



Validation of Thermodynamic Vent System Performance using Thermal Desktop

Erin M. Tesny, Daniel M. Hauser
NASA Glenn Research Center

Presented by Erin Tesny

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Overview of Thermodynamic Vent System (TVS)



- Controlling pressure & temperature inside cryogenic propellant tanks is necessary to prevent venting of liquid in microgravity
- Using a Thermodynamic Vent System (TVS) is one possible solution
 - TVS expands working fluid through a Joule-Thomson device
 - Cooled fluid is then routed through the tank to remove heat from propellant

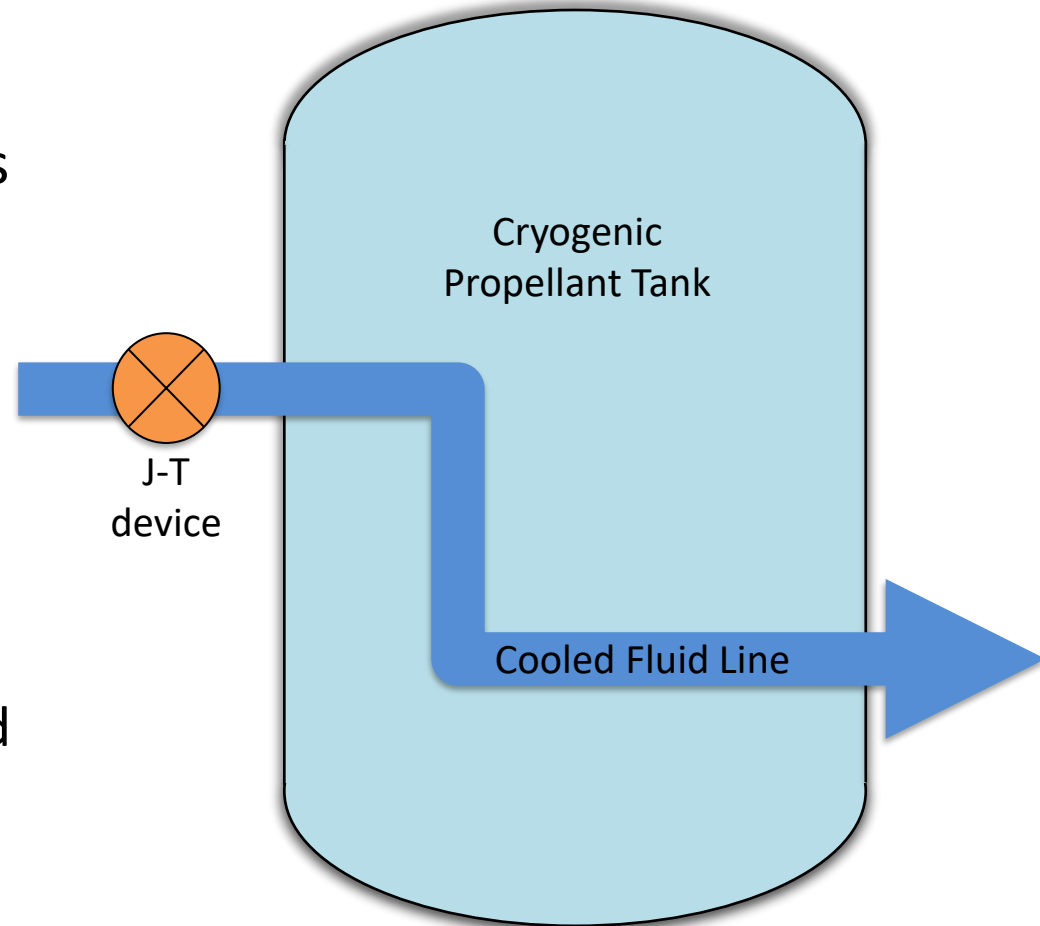


Figure 1. Schematic of potential TVS design showing J-T device and fluid routing through cryogenic propellant tank

Previous Study Overview: Hardware



- A previous study (Christie, 2011) created a simplified model of a TVS with a two-phase cryogenic heat exchanger
- Working fluid: LOX
- Joule-Thomson device: 5,000 LOhm Lee ViscoJet®
- Fluid passes through ViscoJet® and is isenthalpically expanded
- Cooled fluid enters heat exchanger tube coils and extracts heat from the surrounding external flow

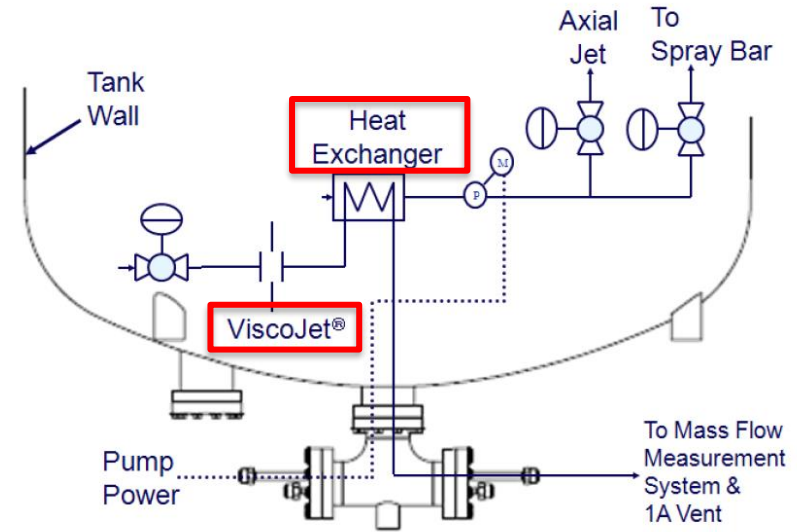


Figure 2. Full tank and TVS schematic (Christie, 2011)

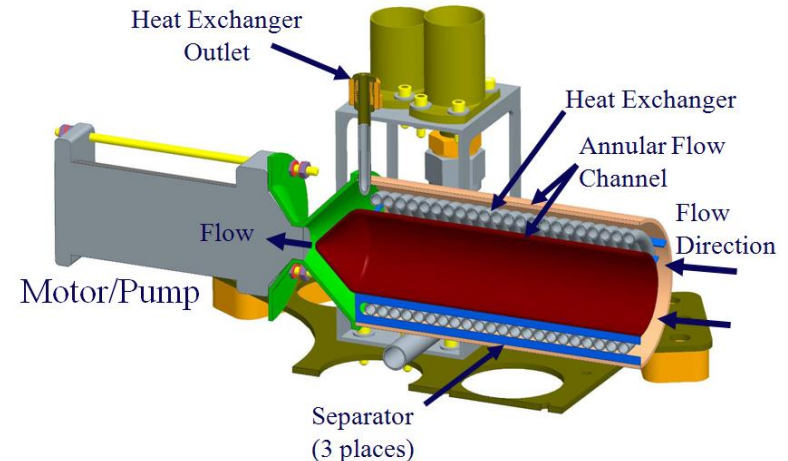


Figure 3. Heat Exchanger CAD model (Christie, 2011)

Previous Study Overview: Model



- The previous study created a simplified model of the ViscoJet® & heat exchanger using SINDA/FLUINT
- Both external & internal flows are represented as a series of lumps
- Model correctly predicts the heat extracted performance of the TVS within 6%
- Validated against experimental data using the same hardware

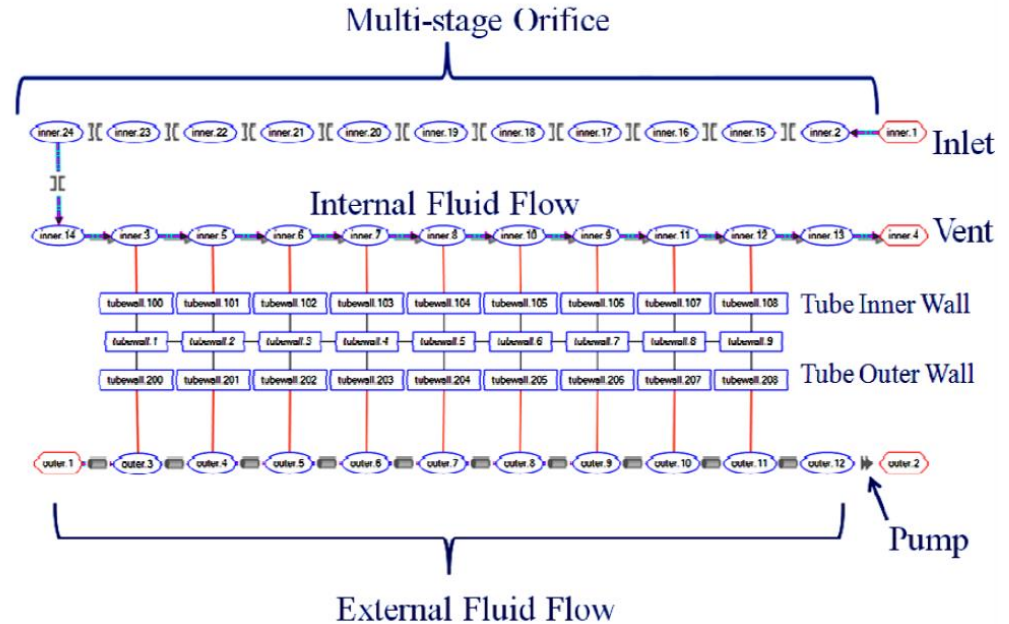


Figure 4. Simplified model of flow through ViscoJet® and two-phase cryogenic heat exchanger (Christie, 2011)

	Heat Extraction (W)
Test Data	631
SINDA/FLUINT Model	595

Recreation of Simple Model in Thermal Desktop



- The simplified TVS model was recreated in Thermal Desktop
- External flow modeled as a series of fluid lumps
- Internal flow modeled as a pipe, a series of fluid lumps and wall nodes
- ViscoJet® modeled as a single orifice with diameter sized for the expected ΔP
- LOX exits the orifice and enters the first internal flow fluid lump at lower temperature and pressure

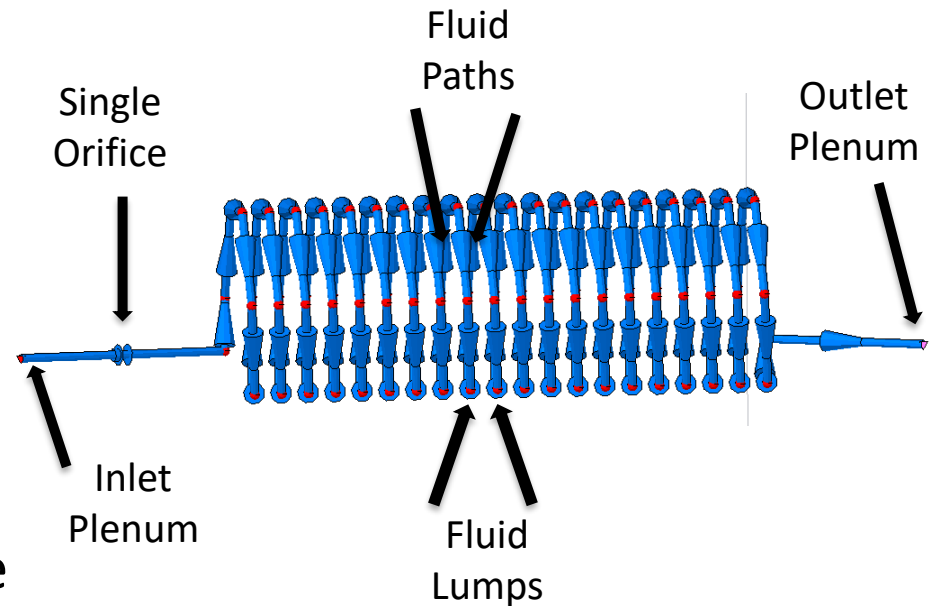


Figure 5. Thermal Desktop model of internal flow path

	J-T Inlet	J-T Outlet
Temperature (K)	113	90.3
Pressure (psia)	250	14.9

Recreation of Simple Model in Thermal Desktop



- User-defined heat transfer tie connects each external flow lump to corresponding internal flow wall node
- Heat transfer tie coefficient was calculated using Chen (1966) correlation and input into TD
- Same initial conditions as original SINDA/FLUINT model

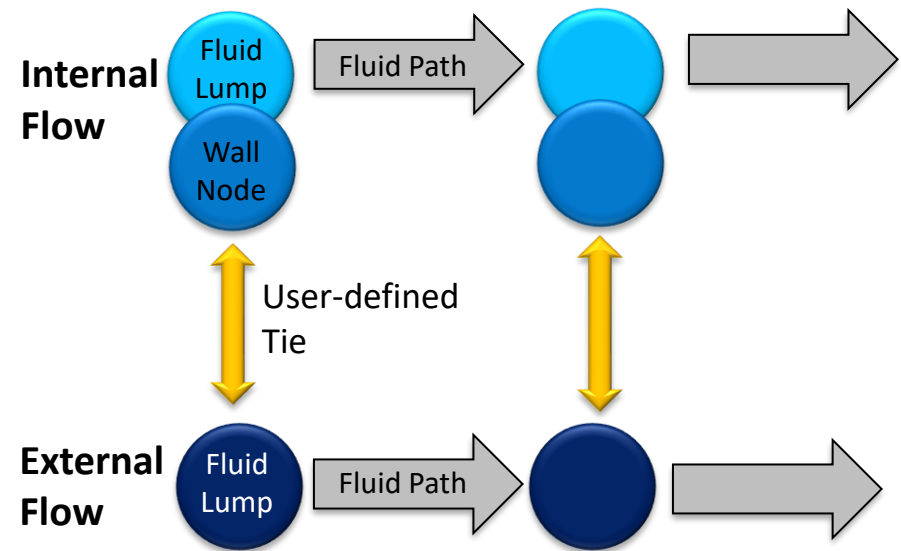


Figure 6. Schematic of Thermal Desktop model showing heat transfer tie between external flow fluid lumps and internal flow wall node

	Internal Flow	External Flow
Inlet Temperature (K)	90.3	113
Inlet Pressure (psia)	14.9	100
Flow Rate (kg/s)	0.0034	0.84

Model Result Comparison



	Heat Extraction (W)
Test Data	631
SINDA/FLUINT Model	595
Thermal Desktop Model	655

- Thermal Desktop model using Chen correlation able to predict heat extraction from external flow within 4% of experimental data and within 10% of original SINDA/FLUINT model

Conclusions



- Thermal Desktop model of simplified TVS geometry able to accurately predict heat extraction of TVS
- Model could be adapted to size other TVS geometries for future flight systems
 - e.g. using different cryogenics, TVS sizes, flow rates, etc.

1. Baldwin, M., Ghavami, A., Ghiaasiaan, S. M., & Majumdar, A. (2021). Flow boiling in liquid hydrogen, liquid methane and liquid oxygen: A review of available data and Predictive Tools. *Cryogenics*, 116, 103298.
<https://doi.org/10.1016/j.cryogenics.2021.103298>
2. Chen, J. C. (1966). Correlation for boiling heat transfer to saturated fluids in convective flow. *Industrial & Engineering Chemistry Process Design and Development*, 5(3), 322–329.
<https://doi.org/10.1021/i260019a023>
3. Christie, R. (2011). Two-Phase Cryogenic Heat Exchanger for the Thermodynamic Vent System. *NASA Technical Memo*. NASA/TM—2011-217220



BACKUP

Chen

$$h = h_{NB}S + h_{FC}(8)$$

(1966) [20]

$$\frac{h_{NB}(T_w - T_{sat})}{\rho_g h_{fg}} \sqrt{\frac{\pi}{\alpha_f}} \left(\frac{\rho_f R^{*3}}{2\sigma} \right)^{0.25} = 0.0015 \left\{ \frac{\rho_f}{\mu_f} \left[\frac{(T_w - T_{sat})k_f}{\rho_g h_{fg}} \right]^2 \frac{\pi}{\alpha_f} \right\}^{5/8} Pr_f^{1/3}$$

(9)

$$R^* = \frac{2\sigma}{P_{sat}(T_w) - P} \quad (10)$$

$$Nu_f = \frac{h_{FC} D_H}{k_f} = 0.023 Re_f^{0.8} Pr_f^{0.4} \quad (11)$$

$$Re_f = \frac{G(1-x)D_H}{\nu_f} \quad (12)$$

$$X_{tt} = \left(\frac{\rho_g}{\rho_f} \right)^{0.5} \left(\frac{\mu_f}{\mu_g} \right)^{0.1} \left(\frac{1-x}{x} \right)^{0.9} \quad (13)$$

$$F = \begin{cases} 1, & \frac{1}{X_{tt}} < 0.1 \\ 2.35 \left(0.213 + \frac{1}{X_{tt}} \right)^{0.736}, & \frac{1}{X_{tt}} > 0.1 \end{cases} \quad (14)$$

$$S = \left[1 + 2.56 \times 10^{-6} (Re_f F^{1.25})^{1.17} \right]^{-1} \quad (15)$$

Figure 7. Chen correlation for nucleate boiling and forced convection heat transfer (Baldwin et al., 2021)