Things to Consider When Designing With Heat Pipes
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As an effective heat conductor, heat pipe can be used in situations when a heat source and a heat sink need to be placed apart, to aid heat conduction of a solid, or to aid heat spreading of a plane. However, not every heat pipe is suitable for all applications. For that reason, the following need to be considered when designing with heat pipes:

1) Heat transport limitation of the heat pipe
2) Wick structure of the heat pipe
3) Length and diameter of the heat pipe
4) Heat pipe orientation
5) Effect of bending and flattening of the heat pipe
6) Heat pipe reliability

What are heat transport limitations of a heat pipe?

There are four heat transport limitations of a heat pipe:

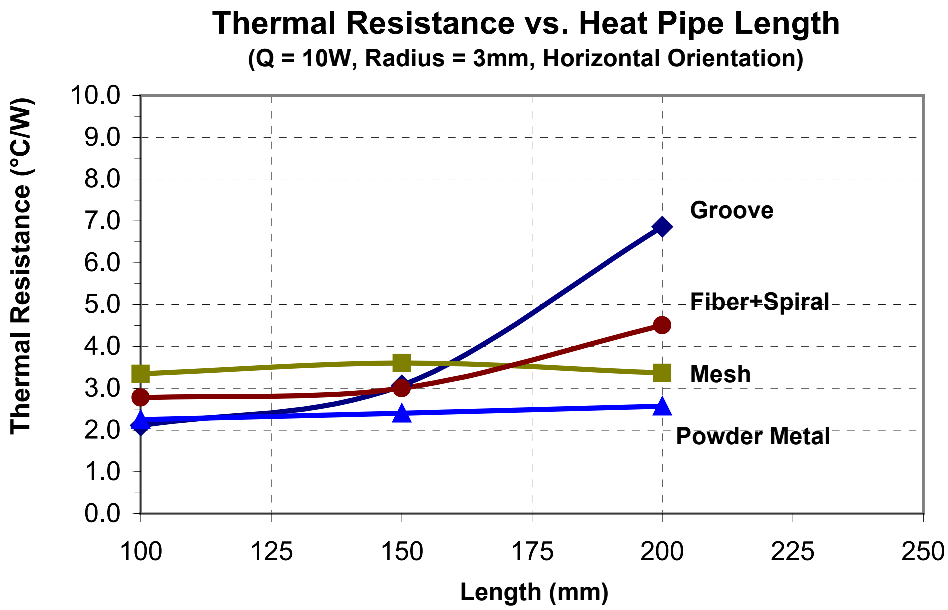
1) *Sonic limit* – the rate that vapor travels from evaporator to condenser.
2) *Entrainment limit* – Friction between working fluid and vapor which travel in opposite directions.
3) *Capillary limit* – the rate at which the working fluid travels from condenser to evaporator through the wick.
4) *Boiling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

What is a wick structure and how does it affect the performance of the heat pipe?

A heat pipe is a vessel whose inner walls are lined up with the wick structure. There are four common wick structures:

a) groove
b) wire mesh
c) powder metal
d) fiber/spring.

The wick structure allows the liquid to travel from one end of the heat pipe to the other via capillary action. Each wick structure has its advantages and disadvantages. Every wick structure has its own capillary limit. Fig. 1 depicts actual test performance of four commercially produced wicks. It can be seen that the groove heat pipe has the lowest capillary limit among the four but works best under gravity-assisted conditions.



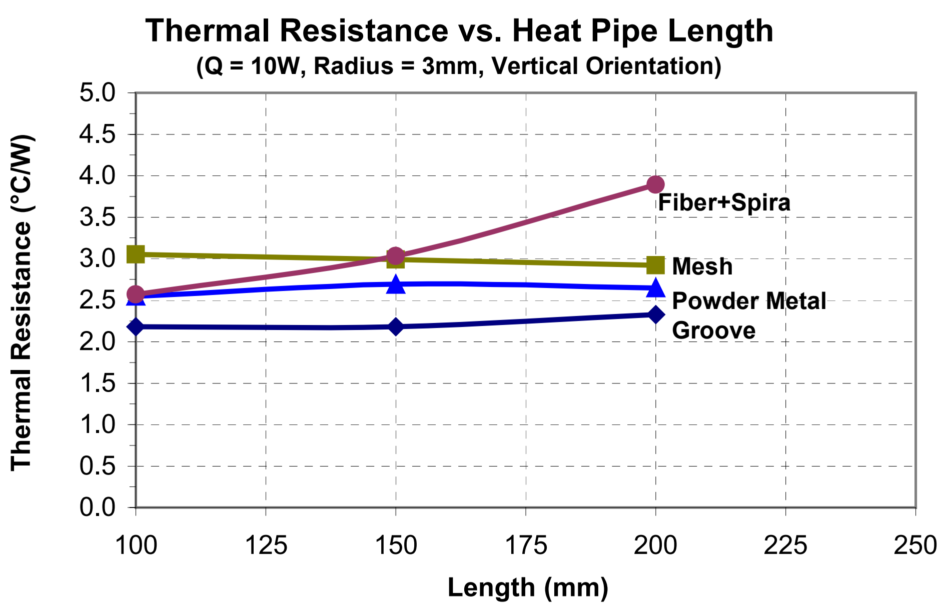


Fig 1. The actual test results of heat pipe with different wick structure at horizontal and vertical (gravity assist) orientations.

How does length and diameter affect the performance of the heat pipe?

The difference in vapor pressure between the condenser and the evaporator governs the rate at which the vapor travels between them. Also, the diameter and the length of the heat pipe affect the rate at which the vapor travels, and therefore need to be considered when designing with heat pipes.

Larger cross sectional areas of the heat pipe (i.e. larger diameter of the heat pipe) will allow higher vapor volume to be transported from the evaporator to the condenser. The cross sectional area of a heat pipe is the direct function of both the sonic and entrainment limit of the heat pipe. However, the operational temperature of the heat pipe also affects the sonic limit of the heat pipe. Fig 2 compares the heat transport for heat pipes with different diameters. One can see, that the heat pipes transport more heat at higher operational temperatures.

The rate of at which the working fluid returns from the condenser to the evaporator is governed by capillary limit and is the reciprocal function of the heat pipe's length. Longer heat pipe transports less heat than shorter heat pipes. In Fig 3, $Q_{max}L_{eff}$ (W-m) (i.e.Y-axis) represents the amount of heat a pipe will carry per meter length. Therefore, if the pipe is half a meter, it can carry twice the wattage a meter long heat pipe would carry.

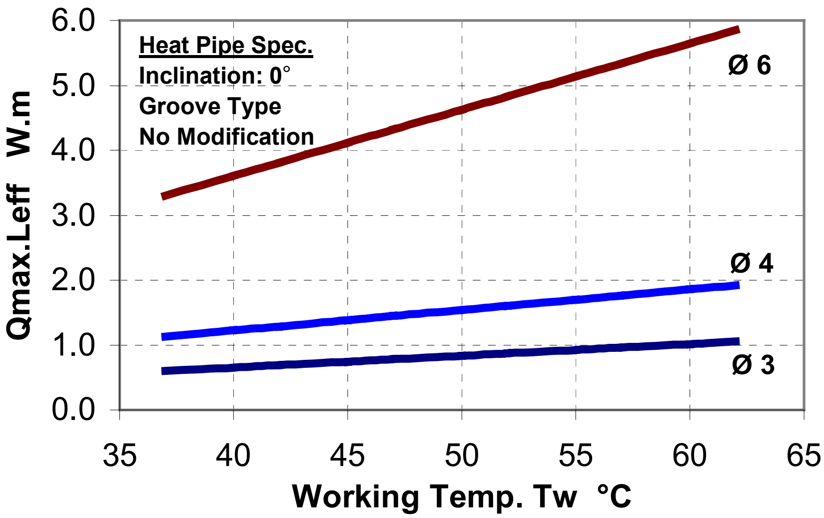


Fig 2. The performance of various groove wick copper water heat pipes

How does orientation affect the performance of heat pipes?

A wick structure with a higher capillary limit can transport more working fluid from the condenser to the evaporator against gravity. But as previously mentioned, the groove heat pipe, with the lowest capillary limit, works best under gravity-assisted conditions where the evaporator is located below the condenser. Fig 3 shows the effect of gravity on groove wick heat pipes.

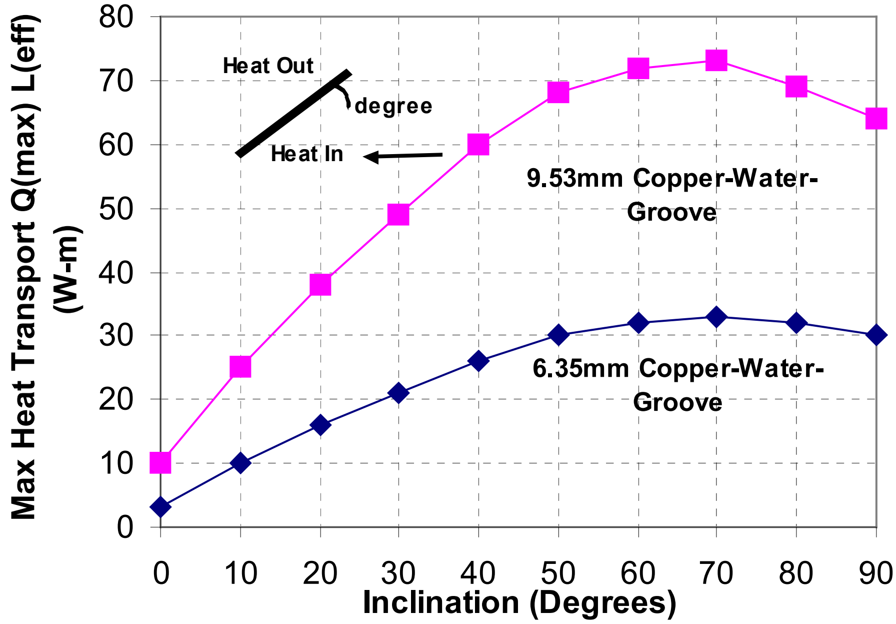


Fig 3. Groove wick heat pipe operated at inclination condition

How is the performance affected by heat pipe flattening or bending?

If a heat pipe is flattened or bent, the sonic limit and entrainment limit will be reduced in relation to the flattened thickness, the number of bends and the angle of each bend. Therefore, any flattening or bending to a heat pipe will reduce the amount of heat that can be transported. Fig 4 shows the effect of the flattening on a heat pipe.

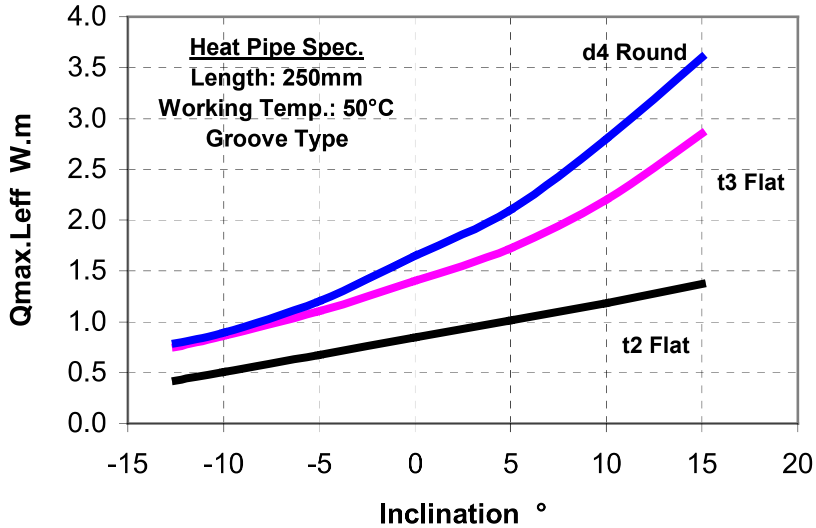


Fig 4. Comparison of round and flat heat pipes under different orientations.

Are heat pipes reliable?

Heat pipes have no moving parts and you are looking at 20 years MTBF operational. However, care must be given when designing and manufacturing the heat pipe. Two manufacturing factors can reduce the reliability of the heat pipe: the seal of the pipe and the cleanness of pipe internal chamber. Any leakage in the heat pipe will eventually fail the pipe. If the internal chamber is not thoroughly clean, when the heat pipe subjected to heat, the residual may generate non-condensable gas and degrade the pipe performance. Improper bending and flattening of the pipe may also cause the leakage on the pipe seal. There are some external factors that may also shorten the life of a heat pipe such as shock, vibration, force impact, thermal shock and corrosive environment.

Based on all of the designing criteria and limitations of the heat pipes, designing with heat pipes might not be an easy task. You can consult Enertron engineer for assist you in clarifying any design dilemmas, or other questions regarding heat pipes that you might have.