



HEAT TRANSFER AND FLUID FLOW IN AN IDEALIZED MICRO HEAT PIPE

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ABSTRACT

Micro heat pipes have been used as a heat-dissipating device in many systems, such as micro electronic components and the leading edge of hypersonic aircraft.^[1, 2] Micro heat pipes transfer heat by evaporation, convection, and condensation, same as the conventional heat pipes. However, the effective thermal conductivity of micro heat pipes is only 1/40 that of conventional heat pipes. Due to the complexity of the coupled heat and mass transport, and to the complicated three-dimensional bubble geometry inside micro heat pipes, there is a lack of rigorous analysis. As a result, the relative low effective thermal conductivity remains unexplained. This work conceptualized an idealized micro heat pipe that eliminates the complicated geometry, but retains the essential physics. The simplified bubble geometry allows a direct comparison between theoretical predictions and experimental data.

The idealized micro heat pipe is a rectangular heat pipe, the top portion of which is made of a non-wetting material, and the bottom portion a wetting material. The lower portion is filled to the rim by a wetting liquid, and the upper portion is filled by its vapor. This configuration ensures that the contact line of the liquid-vapor interface is pinned at the interception between the wetting and non-wetting materials. Pinning of the interface allows a capillary pressure gradient to drive the liquid flow. When this micro heat pipe is driven at small temperature differences, the interface should be roughly flat, allowing the analysis to be greatly simplified.

The evaporation and condensation in the idealized micro heat pipe is analyzed. It is found that the interface can be separated into two regions: an inner region near the wall where evaporation occurs and an outer region away from the wall. The evaporation rate is solved by the method of matched asymptotic expansions, and the leading order evaporation rate is obtained as \ln , where \ln measures the ratio of conductive heat flux in the liquid to evaporative heat flux at the interface. The small parameter ϵ is

$$\epsilon = \frac{k_f T}{c h_{fg}^2 W},$$

where k_f is the liquid thermal conductivity, T is the wall temperature, $c = (2RT)^{1/2}$ with R being the universal gas constant per unit mass of the vapor as determined by the

kinetic theory, ρ_v is vapor density, h_{fg} is liquid latent heat and W is the half width of the pipe. The Stokes flow induced by the surface tension gradient (Marangoni stress) along the interface and by the evaporation at the interface is solved using a finite-difference method.

Fluid flow and heat transfer along the micro heat pipe are also studied. Liquid temperature distribution along the micro heat pipe is given in Figure 2. It is found that the temperature profile is relatively flat except the region near the evaporator, which is the evaporation region. The length scale of the region is calculated as

$$= \sqrt{\frac{(A_w k_w + A_f k_f)}{2 k_f (-\ln \epsilon)}},$$

where A_w and A_f are cross-sectional area of the wall and liquid, respectively, and k_w is wall thermal conductivity. For a micro heat pipe with larger L/W the length of the evaporation region is shorter. Vapor pressure distribution along the micro heat pipe is also given in Figure 3. It is clear that the pressure goes approximately linearly and not affected strongly by L/W . Effective thermal conductivity k_{eff} is evaluated. A longer or wider micro heat pipe will have a larger k_{eff} . And it is found that increasing the evaporation area at the evaporator will increase k_{eff} . It is also affected by the latent heat of the working fluid. A fluid with larger latent heat will produce larger k_{eff} .

FIGURES AND TABLES

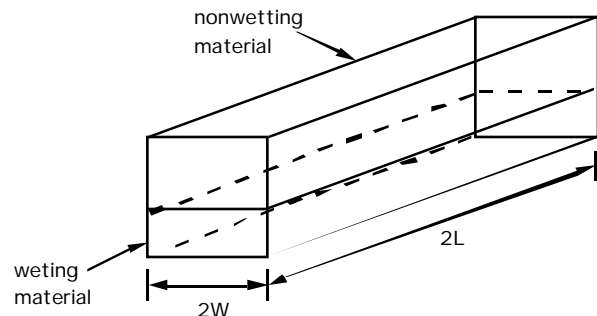


Figure 1 an Idealized Micro Heat Pipe

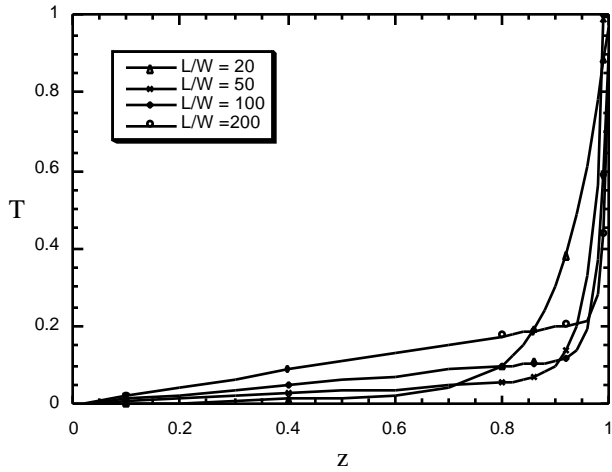


Figure 2 Temperature Distribution along an Idealized Micro Heat Pipe

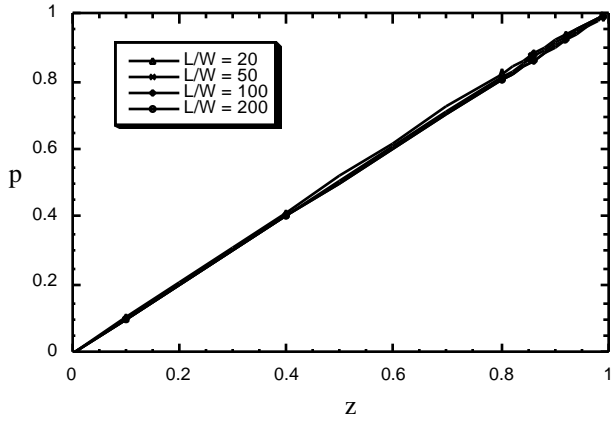


Figure 3 Pressure Distribution along an Idealized Micro Heat Pipe

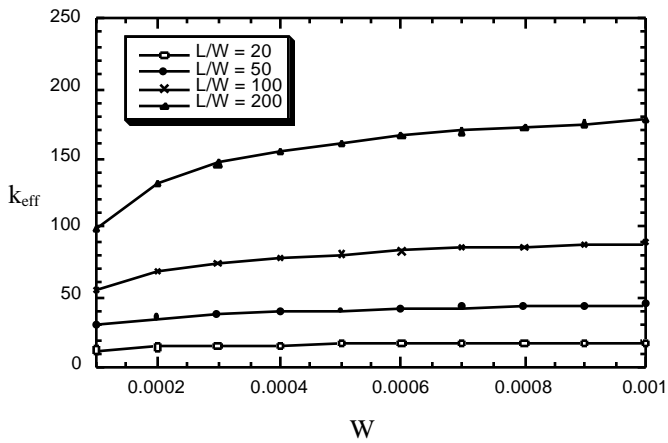


Figure 4 Effective Thermal Conductivity along an Idealized Micro Heat Pipe

ACKNOWLEDGMENTS

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REFERENCES

1. G. P. Peterson, *Appl. Mech. Rev.* 45 (1992) 175-89.
2. P. Dunn & D. A. Reay, in "Heat Pipes" (Pergamon Press, 1982) 16-18.