DESIGN AND FABRICATION OF THERMO ACOUSTIC REFRIGERATION SYSTEM

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ABSTRACT

The pulse tube refrigerator (PTR) is a cryocooler which is capable of reaching temperature of a few tens of Kelvin in a single stage and a few Kelvin in two stages. Unlike ordinary refrigeration cycles which utilize the vapor compression cycle, a PTR implements the oscillatory compression and expansion of gas within a closed volume to achieve the desired refrigeration. Pulse tube refrigerator has the advantages of long–life operation, high reliability and low vibration over the conventional cryocoolers, such as G-M and Stirling coolers because of the absence of moving parts at their low temperature end. Due to its associated advantages, pulse tube refrigerators have several applications such as cooling of infrared sensors, night vision equipments, SQUID, cryopumping etc.

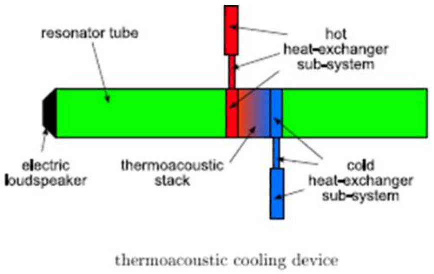
Keywords: Acoustic driver/loudspeaker, Heat exchangers, Resonator, Stack, Thermo acoustics, Tijani’s model

1.INTRODUCTION

Thermoacoustics deals with effects in acoustics wherein heat conduction and entropy variations of a medium play a role. It involves study of interactions between temperature oscillation and pressure oscillations due to sound waves within solid boundaries. Thermo acoustic refrigeration employs thermo acoustic principles to a practical refrigeration problem. Thermo acoustic refrigeration is an innovative alternative for cooling that is both clean and inexpensive. Through the construction of a functional model, we have demonstrated the effectiveness of thermo acoustics for modern cooling. Thermo acoustic refrigeration is an emerging refrigeration technology which does not require any moving parts or harmful refrigerants in its operation s.The illustrated work is also an alternative to conventional systems marred with high energy costs and detrimental effects to the environment.

2.WORKING PRINCIPLE

Thermoacoustic 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 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.



Working layout

3. IMPLEMENTATION

3.1. EXPERIMENTAL SETUP

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

Schematic of the Thermoacoustic Refrigerator

3.2. ACOUSTIC DRIVER

A thermoacoustic 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. Efficiency of this type of loudspeaker is relatively low, and their impedances are 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 thermoacoustic device is the stack inside which, the thermoacoustic phenomenon occurs. Thus, the characteristics of the stack have a significant impact on the performance of the thermoacoustic device. The stack material should have good heat capacity but low thermal conductivity. The low thermal conductivity for the stack 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

STACK

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 lower temperature, or exhibit non ideal behavior.

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 resonator so as to change the fundamental frequency of the resonator.

RESONANCE TUBE

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.

SPEAKER

3.7. THERMOCOUPLE

J-type thermocouples is 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 °C
- Limits of Error:-1.0 °C or 0.75% above 0°C.

3.8. PVC CAP SEALINGS & ALUMINIUM END PLUG

PVC pipes are made to contain the speakers, along with threads to make air tight zones. Aluminium eng plug is placed at the end of the resonator tube to dissipate the heat generated.

4.PRECEDING PROJECTS

There were two previous projects by WPI students. The first project was submitted in 2002 and the second by Andrew Lingenfelter and Megan LaBounty in 2008. Based on the design ideas of Tijani, Labounty and Lingenfelter built a working apparatus that had a maximum of 7K temperature difference across the stack; demonstrating thermoacoustic refrigeration. Due to specific project goals and time constraints, they were not able to develop the project further. Our project is a continuation of their experiments.

5.OUR GOALS AND INTENTIONS

The previous project concluded that the temperature difference they achieved, 7 Kelvin, was due to a thermoacoustic effect. By adjusting several key parameters, the current apparatus can be driven to pump more heat from the cold heat exchanger.

The first adjustable parameter is pressure. It has been proven that the temperature difference across stacks can be increased (to a certain extent) by increasing the internal average pressure (Tijani, 51). For Helium, Tijani et. al. recommend a maximum pressure of 12 atms (Tijani, 51). Previously, the refrigerator could sustain about 1.5 atms. In order to maintain higher pressure, many aspects of the experiment would have to be altered, namely the construction materials used.

Another upgradeable parameter is acoustic power. This is especially true if the refrigerator sustains greater pressures but, a more powerful speaker would be an advantage in itself. We acquired a microphone more suitable for this kind of setup for resonance testing and thermocouples that could be attached permanently for continuous temperature measurement. Measuring resonance of the system gave us the operating frequency with which to run the device.

By changing these parameters, the refrigerator will likely become more powerful (achieve a higher delta T) and perhaps more efficient.

6.PHYSICAL PRINCIPLES

The thermoacoustic effect acts like a conveyor belt for thermal energy. For this to occur, one must exploit two physical principles concerning thermodynamics and acoustics inside the stack. First, through the relation of pressure to temperature by the ideal gas law PV=nRT, the small changes in pressure caused by sound also cause small changes in temperature. Secondly, if the gas through which the sound travels is near a solid surface, the gas may interact by transferring heat to and from it. Combining these two factors, we can create a four-step process similar to a Carnot cycle.

Thermoacoustic cycle consists of four steps. Figures 1-4 below show the steps with a piston as the acoustical driver (Tijani, p.6). Suppose there is gas trapped in a parallel stack of solid plates and there is an acoustic driver that sends a standing wave through the fluid with a pressure node and anti-node at either end of the stack. The first step in the thermoacoustic process is the translational movement and compression of a packet of gas, adiabatically, in one direction away from the pressure anti-node.

7.EXPERIMENTS

The next step in the project was to test the constructed apparatus. Because of the problems with helium leaks and other issues, there was no clear distinction between the “construction” and “experimental” stage. As some experiments were being done, the apparatus was modified (i.e. sealing leaks, modifying heat exchangers etc.). There are three subsections in the “Experiments section”. The “Measurements” section details the work done to set up the experiment and the measurement tools (both hardware and software) used. As explained above, the nature of the project was such that experiments were modified based on previous results. As such, “Experimental procedure” and “results” are combined into the second subsection. The last subsection, “Analysis” explains and interprets the results obtained.

9.CONCLUSION

The Thermoacoustic Refrigeration System consists of no moving parts. Hence the maintenance cost is also low. The system is not bulky. It doesn't use any refrigerant and hence has no polluting effects.From the case study, it is observed that cooling power is dependent on working frequency, cooling load and pressure. It is also observed that for best performance of the system, it is necessary to choose operating parameters wisely. This paper can be used as a reference for design, understanding and improvement in the Thremoacoustic Refrigeration System.

10.SCOPE FOR FUTURE WORK:

The major drawback of above thermo acoustic refrigerator was that air was the workingfluid. The ideal working fluid is Helium (He) gas as it is less dense and sound has maximumvelocity in it i.e. 972m/s. A quarter wavelength resonators can be used instead of half wavelength resonator to minimize losses. To increase the efficiency and to eliminate negative effect due to heating of speaker, awater cooling arrangement can be used.

11.REFFERENCES

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