Simulation and Experimental Studies of Twin Thermoacoustic Prime Mover

Krishna Moorthy V*, Uma, Jaanaki S.M, N. M. Hariharan, S. Kasthurirengan

Abstract: Thermo acoustic prime mover (TAPM) converts thermal energy to acoustic energy and it is one of the alternative method to replace traditional compressor which will drive any cryocooler . The advantages of TAPM are the absence of moving components and they can be driven by solar energy, waste heat etc. In order to develop TAPMs their design and fabrication should be guided by numerical modeling and this may be done by several methods such as solving the energy equation, enthalpy flow model CFD, Delta EC etc. We studied the TAPMs with CFD technique, and Delta EC methods since it provides a better insight into the velocity and temperature profiles. In this article we discuss the influence of working gas (helium, argon and its mixtures). The theoretical results and experimental results are compared and they are in reasonably good agreement

Index Terms: CFD, Thermoacoustic, Delta EC,

I. INTRODUCTION

Thermoacoustic prime mover (TAPM) is one of the alternative methods to replace compressor which is used to drive cryocoolers. Due to the moving components in both cryo and ambient temperature the reliability of the cryocoolers is affected. Compared with GM, Striling type cryocoolers pulse tube cryocoolers have higher reliability because of the absence of moving components in cryo temperature but still Pulse tube cryocoolers uses gas compressor which has moving components at room temperature. In order to reduce the conventional compressor to drive pulse tube cry cooler, thermoacoustic prime mover is an alternative solution.

Thermoacoustic studies have been carried out by many investigators in recent years in the area of renewable energy, Green energy and Etc. These thermoacoustic systems convert thermal energy to sound energy and vice-Versa and are called prime mover and refrigerator respectively. Thermoacoustic system consists of heat exchanger in both Hot and Cold end separated by stack. In order to design efficient TAPMs, the knowledge of influence of its geometry, working fluids and operating temperature are important. The geometry influence and operating parameters are discussed elsewhere [3]. In this paper we discuss the working fluids influence on the performance of TAPMs with helium, argon and their mixtures. We used CFD, Delta EC software to estimate theoretical values and the same is compared with experimental values.

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II. CFD SIMULATION

CFD simulation technique helps us to understand the physical parameters, where we cannot measure in experimental studies. The major components of thermoacoustic system are Resonator, Stack (Porous) and working fluids. The optimization of the above components is essential to design any TAPMs. The geometries of TAPMs are carried out by gambit and the analysis of the same are carried out by Fluent 6.3.26. The geometry of single ended TAPMs is shown in Fig (1a) and fig (1b) shows the meshed structure using Gambit software.

We have chosen the optimum dimension of TAPM to arrive better amplitude and lower operating frequency. Our simulation results shows that the resonator length should be 3300 mm, length of Stack is 200 mm, both cold and hot heat exchanger is 80 mm. Simulation of Twin TAPMs are carried out with different gases. Our results shows that longer the resonator length, the operating frequency is lesser. At the same time the system requires longer ONSET temperature to generate the acoustic waves.

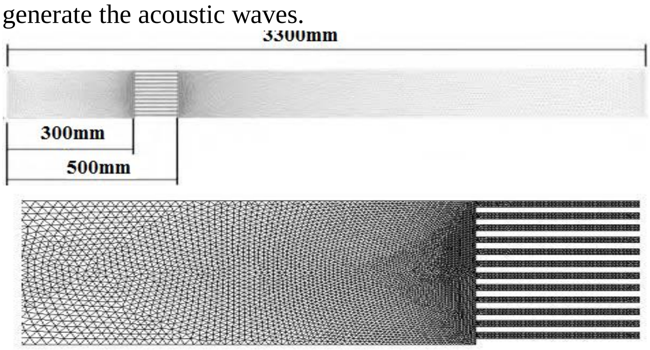

Figure 1: Dimensions of the Computational Domain for the TAE (a), Section of the CFD Grid (b)

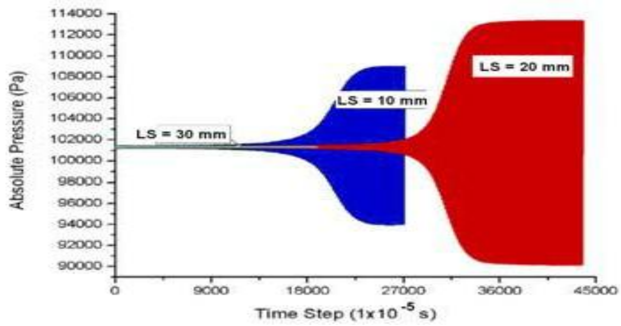

Figure 2. Absolute pressure as a function of time step for different stack lengths 10, 20, 30 mm. The hot end is at 700 K and the cold end is at 300 K

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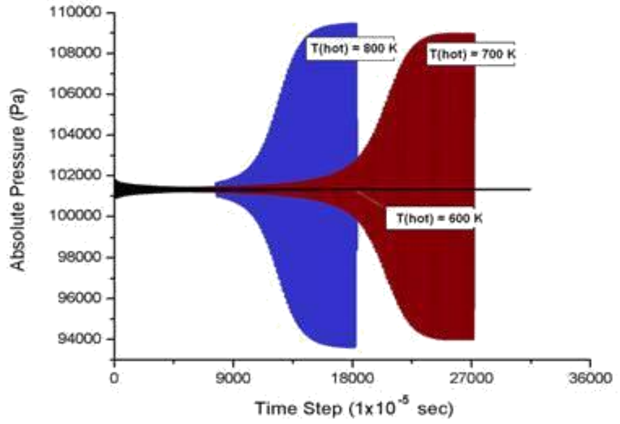

Figure 3. Absolute pressure as a function of time step of varying Hot end temperature of TAPMs and Cold end is maintained at 300K

The above results show that the resonance frequency of a given system is dependent on the working fluid; we have chosen Helium, Argon and their mixtures. Pulse tube cryocoolers needs lesser resonance frequency, so argon gas is lower in frequency but it requires higher ONSET temperature. But helium has lower ONSET temperature and exhibits higher resonance frequency. In order to optimize we have taken equal ratio of helium and argon gas and studied.

III. DELTA EC SIMULATION:

The DeltaEc is freely available software to simulate thermoacoustic system. This software uses standard acoustical equation proposed by Rott and it has been used to simulate many acoustical systems [3]. We have simulated TAPMs using deltaEC to obtain the optimum solution of working gas.The below figure shows the Simulation model of Twin TAPMs, The stack porosity is declared same as CFD and the dimensions of TAPMs are maintained same as CFD simulation to compare the results.

We found the results of CFD and DeltaEC are similar.

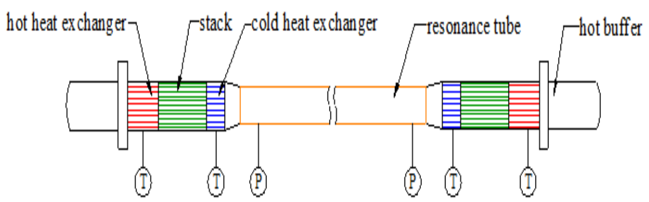

Figure 4(a) schematic diagram of the Twin Thermoacoustic Prime mover

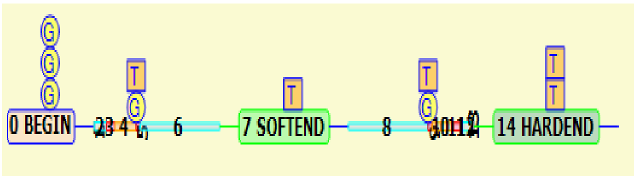

Figure 4(b) Shows the Simulation model. Of Twin Thermoacoustic Prime mover

This Thermoacoustic System consists of Hot and Cold heat exchanger separated by stack, and resonator tube. In order to simulate the Twin Thermoacoustic, the two symmetric TAPMs are connected through resonator tube. Single stage TAPMs have lesser amplitude compared with twin TAPMs. So we simulated the twin TAPMs.

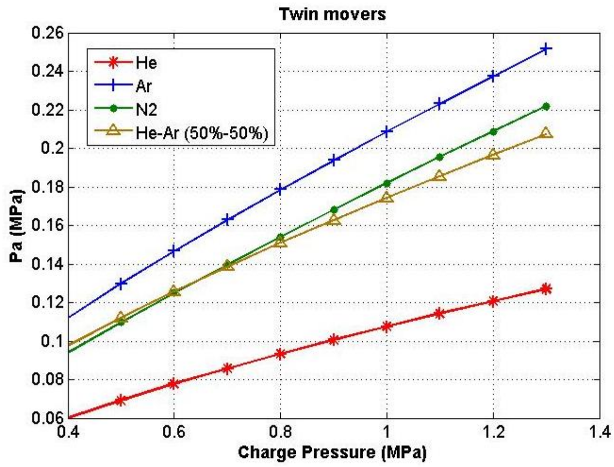

Figure 5. Pressure amplitude Vs different Operating Pressure for Helium, argon and their Mixture

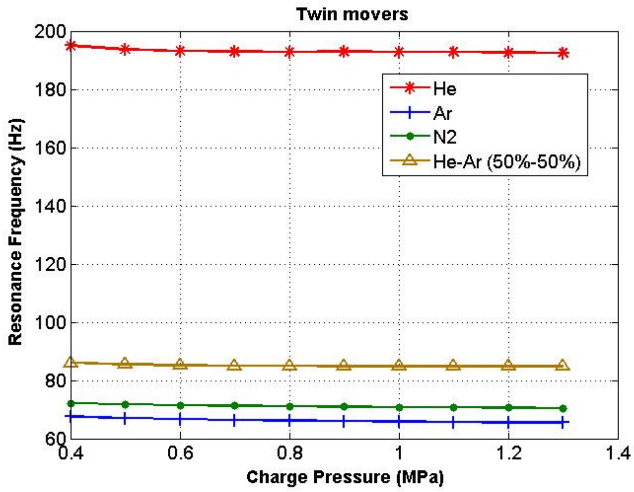

Figure 6. Resonance frequency Vs different operating Pressure for Helium, argon and their Mixtures.

The above results of TAPMs indicate that the resonance frequency of a given system depends on the working fluids and it shown that helium has higher resonance frequency where as argon has lesser. In order to develop the Thermoacoustic system to drive pulse tube cryocoolers, the operating frequency should be lesser for which argon gas is suitable, since Pressure amplitude of argon is lesser. So we have chosen Helium and argon mixtures which are suitable to drive any cryocooler.

IV. EXPERIMENTAL SETUP:

The schematic diagram of the twin TAPM is shown in Figure 4. The two prime movers are connected through resonator tube. Hot and cold heat exchangers are fabricated with copper plate having thickness of 1mm and separated by thin spacer of 0.5mm. Hot heat exchanger is heated by electric heater of 1KW mounted on the surface of heat exchanger. Multilayer thermal insulation is wrapped on heaters to reduce heat loss. Cold heat exchanger is maintained at room temperature. The temperature of hot and cold end is measured by thermocouple temperature sensor. Gefran pressure transducer is mounted on the resonator pipe to measure the pressure amplitude.

Helium and argon gas of purity of 99.9% is used for our studies and Turbo molecular pump is used to create vacuum.

Figure 6. Photo of the experimental setup of twin TAPMs

The stack is prepared with stainless steel plates having thickness of 0.5mm and separated by the spacers of 1 mm. In order to reduce the impedance of acoustic flow, we have chosen the symmetric arrangement of heat exchanger and stack geometry.

Table 1: Comparison of Resonance Frequency using CFD, DELTAEC and Experimental Results.

Working Fluids	DeltaEC (Hz)	CFD (Hz)	Experimental Frequency (Hz)
Helium	190	111	109
Argon	68	66	37
Helium (50%) and Argon (50%)	85	76	54

V. CONCLUSION

The effects of the working gas on the performance of the Thermoacoustic prime mover is simulated by CFD, DeltaEc and experimentally studied.

The Resonance frequencies of TAPM Simulated by DeltaEc, CFD are comparable with experimental values. The theoretical values of TAPMs are higher compared to experimental values. The resonance frequency of helium gas is higher, where as resonance frequency of argon is lower. In order to use TAPMs as a compressor replacement in cryocoolers, Helium and argon mixtures are suitable to drive pulse tube cryocoolers, because of its lower ONSET temperature and higher pressure amplitude.

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