Internal Temperature Distributions in an Operational Heat Pipe

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Theme

FOR the first time in an operational heat pipe, *internal* temperature distributions are measured for three wick designs and two fluids. In all cases a vapor film formed adjacent to the evaporator wall and in most cases film boiling occurred at high-heat fluxes. Speculations are offered concerning burnout mechanisms in heat pipes with low-conductivity fluids.

Content

In recent years there has been a great deal of research conducted on various aspects of heat pipe design and operation. However, experimental evaluations have been limited by a lack of sufficient data, most notably the absence of temperature measurements internal to the heat pipe container. In this paper results of internal temperature measurements in an operational heat pipe are reported utilizing both water and methanol as working fluids.

Although Winter and Barsch[1] have reviewed most of the significant heat pipe research, the work of Phillips[2] is more pertinent to our results since he also dealt with water and methanol as working fluids. He found that "burnout" heat fluxes were over twice as large for water than for methanol although it must be pointed out that his experiments were not conducted in an operational heat pipe. At this point it is also important to note that in all the heat pipe literature to date, burnout is defined as that point at which the external heater temperature no longer increases in a linear fashion with power. As we shall show this is not necessarily indicative of heat pipe failure as implied in previous works.[2-4] The only investigator to report the actual measurement of an internal temperature in an operational heat pipe was McSweeney.[5] Using a single thermocouple which could be traversed along the longitudinal axis of the pipe, McSweeney claimed that burnout could be detected by a large temperature *decrease* in the vapor section of the pipe. As Winter and Barsch[1] point out, this puzzling result might be due to the presence of noncondensables in the condenser portion of his pipe.

Convinced that only through internal measurements could we achieve the required degree of insight into heat pipe operation, we instrumented a 1.5 in. heat pipe with twenty-six internal thermocouples at the locations shown in Fig. 1. In addition we also measured the temperature of the outer heat pipe wall at each of the ten axial stations. Since the thermocouple bundle occupied a maximum of 7.5% of the vapor cross section in the condenser section and only 2% in the heater section, no obvious interference of the thermocouples with the heat pipe performance was noted during the experiments. In addition to the two fluids, two extreme wick designs were also evaluated. One design, typical of some conventional heat pipes, consisted of five layers of 100 mesh stainless-steel screen (0.05 in. thick). The other, a *dual wick* along the lines of that advocated by Kemme,[6] consisted of one layer of 16 mesh stainless-steel screen adjacent to the pipe wall and three layers of 100 mesh screen with a total thickness of 0.05 in.

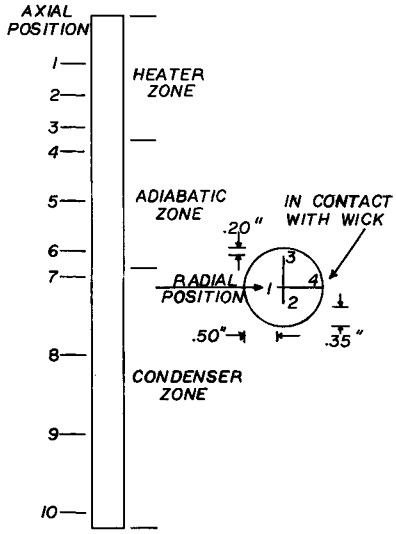

Fig. 1 Thermocouple positions.

The first experiments were conducted with water and the dual wick. At power levels below 400 w the internal temperature distribution was remarkably uniform, differing by no more than 2°F at any point within the pipe. However, at higher power levels the internal temperature distribution was found to be extremely erratic with no apparent consistency. For example, at a power level of 1 kw, adjacent thermocouples in the heater section differed by as much as 80°F. After a large number of experiments it was concluded that we were witnessing a type of boiling phenomena which caused large quantities of superheated vapor to blow through the wick and subsequently impinge on specific thermocouples. The truly surprising result however was that the pipe continued to operate (nonisothermally) even at power levels over twice those at which superheated vapor was first detected.

We then postulated that the 16 mesh portion of the wick was responsible for the formation of a vapor film adjacent to the wall which, at higher power levels, was able to blow through the 100 mesh portion of the wick, i.e., film boiling. To substantiate this hypothesis we conducted a number of experiments with a "modified" wick design. This wick consisted solely of 100 mesh screen except for a small portion (0.75 in. wide) of the dual wick just upstream of station 3. As expected, the first signs of superheated vapor occurred at station 3, although, at higher power levels, superheated vapor was generated throughout the entire evaporator section.

Since we had the ability to monitor the temperatures of both the outside pipe wall and of the vapor-liquid interface, the temperature drop across the wick in the evaporator section could be

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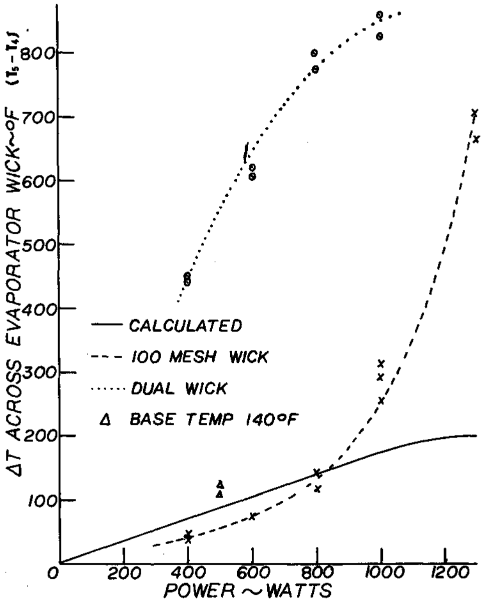

Fig. 2 A Comparison of evaporator wall temperatures (fluid: H_2O; base temperature: 180°F).

compared to calculated predictions. Figure 2 shows these results for water at a base temperature of 180°F (arbitrarily chosen as the temperature of the wick interface at station 9). Here the calculated values are based on the assumption that the wick is saturated with liquid. As can be seen, the dual wick is associated with temperature drops far in excess of that predicted by calculations. It is apparent that a large thermal resistance is present in the dual wick which can be accounted for by the presence of a vapor film with a thickness equal to the thickness of the wick which is occupied by the 16 mesh screen. While this is true at all power levels for the dual wick (although no superheated vapor was detected below 400 w), the results are quite different for the wick consisting only of 100 mesh screen. In this case the results are lower than predicted at low power levels and is apparently due to a recession of the liquid within the wick.[7] However, once the power level reaches 800 w there is clear evidence of the formation of a vapor film. With this wick the first signs of superheated vapor were not detected until the power had reached 1300 w. It is interesting to note that by the criteria of prior investigators, burnout should occur with the 100 mesh wick at 900 w although our pipe continued to operate at powers much above that point. The two triangular data points refer to runs made at a lower base temperature of 140°F and reflect an expansion of the vapor film as the saturation pressure is reduced. This was observed with all wicks and the two fluids and is consistent with Phillips'[2] results.

Experiments were also conducted utilizing methanol in the modified wick. As would be expected, the performance of methanol was much poorer than that of water. At a base temperature of 180°F film boiling first occurred with methanol at 600 w while it did not occur until 800 w with water. One interesting observation of the methanol experiments was that the vapor film did not appear until the initiation of boiling while it was present at all power levels above 200 watts during the water runs. Since the saturation pressure of methanol is nearly five times that of water at this temperature it would appear that at low power levels, higher pressures completely prohibit vapor formation in the wick. This is consistent with Schwartz's[8] results which showed that at higher saturation pressures his heat pipe capacity trebled despite the employment of a less desirable fluid.

There are some important implications of this work concerning burnout mechanisms in low temperature heat pipes. One question which must certainly be asked is whether previous investigators have actually witnessed heat pipe burnout or the initial formation of a vapor film. While it is true that our dual wick is not a good wick design, the fact that the same phenomena occurred with the 100 mesh wick lends a measure of support to the hypothesis that heat pipe failure will always be preceded by a type of film boiling, at least for low thermal conductivity fluids. Whether the actual failure will be due to a cessation of liquid flow, an unacceptable wall temperature or condenser limitations will depend on the pipe design being employed and is in need of investigation. Failure due to condenser limitation may be an important factor which has been overlooked. We base this statement on our observation of the generation of large quantities of noncondensables which appeared whenever film boiling was occurring. This is in spite of exhaustive outgassing procedures prior to the operation.[9]

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