C3PoE - 427

Comparison of Simulated and Experimental Results of Temperature Distribution in a Closed Thermosyphon Cooling System

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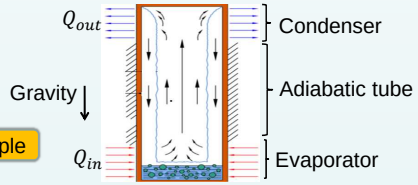
Introduction

Application of HTS bulk or conductor materials to machinery such as motors and generators can make them lighter, compact and more efficient. An HTS motor or generator differs from a conventional one in that it would have an HTS field coil or bulk that is cooled by a cryogenic cooling system. When employed to cool HTS motors and generators, thermosyphon (TS) cooling exhibits high heat transfer rate and near-isothermal operation. It also has simple structure. In this work, an experimental study of neon TS was conducted. Temperature distribution in a TS is important in characterising its performance. So a thermal model was developed to estimate the temperature distribution of the thermosyphon components, especially the evaporator.

Thermosyphon Operating Principle



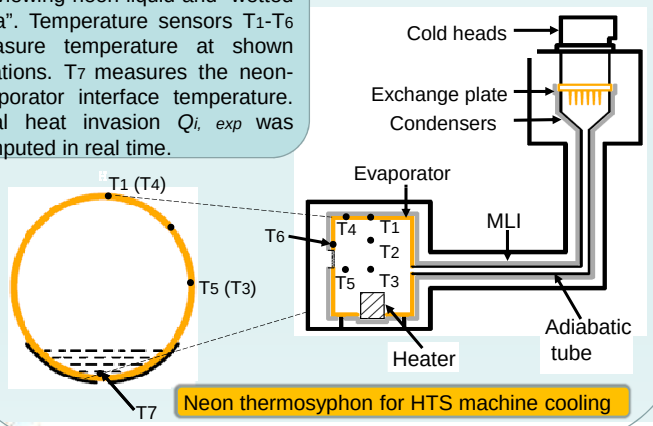
Thermosyphon principle

Experimental Set-Up

The neon thermosyphon has a maximum cooling power of 200W. It comprises of a cylindrical evaporator operating at 30K and two condensers, each mounted on a cold head of a Cryomech G-M cryocooler. Cold heads were regulated at 29.7K. The cold mass is wrapped in a 20-layer MLI and housed in an evacuated cryostat. By applying heat load to the evaporator at varying filling ratios, the behaviour of the TS was studied.

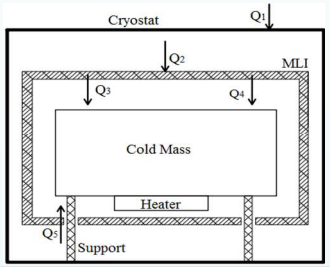
Instrumentation

Evaporator is fitted with viewports for viewing neon liquid and "wetted area". Temperature sensors T_1-T_6 measure temperature at shown locations. T_7 measures the neon-evaporator interface temperature. Total heat invasion $Q_{i,\ exp}$ was computed in real time.



Neon thermosyphon for HTS machine cooling

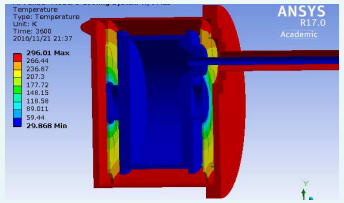
Thermal Analysis



Q_1 – Convection
Q_2 – Radiation through MLI
Q_3 – Radiation to cold mass
Q_4 – Conduction through MLI
Q_5 – Supports conduction

Thermal analysis schematic of thermosyphon

Development of Simulation Model



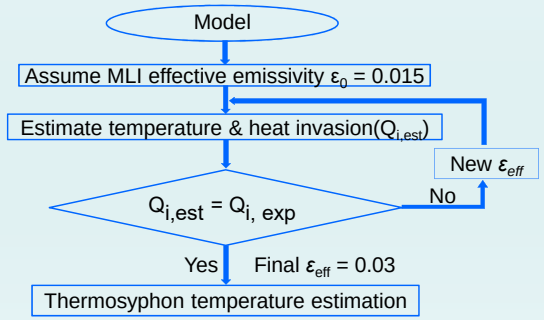
Thermal model

Defined Boundary Conditions
- Temperature
- Heat flux
- Convection
- Radiation

Determination of Effective Emissivity

The thermal effect of MLI was accounted for by defining its effective emissivity $\varepsilon_{\mathrm{eff}}$, which was determined by tweaking $\varepsilon_{\mathrm{eff}}$ until measured and estimated heat invasion. Heat transfer rate through the MLI is modelled by;

$$Q = \sigma A_S \varepsilon_{\mathrm{eff}} (T_S^4 - T_{\mathrm{Surr}}^4) \quad [\mathrm{W}]$$

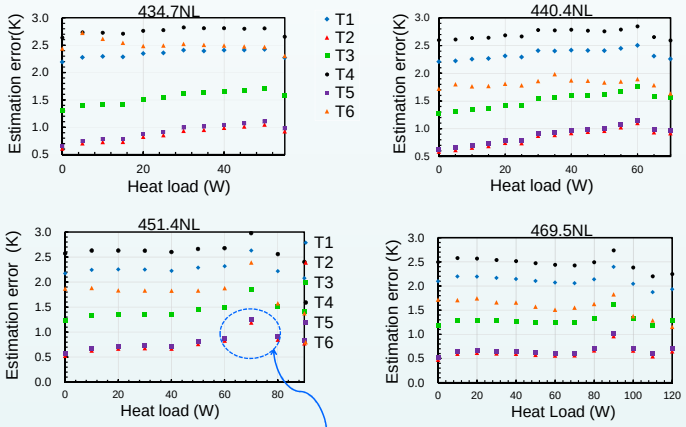


Neon thermosyphon

Results and Discussion

Estimated vs Measured Temperature

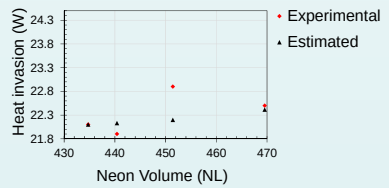
Estimation error at various neon filling ratios & heat loads. (NL= Normal Litres). Error = measured temperature - estimated temperature



Concave down could indicate change in boiling regime as actual "wetted area" is less than calculated "wetted area" at high vapour film.

Estimated temperature varies within 0.5K to 3K of measured data. Temperature is underestimated at at all points.

Estimated vs Measured Heat Invasion



Despite a constant effective emissivity, the model closely estimated experimental heat invasion. Maximum error is 0.8W.

Thermosyphon heat invasion enumeration:
- Through MLI to the cold mass: 48%, Conduction via supports: 52%

Conclusion

Experimental and simulated temperature distributions at various filling ratios and heat loads of a closed two-phase thermosyphon were compared. Effective emissivity approach allows for reasonable estimation of thermal parameters. The modelling approach is acceptable for validating temperature data and fairly useful for HTS cooling system design.