FUNDAMENTALS:

EFFECTIVE THERMAL CONDUCTIVITY OF A HEAT PIPE

The question often arises that what is the effective thermal conductivity of a heat pipe. The correct answer depends on the construction and the wick material inside the heat pipe. To understand this better, consider figure 1 which shows all the resistances from the hot source on the evaporator side to the cold side which is the condenser.

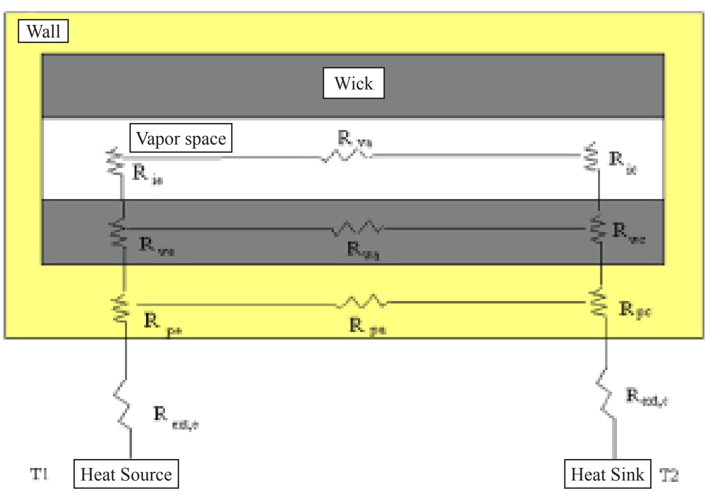

Figure 1. Thermal Resistances of a Heat Pipe [1]

The various thermal resistances are defined as follows:

$R_{ext,e}$ = Contact resistance between hot source and the heat pipe

R_{pe}, R_{pc} = Conduction resistance of the heat pipe wall in the radial direction

R_{we}, R_{wc} = Resistance of the wick liquid structure in the radial direction

R_{pa} = Conduction resistance of the heat pipe wall in the axial direction

R_{wa} = Resistance of the wick liquid structure in the axial direction

R_{ie}, R_{ic} = Resistance of the liquid vapor interface

R_{va} = Resistance of the vapor phase

The total resistance of the heat pipe is a combination of series and parallel resistances and can be calculated as follows:

$$\frac{1}{R_{tot}} = \frac{1}{R_{pe} + R_{we} + \dfrac{1}{\dfrac{1}{R_{va}} + \dfrac{1}{R_{pa}} + \dfrac{1}{R_{wa}}} + R_{wc} + R_{pc}} \quad (1)$$

Considering that the thermal resistance of the vapor space is extremely small in the range of 10^{-8} °C/W, equation 1 can be simplified to:

$$R_{tot} = 2(R_{pe} + R_{we}) \quad (2)$$

To gain a better understanding a simple calculation can reveal some insight. Assume a 6cm long heat pipe with inner and outer diameters of 5mm and 6mm respectively having two layers of #500-mesh copper screens with wire diameters of 0.0215mm. Calculations show that:

$R_{pe} = 3.618 \times 10^{-3}$ °C/W

$R_{we} = 1.474$°C/W

Substituting these values into equation 2 results in:

$R_{total} = 2.95$°C/W

When you compare it to a solid copper with the same sizes results in R = 5.3°C/W, almost a factor of two better, with the added advantage that the heat pipe is much lighter. This results in an effective thermal conductivity of this heat pipe to be 730 W/m·K

Equation 2 shows the importance of the wick structure resistance and is clear that it is one of the dominant factors in the overall thermal performance of the heat pipe.

The above mentioned arguments show that the common assumption of a very high conductivity around 40,000 W/m·K for the heat pipe is not correct. The correct way is to accurately calculate the different thermal resistances based on the geometry of the heat pipe, wall material, wick structure and the liquid to find the total thermal resistance and hence the effective thermal conductivity. If the information is not readily available, the best option is to test the heat pipe to calculate its thermal resistance.

REFERENCE:

Peterson, G.P, “An introduction to Heat pipes – Modeling, Testing and Applications”, New York: John Wiley and sons, 1994