NANOFLUIDS IN HEAT PIPES

Heat pipes are simple heat transfer devices that are ubiquitous in electronics cooling applications. They transfer heat with a very low thermal resistance but are limited in the maximum load by various factors. The performance of the heat pipe is defined by both the maximum heat load and the thermal resistance when operating within that limit. Figure 1 shows the schematic of a heat pipe and the different component thermal resistances. One of the variables that determine the performance of a heat pipe is the thermophysical properties of the working fluid. Because of the temperature range of electronics, the most cost effective working fluid is water. Although water is the best heat transfer fluid, its properties can be enhanced by introduction nano-particles.

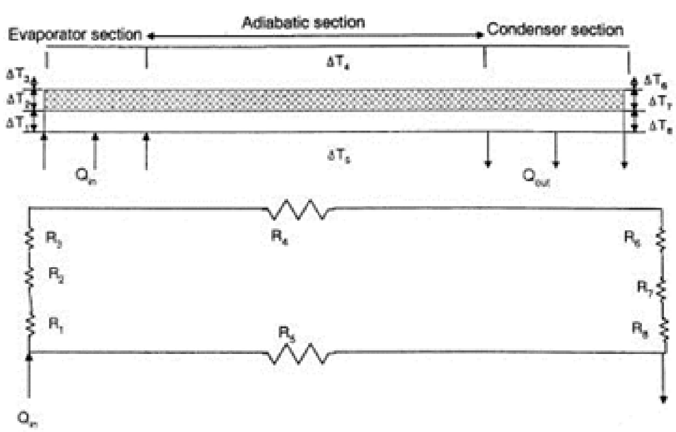

Figure 1. A Heat Pipe and its Thermal Resistance Network [1]

NANOFLUIDS

The mixture of nanoparticles and a base fluid is known as a nanofluid. Nanofluids have been studied extensively over the past few decades because of their use in a wide range of applications [2]. The techniques for creating such colloidal suspensions vary depending on the base fluid and the nanoparticle itself. The most common method is to disperse the nanoparticle powder in water through the use of an ultrasonic bath. Harikrishnan et al. [3] studied CuO nanoparticles in an 80:20 water-glycerin base fluid at different concentrations as seen in Figure 2.

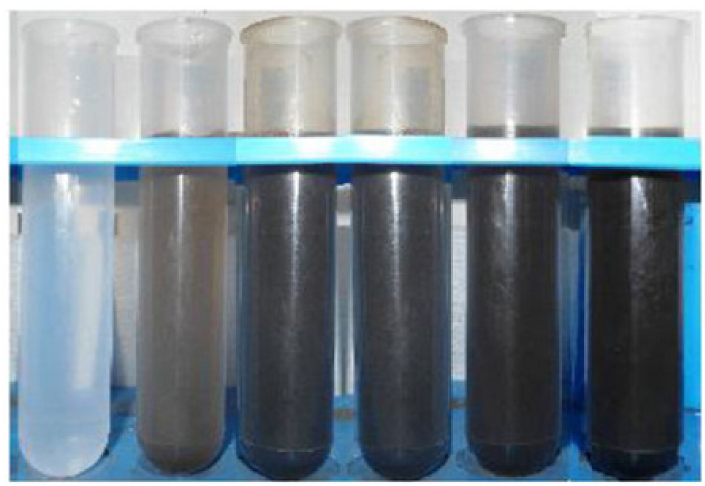

Figure 2. CuO Nanoparticles in an 80:20 Water-Glycerin Base Fluid at Concentrations of 0.1, 0.3, 0.5, 0.8 and 1% by Weight [3]

HEAT PIPE PERFORMANCE

Sureshkumar et al. [4] conducted an extensive review of the considerable research on nanofluids and heat pipes over the past two decades. As an aggregate, the results showed a positive change in the performance of heat pipes by decreasing the thermal resistance and sometimes through maximum allowable heat load.

Shafahi et al. [5] used experimental and theoretical analysis and found CuO to be the most effective nanofluid for use within heat pipes. As Figure 3 shows, the maximum heat transfer from a heat pipe increases 15-20% with a CuO concentration of 0.15. The nanofluid made from Alumina (Al_2O_3) and Titanium Oxide (TiO_2) have little overall effect on the maximum heat transfer rate. However, all three nanofluids reduced the overall thermal resistance of the heat pipe. Figure 4 shows the relative decrease in thermal resistance for the three nanofluids at a 4% concentration.

In addition to the common nanofluids listed above, other researchers have explored more exotic nanofluids. Tsai et al. [6] used gold nanoparticles and found that the thermal resistance of the heat pipe dropped from 0.215 to 0.17°C/W with a specific cocktail of $HAuCl_4$, Na_3 Citrate and Tannic Acid. This is almost the same fluid as Alumina as used in [5] but with added complexity and more expensive gold. Kang et al. [7] found success with 35 nano-meter silver particles at a concentration level of 10 parts-per-million in pure water. The thermal resistance reduced from a range of 0.004-0.005°C/W to 0.001-0.002°C/W for different power loads.

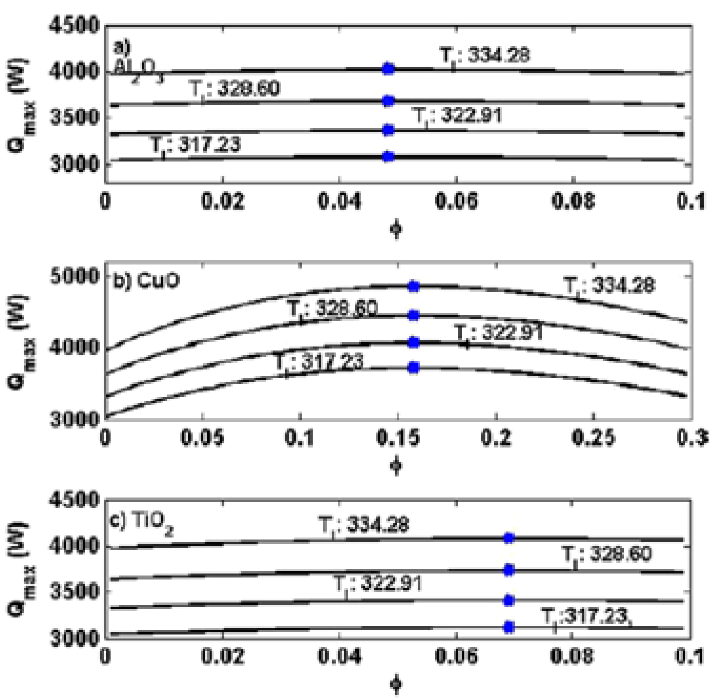

Figure 3. Maximum Heat Transfer Limit of Heat Pipes with Various Nanofluids [5]

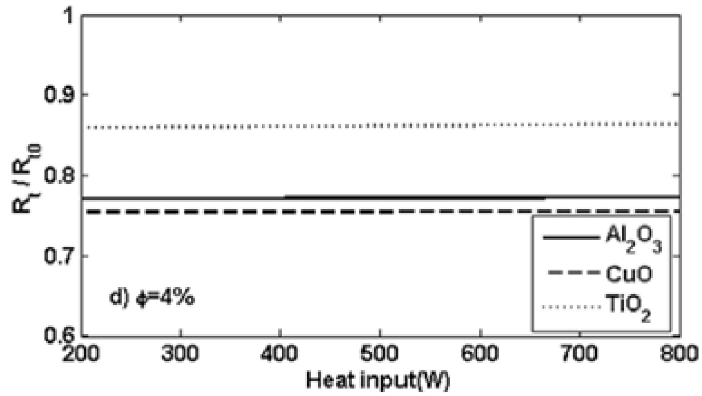

Figure 4. Thermal Resistance of Various Nanofluids Shown as a Ratio of the Thermal Resistance with Pure Water [5]

EXPLANATION FOR THE EFFECT OF NANOFLUIDS

Most of the researchers in this field have concluded that the largest effect of nanofluid on the performance of heat pipe is due to an increase in thermal conductivity over the base fluid [4]. As an example, Figure 5 shows an increase in thermal conductivity by using Copper Oxide (CuO) nanoparticles in an 80:20 water-glycerin base fluid, measured by using differential scanning calorimetry [3]. Curiously, although attempts have been made in understanding the mechanism for the increase in thermal conductivity, there is no clear explanation. Wang et. al summarized the plethora of research work that has gone into understanding the heat transfer characteristics of the nanofluids [7].

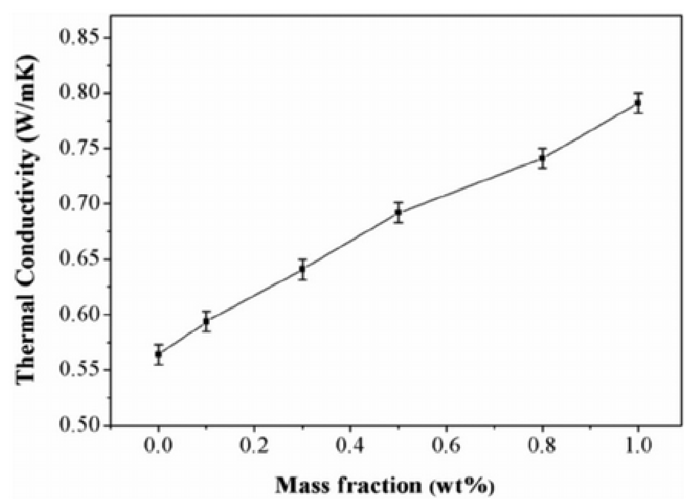

Figure 5. Thermal Conductivity vs Concentration of CuO Nanoparticles in an 80:20 Water-Glycerin Base Fluid [3]

In addition to an increase in thermal conductivity, nanofluids also change the density and viscosity of the fluid. The increase in density allows for a more efficient mass transfer per volume but the increased viscosity leads to a higher pressure drop [5]. The reason for the optimal performance at the middle of the concentration range in Figure 3 can be partially explained due to an increase in pressure loss that is much higher than the increase in mass transfer per volume. In other words, after a certain increase in nanoparticle concentration, the resulting fluid becomes so viscous that it negates any other gains. In practice, higher concentration of nanoparticles also leads to sedimentation and blocking of the wicking material.

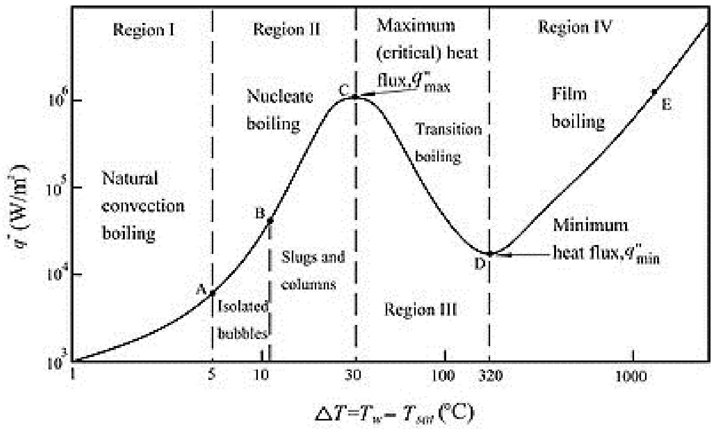

Figure 6. The Pool Boiling Curve. Heat Pipe Evaporators Should Stay in Regions I and II [7]

The increase in maximum allowable heat and the thermal conductance can also be attributed to the shift in the boiling curve. Figure 6 shows the pool boiling curve and its associated regimes [7]. Beyond the critical heat flux (CHF), the heat pipe evaporator requires a higher wall temperature for the same amount of heat flux. Additionally, the larger nucleation bubbles close to and beyond the CHF can also block the liquid flow in the wicking and disrupt the capillary pumping. The general consensus in the operation of heat pipes and thermosyphons (a wickless heat pipe) is to remain to the left, regions I and II in Figure 6, of the CHF [8].

The addition of nanofluids increases the CHF [4]. This phenomenon raises the overall boiling limit of the heat pipe. As an example, Yang and Liu [10] found a 14% increase in allowable maximum heat flux for a looped thermosyphon by using a 1.5% concentration of Al_2O_3 by weight. The researchers attributed that performance increase to an increase in CHF.

CONCLUSIONS

The addition of nanoparticles to a base working fluid can increase the thermal performance of a heat pipe. The performance increase comes as a decrease in thermal resistance and an increase in total allowable heat load. The two most common nanofluids with water are Alumina (Al_2O_3) and Copper Oxide (CuO); although positive effects have also been seen with Titanium Oxide (TiO), Gold and Silver. While many of these nano-particles come in commercially available powder form, manufacturers should evaluate the increased complexity of creating such a heat pipe vs the benefits outlined in this article.

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