AIAA 81-4149

Comment on "Vapor Flow Calculations in a Flat-Plate Heat Pipe"

Michael J. DeSantis*
Lyndhurst, N. J.
Leroy S. Fletcher†
Texas A&M University, College Station, Texas
and
Lawrence S. Galowin‡
National Bureau of Standards, Washington, D. C.

VAN OOIJEN and Hoogendoorn[1] formulated an analysis of vapor flow in a heat pipe and built a laboratory model using a porous flat plate with injection and suction zones to represent the evaporator and condenser, respectively. Their paper is interesting and informative because it attacks a difficult problem from two viewpoints. The heat-pipe flow problem has attracted investigators for many years, but theoretical solutions have met with varying degrees of success. Few have attempted, as the authors have, to perform experiments to confirm their own analyses. The authors are to be commended for their care and attention to detail. Their paper, however, exhibits deficiencies in both the theoretical and laboratory models.

One of the authors' objectives was to explore pressure as an independent variable for steady incompressible, two-dimensional heat-pipe flow. Their claim to be the first to treat pressure as an independent variable is unfounded. Galowin et al.[2] analyzed the flow in a cylindrical porous tube which represented the condenser section of a heat pipe. The axial static pressure and the suction velocity were permitted to vary according to conservation principles. A second-order, ordinary, nonlinear differential equation was derived and integrated numerically to obtain flow property distributions. In both analyses, constant radial and normal static pressures in the condenser zone and Poiseuille flow at the condenser inlet were assumed.

A fundamental assumption used by van Ooijen and Hoogendoorn is that the suction velocity through the porous wall is constant in the condenser zone, viz., $v(x,0) = v_0$. Decoupling of the suction velocity in the flow equations is characteristic of similarity solutions. The analysis of Galowin et al. has revealed that flow distributions predicted by the similarity approach are incorrect.

A lengthy explanation of separation zones in the condenser section for $Re_r \geq 10$ is given. It is not clear whether recirculation is developed because of the numerical procedure or the physics of the flow. Many apparently suitable boundary conditions can show flow separation at stagnation points in sink or suction flow; however, many of these cases are not physically realistic. To "prove" their hypothesis the authors state that a sharp increase in measured pressure at the condenser end wall reveals a strong recirculation (in agreement with their numerical results). Actually, they have demonstrated only that the axial pressure increases in the vicinity of the stagnation point, which is in agreement with the analysis of Galowin et al. and the results of Quaile and Levy.[3]

Van Ooijen and Hoogendoorn emphasize that at higher values of Re_r (e.g., 50) the stream patterns in the evaporation and condensation zones become strongly coupled. The conclusion is that any calculation denying this coupling will lead to incorrect results. The fact is that the flow has been decoupled a priori by assuming that v_0 is constant no matter what Re_r is chosen. A constant v_0 can cause the appearance of recirculation zones to satisfy continuity and can account for the deviations from Poiseuille velocity profiles at high Re_r. Thus, there appears to be a contradiction in their conclusion.

The next part of our discussion concerns the laboratory model. The suction velocity cannot be uniform in their experiment because of the sintered steel plate. Studies conducted with sintered porous walls for rocket and jet engine cooling have demonstrated that both lateral and normal velocity components occur at the wall. More importantly, in this experimental arrangement most of the flow entering the condenser section will exit near the downstream end, because the only mechanism for changing the momentum vector is the stagnation zone and not the sintered porous plate. Only a very carefully designed thin porous wall containing small circular holes, i.e., orifices which vary in diameter and are distributed appropriately over the axial length, will produce a uniform outflow.

The nonuniformity of v_0 is borne out by Fig. 14 of the authors' paper which shows that the varying internal pressure levels are lower toward the downstream end of the condenser. The interpretation is that the flow velocity through the wall is higher where the larger pressure differences occur across the wall and variable over the length, not constant as they assume.

In conclusion, we would like to offer two suggestions to improve an already promising study put forth by van Ooijen and Hoogendoorn. The analysis should be recast to permit variation of the suction velocity in the condenser section. This can be done by relating pressure to velocity in the form of Darcy's law:

$$(v_0)_{\text{wall}} \sim \mathrm{d}p/\mathrm{d}r$$

By combining this expression with the continuity and momentum equations, the suction velocity and injection for the evaporator and axial static pressure are obtained in a naturally coupled way from the conservation principles. The radial pressure gradient can be approximated by the pressure difference between the exterior and interior of the porous wall or simply the gage pressure.

Finally, if the condition of the constant v_0 is enforced, the experimental model must be modified by replacing the sintered porous wall with a specially designed plate. Careful measurements then can be made to demonstrate that the suction and injection flows are indeed uniform.

Received July 28, 1980.

*Engineering Consultant.

†Professor and Associate Dean, College of Engineering. Associate Fellow AIAA.

‡Senior Engineer, Building Service Systems Program. Member AIAA.

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