ME 3264: LAB 2

Heat Pipe

Spring 2023

OBJECTIVE

The objectives of this laboratory are as follows:

a) Understanding the heat transfer characteristics of a heat pipe.

b) Observing the thermal response time of a heat pipe in comparison to a copper rod.

c) Measuring the response time and temperature profile along the heat pipe.

d) Calculating the effective thermal conductivity of the heat pipe and comparing it with high thermal conductivity materials.

BACKGROUND AND ANALYSIS

Heat pipes are passive heat transfer devices that transfer energy with a much smaller energy drop than solid devices made of high thermal conductivity materials. Heat pipes combine the principles of thermal conductivity and phase transition to effectively transfer thermal energy between two solid interfaces.

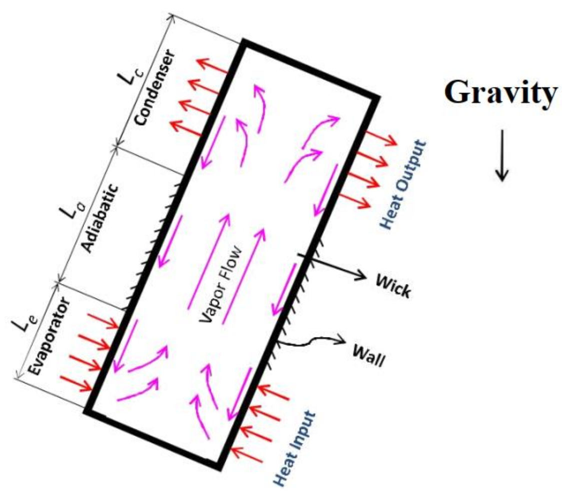

Figure 1: Schematic of heat pipe

In general, heat pipes consist of a shell (wall), a wick and a small amount of working fluid, as shown in Figure 1. Typically, three sections can be identified in a heat pipe: the evaporator, the condenser, and the adiabatic sections. The evaporator section absorbs heat from a high temperature source and vaporizes the working fluid inside. The vapor then flows through the adiabatic section and condenses at the condenser section, releasing its latent heat of condensation to a low temperature source. The condensed liquid returns to the evaporator through the wick driven by capillary force (Fig. 1).

This capillary force can be aided by or (for some operating orientations) replaced by gravitational or centrifugal force.

For one dimensional heat conduction in a solid rod of length L (m) and conductivity k ($W \cdot m^{-1} \cdot K^{-1}$), the heat flux q ($W \cdot m^{-2}$) can be expressed according to Fourier's law (assuming a linear temperature profile in the rod):

$$q = k\frac{\Delta T}{L} \tag{1}$$

where ΔT is the is the temperature difference (K) between the hot and cold ends.

To quantify the performance of a heat pipe, the concept of effective thermal conductivity k_{eff} is introduced. Effective thermal conductivity is a conductivity that a hypothetical rod with the same diameter as the heat pipe must have to be able to transfer the same amount of heat as the heat pipe over the same effective length L_{eff}.

$$L_{eff} = \frac{L_e}{2} + L_a + \frac{L_c}{2} \tag{2}$$

where L_e, L_a, and L_c are the lengths of the evaporator, adiabatic, and condenser sections of the pipe, respectively.

The thermal resistance, R ($K \cdot W^{-1}$), of such a hypothetical rod would be:

$$R_{HP} = \frac{\frac{L_e}{2}+L_a+\frac{L_c}{2}}{k_{eff}A_c} = \frac{(T_{e,ave}-T_{c,ave})}{Q_{HP}} \tag{3}$$

where $T_{e,ave}$ and $T_{c,ave}$ are the average evaporator and condenser temperatures, and Q_{HP} is the heat transfer rate (W) through the heat pipe.

The effective thermal conductivity is then:

$$k_{eff} = \frac{\left(\frac{L_e}{2}+L_a+\frac{L_c}{2}\right)Q_{HP}}{(T_e-T_c)A_c} \tag{4}$$

and the heat flux through the heat pipe, q_{HP}, can be expressed as:

$$q_{HP} = k_{eff}\frac{\Delta T}{L_{eff}} \tag{5}$$

SUGGESTED READING

1. Faghri, A., 2012, "Review and Advances in Heat Pipe Science and Technology," *J. Heat Transfer*. 134(12) 123001. **(In HuskyCT)**
2. Faghri, A., 1995 "Heat Pipe Science and Technology", Taylor & Francis Group, Washington, DC
3. "Heat Pipe Technology: Passive Heat Transfer for Greater Efficiency," Aavid Thermocore, https://web.archive.org/web/20170617085721/http:/www.thermacore.com/thermal-basics/heat-pipe-technology.aspx

EQUIPMENT AND DESCRIPTION

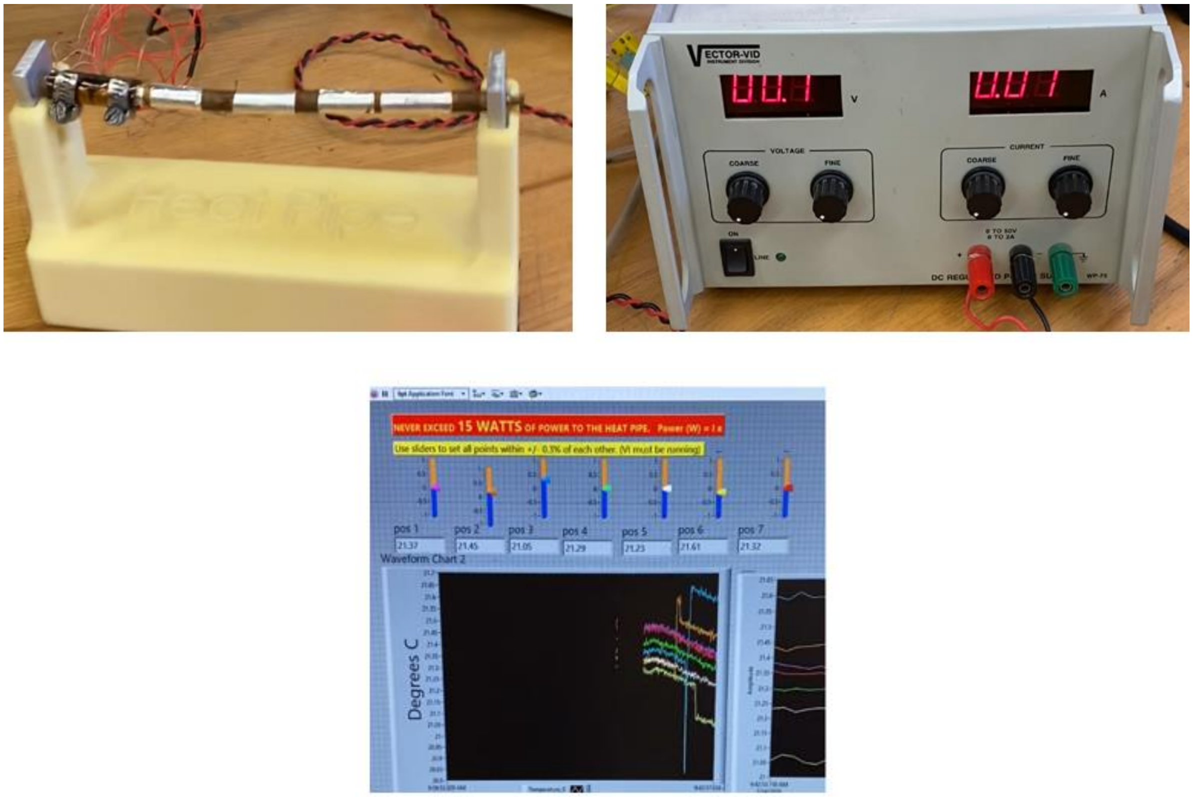

Figure 2: Lab Equipment

- 0.2 m long copper-water heat pipe with an outer diameter of 8 mm, equipped with:
    - Flexible resistance heating element
    - k-type thermocouples
- Digital variable regulated DC power supply
- Data acquisition system (DAQ)
- Computer with data processing software LabView
- Example copper water heat pipe
- Example copper rod
- Cold and hot water

Instrumentation has been applied to the 0.2m heat pipe. The resistance heater is attached to the evaporator end (L_e is 45mm) and three thermocouples have been installed beneath the heater. The rest of the heat pipe is exposed to the air and cooled by natural convection, serving as the condenser section (L_c is 155mm). Four thermocouples have been placed along the condenser length.

The thermocouple readings over time can be read in LabView and saved to Excel.

The thermal energy (i.e., wattage) applied to the heat pipe can be varied by adjusting the power supply, remembering that power is the product of voltage and current.

PROCEDURE

1. Before applying heat to the heat pipe, zero the thermocouples using the sliders in the LabView VI. Make sure they are all reading the ambient temperature to within ±0.3% of one another.
2. Start the VI running and leave it running for the duration of the experiment. **You will need to save the recorded data for analysis**.
3. Turn the heater on and apply 3±0.1 W of heat to the evaporator section of the heat pipe.
4. Wait for the heat pipe to reach steady state (~15 minutes). The temperature variation of each point within 1 minutes should be less than ±0.5°C. Note the input power and temperature readings of the thermocouples.
5. Increase the power to the evaporator by 3W. There is no need to let the heat pipe cool before increasing the wattage (i.e., **do not turn off the heater**).
6. Repeat steps 5-6 until the average evaporator temperature exceeds 100°C or you reach 15W of applied power to the heat pipe.
7. Export the temperature vs. time data by right clicking the graph in the LabView VI.
8. While waiting for the heat pipe to heat between wattage changes, qualitatively experiment with the free heat pipe and copper rod. Immerse one end in cold or hot water and feel the difference in temperature drop between the pipe and the rod.
9. Zero the output and turn off the power supply when finished.

REPORT REQUIREMENTS

1. Report your qualitative observations of the responses of the heat pipe and copper rod
2. Use the measured heat pipe data to produce a graph that shows the variations in average evaporator and condenser temperatures with time
3. Use the measured heat pipe data to produce a graph that shows the variations of input power to the heat pipe vs. the temperature drop along the heat pipe ($T_{e,ave} - T_{c,ave}$).
4. Calculate the effective thermal conductivity, k_{eff}, for each input power based on your data. How does this compare to the thermal conductivity of copper?
    a. Include uncertainty estimates for your effective conductivity calculations
    b. Assume negligible uncertainties in the dimensions of the heat pipe
    c. Assume only zero-order (1/2 resolution) uncertainty in the voltage and amperage supplied by the power supply
    d. When considering the uncertainty in the temperature measurements, you may either use a mean (i.e., the average evaporator and average condenser temps) and 95% confidence interval using Student's t-tables, or a 2σ (95%) confidence interval based on

the signal noise (i.e., twice the standard deviation of the temperature measurement at steady state).

5. Produce a graph showing the relationship between the input power and effective thermal conductivity of the heat pipe. How does the effective thermal conductivity change with increasing input power?
6. Using your qualitative and quantitative observations, what can you say about the difference in performance between a solid copper rod and a copper/water heat-pipe?
7. **You are limited to 5 pages (not including the Title Page, References, or Appendix) and must include at least two figures in your report.**
8. **Due at the start of your lab section two weeks after completing the lab, in hard-copy and digitally.**
9. **This is a joint assignment – only one of your group needs to submit the report.**