A novel lumped parameter model for Loop Heat Pipes – validation and parametric analysis

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Abstract A one dimensional lumped parameter model has been developed within the general framework of the open source software Octave, in order to describe the physical behaviour of a Loop Heat Pipe. By means of the electro-thermal-hydraulic analogy, this model gives the values of temperature and pressure for every part of the device, in response to varying boundary conditions. Furthermore, a novel approach in describing the phase change at the condenser has been adopted, differentiating the vapour quality variation over time. The code is initially validated against both simulation and experimental data found in literature. Since the present work aims to produce a design tool for the automotive industry, a parametric analysis on the geometrical characteristics of a Loop Heat Pipe is then performed, identifying and quantifying the most influential design parameters.

Keywords: Loop Heat Pipe, One dimensional, Lumped parameters, Numerical analysis.

1. Introduction

A Loop Heat Pipe (LHP) is a special type of Heat Pipe. It was originally developed in the Soviet Union in the early 1980s and its most unique feature is that it can transfer heat over long distances (~10-20 m), with relatively small costs since the wick structure is in the evaporator only [1, 2]. It is composed by an evaporator, a compensation chamber, a vapour line, a condenser and a liquid line, as illustrated in Fig. 1.

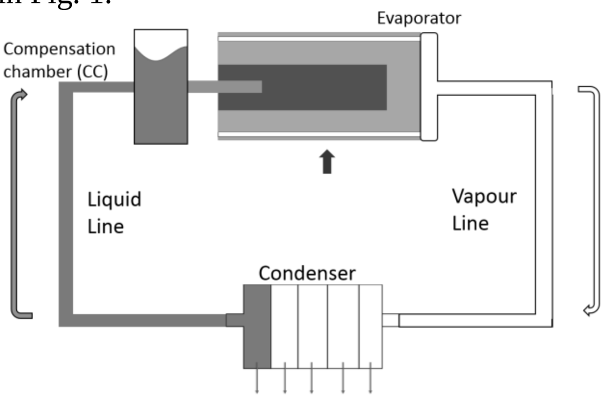

Fig. 1: LHP schematic.

In the present investigation, a 1-D lumped parameter model in Octave programming language (Innovate UK Research Project LOOPER), has been developed by means of the electrical-thermal-hydraulic analogy.

2.Mathematical Framework

In the start-up phase this transient condition has to be treated as an isochoric heating, pressure needs to be incremented alongside the temperature in order to get to the point when temperature is high enough to dissipate the required amount of heat. The procedure is to update the pressure corresponding to the new value of internal energy of the liquid-vapour mixture each time.

The evaporator was de-coupled from the compensation chamber and analysed with the thermal network shown in Fig. 2.

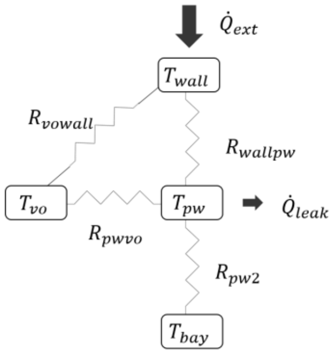

Fig. 2. Thermal Network schematic.

The vapour line is adiabatic and in the liquid line the liquid is incompressible and it exchanges heat with the ambient.
Combining the equation of energy and mass balance, the following differential equation describing the condenser node as vapour quality variation is derived:

$$\frac{dx}{dt} = \frac{T_c - T_i(P_i)_{sat}}{R_{t,i} m_i h_{LV}} + \frac{\dot{m}}{m_i} \frac{(h_{i-1} - h_i)}{h_{LV}} \qquad (1)$$

where the first right hand term is the difference between the temperature of the fluid and the cold source divided by the thermal resistance, the node mass and the latent heat of vaporisation; the second term is the mass flow rate times the enthalpy difference between two nodes divided by the node mass and the latent heat of vaporisation.
This approach, to the author's best knowledge, is a novelty regarding the description of the condenser behaviour.

3. Validation and Parametric Analysis

Satisfactory results were obtained on the numerical validation reproducing the results by Pouzet et al. [3], where the applied heat undergoes a 200/400/200W cycle.

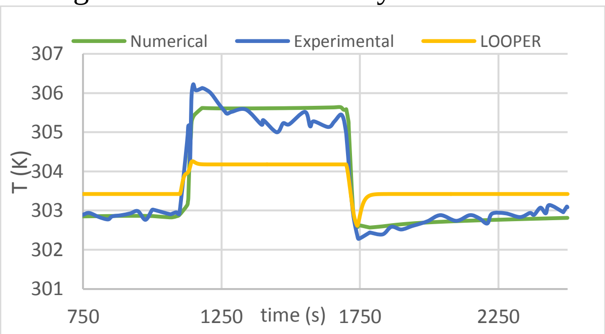

Fig. 3: Evaporator wall temperatures comparison

From Fig. 3,6,7 the comparisons show that the model is able to capture the trends of the temperature with acceptable errors, but is also able to predict the overshoot in the upward variation of external heat, in contradiction to the numerical model of the proposed paper. The model is also able to predict the opposite behaviour of the evaporator wall and the primary wick (see Fig. 5).

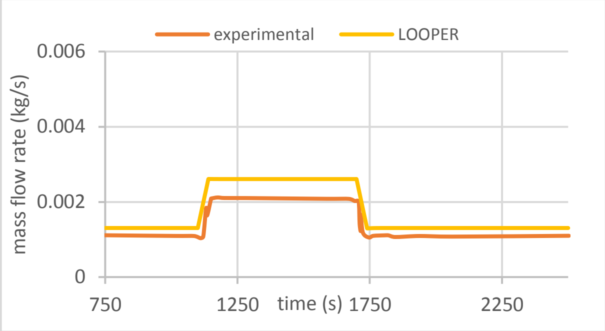

Fig. 4 - Mass flow rate comparison

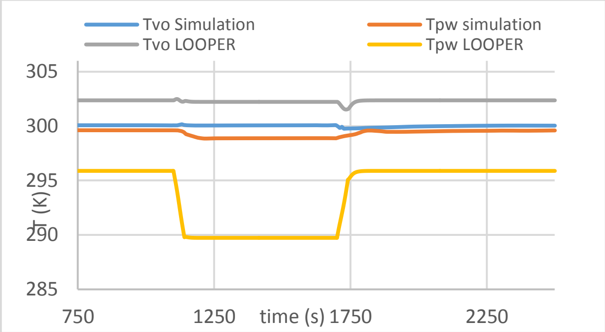

Fig. 5 - Primary wick and vapour grooves temperatures comparison

The parametric analysis gives useful information on the most influencing geometrical parameters such as internal and external radius of the condenser, thickness and length of the evaporator shell.

4. Conclusions

A 1-D lumped parameter model has been successfully created and validated against numerical and experimental data found in literature. This model has been used to perform a parametric analysis.

References

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