CFD ANALYSIS OF VORTEX TUBE REFRIGERATION (RANQUE-HILSCH REFRIGERATOR)

Objective

To assess the flow pattern of compresssed air inside the swirl chamber of a vortex tube and predict its performance vide air temperature obtained at hot and cold outlets.

Challenges

- Choosing appropriate solver schemes since flow inside the swirl chamber is expected to be highly compressible.
- To understand the outer and inner flow stream pattern inside the swirl chamber.

Description

Vortex tube, commonly known as Ranque-Hilsch vortex tube is a non-conventional type of refrigeration system used to seperate hot and cold gas inside a swirl chamber when pressurized gas is injected tangentially from an injecting nozzle. The Hot and cold streams temperature at the exit of the tube is controlled by outlet pressure, set by an adjustable conical control valve placed near hot outlet.

Geometry

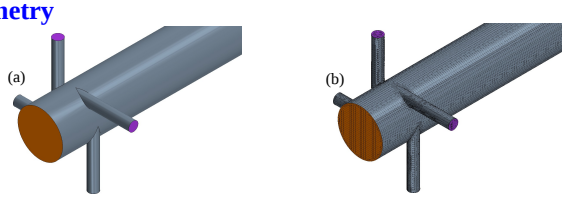


Fig (I) (a)Vortex tube- CAD model (b) Discretized Model

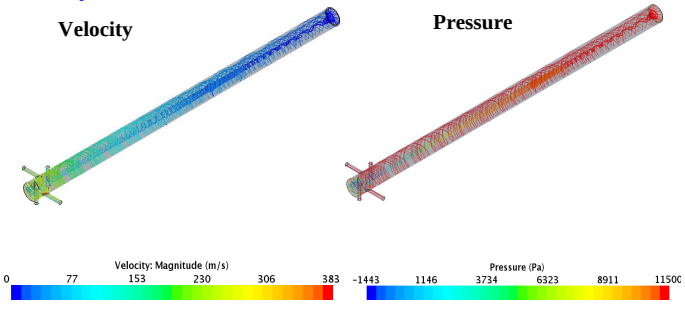
Approach

In this case study a vortex tube with four entry nozzle of dimensions, L/D=21 hot outlet=2 mm, cold outlet=9.525 mm and inlet nozzle diameter= 4 mm was analysed. Air was considered to be the working fluid.

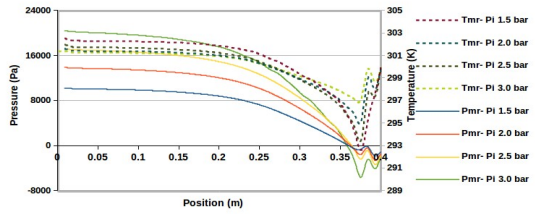
Structured mesh was used to discretize the model into finite volume representation.The problem was solved with 3D pressure based solver with K-epsilon (RANS) for modelling turbulence.Density variation in the gas due to the compressible nature of the flow was computed through ideal gas equation.

The performance of four entry nozzle vortex tube was assessed for various inlet ($\mathbf{P_i}$) and hot outlet pressure ($\mathbf{P_h}$) conditions. The results of hot and cold outlet temperature obtained through the CFD analysis is summarized in plot III and IV.

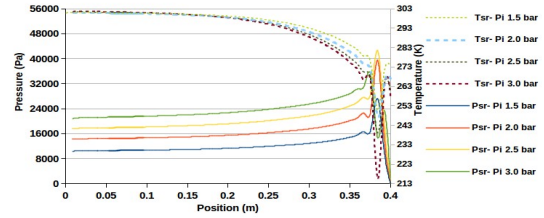
Velocity and Pressure streamlines



Pressure & Temperature Distribution in Tube

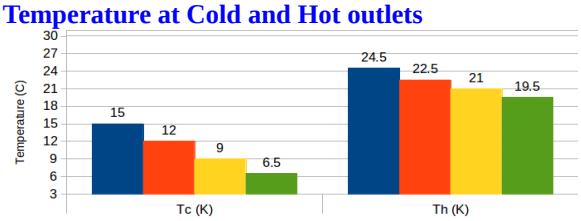


Plot (I) Temperature (T_{mr}), Pressure (P_{mr}) plot- Vortex tube middle region @P_h = 0.045 bar



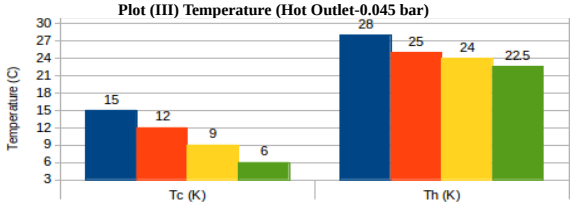
Plot (II) Temperature (T_{sr}), Pressure (P_{sr}) plot-Vortex tube outer shell region @ P_h = 0.045 bar

Temperature at Cold and Hot outlets



1.5 bar 2 bar 2.5 bar 3 bar

Plot (III) Temperature (Hot Outlet-0.045 bar)



1.5 bar 2 bar 2.5 bar 3 bar

Plot (IV) Temperature (Hot Outlet-0.09 bar)

Conclusion

The inlet nozzle configuration and operating parameters such as the inlet and outlet pressure of working fluid plays a vital role in determining the hot and cold exit stream temperature in a vortex tube. Though the **predicted CoP of the design considered in this case study is 18%**, vortex tube refrigeration system can be used as an alternate and eco-friendly refrigeration system for applications with less demand.

Benefits

- No moving parts
- Air can be used as refrigerant.
- Cold and hot gas stream can be separated simultaneously.

Applications

- Natural gas processing
- Cooling of cutting tools (Lathes and Mills)

Ref.:-Numerical analysis of curvature effect on Ranque- Hilsch vortex tube refrigerators- Masoud Bovand et al.,: Yr2013

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