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An Experimental Investigation of Thermoacoustic Refrigerator

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Abstract:- *This paper deals with the experimental analysis of a thermoacoustic refrigerator. The project aims is develop the thermoacoustic refrigerator which does not require any moving parts and harmful refrigerants in its operation. Conventional refrigeration techniques have high energy costs and continue to generate greenhouse gases. Thermoacoustic is a combined branch of acoustics and thermodynamics which studies the transfer of heat by sound waves. Lots of research is going on in this area. This paper is focuses on improving the efficiency of thermoacoustic refrigeration by fabrication of hybrid stack with two different material high thermal conductive at hot side and low thermal conductive at cold side. The present work describes experimental result of thermoacoustic refrigerator.*

Keywords: -*Thermoacoustic, hybrid stack, resonator, sound waves, performance*

I. INTRODUCTION

Thermoacoustic devices use the Ideal gas law and the second law of thermodynamics to transform heat into sound waves or to use the oscillation of sound to transport heat. When a sound wave travels through air or any other gases, it creates pressure and motion oscillations in the gas. However the temperature of the gas oscillates as well. When the sound travels through gas in small channels, heat also flows to and from the channel walls. The combination of all such oscillations produces a rich variety of thermoacoustic effect.

Thermoacoustic refrigerator mainly consists of a loudspeaker attached to an acoustic resonator filled with a gas. In the resonator, a stack consisting of a number of parallel plates and two heat exchanger are placed. The source of acoustic energy is called acoustic driver which can be a loudspeaker. The acoustic drivers emits sound waves in a long hollow tube filled with gas at high pressure [1, 2].

Advantages of thermoacoustic refrigerator are that it is environmental friendliness, potentially high reliability due to simple structure and minimum number of moving parts, and reasonable efficiency. These characteristics could lead to low manufacturing and maintenance costs.

This paper starts with an experimental result of the different material and different gases. The thermoacoustic refrigerator gives result on two different gases with different pressure and hybrid stack [3].

II. EXPERIMENTAL SETUP

Fig.1 Experimental Setup

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Experimental setup has been developed during present work for carrying out experiments. This experimental setup was provided with sufficient instrumentation for measuring temperature at the cold end of stack [4]. The present results are only a part of extensive experiments possible with this setup [7]. The results obtained from present work are presented and discussed under section as experimental procedure and result of experimental work [2].

III. EXPERIMENTAL PROCEDURE

Procedure to carryout experiment is very important for any practical work so is here. Before starting experiment, availability of all the necessary equipment's was checked, they were gathered, and their working as well as connections was understood. After assembling all TAR components, setup is ready for experiment. First of all speaker test was carried out. Here it is checked that after assembling, speaker is working or not. For this it was run at some frequency and particular sound was observed. Secondly working of temperature sensors was checked. This was done by observing temperature at both end of the stack to be same after switching on temperature indicator [5].
At last all the fittings are done and system was charged with working gas to carryout leak test. During the same pressure was constantly observed in PC. If any drop in pressure was observed, system was checked for leak with soap water and it was fixed. When pressure remains constant, it means system is leak proof.
The Procedure is divided into two section first one is explaining the experimental method and second one is explaining results of experimental investigation.

IV. EXPERIMENTAL WORK

Experiments were done using two different working fluids air and helium with conventional and hybrid stack materials at two different pressure (5 and 8 bar). Combination of each gas with each stack material was made for getting maximum cooling effect and to find out effect of operating pressure. Results of each combination are briefly described below [3].

4.1 Mylar stack with Air as working fluid at 5 bar pressure

Initially compressed air is filled into the system as working gas for experimentation. When the power was supplied to speaker with the help of AC power source it started to vibrate. The starting frequency of loudspeaker was set to be around 400 Hz. All results were taken at constant frequency. The pressure in the system was set at 5 bar throughout the experiment. Results of experiments are shown by graph below. Before starting the driver temperature at the both sides was 34.9^{0}C.

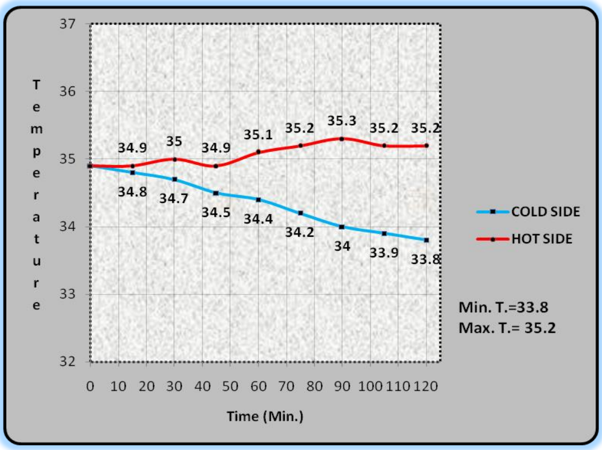

Fig.4.1.1 Time VS Temperature profile [Mylar/Air/5 bar]

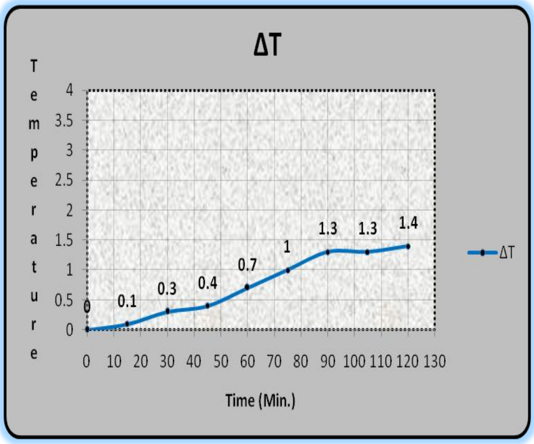

Fig.4.1.2 Temperature gradient profile [Mylar/Air/5bar]

As the graph shows that initially the temperature at the both side was 34.9^{0}C after 120 minutes there is heat reduction of 1.1^{0}C at cold side and 0.3^{0} heat increased at hot side of the stack was observed.

4.2 Hybrid stack with air as working fluid at 5 bar pressure

The same procedure was followed again but this time instead of stack of Mylar material hybrid stack which has a combination of Copper and Mylar was used. The frequency was set to 400 Hz and pressure at 5 bar. At the starting of experiment initial temperature at both sides was 37.7^{0}C indicated.

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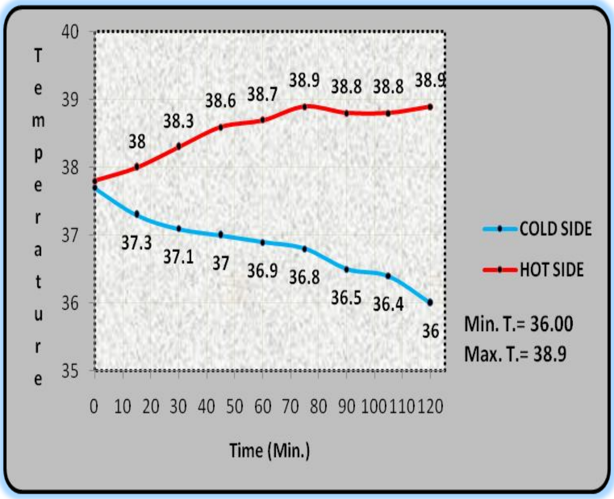


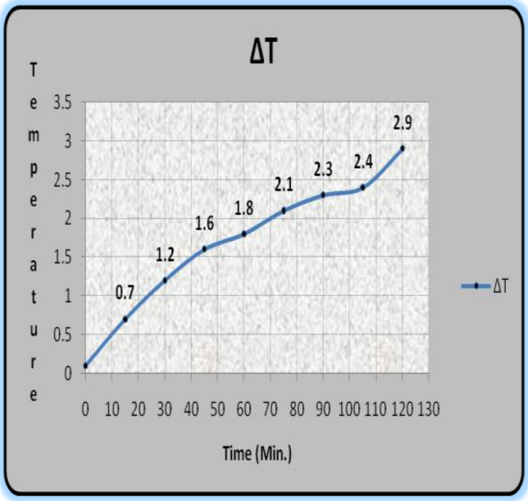


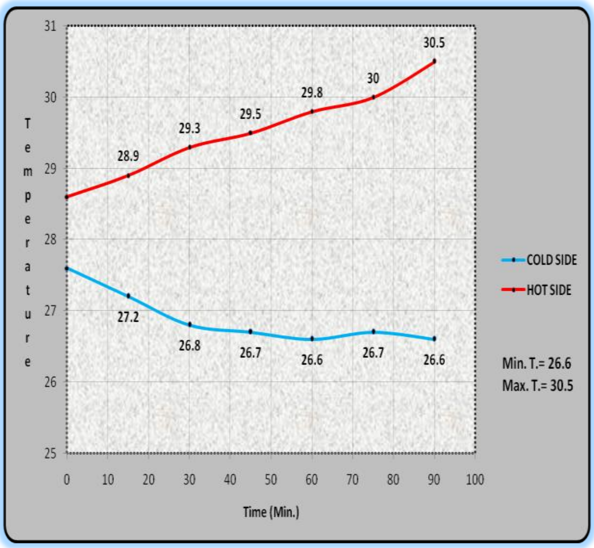
Fig.4.2.1 Time VS Temperature profile [Hybrid/Air/5 bar]

Fig.4.2.2 Temperature gradient profile [Hybrid/Air/5bar]

From the graph we can see that after 30 minutes there is rise in temperature at the hot side and continuous reduction in temperature at the cold side of stack. After 120 minutes there is 1.7^{0}C temperature reduction at the cold side and 1.0^{0}C temperature increased at the hot side. From this result we can conclude that for the same condition and for the same parameters hybrid stack gives better temperature gradient as compare to Mylar stack.

4.3 *Mylar stack with air as working fluid at 8 bar pressure*

Now after the analysis of effect of hybrid stack on the performance of TAR, we want to analyse the effect of operating pressure on the performance of TAR. So for that this time pressure is set to be 8 bar and frequency is set to be 400 Hz again.



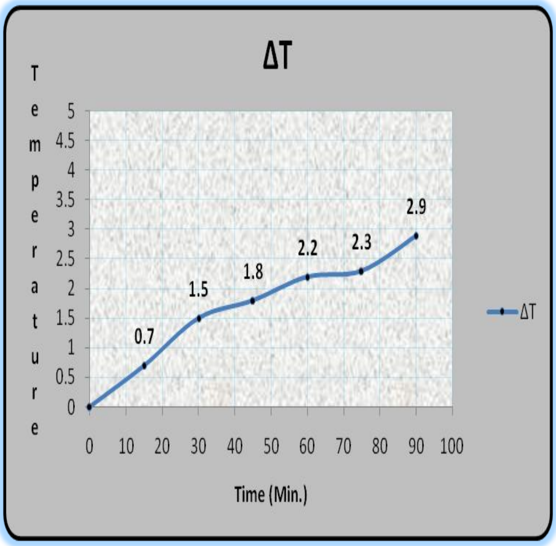


Fig.4.3.1 Time VS Temperature profile [Mylar/Air/8 bar]

Fig.4.3.2 Temperature gradient profile [Mylar/Air/8 bar]

As the graph shows that there is 1.0^{0}C temperature reduction at cold side of the stack and 1.9^{0}C increased temperature at the hot side of the stack. So this result shows that as the operating pressure increased the temperature gradient is also increased but too much operating pressure may damage to the strength of the resonator.

4.4 Hybrid stack with air as working fluid at 8 bar pressure

Now at the same pressure of 8 bar and 400 Hz frequency hybrid stack was inserted to the resonator. The initial temperature at the both side of stack was 33.2^{0}C observed by the indicator.

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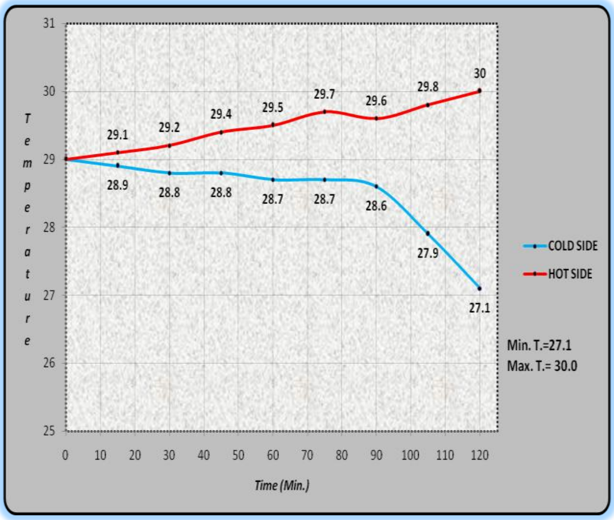


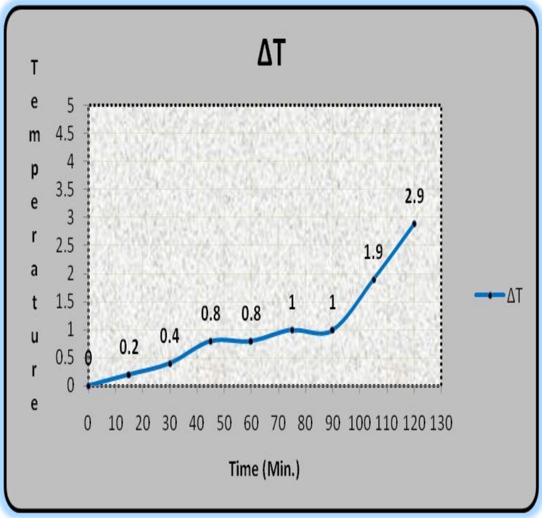


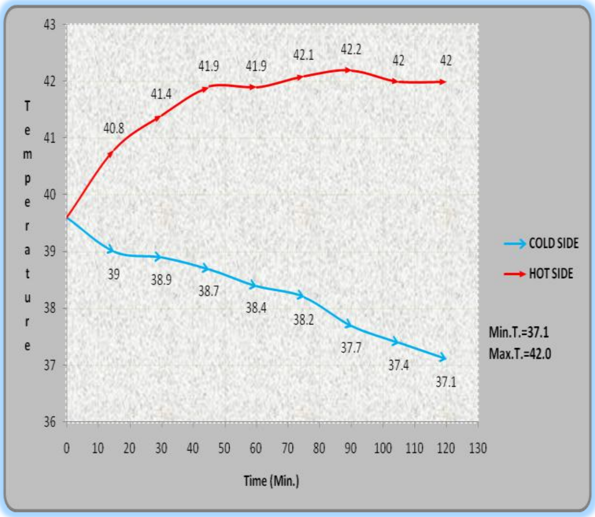
Fig.4.4.1 Time VS Temperature profile [Hybrid/Air/8 bar]

Fig.4.4.2 Temperature gradient profile [Hybrid/Air/8 bar]

As the graph shows that after 30 minutes there was considerable amount of heat reduction at cold side. Finally after two hour there was 1.9^{0}C temperature drop at the cold side and 1.2^{0}C increased at hot side which is superior result as compare to Hybrid stack at 5 bar.

4.5 Mylar stack with Helium as working fluid at 5 bar pressure

After using compressed air as working fluid Helium was used as per our design consideration, as already explained in previous chapter that reason for choosing He is because it has maximum velocity in sound as compare to other inert gases.



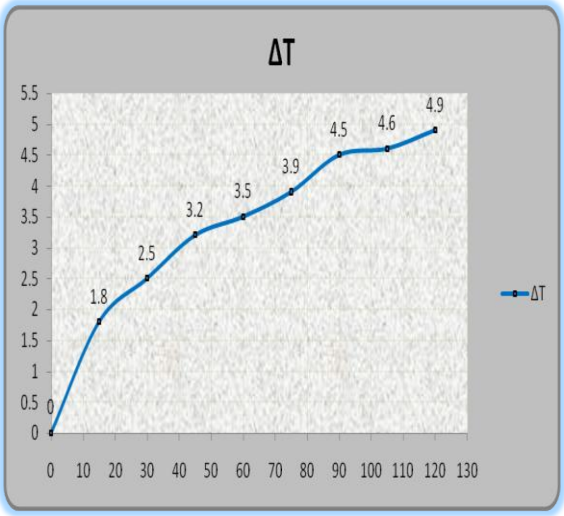


Fig.4.5.1 Time VS Temperature profile [Mylar/Helium/5 bar]

Fig.4.5.2 Temperature gradient profile [Mylar/Helium/5 bar]

Using Helium as working fluid gives better result as compare to compressed air as predicted. According to graph up to 30 minutes there is not considerable amount of heat reduction or increment in temperature at cold side and hot side of the stack respectively. But after two hours 2.5^{0}C temperature decreased at cold side and 2.4^{0}C increased in temperature at hot side.

4.6 Hybrid stack with helium as working fluid at pressure of 5 bar

Now again at same pressure of 5 bar and at same frequency of 400 Hz, hybrid stack was used for experimentation. Initial temperature at the cold side and hot side was 31.71^{0}C.

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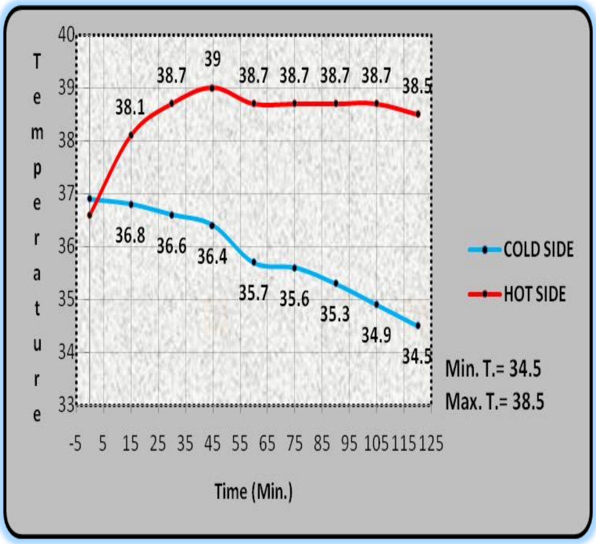

Fig.4.6.1 Time VS Temperature profile [Hybrid/Helium/5 bar]

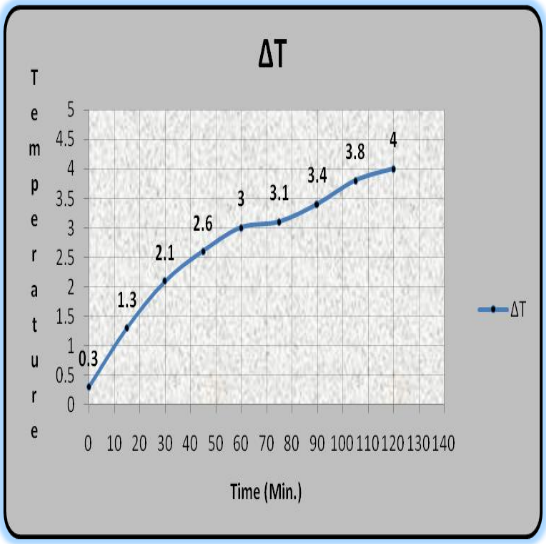

Fig.4.6.2 Temperature gradient profile [Hybrid/Helium/5 bar]

Result shows that hybrid stack at same pressure and frequency with helium as working fluid gives better result as compare to Mylar stack. Temperature reduction at cold side was measured 2.4^{0}C and 1.9^{0}C increased at hot side of the stack.

4.7 Mylar stack with helium as working fluid at 8 bar pressure

For analyze the effect operating pressure on the performance of the thermoacoustic device, instead of 5 bar pressure 8 bar was set with Mylar stack and helium gas as a working fluid.

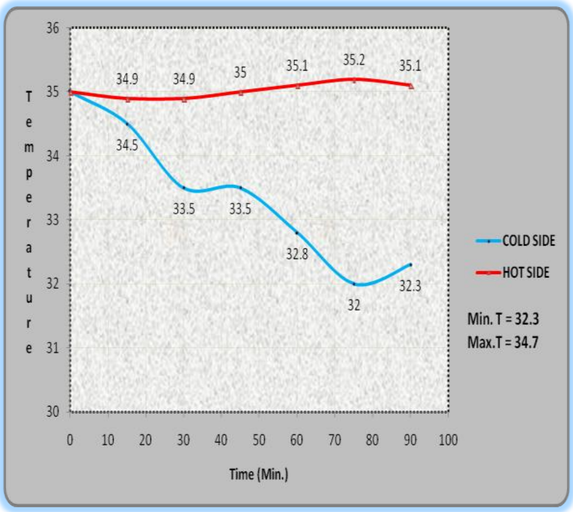

Fig.4.7.1 Time VS Temperature profile [Mylar/Helium/8 bar]

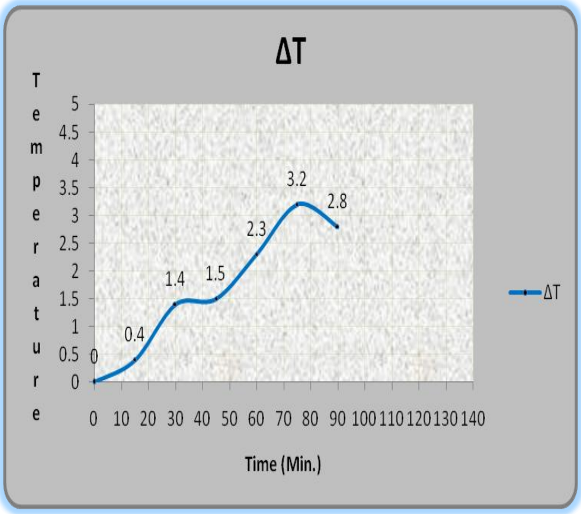

Fig.4.7.2 Temperature gradient profile [Mylar/Helium/8 bar]

The result again proves that with increasing operating pressure cooling power of the TAR is also increased.

4.8 Hybrid stack with helium as working fluid at 8 bar pressure

At last same procedure was followed, only instead of Mylar stack hybrid stack was used and other parameters were kept same. The initial temperature at cold side and hot side was 38^{0}C.

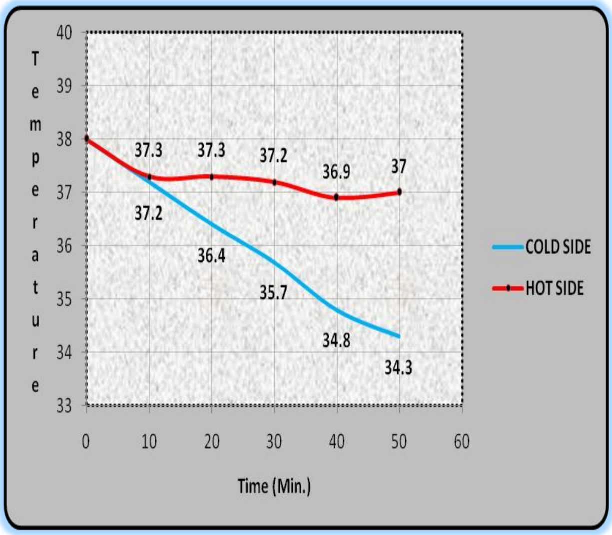

Fig.4.8.1 Time VS Temperature profile [Hybrid/Helium/8 bar]

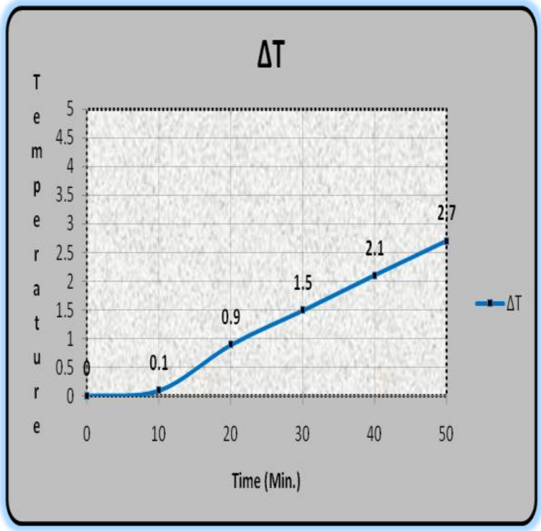

Fig.4.8.2 Temperature gradient profile [Hybrid/Helium/8 bar]

Graph shows that here temperature drop occurred at the both sides of the stack, reason behind it is environmental effect. After 50 minutes there is 3.7°C temperature drop at cold side and 1°C at the hot side.

V. CONCLUSION

In the Paper of Experimental investigation of TAR, we assumed temperature gradient up to 75 K. However experimentally we get max. 3.7^{0}C temperature drop at cold end for same operating parameters.
Thus there is huge deviation of experimental observation from theory. This deviation can be explained with the following:

Lack of insulation around the resonator tube:

In the present TAR assembly, whole resonator (Stack holder, small dia. Tube, Buffer volume) is without an insulation or vacuum around the assembly. As a result, there is unwanted heat load due to heat leak from the ambient to the cold heat exchanger block. The maximum pressure obtained inside the TAR setup is 5000 Pa for helium gas.

Ambient Heat Exchanger

The Thermoacoustic effect causes heat to flow from one end of the stack to the other. As a result, the stack end near to the pressure anti node begins to heat up while that near to the pressure starts to cool down. Thus, a temperature difference (Th - Tc) is generated across the stack. The cold end temperature Tc becomes low only when the level of high temperature Th is maintained close to ambient. This has to be accomplished by removing heat from the stack end which is getting heated up. For this purpose, a proper design of heat exchanger is necessary. In present case less emphasis was given on design of heat exchangers hence, the ambient heat exchanger was not efficient.

Heating in the acoustic driver

The assumption we made during design was to get temperature difference up to 75 K. This can be achieved, even more efficient result could be obtained when the TAR is run for more than 2 hours but there is limitation in doing this. Because when the refrigerator is run, the heating of loudspeaker coil is taking place so due to this there is possibility of damage of the coil. So proper cooling arrangement is required for cooling of the loudspeaker. In the present setup the cooling of loudspeaker is not done so there is time limitation for doing the experimentation. So experimentation was done for up to 120 minutes.

VI. REFERENCES

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