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THERMOACOUSTICS

T B Uday Shankar Aradhya[1], Shashank M R[2], Suhruth G Ujjni[3] and Sagar B[4]

[1]Associate Professor, Dept Mechanical Engineering,
[2,3,4]Students, Dept Mechanical Engineering, Shridevi Institute of Engineering & Technology, Tumakuru, Karnataka, India

ABSTRACT

Today, we use various heating and cooling systems which are all the applications of the thermal engineering. One of its applications is seen in the technology of “Thermoacoustic refrigeration”. This paper mainly deals with the construction and performance of a thermoacoustic refrigerator. This system uses sound waves to produce cooling power. Hence the thermal interaction between these sound waves and the surface of the stack (parallel plates, installed in the resonator) generates heat pumping process. The setup consists of three major parts: The refrigerator which is contained in a vacuum vessel, the electronic apparatus necessary for the measurements and the gas-control panel. The commercial viability of this technology is determined by comparing it to a vapor compression system.

Keywords: *Thermoacoustic, Stack, Performance.*

1. INTRODUCTION

The thermoacoustic effect was first discovered in 19th century when heat driven acoustic oscillations were observed in open ended glass tubes. These devices were the first thermo acoustic engines, consisting of a bulb attached to a narrow long tube (Fig 1).

What thermo acoustic refrigerators offer is both simplicity and reliability. Unlike current commercial devices that require crankshafts and pistons, these devices use only a single moving part- the diaphragm of a loudspeaker. What currently makes them very attractive as an alternative to other approaches is their use of an inert gas as the working fluid, making them environmentally clean.

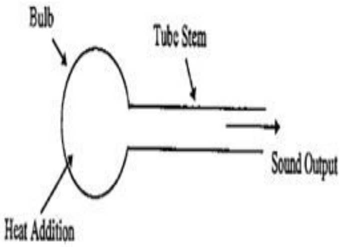


Fig 1: Bulb Attached to Narrow tube.

2. BASICS OF THERMOACOUSTIC REFRIGERATION

A basic thermoacoustic refrigerator consists of a stack of thin parallel plates housed within a resonator, as shown schematically in Fig 2. Heat can be pumped from cold to warm end of the stack by setting up a standing wave within the resonator. This effect, where heat is pumped up a temperature gradient by the use of sound, maybe explained by considering an element of fluid as it oscillates back and forth along the stack. The element experiences a cyclic temperature oscillation about its mean temperature, due to adiabatic compression and expansion of the gas. Irreversibility caused by a temperature difference between the oscillating working fluid and the stack result in the correct phasing between the pressure and the temperature oscillations.

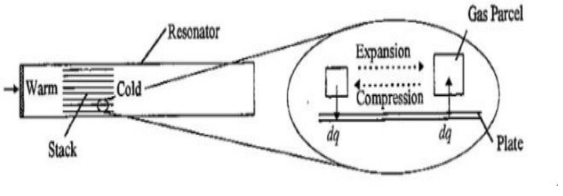


Fig 2: Thermoacoustic Refrigerator

The phasing is such that when the element is in its right-most position it has been expanded to a temperature that is cooler than the local stack temperature, and so absorbs heat from the stack, and when the gas parcel is displaced up the plate to its left-most position it is compressed to a temperature that is hotter than the stack, thereby rejecting the heat to the stack. As all gas elements within the stack behave in a similar manner the net result is the transport of heat up a temperature gradient (from the cold to the warm end of the stack). This heat transports between the gas and the stack occurs only within a region close to the stack known as the thermal penetration depth (δ_K). Work is absorbed by the gas element as the thermal expansion occurs during the low pressure phase and the thermal contraction during the high pressure phase of the acoustic cycle. If a temperature gradient is imposed along the stack and the temperature gradient is large enough, the device ceases to be a thermo acoustic refrigerator and starts producing work- it becomes a thermo acoustic engine. This is because after the gas parcel has been adiabatically compressed it will no longer be hotter than the stack and will absorb heat (instead of rejecting it) at high pressure and expands, thereby doing work.

A thermoacoustic refrigerator has three major components apart from the stack and the resonator. They are the driver, and hot and the cold exchangers. The driver is responsible for producing the standing wave. Typically this an electromagnetic device, but a thermoacoustic engine coupled to the hot end of the stack has been used. The heat exchangers are responsible for getting the desired heat into and out of the stack.

There is a variety of configurations for these components but a device similar to the design is shown in the Fig 3, as this has been shown to be an efficient design. The device consists of a spirally wound stack which has spacing of about four times the thermal penetration depth. The heat exchangers are parallel copper strips extending across the length of the tube. This is a quarter wavelength design and can be pressurized allowing higher power densities. The operating frequency of the system is determined by the length of the resonator and the speed of sound in gas, and typically ranges from 50 to 1000 Hz. The working fluid is typically helium and another inert gas. Gas mixtures that reduce the Prandtl number increase the efficiency, but unfortunately also reduce the heat load. Current gas mixtures have Prandtl numbers significantly below 2/3.

The capacity of a thermoacoustic refrigerator is determined primarily by the cross sectional area of the stack and the driving ratio Posc / Pm. This is the ratio of peak oscillating pressure Posc to the mean pressure Pm. An increase in either of these factors increase in the heat load.

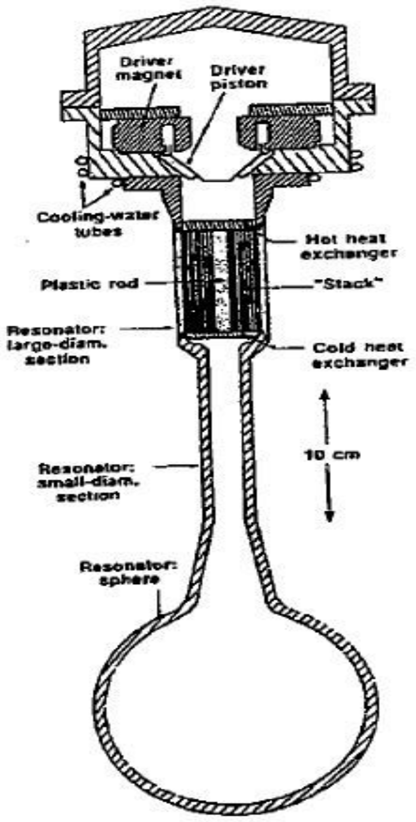


Fig 3: Hofler's Design of Thermoacoustic Refrigerator.

THERMOACOUSTIC REFRIGERATOR MODEL

The thermo acoustic refrigerator was modeled using DeltaE (Design environment for Low Amplitude Thermo Acoustic engines). Delta is a program which solves the one dimensional wave equation for a acoustic and thermoacoustic elements based on low amplitude acoustic approximations. Within the stack the wave equation is solved simultaneously with the enthalpy equation in order to find both the temperature and pressure profiles. For other components in the system, the appropriate wave equation is used with the continuity of pressure and volumetric applied at the intersection of each section. The program does not take account of non-linear effects.

Before using Delta E an initial design for 200W thermoacoustic refrigerator was obtained using closed form solutions of the short engine equations. These engines do not provide an accurate enough estimate to predict the actual performance, but do give an initial design that can be used by Delta E.

3. COMPARISON OF THERMOACOUSTIC AND VAPOUR COMPRESSION REFRIGERATION SYSTEM

The co-efficient of performance (COP) is the standard measure of the efficiency of refrigeration systems. The COP of thermoacoustic and vapor refrigeration systems shown in Fig 4 respectively.

$$COP = \frac{Q_c}{W_a} \quad ; \quad COP = \frac{Q_{evap}}{W_{Comp}}$$

Equation (1)

Where, for the thermoacoustic system, Qc is the heat load into the cold end of the stack and Wa is the acoustic power into the resonator. From the vapor compression system Qevap represents the evaporator capacity (i.e.

the heat load that the refrigerant in the evaporator has to remove to keep the fridge air at the desired temperature, normally 3 C) and Wcomp the mechanical work into the compressor.

For a refrigeration cycle, COP is bounded by the Carnot efficiency which is given by

$$\mathrm{COP}_{\mathrm{Carnot}} = \frac{T_{evap}}{T_{cond} - T_{evap}}$$

Equation (2)

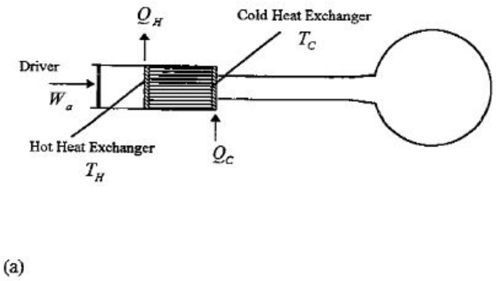


Fig 4(a): Simple thermoacoustic Refrigerator

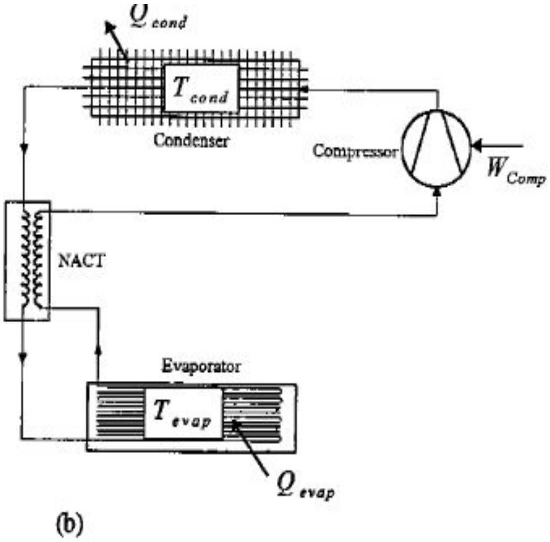


Fig 4(b): Composed Diagram Vapor Compression house hold Refrigerator

The thermoacoustic system was compared to a vapor compression system for two evaporator temperatures, Tevap, of -15 C and -25 C, corresponding to a refrigerator and freezer configuration respectively. The evaporator temperature corresponds to cold heat exchanger temperature, Tc in the thermo acoustic system. These temperatures were chosen in order to keep the internal air temperature at 3 C for a refrigerator and -15 C for a freezer as required by the New Zealand Standard. The condenser temperature, Tcond, which corresponds to the hot heat exchanger temperature, TH of the thermoacoustic system was held at 43 C for both of these evaporator temperatures. From equation (2) the Carnot efficiency for the fridge and freezer are respectively 4.45 and 3.65.

4. COP COMPARISON

A comparison of the COP of the each system was made for both the refrigerator and the freezer at variety of heat loads namely Qc and Qevap of 50,100,150 and 200 W. The results are shown in Fig 5. The amount of heat that the thermoacoustic system could pump was altered by changing the driving ratio as shown in Fig 5. The higher the driving ratio, the more heat that could be pumped, but at lower efficiency. The highest driving ratio obtained was 0.049, which corresponds to a freezer with a 200W heat load. Here, non-linear effects are becoming significant, but linear theory still gives reasonably accurate results. As already stated, the heat load in the vapor compression system was altered by varying speed of the compressor, the appropriate compressor size as calculated by BICYCLE for each heat load is given in Fig 5.

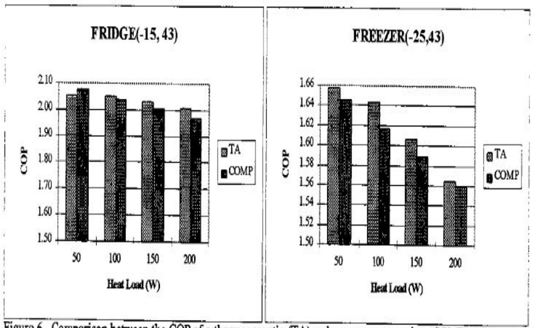
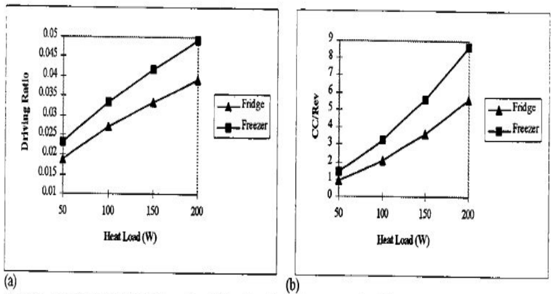


Figure 6. Comparison between the COP of a thermoacoustic (TA) and vapour compression (COMP) refrigerator and freezer for heat loads of 50, 100, 150, and 200 W.



(a) (b)

Figure 7. (a) Variation of the driving ratio with heat load for a thermoacoustic refrigerator and freezer, and (b) The CC rating of a vapour compression refrigerator and freezer at different heat loads.

Fig 5

5. CONCLUSIONS

For the relatively small heat loads of household refrigerators and freezers thermoacoustic refrigeration is good compared to vapor compression system. However they are not competitive when the application requires large heat loads. They are ideal for the application that requires low heat loads, such as the cooling of the electronic equipment. There is still much can be done to improve the performance of thermoacoustic engine. One area where efficiencies of these devices can be increased is the reduction of the viscous loss within the stack. The viscous loss is a result of work being required to overcome the viscous shear force as the gas oscillates. Due to the viscous and thermal penetration depths being comparable most of the area within the stack experiences viscous shear. This loss may be reduced by alternative sack geometries. A general formulation for channel stacks of arbitrary geometry concludes that parallel plate’s channels are most efficient.

I. *REFERENCES*

1. R. Starr, The Reality of a Small Household Thermoacoustic Refrigerator,University of Auckland, 1996.
2. M.E.H..Tijani, J.C.H. Zeegers, A.T.A.M. de Waele , Construction and Performance of a Thermoacoustic Refrigereator , Eindhoven University of Technology, 2011.
3. http://rott.esa.lanl.gov/