Analysis of Inertance Pulse Tube Refrigerator using CFD

M. Sai bab\textsuperscript{1}, Pankaj kumar\textsuperscript{2}

\textsuperscript{1}M. Tech Scholar, Department of Mechanical Engineering, GMRIT, Rajam, Srikakulam-532127, Andhra Pradesh, India.

\textsuperscript{2}Assistant Professor, Department of Mechanical Engineering, GMRIT, Rajam, Srikakulam - 532127, Andhra Pradesh, India.

Email: mandalemulasibaba@gmail.com, pankajcryo@gmail.com

Abstract. The current research focuses on the study of the Inertance pulse tube refrigerator [IPTR] using ANSYS FLUENT code. In the workbench with suitable dimensions, an axis symmetric model is developed, which could then be modeled to determine the validity of the Inertance pulse tube refrigerator. The additional Inertance pulse tube refrigerator is updated, i.e. 2 further reservoirs were attached to above system and they are respectively connected by valves. The efficiency of this new model of pulse tube refrigerator is analyzed and connected with the refrigerator of the Inertance pulse tube.

Keywords: PT, IPTR, CFD, 3RPTR.

1. Introduction

The pulse tube cooler has become a closed mechanism where there will be no mass contact in between device and the atmosphere [1]. The only moving component in PTR is the compressor that oscillates back and forth creating pressure waves (and rotary valve if the PTR is G-M type) [2]. The mostly used working fluid in PTR is the helium [3]. Helium has the lowest critical temperature than other gases which can be used as working fluid. It also has thermal conductivity [4]. Because of the periodic flow, the analysis of the PTRs is difficult and accurate analysis is required for optimum design of the PTR [5]. In order to design the PTR, the thermos-fluid processes in the system must be thoroughly analyzed. One-way of doing that is solving the spectrum is numerically governed based on the universal theory without having any conditional conclusions [6]. While using efficient computational fluid dynamics (CFD) software that is capable of modeling and addressing dynamic and multidimensional flow and temperature difference in complicated geometrical, its other approach analyses the problems [7].

2. Objective

In the present work the continuum governing equations are solved numerically using CFD software FLUENT for analysis of the IPTR and 3RPTR. The objectives of the current work are as follows:

- The simulation of the IPTR by using 3D axisymmetric model by using FLUENT software.
- To develop the geometric model for new type of the PTR i.e. 3 RPTR using commercial software analysis of 3RPTR.
- To study the performance of the 3RPTR by simulating it by using FLUENT software.
- To compare the results of the IPTR and 3RPTR to evaluate the performance the 3RPTR.
3. Modeling and mesh generation of IPTR and 3RPTR

The modeling of IPTR and 3 buffers PTR is done using ANSYS software. The schematic geometry is shown for both in following figures. The system is composed of a transfer pipe, a cooler and a regenerator, a heat exchanger with a cold end, a connecting tube and a reservoir. Each part of the IPTR system is actually circular in shape and all the parameters are arranged in series to create an axis-symmetric system in Figure 1. Consequently, in a three dimensional axis-symmetric reference method, the IPTR is defined.

![Figure 1. Geometry 3D modeling of Inertance](image)

![Figure 2. Schematic diagram of 3D Model of 3 RPTR Pulse tube refrigerator with single reservoir](image)

For 3 buffer type dimensions are similar only 2 more buffers are added to this geometry. The system consists of a transfer line, a cooler, a regenerator, a heat exchanger with a cold end, a PT, a hot end heat exchanger, a connecting tube and a tank. Figure 2 indicates that each 3-buffer form PTR part is then classified on an IPTR-like 3-dimensional axis-symmetric co-ordinate structure.

A dimensions of various components IPTR and 3RPTR are shown Table 1. The dimensions are same both IPTR and 3RPTR has extra dimensions of two reservoirs [last two dimensions].

| Sl. No | Components                  | Radius[m] | Length[m] |
|-------|-----------------------------|-----------|-----------|
| 1     | Compressor                  | 0.00954   | 0.0075    |
| 2     | Transfer line               | 0.00155   | 0.101     |
| 3     | After cooler                | 0.004     | 0.02      |
| 4     | Regenerator                 | 0.004     | 0.058     |
| 5     | Cold end heat exchanger     | 0.003     | 0.0057    |
| 6     | Pulse tube                  | 0.0025    | 0.06      |
| 7     | Hot end heat exchanger      | 0.004     | 0.01      |
| 8     | Inertance tube              | 0.000425  | 0.0684    |
| 9     | Reservoir 1                 | 0.013     | 0.13      |
| 10    | Reservoir 2                 | 0.013     | 0.0433    |
Pressure inlet is given at inlet of transfer line by defining the pressure profile in UDF as given below:

```c
#include "udf.h"
DEFINE_PROFILE (unsteady_pressure, thread, position)
{
  face_t f;
  real t = CURRENT_TIME;
  begin_f_loop (f, thread)
  {
    F_PROFILE (f, thread, position) = 101325.0*(5.0 * sin(2*3.141592654*34*t));
  }
  end_f_loop (f, thread)
}
```

Mesh of IPTR and 3 RPTR is shown in following Figure 3.

**Figure 3.** Mesh of different components of IPTR and 3R PTR

4. Results and discussion

Inertance pulse tube refrigerator has been simulated using FLUENT software and results are shown below. Figure 5 shows the temperature cool down with respect to time. Since the simulation is initiated 100k it shows increase in temperature for initial period then starts to cool off. The temperature appears in Figure 6 variation with time when steady periodic state is reached.

**Figure 4.** Temperature cool down of IPTR

**Figure 5.** Cyclic variation of temperature in IPTR
As shown in above figures the lowest temperature of CHX wall achieved in IPTR is 76.7k, this temperature is reached after 24 seconds of flow time since the simulation is initiated from 100k. FIGURE 6 and 7 shows the Density and temperature over the duration of the IPTR. As seen from these figures in CHX while density is highest in CHX. Figure 8 and 9 shows the contours of the temperature and density for regenerator, CHX and pulse tube of IPTR.

The Figure 10 shows the graph showing Pressure and intensity of mass transfer versus the time step. That could be clearly seen that there is phase difference of 74o. The 3-buffer type pulse tube refrigerator [3RPTR] is simulated using fluent software with initial guess of 100 K. Initial temperature profile is shown in fig. 11 this can be done by using patch option provided by FUENT.

The simulation of 3 RPTR is done with two cases: one with only valve operating and one with all three valves operating figure 12 and 13 shows the temperature cool down for case with 1 valve and case with all valves working respectively.
Figure 12. Temperature cool down of case 1  

Figure 13. Temperature cool down of case 2

Figure 14 and 15 shows the cyclic temperature of case 1 and case 2 respectively. As shown from above figures, it shows that in case 1 minimum temperature of 153.24k is reached in 25 seconds and in case 2 minimum temperatures of 173.86k is reached in 22 seconds. Figure 16 and 17 shows the temperature and density variation for case 1 and figure 18 and 19 shows the same case 2.

Figure 14. Cyclic temperature for case 1  

Figure 15. Fig 15 Cyclic temperature for case 2

Figure 16 Temperature variation for case 1  

Figure 17. Density variation for case 1
Following figures show the contours of temperature and density for Case 1 and case 2, respectively.

Figure 18. Temperature variation for case 2

Figure 19. Density variation for case 2

Figure 20. Temperature contour for case 1

Figure 21. Density contour for case 1

Figure 22. Temperature contour for case 2

Figure 23. Density contour for case 2

Figure 24. Phase relation for case 1

Figure 25. Phase relation for case 2

Figure 24 and 25 shows the phase relation between pressure and mass flow rate for case 1 and case 2 respectively. As seen from these graphs the phase difference between pressure and mass flow rate is almost same for both cases (250 for case 1 and 310 for case 2) and lower than that of IPTR.
5 Conclusions

The simulation of IPTR and two cases of 3RPTR is done by using ANSYS FLUENT software. The lowest temperature observed in IPTR is 76.7 k after 24 seconds flow time. For IPTRR, its phase difference in pressure and mass flow rate is 74°. Two cases of 3 RPTR which are case 1 where only one valve is operating and other two are closed and case 2 where all valves are operating. The lowest temperature is achieved in case 1 which is 152.24k in 25 seconds of flow rate and in case 2 is 178.5k in 22 seconds.

6 Future work

The simulation of 3RPTR can be extended by using different valve operating timings and different valve openings. As can be seen from results, by adjusting the parameter to achieve the higher output, there is potential for improving 3RPTR efficiency.

7 References

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