Original Article

Experimental Analysis In The Implementation Of The Thermo-Acoustic Refrigeration System By Means Of Air As A Working Medium

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Abstract

A more contemporary technique that has recently received attention from the scientific society is thermoacoustic refrigeration. It involves using acoustic sound waves to generate low temperatures. A thermoacoustic refrigeration system is a device that uses acoustic sound energy as an input to transport heat via a solid material known as a stack in a resonator tube. The temperature differential formed throughout the stack affects how well thermoacoustic refrigerators work. The thermoacoustic system's stack is its most important component. The honeycomb-shaped stack, constructed of Mylar material, is employed in the current experimental investigation. The system and the experimental data were analyzed using a combination of set independent and dependent variables. The working medium of the system was air, and it was operated at different pressures and resonance frequencies to ascertain the optimal performance parameters of the device. The results are presented, and they are consistent with the notion that the thermoacoustic refrigeration system's capacity to operate at its peak depends critically on the stack and the parameters that affect it. The study provided makes suggestions for enhancing thermo acoustic refrigerators' efficiency, which is currently lacking as a result of their rather underwhelming performance. Changes to the resonance frequency and resonator tube material can both enhance the system's performance coefficient.

Keywords: Thermoacoustic Refrigeration, Stack, Coefficient of Performance

INTRODUCTION:

The term "thermoacoustic refrigeration" refers to procedures where sound acoustic energy is converted into heat energy, producing the necessary temperature differential for refrigeration. The scientific world has recently paid a lot of attention to this functionality of turning sound energy into creating a temperature differential. [1, 2]. Thermo acoustic refrigeration systems create a temperature differential between a low-temperature environment and a high-temperature space using the power of sound. Thermoacoustic systems are becoming more popular not just because of their favorable effects on the environment, but also because they are easy to construct and maintain. They differ from typical devices in that they don't have any moving parts or components and don't utilize any hazardous chemicals or refrigerants [3-5]. Additionally, due to their lower performance when compared to vapor compression refrigeration systems specifically, their 10% to 20% Carnot efficiency as opposed to the 30% to 45% achieved by the latter thermoacoustic refrigeration systems are limited in their current uses [6]. An acoustic driver, or loudspeaker, provides the sound energy in a refrigerator that operates on the thermoacoustic principle. The following diagram illustrates a standing wave thermoacoustic refrigeration system that is powered by a loudspeaker (Figure 1a). A loudspeaker, a resonator tube, a stack, heat exchangers, and a working medium typically air or another inert gas make up the system. By a standing acoustic wave supported by the loudspeaker and operating at the resonant fundamental frequency for the particular resonator tube, the gas parcels inside the resonator tube are expanded and compressed adiabatically.

The thermal interface with the stack alters the initial temperature fluctuations brought on by the acoustic sound wave, both in the phase and the amplitude, for the gas parcels oscillating inside the stack, at around some depth of thermal penetration. An rise in the wave's temperature and pressure as well as a transfer of heat from the fluid to the plate help to move the gas fluid parcel towards the pressure antinode (Figure 1b). Following the subsequent expansion of the gas fluid parcel, temperature and pressure drop, and heat is subsequently transferred from the plate back to the gas fluid [7, 8]. As there are numerous gas fluid parcels fluctuating in the stack at the location of the thermal penetration depth from the plate, heat is transferred by one gas fluid parcel and is deposited on the plate and, at the same time, the same amount of heat is transferred by the adjacent parcel, resulting in the development of a temperature difference along the stack [9–10]. (See Figure 1c.) Heat exchangers are linked to both the hot end and the cold end of the stack in order to exploit the impact of the temperature differential created for the heat pumping operation. The hot heat exchanger rejects heat to the surroundings, whereas the cold heat exchanger takes heat from the low temperature region to be cooled [11, 12].

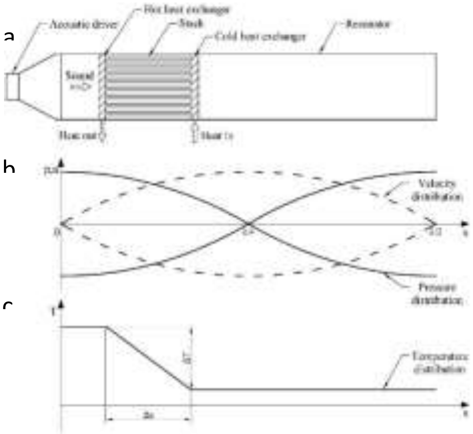

Figure 1 Working Principle Of The Standing-Wave Thermoacoustic Refrigerator With Pressure, Velocity And Temperature Distribution

Numerous parameters, including material parameters (density, specific heat of working fluid, thermal conductivity, and stack material), working parameters (resonant frequency, mean temperature and pressure, cooling load), and geometrical design parameters (stack position, stack length, and stack porosity), affect how well the thermoacoustic refrigeration system functions [13]. Recently, there have been several theoretical and practical efforts made to enhance and optimize the performance of thermoacoustic systems. The geometrical design parameters, particularly the stack, have been the subject of the majority of the investigation [14].

According to their findings, the optimal space between the plates should be between $\lambda/2$ and $\lambda/4$ thermal penetration depths. Different stack designs, including spiral-like and honeycomb-like ones, were also tentatively tested. [13] Investigated the effects of stack material, calculation, length, and position on the temperature difference created over the end of the stacks. A 4 cm corning Celor stack placed 4 cm away from the speakers achieved the greatest temperature differential. Numerous tests were conducted only on the stack area as well. According to the COP [14] and temperature gradient [14, 15], the optimal stack location has been calculated.

The optimal range often lies between $\lambda/8$ and $\lambda/20$, where λ stands for the sound wavelength [9]. In their study on the impact of the resonator tube on the operation of the stack, Picollo and Wetzel et al. [15, 16] found that the ideal effective resonant frequency differs from the plan under the assumption that $f_0 = a / (2L_0)$ and that the right combination of the resonant frequency and the resonance tube length causes an increase in the temperature difference between the two ends of the stack by about 56%. Additionally, Wetzel et al. [16] shown that the resonant frequency is significantly influenced by the length of the resonator tube. According to their calculations, the resonant frequency decreased as the length of the resonator tube increased. The review discussed in this paper investigates how the length of the resonator tube and various operating frequencies affect the operation of the thermoacoustic refrigeration system. A model thermoacoustic refrigeration system using air as the working fluid was assembled inside referenced bounds for testing. The system was operated by an acoustic loudspeaker connected to the amplifier and the signal generator. The exploratory device was stripped of its hot and cold heat exchangers. The effect of the temperature differential created throughout the stack alone was used to assess the thermoacoustic impact.

EXPERIMENTAL SETUP AND DETAILS:

The schematic for the exploratory thermoacoustic system is shown in Figure 2. The thermoacoustic refrigeration system lacked a cold and hot heat exchanger since the device was only used to measure the temperature differential created between the two ends of the stack. The standing acoustic wave of the necessary frequency was produced using an input acoustic device, a commercial amplifier-driven loudspeaker with 50 W of constant power. One end of the stack, which was also linked to the resonance tube and the buffer volume, housed the acoustic loudspeaker. The hot temperature and cold temperature chambers were located at the two ends of the stack. The stack's material and shape were made up of a porous stack of Mylar with round pores. The exchanges between the working fluid and the stack material, which were detected by the type-T digital thermocouple, are what caused the temperature differential that was produced between the two ends of the stack. With a 1 K precision, the temperature values for each end of the stack were presented. The total precision and correctness of the experimental data, taking into account all significant factors that have an impact on performance, is in the range of 10%.

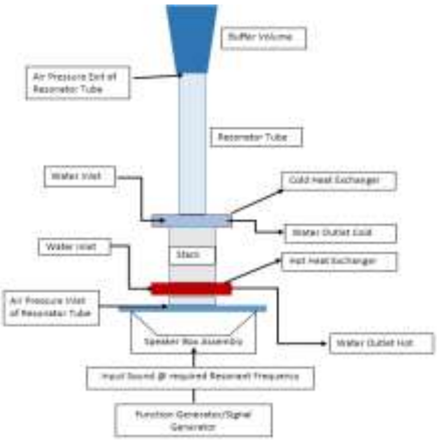

Figure 2 Schematic Illustration Of Experimental Setup.

The studies were designed to evaluate how the thermoacoustic refrigeration system performed at various pressures and operating frequencies. The following equation may be used to determine the resonant frequency that depends on the length of the resonator tube and the sound speed in air as the working medium.

$$f0 = \frac{C}{4 * Lt} \qquad (1)$$

Where Lt is the length of the resonator tube, C is the sound velocity in air, and f_0 is the resonant frequency. Three distinct modes—(λ/4), (3λ/4), and (5λ/4), needed for the creation of the standing acoustic wave were each assigned a resonant frequency estimate. The resonant frequency was estimated for three distinct modes, with f_0 = 294 Hz for (λ/4), f_0 = 885 Hz for (3λ/4), and f_0 = 1474 Hz for (5λ/4), taking into account the constant length of the resonator tube (Lt). The data was collected for each series of experimental measurements until the temperature differential between the ends of the stack proved to be stable. In order to integrate the comparative analysis with reliance on time, the experiment was performed for a defined amount of time after being run for the required resonant frequency range.

RESULTS AND DISCUSSIONS:

The following figures show the numerous variables that were taken into account for the comparative analysis of the experimental results.

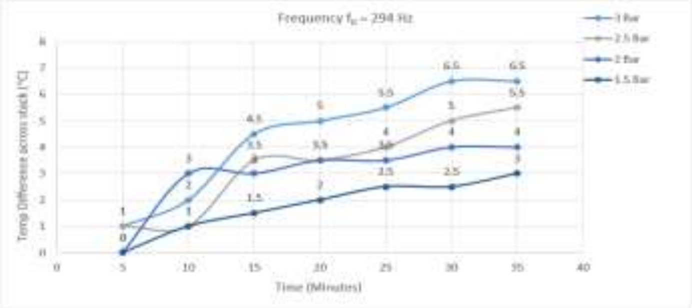

Figure 3 Variation Of Temperature Difference With Time At F_0 = 294 Hz

Figure 3 shows the fluctuation of the temperature difference produced across the stack at the resonant frequency of 294 Hz; the variation shows that the temperature difference across the stack also grows proportionately when the air pressure in the system increases from 1.5 bar to 3 bar.

Similar to this, Figures 4 and 5 illustrate the experimental results for the change of the temperature differential created throughout the stack at the resonant frequencies of f_0 = 885 Hz for (3λ/4), and f_0 = 1474 Hz for (5λ/4). Higher resonant frequencies showed a similar performance pattern.

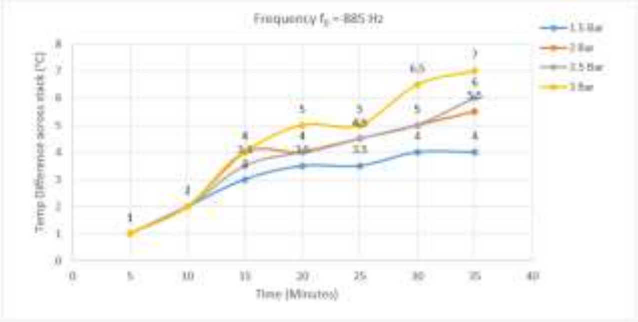

Figure 4 Variation Of Temperature Difference With Time At F_0 = 885 Hz

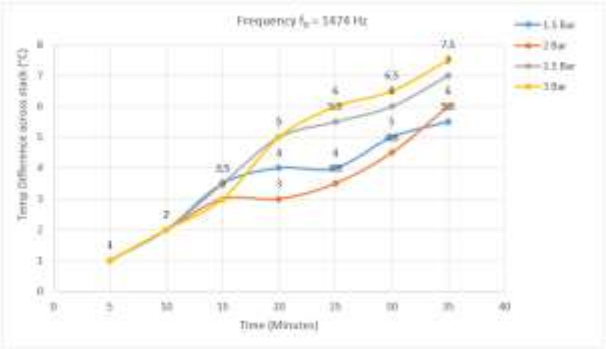

Figure 5 Variation Of Temperature Difference With Time At *F0* = 1474 Hz

A temperature differential starts to form between the hot end and cold end of the stack when the acoustic sound power is fed into the system. It was shown in all of the aforementioned graphs and experimental data that the temperature differential between the ends of the stack likewise grows as the system pressure rises. According to the results of the experiment, it is evident that the temperature differential created throughout the stack is mostly related to the fluid pressure within the system.

Additionally, the highest temperature difference across the stack of 7.5°C was attained at a pressure of 3 Bar for a resonant frequency of f_0 = 1474 Hz, followed by 7.0°C at a pressure of 3 Bar for a resonant frequency of f_0 = 885 Hz, and 6.5°C at a pressure of 3 Bar for a resonant frequency of f_0 = 294 Hz.

CONCLUSION:

The effect of the working medium, air, with a constant resonator tube length on the presentation of the standing wave thermoacoustic refrigeration system with different resonant frequencies and pressures, was anticipated in this experimental investigation. The temperature differential between the ends of the stack was examined for three distinct resonating frequencies, corresponding to f0 = 294 Hz for (λ/4), f0 = 885 Hz for (3λ/4), and f0 = 1474 Hz for (5λ/4) as pressures within the resonator tube increased from 1.5 Bar to 3 Bar.

The results of the experiment indicate that the thermoacoustic refrigeration system's operation is influenced by both the resonant frequency and the pressure of the working medium, in this instance air. The results also demonstrate that greater resonant frequencies are required to achieve the highest temperature differences across the stack. Additionally, different investigations may be conducted by modifying the resonator tube's length, the working medium, and the form and geometry of the stack size.

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