Thermo Acoustic Cooling Effects

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ABSTRACT: This paper will discuss the development of a thermo acoustic setup to create cooling effect by utilizing sound energy, and its performance. A setup was made from 2 feet of Stainless Steel (SS) tubing and a hi-fi loudspeaker, which develops a temperature at stack region difference when using hydrogen gas and being driven with 40 watts of acoustic power. This work also studied the effects of the design and location of the thermo acoustic stack and the relative efficacy of different gases. Some previous research efforts have emphasized theoretical studies, including the development of design optimization tools. These studies suggest that thermo acoustic coolers may be suited for applications requiring a range of relatively modest temperature lifts. It was found that performance was hindered in small lift applications due primarily to the increased significance of heat transfer irreversibility. Furthermore, the temperature lift for a single stage is limited by the necessity of keeping acoustic pressure amplitudes small in order to minimize shock formation.

1. Introduction
Thermo acoustics as the name suggests is a field, which involves the use of knowledge in both acoustics and thermodynamics. Due to the theoretical complexity of each of these fields on their own, there has been little progress in thermo acoustics. The numerical complexities of thermo acoustic refrigerator are outweighed by the advantages of using the phenomenon. Thermo acoustic devices in operation are "low tech" devices which have no moving parts and hence should require low maintenance. This makes the potential for their application desirable in many fields; applications would include aerospace, industrial etc, Thermo acoustic devices are currently used by high budget industries but are still able to be constructed from smaller budgets A sound wave in a gas is usually regarded as consisting of coupled pressure and motion oscillations, but temperature oscillations are always present, too. When the sound travels in small channels, oscillating heat also flows to and from the channel walls. The combination of all such oscillations produces a rich variety of "thermo acoustic" effects. Thermo acoustics is the study of the conversion of acoustic energy - compression waves in a gas (sound) - into heat energy and vice versa. Acoustic energy can be harnessed in sealed systems and used to create powerful heat engines, heat pumps, and refrigerators. Thermo acoustic devices use these compression waves to replace mechanical pistons, crankshafts, and valves, reducing the number of moving parts in their design and making them simple, reliable machines. Thermo acoustic refrigeration is a new technology to provide cooling without the need for refrigerants such as chlorofluorocarbons. Thermo acoustic refrigeration systems operate by using sound waves and a non-flammable mixture of inert gases to produce cooling. The device produces a standing wave in a tube containing a gas (helium, argon, air) using a loudspeaker. A porous component called a "stack" is placed in the tube in such a way that a temperature difference is created along its length. With the addition of heat exchangers, this temperature difference can be made to provide refrigeration. Because the thermo acoustic refrigerator only has one moving part, it will be relatively simple and inexpensive to construct and maintain. Thermo acoustic refrigerators tend to be compact and lightweight, and contain no refrigerants, making them a very environmentally friendly technology. This aspect will make it a very appealing option in the future.

2. Construction of the Apparatus (For half wave length)
The thermo acoustic refrigerator demonstration described in this note is of the standing wave variety, and consists of a half-wavelength resonator an open-closed tube driven by loudspeaker. The resonator for this refrigerator was a 44 cm length of SS tubing with an inner diameter of 4.32 cm. The length defines the resonance frequency of the system, which was 400 Hz for our apparatus. The speaker was a 4.5-inch speaker capable of handling 40W, and a 5-inch diameter...
Perspex plate was used to provide a seal around the edge of the speaker. The stack was positioned in the tube approximately 7.62 cm from the end of the speaker. The stack for this apparatus was constructed, as suggested by Hofler, by winding a roll of 35-mm photographic film around a central spindle so that adjacent layers of the spirally wound film provide the stack surfaces. Lengths of 15-lb nylon fishing line separated adjacent layers of the spirally wound film stack so that air could move between the layers along the length of the stack parallel to the length of the resonator tube. The primary constraint in designing the stack is the fact that stack layers need to be a few thermal penetration depths apart, with four thermal penetration depths being the optimum layer separation! The 15-lb nylon fishing line has a diameter of 3.403 \times 10^{-2} \text{ m}; the stack layers in this apparatus were therefore separated by about 2.5 thermal penetration depths. To construct the stack, a roll of 35-mm film was unrolled. Lengths of fishing line were glued across the width of the film at equal intervals using a spray adhesive.

3. METHODS AND ANALYSIS

Thermo acoustic device consists, in essence, of a gas-filled tube containing a "stack" (top), a porous solid with many open channels through which the gas can pass. Resonating sound waves (created, for example, by a loudspeaker) force gas to move back and forth through openings in the stack. If the temperature gradient along the stack is modest (middle), gas shifted to one side (a) will be compressed and warmed so that a parcel of gas with dimensions that are roughly equal to the thermal penetration depth (5k) releases heat to the stack. When this same gas then shifts in the other direction (b), it expands and cools enough to absorb heat. Although an individual parcel carries heat just a small distance, the many parcels making up the gas form a "bucket brigade".

4. Performance Test

The experimental set up, shown in Fig.1, for the testing of the constructed thermo acoustic cooler consists of an Audio speaker, a frequency generator, an amplifier, an oscilloscope and constructed resonance tube including stack & heat exchangers. Different types of thermocouple geometries are used in thermo acoustics i.e. one researcher were made two thermocouples by soldering copper and constantan wires together. Another researcher was made two thermocouples by Nickel-Chromium wire. For this project, K type thermocouple wires are considered because K type thermocouple wires are available in the lab. And also data logger is used to measure the temperatures of different points.

Outer diameter of heat exchanger tube, \( D = 2.6 \text{ mm} \)
Outer Diameter of pressure tube, \( D = 1.95 \text{ mm} \)
Diameter of fishing line = 0.50 mm
Thickness of X-ray plate - 0.20 mm
Thickness of transparent perplex plate = 4.5 mm
Length of stack = 25.40 mm
Diameter of PVC pipe = 48 mm
Outer diameter of speaker = 114.30 mm
Speaker rating 40 Watt, 24 Ohm.
Oscilloscope: Model=COS 5020, 20 MHz, It has 2 channels, Use 1 channel when the performance was tested of that device.

Hybrid recorder: Model=DR230
Company=YOKOGAYA It has 10 channels, Use 6 channel when the performance was tested of that device.

5. Experimental Results

Figure 3 shows typical results for the temperatures above the stack (\( T_{\text{hot}} \)) and below the stack (\( T_{\text{cold}} \)) as a function of time. The starting temperatures were normalized to 23°C, so the plot shows the changes in temperature as measured by each thermocouple. To produce this plot the thermocouple leads were connected to a two-channel digital oscilloscope with a 1.5 minute capture time. The plot shows that the temperature below the stack (\( T_{\text{cold}} \)) begins decreasing immediately after the sound is turned on, dropping 2 °C in the first 30 seconds, with the rate of temperature change decreasing with time. After 1.5 minutes of operation the temperature below the stack has dropped by 2.3°C and is still decreasing. The temperature above the stack (\( T_{\text{hot}} \))
increases, also more rapidly at first, as the heat is being pumped through the stack. After approximately 0.5 minutes the temperature above the stack has increased by 5 °C. After that it stops increasing as the rate at which heat is moved through the stack equals the rate at which heat is conducted through the Perspex plate into the surrounding room. After 1.5 minutes of operation, the temperature difference between the top and bottom of the stack is about 9.9 °C, a difference large enough to be detected by touching a finger along the outside of the acrylic tube. Figure 4 shows typical results for the variation of the temperature with the applied voltage. When the variation of the temperature increases the applied voltage will also increases.

6. Conclusion and future recommendation

Production of the thermo acoustic cooler has started after long periods of design work. Large portions of time were spent understanding the complex behavior and interaction between the thermo acoustic elements of the cooler. Using cheaper materials and lower tolerances for thicknesses of the stack we should have a cooler that is near enough to the optimal design and significantly cheaper, with new understanding of thermo acoustics now appreciate the relative simplicity of important elements irrespective of the mathematical complexity. In light of this device that are constructed and able to produced cooling effect. The device can able to reduce the temperature up to 4-5°C and produce 10-12°C temperature difference between the cold and hot end. Thermo acoustic cooling is a relatively new technology and has only been investigated by a relatively small number of researchers. Industry has been reluctant to fully develop thermo acoustics without a clear demonstration of the competitive performance of actual prototypes and without a broader understanding of the best applications. One of the next steps to spur development of this technology is to demonstrate the performance potential for a range of applications and to identify the most promising applications for this technology. These are the long-term goals associated with the ongoing research activities.

References


Fig. 1a) Schematic diagram of the thermo acoustic cooler; b) Cross section of the stack showing how the film layers were Separated by fishing line.

Fig. 2 Basic thermo acoustics device
Fig. 3 Temperature variation of cold and hot water with time

Fig. 4 Temperature Vs. applied voltage