

Effect of Dynamic Pressure on the Performance of Thermoacoustic Refrigerator with Aluminium (Al) Resonator

Bheemsha Arya¹, B Ramesh Nayak², and N V Shivakumara¹

¹Department of Mechanical Engineering, BMS College of Engineering, Bengaluru 560019, India

²Department of Industrial Engineering and Management, BMS College of Engineering, Bengaluru 560019, India

Corresponding Author: baryabms@yahoo.co.in

Abstract: In practice the refrigerants are being used in the conventional refrigeration system to get the required cooling effect. These refrigerants produce Chlorofluorocarbons (CFCs) and Hydro chlorofluorocarbons (HCFCs) which are highly harmful to the environment, particularly depleting of ozone layers resulting in green house emissions. In order to overcome these effects, the research needs to be focused on the development of an ecofriendly refrigeration system. The thermoacoustic refrigeration system is one among such system where the sound waves are used to compress and expand the gas particles. This study focuses on the effect of dynamic pressure on the thermoacoustic refrigerator made of aluminium with overall length of 748.82 mm, and the entire inner surface of the resonator tube was coated with 2mm thickness of polyurethane to minimize the heat losses to the atmosphere. Experiments were conducted with different stack geometries i.e. parallel plates having 0.119 mm thick with spacing between the plates maintained at 0.358 mm, 1mm diameter pipes, 2mm diameter pipes and 4 mm diameter pipes. Experiments were also conducted with different drive ratios of 0.6%, 1% and 1.6% for a constant dynamic pressure of 2 bar and 10 bar for helium and air as working medium. The results were plotted with the help of graphs, the variation of coefficient of performance (COP) and the relative coefficient of performance (COPR) for the above said conditions were calculated.

Keywords: Thermoacoustics, Dynamic pressure, COP, COPR, Stack, Drive ratio

1. Introduction

Sustainability, green technology, and renewable energy have been among the household words discussed by governments across the globe during last two decades, the use of ice to refrigerate and thus preserve food goes back to pre-historic times. Most of the industrial processes use lots of thermal energy by burnings fossil fuel to produce steam or heat for this purpose. After these processes, heat should be rejected to the surrounding as waste, this waste heat can be converted to useful refrigeration by using heat operated refrigeration system such as a vapour absorption refrigeration cycles. From creating comfortable home environments to manufacturing fast and efficient electronic devices, air conditioning and refrigeration remains expensive, yet essential services for both homes and industries. However in an age of impending energy and environmental crisis current cooling technologies continue to generate greenhouse gases with high energy costs. In practice the refrigerants which are used in the conventional refrigeration system to get the required cooling effect produces Chlorofluorocarbons (CFCs) and Hydro chlorofluorocarbons (HCFCs). These CFCs and HCFCs are



highly harmful to the environment particularly depleting of ozone layers which leads to the greenhouse emissions. To reduce greenhouse emissions, research and development is intended internationally to improve the performance of presently existing conventional refrigeration system. Many researchers have oriented towards the development of thermoacoustic refrigeration system in which sound waves and non-flammable inert gases like helium, argon, Neon, air are used in a resonator to produce cooling. Thermoacoustic refrigerator is constructed by using heat exchangers, resonator and a stack. Depending on the type of engine a loudspeaker or driver might be used to generate sound waves, resonance occurs only at certain frequencies called resonance frequencies and these are mainly determined by the length of resonator. When the stack is placed at a certain location in the resonator, though having a standing wave in the resonator, a temperature difference (ΔT) can be measured across the stack by placing heat exchangers at both sides of the stack. Thermoacoustic refrigeration systems operate by using sound waves and non-flammable inert gases like helium, Neon, argon, etc. in a resonator to produce cooling effect.

2. Experimental Setup

The photograph of the experimental setup arrangement has shown in Figure.2.1. The setup consists of a loudspeaker, a resonator tube, a parallel plate stack and two heat exchangers are installed in a thin walled cylinder. The system is built as separate components so that any specific parts can be changed according to the requirement.

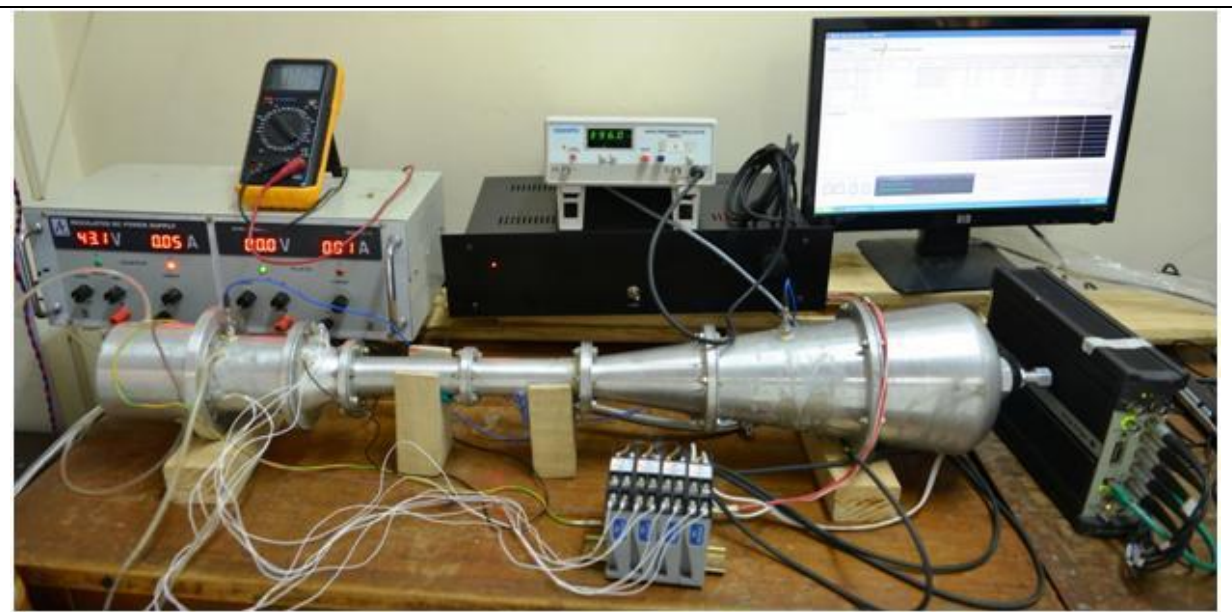


Figure.2.1 Photograph of Experimental setup of Standing wave Thermoacoustic Refrigerator

In this section construction details of the different parts of the thermoacoustic refrigerator are described.

Acoustic driver: The acoustic driver must provide the total acoustic power used by the stack to transfer heat and also the power dissipated in the different parts. A commercially available Loudspeaker with frequency range of 5Hz to 60000Hz and power output of 50W was selected. The loudspeaker coil diameter is 50 mm, resonator with an inner diameter of 70 mm is used, and therefore a fabric dome is adjusted to fit in to the driver housing tube with the help of screw and clamping arrangements. The driver is placed in aluminium housing which forms the interface with the resonator tube. A groove is

made in the housing, therefore the heat released in the driver is removed by the cooling water circulating inside the copper tubing around the speaker assembly.

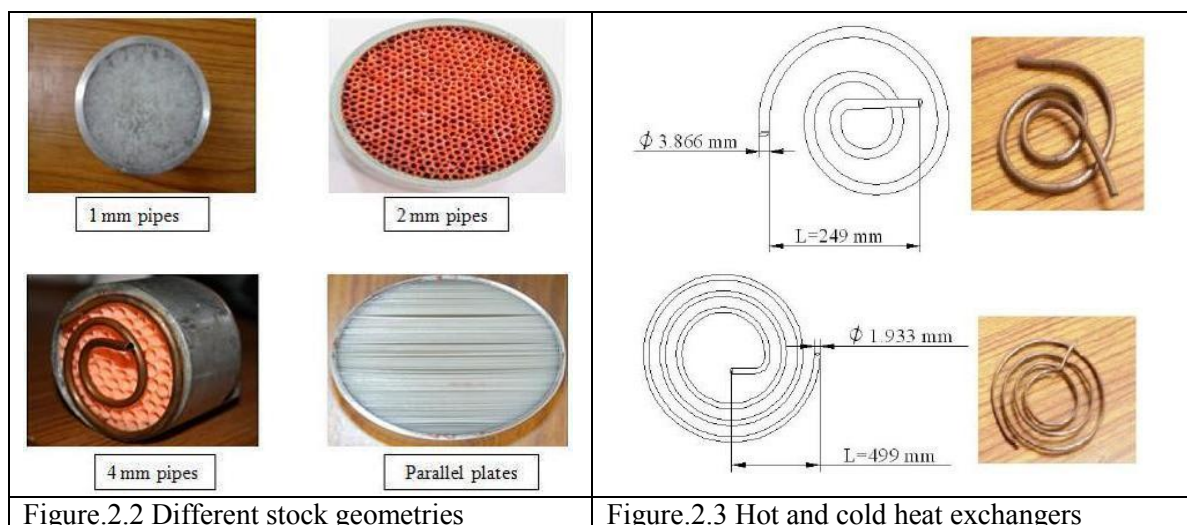
Resonator: The resonator comprises of a large diameter tube in which the stack is placed, a small diameter tube, and a buffer volume. One end of the large diameter tube is connected to driver housing where has the other end is connected to the small diameter tube. The entire inner surface of the resonator tube has been coated with polyurethane of 2 mm thickness to minimise the heat transfer from the resonator to the atmosphere.

Connector tube: Connector tube is also made up of aluminium, An aluminium blank of 100 mm in diameter and 60 mm length is taken and machining Operations are performed to reduce it to a length of 50 mm. Taper turning operation was done with a taper angle of 22° to obtain required diameter from 70.069 mm to 30.925 mm. Six holes are drilled on each side of the flange to accommodate the bolts and nuts for assembly, Polyurethane coating and buffing operations are also performed.

Buffer volume: The buffer volume is also made with aluminium having three pieces; the wall thickness of 10 mm is maintained with overall length of 374.41 mm. It is connected to the small diameter tube with the help of flange, bolts and nuts. Taper angle of 9° is provided to reduce irreversibilities.

Stack holder: The two key requirements for the stack holder are low thermal conductivity and rigidity. In the present research work ertacetal material is chosen, with an inner diameter of 68 mm, wall thickness of 2 mm and length of 40.54 mm is maintained, A specialized manufacturing process is used to cut the radial grooves in the stack holder to accommodate parallel plates having 0.119 mm thick and a spacing between the plates maintained at 0.358 mm.

Stack: The stack design and material selection is the most important aspect of a thermoacoustic refrigerator as it forms the heart of the refrigerator. To ensure low thermal conductivity, Mylar material is chosen for parallel plate stack. The spacing between the layers is obtained by specialized manufacturing process to cut the radial grooves in the stack holder to accommodate parallel plates having 0.119 mm thick and spacing between the plates maintained at 0.358 mm. Also stack of different diameters pipes are used to conduct the experiment and compare the results. A stack made of plastic circular pipes having inner diameter of 1 mm, 2mm and 4 mm are used. Figure 2.2 shows different stack geometries used during the experiments.



Heat exchangers: Two heat exchangers are required for the thermoacoustic refrigerator, one for supplying heat to the cold side of the stack and another to extract heat from the hot side of the stack. The cold heat exchanger used in the present study is a spiral winding of copper tube of diameter 2 mm and 499 mm in length. The cold heat exchanger is mounted and gloved on to the surface of the stack holder. A heating coil wound around the cold heat exchanger to induce required quantity of heat by external regulated DC power supply. Two thermocouples are mounted on the cold heat exchanger to record the temperature. The electrical and thermocouple leads are drawn out through the holes drilled on the connector surface. Hot heat exchanger is also prepared with similar techniques as that of cold heat exchanger. However a coil diameter of 4 mm and length 249 mm is used. The cooling arrangements are made by means of hose pipes maintaining with variable flow rate. Here also two thermocouples are mounted to measure the temperature. The hot and cold Heat exchangers has shown in Figure.2.3

3. Results and discussions:

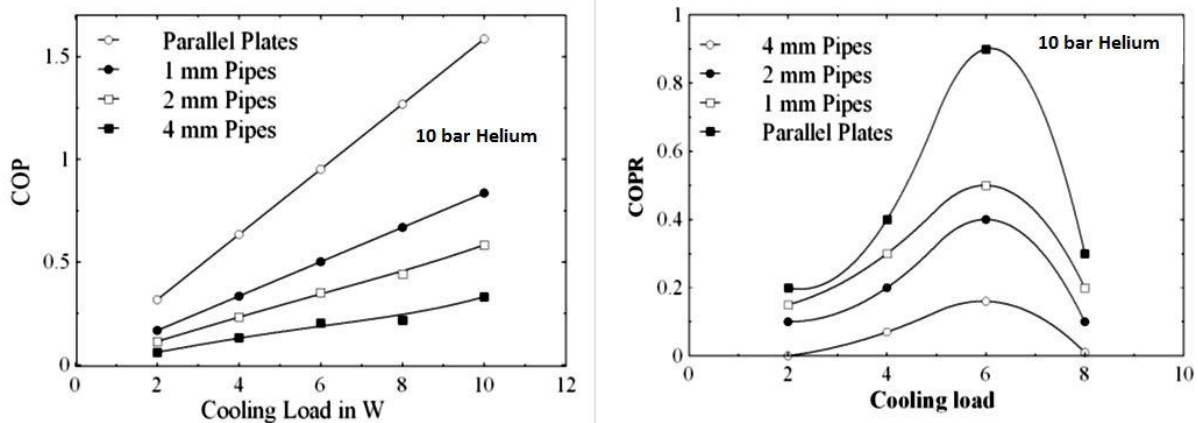


Figure 3.1 : The variation of COP and COPR for different cooling loads for different stack geometries for a Constant dynamic pressure of 10 bar with constant frequency of 400 Hz with Helium as working fluid.

Figure 3.1 depicts the COP and COPR for different stack geometries shown for Helium at 10 bar constant dynamic pressure with a constant frequency of 400 Hz. COP increases with the increase in cooling load as it is directly proportional to cooling load. The COPR is increases with increase in COP as it is proportional to the COP and is found maximum at 400 Hz frequency corresponding to a mean pressure of 10 bar. The COPR increases to certain extent and reaches maximum value and starts' decreasing this is due to the presence of weak thermal penetration depth in the stack at higher operating frequencies leading to the increase in viscous loss and reducing the thermoacoustic effect. It can be noticed that parallel plate stack has a highest COP and COPR as compared with other stack geometries as the parallel plate stacks is more capable of creating maximum temperature difference compared to other stack geometries. This variation is due to better thermal and viscous penetration depth as the spacing between the two plates is quite small. The drive ratio play a very important role in enhancing thermoacoustic effect leading to better heat transfer and hence temperature difference. This measurement shows the importance of the stack spacing on the performance of the thermoacoustic refrigerator. Uniform channel structure in the stack is an essential factor for the better performance.

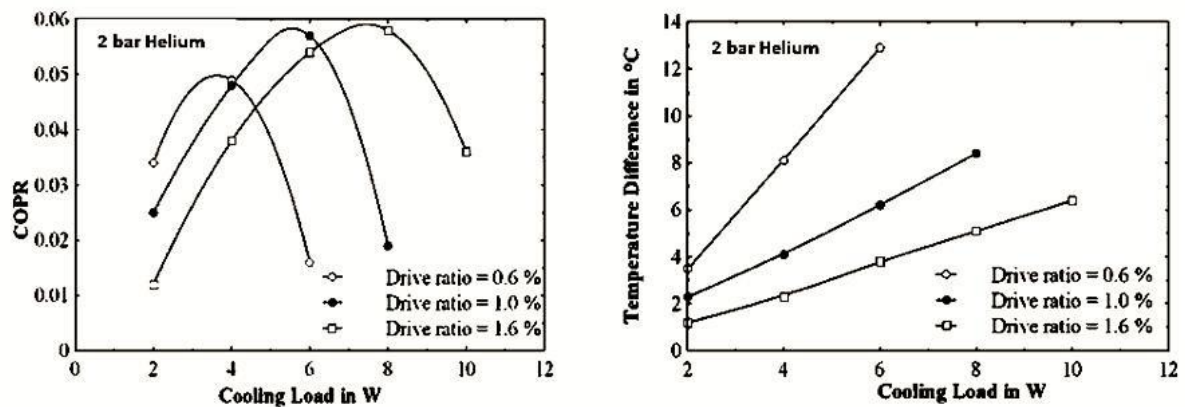


Figure 3.2 : The variation of COPR and Temperature difference (ΔT) with different cooling loads for parallel plate stack with Helium at 2 bar mean pressure for different drive ratios of 0.6%, 1% and 1.6%.

From Figure 3.2 COPR and the Temperature difference (ΔT) increases with increase in cooling load for Helium at 2 bar mean pressure, also the COPR and ΔT found higher for lower drive ratio of 0.6% as compared to higher drive ratios.

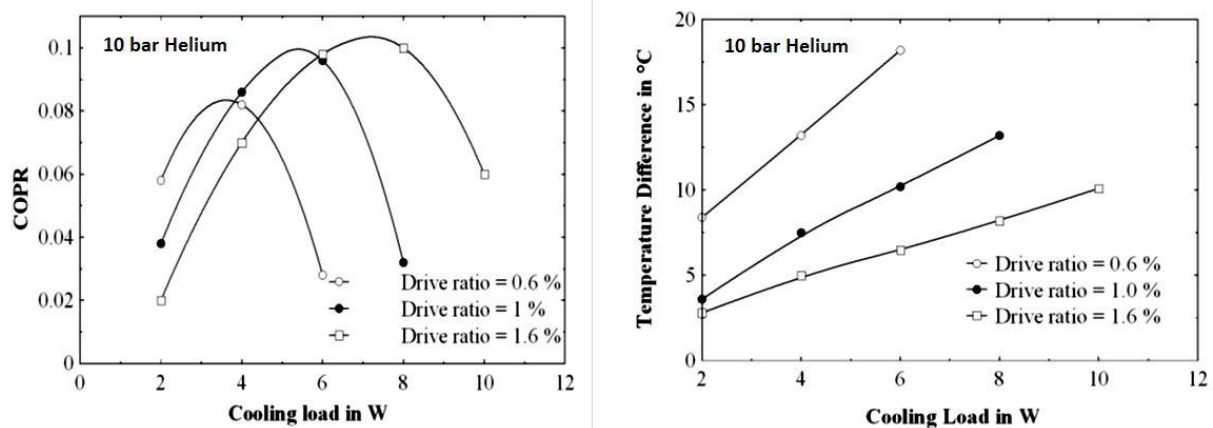


Figure 3.3 : The variation of COPR and Temperature difference (ΔT) with different cooling loads for parallel plate stack with Helium at 10 bar mean pressure for different drive ratios of 0.6%, 1% and 1.6%.

From Figure 3.3 The COPR and the Temperature difference (ΔT) increases with increase in cooling load for Helium of 10 bar mean pressure, also the COPR and ΔT found higher for lower drive ratio of 0.6% as compared to higher drive ratios.

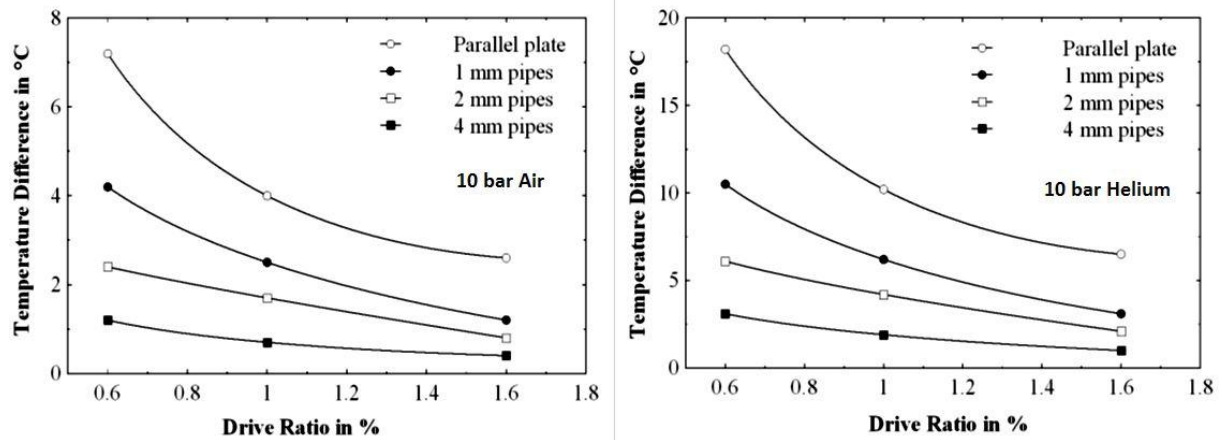


Figure 3.4: Variation of temperature difference (ΔT) with different drive ratios for air and helium with constant mean pressure of 10 bar for different set of stock geometries.

From Figure 3.4 the Temperature difference (ΔT) decreases with increase drive ratios for both Air and Helium with 10 bar mean pressure for different set of stock geometries of parallel plate stock, 1 mm pipes, 2 mm pipes and 4 mm pipes. It is very clear that the parallel plate stock geometry produces higher temperature difference (ΔT) for both working fluids compared to other stock geometries.

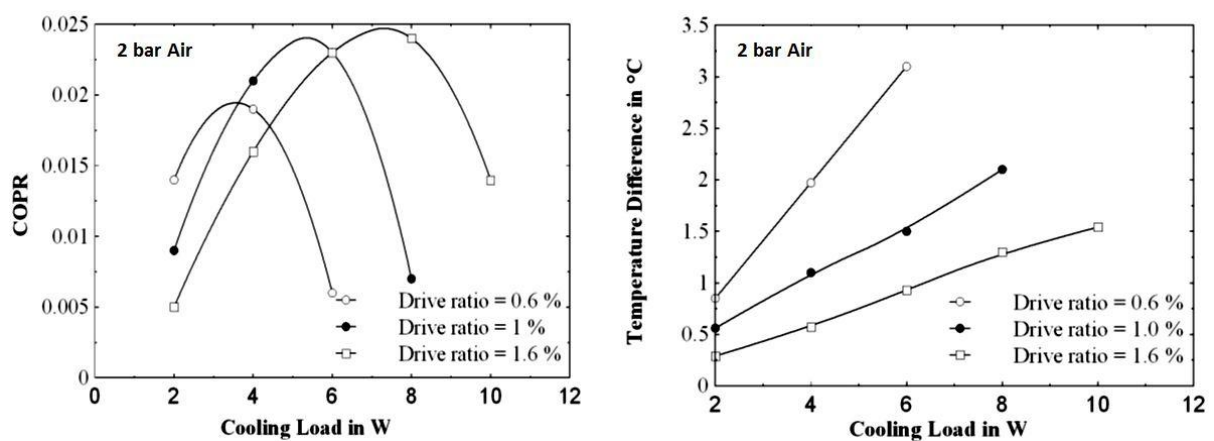


Figure 3.5: Variation of COPR and Temperature difference (ΔT) with different cooling loads for air at 2 bar mean pressure for different drive ratios.

From Figure 3.5 the Temperature difference (ΔT) increases with increase in cooling load for Air of 2 bar mean pressure, and ΔT found higher for lower drive ratio of 0.6% as compared to higher drive ratios.

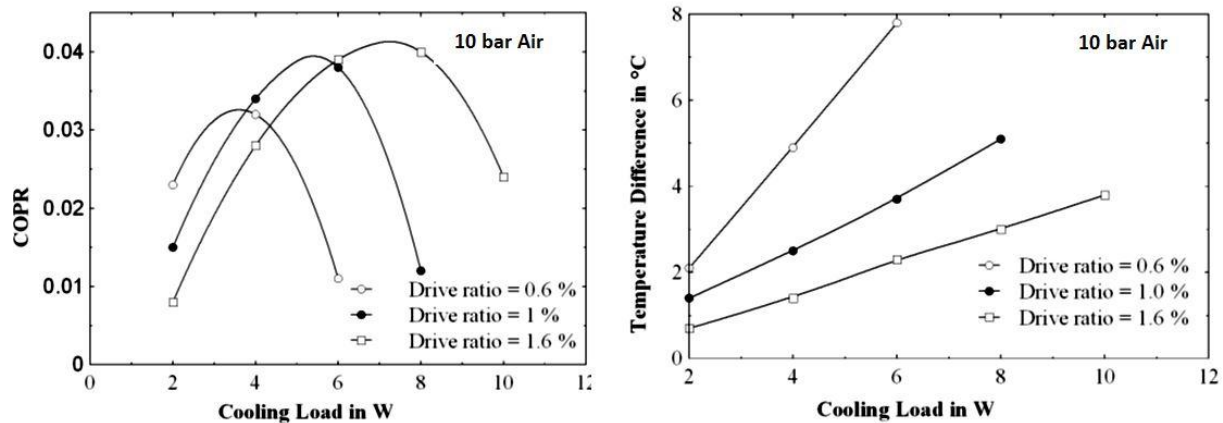


Figure 3.6 Variation of COPR and Temperature difference (ΔT) with different cooling loads for air at 10 bar mean pressure for different drive ratios.

The Temperature difference (ΔT) is increasing linearly as a function of heat load, the lower temperatures are reached with higher dynamic pressure. The COPR is also increasing as a function of the mean pressure. In the present investigation an average mean pressure up to 10 bar and drive ratio less than 2% is chosen, the temperature difference between hot and cold end of the stack increases with the increase in drive ratio for all stack geometry at constant cooling load and mean pressure. Results indicate that parallel plate stack is more capable of creating higher temperature difference compared to other stack geometries. Experiments were conducted and measurements were made for three different drive ratios in each case for parallel plate stack with helium as working fluid. The slope temperature difference (ΔT) decreases as the drive ratio increases. Lower temperatures are achieved with higher drive ratios; the maximum COPR was achieved with this stack is about 4% with a mean dynamic pressure of 10 bar and a drive ratio of 1.6%.

4. Conclusion: The experiments were conducted for two constant mean dynamic pressures of 2 bar and 10 bar, with constant frequency of 400 Hz for different stack geometries of parallel plate, 1 mm pipes, 2 mm pipes and 4 mm pipes for different drive ratios of 0.6%, 1% and 1.6% for Helium and air as a working fluid. The results are summarized by using graphs and found that the combination of parallel plate stack with helium as working fluid with 10 bar mean pressure has better COP and COPR as compared to all other combinations.

5. References

- [1] Tijani MEH, Zeegers JCH, de Waele ATAM, (2002), - Design of thermoacoustic refrigerators.
- [2] M.E.H Tijani, J.C.H. Zeegers, A.T.A.M de Waele- Construction and performance of a thermoacoustic refrigerator.
- [3] Jonathan Newman, (2006) "Thermoacoustic refrigeration", GSET Research journal
- [4] Hofler T J, (1997)-Thermoacoustic engines and refrigerators, Encyclopedia Appl phys, 21, pp.245-264

- [5] Jonathan Newman, Bob Cariste, Alejandro Queiruga, Isaac Davis, Ben Plotnick, Michael Gordon, and Sidney San Martin- Thermoacoustic refrigeration.
- [6] Bheemsha, Ramesh Nayak, Pundarika, - 'Performance Evaluation of Thermoacoustic Refrigerator Using Air as Working Medium'. International Journal of Thermal Engineering (SSRG-IJTE) **volume 1Issue3May to June 2015**.
- [7] Bheemsha, Ramesh Nayak&Pundarika.G, 'Design and Optimization of a Thermoacoustic Refrigerator', *December 2011*.International Journal of Emerging Trends in Engineering and Development, issue1, **Vol2, pp 47-65**.
- [8] Bheemsha, Ramesh Nayak&Pundarika.G, 'Design of a Parallel Plate Stack for a Thermoacoustic refrigerator' *December 2011*.International Journal of Advanced Scientific & Technical Research, Issue1, **Vol 2, pp 1-20**.
- [9] Bheemsha, Ramesh Nayak&Pundarika.G, 'Design of the Resonator Tube and Buffer Volume for Thermoacoustic Refrigerator' *December 2011*.International Journal of Advanced Scientific & Technical Research, Issue1, **Vol 2, pp 276-288**.
- [10] S.W. Swift, Thermoacoustic engines and refrigerators, *Physics Today* 48 (7) (1995) pp 22-28