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Design And Development of Thermoacoustic Refrigeration System

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Abstract: Thermoacoustics is a field that joins thermodynamics, liquid elements and acoustics. In thermoacoustics it is feasible to develop thermodynamic motors, central players and intensity siphons which separately use intensity to make work, and use work to make or move heat. Thermoacoustic is a somewhat new area of science and designing. The subject is still very obscure and not much writing is accessible regarding the matter. This task inspected the viability of thermoacoustic refrigeration, which is the hypothesis of involving sound waves as a coolant. We concentrated on the elements of sound, Temperature and the Carnot cycle and utilized this information to come to a comprehension of thermoacoustics. We then, at that point, applied this comprehension to the development of a little thermoacoustic cooler, which was worked from cheap and promptly accessible parts. The analyses showed that while thermoacoustic cooling was conceivable, high effectiveness was past our range because of materials limitations. However, from these limitations we devised several proposals for increasing the efficiency of thermoacoustic refrigerator.

***Index Terms*–** Thermoacoustic, Thermoacoustic refrigerator, Refrigerating effect, Cooling effect

I. INTRODUCTION:

From establishing agreeable home conditions to assembling quick and productive electronic gadgets, cooling and refrigeration stay costly, yet fundamental, administrations for the two homes and enterprises. Notwithstanding, during a time of looming energy and ecological emergencies, current cooling innovations keep on producing ozone depleting substances with high energy costs. Thermoacoustic refrigeration is an imaginative option for cooling that is both spotless and economical. Through the development of a practical model, the viability of a thermoacoustic cooler will be illustrated. Refrigeration depends on two significant thermodynamic standards. Initial, a liquid's temperature climbs when packed and falls when extended. Second, when two substances are put in direct contact, intensity will move from the sultrier substance to the cooler one. While traditional coolers use siphons to move heat on a perceptible scale, thermoacoustic fridges depend on sound to create rushes of tension that on the other hand pack and loosen up the gas particles inside the cylinder.

Thermoacoustic depends on the rule that sound waves are pressure waves. These sound waves spread through the air by means of sub-atomic impacts. The sub-atomic crashes cause an unsettling influence in the air, which thusly makes useful and damaging impedance. The valuable obstruction makes the atoms pack, and the disastrous impedance makes the particles grow. This rule is the premise behind the thermoacoustic fridge. One technique to control these strain unsettling influences is with standing waves. Standing waves are regular peculiarities displayed by any wave, like light, sound, or water waves.

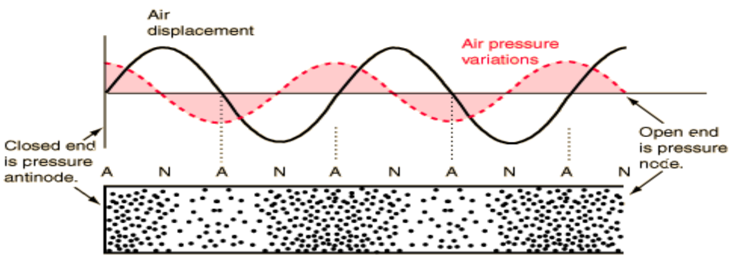

Fig1: Relationship between the phase of the wave, the pressure and the actual arrangement of the molecules

In a shut cylinder, segments of air exhibit these examples as sound waves ponder back themselves subsequent to slamming into the finish of the cylinder. At the point when the occurrence and reflected waves cross-over, they meddle helpfully, creating a solitary waveform. This wave seems to make the medium vibrate in confined segments as the voyaging waves are veiled by the interference.1 Hence, these "standing waves" appear to vibrate in steady position and direction around fixed hubs. These hubs are found where the two part sound waves meddle to make areas of zero net uprooting. The areas of greatest dislodging are found somewhere between two hubs and are called antinodes. The most extreme pressure of the air additionally happens at the antinodes. Due to these node and antinode properties, standing waves are useful because only a small input of power is needed to create a large amplitude wave. This large amplitude wave then has energy to cause visible thermoacoustic effects.

II. LITERATURE REVIEW:

In 1686 work Principia, Newton included a mechanical interpretation of sound as being pressure pulses transmitted through neighbouring fluid particles. Newton though this expansion sand compression sharpened without affecting the temperature, while in fact they do produces light variations in temperature as found by LaPlace. This was observed by 19th-century glass blowers who not iced that as the glass was heated up sound was produced (Garrett). This made people wonder if a change temperature could produce sound, could sound produce a change in temperature?

In the mid-1800s, Rijke and Sondhaus made numerous discoveries significantly progressing the study of thermoacoustics. Rijke determined that a large vertical tube, open at both ends, emitted sound when heat was place at one quarter of the tube length. Additionally, Send Haus describe downtube close at one end will produce sound when the closed end is heated.

In 1975, Merkli and Thomann were able to observe sound producing a temperature difference (Symko,646). Rotter searched these effects and developed the mathematics describing oscillations in a tube with a temperature gradient (Swift, Unifying Perspective 2380). These results confirmed the connection between sound and heat.

In 1983, Wheatley developed a thermoacoustic refrigerator, which produced a temperature difference of 100oC when pumped withs found at 500Hz at a level above 185 d B in pressurized helium gas (Symko,648). Five years later, Hofler invented as tending-wave thermoacoustic refrigerator, confirming the validity and accuracy of Rott's approach to acoustics in small channels (Swift, A Brief Description1). The Space Thermoacoustic Cooler (STAR) was the first electrically-determined thermoacoustic chiller intended to work outside a research canter. It was sent off on the Space Transport Revelation (STS-42) on January 22, 1992.

Table 1: Literature Review of Papers

Sr no.	Title of paper	Author name and date	Conclusions
1.	Optimizing the design of a TR	B L. Minner, Braun, L. Mongeau 1996	Cu alloy exchanger used He & Xe mixture results in shorter device a lower operating frequency as compared to pure helium and results were nearly optimal
2.	Thermo-acoustic natural gas liquefier	Gregory Swift,1997	Thermoacoustic skill successfully implemented to liquefy natural gas
3.	Design of TR	J.C.H. Zeegers, Nov2001	Even after reducing the parameters results obtained were 95% accurate as that of the original one
4.	Resource letter on thermoacoustic engines and refrigerators	Garrett, Jan2004	It does not matter if wave is travelling or standing the heat that is pumped matters
5.	An overview of stack design for TR	Bhansali. S, June 2015	Stack spacing affects stack performance too low spacing leads to higher viscous losses and too larger spacing results in only a small volume of gas involved in thermal interaction
6.	Measuring the performance of different	David Bartos,2015	Best performing material is stainless steel followed by plastic and then paper

	stack materials in thermo acoustic device		
7.	Performance evaluation of TR using air as working medium	Ramesh Nayak, June 2015	The temperature difference across the hot end and cold end of the stack increases with increase of acoustic power for mean pressure of 10 bar
8.	A study of TR system	Pranav Mahamuni, Feb 2015	Parallel type stacks of thermoplastic gave satisfying results
9.	Design of thermoacoustic refrigerators	M.E.H. Tijani, J.C.H. Zeegers, And A.T.A.M. De Waele,2001	Short stack approximation for design of TAR gave satisfactory results.

III. EXPERIMENTAL SETUP AND INSTRUMENTATION:

The schematic of the experimental setup is shown in Figure 2. The TAR is powered by a variable frequency variable voltage power source. The input power, the voltage and the current are measured by means of a digital AC power meter. The magnitude of the dynamic pressure wave generated by the acoustic driver in the resonator is measured using a dynamic pressure transducer. The transducer is placed inside the resonator downstream of the stack. The small voltage signal from the pressure transducer is amplified by a differential amplifier and fed to the digital oscilloscope. The dynamic pressure is calculated from the voltage waveform observed on the digital oscilloscope. For cold temperature measurement, a copper constant in (type-T) thermocouple is used. The thermocouple is gone through a little opening penetrated through the CHX block where it is in direct contact with the virus gas inside the TAR.

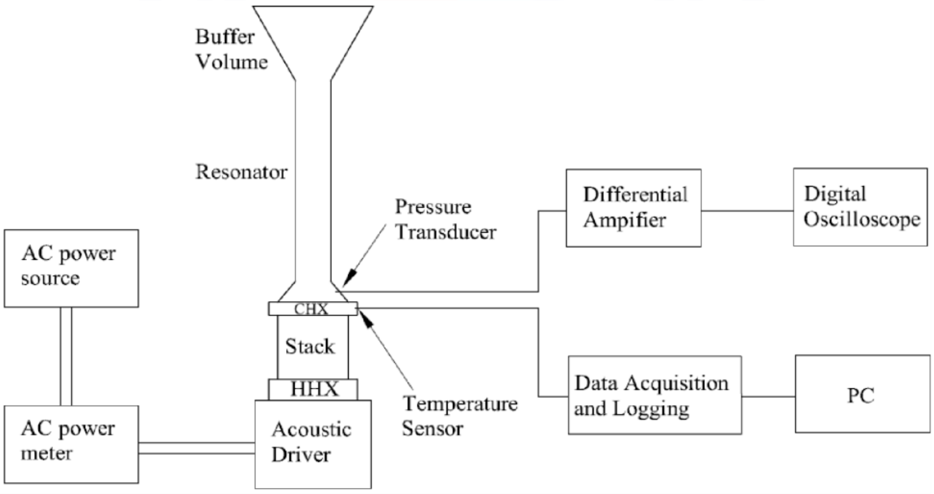

Figure 2 Schematic of the Experimental Setup and Allied Instrumentation

After switching on the power supply, the temperature at the CHX of the TAR starts to fall below ambient. This fall of temperature is continuously acquired and logged by means of a DAQ system. The DAQ system is controlled by a computer. All the temperature data logged in the DAQ system is then unloaded into the PC, where it is available for post-processing.

IV. FABRICATION OF MODEL:

a) The Spiral Stack:

The stack is manufactured from a 0.18 mm thick Copper film. 0.3 mm thick Nylon fishing lines are used as spacers. As discussed in the previous chapter, spiral geometry is chosen for the stack, because of its ease in manufacturing. The distance between two adjacent spacing lines is 3 to 5 mm throughout the stack cross section. This particular spacing ensured that the two layers of the Copper film do not touch each other and the gas passage channels are uniform. This has been realized through repeated attempts of making the stack. The length of the stack is 100 mm and its diameter is 32 mm. The stack manufacturing process is described as follows: A PVC pipe enough to accommodate the width of Copper film is taken and equidistant slits at 5 mm from each other are made on both its edges. The Copper film is then held tightly on the pipe. Nylon fishing line is wound over the Copper film. This can be visualized better from below fig. After each turn, the fishing line passes through the next slit which is as 5 mm from the previous one. This ensures a winding pitch of 5 mm and hence, a spacing of 5 mm between two consecutive fishing lines. The fishing lines are then glued to the Copper film. This can be either done by means of an adhesive tape or an adhesive like insulating varnish. It is found that the use of adhesive tape increases the thickness of the Copper film layer and hence, use of insulating varnish is advisable. The fishing lines are then cut along the edges of the Copper film. Thus, the stack is ready for rolling. Rolling is carefully done so as not to disturb the spacing lines.

b) The Stack Holder:

The stack holder houses the stack and is sandwiched between the two intensity exchangers. The stack holder material should have a low thermal conductivity to minimize the axial conduction losses when a temperature difference is generated across the stack. It should be strong enough to hold the gas at the desired charging pressure. To meet these requirements, Delrin was chosen as the material for the stack holder. Apart from being light weight (ρ = 1420 kg/m3) and poor conductor of heat (k = 0.3 W/m-k), it has the best machinability among other polymers like PTFE, nylon, etc.

The total length of the stack holder is 100 mm and its inner diameter is 200 mm. The outer diameter 205 mm and thickness 5 mm at each of its end. The entire structure is machined out as an integral part from a Delrin.

c) Heat Exchangers (HXs) :

The HXs facilitate the exchange of heat from gas near the hot/cold end of the stack and the ambient. It also provides a surface to mount the sensors for measurement of temperature. Because of the requirement of high thermal conductivity, the HXs are made out of soft copper.

The CHX has the shape of a ring of 200 mm ID and 205 mm OD. The length of the CHX was 5 mm. This length provided easy access to the CHX circular surface and enough space so as to mount a sensor for temperature measurement. However, this length is much more than the optimal HX length as given in literature [1]. The gas side of the CHX is filled with a stack of copper screens of size 100.

The body of warm HX is to be maintained at ambient by circulating cooling water. Hence, to increase the heat exchange area, circular fins are provided. The ID of warm HX is 200 mm and its OD is 205 mm. Its total length is 11 mm with four circular fins of thickness 1 mm and length 5 mm.

d) Resonator Tube:-

The resonator tube is the hollow component of the resonator system. It is placed between the cold HX and the buffer volume. To ensure low thermal conductivity, high strength and light weight, the resonator tube was machined out of a Delrin rod. The resonator tube consists of a conical taper followed by a straight hollow tube. The conical taper provides the reduction of diameter from 200 mm at the cold HX side to the 70 mm diameter tube. The total length of the resonator tube is 295 mm. The resonator tube has flanges of diameter 80 mm on both the end for fastening to other components of the assembly. The resonator tube a tapped hole for connection of dynamic pressure transducer.

e) Buffer Volume:

The buffer volume is a large open conical volume which simulates the 'open end' of the quarter wavelength resonator. It is made of a SS 304 sheet of 1 mm thickness. The sheet is cut in the required shape and then turned into a truncated cone on a rolling machine. The cone is then welded using argon welding technique along its slant length. The larger end of the truncated cone is closed by welding a circular cut SS 304 sheet.

The total height of the buffer volume is 100 mm, the larger and smaller diameters are respectively 200 mm and 70 mm.

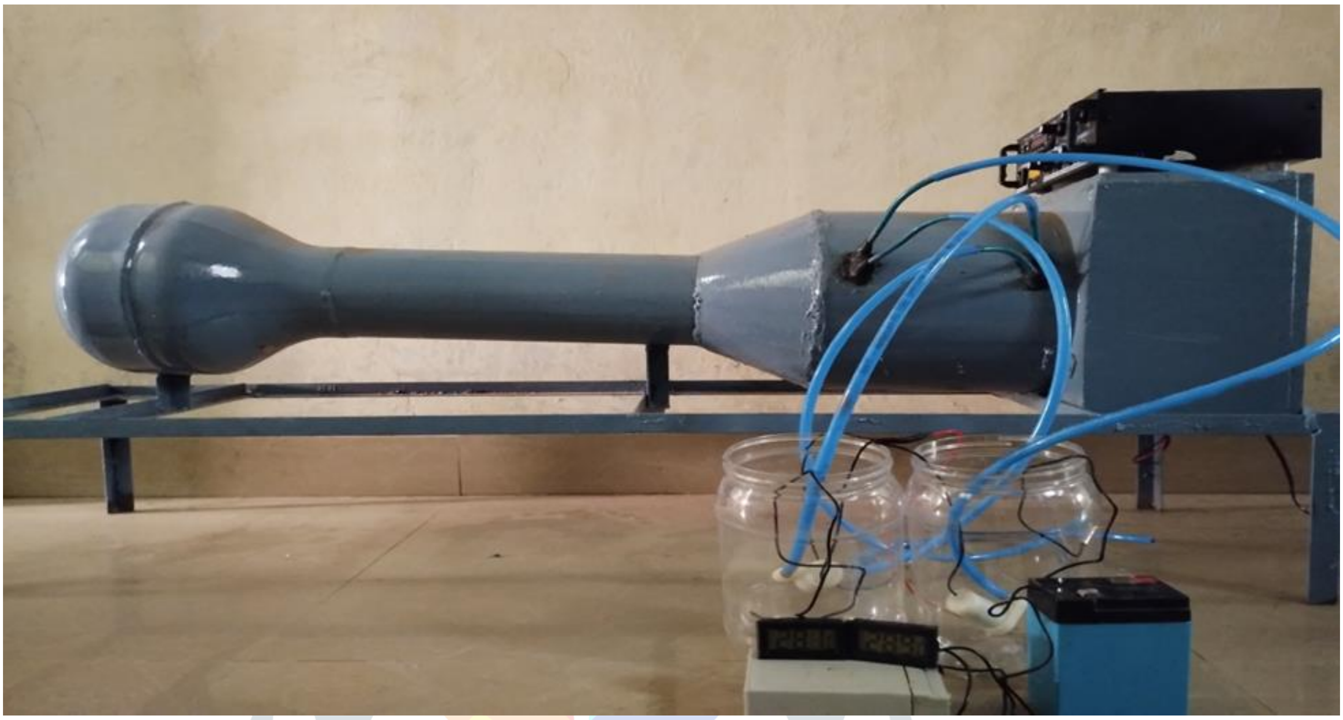

***Figure 3**. Actual Model*

V. **OBSERVATION AND RESULTS:**

1. Experiments are carried out on a TADTAR with the gas as a working fluid to analyse the influence of an operating parameter. The effect of two geometric parameters, TAR stack position and the Resonator length, are also assessed on the performance of TADTAR.

2. Theoretically, a temperature drop of 283 Kelvin can be achieved by considering all the other parameters constant, but a temperature of 302.9 Kelvin achieved from the temperature of 305 Kelvin, the reason is because the theoretical calculations were done at 10 bar and the experiment was conducted at 1 bar pressure.

Inlet Water Temperature (K)	Time (Sec.)	Changed Temperature (K)
305	600	304.6
305	900	304.2
305	1200	303.8
305	1500	303.5
305	1800	302.9

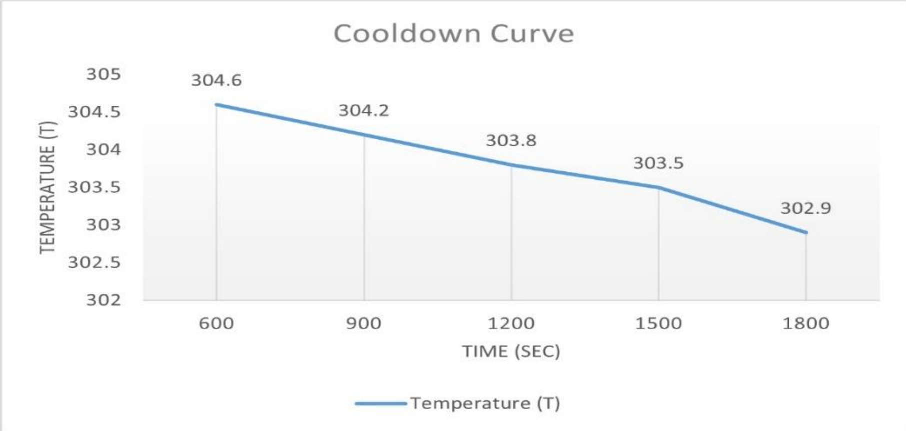

Figure 4. Graph (Time Vs. Temperature)

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