**A PROJECT REPORT**

**ON**

# "THERMOACOUSTIC REFRIGERATION"

Submitted by

**(18DME28) Sahil Yasin Parbulkar**

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*In partial fulfillment for the award of the Degree*

*Of*

**BACHELOR OF ENGINEERING**

**IN**

**MECHANICAL ENGINEERING**

**UNDER THE GUIDANCE**

**Of**

**Prof. Rizwan Shaikh**

***DEPARTMENT OF MECHANICAL ENGINEERING***

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL,

NAVI MUMBAI – 410206

UNIVERSITY OF MUMBAI

**ACADEMIC YEAR 2020-2021**

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL

**(Approved by AICTE, recg. By Maharashtra Govt. DTE,**

**Affiliated to Mumbai University)**

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# *CERTIFICATE*

This is to certify that the project entitled

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To the Kalsekar Technical Campus, New Panvel is a record of bonafide work carried out by him under our supervision and guidance, for partial fulfillment of the requirements for the award of the Degree of Bachelor of Engineering in Mechanical Engineering as prescribed by **University Of Mumbai**, is approved.

**Internal Examiner** — **External Examiner**

(Prof. Rizwan Shaikh) — (Prof.____ )

**Head of Department** — **Principal**

(Prof. Zakir Ansari) — (Dr.Abdul Razaq Hannutagi)

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## APPROVAL OF DISSERTATION

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**(Internal Examiner)** **(External Examiner)**

Prof. Rizwan Shaikh ____________________

Date: __________

# ACKNOWLEDGEMENT

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I take this opportunity to give sincere thanks to **Mr._____** , Manager/Owner in "*Name of Industry",* for all the help rendered during the course of this work and their support, motivation, guidance and appreciation.

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# ABSTRACT

Thermoacoustic refrigeration technology is a green alternative for the conventional refrigeration system in vehicles. The former uses environmentally friendly inert gases whereas the latter uses chemical refrigerants that can have severe impacts on the environment. In order to apply thermoacoustic technology commercially, the conventional sensitive and complex Acoustic drive needs to be replaced with an alternative robust acoustic source.

The design of a new compact thermoacoustic refrigerator is described in this study. This thermoacoustic refrigerator uses a Rotary Drive Mechanism as an alternative to conventional Acoustic source which is a relatively compact and robust mechanism. The technical details of design, fabrication, and testing processes are presented. Also the fabricated model is Experimentally Analyzed by integrating different stack materials into the new Rotary Drive Mechanism as a new Acoustic source system to evaluate its effects on performance.

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# ABBREVIATION AND NOTATION

- PVC: Poly-Vinyl-Chloride
- $\Delta T$: Temperature Difference
- DR: Drive Ratio
- COP: Coefficient of Performance
- TAR: Thermoacoustic Refrigerator
- TADAR: Thermoacoustically Driven Thermoacoustic Refrigerator
- CFCs: Chlorofluorocarbons
- HCFCs: Hydro-Chlorofluorocarbons

# CHAPTER 01: INTRODUCTION

## 1.1 General Introduction To Thermoacoustic Refrigeration System:

Conventional vapor-compression refrigeration systems suffer from being dependent on harmful gases that are unsafe environmentally, such as CFC, HCFC and ammonia. Despite of their suitable thermodynamic properties and stability in the atmosphere, their environmental impact in terms of their corresponding global warming potential -thousands of times greater than CO2- raises concerns about their applications. Thus, the need for clean/green alternative refrigeration systems that are cheap and simple in construction has strongly motivated the development of thermoacoustic energy conversion systems. Thermoacoustic refrigerators (TARs) are mechanical systems that enable useful conversion of acoustic energy, carried by continuous propagation of sound waves generated by conventional loudspeakers (Or, advanced acoustic drivers), into heat that is deliberately transported from low-temperature reservoir into high-temperature one. TARs not only rely on clean energy conversion technology, but can also be driven by joint thermoacoustic engines powered by waste heat or renewable energy, such as solar energy. Furthermore, they almost have no moving parts and can be made of inexpensive materials, such that low fabrication cost and maintenance needs are considered another advantage of these devices, however, careful design is necessary for optimum operation. Therefore, TARs offer promising potential.

A standing half-wavelength thermoacoustic refrigerator is typically consisting of a long resonator with a sustainable acoustic source, responsible of maintaining continuous supply of acoustic excitation with specific frequency, placed at one end and a rigid wall located at the other end. The resonator is made of a long tube that usually has a circular or rectangular cross sectional area -as considered in this study-filled with the working gas, such as air or any other inert gas. At least, three main components have to be carefully positioned within the resonator: A short porous media that is usually made of relatively low-thermal-conductivity ceramic materials -referred to as the stack when operating in standing mode and the regenerator when operating in traveling mode-, surrounded by two ‘hot and cold’ heat exchangers. The stack contains a large number of square pores ‘channels’ aligned with the direction of the resonant wave, while the hot and cold heat exchangers are made of copper to allow for efficient heat transfer between the working gas and the external heat source and sink respectively.

➢ The Working Principle Of Thermoacoustic Cooling Consists Of 4 Stages That Occur Repeatedly.

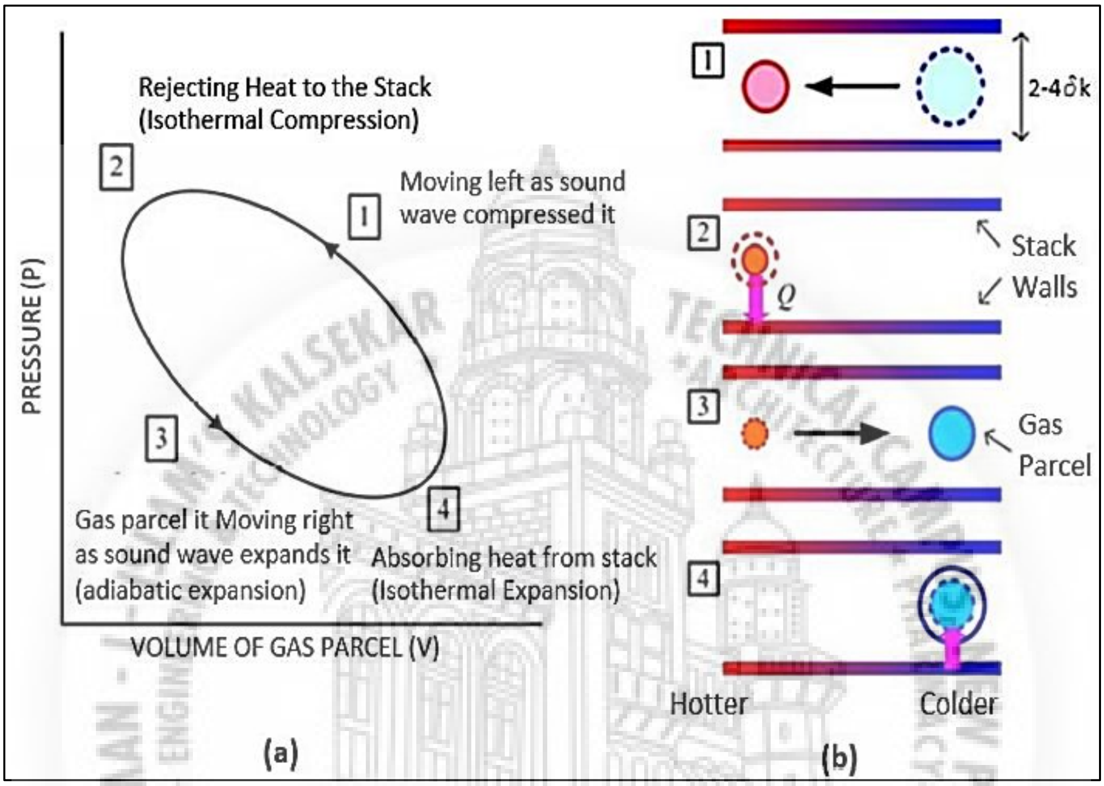



**Figure 1.1.** (a) Thermoacoustic cycle (b) Heat transfer processes in the stack

- *Adiabatic Compression (1-2)*: When the acoustic wave causes the gas package between the plate channel to move to the left, the compressed gas and the pressure increase
- *Isothermal Compression (2-3)*: The compressed gas package gets hotter than the stack wall, causing heat transfer from the gas to the stack wall because the stack temperature is lower and the volume of the gas parcel begins to shrink
- *Adiabatic Expansion (3-4)*: When the upright wave continues the cycle the gas package returns to the right direction, it will expand the air so the pressure drops again. The gas becomes more tenuous, this pressure drop will simultaneously reduce the air temperature so that the gas temperature is lower than the plate temperature
- *Isothermal Expansion (4-1)*: At this stage, heat moves from the stack to the gas because the gas absorbs heat from the stack wall and the gas package expands so that the temperature and pressure return to the initial state of the cycle.

1.2 Problem Definition**:**

- Conventional refrigeration system is being used widely for cooling purposes using various chemical refrigerants currently. However, this present scenario poses a major threat to the environment as the emission of harmful gases like ChloroFluoro Carbon (CFC), Hydro ChloroFluoro Carbon (HCFC) are on the rise due to the excess use of chemicals, and the requirement for refrigeration system is increasing. Hence, there is a necessity to find an alternative to conventional refrigeration.
- Present Thermoacoustic system utilizes Electronic Acoustic Drive which is Feeble and Expensive.
- Due to the Feeble and Expensive Acoustic source Thermoacoustic refrigeration systems lacks commercial scalability.
- Thermoacoustic systems have lesser Coefficient of Performance.

1.3 Objective**:**

- The aim of present work is to replace Electronic Acoustic drive with Rotary Drive Mechanism (Piston Cylinder Assemblie)
- Evaluate the effect of new Acoustic Drive on the Performance of ThermoAcoustic refrigeration System.
- To evaluate the influence of different Stack materials on COP of thermoacoustic refrigerator driven by a rotary drive mechanism.

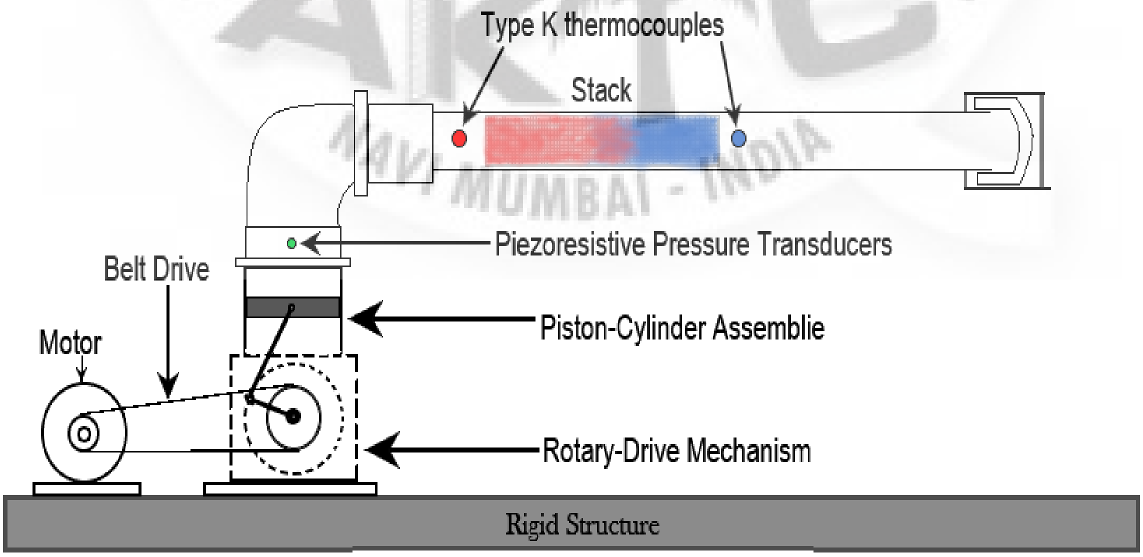



**Figure 1.2.** Propound System Design

# CHAPTER 02: LITERATURE SURVEY

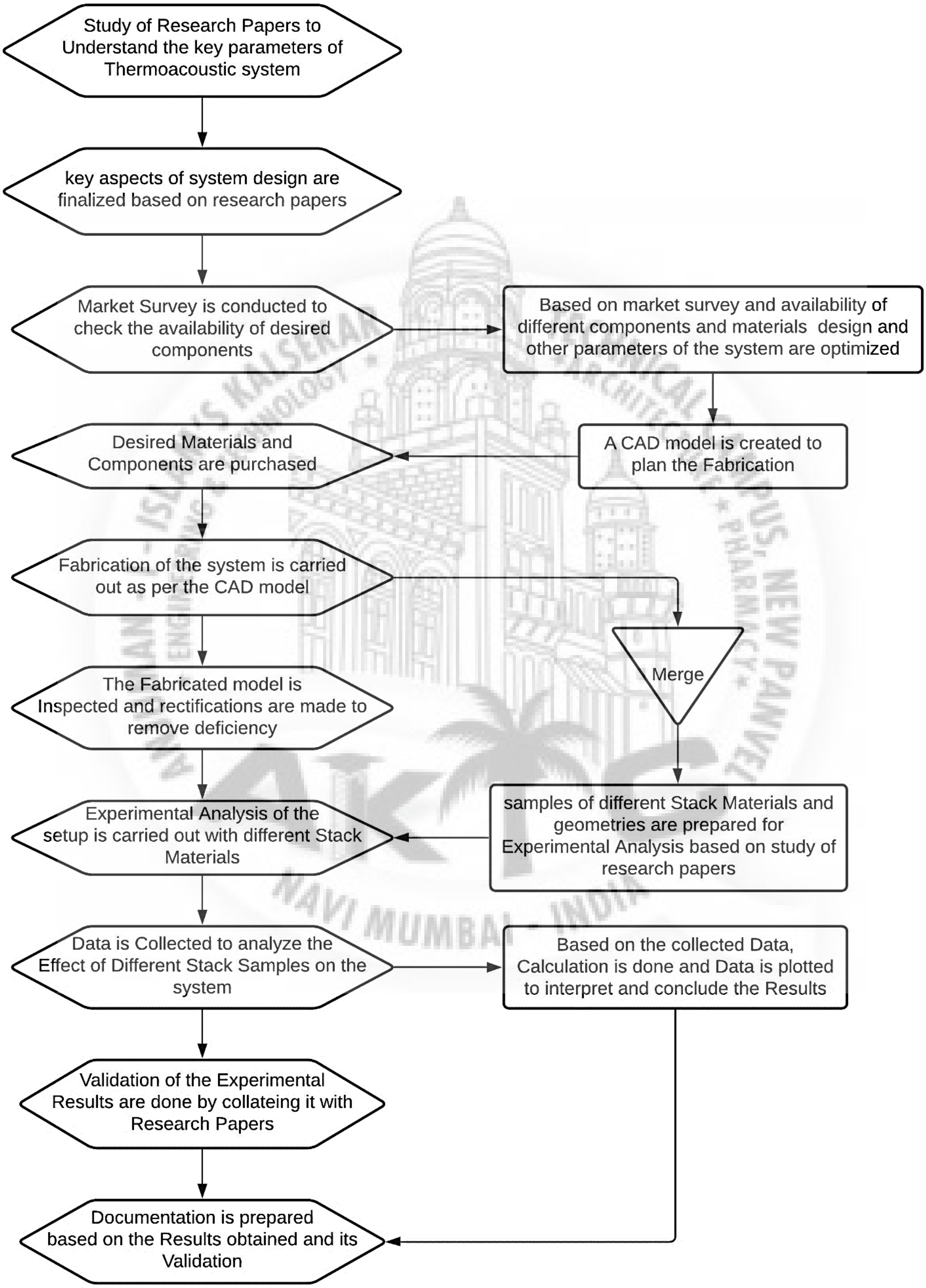
| I. | |
|---|---|
| Title | A Compact Standing-Wave Thermoacoustic Refrigerator Driven By A Rotary Drive Mechanism |
| Author | *Ahmed I. Abd El-Rahman, Waleed A. Abdelfattah , Karim S. Abdelwahed (The Department of Mechanical Power Engineering, Cairo University, Giza 12613, Egypt)* |
| Publication | Case Studies in Thermal Engineering (2020) (https://doi.org/10.1016/j.csite.2020.100708) |
| Abstract | The system consists of two similar harmonically-oscillating pistons driven by a commercial 1-HP rotary drive mechanism operating at a frequency of 42 Hz -hereby, replacing typical expensive acoustic drivers |

| II. | |
|---|---|
| Title | Experimental investigation of thermal performance of random stack materials for use in standing wave thermoacoustic refrigerators |
| Author | *Samir Gh. Yahya, Xiaoan Mao, Artur J. Jaworski (Faculty of Engineering, University of Leeds, United Kingdom)* |
| Publication | International journal of refrigeration (2017) (http://www.elsevier.com/locate/ijrefrig) |
| Abstract | Problems like costly and impractical to fabricate Stack due to material and assembly costs, which limits the cost benefits of thermoacoustic systems. could be solved by the application of stacks that have irregular geometries, for instance stacks made of “random” materials from metal machining (swarf), which are often considered as waste |

| III. | |
|---|---|
| Title | Influence of stack geometry and resonator length on the performance of thermoacoustic engine |
| Author | *N.M. Hariharan , P. Sivashanmugam , S. Kasthurirengan* *(Centre for Cryogenic Technology, Indian Institute of Science, Bangalore 560 012, India)* |
| Publication | Applied Acoustics (2012) (http://dx.doi.org/10.1016/j.apacoust.2012.05.003) |
| Abstract | This work illustrates the influence of stack parameters such as plate thickness (PT) and plate spacing (PS) with resonator length on the performance of thermoacoustic engine, which are measured in terms of onset temperature difference, resonance frequency and pressure amplitude using air as a working fluid. |

| IV. | |
|---|---|
| Title | Study of a coaxial thermoacoustic-Stirling cooler |
| Author | *M.E.H. Tijani *, S. Spoelstra* *(Energy research Centre of the Netherlands (ECN), P.O. Box 1, 1755 ZG Petten, The Netherlands)* |
| Publication | Cryogenics 48 (2008) 77–82 (www.elsevier.com/locate/cryogenics) |
| Abstract | A coaxial thermoacoustic-Stirling cooler is built and performance measurements are performed. The cooler uses the acoustic power produced by a linear motor to pump heat through a regenerator from a cold heat exchanger to an ambient one. The cooler incorporates a compact acoustic network to create the traveling-wave phasing necessary for the operation in a Stirling cycle. The network has a coaxial geometry instead of the toroidal one usually used in such systems. The design, construction and performance measurements of the cooler are presented. |

# CHAPTER 03: METHODOLOGY



# CHAPTER 04: EXPERIMENTAL SETUP

- Fabricated Setup**:**

**Figure 4.1.** Fabricated Experimental Setup

In the fabricated setup Air compressor is incorporated as a Rotary drive mechanism which acts as an acoustic source for our thermoacoustic system design, along with that on the opposite side of the resonator a diaphragm element is added which acts as an another reciprocating element, the diaphragm element works under the action of Air compressor stroke hence simultaneously reciprocating and creating a sinusoidal standing wave into the system hence adding to the acoustic power of system.

The Diaphragm element consists of a PVC End-Cap shown in Fig.4.8 which acts as an another reciprocating element, this end cap is enclosed into the PVC Coupling shown in Fig.4.5 to restrict its movement and make it act like a reciprocating element, the PVC-coupling is closed at both ends with the circular wooden sheet to enclose the PVC end cap inside the coupling and this coupling and end-cap assemblie is attached over resonator pipe, by doing such the end cap is enclosed into the coupling but is free enough to reciprocate a fix distance, some lubricating oil is applied on the mating surfaces of joints for smooth movements also all contact surfaces were well polished with sand paper for a smooth movement.

**Figure 4.2.** 0.5 HP Single stage Reciprocating Air Compressor Head

**Figure 4.3.** 0.5 HP 3-Phase Electric Motor

**Figure 4.4.** M-Fit PVC Fitting

**Figure 4.5.** PVC Coupling

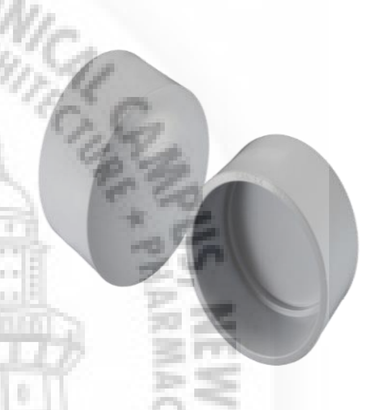


**Figure 4.6.** PVC End-Cap

**Figure 4.7.** PVC Bush

**Figure 4.8.** Galvanized Reducer

**Figure 4.9.** Galvanized 90 Elbow

**Figure 4.10.** PVC Pipe

# CHAPTER 05: INSTRUMENTS USED TO RECORD DATA

- Digital Temperature Sensor:


**Figure 5.1.** Digital Temperature Sensor

**Specifications:-**

- Temperature range: -50~ +70Â°C
- Temperature display resolution: 0.1
- Temperature measurement accuracy: Â±1Â°C
- Item Weigh 80.0 grams
- Product Dimensions : 10 x 10 x 5 cm; 80 Grams

- Tachometer:

**Figure 5.2.** Digital Non- Contact Type Tachometer

**Specifications:-**

- Speed Measure Range: 2.5 to 999.9 1000 to 99999
- Resolution 0.1RPM/1RPM
- Laser or photoelectric measure range 5 cm to 60 cm
- Measurement Accuracy ±0.05% 1d
- Item Weight 220 grams

- Pressure Transducer:

**Figure 5.3.** Pressure Transducer

**Specifications:-**

- Working Voltage: 5VDC
- material: Metal + ABS
- Output Voltage: 0.5-4.5 VDC
- Working Current: less than equal 10 mA
- Working Pressure Range: 0-1.2 Mpa
- Measuring Error: +/-1.5 %FSO
- Temperature Range Error: +/-3.5 %FSO
- Response Time: less than equal 2.0 ms
- Cycle Life: 500,000 pcs

# CHAPTER 06: COSTING OF STUDY

| Sr. no. | Components | Cost (₹) |
|---|---|---|
| 1. | 3-Phase , 0.5 HP Electric Motor | 2,500 |
| 2. | 0.5 HP , Single stage Air Compressor Head | 2,000 |
| 3. | PVC Fittings | 1,000 |
| 4. | Galvanized Fittings | 500 |
| 5. | V-Belt & Pulley Assemblie | 500 |
| 6. | Wooden Base | 100 |
| 7. | Adhesives | 500 |
| 8. | Sensors | 1,000 |
| 9. | Stack Materials | 100 |
| 10. | Miscellaneous | 1,800 |
| Total | | 10,000 |

**Table 6.1: Costing of study**

# CHAPTER 07: DATA COLLECTION & ANALYSIS

➢ Strategy to collect Data**:**

- The samples of different Stack Materials are fabricated with Similar Dimensions.
- Then the samples of stack are placed into the system at a fixed distance from acoustic source.
- Temperature sensors are attached on either side of the stack to Measure the temperature gradient.
- Now the experimental model is switched ON and the output from sensors are noted down
- The output from the sensors are noted for every minute as such the model is switched off after 30 minutes of data recording from sensors.
- The process is repeated for each stack after the sensors are cooled-off and returned to show initial ambient readings.
- Hence each stack is tested for 30 minutes from ambient conditions and readings are noted for every 1 minute interval.

➢ Strategy to Analyze Data**:**

- The collected Data for each Stack is plotted over Time VS Temperature graph to interpret the Maximum temperature difference achieved by each stack.
- Next the COP is calculated for each stack hence justifying the efficient stack for new rotary drive mechanism integrated thermoacoustic system.

➢ Data Plotting for Stack Samples**:**

(A) (B) (C)

**Figure 7.1.** Stack Samples**:** (A) Metal Scrubber (B) Steel wool (C) Sponge Scrubber

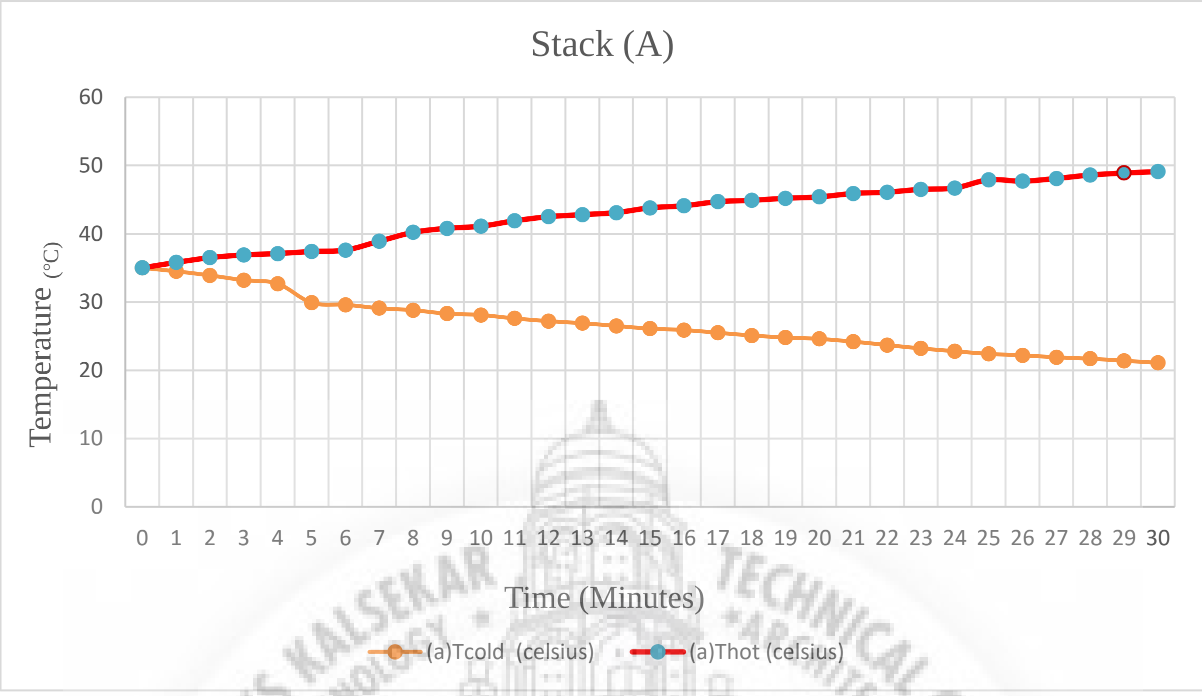



**Figure 7.2.** (Time VS Temperature) graph for
Stack Sample**:** (A) Metal Scrubber

Figure 7.2 shows the Time verses Temperature graph for stack (A) i.e. Metal Scrubber the Maximum Temperature difference achieved at the end of experiment i.e. after 30 Minutes is 28 degree Celsius with temperature at cold side reaching to 21.1 degree Celsius and at hot side reaching to 49.1 degree Celsius.

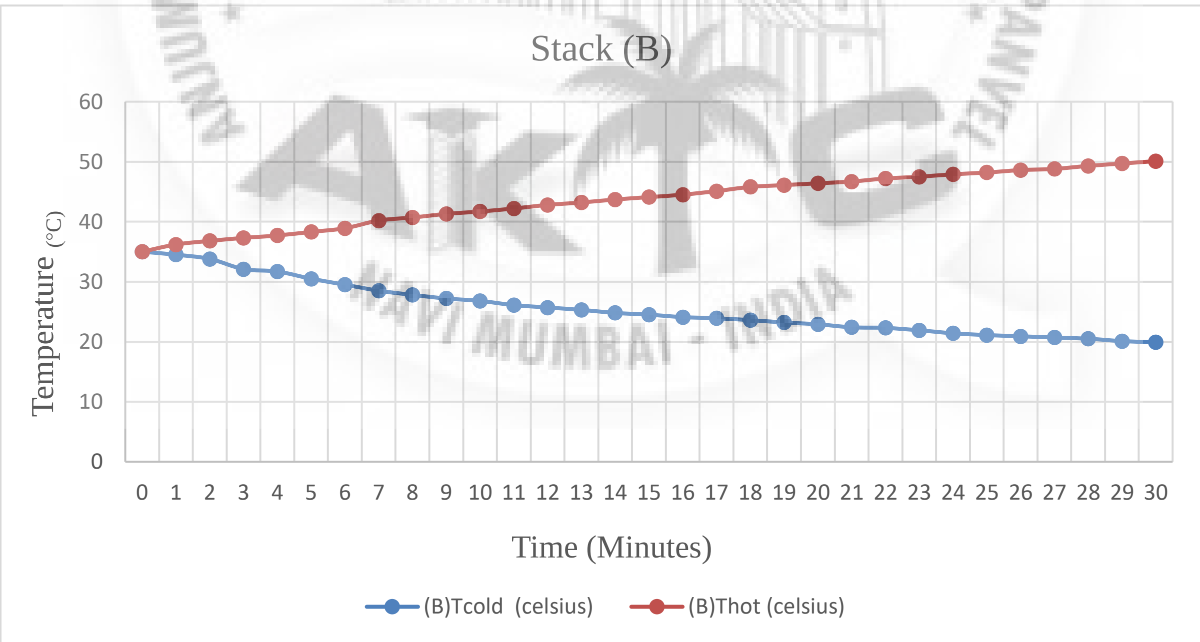



**Figure 7.3.** (Time VS Temperature) graph for
Stack Sample**:** (B) Steel Wool

Figure 7.3 shows the Time verses Temperature graph for stack (B) i.e. Metal Wool the Maximum Temperature difference achieved at the end of experiment i.e. after 30 Minutes is 30.2 degree Celsius with temperature at cold side reaching to 19.9 degree Celsius and at hot side reaching to 50.1 degree Celsius.

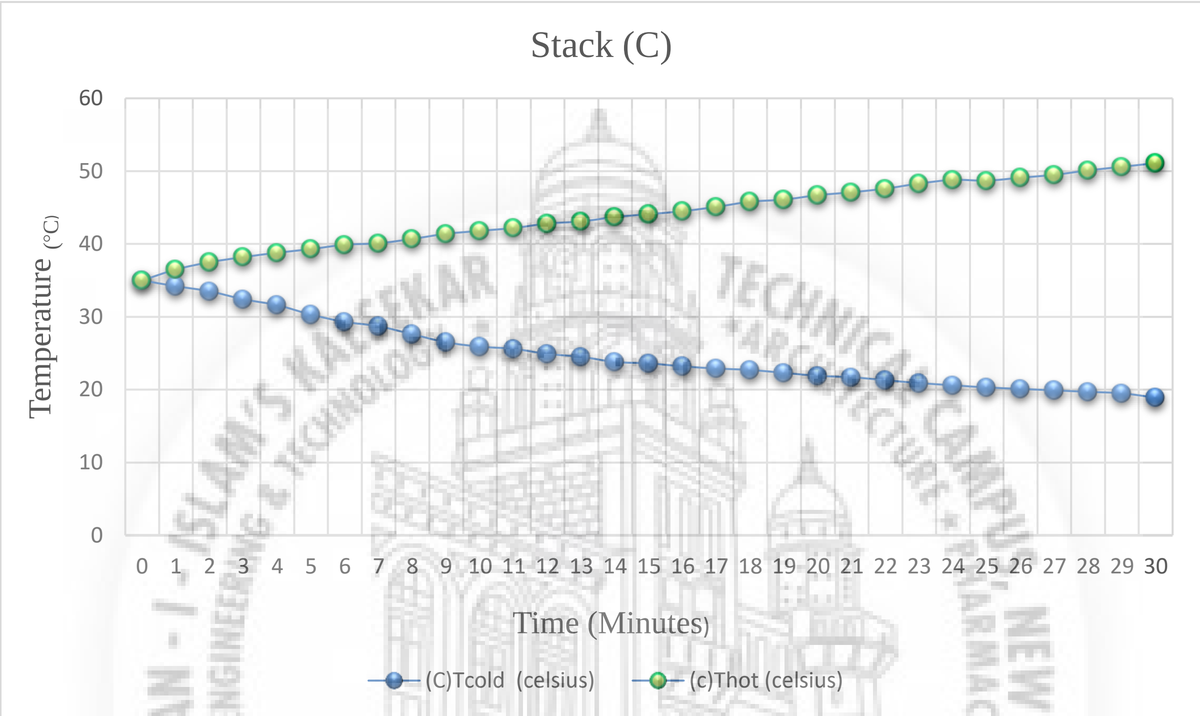



**Figure 7.4.** (Time VS Temperature) graph for Stack Sample**:** (C) Sponge Scrubber

Figure 7.4 shows the Time verses Temperature graph for stack (C) i.e. Sponge Scrubber the Maximum Temperature achieved at the end of experiment i.e. after 30 Minutes is 32.2 degree Celsius with temperature at cold side reaching to 18.9 degree Celsius and at hot side reaching to 51.1 degree Celsius.

**Table 7.1**
(Time VS Temperature Results for Stack Samples)

| Stack Sample | $T_{cold}$ (°C) | $T_{hot}$ (°C) | $T_{Difference}$ (°C) |
|---|---|---|---|
| (A) | 21.1 | 49.1 | 28 |
| (B) | 19.9 | 50.1 | 30.2 |
| (C) | 18.9 | 51.1 | 32.2 |

- Calculation of Coefficient of Performance (COP)**:**
  - Power: The acoustic power input from the Rotary Drive Mechanism is given by

$$\dot{W} = \tfrac{1}{2}\, p\, \mu\, A \cos\phi \quad \text{------------}(1)$$

*Where,*

*P: amplitude of the dynamic pressure at the location of the piston*

*μ: velocity of the piston*

*A: area of the piston*

*Ø: phase difference between p and μ*

*The velocity is deduced from the displacement through "μ=ωd"*

*Where, d= peak displacement of the piston*

*ω= angular frequency*

$$Q_c = VI \quad \text{------------}(2)$$

*Where,*

*$Q_c$: Heat Load Generated*

*V: Voltage*

*I: Current*

- Performance indicators:

$$COP = Q_c / \dot{W}$$

*Where,*

*COP: The performance of the cooler, also called the coefficient of performance (COP)*

*$\dot{W}$ and $Q_c$ are given in (1) and (2)*

$$COPC = (T_c) / (T_a - T_c)$$

*Where,*

*COPC: The Carnot coefficient of performance is the maximal theoretical performance a cooler can achieve*

*$T_c$: Temperature of the cold side*

*$T_a$: Temperature of the hot side*

$$COPR = COP / COPC$$

*Where,*

*COPR: The coefficient of performance relative to Carnot*

- Sample COP Calculation [ For Stack Sample (A) ]:

Drive Ratio = (Dynamic Pressure Amplitude at Piston) / (Mean pressure of gas)

*Drive Ratio = 2% = 0.02*

*Mean pressure of air at ambient = 101.325 kpa*

0.02 = (x) / (101.325)

Dynamic Pressure amplitude at piston = 2.0265 kpa

Acoustic Power: $\dot{W} = \frac{1}{2}\, p\, \mu\, A \cos\phi$

$p = 2.0265$

$A = (\pi/4) * (D^2) \Rightarrow (\pi/4) * (0.05^2) \Rightarrow 1.9634*10^{-3}\ m^2$

$\mu = \omega d \Rightarrow [(2\pi N) / (60)] * (0.05) \Rightarrow 3.6547\ m/sec$

$\dot{W} = \frac{1}{2} * (2.0265) * (3.6547) * (1.9634*10^{-3}) * [\cos(0)]$

$\dot{W} = 7.275$

$Q_c = VI \Rightarrow (440*1) \Rightarrow 0.440$ kwatt

COP = (0.440) / (7.275)

COP = 0.06

COPC = [(21.1) / (49.1 – 21.1)]

COPC = 0.75

COPR = (0.06) / (0.75)

COPR = 0.08

**Table 7.2**
(Result of Coefficient of performance)

| Stack | COP | COPC | COPR |
|---|---|---|---|
| (A) | 0.06 | 0.75 | 0.08 |
| (B) | 0.06 | 0.61 | 0.09 |
| (C) | 0.06 | 0.58 | 0.10 |

➢ Results Achieved from Experimental Analysis:

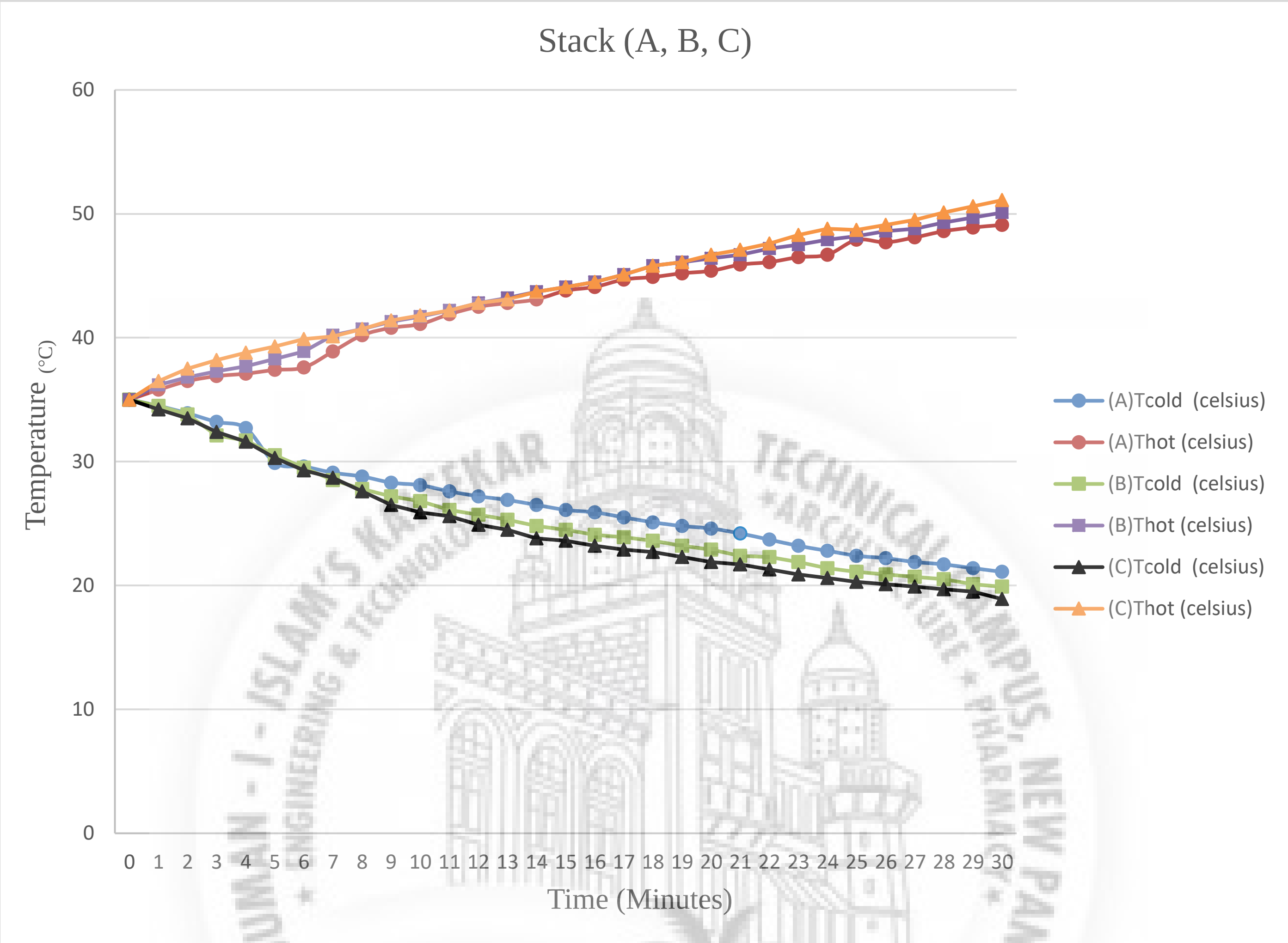



**Figure 7.5.** Cluster Comparison between All Stack Samples

**Table 7.3**
(Experimental Results Achieved)

| Stack | $T_{cold}$ (°C) | $T_{hot}$ (°C) | $T_{difference}$ (°C) | Time (min) | COPR |
|---|---|---|---|---|---|
| (A) | 21.1 | 41.1 | 28 | 30 | 0.08 |
| (B) | 19.9 | 50.1 | 30.2 | 30 | 0.09 |
| (C) | 18.9 | 51.1 | 32.2 | 30 | 0.10 |

Figure 7.5 shows the collective comparison between all Stack Samples on a Time verses Temperature graph, the results obtained from all three stacks are very close to each other being the maximum temperature difference achieved at the end of the experiment is for stack sample (C) while the minimum is achieved by Stack Sample (A), despite this the temperature difference achieved between each stack is not more than 2 degrees. This is because all Key parameters of the system are kept constant for each experiment of different stack samples, hence there is not big difference between results obtained from different stack Samples which can be easily interpreted from above graph.

The difference in performance of stacks despite keeping all parameters same is due to factors:-
(a) Thermal Conductivity of the stack material:- *[Stack(A) = Stack(B) > Stack(C)]*
(b) Porosity of the stack Sample: - *[Stack(A) > Stack(B) > Stack(C)]*

For the best performance of stack it must have a low thermal conductivity as well as low porosity, Hence the best performing stack i.e. Stack(C) have the lowest thermal conductivity as well as higher porosity, the next best is Stack(B) followed by Stack(A). The stack sample (A) & (B) have same material with similar thermal conductivity but Stack(B) have higher porosity compare to Stack(A) which ultimately resulted in difference in performance between the two stacks despite their similar factors.

# CHAPTER 08: VALIDATION

| VALIDATION REFERENCE I | | | | | |
|---|---|---|---|---|---|
| **Reference Paper** | A Compact Standing-Wave Thermoacoustic Refrigerator Driven By A Rotary Drive Mechanism<br>*Case Studies in Thermal Engineering (2020)*<br>*https://doi.org/10.1016/j.csite.2020.100708* | | | | |
| **Results** | **$T_{cold}$ (°C)** | **$T_{hot}$ (°C)** | **$T_{difference}$ (°C)** | **Time (min)** | **COPR** |
| | 25.4 | 52.5 | 27.1 | 20 | 0.11 |

| VALIDATION REFERENCE II | | | | | |
|---|---|---|---|---|---|
| **Reference Paper** | Performance evaluation of 10W cooling power thermoacoustic refrigerator with spiral stacks using air as working fluids<br>*Engineering Research Express (2020)*<br>*https://doi.org/10.1088/2631-8695/ab6e26* | | | | |
| **Results** | **$T_{cold}$ (°C)** | **$T_{hot}$ (°C)** | **$T_{difference}$ (°C)** | **Time (min)** | **COPR** |
| | 10.57 | 32.58 | 22.01 | 20 | 0.10 |

| EXPERIMENTAL RESULTS ACHIEVED | | | | | |
|---|---|---|---|---|---|
| **Stack** | **$T_{cold}$ (°C)** | **$T_{hot}$ (°C)** | **$T_{difference}$ (°C)** | **Time (min)** | **COPR** |
| (A) | 21.1 | 41.1 | 28 | 30 | 0.08 |
| (B) | 19.9 | 50.1 | 30.2 | 30 | 0.09 |
| (C) | 18.9 | 51.1 | 32.2 | 30 | 0.10 |

# CHAPTER 09: CONCLUSION

The results obtained from the experimental analysis of the fabricated model are in good agreement with the previous research models as such the performance observed is similar despite the use of readily available stack materials compared to ceramic and honey-comb structured stack used in reference researches.

Also the performance achieved from new rotary drive mechanism integrated system are in good agreement compared with the conventional electronically driven thermoacoustic refrigeration systems as such the temperature difference achieved is likewise, hence the new rotary drive can be integrated with future thermoacoustic refrigeration systems without any compromise in performance.

The integration of new rotary drive mechanism into the hereafter thermoacoustic systems will improve the influential elements like commercial scalability, Compactness, Cost and robustness of the overall system.

# CHAPTER 10: FUTURE SCOPE

- The compactness of rotary drive mechanism can be improved by using an integrated arrangement similar to air compressor used in domestic refrigerators.
- The design of diaphragm element can be improved in future to make it more efficient.
- Heat exchangers can be incorporated into the system in hereafter rotary mechanism driven thermoacoustic systems to analyze its effect, as well as to practically define systems commercially scalability.
- The design of the system could be made more linear or the new looping type arrangements can be integrated to increase the system efficiency.
- The system should me made as air tight as possible so that it can be checked with higher pressure working fluid.

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