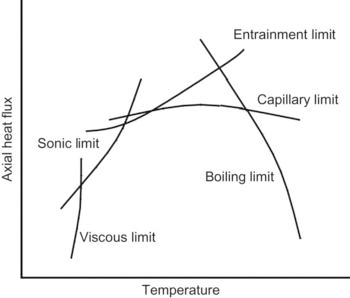
Heat Pipes – Theory and Design

# 1.0 Overview

Overall Thermal Resistance of a Heat Pipe (should be low):

Operating limits for a wicked heat pipe (limits may be considered in isolation):



* To operate,
  + Where is **the maximum capillary pumping pressure**
  + is the pressure drop required to return liquid from the condenser to evaporator
  + is the pressure drop required to cause vapor to flow from evaporator to condenser
  + is the pressure due to the **gravitational head** (inclination dependent)

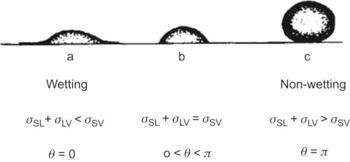
The maximum allowable heat flux for which the equation above remains true is the **capillary limit**.

# 2.0 Theory

**Gravitational Head Pressure Difference:**

* – liquid density
* – gravitational acceleration
* – length of the heat pipe
* – angle b/w pipe and horizontal, evaporator above condenser is positive

**Surface Tension:**

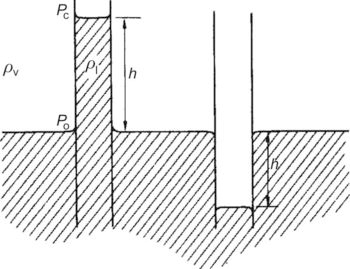


* – surface energy per unit area between solid and liquid
* – surface energy per unit area between liquid and vapor
* – surface energy per unit area between solid and vapor
* – contact angle

**In heat pipes, wetting liquids are always used, as the give rise to capillary action!**

**If contact angle is negative, liquid resists capillary action!**

**Capillarity (capillary action):**

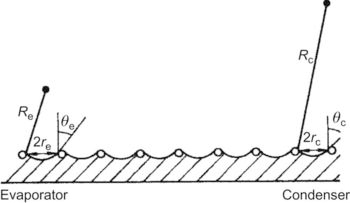
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Capillary action (for a circular tube of radius r):

* liquid density
* – vapor density
* – contact angle

Capillary force:

Capillary Pressure…



Capillary Pressure At Evaporator:

* – the effective radius of the wick pores
* – contact angle

Capillary Pressure At Condenser:

**Flow Regimes -** For fully developed flows:

Reynolds number:  
laminar/turbulent transition in heat pipe: 2100 … <2100 is laminar, >2100 is turbulent

* – Reynolds number
* – fluid density
* – velocity
* – hydraulic diameter (representative dimension) =
* – dynamic viscosity

Velocity:

*For detailed velocity/pressure gradient relationships see Chapter 2 Section 2.3.3.2*

*See 2.3.3.3 For Turbulent Flow Equations*

**Liquid Phase Pressure Difference (Flow in Wicks):**

Mass flow varies in the evaporator and condenser regions, so an effective length is necessary.

* = total effective length for fluid flow
* = adiabatic section length
* = length of the condenser section
* = length of the evaporator section

For homogeneous wicks:

* – Flow cross-sectional area
* – The fractional void of the wick
* – The outer radius of the wick
* – The inner radius of the wick
* – dimensionless constant to account for tortuosity (10 < b < 20), b = 8 for round tubes.
* – heat input =
* L – Latent hear of vaporization

**OR**

**Darcy’s Law:**

* – wick permeability

*See section 2.3.4.3 for Non-Homogeneous Wicks*

**Vapor Phase Pressure Difference:**

Radial Reynolds Number (positive in evaporator section, negative in condenser section):

* radial velocity component

Total vapor pressure drop in the evaporator region (laminar flow assumption):

Total vapor pressure drop in the condenser region (laminar)

Total vapor pressure drop in the adiabatic region (laminar):

Therefore, total vapor pressure drop with **NO pressure recovery:**

And, total vapor pressure drop with **FULL pressure recovery:**

**Entrainment:**

Weber number (We) is the ratio of inertial vapor forces to liquid surface tension forces. It gives an idea of how likely entrainment will be:

* – a dimension characterizing the vapor-liquid surface. (related to wick spacing in a heat pipe)

Entrainment may occur when We is of the order 1. Therefore, the limiting vapor velocity is