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Performance Evaluation of Thermoacoustic Refrigerator using Air as Working Medium

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ABSTRACT:

This work is to study the performance of the thermoacoustic refrigerator with respect to some operating parameters. The experiments were conducted to evaluate the performance of the thermoacoustic refrigeration system under various operating conditions and different stack geometries. The entire resonator system was constructed from aluminium. The inner surface of the resonator tube was coated with polyurethane material to reduce heat loss from conduction and the resonator tube was filled with Air with the help of regulating systems to the required mean pressure. The factors that influence the performance of the system were identified. The COP of the refrigerator increases with increases of heating load and decreases at higher acoustic power. The temperature difference (ΔT) between hot end and cold end of the stack is higher at 2W heating load for 400Hz operating frequency. The temperature difference across the hot end and cold end of the stack increases with the increase of acoustic power for a mean pressure of 10 bar.

Keywords: *Acoustic Power, COP, Frequency, Heatingload, Stack*

1. INTRODUCTION

Thermoacoustic cooling is a recent technology that has been proposed to obtain cooling energy from high amplitude sound waves. Periodic compression and expansion of gas particles combined with heat transfer within regions near boundaries, result in heat pumping cycles with environmental friendly working fluids. There is important concern in thermoacoustic cooling systems because they are more advantages than other technologies. These advantages comprise the use of environmental friendly working fluids, simple design and constant cooling capability. There are important technical challenges related to the design and construction of efficient, robust, economical thermoacoustic cooling systems. Thermoacoustic system performance is very sensitive to the choice of design parameters and should be optimized to achieve a reasonable efficiency [1, 2].

Thermoacoustic cooler prototype is developed by Hofler in 1986. Early prototypes achieved are low operating temperatures with cooling capacity less than 20 W and the largest thermoacoustic cooler built is having a maximum cooling capacity of 10 kW. Efforts have been made to optimize the design of thermoacoustic coolers by improving the stack geometry, stack plate spacing, resonator length and gas mixture [2].

As an advanced cooling technology with advantages of simplicity, lower manufacturing cost, environmental friendly thermoacoustic refrigerator (TAR) consists of acoustic driver (loudspeaker), resonator, stack and the two heat exchangers either end of the stack. Interaction between the gas particles at the surface of the stack plates brings out heat transport effect when acoustic wave generated by the loudspeaker makes gas oscillate in periodical compressing and expanding style. Then the temperature difference across the two ends of the thermoacoustic stack is generated [3].

It is important in the design and development of thermoacoustic cooling systems to consider environmental impacts. To eradicate the use of environmentally hazardous refrigerants, research efforts are focusing more on the development of alternative refrigerants and refrigeration technologies. The method for alternative technology is the thermoacoustic refrigeration which produces temperature difference from sound. Gas inside the resonator of the system interacts thermally with the stack plates aligned properly to the direction of vibration of the standing waves supported by the fluid. The effects that result from the communication between the sound waves and the solid boundary of the stack plates are the absorption of acoustic power and a heat transfer at the surface of the plates in the direction of acoustic vibration [4, 5].

Mathewlal T and et al designed, fabricated and tested thermoacoustic refrigerator for 10 W acoustic power. The model was tested for air has the working medium at 310 Hz natural frequency and 10-15 watt power.

The temperature difference obtained between hot end and cold end of stack was 5.5˚C. Temperature at cold end rose by 3.85˚C whereas temperature at hot end rose by 9.3˚C in 4 minutes [6].

S.H. Tasnim and et al numerically investigates the effects of variation in working fluids and operating conditions on the performance of a thermoacoustic refrigerator. The performance of a thermoacoustic refrigerator is evaluated based on the cooling power, coefficient of performance (COP), and the entropy generation rate within the device. The effect of the variation of the working fluid is observed by changing the Prandtl number (Pr) between 0.7 and 0.28. The operating conditions investigated are drive ratio (DR), stack plate spacing (y_0), and mean pressure (pm). The research work shows that lowering the Prandtl number of the working fluid does not improve the performance of a thermoacoustic refrigerator for all of the selected operating conditions. COP increases 78% by reducing the Prandtl number from 0.7 to 0.28 at stack plate spacing is equal to 3.33 times of thermal penetration depthfor atmospheric pressure and a drive ratio of 1.7%. While the COP decreases by reducing the Prandtl number from 0.7 to 0.28 at stack plate spacing is equal to thermal penetration depthfor atmospheric pressure and a drive ratio of 1.7%. The numerical results are compared with the experimental data. Therefore, it is concluded that a stack plate spacing is equal to 3.33 times of thermal penetration depth should be optimal for thermoacoustic refrigeration. The cooling power and acoustic power absorbed by a thermoacoustic refrigerator increase as the mean pressure and drive ratio increase, but the increase of acoustic power is more important than the cooling power at higher drive ratio and mean pressure. Therefore, COP decreases at higher drive ratio and mean pressure [7].

2. EXPERIMENTAL SETUP

Thermoacoustic refrigerator is designed for a cooling power of 10W considering pure Helium and compressed air as the working medium. The design of various components such as Stack, different stack geometry, variable pressure, resonator tube, heat exchangers and buffer volume has been carried out with the help of relevant thermoacoustic equations.

Figure1 shows the schematic layout of the thermoacoustic refrigerator. The principal parts of thermoacoustic refrigerator consists of acoustic driver, two heat exchangers, stack which acts as a heat pumping element, the resonator system and air as the working medium.

The resonator system consists of large diameter tube of D_1=70.06mm and small diameter tube of D_2 = 30.12mm.The entire resonator system was constructed from aluminium. The inner surface of the resonator tube was coated with polyurethane material to reduce heat loss from conduction. A stack of 40.55 mm length and 69mm diameter having parallel plates constructed of 0.1194mm thick Mylar sheets spaced with 0.3582mm apart. The stack made up of Epoxy glass having holes of 1mm, 2mm and 3mm diameters were also considered for the purpose of comparing the results. Copper tube type heat exchangers were employed at two ends of the stacks. A 10 watt electric heater is placed on cold heat exchanger of 1.933mm diameter and 498.6 mm length, for cooling power measurement. The hot heat exchanger of diameter 3.866 mm and 249.3mm length is provided with cooling arrangement. An acoustic driver with a variable power input 0-120 W, 8Ω was selected in conjunction with amplifier and audio generator to produce required frequency of 100 to 600Hz sound waves in the resonator.

Fig.1 Experimental Setup of a Thermoacoustic Refrigerator

2.1 Experimental Procedure

The experiments were conducted to evaluate the performance of the thermoacoustic refrigeration system under various operating conditions and different stack geometries. The resonator tube was filled with Air with the help of regulating systems to the required initial mean pressure from 2 bar to 10 bar insteps of 2 bar. The desired frequency was set and then increased slowly from 200 Hz to 600 Hz insteps of 100 Hz for each of the experiment. The heating load was controlled using resistance heating coil placed on the cold heat exchanger initially set for a constant load. For each experiment the data were recorded from the initial time until the system became stable. The frequency was then varied and repeated the experiment. The pressure was varied and the experiment was repeated for the same set of frequencies and the heating load. The experiments were repeated in the same manner for various values of heating load starting with 2W to 10W insteps of 2W. The experiments were repeated for different input power to the acoustic driver.

Fig. 2 Parallel plate stack

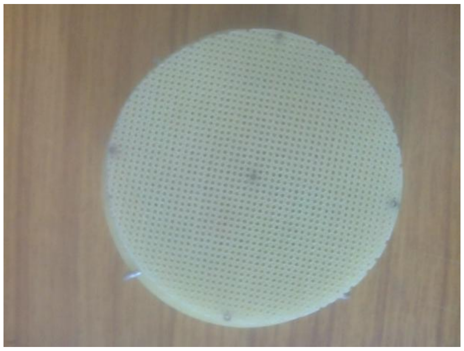

Fig. 3 Holes of 1mm diameter stack

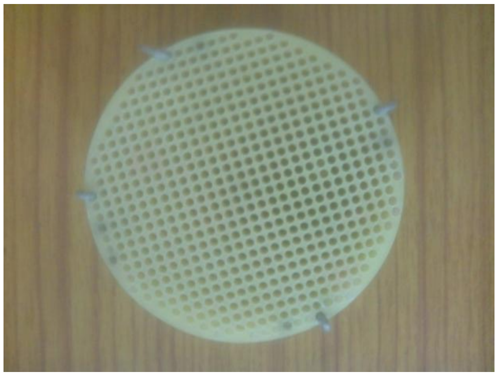

Fig. 4 Holes of 2mm diameter stack

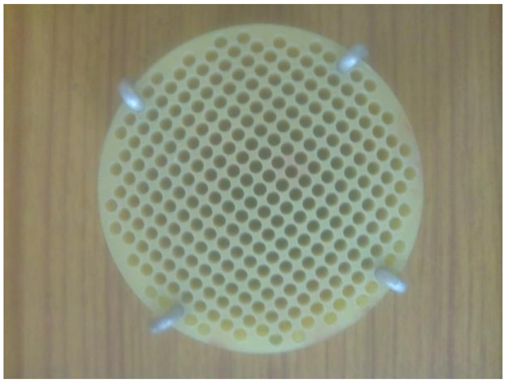

Fig. 3 Holes of 3 mm diameter stack

3. RESULTS AND DISCUSSIONS

The experimental results are presented and discussed in the form of graphs. The thermal performance of a thermoacoustic refrigerator subjected to various operating conditions such as frequency, mean pressure, stack geometry, input power and heating load are discussed.

3.1 Performance measurements

The performance of the thermoacoustic refrigeration is calculated using performance parameters evaluated such as theheating loadand the steady-state temperature difference for various operating parameters. The electric power introduced into the system is converted into work, i.e. acoustic power in the acoustic driver. The coefficient of performance (COP) is the ratio of heating load to the acoustic power (P_{ac}).

3.2 Effect of Frequency

As the frequency increases the temperature difference across the stack is increases as depicted in the Figs 6, 7, 8, and 9. For each frequency, the temperature increased at the beginning and then stabilized after a time. The experiment is performed for various constant pressure and heating load values and it is found that the stabilization time increased as the pressure increased. This could be because the thermoacoustic process increased with mean pressure in the system and therefore it took more time for the temperature to stabilize. The temperature difference between hot end and cold end of the stack is more at 2W heating load which is supplied to the cold heat exchanger for all the pressure varying from 2 bar to 10 bar at 400 Hz frequency. When the operating frequency is further increased, the temperature difference across the stack is decreases due to influence of the thermal penetration depth in the stack. The temperature difference is more for parallel plate geometry compare to other geometries. This measurement illustrates the importance of the stack spacing on the performance. A uniform channel structure is important for the better performance. Spacing between the stack is less,thenthe heat transfer rate will be more which leads to more temperature difference for parallel plate stack have spacing between the two plates is 0.35mm compared to the diameter of 1mm, 2mm and 3mm diameter holes.

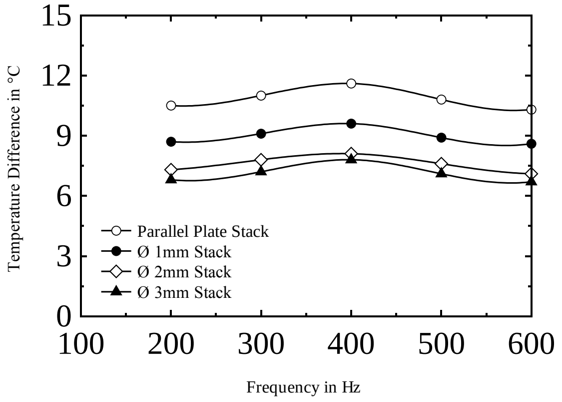

Fig. 6 Variation of ΔT with Frequency for different stack geometry at 2 bar pressure and 2W heating load

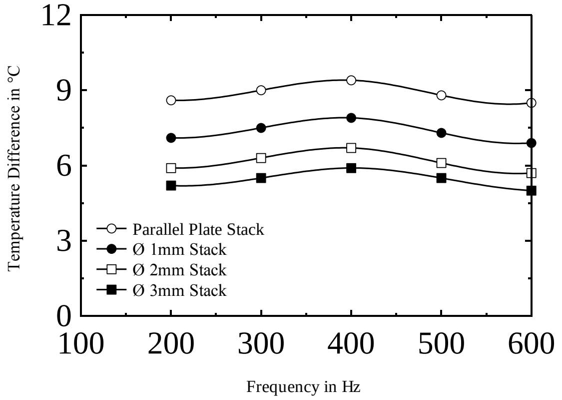

Fig.7 Variation of ΔT with Frequency for different stack geometry at 2 bar pressure and 10W heating load

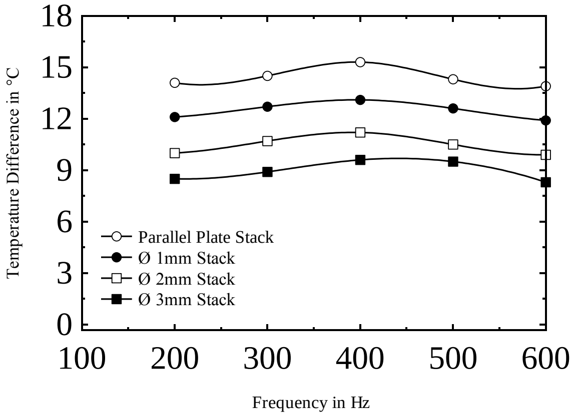

Fig. 8 Variation of ΔT with Frequency for different stack geometry at 10 bar pressure and 2W heating load

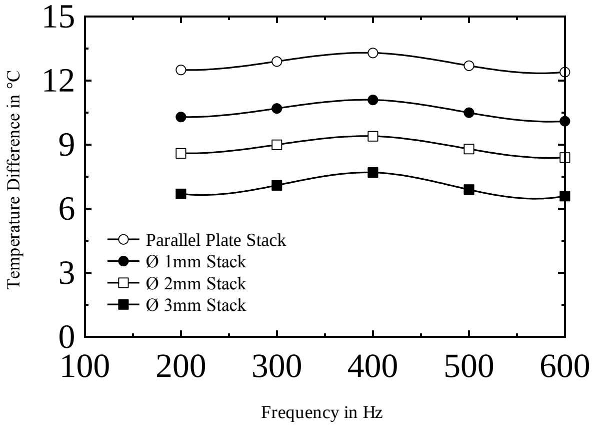

Fig. 9 Variation of ΔT with Frequencies for different stack geometry at 10 bar pressure and 10 W heating load.

3.3 Effect of COP

COP of the refrigerator is directly proportional to the heating load and inversely proportional to acoustic power which is supplied to the acoustic driver. COP is increases with the increase of heating load and decreases at higher acoustic power as shown in the Fig. 10.

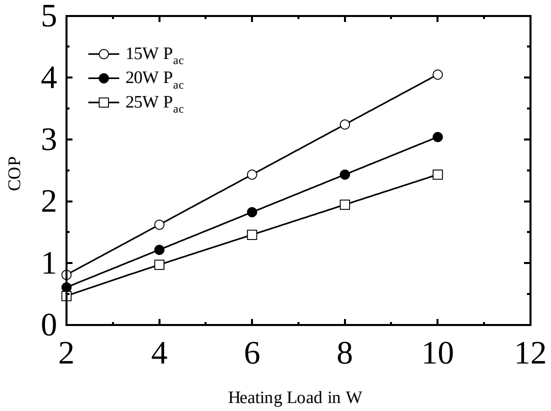

Fig. 10 Variation of COP with Heating Load for different acoustic power (P_{ac})

3.4 Effect of heating load

Temperature difference is a function of the heating load. Higher temperatures are attained with higher dynamic pressure. Measurements are made using three acoustic powers fordifferentgeometries of stack with air as the working fluid. Temperature difference is more at 2W heating load because acoustic power required is sufficient to remove heat which is developed in the stack is depicted in Fig. 11 and Fig. 12 for different pressures. At 10W heating load, acoustic power required is not sufficient to remove heat so temperature difference is less.

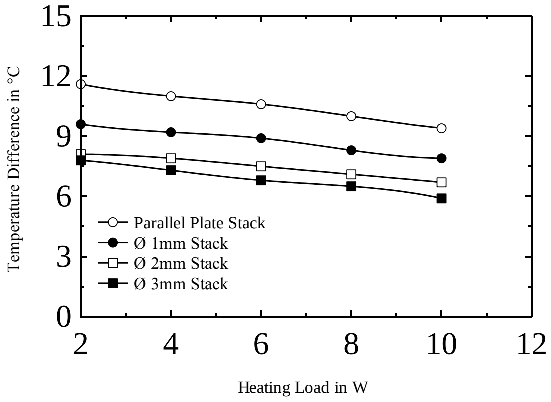

Fig. 11 Variation of ΔT with Heating Load for different stack geometry at 2 bar pressure and 400 Hz frequency

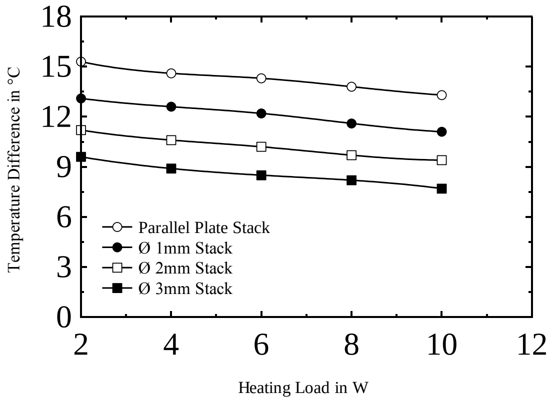

Fig 12 Variation of ΔT with Heating Load for different stack geometry at 10 bar pressure and 400 Hz frequency

3.5 Effect of Acoustic Power

The temperature difference is increased with the increase of acoustic power. The temperature difference is decreaseswith the increases of heating load. The spacing between the two plates in the stack is less the temperature difference is more. The temperature difference between the cold end and hot end of the stack is more for the parallel plate stack and less for the holes having 1mm, 2mm and 3mm diameter stacks shown in the Figs 13, 14, 15 and 16

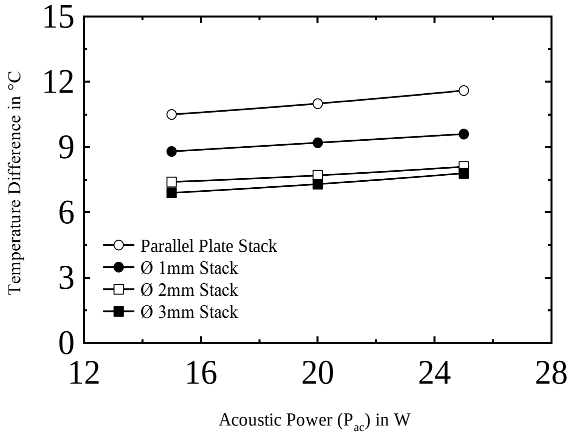

Fig.13Variation of ΔT with acoustic power (P_{ac}) for different stack geometry at 2 bar pressure and 2W Heating Load

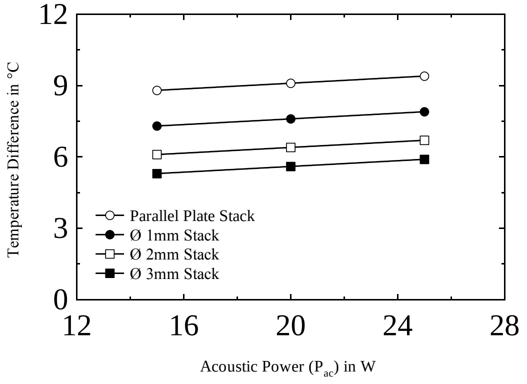

Fig.14Variation of ΔT with acoustic power (P_{ac}) for different stack geometry at 2 bar pressure and 10W Heating Load

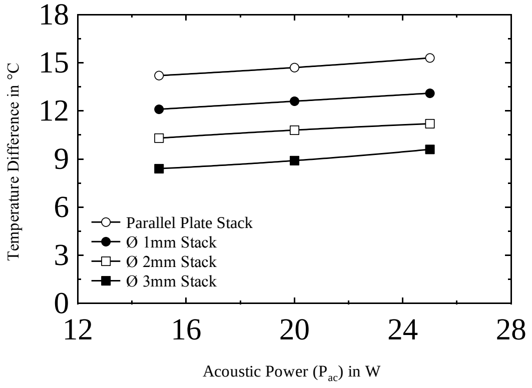

Fig.15 Variation of ΔT with acoustic power (P_{ac}) for different stack geometry at 10 bar pressure and 2W Heating Load

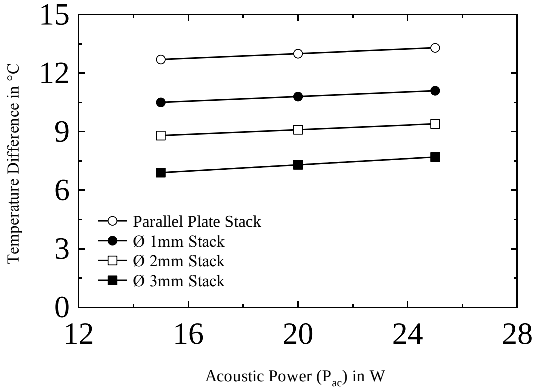

Fig.16 Variation of ΔT with acoustic power (P_{ac}) for different stack geometry at 10 bar pressure and 10W Heating Load

4. CONCLUSIONS

The research work investigates the effects of operating conditions on the performance of a thermoacoustic refrigerator. The performance of a thermoacoustic refrigerator is evaluated based on the heating load, frequency and coefficient of performance (COP). The operating conditions investigated are acoustic power, stack geometry and pressure.

The research work shows that COP of the refrigerator increases with increase of heating load and decreases at higher acoustic power. The temperature difference between hot end and cold end of the stack is higher at 2W heating load and lower at 10W heating load for operating frequency 400 Hz.The temperature difference across the hot end and cold end of the stack is increases with the increase of acoustic power for a mean pressure of 10 bar.

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