outlet temperatures of both the heat exchangers. The inlet and outlets of both heat exchangers are extended and connected with rubber pipes for the flow of water through the heat exchanger. After passing the inlet and outlet pipe from the stack holder wall, the holes are sealed using araldite. Finally, the acoustic driver is attached to its housing with the resonator tube using six M8 bolts.

Fig.4 Experimental set up after the whole assembly

6.1. Measurements

In this section, some basic thermo acoustic measurements, using the experimental set-up is introduced.

6.2. Set-Up

The thermo acoustic refrigerator that having a tube of length 645mm, and inner diameter 49.8mm.The resonator is filled with air at atmospheric pressure. The stack has a diameter of 49.8mm and a length of 50mm, and can easily be installed inside the resonator tube. At one end the resonator is driven by a commercially available loudspeaker. This driver is mounted in an acrylic housing to which the resonator is connected. The other end of the resonator is closed by a thick removable cover plate. The system is not thermally insulated, and can simply be set on a table to demonstrate thermo acoustic cooling.

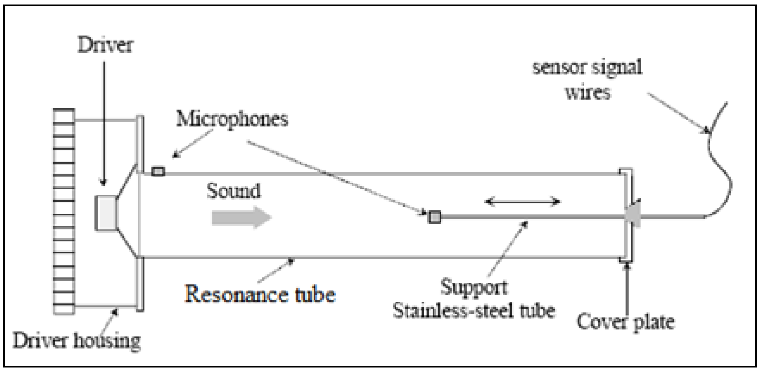

Fig.5 Set up used to measure the acoustic pressure distribution

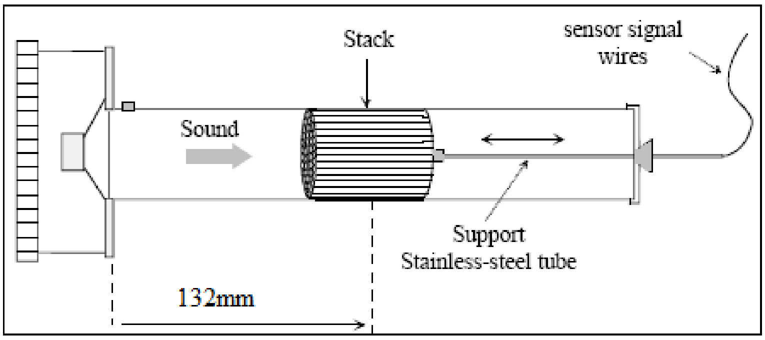

Fig.6 Set up used to measure the temperature difference over the stack as a function of position.

The acoustic pressures are measured using microphones. To measure the pressure distribution along the resonant tube, a microphone is mounted on the end of a hollow 1mm diameter stainless steel tube. The tube serves both to allow a free positioning of the microphone inside the resonance tube and to extract the microphone leads. It measures the dynamic pressure and is used for determining the resonance frequency.

VII. EXPERIMENTAL RESULTS

In this chapter the experimental results are presented. Here the results after the complete installation of the heat exchangers are being presented.

7.1. Temperature Distribution in the Resonator Tube with Stack

In this set of experiments, the effect of the nomex stack on the temperature field inside the resonator was investigated. The centre of the stack was mounted inside the resonator at a distance of 127mm from the driver end and a standing wave was generated inside the resonator. Two thermocouples were placed on either side of the stack. The data was acquired for 16 minutes 20 sec.

Table.1 Temperature Difference across the Nomex Stack at NTP

Time (sec)	Cold Heat exchanger	Hot Heat Exchanger
0	31	29
1	30	30
2	29	30
2.3	29	31
3.55	28	31
7.05	27	31
7.42	28	31
8.04	28	32
8.28	28	31
9.3	27	31
10.1	28	31
11.3	28	33
11.45	27	32
13.43	28	32

The time series of the temperature at both the location are plotted at NTP. The plot shows that the all the locations were at the same temperature 29°C. When the speaker was turned on, a standing wave was created inside the resonator, and the thermo acoustic process was initiated. Once, the thermo acoustic process started, the parcel of air start transferring heat from the cold-end of the stack started to decrease and the temperature of the hot end of the stack started to increase. A temperature difference as high as 7°C was observed across the stack approximately 16 minutes 20 seconds after the beginning of the thermo acoustic process.

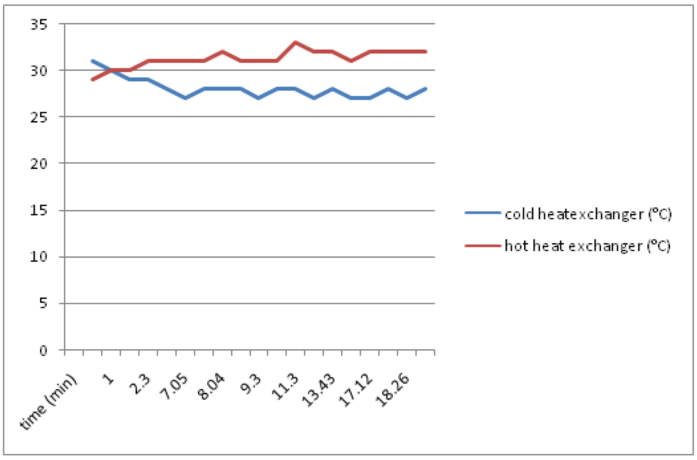

Fig.7 Time evolution of the measured temperature across the nomex stack at NTP

The plot shows that the temperature at the hot end of the stack increases continuously with time, whereas, the temperature at the cold end of the stack decreases sharply for the first 12 minutes, remains constant for approximately 90sec and the increased by 1°C.

7.2. Temperature Distribution in the Resonator Tube with Ceramic Stack

In this set of experiments, the effect of the ceramic stack on the temperature field inside the resonator was investigated. The centre of the stack was mounted inside the resonator at a distance of 127mm from the driver end and a standing wave was generated inside the resonator. Two thermocouples were placed on either side of the stack. The data was acquired for 17 minutes 49 seconds.

Table.2 Temperature Difference across the Ceramic Stack at NTP

Time (sec)	Cold Heat exchanger	Hot Heat Exchanger
0	32	32
0.29	31	33
1.2	31	32
1.31	31	33
2.26	30	32
2.37	30	31
2.59	30	32
4	30	33
4.24	30	32
5.07	30	33
6	30	32
7	30	33
8	30	32
9	30	32
10	30	33

The time series of the temperature at both the location are plotted at NTP. The plot shows that the all the locations were at the same temperature 29°C. When the speaker was turned on, a standing wave was created inside the resonator, and the thermo acoustic process was initiated.

Once, the thermo acoustic process started, the parcel of air start transferring heat from the cold-end of the stack started to decrease and the temperature of the hot end of the stack started to increase. A temperature difference as high as 4°C was observed across the stack approximately 17 minutes 49 seconds after the beginning of the thermo acoustic process.

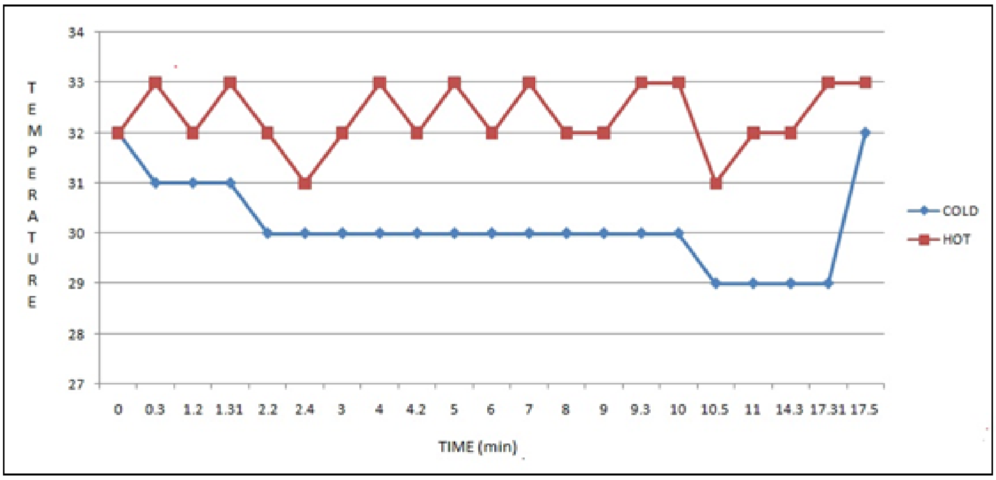

Fig.8 Time Evolution of the Measured Temperature across the Ceramic Stack at NTP

The plot shows that the temperature at the hot end of the stack increases continuously with time, whereas, the temperature at the cold end of the stack decreases sharply for the first 14 minutes, remains constant for approximately 75seconds.

VIII. APPLICATIONS

Low cost, high efficiency eco-friendly cooling devices such as Thermo acoustic have broad applications in households and commercial industries. Since most of the noise generating electronic components, e.g. semiconductor devices, operate faster and more effectively at lower temperatures. If Thermo acoustic could be employed in electronic industries then overall efficiency of electronic devices can be increased. Future applications of Thermo acoustic cooling devices would not be restricted to industrial uses only but also could provide inexpensive heating and cooling for homes.

IX. CONCLUSIONS

Thermo acoustic is a promising area which if properly explored could serve as a replacement to conventional refrigeration. In a thermo acoustic system the acoustic wave is used as a input to generate refrigeration effect. However the efficiency of these systems id currently low so cannot compete with their conventional counter parts. The main motive for the present work was to develop a simple thermo acoustic refrigerator that is completely functional. This project reports on the fabrication, development and testing of a simple thermo acoustic system for the refrigeration application. The results have shown the performance of the refrigerator depends on the working gas, pressure in the resonator tube, position and length of the stack.

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