IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 7, Issue 8, August 2020
DOI 10.17148/IARJSET.2020.7818

To Study and Analyse the Performance of a Standing Wave Thermoacoustic Refrigerator

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Abstract: The work reported here tells us about the design of standing wave thermoacoustic refrigerator, which can provide the proper heat management where heat can dumped, or spot cooling may be achieved. For the last 4 decades, everyone is dealing with deteriorating environmental conditions, i.e. global warming and ozone depletion due to various FCs, CFCs, HCFCs and HFCs. To remove such tyrannical aspects of environmental eradication, thermoacoustic refrigeration concepts should be involved. Thermoacoustic refrigerator design may face some technical problems in sealing but it may prove very useful if further exploration and analysis have done because it is harmless type of refrigeration system. Thermoacoustic Refrigerators works on the pressure waves developed due to sound and provide the cooling effect. Establishment of refrigerators based on thermoacoustic technology is an innovative solution to the contemporary and upcoming day need of cooling system, without jeopardising environment and ecosystem. In designing and analysis of TAR, some CAE tools are used, i.e. SOLIDWORKS for the CAD model design and MATLAB for the performance analysis of the model at different stack position and for different working gases.

Keywords: Fin Spacing, Fin Geometries, Temperature Distribution, Height, Length, Heat Transfer Rate Thermoacoustic Cooling Effect, Penetration Depths, Stack Geometry, Environmentally Auspicious.

I. INTRODUCTION

Tyrannical issues regarding the vapour compression cycle requires the substitute of harmful gases like HCFCs, CFCs, FCs, etc as their leakage or direct inhalation were causing the serious health and environmental problems according to the regulation led by Montreal Protocol. Thermoacoustics is the combination of acoustics and thermodynamics taken together to transfer or carry heat by using sound wave. Acoustics is primarily involved with the macroscopic effects of pressure waves transfer, like coupled pressure and motion oscillations. Thermoacoustics deals with the microscopic temperature oscillations that co-exists with these pressure variations. Thermoacoustics takes advantage of these pressure oscillations to move heat on a macroscopic level resulting in a large temperature gradient between both heat exchangers of the stack.

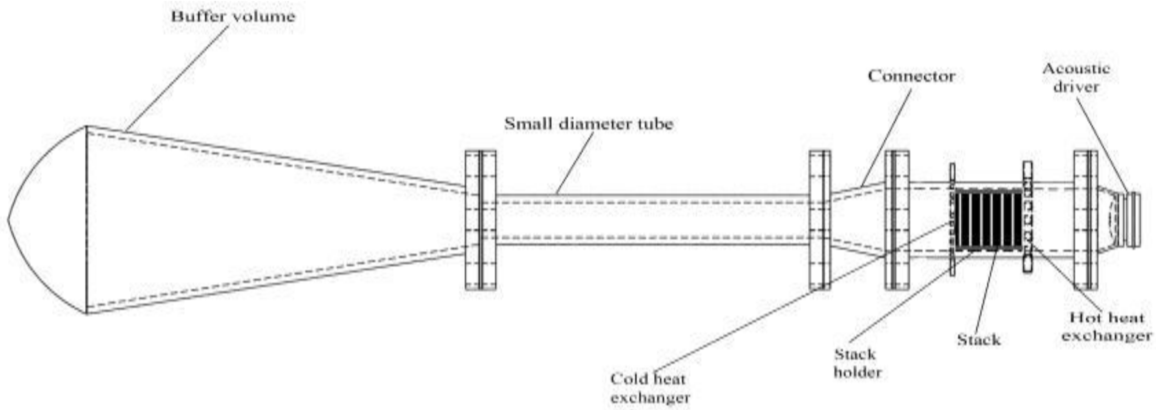

Figure1: Schematic diagram of a typical Thermoacoustic refrigerator

Thermal management has always been a concern for computer systems and other electronics. Computational velocities will consistently be restricted by the measure of clamor delivered by PC chips. Since most clamor is created by squandered warmth, PC segments and other semiconductor gadgets work quicker and all the more productively at lower temperatures (Yuan and Jung, 1999).The need to manage heat fluxes of orders 15–55 W/cm2 and higher in microcircuits

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has emphasized the importance of developing devices which can cope with such heat levels. Many intriguing gadgets have been proposed for such applications, going from constrained convection cooling gadgets to thermoelectric gadgets, heat pipes, fluid coolants, and evaporative shower cooling gadgets (Joshi and Garimella, 2003).

II. THERMOACOUSTIC REFRIGERATOR

Thermoacoustic refrigerators (Figure 1) consist primarily of a speaker (a vibrating diaphragm or thermoacoustic prime mover) attached to a resonator filled with gas, a stack usually made of thin parallel plates, and two heat exchangers placed at either side of the stack. The stack forms the heart of the refrigerator where the heat-pumping process takes place, and it is thus a critical element for determining the performance of the refrigerator (Swift, 1988). Thermoacoustic started as an anecdotal curiosity, however after a fairly lengthy length with little development, a resurgence of hobby has led to many advances in idea and experimental methods. Evidence of thermoacoustic phenomena dates returned centuries to when glass blowers first seen that a warm bulb at the cease of a cool tube produced tonal sound. According to Putnam and Dennis [1], research in thermoacoustics started as early as 1777, when Byron Higgins [2] positioned a hydrogen flame in a massive pipe open at each ends, producing sound. Higgins mentioned that the acoustic oscillations produce by using the tube depended upon the function of the flame. Later, in 1859, Rijke [3], as indicated through Feldman [4] and Bisio and Rubatto [5], investigated acoustic oscillations in a comparable equipment however with the hydrogen flame changed via a mesh of heated metallic wire. He determined that sound was once solely produced whilst the tube was once in a vertical orientation and the heating factor was once in the decrease 1/2 of the tube, indicating that the convective drift created by way of heating air in the pipe used to be necessary to its sound production . The pressure and displacement oscillations in the sound wave are accompanied by temperature oscillations. For an adiabatic sound wave propagating through an ideal gas, the, temperature oscillations, T_1 are related to the pressure oscillations P_1, as:

$$T_1/T_m = (P_1/P_m)^{\gamma-1/\gamma} \qquad (1.1)$$

Where T_m and P_m are mean temperature and mean pressure respectively while T_1 and P_1 are working temperature and pressure respectively.

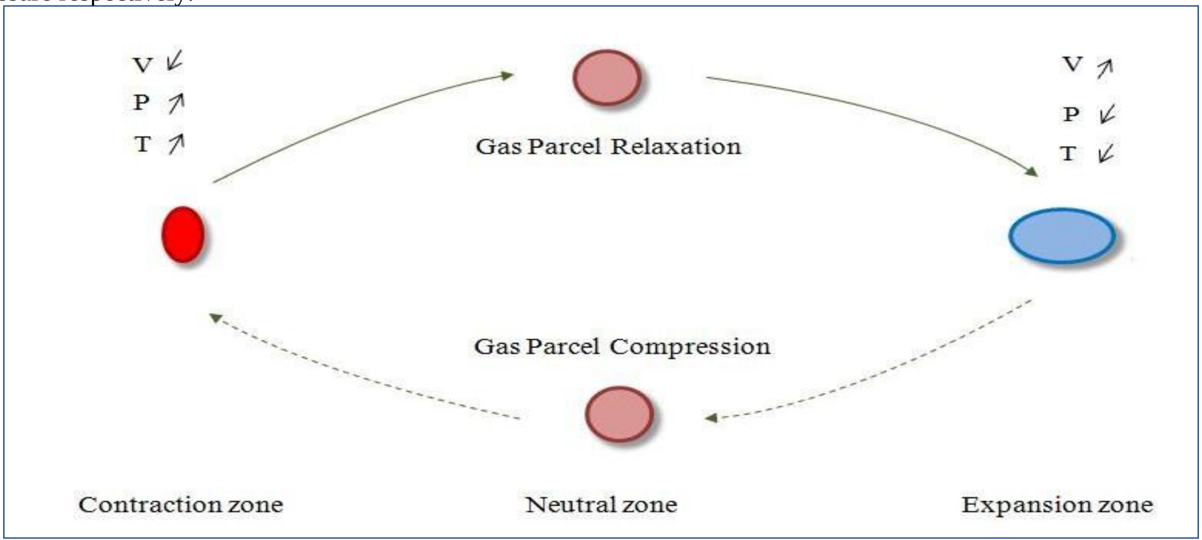

Figure 2: Results of the sound wave zones on the volume, pressure, and temperature of a single gas parcel

Advantages & Disadvantages of TAR

The main advantage of thermoacoustic refrigeration system is that it does not release any harmful element that can be proved dangerous to the environment or living beings. It also can work on low grade energy (i.e. heat) and this system is known as Thermoacoustically driven TAR. It is simple to construct and can easily be carried. It does not employ any rotating or reciprocating component. The power supplied for working of TAR is very less when compared to other refrigeration systems.

Apart from advantages, this system too have some disadvantages like it should be hermitically or adiabatically sealed as the working substance is a gas. Also, the COP of TAR is comparatively less than the Vapour compression and absorption cycles.

Application

TAR can be used for cooling of those components where fins cannot be employed, i.e. for cooling of small electronic circuits and chips. It can also be used for the refrigeration purposes on naval ships and space crafts. A better model can also be used to convert industrial waste sound and heat energy to provide cooling effect.

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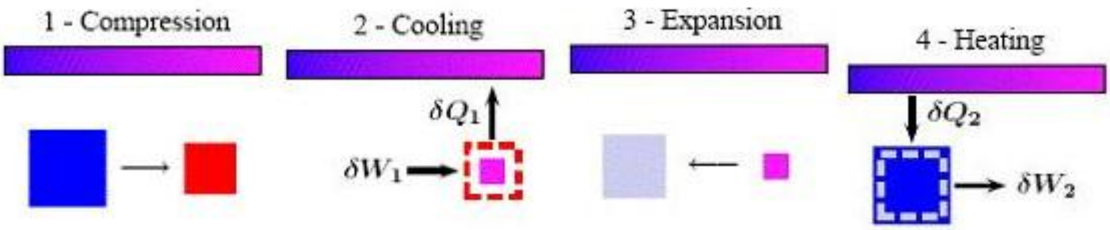

Figure 3(a): Fluid parcels working in a stack based standing wave refrigerator.

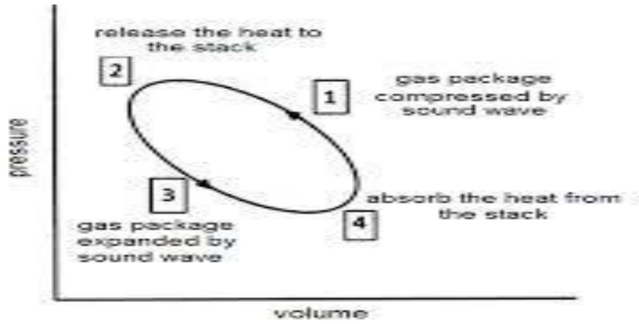

Figure 3(b): Thermodynamic working cycle of TAR

III. OBJECTIVES

In the present work, the main objectives are:

- To develop structural modeling of TAR and the stack by using SOLIDWORKS software.
- Test drop analysis of model by using SOLIDWORKS software.
- Thermal analysis of TAR by using MATLAB software.
- Compare the performance parameters for different working gases and different stack positions.
- Stack materials and resonator tube may be selected according to the working conditions and requirements.

IV.WORKING FORMULAS

1. WORKING GAS

Thermal conductivity of helium at required temperature is given by:

$$k = k_o\,(1 + \alpha T) \quad (1)$$

$$C_p = \frac{\gamma R}{\gamma - 1} \quad (2)$$

$$P = \rho RT \quad (3)$$

The Prandtl number written in terms of thermal and viscous penetration depth is:

$$Pr = \left(\frac{\delta_v}{\delta_k}\right)^2 \quad (4)$$

$$\delta_k = \sqrt{\frac{2k}{\rho m \omega C_p}} \quad (5)$$

$$\delta_v = \sqrt{\frac{2\mu}{\rho m \omega}} \quad (6)$$

Where δ_k and δ_v are thermal penetration depths and viscous penetration depths respectively.

2. SOUND SPEED

$$a = \sqrt{\left(\frac{C\gamma V}{nMV^{\gamma}}\right)} \quad (7)$$

3. STACK DESIGN

$$\dot{Q}_{cn} = -\frac{\delta_{kn} D^2 \sin(2x_{cn})}{8y(1+Pr)\Lambda}\left(\frac{\Delta T_{mn}\tan(x_{sn})}{(\gamma-1)BL_{sn}}\frac{1+\sqrt{Pr}+Pr}{1+\sqrt{Pr}} - (1+\sqrt{Pr} - \delta_{kn}\sqrt{Pr})\right) \quad (8)$$

$$\dot{W}_n = \frac{\delta_{kn} L_{sn} D^2}{4\gamma}\left[(\gamma-1)B\,cos^2(x_{sn})\left(\frac{\Delta T_{mn}\tan x_{sn}}{BL_{sn}(\gamma-1)(1+\sqrt{Pr})\Lambda} - 1\,\frac{\sqrt{Pr}sin^2(x_{sn})}{B\Lambda}\right)\right] \quad (9)$$

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Where Λ is used as an intermediate variable and is defined as

$$\Lambda = 1 - \delta_{kn}\sqrt{Pr} + Pr{\delta_{kn}}^2 \quad (10)$$

V. OPERATION PARAMETERS

Operation parameters
Drive ratio: $D = {}^{P}/_{P_m}$
Norm. cooling power: $Q_{cn} = {}^{Q_c}/_{P_m aA}$
Norm. acoustic power: $W_{cn} = {}^{W}/_{P_m aA}$
Norm. temperature difference: $\Delta T_{mn} = {}^{\Delta T_m}/_{T_m}$
Gas parameters
Norm. thermal penetration depth: $\delta_{kn} = \delta_k / y_0$
Stack Geometry
Norm. stack length: $L_{sn} = K * L_s$
Norm. stack center position: $x_{sn} = K * x_s$
Porosity: $B = \frac{{y_0}^2}{(y_o + l)^2}$

VI. CAD MODELLING

Designing of TAR model is done by using SOLIDWORKS software.

Figure 4: Isometric CAD rendering of design alternative

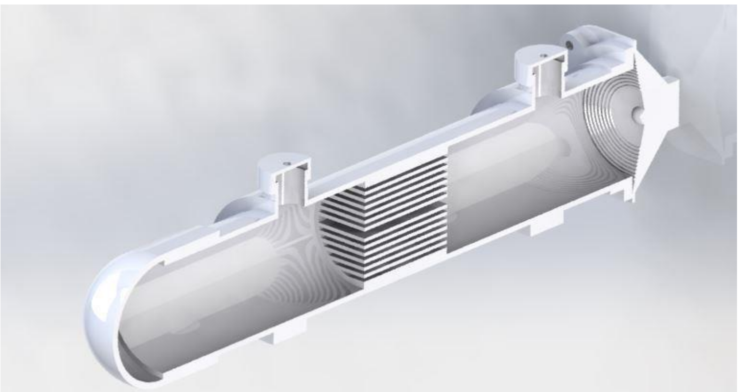

Figure 5: CAD rendering of section view of design alternative

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VII. DROP TEST ANALYSIS

Historically, gravity cause people and things to accelerate towards Earth's center. This drop test analysis will be to verify that this device may be able to withstand a falling distance and not have its major internal components damaged. Before carrying out the analysis, it is noteworthy to mention that the only portion of the device that might be critically affected by the fall is the loudspeaker.

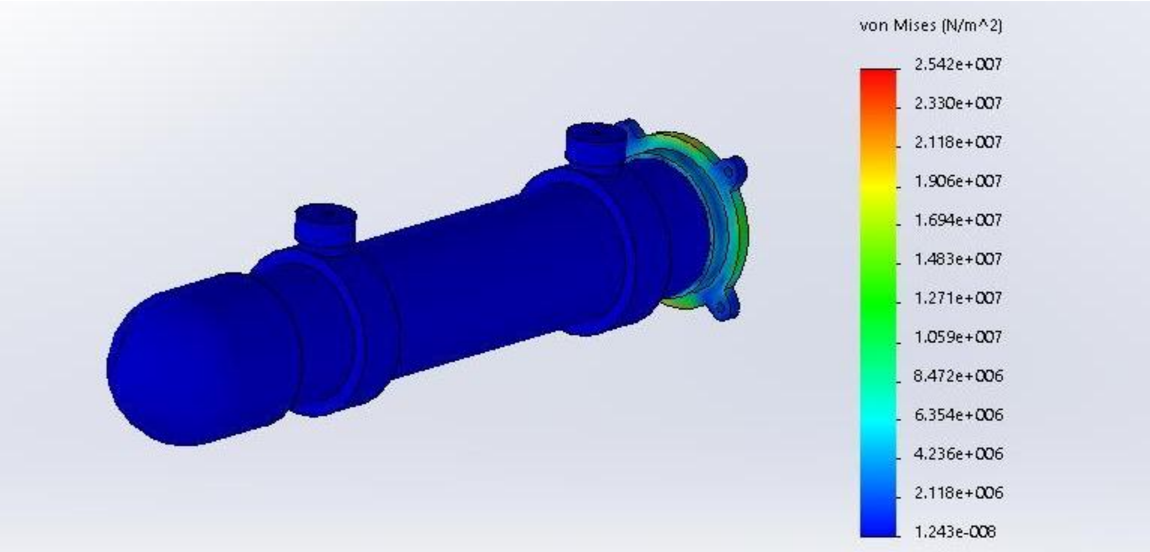

Figure 6: CAD analysis that shows stress during drop test, stress is in (N/m^2)

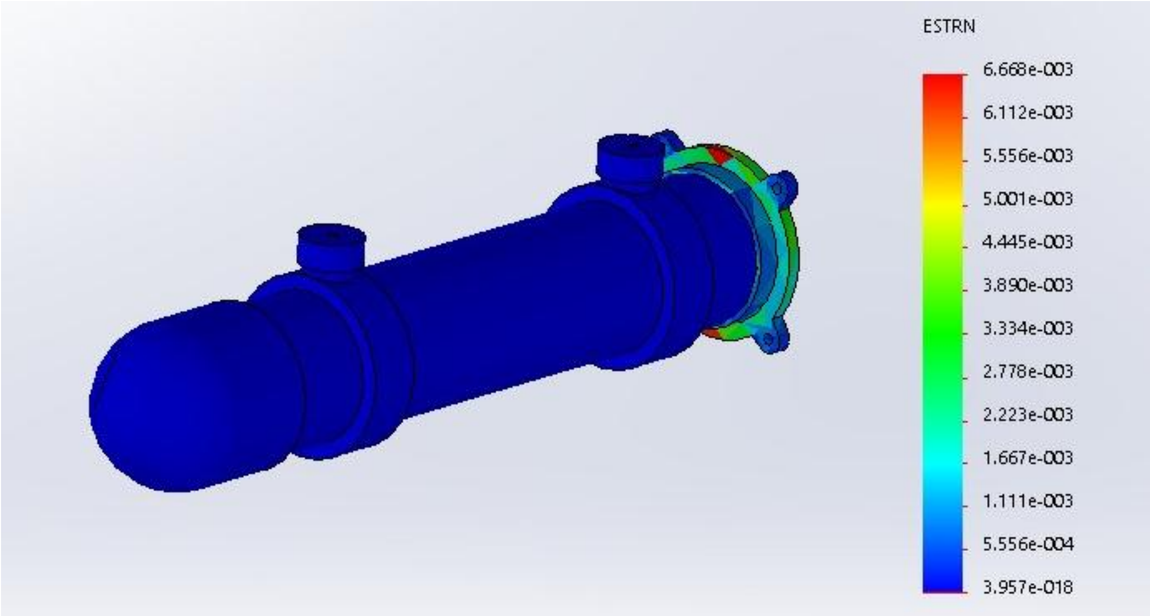

Figure 7: CAD analysis that shows strain during drop test. Strain is in ESTRN

VIII. RESULT AND OBSERVATIONS

The mean pressure has a monotonic behavior on the performance of the Thermoacoustic Refrigerator. Increasing the mean pressure increases the COP of the Refrigerator. As increasing the mean pressure while keeping the acoustic pressure constant (input from the loudspeaker) decreases the *Drive Ratio* (DR= P_{ac}/P_m). Since the acoustic power is proportional to the DR, the input acoustic power decreases with the increase in the mean pressure which mean higher COP
When Helium is used as a working fluid:

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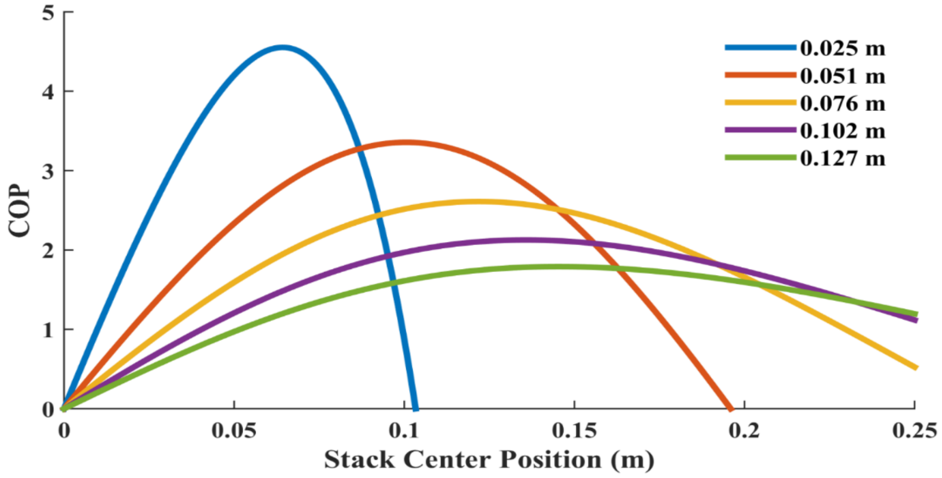

Figure 8: Coefficient of performance vs. stack center position for various stack length

When air is used as a working fluid:

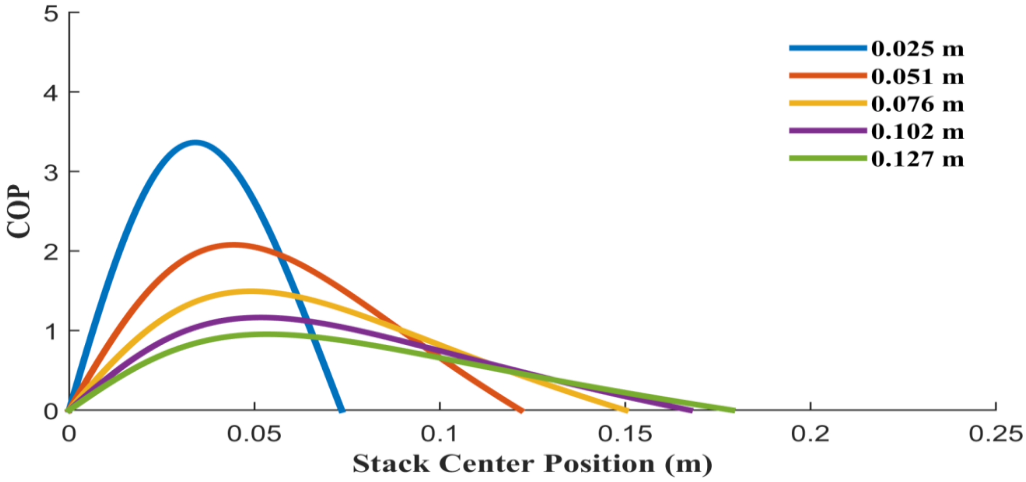

Figure 9: Coefficient of performance vs. stack centre position for various stack length

When Argon is used as a working fluid:

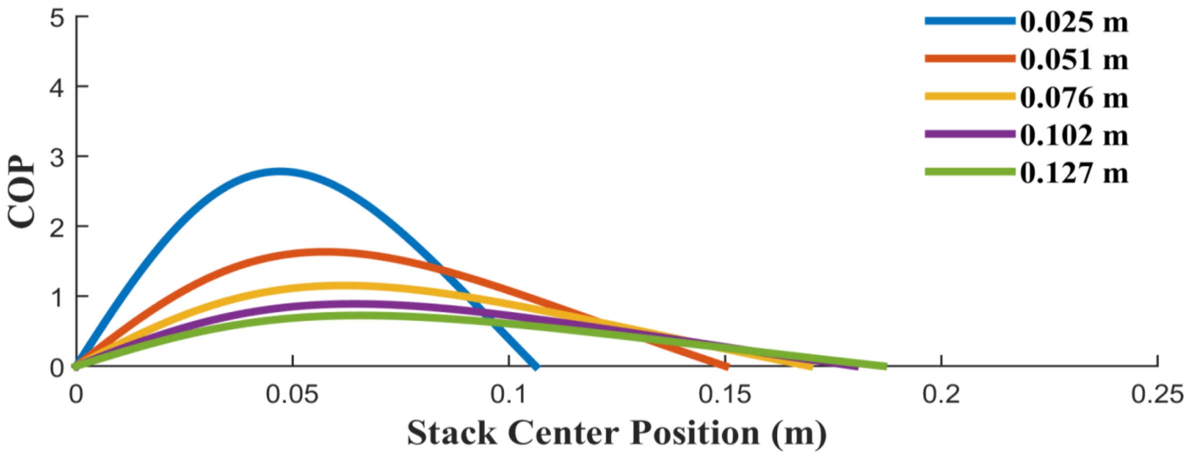

Figure 10: Coefficient of performance vs. stack center position for various stack length

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Comparison of COP of different gases used as a working fluid with stack centre position:

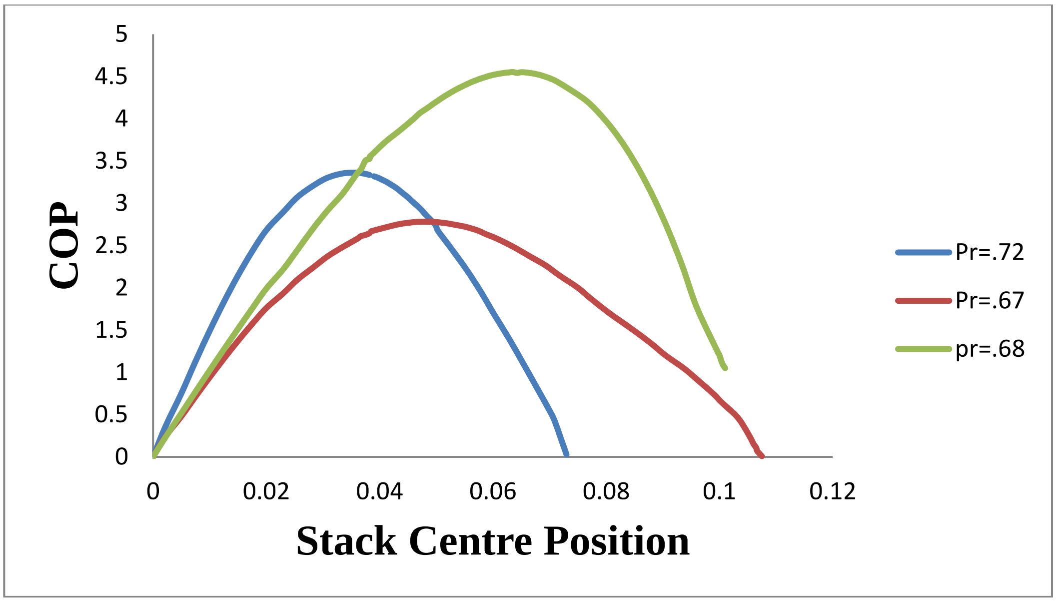

Figure 11: Coefficient of performance vs. stack center position for single stack length

IX. CONCLUSION

It can be summarised by the literature that the theory of standing wave thermoacoustics is well established. Several theoretical fashions as nicely as simulation software program to forecast the overall performance of TAR at consistent kingdom is additionally available.it is determined to sketch and strengthen a standing wave thermoacoustic fridge successful of cooling to temperatures close to 250 K. Due to time restricted layout statistics on acoustic drivers, a commercially accessible electro-dynamic motor will be used. All different elements of the fridge would have designed to adapt to the reachable motor. The impact of working parameters on TAR overall performance at constant as nicely as transient nation would have investigated theoretically and experimentally.

Thermal penetration depth and position of stack towards the acoustic driver is the main concern we have to take care of. Viscous penetration depth is inevitable and cannot be changed much as our accordance and hence it is considered to be an independent variable. Working gas should be the mixture of helium and any other noble gas and the sheet used should be the mylar sheet.

Thermoacoustic devices have a two basic advantages; generating power (or cooling capacity) as a clean source of energy, and the simple structure. However, the power density of the thermoacoustic devices is very low compared with their conventional counterparts. So, optimization of the thermoacoustic devices is required in order to bring the thermoacoustic devices into the real-life applications.

The following conclusion could be deduced from the presented results. The efficiency of the thermoacoustic engine can be increased by understanding the underlying physics and the relationships between thermodynamics and acoustics. The targeted parameters for the optimization process are the mean pressure, frequency, and stack geometry. Following the optimization guidelines presented before increases the efficiency of thermoacoustic from 9.8 % to 16 %.

In this section, a multi-objective approach that provides fast initial engineering estimates to initial design calculation of thermoacoustic refrigerators is discussed. Their performances were evaluated using three criteria: 1) maximum cooling, 2) best coefficient of performance, and 3) the acoustic power loss. Four different parameters - stack length, stack centre position, stack spacing and blockage ratio - describing the geometry of the device have been studied. For different arbitrary values of stack length, this process generates optimal solutions describing geometry of the TAR, solutions which depend on the a priori design goal for maximum cooling or maximum coefficient of performance. This present study reveals and quantifies that the results obtained with these two objectives are different. There is a specific stack length which corresponds to a specific stack centre position, specific stack spacing and a specific blockage ratio depending on the design goal. In conclusion, it was determined that the design parameters are interdependent. This clearly supports the use of a lexicographic multi-objective optimisation scheme to design TARs.

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