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Performance Of Thermoacoustic Refrigerator With 3d Printed Stack

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Abstract:
Background*: Efforts are extended now to improve the performance of thermoacoustic refrigeration system by using modern technology for fabricating the important and delicate components along with the use of tools for analysing the phenomenon for its better understanding. Out of the different components, stack is the most important because the actual heat exchange that is the process of the cooling or rferigeration is taking place in here. Investigators have used differnet shapes and material for stack, to ascertain the best combination with optimized geometrical dimensions for improved performance of thermoacoustic devices. Technology available at different time span had a great impact on various design and governing parameter choices and its successful implimentation.*
Materials and Methods*: In the present work, performance of thermocoustic refrigeration system is analysed for 3D printed parallel stack. The experiments were conducted at different frequency with helium as working gas, at atmospheric pressure for parallel stack made by conventional method and by 3D printing technology. The performance of stack is measured and compared in terms of temperature difference attained for stack manufactured by conventional method and 3D printing technology.*
Results*: The experiments have shown that 3D printed stack have improved perfomance compared to conventionally made stack. The lowest temperature achieved at 200 Hz, 400 Hz and 484Hz was 29.3°C, 20 °C and 14 °C. With 3D printed stack at optimized stack length and stack spacing, there is 60-70% attainment of the designed temperature differnce for 3D printed stack. The 3D printed stack is 5-7 % more efficient in achieving temperature differnce compared to conventional made stack.*
Conclusion: *This study signifies the need for use of additive manufactring technologies to step towards the attainment of optimized design for improved performance of system. The use of such technology for manufacturing the components reduces the erros, elliminates the iiregularities and aslo ensure reduction in production time which will lead to more affordable and measurable efforts for better development of thermoacoustic systems.*
Key Word*: Thermoacoustic; Stack; 3D printing; performance; refirgeration.*

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I. Introduction

Environmental concerns and regulations on use of conventional vapour compression systems for refrigeration purposes, have expedited the research activity and interest in environmental frendly technologies like thermaocoustics. The use of ozone depleting refrigerants is elliminated completetly in this refrigeration system along with there is no moving components which makes it promising choice as a future substituting technology to vapour compression refrigeration systems. it consists of four important components like resonator, stack, inert gas and acoustic driver. The linear thermoaocustic theory was introduced by N Rott [1]. Swift[2] further explains the working of thermoacoustic engines and refrigerators. The interest in thermoacoustic refrigeration system was dwvwloped further whan Hofler developed the thermoacoustic cooler [3]. Different researchers have selected the different parameters for its optimization. Work is reported on resonator tube length and shape, operating frequency of acoustic drivers, use of inert gases and with different combination and stack. all aimed at improvement of coefficient of performance which is measured as temperature difference of thermaocoustic system through optimization of governing parameters related to the components of the system.

Stack parameters considered by reserachers were related to Stack position [12, 13]. Stack length [14,15], stack spacing [16,17], stack geometry [18, 19,20,21] Stack thickness [22, 23, 24], stack material.
Regardless of the use of optimized parameters the coeficient of performance had not achieved a singifinant improvment may be owing to absence of practical use of new technology. The use of technology like 3D printing for accuracy in manufacturing will have a promising results. {4}

Stack is most important component and the performance of system depends on how efficicently the stack is doing it work of heat transfer. the efficiency of stack obviously depends on the accuracy of stack manufacturing which describe by the fabrication methods. presently most of the stack used in research are either hand made from mylar sheet [5,6,7,8] having given parallel plate and spiral shape or hand cut celsor ceramic ready made[9,10]

The main drawback of the stack so produced have the consistency lack for closely spaced plates of stack. further the process of fishing to crete spacing by applying glue increases the irregularity by changing the expected thermal property of material taking part in thermoacoustic process [11].

The stack for thermoacoustic refrigeration can be produced by different technique depending on the stack geometrical parameters like plate spacing and thickness. In the present study experiments were conducted to report the performance of stack measured as temperature difference across the stack, fabricated by 3D manufacturing technology.

II. Material And Methods

Design parameter of Thermoacoustic Refrigerator:

The actual heat exchange is taking palce in stack resulting in temperature difference at its two ends. The effective performance of stack is dependent on various geometrical parameters of stack including stack length, stack centre position, stack thickness, stack spacing, viscous and thermal penetration depth. The viscous penetration depth accounts for the frictional losses which needs to be small. Viscous penetration depth is determined by using the expression for δ_ν

$$\delta_\nu = \sqrt{\frac{2\mu}{\ }}$$

As 0.087 mm. The thermal pentration depth is the extent by which the heat will diffuse through the gas is the function of thermal conductivity, density and specific heat capacity of gas with operating frequency. The thermal penetraition depth is determined by using expression for δ_t

$$\delta_t = \sqrt{\frac{\ }{\ }}$$

as 0.11 mm.

The normalised stack length Lsn and normalized stack centre position Xsn were 0.8183 and 0.516 respectively. The optimized stack length and centre position based on the work of Tijani [18] selected as 6 cm and 9.5 cm.the optimum stack plate spacing is 2y0 = 0.47 mm.

The coefficient of performance is defined by the ratio of the heat pump by the stack to the acoustic power utilized to pump this heat by Tijani. It is given by Tijani [18] as

$$COP = \frac{Qcn}{Wn}$$

where Q_{Cn} is the heat flux or flow in is dimensionless form and can be expressed as

$$Q_{Cn} = \frac{-\delta_{kn} D^2 \sin 2x_n}{8\gamma(1+\sigma)\Delta} \times \left(\frac{\Delta T_{mn} \cdot an(x_n)}{(\gamma-1)BL_{sn}} \cdot \frac{1+\sqrt{\sigma}+\sigma}{1+\sqrt{\sigma}} - (1+\sqrt{\sigma} - \sqrt{\sigma}\delta_{kn})\right)$$

The dimensionless parameter is accomplished between the temperature gradient over the stack and critical temperature gradient and it can be written in modified form

$$\Gamma = \frac{\Delta T_{mn}}{(\gamma - 1)BL_{s=1}} \cdot \tan(x_n)$$

The stack perimeter, Π can be expressed as a function of cross-sectional area as

$$\Pi = \frac{A}{y_0 + 1}$$

Wn, the acoustic power dissipated through stack

$$w_n = \frac{\delta_{kn} L_{5n} D^2}{4\gamma}(\gamma - 1)B\cos^2 x_n \times \left(\frac{\Delta Tmn \tan(x_n)}{BL_{sn}(\gamma-1)(1+\sqrt{\sigma})\Lambda} - 1\right) - \frac{\delta_{kn} L_{sn} D^2}{4\gamma} \frac{\sqrt{\sigma}\sin^2 x_n}{B\Lambda},$$

Where Λ is defined as

$$\Lambda = 1 - \sqrt{\sigma}\delta_{kn} + \frac{1}{2}\sigma\delta_{kn}^2$$

The performance of the stack where the temperature difference at the extremities are obtained can be measured in term of cold side temperature or the difference in temperature obtained between two ends of stack taken as ΔT_m. The table 1 shows the properties of fluid which is Helium and normalised parameters selected for experimentation.

Table 1 Properties of fluid and normalised parameters

Fluid properties	**Normalised operating parameters**
Dynamic Viscosity u = 1.8156 × 10-6 kg/s.m Thermal Conductivity k = 0.02619 W/mKSound Velocity s = 353.03 m/s Heat capacity ratioý $=1.4$	Drive Ratio=Po/Pm Normalized Temperature Difference ΔTm=ΔTm/Tm Cooling Power Qcn=Qc/Pm a A Acoustic Power Wn=W/Pm a A
Normalised Gas parameters	**Normalised stack geometry parameters**
Prandtl No σ =0.7198 Viscous Penetration Depth=δ_ν/y_0= 0.4243 mm Thermal Penetration Depth =δ_t/y_0= 0.5 mm	Stack LengthL sn=Kwn Ls Stack center Position Xn=Kwn Xs Porosity or Blockage ratio B=$y_0(y_0+1)$

The system is designed for operating frequency of 484 Hz, with mean temperture of 300 K and ΔT_m = 30 K.

Development of Stacks with 3D printing Technology: Development of Stack with 3 D Printing Process.With the advancement in manufacturing technology, 3D printing facilitates the development of complex shape prodcuts more easier. By adopting 3D printed technology the stacks are developed using following steps for the present investigation

As per the obtained dimensions of stacks a Solidworks software is used to design the stack geometry and these stacks are well optimised for the desired thermal properties, acoustic parameters and have been considered prominent factors such like gas flow and heat transfer etc by using Ansys Software flow Analysis tool.

Selection of Material: For the Present Stacks a Mylar material is selected consisdeing its thermal and viscous properties

3D Printing of Stack: A Material Jetting process is used for the present 3D Printing machine in which a small dimater nozzle injects the material on a patform interms of coontinous or drop in Sequencial ie drop on drop approach. A layer by layer is developed through the injection process and then it has been hardended by UV Light. A filler base dissovlable material is used for buiding the stack the dissovalable material is then removed after development.

Post Processing Operation and Quality check: It was required to have good surface finishing and strength of the stack.

Experimental set-up: A thermoacoustic refrigerator based experimental set up is constructed keeping standing wave generation. This set up is developed for 2 bar pressure with helium gas. The standard design equations[] are used to obtained the detail dimensions of diffrent parts of the setup.

The standing wave is established with the help of speaker aided wqith wave generator. This generator is connected with an amplifire for variable frequencies and power.The pressure node and anitnode is established at buffer section and at speaker section.

The cold heat exchanger is developed with the help of circular section whose inner radius is 16mm with 7mm thickness and 8 mm long . This circular section facilitates to mount tempertaur. Similarly the hot heat exchanger is developed with circular section of 11m inner radius 7 mm and having 8 mm length. The 1mm thick circular fins of 8mm length are also provided.

A 3D printed three diffrent stacks are used with the specifications of 32 mm diameter and 100 mm length. The three diffrent stacks are used with geometries like parallel, tubular, and spiral as shown in figure 1. The stacks are developed with the help of mylar film of 0.18mm.

The resonator tube of λ/4 length develped by joing the two straight circular tubes. one is 32mm diameter and another is a 12.6mm diameter. these two tubes are joined with conical hollow joint. The open end of larger tube is closed by fitting spealer assembly whilst the open end smaller tube is joined by the conical buffer volume. The stacks is placed at the desiged length from speacker end nearere to conical joint.

A buffer volume is constructed with conical shape having larger end diameter and base diamaters are 175 mm and 30 mm. flanges are used to connect the buffer volume and resonance tube.

Figure 1: Stack Geometry

Procedure of Experimentation: The experimentation is carried out for evaluating the performance of thermoacosutic refrigeration by using two diffrent stack of same geometry for three frequency sets. . The setup was maintained at 2 bar pressure and the set up was charged with helium gas.The variable voltage power source was fed to the speaker and TARS system. The measurement of current and voltage had done with digital AC power meter. Similarly the Digital oscilloscope was used to measure the dynamic pressure.

The constant in (Type-T) thermocouple is used to measure the temperature at cold CHX and hot HHX. When the power unit had started the measurement were started it was confirmed that temperature at CHX falls below ambient temperature. Thus the reading have been recorded at personal computer through data acquisition system for temperature at the cold and hot heat exchanger

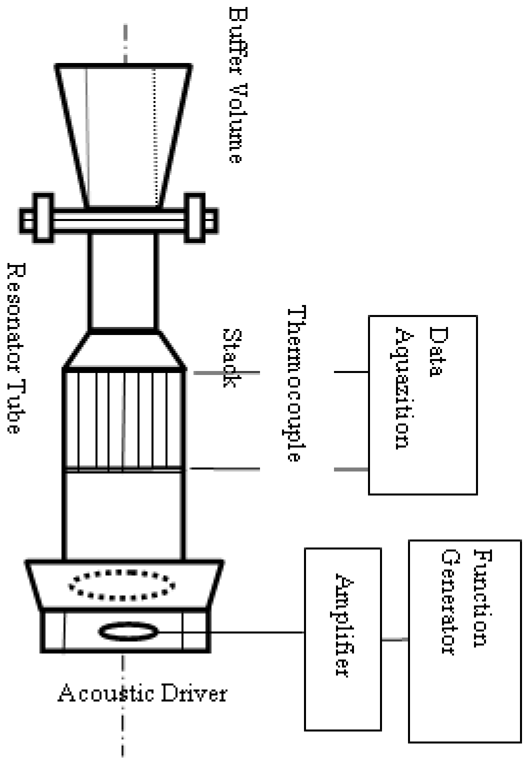

Figure 2: Experimental set up

III. Result And Discussion

Figure 3, 4, 5 shows the results of experimentation at frequency 200 Hz, 400 Hz and 484 Hz. There is an improved cold heat exchanger temperature at all the three frequency for 3D printed stack over the conventionally fabricated stack. The experiments were conducted for the duration of 60 minutes. The lowest temperature for cold heat exchanger were observed as 29.3 ºC for 200 Hz, 21.2 ºC for 400 Hz and 14 ºC for 484 Hz frequency.

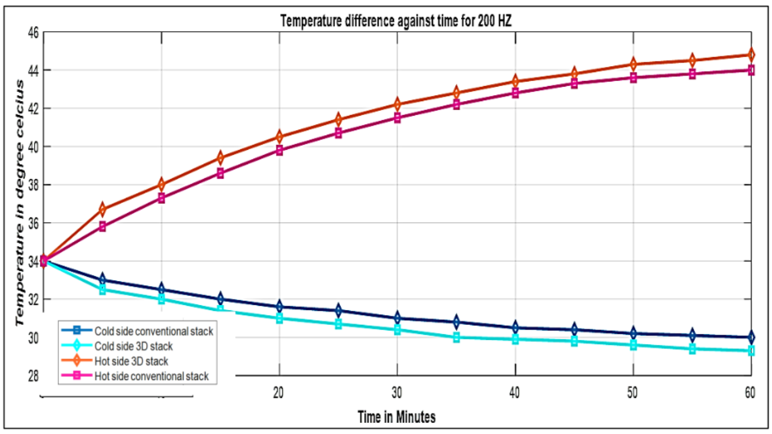

Figure 3: Temperature difference against time at 200 Hz

At 200 Hz frequency, the conventionally made stack gives the lowest temperature of cold heat exchanger as 30 ºC and the temperature difference as 14.8 while the lowest temperature observed for 3D printed stack is 29.3 ºC. While temperature difference between cold and hot heat exchanger was 15.5 and 14ºC for 3D printed stack and conventional stack respectively. At 400 Hz frequency the lowest temperature for cold heat exchanger was 21.2 ºC and 20.5 ºC respectively for conventionally made stack and 3D printed stack respectively. while the temperature difference for cold and hot heat exchanger were 20.5 ºC and 22.5 ºC for hand made and 3D printed stack. There was an improvement of nearly 8 % towards attainment of designed temperature difference by using 3D printed stack.

At 484 Hz frequency the lowest temperature observed were 14.8 and 14 ºC further improving the temperature difference between the hot and cold heat exchanger. In this case also there is observed the increament in temperature difference for 3D printed stack compared to conventionally manufactured stack.

The ellimination of irregularities and inconsistency during fabrication by 3D printing technology improves the accuracy of stack geometry. This leads to attainment of higher temperature difference across the stack. There are different geometrical parameters of stack which affects the thermal and viscous effect causing variation in performance of stack. The accuracy of fabrication of thin plates for parallel stack improved the ability of stack to have higher heat transfer with less viscous effect improves the temperature difference across the stack at two heat exchanger.

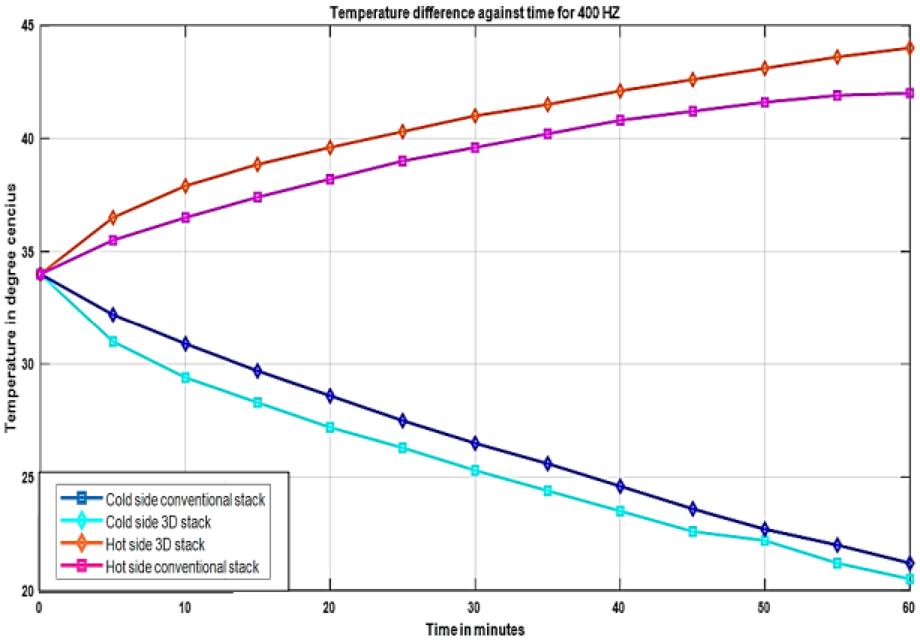

Figure 4: Temperature difference against time at 400 Hz

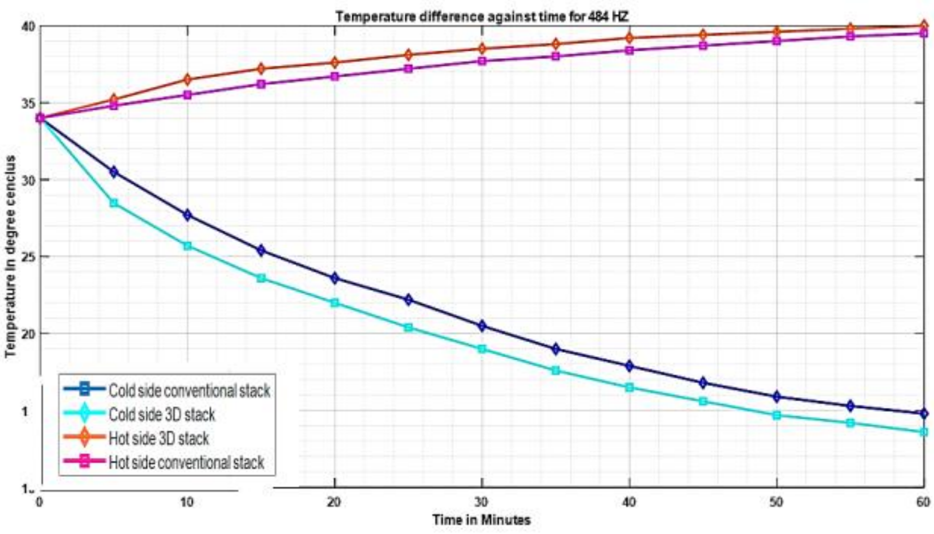

Figure 5: Temperature difference against time at 484Hz

IV. Conclusion

The comparison of the performance of the hand made stack and 3D printed stack is presented. There is increase in temperature difference for 3D printed stack compared to hand made stack at all tested frequencies. The lowest temperature achieved at 200 Hz, 400 Hz and 484 Hz was 29.3 ºC, 20 ºC and 14 ºC. With 3D printed stack at optimized stack length and stack spacing, Nearly 60-70% of the designed temperature difference has been achieved. The 3D printed stack can be considered for reducing production error, production time and achieving the accuracy and improvement in designed objectives of the thermoacoustic refrigeration system.

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