DESIGN AND TESTING OF A THERMOACOUSTIC SYSTEM FOR THERMAL MANAGEMENT

Masoud Akhavanbazaz[1], M. H. Kamran Siddiqui[2], and Rama B. Bhat[3]
[1] mas_akhavan@yahoo.com, [2] siddiqui@encs.concordia.ca, [1]rbhat@encs.concordia.ca
Dept of Mechanical and Industrial Engineering, Concordia University, Montreal, Quebec, Canada

1. INTRODUCTION

The thermoacoustic phenomenon was known more than a century ago, but the principle was not exploited in a significant way until two decades ago when Greg Swift and his research group at the Los Alamos National Laboratory developed different types of thermoacoustic refrigerators and heat engines [1]. Even after two decades of research by his group and a few other groups across North America and Europe, the development of such devices is still at preliminary stages. Garret et al. [2] developed a spacecraft cryocooler, using resonant intense sound waves in pressurized inert gases in a resonator to pump heat. This cryocooler was used in the space shuttle Discovery. Tijani et al. [3] were able to obtain temperature as low as -65° C in their device. Using this device, they studied the effect of some thermoacoustic parameters, such as the Prandtl number and the spacing of stack plates. Bailliet et al. [4] measured the acoustic power in the resonator of a thermoacoustic refrigerator using Laser Doppler Anemometry (LDA) along with sound pressure level measurements with microphones. They observed good agreement between the experimental and theoretical results. A thermoacoustic engine was used by Jin et al. [5] to drive a thermoacoustic refrigerator. The device established an impressive temperature difference of approximately 120 K across the stack.

Although efficiencies of existing thermoacoustic refrigerators are lower than their conventional counterparts, efficiency comparable to vapor-compression refrigerators have been predicted theoretically [6]. The thermoacoustic devices have many advantages over conventional refrigerators. No environmentally hazardous refrigerants are required in thermoacoustic devices. They use air or other inert gases and thus, they do not have any harmful effect on the environment. In addition, these devices are simple in design and have no moving parts. Thus, they are more reliable and have low fabrication cost.

In the present paper, a simple thermoacoustic device is designed and tested to study the thermal gradient established at the two ends of its stack. The results are presented and discussed.

2. THERMOACOUSTIC PHENOMENON

A thermoacoustic device consists of an acoustic resonator (tube) containing a working fluid, that can be air or an inert gas. The resonator is driven by an exciter such as a speaker or an electrodynamic exciter to generate a standing acoustic wave inside the resonator. The length of the acoustic resonator is typically set equal to half the wavelength of the standing acoustic wave [6]. A stack of thin parallel plates are installed towards one end inside the resonator. The gas parcels inside the resonator experience displacement and temperature oscillations along with the pressure variations. When such oscillations in the gas occur close to a solid surface, such as a stack of closely spaced parallel plates, heat can be transferred to or from the surface. The gas parcels transfer heat from the end of the stack that is close to the pressure node to the other end of the stack, creating a temperature gradient across the two ends of the stack. Swift [6] gives detailed explanation of the thermoacoustic process. If heat exchangers are attached at both ends of the stack then the heat is transferred from the fluid of the cold-end heat exchanger to the stack and by the thermoacoustic process, this heat is delivered to the hot-end of the stack from where it is transferred to the fluid of the hot-end heat exchanger. Thus, the heat is pumped from a cold medium to a hot medium and the device works as a refrigerator.

3. FABRICATION OF THE DEVICE AND EXPERIMENTAL SETUP

A simple thermoacoustic device was designed, fabricated and tested in the laboratory [7]. An acrylic tube of length 0.385 m corresponding to half the wavelength of the acoustic wave at 450 Hz was used as the resonator tube. The internal diameter of the tube was 6.3 cm and wall thickness was 6 mm. A schematic of the device is shown in Fig. 1. A 15 watt, 8 Ω, electrodynamic-type loudspeaker was used as the acoustic driver. The loudspeaker was driven by a function generator at a frequency of 450 Hz. A power amplifier was used to provide the required acoustic power to excite the working fluid inside the resonator.

Air at the atmospheric pressure was used as a working fluid. The optimum length of the stack and the spacing between the stack plates was determined through a theoretical analysis [7]. The length of the stack was set equal to 3 cm. The stack was made of 0.13 mm thick Mylar sheet. Fishing line spacers (0.36 mm thick) glued onto the surface of the sheet provided the spacing between the sheets. The Mylar sheet was wound around a 4 mm PVC-rod to obtain a spiral stack [3]. Thermocouples were used to simultaneously measure the temperature at both ends of the stack. The accuracy of the thermocouple was ± 0.1 °C.

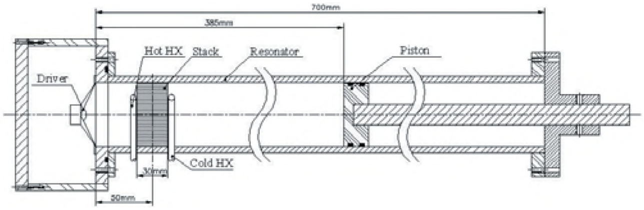


Fig. 1: Schematic of the fabricated thermoacoustic refrigerator.

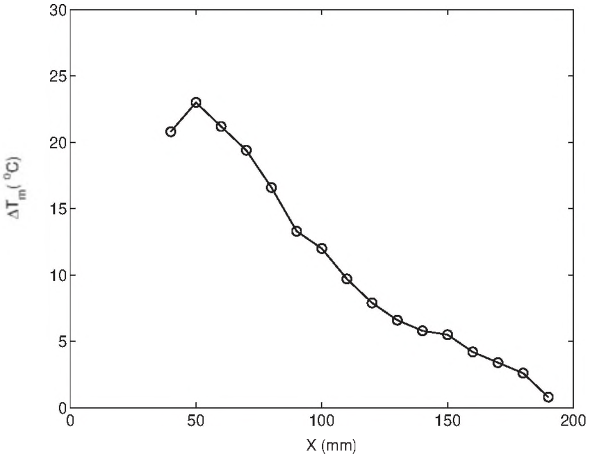
4. RESULTS

The position of the stack inside the resonator is crucial for the optimum performance of the thermoacoustic refrigerator. The position of stack (X_s) inside the resonator tube was changed from 40 mm to 190 mm from the driver-end of the resonator, with 10 mm increments. The temperature difference across both sides of the stack, ΔT_m, was measured at each stack position. The data was sampled for 350 s at each stack position at a sampling rate of 100 Hz. The values of ΔT_m are plotted in Fig. 2, against the stack position. The plot shows that the temperature difference across the stack is minimum (approximately 1 °C) when the stack was placed at the center of the resonator (i.e. at 190 mm from the resonator end). As the stack was shifted towards the pressure antinode, ΔT_m increased from 1 °C to 23 °C up to X_s = 5 cm. As the stack was shifted further towards the pressure antinode (i.e. X_s < 5 cm), a decrease in ΔT_m is observed. Thus, the results indicate that the optimal stack position of the stack is 5 cm. The optimum position of the stack obtained experimentally is in agreement with that predicted theoretically [7].

REFERENCES

1. Swift, G.W. (1995) Thermoacoustic engines and refrigerators. Physics Today, 48 (7), 22-28.
2. Garrett, S.L., Adeff, J.A., and Hofler, T.J. (1993) Thermoacoustic refrigerator for space applications. J. Thermophysics Heat Transfer, 7 (4), 595-599.
3. Tijani, M.E.H., Zeegers, J.C.H., and De Waele, A.T.A.M. (2002) Construction and performance of a thermoacoustic refrigerator. Cryogenics, 42 (1), 59-65.
4. Bailliet, H., Lotton, P., Bruneau, M., Guesev, V., Valiere, J.C., and Gazengel, B. (2000) Acoustic Power Flow Measurement in a thermoacoustic resonator by means of Laser Doppler Anemometry (L.D.A.) and microphonic measurement. J. Applied Acoustics, 60, 1-11.
5. Jin, T., Chen, G.B., Wang, B.R., and Zhang, S.Y. (2003) Application of Thermoacoustic Effect to Refrigeration. Review of Scientific Instruments, 74 (1), 677-679.
6. Swift G. W. (2002) Thermoacoustics. The Acoustical Society of America, Melville, NY.
7. Akhavanbazaz, M. (2004) Design, Analysis, Testing and Development of a Thermoacoustic System for Refrigerator Applications. M.A.Sc. thesis, Department of Mechanical and Industrial Engineering, Concordia University, Montreal, Canada.

Fig. 2: Temperature difference across the stack (ΔT_m) versus the mid-stack position. The mid-stack position is measured from the speaker-end of the resonator.



ACKNOWLEDGEMENTS

This research was funded by the grants from the Natural Sciences and Engineering Research Council of Canada to Kamran Siddiqui and Rama Bhat.