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CFD ANALYSIS OF STRAIGHT AND FLARED VORTEX TUBE

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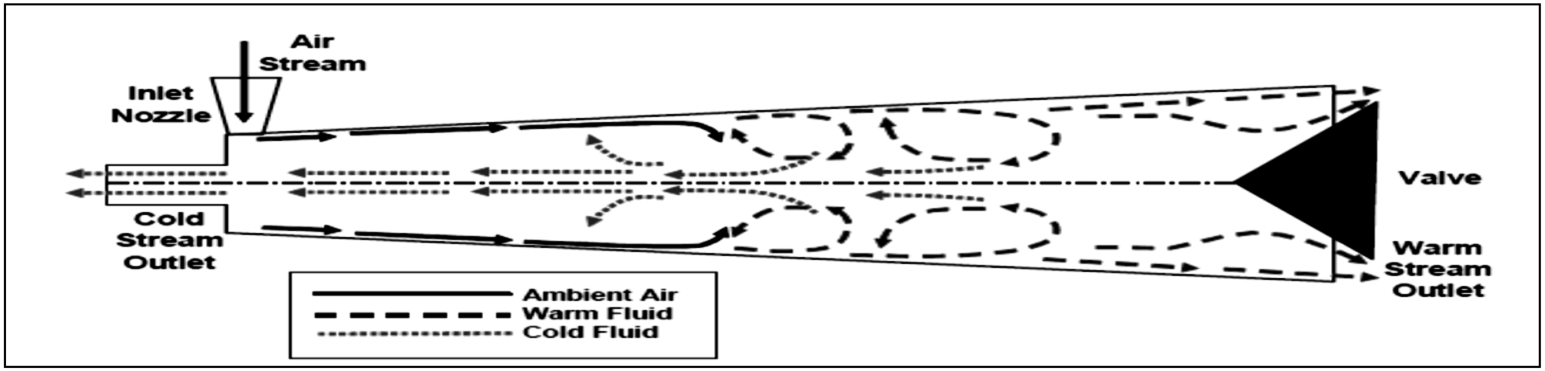
SEPARATION SCIENCE LAB

OUTLINE

Introduction

- Vortex Tube (VT) is a simple and compact device
  - Used as heat pump as well as refrigeration device
- It is extensively used in industries for small scale cooling or heating application
  - Cooling of cutting tools
  - Cooling and dehumidification of food products
  - Electrical cabinets cooling



Counterflow vortex tube with flared hot tube (Crocker et al. 2003)

Approach Toward the Problem

- VT has a simple geometry and complex flow
  - Difficult to understand clearly the energy separation phenomenon
- Ranque (1933) proposed that expansion and compression are the reasons for energy separation in VT
- The effect of inner friction is also an important factor with expansion and compression for energy separation (Hilsch, 1947)
- Aljuwayhel et al. (2004) and Behara et al. (2005) evaluated the energy transfer to explain the temperature
- Evaluation of heat and work transfer in both straight and flared VT was done to compare the performance of VTs using CFD based software

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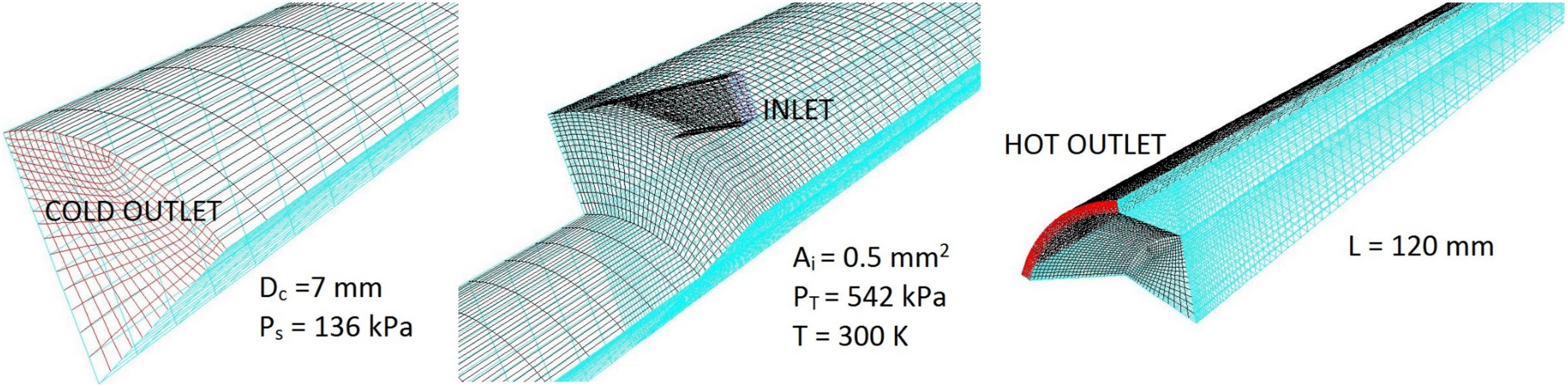
CFD Modelling

- CFD based Ansys Fluent 14.0 software was used
- Standard k-ε Turbulence model considering R-K real gas equation of state was used
- Divergence angle of Flared (Divergent) VT is 2°



- To remove error due to coarseness, 160,000 number of CV cells are used for mesh generation

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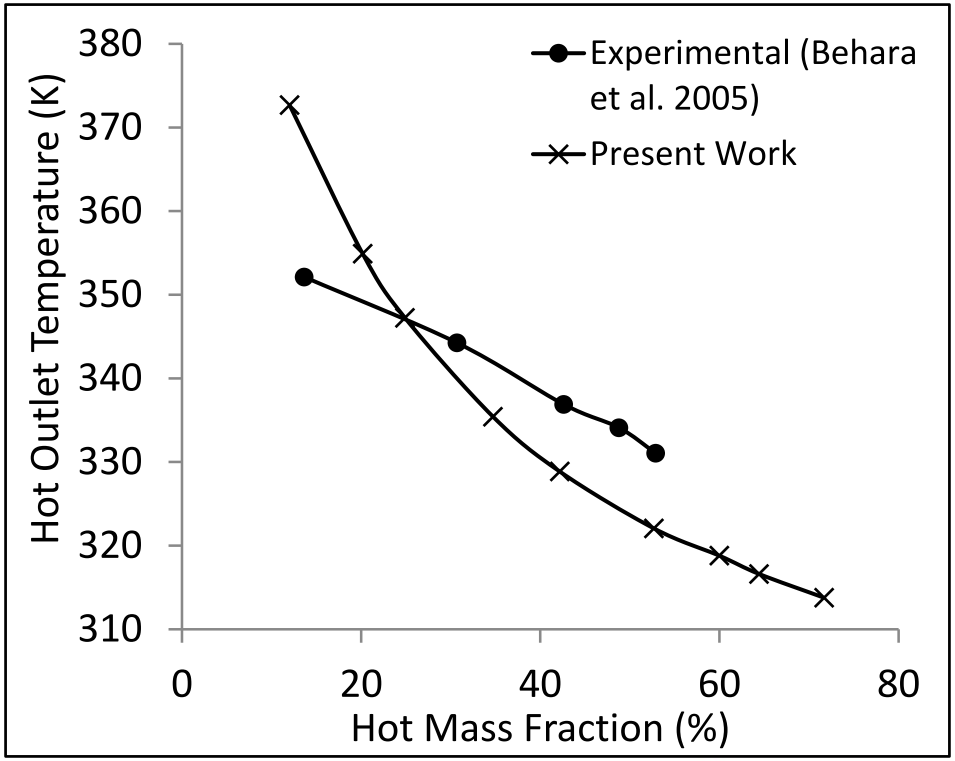
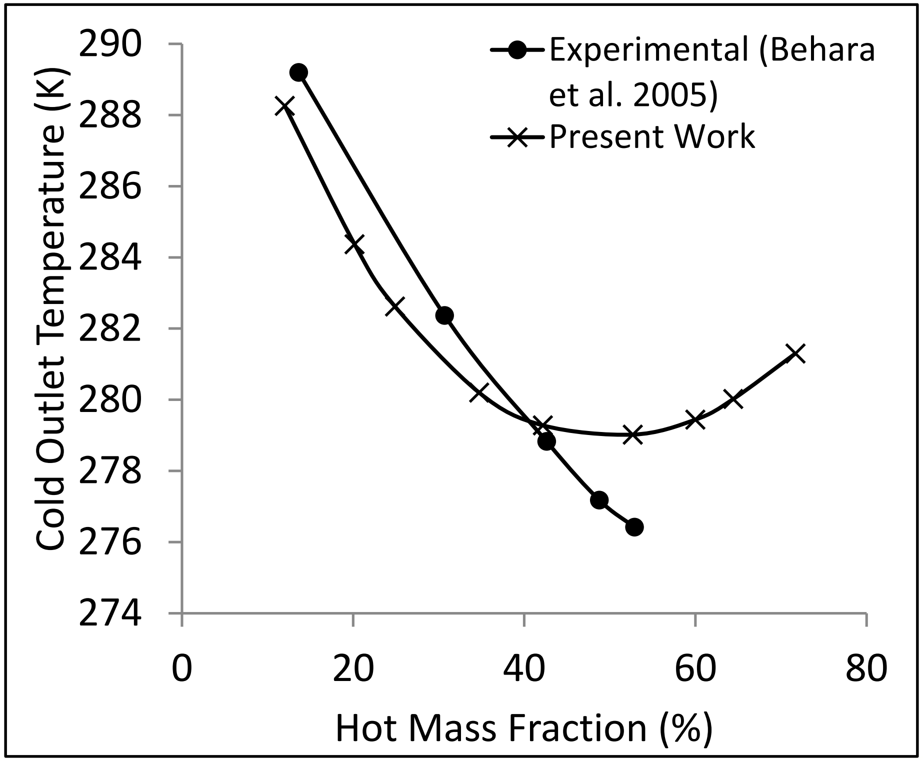
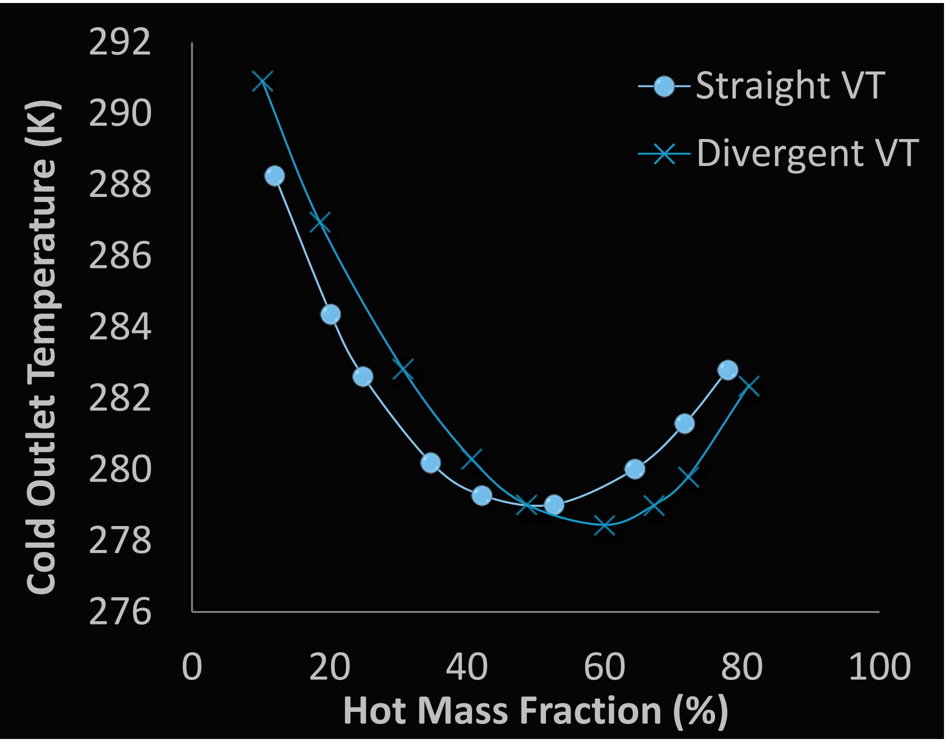
Validation of Model

- Validate with experimental data available in literature
- Maximum deviation from experimental results is under 5 %

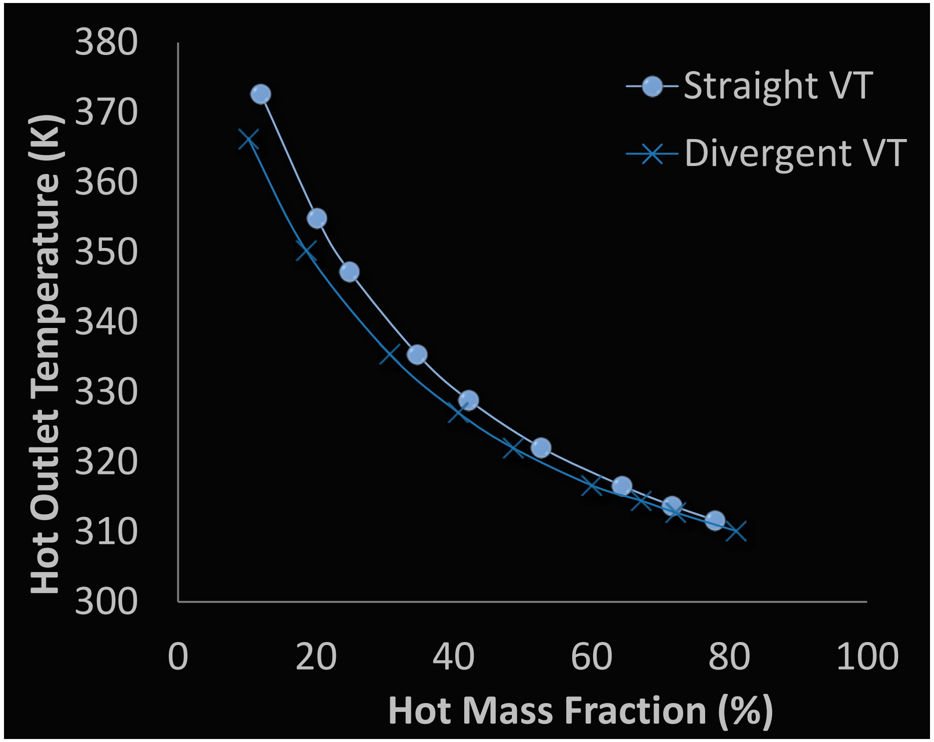




Temperature Separation in VTs

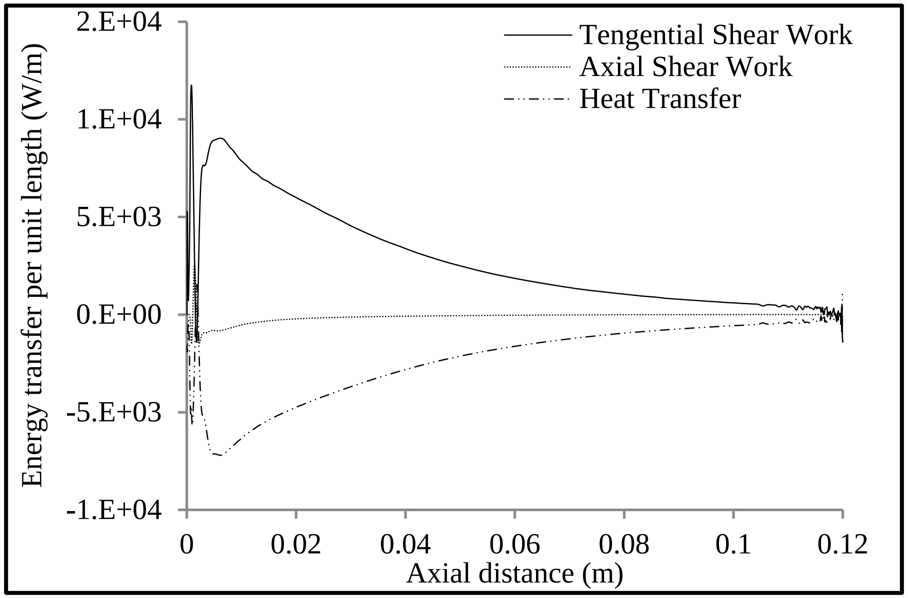


Cold Outlet Temperature



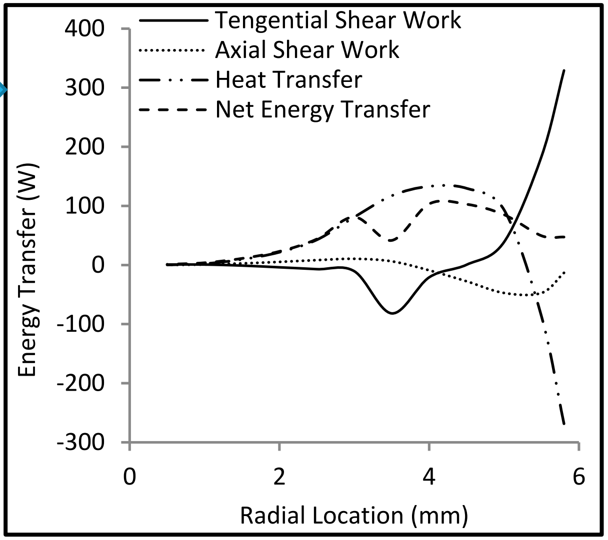
Hot Outlet Temperature

Energy Transfer in Both VTs

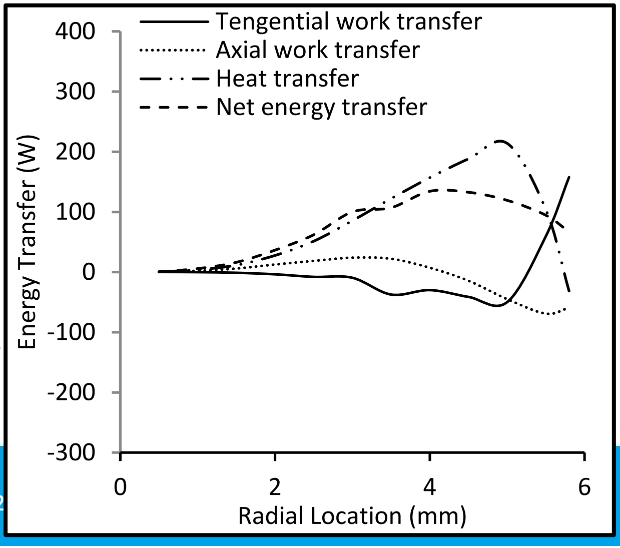


Energy transfer along the axial length at a radial location of 0.005 m

Straight VT



Flared VT



Performance Characteristics of VTs

STRAIGHT VT	FLARED VT
Maximum COP as Refrigeration device is 0.110	Maximum COP as Refrigeration device is 0.100
Maximum COP as Heat pump is 0.104	Maximum COP as Heat pump is 0.093
Maximum Efficiency is 21.43 %	Maximum Efficiency is 22.02 %

Conclusions

- The tangential shear work has an important contribution in energy separation. The heat is transferred from cold fluid to hot fluid.
- Flared tube performs better than a straight tube for a hot mass fraction above 0.5.
- Energy transfer along the axial direction in flared VT is more than straight VT.
- Maximum COP as refrigerator and heat pump is observed to be 0.11 and 0.10, respectively in a straight VT and maximum efficiency is observed to be 22.02% in a flared VT.

Q & A

Thank you

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References

Important Formulas

Sensible heat transfer rate per unit length:

$$\frac{\delta q}{\delta z} = 6 \times \int_0^{\pi/6} -K_{eff} . \frac{\partial T_s}{\partial r} . r . d\theta$$

Tangential shear work transfer rate per unit length:

$$\frac{\delta w_\theta}{\delta z} = 6 \times \int_0^{\pi/6} -\mu_{eff} . \left(\frac{\partial w}{\partial r} - \frac{w}{r}\right) . w . r . d\theta$$

Axial shear work transfer rate per unit length:

$$\frac{\delta w_z}{\delta z} = 6 \times \int_0^{\pi/6} -\mu_{eff} . \frac{\partial u}{\partial r} . u . r . d\theta$$

COP as Refrigeration device

$$COP_{rf} = \frac{\gamma}{\gamma - 1} \frac{(1 - \dot{m}_h)(T_i - T_c)}{T_i \ln\frac{P_i}{P_c}}$$

COP as Heat Pump

$$COP_{hp} = \frac{\gamma}{\gamma - 1} \frac{\dot{m}_h (T_h - T_i)}{T_i \ln\frac{P_i}{P_c}}$$

Efficiency

$$\eta_{is} = \frac{T_i - T_c}{T_i \left(1 - (P_a/P_i)^{\left(\frac{\gamma - 1}{\gamma}\right)}\right)}$$