Effect of Vertical Heater on Working of TAE Using CFD Analysis

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Abstract- *The thermoacoustic engines, working fundamental depends on the temperature, velocity and pressure gradients developed during operations. The efficiency of engines depends on the nature of gradient developed, higher the gradient the working efficiency is high. Heater is one of the main element for the development of temperature gradient. This paper focused on the CFD simulation of Thermoacoustic Engine using vertical heater in Hot Heat exchanger. Its effect on the system is simulated using Computational fluid dynamics (CFD) simulations, CFD have become prevalent tools in the numerical modeling of complex thermoacoustic phenomena. The basic problem concerning a CFD simulation of a complete system is the computational cost. In the solving of problem crucial steps are Modeling and simulation. The modeling has done in CATIA VS R19 modelling software. For the different approach (CFD and FEA) different kind of mesh has to be generating in the respective software. In the FEA analysis Eulerian Mesh, ALE Mesh were popular for the solving the TAE problem. The available mesh elements in FLUENT are Prism, Tetragonal, Hexagonal, Triangle and Hexagona. In this report we have studied the effect of vertical heater on thermoacoustic engine. Its effect on pressure, temperature and velocity gradients at 5bar 300˚C.*

Keywords- Thermoacoustic engine, CFD, CFD simulation

I. INTRODUCTION

Thermoacoustics combines thermodynamics, fluid mechanics and sound waves to describe the interactions that exist between heat and sound. Under the right conditions, these interactions can be used to design useful devices that convert heat into sound or pressure waves and vice-versa. A thermoacoustic engine turns pressure waves flowing through a temperature gradient inside a porous solid into sound waves. The work in these sound waves can then be harnessed with suitable conversion devices. Thermoacoustic devices overcome conventional technologies due to: their inherent mechanical simplicity, and the use of environmentally friendly working gases. Guoyao Yu et. al. focuses on using computational fluid dynamics (CFD) to investigate nonlinear phenomena and processes of a 300 Hz standing wave thermoacoustic engine (SWTE). The calculated model was tested in detail, which indicated that the co-axially stacked tube model was suitable for the simulation of SWTEs. Two methods of imposing temperature gradient across the stack were studied, and the processes of mean pressure increasing, pressure wave amplification and saturation were obtained under the thermal boundary condition of applying heating power. [3]. Florian Zink et. al author done CFD analysis of a whole thermoacoustic engine was developed and the influence of a curved resonator on the thermoacoustic effect is discussed. The variation of pressure amplitude and operating frequency serves as metrics in this investigation. It was found that the introduction of curvature affects the pressure amplitude achieved. Severely curved resonators also exhibited a variation in operating frequency.[4]

II. WORKING CONDITION

The temperature of heater is maintained at T=300°C. Therefore hot wall temperature is about 300°C, ambient temperature is taken as Tamb=25°C. The pressure applied is about P=5bar uniformly and continuous. The other two walls, i.e. top and bottom are considered to adiabatic walls i.e. heat flux q=0. Rayleigh number calculation based on dimension of domain and assuming constant properties.

III. CFD MODELING

The thermodynamic processes were simulated using a two-dimensional numerical solution for the compressible Navier–Stokes equations, Energy equations. The boundary condition were derived from experimental data. From the simulations, features of the flow field such as nonlinear vortex generation around the regenerator and heat-exchanger plates were observed that were not present in the analytical solutions. Furthermore, the temperature oscillations were obtained around regenerator plates, and the operating mechanism of a looped-tube travelling-wave thermoacoustic engine was characterized both qualitatively and quantitatively. The CFD tool was validated by obtaining good agreement when comparing results with those from experimental data and analytical solutions. As a result, it was effective in predicting actual flow behaviours in a travelling-wave thermoacoustic engine.

Assumptions:

1. Model considered as steady state problem.
2. The Flow of the fluid is taken as Transient Flow.
3. Assumed no radiation losses from the surface.
4. Taken Constant Shear stress.
5. Fluid is considered as Non Newtonian, Viscous Plastic Material, Incompressible , single phase fluid.
6. Heat generation rate is taken as constant rate.

Creation of the Model:

For solving the fluid flow problems to know velocity at each location in the fluid field and temperature distribution in the fluid we need to solve Continuity, Momentum and energy equations. These equations will solve at every mesh cell. These equations are given below.

Continuity equation:

In fluid dynamics, the continuity equation is an expression of conservation of mass. In (vector) differential form, it is written as

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0.$$

where ρ is density, t is time, and $\vec{u}$ is fluid velocity. In cartesian tensor notation, it is written as

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = 0.$$

For incompressible flow, the density drops out, and the resulting equation is

$$\frac{\partial u_j}{\partial x_j} = 0$$

in tensor form or

$$\nabla \cdot \vec{u} = 0$$

in vector form. The left-hand side is the divergence of velocity, and it is sometimes said that an incompressible flow is divergence free.

$$\nabla.(\rho\vec{v}) = 0 ------(1)$$

Momentum Equation:

$$\frac{\partial(\rho\vec{v})}{\partial t} + \nabla.(\rho\vec{v}\vec{v}) = -\nabla P + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F} ----- (2)$$

where$P$ is the static pressure, $\bar{\bar{\tau}}$ is the stress tensor, and $\rho\vec{g}$ and $\vec{F}$ are the gravitational body force and external body forces (for example, that arise from interaction with the dispersed phase), respectively also contains other model dependent source terms such as porous-media and user-defined sources.

The model is considered for Steady State problem, Constant pressure, No Gravity forces, No External Sources.

Hence the final equation becomes,

$$\nabla.(\rho\vec{v}\vec{v}) = \nabla.(\bar{\bar{\tau}})$$

Where stress tensor $\bar{\bar{\tau}}$ given by,

$$\bar{\bar{\tau}} = \mu\left[(\nabla\vec{v} + \nabla\vec{v}^{T}) - \frac{2}{3}\nabla.\vec{v}I\right]$$

Where μ is the molecular viscosity,I is the unit tensor, and the second term on the right hand side is the effect of volume dilation.

Energy Equation:

To calculate heat transfer in the material energy equation has to be solved. The energy equation is

$$\rho c\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + S_i$$

Here, c is the specific heat of material, k is the thermal conductivity of material, and T is the temperature of fluid.$S_i$is the heat generated due to the viscous dissipation.

$$S_i = f_m \mu \emptyset$$

$$\emptyset = 2\left(\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right) + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)^2 --(7)$$

$f_m$is an arbitrary constant that indicates the extent of atomic mixing in the system. The value of f_m will tend to 1 for a well-mixed system in the atomic scale. In systems where the grains remain largely intact, the value of f_m will be very small.

IV. SIMULATION RESULTS

The results are plotted at working condition. The working condition is considered at 5bar and 300˚C. Considering air, helium and hydrogen as working fluid.Pressure distribution is shown in below image. It is a contours of static pressure distribution. Different colours shows, different pressure distribution range. Red colour indicates maximum and with blue colour it shows least. At inlet there is least pressure as we can see in fig below. The pressure starts increasing gradually as soon as it enters the hot heat exchanger and there is decrease in pressure as it leaves the hot heat exchanger.

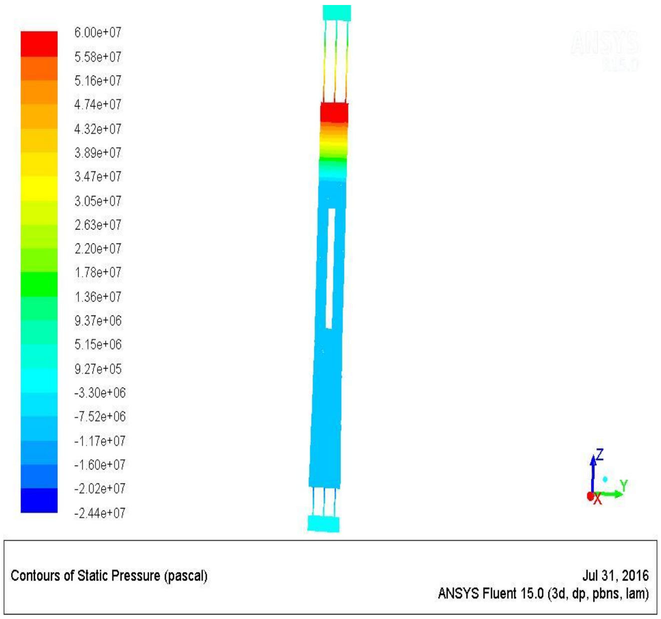


Fig.1Pressure distribution at 5bar 300˚C

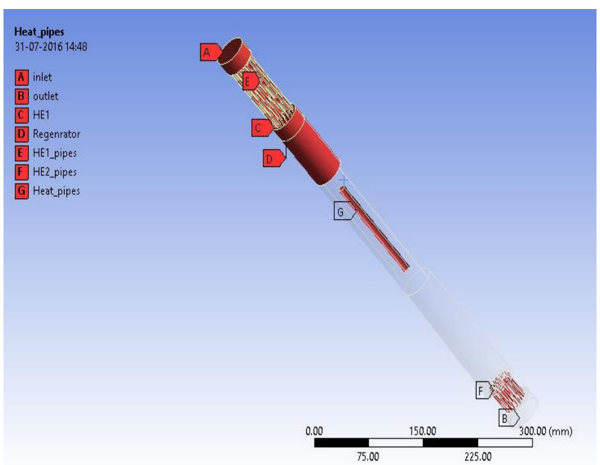


Fig.2 Schematic diagram showing various parts in fluent

The above is schematic drawing showing various parts in current setup. Inlet and outlet ports, heat exchangers, regenerator is shown in fig.

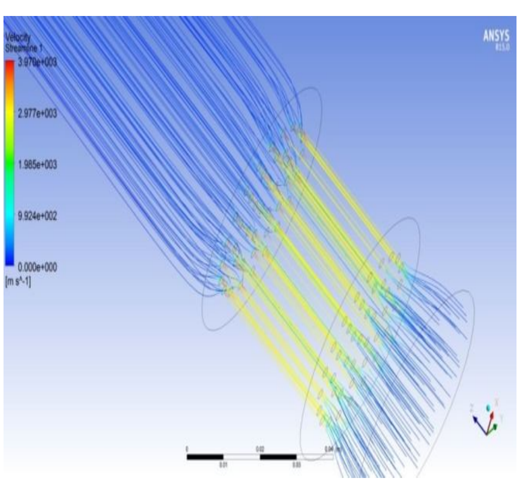


Fig.3 Velocity streamlines at inlet

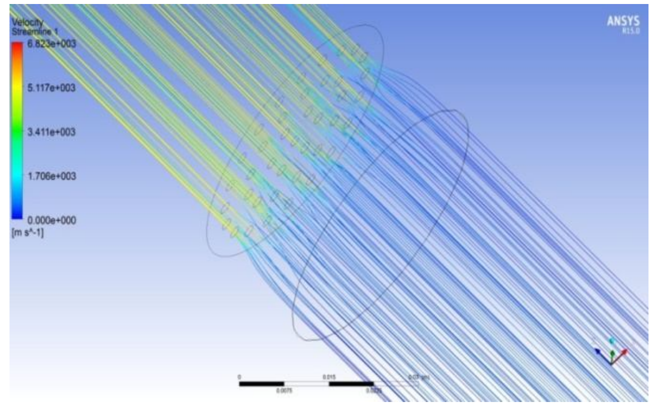


Fig.3 Velocity streamline at Regenerator inlet

These are the velocity streamline at entry and exit point in the HHX. The streamlines are obtained at 5bar 300˚C .As we can see from the simulation obtained at 5bar and 300˚C. the pressure at inlet is as per input given as fluid progresses there is sudden fall in pressure.

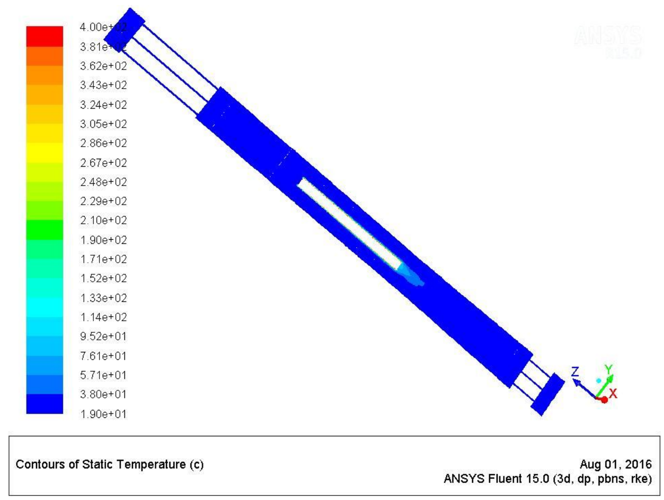


Fig.4 Temperature distribution at 5bar 300˚C

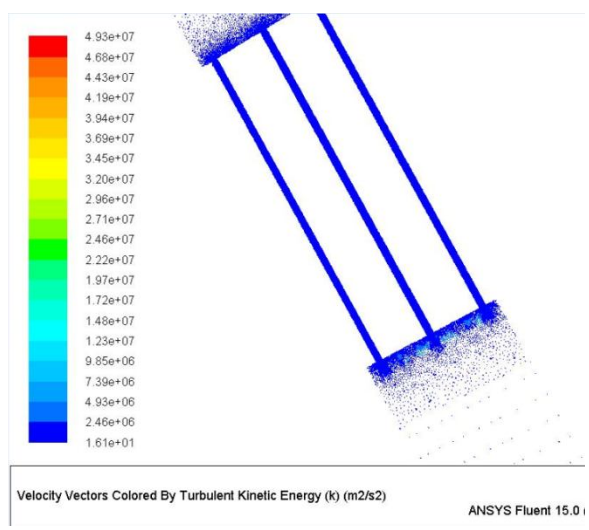


Fig.5Temperature distribution at 5bar 300˚C

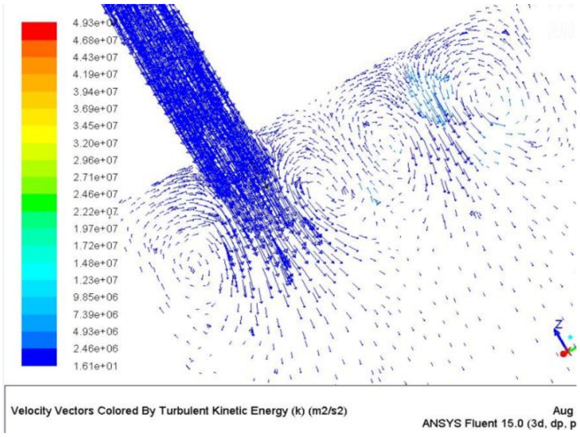
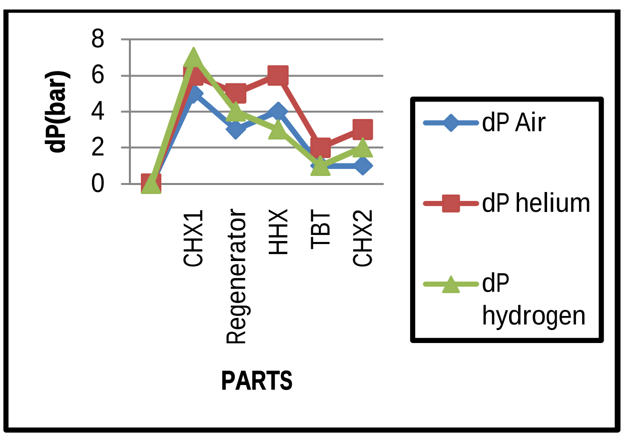


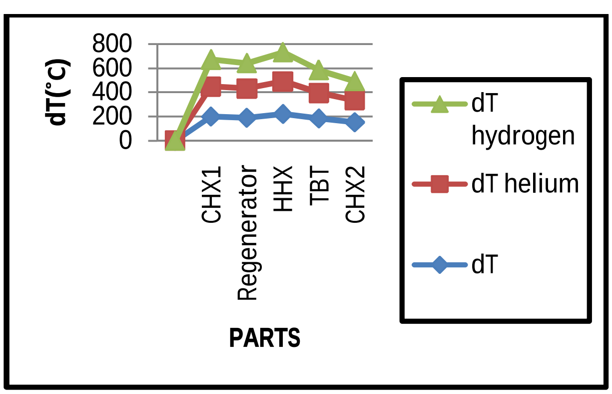
Fig.6 Turbulence created during analyses at entry nodes of pipes

V. GRAPHS

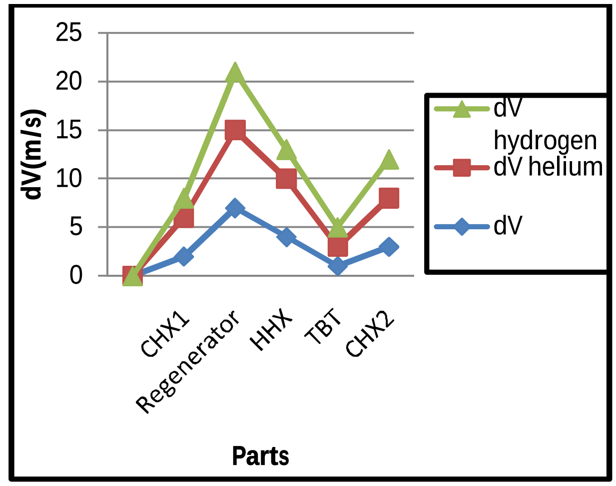
Graphs are plotted at working condition at 5bar 300˚C, the graphs are plotted according to results obtained during simulation. The result obtained from graphs are the deviation in temperature, velocity and pressure across each parts in the setup, for CHX1,REGENERATOR, HEATER, TBT, CHX2



Graph1 Pressure distribution Graph at 5bar 300˚C



Graph2 Temperature distribution Graph at 5bar 300˚C



Graph1 Velocity distribution Graph at 5bar 300˚C

VI. CONCLUSIONS

The main purpose of this report is to study the effect of heater on thermoacoustic engine. The CFD results clearly show strong nonlinear effects at high pressure amplitudes, high velocities. The use of vertical heater is making obstruction to the flow of fluids, causing sudden drop in pressure and velocities which is not useful for getting efficient system. The drop in pressure varies with medium. As per analyses at 5bar 300˚C there is sudden variation in temperature, pressure, velocities as per result table above.

We think that CFD may prove to be a useful tool in the study of thermoacoustic phenomena that cannot be captured by today's one-dimensional linear codes. In the near future, the present CFD model will be extended to include temperature-dependent material properties, finite heat transfer in the regenerator and the heat exchangers, losses in the resonator, and the effect of gravity. In addition, higher average pressures and different working media will be used. And, last but not least, the CFD model should be validated against experimental data to obtain a design tool for a real thermoacoustic system.

APPENDIX

Journal Paper submitted
Sumeet B Turup, Prof. M. K. Gaikwad," Design and Devepopment of thermoacoustic engine", MECHPG CON2016.

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