TECHNICAL NOTE:

EFFECT OF VACUUM AND FILL RATIO ON THE PERFORMANCE OF HEAT PIPES

The discussion generally arises as to what would be the heat pipe performance as a function of liquid fill ratio and vacuum. Before we show some results, lets see how a heat pipe works. The thermodynamic cycle of a heat pipe is shown in figure 1 in a T-S diagram[1].

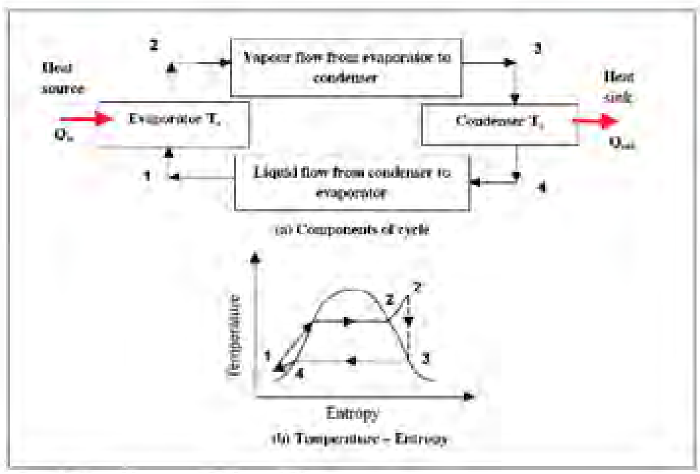

Figure 1. Thermodynamic Cycle of a Heat Pipe [1]

Liquid at state 1 enters the evaporator and after absorbing the heat vaporizes to a mixture at 2 or to a saturated vapor at 2’. This vapor travels through the length of the heat pipe and enters the condenser at state 3. This vapor after loosing its heat in the condenser exits at state 4 which is saturated liquid and upon travelling through the wick looses its temperature until it reaches point 1, which the cycle begins. If one looks at the phase diagram for a liquid, for example water in figure 2, it is apparent that the state of the liquid should be very close to the liquid vapor line in order for the liquid to promptly changes phase from liquid to gas upon heating. The triple point of water is at 4.58 torr at temperature of 0.0075 °C. The state of liquid pressure should be in the region below atmosphere (vacuum) and above the complete vacuum. To obtain lower operating temperature the heat pipe pressure should be decrease and vice versa. The state of liquid after the condenser has to be saturated liquid, so the wick can create the liquid motion.

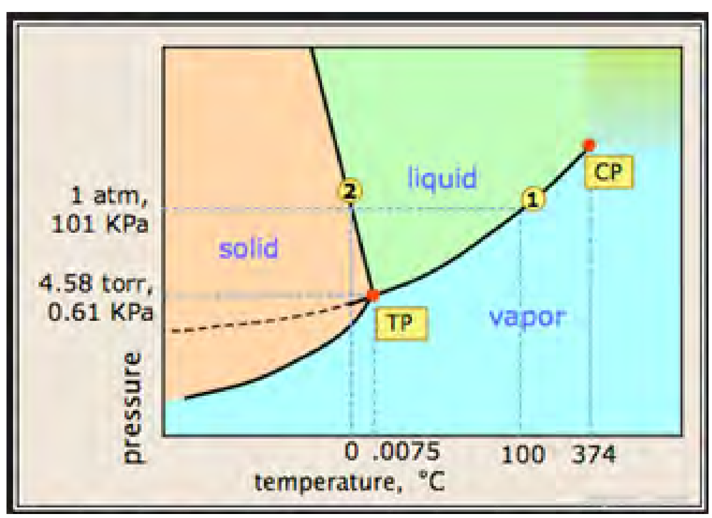

Figure 2. Phase Diagram of Water

Lin, et al. [2] have shown that maximum heat transfer in a heat pipe is an exponential function of vacuum pressure according to the following formula.

$$Q_{max} = Q_{max,0} \cdot e^{-\left(\frac{P_{NCG}}{\Delta P_{cg}}\right)} \qquad (1)$$

Where,

$Q_{max,0}$ = maximum heat transfer at 0 pressure (no condensable gas)

P_{NCG} = pressure of the non condensable gas

ΔP_{cg} = pressure drop difference between capillary and gravity

This equation clearly shows that by decreasing vacuum pressure, Q_{max} increases.

Another important factor is the amount of liquid in the heat pipe which is commonly called the fill ratio or inventory. If there is too much liquid, evaporation will not happen or delayed, and if there is not enough liquid, the dry out condition will happen. The rule of thumb is the volume of the liquid should be higher than the volume of the pore volume of the wick.

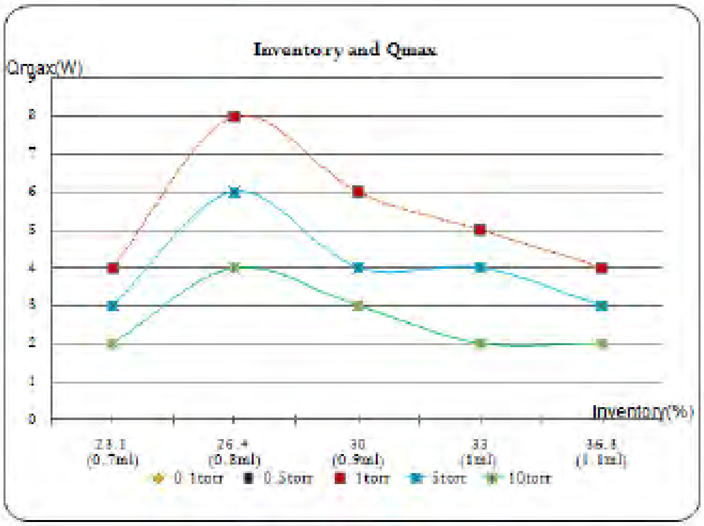

Figure 3. Q_{max} As a Function of Vacuum Pressure and Fill Ratio For a Heat Pipe [2]

Figure 3 shows that as the pressure decreases from 10 torr to 1 torr the Q_{max} increases. The graph also shows that as the inventory(fill ratio) increases from 0.7 ml to 1.1 ml, Q_{max} peaks at 0.8 ml. This corresponds to a fill ratio of 26.4% which is ratio of the liquid volume to total volume of the heat pipe when it is empty. This graph shows the importance of fill ratio. If the fill ratio is not optimized as is shown for example for 1 tor, Q_{max} drops from 8W to 4W, a 50% drop which can be catastrophic for the application. Mozumder et al.[3], in their experiment measured the thermal resistance of a heat pipe for different fill ratios and power.

Figure 4 shows that as the fill ratio increases from dry run to 85% (in their experiment fill ratio is defined as the volume of liquid to the volume of the evaporator section), thermal resistance decreases, but then increase with further increase of fill ratio.

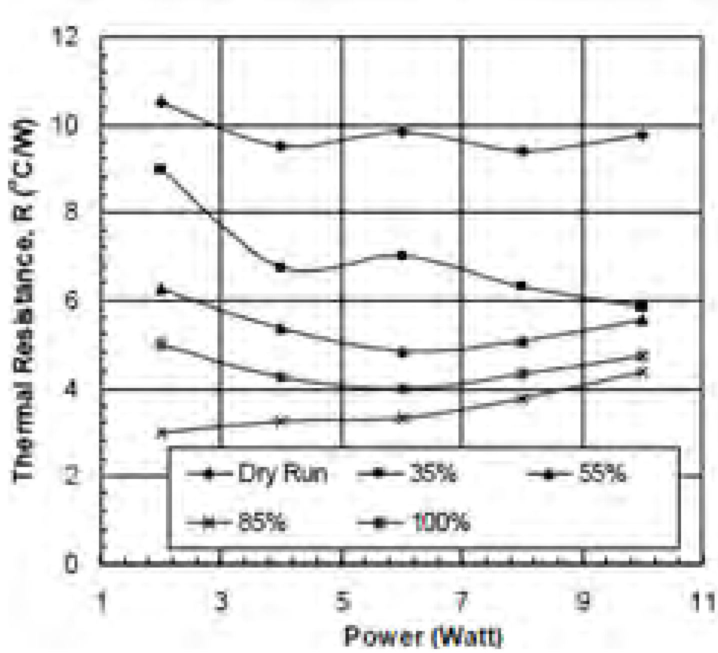

Figure 4. Heat Pipe Thermal Resistance As a Function of Fill Ratio [3]

The aforementioned arguments demonstrate that the fill ratio and vacuum pressure are very important in the proper design of a heat pipe. There is not much data in the literature about the effect of these two factors on the performance of the heat pipe. And it appears that most heat pipe manufacturers either resort to a try and error procedure or use the information from past experience. This topic needs further research.

REFERENCES

1. Ong, S., “Heat Pipes”, Jurutera, April 2008

2. Lin, W., Chao, C., Calvin, Y., Hsu, G., Chou, S., “Effect of vacuum pressure and the Working Fluid Inventory to the Maximum Heat Loading(Qmax) of the Heat Pipe”, 10th IHPS, Taipei, Taiwan, Nov. 6-9, 2011

3. Mozumder, A., Akon, A., Chowdhury, M. Banik, S., “Performance of Heat Pipe with Different Working Fluids and Fill Ratios”, Journal of Mechanical enginnering, Vol. ME 41, No. 2 December 2010

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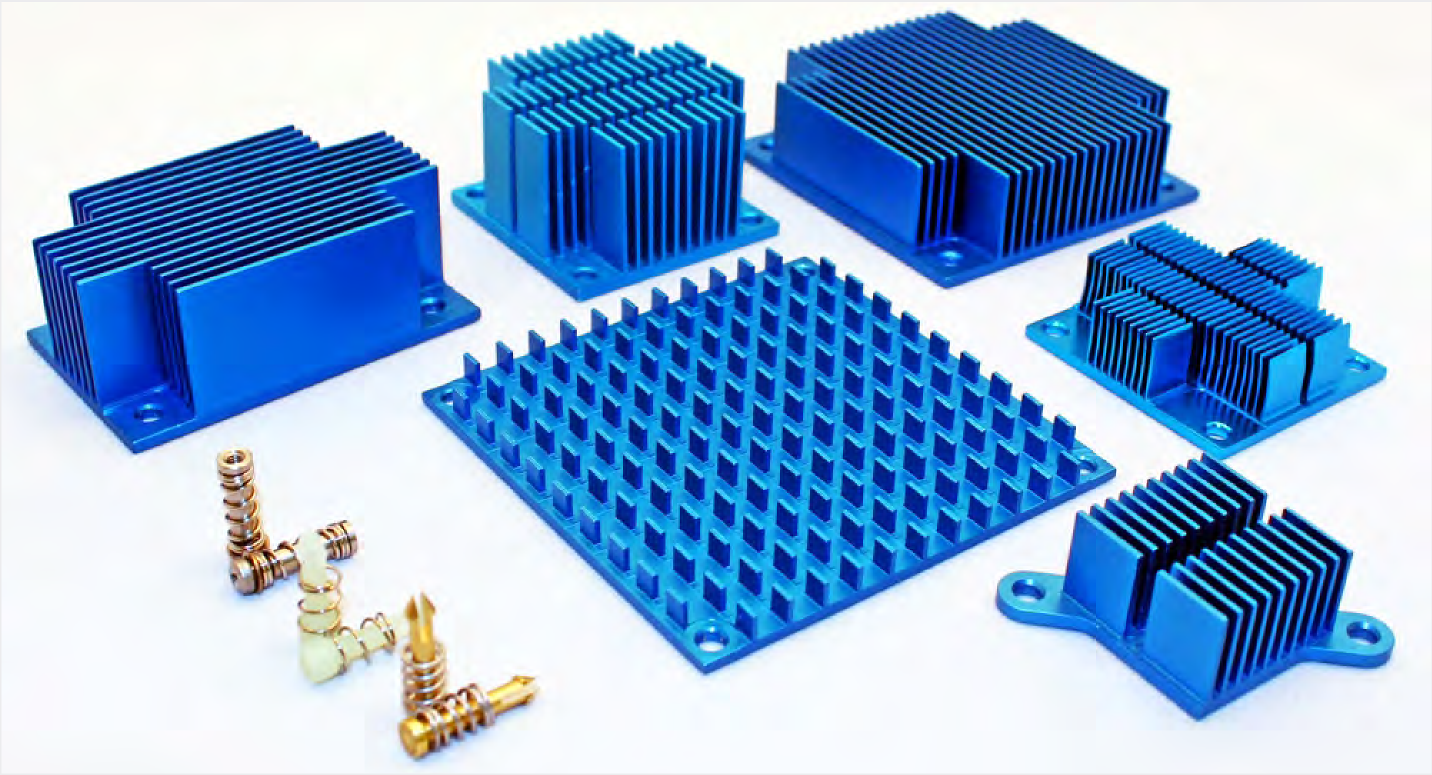

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