Experimental And Theoretical Investigation To Study Pressure Drop in Regenerators

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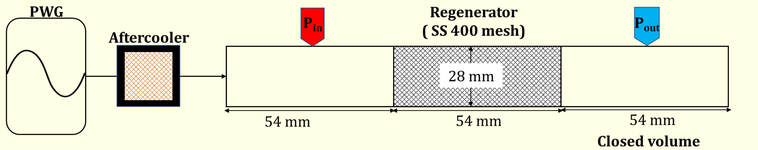
Abstract

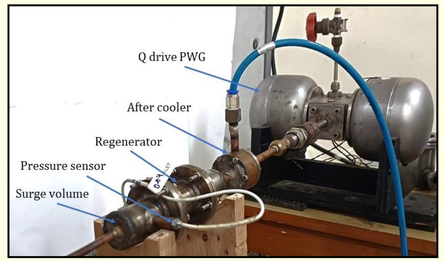
Regenerator is an essential part of Pulse tube cryocoolers, The study focuses on SS 400 mesh with 0.69 porosity and diameter of 25 μm.

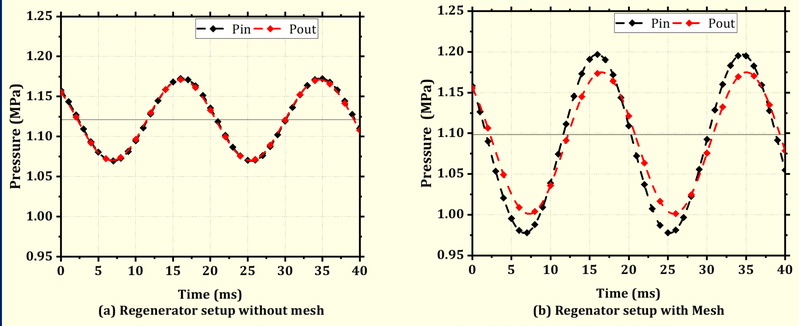
Hydrodynamic parameters namely Darcy permeability (α) and Forchheimer coefficient (C2) of the mesh material are obtained from a separate experimental setup at 300 K.

These parameters are used as input parameters in the numerical simulation to determine the pressure drop across the inline pulse tube cryocooler, and these results are compared with the experimental pressure drop in the Pulse tube Cryocooler.

Regenerator Setup



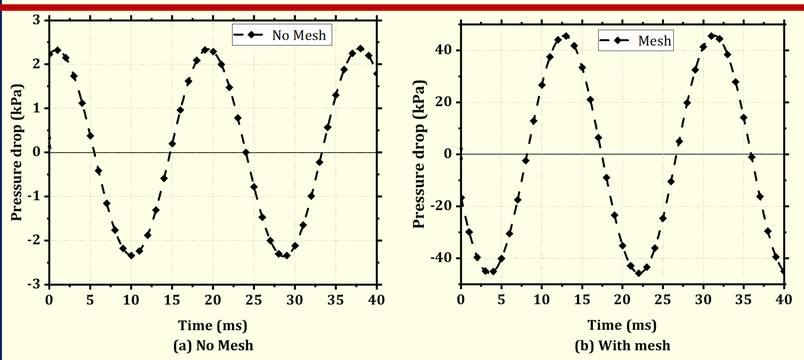




- Charge pressure difference between mesh and no mesh is 0.022MPa
- $\left(P_{in\,avg} - P_{out\,avg}\right)_{no\,mesh} = 0.4\ kPa$
- $\left(P_{in\,avg} - P_{out\,avg}\right)_{mesh} = 5.9\ kPa$
- $P_{in\,avg\,mesh} = 1.098\ MPa$
- $P_{in\,avg\,mesh} = 1.092\ MPa$

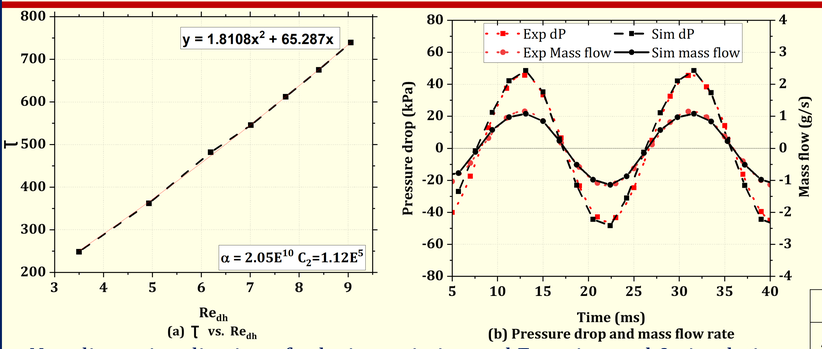
Net Pressure drop = $(\Delta P)_{\text{mesh}}$ - $(\Delta P)_{\text{no mesh}}$

Experimental pressure variation for 50 W, 54 Hz, 300K



- The net peak pressure drop is the amplitude of peak pressure drop curve.
- Amplitudes of net pressure drop
  Without mesh = 2.4 kPa
  With mesh = 46 kPa
- Net Peak Pressure Drop = 43.6 kPa
- Net peak pressure drop at varying input power is obtained.

Experimental Peak Pressure drop for 50 W, 54 Hz, 300K



- $\dot{m} = \frac{V}{\gamma RT}\frac{dP}{dt}$, $u_{peak} = \frac{\dot{m}_{peak}}{A_f \rho}$
- Momentum Source term in Ansys Fluent,

$$S_i = -\left(\frac{\mu}{\alpha} v_i + C_2 \frac{1}{2}\rho |v| v_i\right)$$

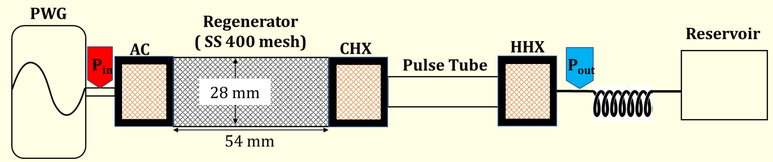
$$\frac{\Delta P}{L}\frac{\rho d_h^3}{\mu^2} = \frac{\epsilon d_h^2}{\alpha} Re_{dh} + \frac{\epsilon^2 C_2 d_h Re_{dh}^2}{2}$$

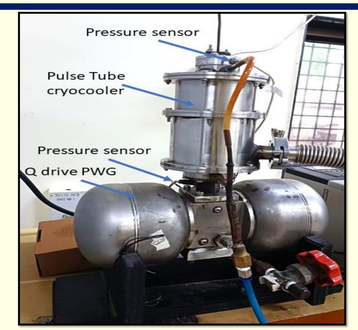
$$\tau = A Re_{dh} + B Re_{dh}^2$$

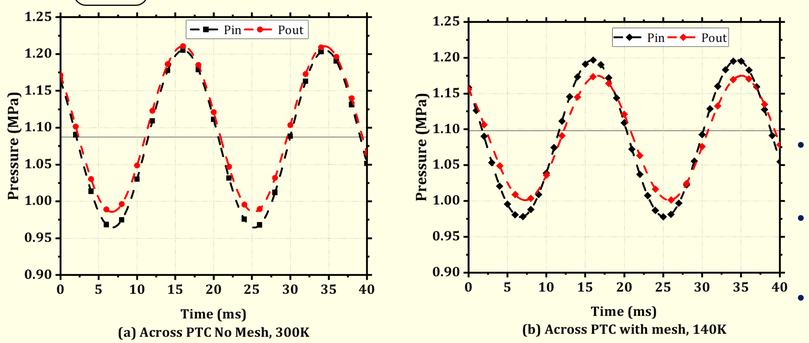
	Experiment	Simulation	% Error
ΔP_{peak} (kPa)	45.7	48.4	6
$\dot{m}_{peak}$ (g/s)	1.16	1.08	7

Non dimensionalisation of velocity variation and Experimental & simulation results comparison of regenerator setup

Inline Pulse Tube Cryocooler setup



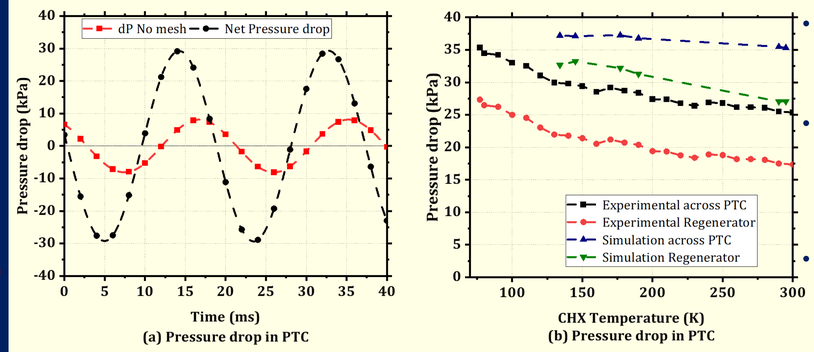




- Average charge Pressure difference with & without mesh = 0.011MPa
- $\left(P_{in\,avg} - P_{out\,avg}\right)_{no\,mesh} = 13.5\ kPa$
  (CHX, HHX, after-cooler all at 300 K)
- $\left(P_{in\,avg} - P_{out\,avg}\right)_{mesh} = 7.8$ kPa
  (at 140 K CHX)

PTC setup pressure variation 50 W 54 Hz, 300K

- $\Delta P_{net\,peak} = \Delta P_{peak,\,mesh\,@\,CHX\,Temp} - \Delta P_{peak,\,no\,mesh\,at\,300K}$
- This isolates the pressure drop caused by the regenerator mesh.



- From 290 K to 190 K increases experimental pressure drop by 11% and simulated pressure drop by 4%.
- Simulation has pressure boundary conditions, simplifying the model by neglecting transient effects of mechanical motion of the piston-cylinder assembly.
- Simulated pressure drops consistently exceed experimental values, with deviation decreasing from 38% at 300 K to 20% at 140 K

PTC setup pressure variation 50 W 54 Hz, 300K

Conclusions:

- The study focuses on SS 400 regenerator material in cryocoolers, analyzing the pressure drop phenomenon.
- Hydrodynamic parameters α (Darcy permeability)= $2.05E^{10}$ and C_2 (Forchheimer coefficient)=$1.12E^5$ are determined at 300 K and compared with numerical simulations show reasonably good agreement.
- However, For the Pulse Tube Cryocooler (PTC), the simulations over predicts the pressure drop. This is due to the calculation of hydrodynamic parameters at isothermal conditions. This needs further investigation.

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