Heat Pipe Selection

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Heat pipes are being used very often in particular applications when conventional cooling methods are not suitable. Once the need for heat pipe arises, the most appropriate heat pipe needs to be selected. Often this is not an easy task, and the following needs to be considered.

How to select a heat pipe?

1) Investigate and determine the following operational parameters:
    a. Heat load and geometry of the heat source.
    b. Possible heat sink location, the distance and orientation relative to the heat source.
    c. Temperature profile of heat source, heat sink and ambient
    d. Environmental condition (such as existence of corrosive gas)
2) Select the pipe material, wick structure, and working fluid. (consult with an Enertron engineer or original heat pipe manufacturer to select the most appropriate heat pipe)
    a. Determine the working fluid appropriate for your application
    b. Select pipe material compatible to the working fluid
    c. Select wick structure for the operating orientation
    d. Decide on the protective coating.
3) Determine the length, size, and shape of the heat pipe (consult with Enertron engineer) Fig 1 gives the performance of heat pipes with diameter from 3 to 22.23mm.

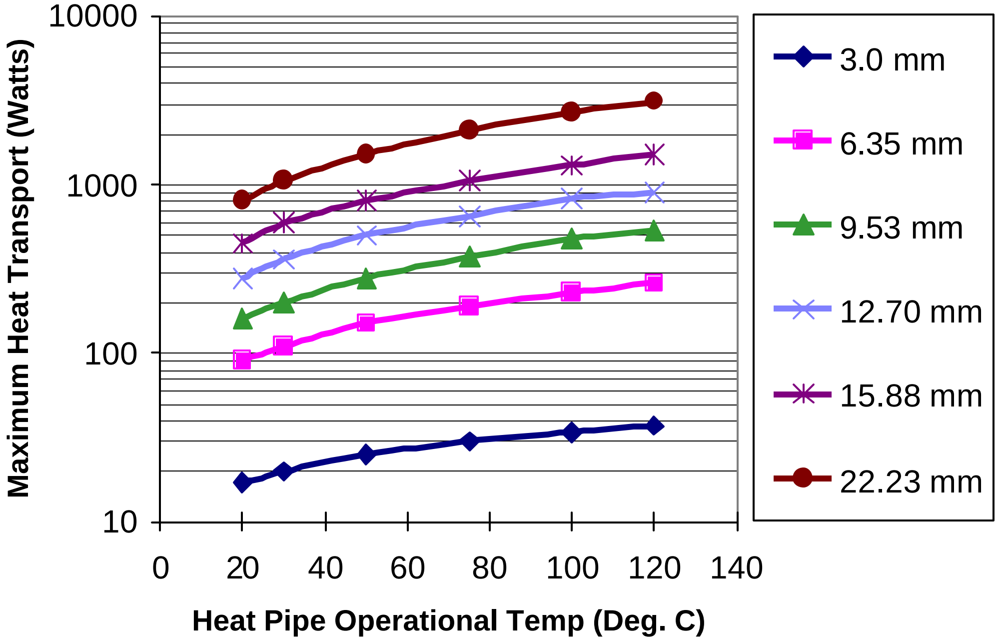

Fig 1. Performance of copper water groove heat pipe at vertical orientation (gravity assist)

What materials can be used to construct a heat pipe?

A particular working fluid can only be functional at certain temperature ranges. Also, the particular working fluid needs a compatible vessel material to prevent corrosion or chemical reaction between the fluid and the vessel. Corrosion will damage the vessel and chemical reaction can produce a non-condensable gas.

Refer to Table 1. For example, the liquid ammonia heat pipe has a temperature range from –70 to +60^{o}C and is compatible with aluminum, nickel and stainless steel.

Table 1. Typical Operating Characteristics of Heat Pipes

Temperature Range (°C)	**Working Fluid**	**Vessel Material**	**Measured axial[8] heat flux (kW/cm^2)**	**Measured surface[8] heat flux (W/ cm^2)**
-200 to -80	Liquid Nitrogen	Stainless Steel	0.067 @ -163°C	1.01 @ -163°C
-70 to +60	Liquid Ammonia	Nickel, Aluminum, Stainless Steel	0.295	2.95
-45 to +120	Methanol	Copper, Nickel, Stainless Steel	0.45 @ 100°C[X]	75.5 @ 100°C
+5 to +230	Water	Copper, Nickel	0.67 @ 200°C	146@ 170°C
+190 to +550	Mercury⋆ +0.02% Magnesium +0.001%	Stainless Steel	25.1 @ 360°C*	181 @ 750°C
+400 to +800	Potassium⋆	Nickel, Stainless Steel	5.6 @ 750°C	181 @ 750°C
+500 to +900	Sodium⋆	Nickel, Stainless Steel	9.3 @ 850°C	224 @ 760°C
+900 to +1,500	Lithium⋆	Niobium +1% Zirconium	2.0 @ 1250°C	207 @ 1250°C
1,500 + 2,000	Silver⋆	Tantalum +5% Tungsten	4.1	413

[8] Varies with temperature

[X] Using threaded artery wick

*Tested at Los Alamos Scientific Laboratory

⋆Measured value based on reaching the sonic limit of mercury in the heat pipe

Reference of “Heat Transfer”, 5th Edition, JP Holman, McGraw-Hill

The liquid ammonia heat pipe has been widely used in space and only aluminum vessels are used due to lightweight. Water heat pipes, with a temperature range from 5 to 230 ^{o}C, are most effective for electronics cooling applications and copper vessels are compatible with water.

Heat pipes are not functional when the temperature of the pipe is lower than the freezing point of the working fluid. Freezing and thawing is a design issue, which may destroy the sealed joint of a heat pipe when place vertically. Proper engineering and design can overcome this limitation.

What are the four heat transport limitations of a heat pipe?

The four heat transport limitations can be simplified as follows;

1) *Sonic limit* – the rate that vapor travels from evaporator to condenser.
2) *Entrainment limit* – Friction between working fluid and vapor that travel in opposite directions.
3) *Capillary limit* – the rate at which the working fluid travels from condenser to evaporator through the wick.
4) *Boiling limit* – the rate at which the working fluid vaporizes from the added c heat

What is the common wick structure?

There are four common wick structures used in commercially produced heat pipes; groove, wire mesh, powder metal and fiber/spring. Each wick structure has its advantages and disadvantages. There is no perfect wick. Refer to Fig. 2 for a brief glance of actual test performance of four commercially produced wicks. Every wick structure has its own capillary limit. The groove heat pipe has the lowest capillary limit among the four, but works best under gravity assisted conditions where the condenser is located above the evaporator.

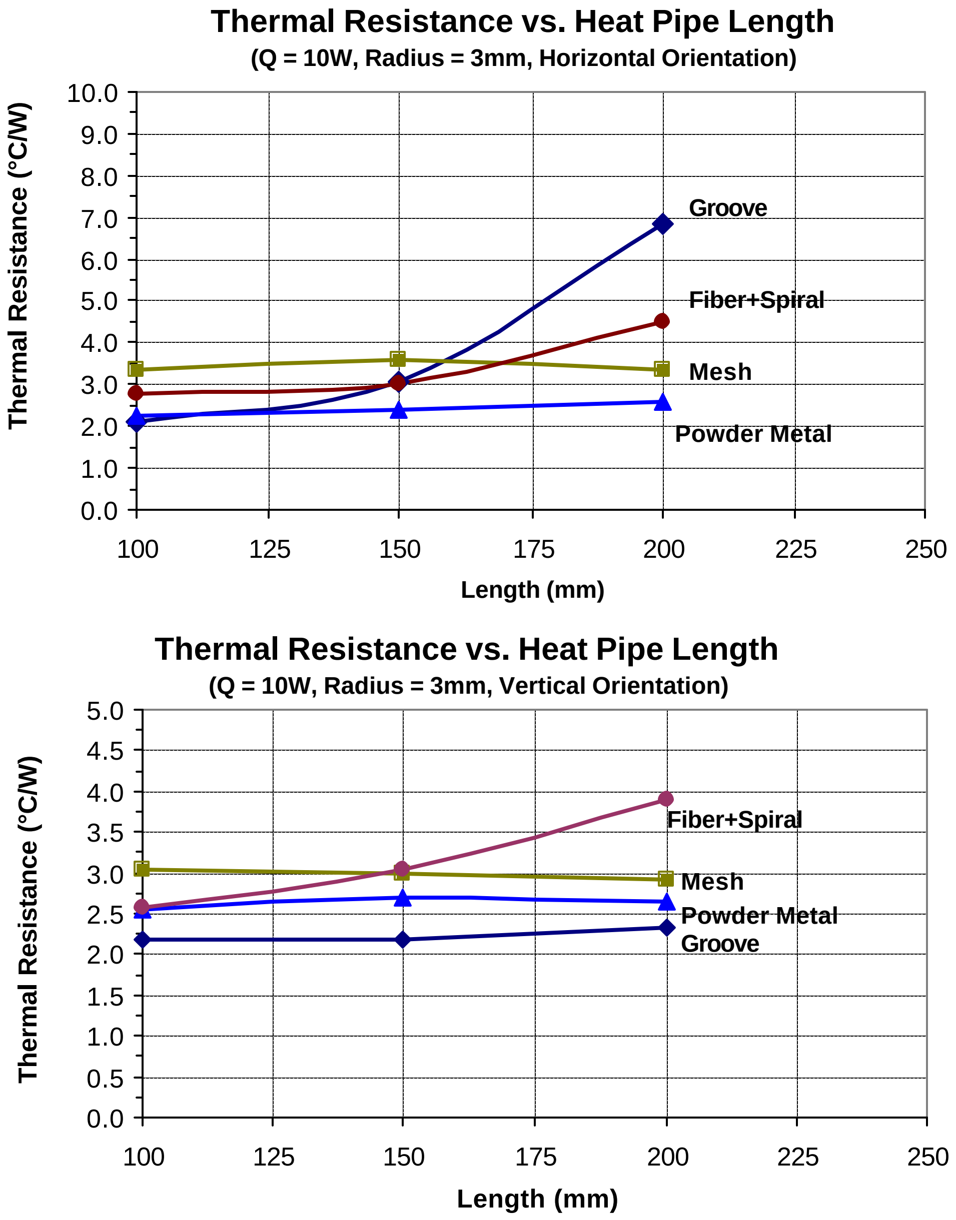

Fig 2. The actual test results of heat pipe with different wick structure at horizontal and vertical (gravity assist) orientations.

The rate of vapor traveling from the evaporator to the condenser is governed by the difference in vapor pressure between them. It is also affected by the diameter and the length of the heat pipe. In the large diameter heat pipe, the cross sectional area will allow higher vapor volume to be transported from the evaporator to the condenser than in a small diameter pipe. The cross sectional area of a heat pipe is the direct function for both the sonic limit and entrainment limit. Fig 3 compares the heat transport of heat pipes with different diameters. Also, the operational temperature of a heat pipe affects the sonic limit. We can see, in Fig 3, the heat pipes transport more heat at higher operational temperatures.

The rate of working fluid return from the condenser to the evaporator is governed by capillary limit and is the reciprocal function of the heat pipe length. A longer heat pipe transports less heat versus the same heat pipe with a shorter length. In Fig 3, the unit of the Y-axis is $Q_{max}L_{eff}$ (W-m) representing the amount of heat a pipe can carry per meter length. If the pipe is half a meter, it can carry twice the wattage.

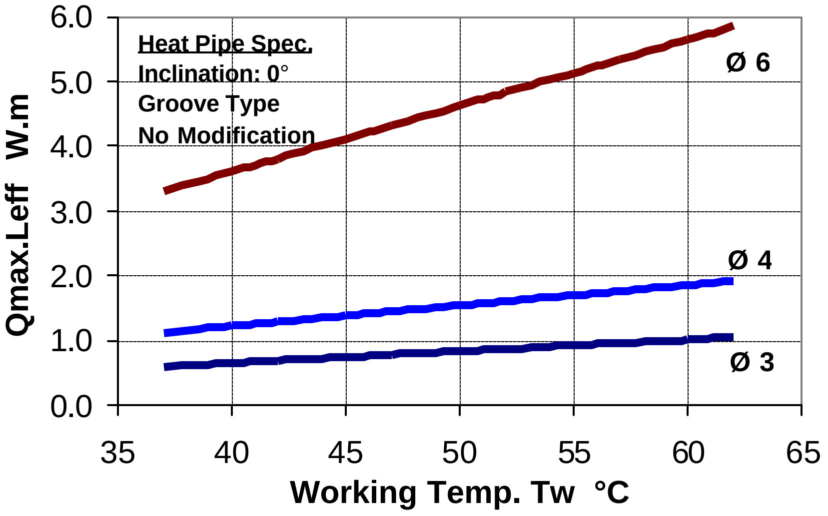

Fig 3. The performance of various groove wick copper water heat pipes

As it can be seen, the selection of an appropriate heat pipe can be a complicated process. For any assistance in this process you can consult with Enertron engineer.