Thermal Analysis of a Thermo Acoustic Cryocooler

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Abstract:- Thermo acoustically driven pulse tube cryocoolers are gaining significant interest in the recent time due to the key advantage of complete absence of moving components for the entire system.The geometrical parameters are the stack length, the stack position, the resonator length. This work deals with the 2-D computational fluid dynamics analysis of flow in a Thermo acoustic Cryocooler. The software used for this purpose are GAMBIT and FLUENT. The 2 D model of the parts of the Cryocooler are made by GAMBIT and analysis are to be carried out by FLUENT. The models are first generated using the data and then are meshed and then various velocity and pressure contours are drawn and graphed in this paper to analyze the flow through the cryocooler.

***Keywords**: Pressure Inlet, Stack, Cryocooler, Gambit, Fluent*

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1. INTRODUCTION : THERMO-ACOUSTIC CRYOCOOLER

Thermo-Acoustic Cryocooler can be simply defined as a refrigeration machine that provides refrigeration in the temperature range of 0K-150K. recent development of technologies, especially in the domain of space and military application, has significantly enhanced the application of cryogenics. In the present problem the Thermo-Acoustic cryocooler has been modeled and simulated using commercially available software.

1.2 THERMO ACOUSTIC CRYOCOOLING

Thermoacoustics is the only technology that can cool to temperatures close to the absolute zero without using moving parts and is therefore very interesting for applications requiring cryocooling. One such application is the liquefaction of natural gases which requires very low temperatures. At the Los Alamos National Laboratory (LANL) a heat-driven thermo acoustic refrigeration system [134, 138] has been designed capable of liquefying natural gases. Their system uses a toroidal geometry attached to a long resonator tube, with a prime mover located in the toroidal part and a refrigerator located near the end of the resonator. Part of the natural gas is burned to supply heat which is converted into acoustic power by the prime mover. The acoustic power is then provided to the refrigerator and subsequently used to cool the remainder of the natural gas until it is liquefied.

1.3 APPLICATIONS:-

Typical applications of cryocoolers are:

1 Cooling of super-conducting magnets
2 Cooling of infra-red sensors for missile guidance
3 Cryo vacuum pumps
4 SQUID magnetometers
5 Gamma ray sensors for monitoring nuclear activity
6 Cooling of high temperature superconductors and semiconductors
7 Cryosurgery
8 Preservation of biological materials, blood, biological specimens etc.

2. MODEL DESCRIPTION

In the present problem, 2-D numerical simulation of air flow through in Thermo-Acoustic Cryocooler is carried out. The Turbulent Flow Models is emplyed to study the variation of flow and thermal parameters.

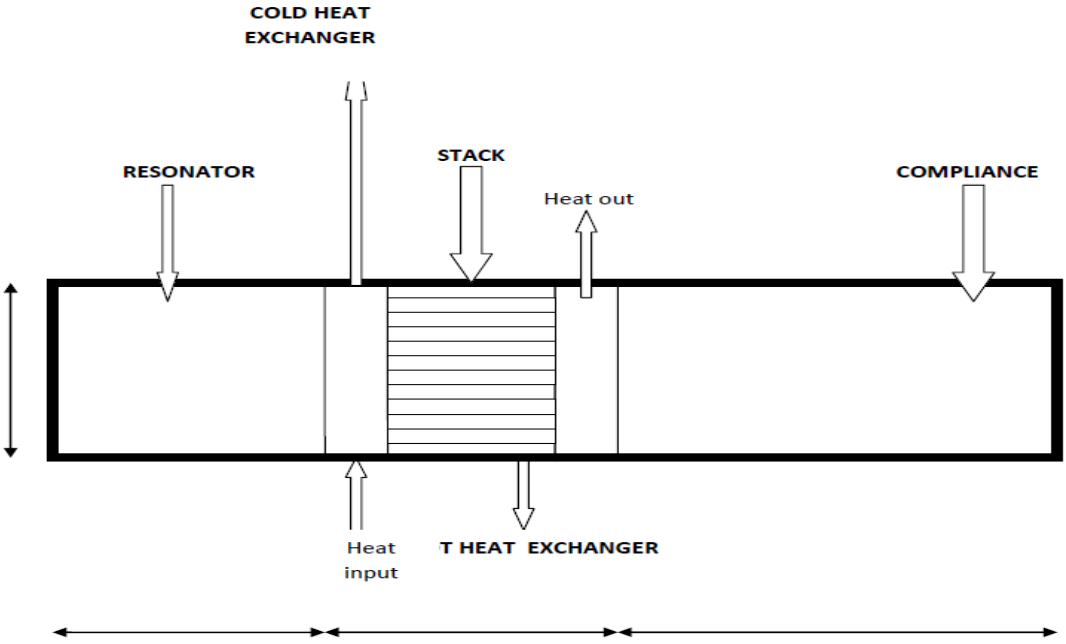
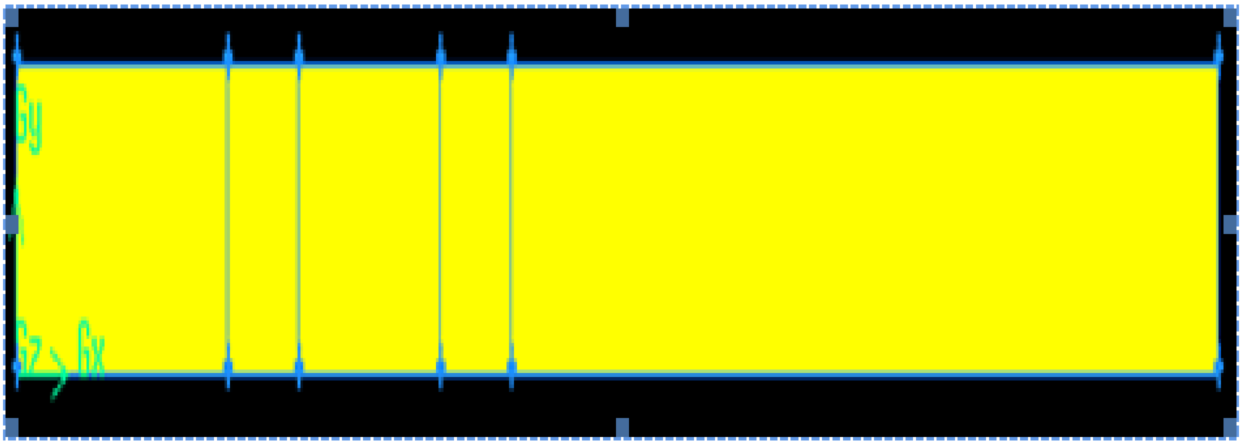


Fig: 2.1 2-D Geometrical Model for Thermo-Acoustic Cryocooler

2.1 GAMBIT MODELING:

Number of cells for the present problems are 180000.



PROCEDURE FOR MODELING

STEP 1:

Specify that the mesh to be created is for use with FLUENT 6.1:

Main Menu > Solver > FLUENT 5/6

Verify this has been done by looking in the *Transcript Window* where you should see. The boundary types that you will be able to select in the third step depends on the solver selected.

STEP 2:

Select vertex as tool geometry

TOOL> GEOMETRY> VOLUME

Vertexes at various points are located. The vertex were created at

A= (0, 0),
B= (0, 12),
C= (30, 12),
D= (40, 12),
E= (60, 12),
F= (70, 12),
G= (170, 12),
H= (170, 0),
J= (70, 0),
K= (60, 0),
L= (40, 0),
M= (30, 0),

TOOL> GEOMETRY >EDGE

Then the edges were created using the vertexes. The vertexes were selected using shift and left clicking on the vertexes. Then the points A,B,C,D,E,F,G,H,J,K,L and M are joined to get the required geometry.

TOOL> GEOMETRY >FACE

Then using the edges the face was formed by selecting all the edges together.

STEP 3: MESH

The element is of Tri and the type is pave.

STEP 4 :(set boundary types)
ZONES > SPECIFY BOUNDARY TYPES.
The edges are selected to assign them particular boundary conditions. The edge AB is the inlet which is of the type presure inlet.
The edge CM is the CHX boundary which is of the type INTERIOR
The edge DL & EK are the stack boundaries of the type INTERIOR.
The edge FJ is the HHX boundary which is of the type INTERIOR.
Rest all are walls.
STEP 5: (Export the mesh and save the session)
FILE > EXPORT > MESH
File name was entered for the file to be exported. Accept was clicked for 2-D.
Gambit session was saved and exit was clicked.
FILE >EXIT

2.2 ANALYSIS IN FLUENT

PROCEDURE:
STEP 1: (GRID)
FILE > READ > CASE
The file channel mesh is selected by clicking on it under files and
Then ok is clicked.
The grid is checked.
GRID > CHECK
The grid was displayed.
DISPLAY > GRID
Grid was copied in ms-word file.
STEP 2 :(Models)
The solver was specified.
DEFINE > MODELS > SOLVER
Solver is segregated
Implicit formulation
Time unsteady
DEFINE > MODEL >ENERGY
Energy equation is clicked on.
DEFINE > MODELS > VISCOUS
The standard k- turbulence model was turned on.
K- model (2-equation) - Standard
No viscosity
STEP 3: (Materials)
The working fluid for the present problem is air with following properties.
Viscosity, μ = 1.7894 x 10-5 kg/ms
Density, r= 1.225 kg/ m3.
Thermal Conductivity, K=0.0242 W/mK
Specific heat, Cp= 1.00643kJ/kg K
Molecular weight= 28.96
STEP 4: (Operating conditions)
Operating pressure= 101.325 KPa
No Gravity.

STEP 5: (Boundary conditions)
DEFINE > BOUNDARY CONDITIONS
Cold heat exchanger:
Walls: adiabatic; material: aluminium
Porous medium:
Porosity: 0.69 ; viscous resistance : 9.433e+09 1/m2; inertial resistance: 76090 1/m; material aluminium; internal fluid : air
Hot heat exchanger:
Walls: isothermal maintaining temperature of 300K; material : aluminium
Porous medium:
Porosity: 0.69; viscous resistance: 9.433e+09 1/m2; inertial resistance: 76090 1/m; material aluminium; internal fluid: air
Compliance:
Wall: adiabatic; material: aluminium
Internal fluid: air
Resonator:
Pressure inlet – pressure defined by UDF generating sinusoid pressure wave
Resonator walls: aluminium
Stack:
Walls: adiabatic; material: aluminium
Porous medium:
Porosity: 0.69; viscous resistance : 9.433e+09 1/m2; inertial resistance: 76090 1/m; material aluminium; internal fluid : air
STEP 6: (Solution)
SOLVE > CONTROLS>SOLUTIONS
All flow, turbulent and energy equation used.
Under relaxation factors
Pressure= 0.2
Density= 1
Body Force= 1
Momentum= 0.4
Turbulence Kinetic energy= 0.8
Turbulence Dissipation Rate= 0.8
SOLVE >INTIALIZE
Click **INIT**
~Initial pressure was chosen to be 15 atm
SOLVE>MONITOR>SURFACE
SOLVE>ITERATE
Time step= 0.005 s Number of Time step= 5000 Maximum number of iteration per time step=20
REPORT>SURFACE INTEGRALS
Temperature at cold heat exchanger, pressure at resonator was noted by taking the area weighted average.
The data was saved.
FILE>WRITE>CASE & DATA
STEP 7: (Displaying the preliminary solution)
Display of filled contours of velocity magnitude
DISPLAY>CONTOURS

~ Velocity was selected and then velocity magnitude in the Drop down list was selected.
~filled under option was selected.
~Display was clicked.

Display of filled contours of temperature

DISPLAY>CONTOURS

~Temperature was selected and then Static temperature in the drop down list was selected..
~filled under option was selected.
~Display was clicked.

Display of filled contours of pressure

DISPLAY>CONTOURS

~ Pressure was selected along various planes
~filled under option was selected.
~Display was clicked.

Display velocity vector.

DISPLAY>VECTOR

~Display was clicked to plot the velocity vectors.

PLOT>XY PLOT

~ Three graphs were plotted.
~ One was Static temperature v/s position, another was static pressure v/s position and the third one was velocity magnitude v/s position.
~ The graphs give the magnitude of each at inlet, hot exit and cold exit.

3. INPUT FOR THE PRESENT PROBLEM

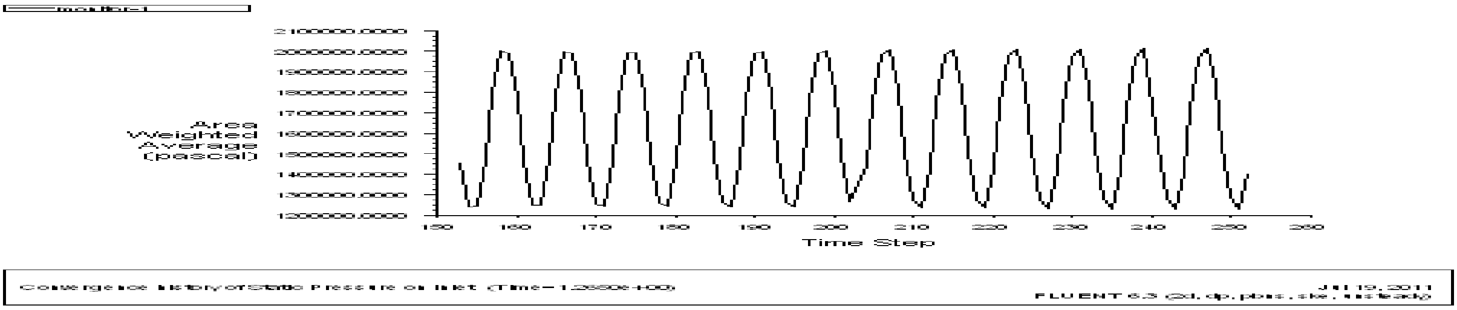


Fig 3. shows the sinusoidal pressure UDF that is fed from the acoustic loud speaker.

CONVERGENCE CRITERIA

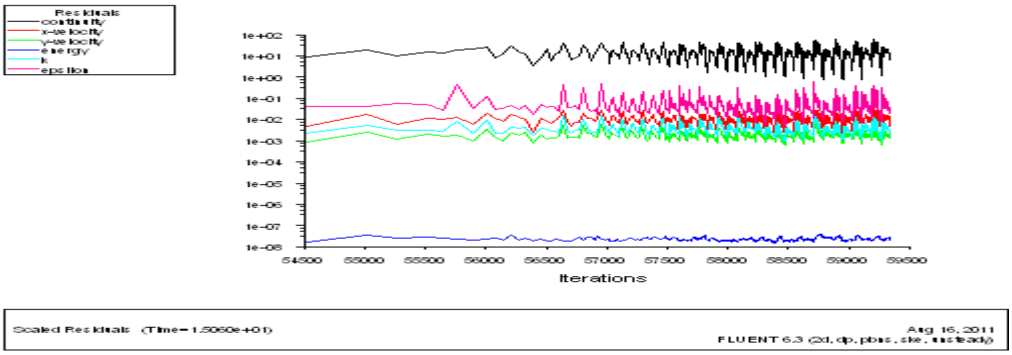


Fig shows the iteration curve. The curve shows convergence of various scaled residuals consisting of continuity, x velocity, y velocity, swirl, energy, K and epsilon.

<u>3. RESULTS AND DISCUSSION</u>

This section gives the insight about the variations pressure and temperature through the Thermo-acoustics pulse tube crycooler for the given acoustic wave input. The problem basically incorporates the porous region for the regenerator. The temperature of the working fluid is 298K whereas the temperatures of the walls are 350K.

3.1 Study of Temperature Profile for the Cryocooler

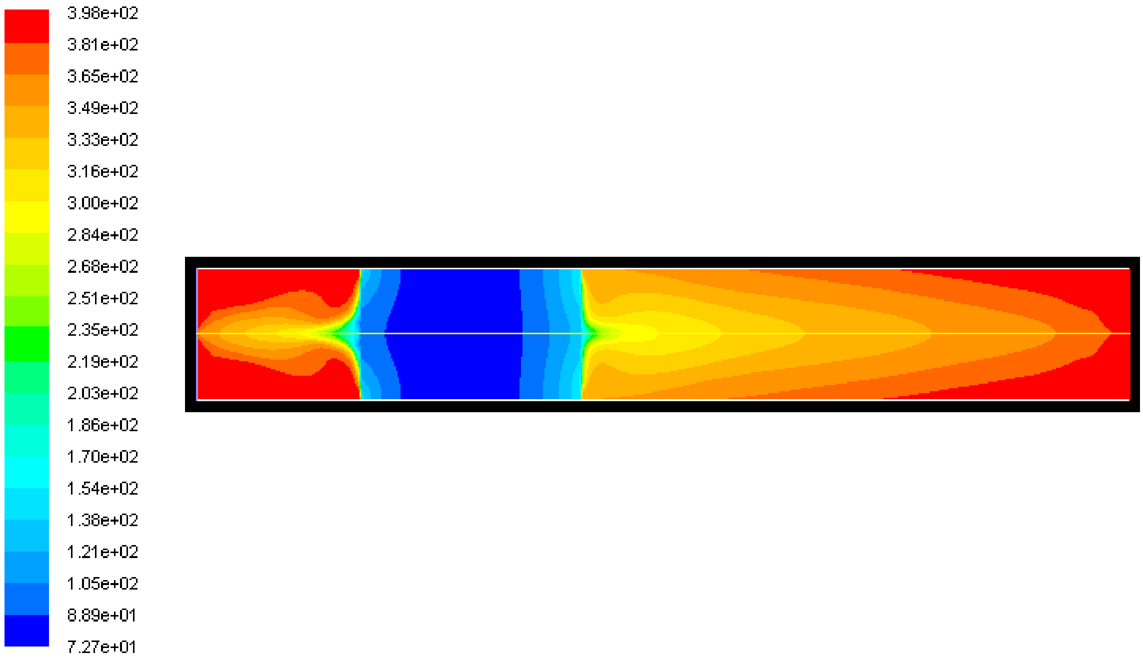


Figure: 3.1 Temperature Profile the Thermo-Acoustic Cryocooler

The sinusoidal pressurized acoustic input having angular frequency of 1100Hz is fed from the load speaker which activates the gas particles. These highly pressurized air packets get thermally charged and due to high input pressure they get compressed and start moving toward the cold heat exchanger. The cold heat exchanger is nothing but a porous region as that of heat exchanger which executes the same function as that of regenerator. The cold heat exchanger basically takes away the heat of the air packets. The air packets on discharging heat to the cold heat exchanger again gets lighter and move back to the inlet of the pulse tube cryocooler. The process of thermal excitation of the air packets is essentially compression process. The light air packets again take the heat from the acoustic waves and again get thermally charged to repeat the same action.

It is important to note that the air fluid which is having a temperature of 298K, as it passes through the cold heat exchanger as well as the regenerator its temperature keeps on decreasing. As the heat is transmitted to hot heat exchanger its temperature keeps on rising .The temperature decreases up to the value 70K.

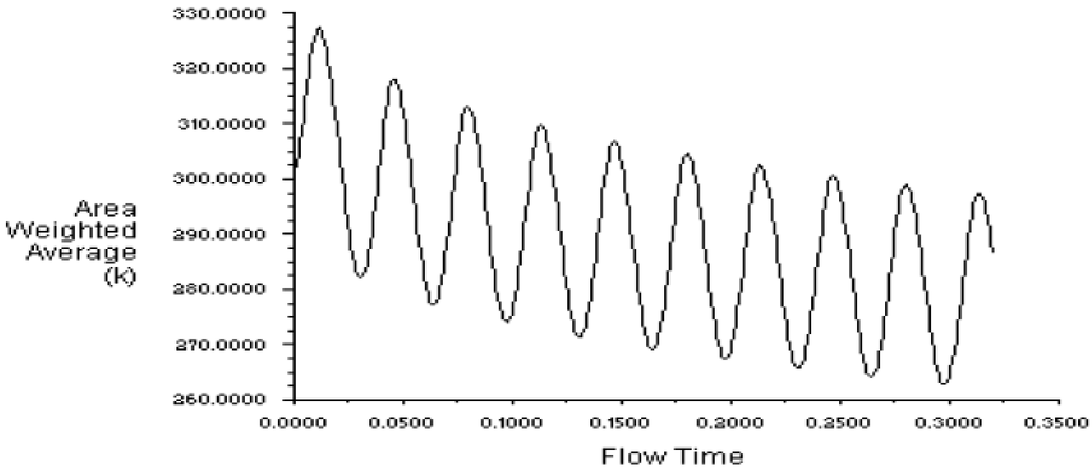


Fig: 3.2 Sinusoidal Behavior of Cryocooler in the Cooler Space

Here it is being observed that with the flow time approaching equals to 0.35s the temperature of the air decreases from 298K to 260K. This depicts the sinusoidal behavior of cryocooler inside the cold space. Similarly it is being observed that the temperature of CHX wall also keeps on decreasing with time. It experiences a fall in air temperature from 300K to 70K.

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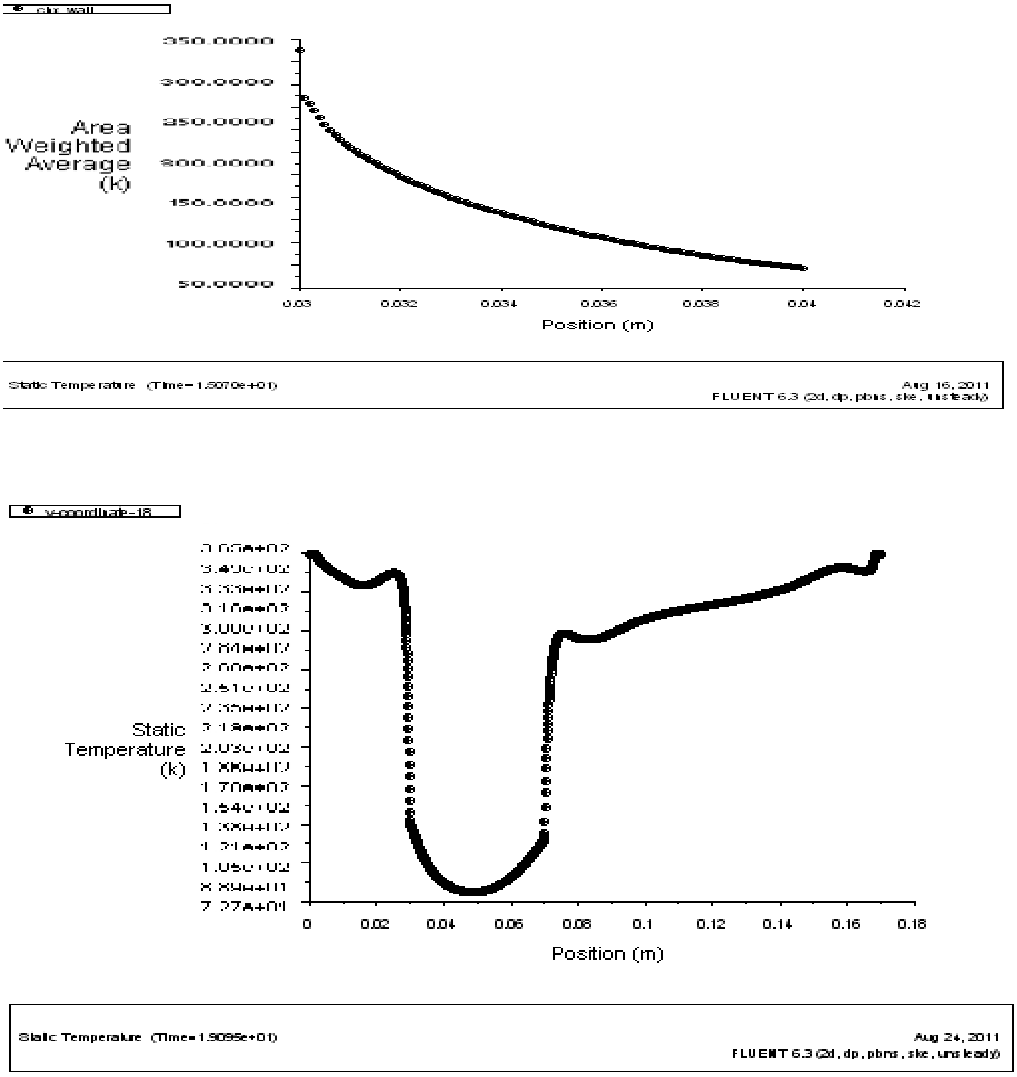


Fig: 3.3 The temperature distribution across the Thermo-Acoustic Cryocooler

It is being seen that the thermally charged air pockets experiences a rise in temperature. The temperature of the air becomes nearly around 350K. As the air approached the cold heat exchanger and passes through the porous region of the two the temperature decreases from 350K to 70K.

3.2 Pressure Distribution Characteristics for the Thermo-Acoustic Cryocooler

The pressure distribution diagram is shown in figure 7.6 which clearly indicates that the pressure is very low at the start. As the thermally charged air packets move towards the cold heat exchanger the pressure starts gradually rising to the compression being developed by the acoustic waves. As the air packets approach the cold heat exchanger, they basically discharges the heat content available with them. The action of the porous medium present in the cold heat exchanger and the regenerator transmits this heat to hot heat exchanger. Part from carrying heat to the hot heat exchanger, the regenerator also brings about sharp decrease in the temperature of the working fluid as it passes through the regenerator. The pressure thereby in the regenerator and cold heat exchanger decreases. Now as the heat propagates through the hot heat exchanger the temperature experiences a sharp rise across the hot heat exchanger. Similarly the pressure across the hot heat exchanger as well as through rest of the region of the cryocooler experiences a sharp rise which is clearly depicted in the figure shown below.

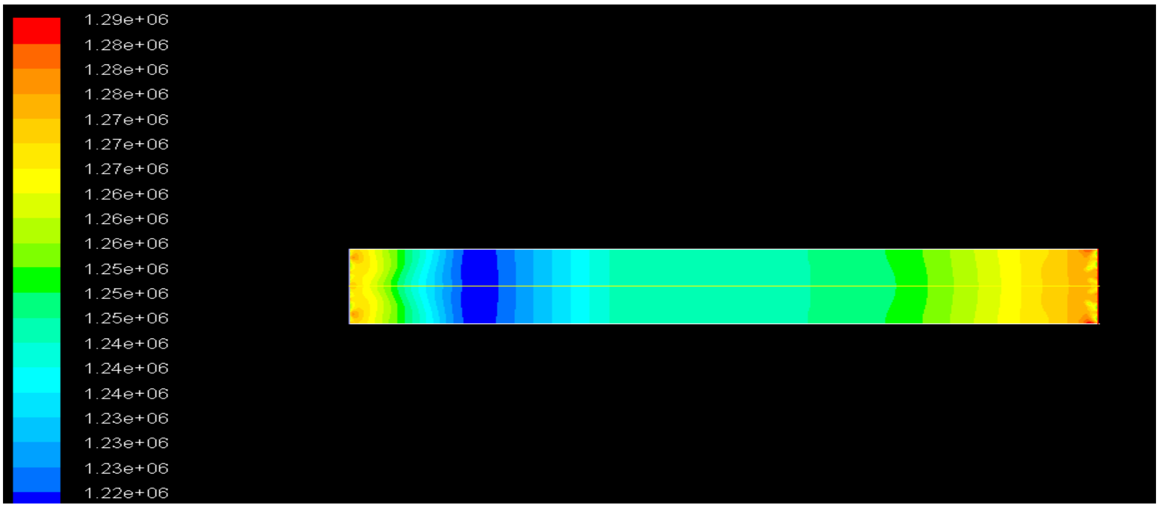
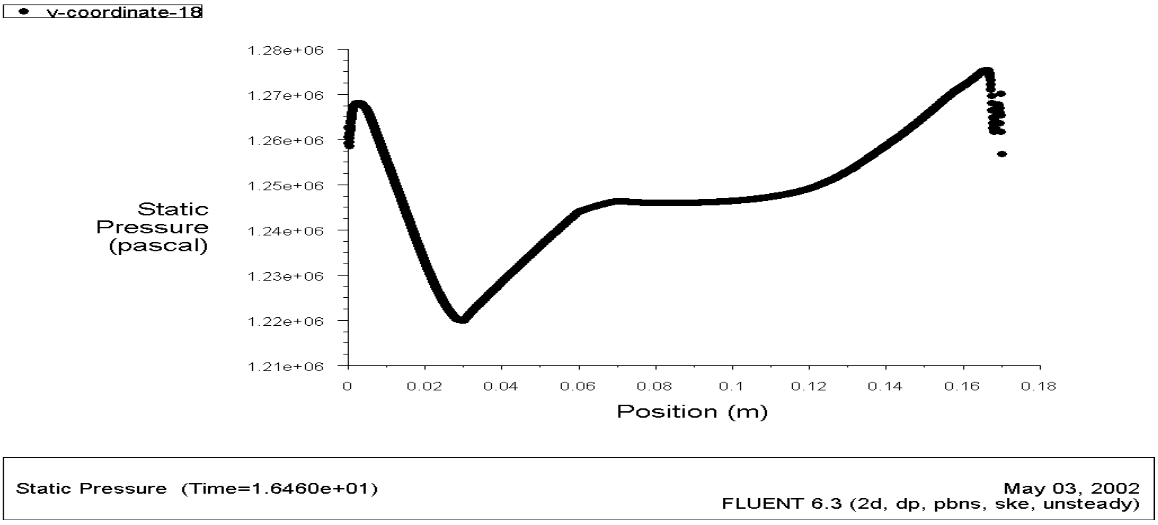


Fig: 3.4 The Pressure Distribution Characteristics across the Thermo-Acoustic Cryocooler



Here also the same thing is being observed that pressure first rise due to the compression been produced by the acoustic waves. We observe the significant rise in the pressure thereafter as the working fluid passes through the cold heat exchanger and regenerator region the pressure keeps on continuously decreasing as the temperature decreases. But due to the action of the hot heat exchanger the heat is emitted to the rest of the region of the cryocooler. There the temperature starts rising, the same trend is observed in the pressure distribution in rest of the cryocooler region.

4. CONCLUSIONS

After interpreting the results and carrying out extensive discussion the following conclusions have been drawn.

1. From the simulations it is clear that that the due to pressurised acoustic wave input the air packets gets thermally charged up to the temperature range of 350K to 398K, due to these highly charged air packets the working fluid develops compression force which stands responsible for the rise in the pressure just before cold heat exchanger.
2. This highly charged air packet discharge the heat to cold heat exchanger and again comes back to inlet of the pulse tube cryocooler to repeat the same cycle. The temperature falls across the regenerator and cold heat exchanger from 350K to 70K.
3. The region before the cold heat exchanger and after the hot heat exchanger is highly pressurised region whereas the region of regenerator is the low pressure and low temperature region.

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