

**Design, Fabrication and Experimental Analysis of Thermoacoustic Refrigerator –
A Review**Payal Jha¹, Gaurav Patel², Krunal Shah³¹Mechanical Engineering, Indus University (Ahmedabad)²Mechanical Engineering, Indus University (Ahmedabad)³Mechanical engineering, HGC (Ahmedabad)

Abstract: -Thermoacoustic refrigerator is new refrigeration technology which does not require any moving parts and harmful refrigerants in its operation. This technology uses acoustic waves to pump heat across a temperature gradient. The vast majority of thermoacoustic refrigerator to date have used electromagnetic loudspeakers to generate the acoustic input. In this thesis, the design, fabrication, and experimental analysis of thermoacoustic refrigerator (TAR). As it does not contain any moving part other than speaker which increase the lifespan of product the decrease the maintenance cost. So it does not use lubricant. It only uses the sound wave which is pressure wave for cooling. The present work describe theoretical study and experimental analysis of standing wave TAR and mainly focuses on improving the performance of TAR by fabrication of hybrid stack with two different material high thermal conductive material at hot side and low thermal conductive material at cold side.

Keywords:- Thermoacoustic; Refrigeration; Hybrid stack; performance; Resonator tube; heat exchanger; buffer volume; Quarter wave resonator; sound wave; buffer volume

I. INTRODUCTION

Thermoacoustic is the study of things that involves both acoustic(sound waves) and Thermodynamics(energy conversion). The interaction of heat and sound has interested since 1816. Newton had assumed that the expansions and compressions of sound wave in gas happened without affecting temperature. But Laplace accounted for slight variations in temperature that in fact take place. The meaning of the term TAR, according to Nicholas Rott is fairly self-explanatory. As its name suggests, thermoacoustics is a science that is concerned with the interaction between heat and pressure oscillation in gases. This field can be broken two subcategories. The first is the forward effect which is concerned with the generation of pressure oscillation from heat. The advantages of TAR are that it is environmental friendliness, reliability due to simple structure, potentially high and minimum number of moving parts and better efficiency.

The TAR system which use sound to generate cooling power. They consists mainly 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 exchangers, are installed. The loudspeaker sustains an acoustic standing wave in the gas at the fundamental resonance frequency of the resonator. The acoustic standing wave displaces the gas in the channel of the stack while compressing and expanding. The thermal interaction between oscillating gas and surface of the hybrid stack generates an acoustic heat pumping. The heat exchanger then exchange heat with surroundings, at hot and cold side of the hybrid stack.

II. THERMOACOUSTIC REFRIGERATOR

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

This long hollow tube is called 'resonance tube' or 'resonator'. The frequency of the driver and the length of the resonator are chosen so as to get a standing pressure wave in the resonator. A solid porous material like a stack of solid plates is kept in the path of sound waves in the resonator. The schematic diagram is follows[1], [4].

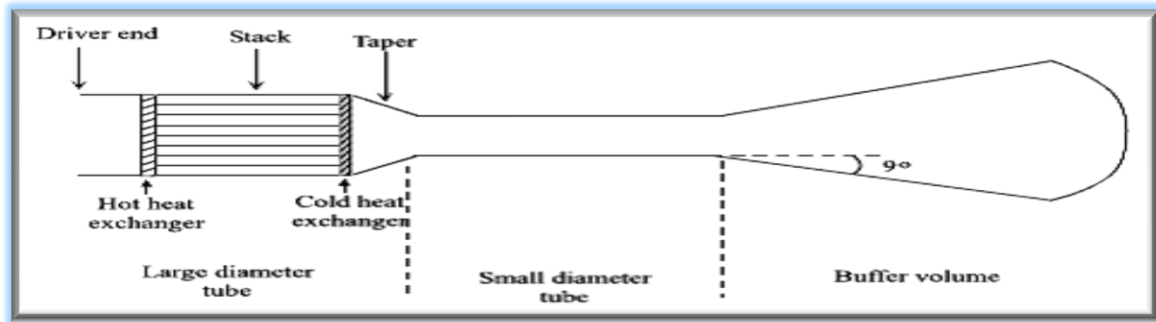


Fig.1 Schematic Diagram of TAR

The loudspeaker sustains an acoustic standing wave in the gas at the fundamental resonance frequency of the resonator. The acoustic standing wave in the gas in the channels of the hybrid stack while compressing and expanding. The thermal interaction between the oscillating gas and the surface of the stack generates an acoustic heat pumping. The heat exchangers exchange heat with the surroundings, at the hot and cold sides of the hybrid stack.

III. DESIGN OF THRMOACOUSTIC REFRIGERATOR

3.1 Design strategy

Designing the hybrid stack in such a way as to be able to meet the cooling requirements. This stack design is performed by first making choices for the average pressure, frequency, working gas and hybrid stack. [1], [4], [5]

After these variables have been selected, the material, geometry, and position of the actual stack is designed and fabricated. The resonator is then designed under the constraints of the natural frequency and minimizing loss at the walls. The heat exchangers are then designed though the authors concedes that not much is known about heat exchangers in oscillatory flow with zero mean displacement.

The acoustic driver is then the final part of the refrigerator to be designed. In another publication, Tijani describes in detail how the refrigerator parts were manufactured and built. The most simple design approach is that of Tijani's which is being used here in the design of the TAR.

In attempt to optimizing the design of TAR, Wetzel developed an algorithm for optimizing the design of TAR. The developed algorithm splits the optimization process into the four basic parts. It is concluded that efficient TAR that are competitive with traditional refrigerators are theoretically possible if hang ups such as better heat exchangers can be overcome.

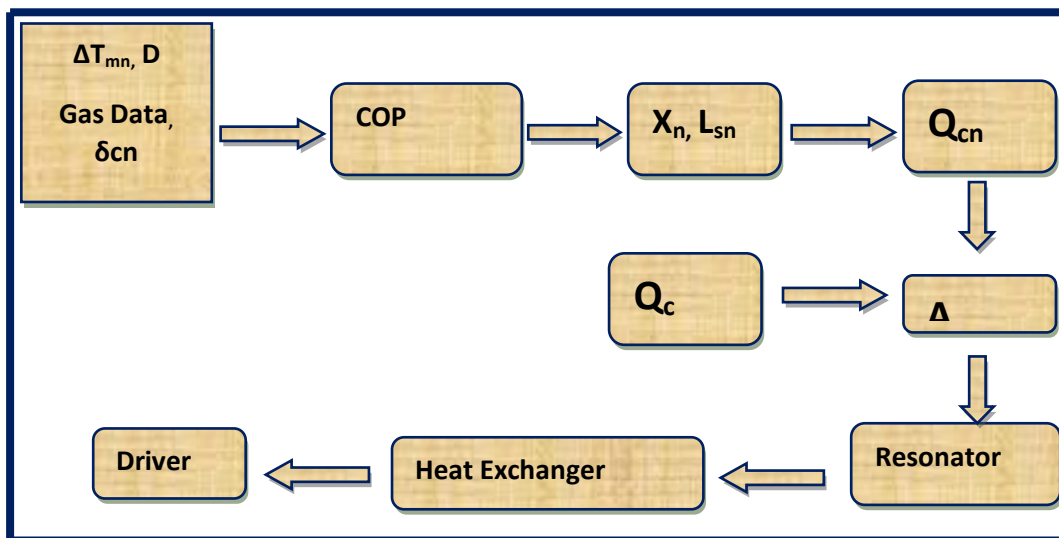


Fig.2 Design Strategy

The Dimensionless cooling power and dimensionless acoustic power are calculated by this equation, [1], [5]

$$Q_{cn} = \frac{\delta_{kn} D^2 \cdot \sin(2x_n) \cdot x \Delta T_{mn} \cdot \tan(x_n)}{8\gamma(1 + \sigma)} \frac{1 + \sqrt{\sigma} + \sigma}{(\lambda - 1) \cdot B \cdot L_{sn}} - (1 + \sqrt{\sigma} - \sqrt{\sigma} \delta_{kn})$$

$$W_n = \frac{\delta_{kn} L_{sn} D^2 (\gamma - 1) B \cos(x_n) x}{4\gamma} \frac{\Delta T_{mn} \tan(x_n)}{B L_{sn} (\gamma - 1) (1 + \sqrt{\sigma}) \Lambda} - \frac{\delta_{kn} L_{sn} D^2 \sqrt{\sigma} \sin(x_n)}{4\gamma B \Lambda}$$

3.2 Design choices

For this investigation we choose to design a refrigerator for a temperature difference of $\Delta T_m = 75$ K and a cooling power of 5 W. in the following, we will discuss [1], [5],

Table. 1 list of operating parameters

Operating frequency (f) = 400 HZ	Mean temperature (T_m) = 300 K
Average pressure (p_m) = 5 and 8 bar	Temperature gradient (ΔT_m) = 75 K
Dynamic pressure (p_o) = 0.2 bar	Normalized temp. difference (ΔT_{mn}) = 0.25
Drive ratio (D) = 0.02	Cooling power (Q) = 5W

Table. 2 list of working gas parameters

Thermal conductivity (K) = 0.13 W/mK	Gas dynamic (ρ_m) = 1.9 kg/m ³
Sound velocity (a) = 935 m/s and 1013 m/s	Dynamic viscosity (μ) = 1.7* 10 ⁻⁵ kg/s.m
Specific heats ratio (γ) = 1.67	Prandtl number (pr) = 0.68
Heat capacity (C_p) = 5200 J/kg.K	

3.2.1 Average pressure

After fixing the temperature, the average pressure was calculated. Since the power density in a thermoacoustic device is proportional to the average pressure p_m , it is favourable to choose p_m as large as possible. This is determined by the mechanical strength of the resonator. On the other hand, δ_k is inversely proportional to square root of p_m , so a high pressure results in a small δ_k and a small stack plate spacing. This makes the construction difficult. Taking into account these effects and also making the preliminary choice for helium as the working gas, the maximal pressure is 10 bar. We choose to use 5 and 8 bar. To minimize heat conduction from hot and cold side we used a high and low thermal conductive material [3].

3.2.2 Frequency

As per the power density in the thermoacoustic devices is a linear function of the acoustic resonance frequency an obvious choice is thus a high resonance frequency. On the other hand δ_k is inversely proportional to the square root of the frequency which again implies a stack with very small plate spacing. Marketing a compromise between these two effects and the fact that the driver resonance has to be matched to the resonator resonance for high efficiency of the driver, we choose to use a frequency of 400 HZ. [3]

3.2.3 Working gas

After fixing the above values, it's time to choose the working gas. It should not be chemically reactive and should also have a high thermal conductivity. Helium and Air is used as working gas. The reason for this choice is that helium has the highest sound velocity and thermal conductivity of all inert gases. Furthermore, helium and air is cheap in comparison with the other noble gases. [3]

3.2.4 Hybrid stack

The heat conduction through the stack material and gas in the stack region has a negative effect on the performance of the refrigerator. The stack material must have low and high thermal conductivity. In the fabrication of hybrid stack, Mylar sheet is attached with a Copper and Aluminium sheet with the help of adhesive tap.

IV. FABRICATION OF HYBRID STACK

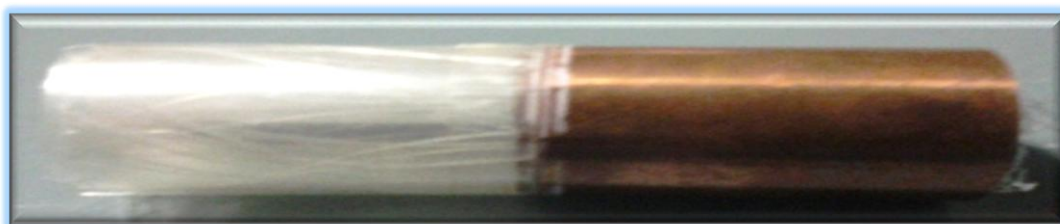


Fig.3 Hybrid Stack

The stack is manufactured from Mylar film, copper and fishing lines are used as spacers. By considering easiness in manufacturing we decide spiral geometry for the stack. The distance between two spacing lines is 5 mm throughout the cross section. This particular ensured that the two layer of Mylar film and copper do not touch other and the gas passage channels are uniform. The Mylar sheet and copper sheet both are attached with the help of adhesive tap.

V. ASSEMBLY



Fig. 4 Assembly of TAR

As shown in fig. the buffer volume and small diameter tube are welded together, in second half portion housing of driver and stack holder are attached. Once the hybrid stack is properly fitted into the stack holder the second portion is attached tap the first half with the help of nut. Then gas filled up to 5 and 8 bar as per experimental analysis.

VI. EXPERIMENTAL SETUP



Fig. 5 Experimental Setup of TAR

The schematic of the experimental setup is shown in fig. The TAR is powered by an AC power source. The mean pressure is first set by filling the gas through valve up to 5 bar. Cold and hot end temp. Is measured using thermometer. The signals we got from signal generator are supplied to amplifier which is connected to the speaker.

VII. CONCLUSION

All Literature review reveals that stack material should be low thermal conductive, because if thermal conductive material is used in fabrication of stack than heat will flow from hot side to cold side of the stack. Which affect the performance of the TAR. But as discussed in previous points low thermal conductivity decrease thermal effusivity of material which is measure of ability of the material to absorb heat from the surrounding. So increase thermal effusivity of stack, high thermal conductivity material should be used and preventing heat flow from hot side to cold side. The conclusions derived based on these experimental investigation are as follow

Effect of Operating Pressure

Experiments were taken at two different operating parameters. Results show that by keeping other parameters constant, higher operating pressure gives better temperature reduction at the cold side. Because operating pressure is directly proportional to power density. So selection of the operating pressure is depends on the two factors i) strength of the resonator and ii) thermal penetration depth.

Effect of Working fluid

Here we had used two different working fluids i) Air and ii) Helium. Both were used with each combination of stack material and operating pressure. Result show that He gives better results as compare to air. Helium is a high velocity as compare to air in the sound and higher thermal conductivity also.

Effect of Stack Material

Now, we have already mentioned that the objective of present work is observe to the effect of hybrid stack on the performance of TAR. Here meaning of hybrid is combination of two different materials, so we have used Copper and Mylar sheet for the fabrication of hybrid stack the reason for choosing copper sheet is because it contains higher thermal conductivity as compare to Mylar. As expected hybrid stack gives better performance as compare to conventional stack.

VIII. FUTURESCOPE

Based on the above investigations some suggestion, for future work in order to fabricate more efficient thermoacoustic refrigerator devices are given below.

- Fabricating and testing the refrigerator with different hybrid stack (made by combination of two materials) and heat exchangers types.
- Modifying the loudspeaker in order to be used in pressurized environment.

IX. REFERENCES

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