Numerical Simulation of Flow Inside Grooves of a Loop Heat Pipe Evaporator

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Introduction

Context: As satellite can be submitted to a wide range of temperature differences, it is necessary to keep their electronic components inside their working temperature range. One of the devices used to ensure a good thermal control of those equipments are the Loop Heat Pipes (LHP). Yet the accurate prediction of their behavior is still a challenge.

State of art: In a previous work \cite{1}, a Pore Network Model (PNM) was developed with success and permitted to study the thermal and fluid behavior within a LHP’s unit cell (fig.2) (fig.3). However some assumptions (temperature inside the vapor grooves, thermal exchange between vapor and casing and the wick...) have to be checked. Only a few studies are devoted to what happens in the vapor grooves \cite{2}.

Objective: Check the validity of previous assumptions and study their impact on the LHP’s evaporator.

Method: In a first approach the maximal temperature of the casing and the flow rate produced by the unit cell for each heat flux applied are extracted from the PNM (fig.4). These data are inputs for a Comsol Multiphysics model which solves the thermal and fluid flow inside one groove. It is then possible to compare the fluid temperature and the exchange coefficients inside the groove with the correlation usually used.

Mathematical model

Hypothesis:

- Gravity is neglected,
- Vapour flow is incompressible
- Wick interface is in saturated state
- Constant thermophysical properties

Heat transfer:

- Casing: $P \cdot (k_c \nabla T) = 0$
- Groove: $(\rho_g C_p u_c) \cdot \nabla T = P \cdot (k_u \nabla T)$

Flow in groove:

- Continuity equation: $P \cdot (\rho u) = 0$
- Momentum equation: $P \cdot (\rho u \nabla u) = - P \nabla p + \rho C_p (\nabla T)^2 - \frac{2}{3} \rho C_p (u \nabla u)^2$

Main boundary conditions: (fig.5)

1. Top of casing: $T = T_{\text{max casing}}$
2. Casing part in contact with Compensation Chamber (CC/Tank): $(k_c \nabla T) \cdot n = \frac{k_u (T_{\text{sat}} - T)}{\text{casing thickness in contact with CC/Tank}}$
3. 8: Symmetry on lateral faces: $(k_c \nabla T) \cdot n = 0$ and $u = 0$
4. Wick-groove interface: $T = T_{\text{sat}}$ and $u = U_{\text{inj}} \cdot n$
5. 7: Outflow conditions and no stress: $(k_c \nabla T) \cdot n = 0$ and $P \nabla p + \rho C_p (\nabla T)^2 - \frac{2}{3} \rho C_p (u \nabla u)^2 = 0$
6. Wick-casing interface: $T = T_{\text{sat}}$

Results:

Pressure drops inside the groove: The pressure drop in a pipe can be written as $AP = \frac{\mu}{2} \cdot \frac{\rho u^2}{A}$, based on Poiseuille law where $\mu$ is the dynamic viscosity and applying mass conservation $\rho = \frac{\rho_0}{\rho_{\text{sat}}}$ which is possible to plot the computed pressure drop inside the groove versus the Poiseuille pressure drop: $AP = \frac{\mu}{2} \cdot \frac{\rho u^2}{A}$ (fig.6).

Temperature inside the groove: The average temperature inside the groove is based on a mixing approach: $\bar{T}_{\text{avg}}(x) = \frac{\rho u_0 \bar{T}_{\text{sat}} + \rho_0 \bar{T}_{\text{sat}}}{\rho u_0 + \rho_0}$ with: $\rho u_0 = 7 B C D$ and $\rho_0 = 7 B C D$ (fig.7).

Heat Transfer coefficient: (fig.8)

- The local heat transfer coefficient at a point is computed as $h_{\text{local}}(x) = \frac{Q}{\frac{1}{2} \rho_0 C_p \bar{T}_{\text{sat}}}$ with $\bar{T}_{\text{sat}} = \frac{\rho_0}{\bar{T}_{\text{sat}}}$ for the top and side faces and $\bar{T}_{\text{sat}} = \frac{\rho_0}{\bar{T}_{\text{sat}}}$ for the injection side.

Conclusions and prospects

The assumptions and correlations used previously underestimate the heat transfers which occur within the groove inside the evaporator.

Current work: Study of the impact of these observations on the conductance and mass flow rate of the evaporator with the PNM model.