Contact an Engineer

ADVANCED COOLING TECHNOLOGIES

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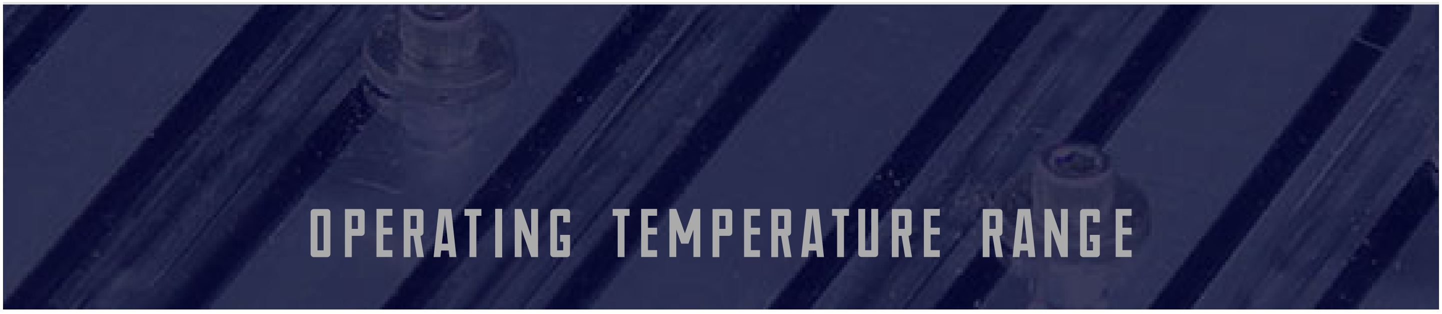

WORKING FLUIDS THEORETICALLY OPERATE FROM THE TRIPLE POINT TO THE CRITICAL POINT

Heat pipes are two-phase heat transfer devices. For a heat pipe to operate, a saturated working fluid is required, with both liquid and vapor in the heat pipe. The working fluid latent heat is transferred by vaporizing the liquid in the evaporator, and condensing the vapor back to liquid in the condenser. Theoretically, the heat pipe will operate at temperature just above the triple point (the unique temperature and pressure where the working fluid can be in liquid, vapor, and solid form), to just below the critical point (vapor and liquid have the same properties). As discussed below, there are other constraints that shrink the practical temperature range.

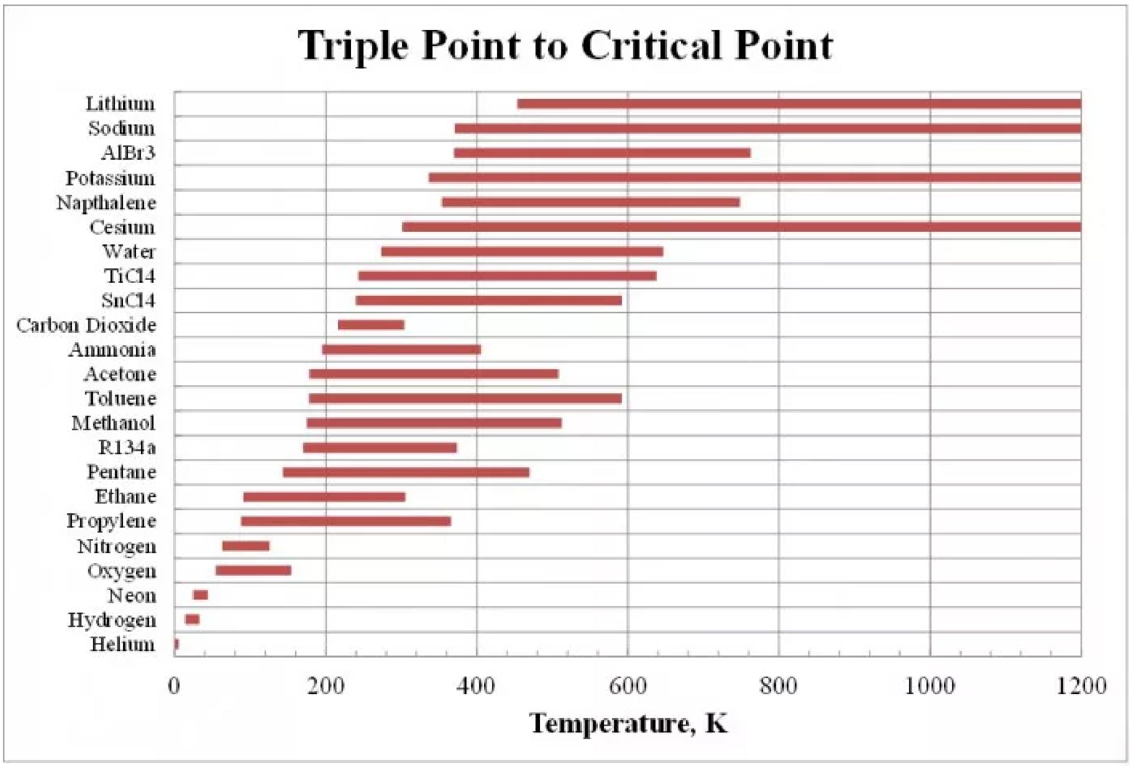

Figure (1)

The triple point and critical point for a number of common heat pipe working fluids are shown in Figure (1) and Table 1. Two points should be noted. First, there are gaps in the cryogenic heat pipe temperature range (below about 100 K), where there is no currently known working fluid.

Second, there are many potential working fluids at a given temperature, for temperatures above 200 K. The fluid selected is normally the fluid with the highest **Merit Number** when a **compatible heat pipe envelope** are acceptable. For example, while ammonia is a better-working fluid than methanol, methanol must be chosen when a copper wick and envelope are used. For large geothermal **thermosyphons** a fluid with a low global warming potential may be selected.

Table 1. Selected Heat Pipe Working Fluids, Triple Point and Critical Point. Freezing point is used for the halides, cesium, and lithium, since the triple point is unavailable.

*Scroll right to view table

Fluid	Triple Point Temp., K	Critical Point, K	Triple Point Temp., °C	Critical Point, °C
Helium	–	5.20	–	-268.0
Hydrogen	13.95	33.15	-259.2	-240.0
Neon	24.56	44.49	-248.6	-228.7
Oxygen	54.33	154.58	-218.8	-118.6

Nitrogen	63.14	126.19	-210.0	-147.0
Propylene	87.8	365.57	-185.4	92.4
Ethane	91	305.33	-182.2	32.2
Pentane	143.46	469.7	-129.7	196.6
R134a	169.85	374.1	-103.3	101.0
Methanol	175.5	512.6	-97.7	239.5
Toluene	178.15	591.75	-95.0	318.6
Acetone	178.5	508.1	-94.7	235.0
Ammonia	194.95	405.4	-78.2	132.3
Carbon Dioxide	216.58	304.1	-56.6	31.0
$SnCl_4$	240.15	591.85	-33.0	318.7

$TiCl_4$	243	638	-30.2	364.9
Water	273.16	647.10	0.0	373.9
Cesium	301.6	2045	28.5	1771.9
Napthalene	353.5	748.4	80.4	475.3
Potassium	336.35	2239	63.2	1965.9
$AlBr_3$	370.15	763	97.0	489.9
Sodium	370.98	2507	97.8	2233.9
Lithium	453.64	3503	180.5	3229.9

PRACTICAL TEMPERATURE LIMITS FOR WORKING FLUIDS

In practice, the fluid range is smaller, at both the low and high end of the temperature range. For example, a water heat pipe will carry some power between the water triple point (0.01°C) and the critical point (373.9°C). Maximum power calculations for a typical water heat pipe are shown in Figure 5. The peak power occurs at a temperature near 150°C), and drops off at lower and higher temperatures. Practically, most water heat pipes are designed to operate above ~25°C). At lower temperatures, the vapor pressure decreases, as well as the vapor density, so the vapor velocity for a given amount of p increases. At temperatures below about 25°C, the viscous and sonic limits become important, limiting the heat pipe power.

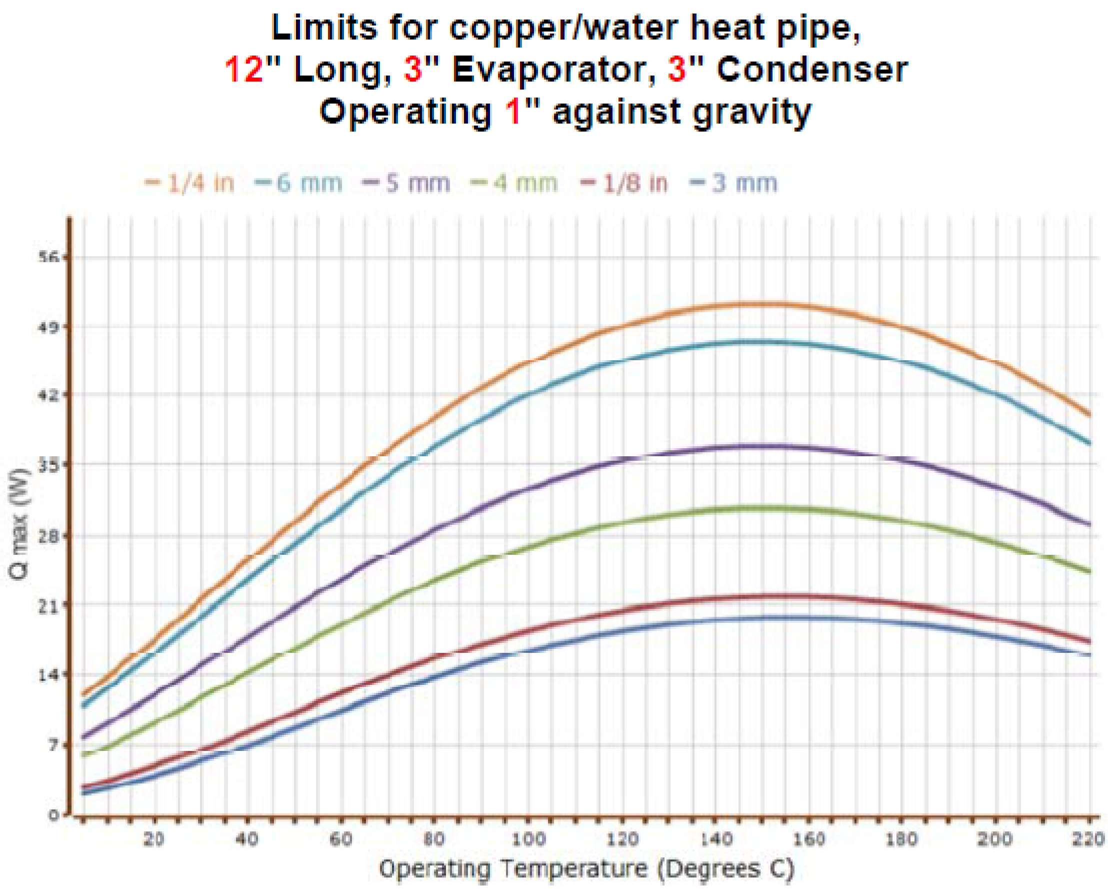

Figure (2) Heat pipe performance typically peaks somewhere in the middle of the temperature range between the triple point and the critical point.

PRACTICAL OPERATING TEMPERATURES FOR WATER

The practical upper temperature limit for copper/water heat pipes is roughly 150°C, and is set by the maximum allowable stresses in the copper envelope; see Figure 6. At 150°C, the saturated water vapor pressure is 69 psia (477 kPa). Since copper is relatively soft, the required diameter at wall thickness above 150°C C becomes impractical.

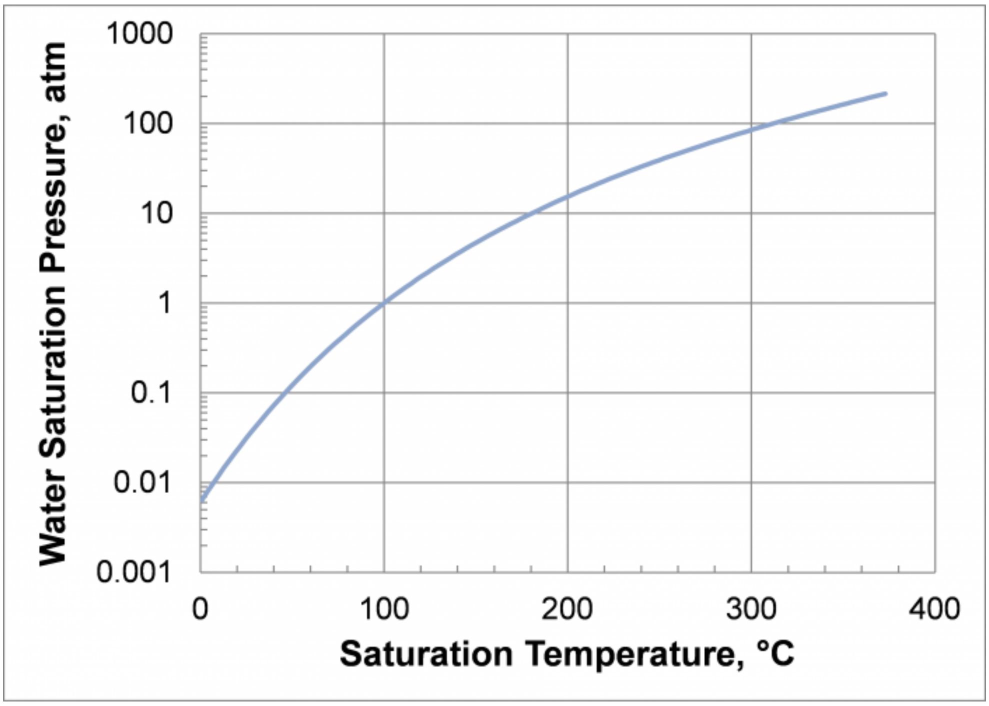

Figure (3) Saturated Water Vapor Pressure as a Function of Temperature.

Titanium or Monel envelopes increase the maximum operating temperature range for water to 300°C. In this case, the upper temperature limit is set by the fluid properties. As with any saturated fluid, the saturated vapor and liquid properties become more and more similar as the critical point is approached. A good heat pipe working fluid has a large latent heat and a large surface tension. As shown in Figure 7 and Figure 8, both the latent heat and the surface tension approach zero near the critical point (373.9°C).

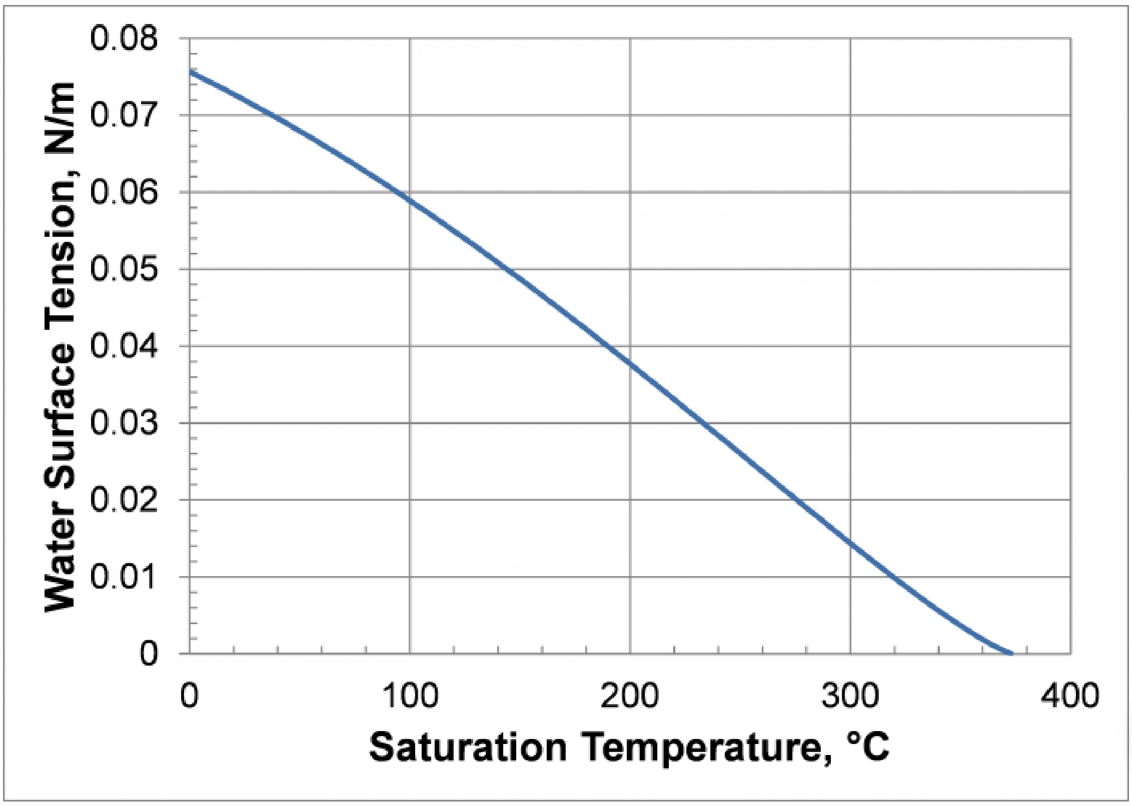

Figure (4) Water Surface Tension as a Function of Temperature.

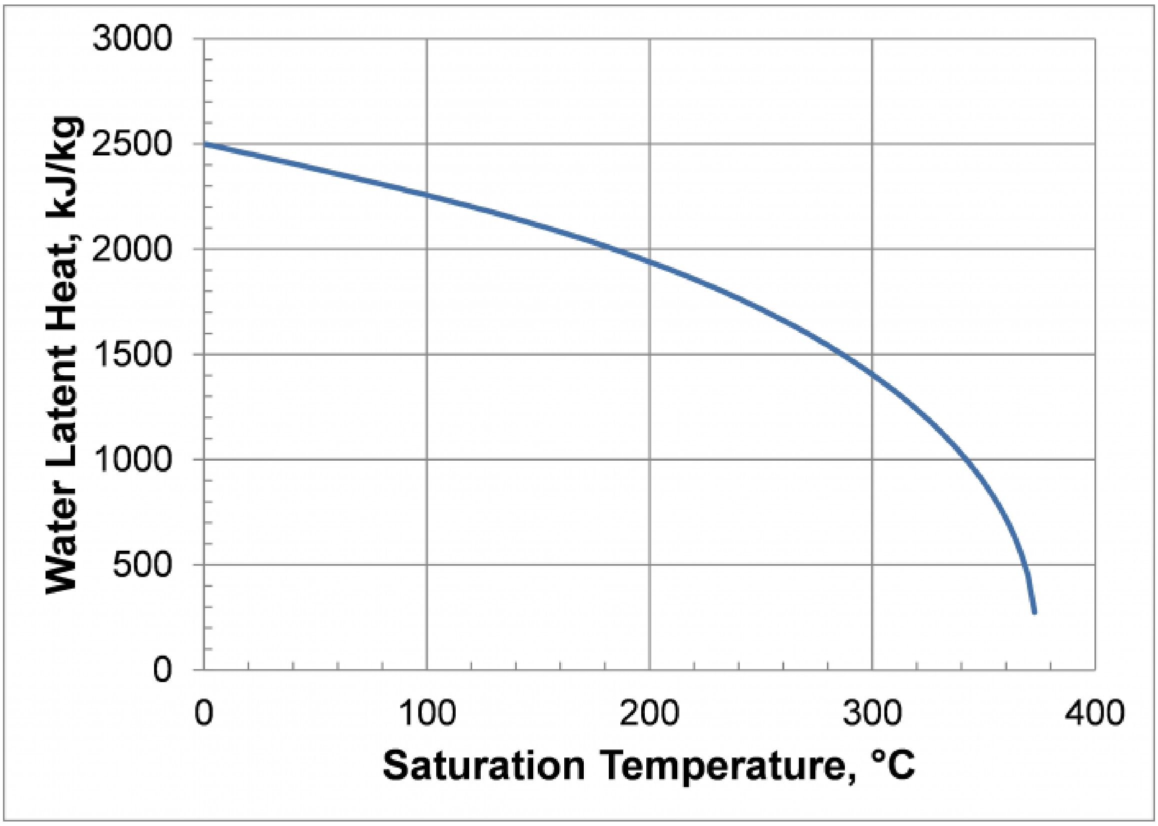

Figure (4) Water Latent Heat as a Function of Temperature.

PRACTICAL TEMPERATURE LIMITS

Table 2 lists practical temperature limits. Note that the upper-temperature range for some of these fluids is set by the fact that a superior fluid can be used at higher temperatures. This is discussed in more detail in Compatible Fluids and Materials.

*Scroll right to view table

Operating Min Temp., °C	Operating Max Temp., °C	Working Fluid	Envelope Materials	Comments
-271	-269	Helium	Stainless Steel,	

			Titanium	
-258	-243	Hydrogen	Stainless Steel	
-246	-234	Neon	Stainless Steel	
-214	-160	Oxygen	Aluminum, Stainless Steel	
-203	-170	Nitrogen	Aluminum, Stainless Steel	
-170	0	Ethane	Aluminum, Stainless Steel	CCHPs below Ammonia Freezing point
-150	40	Propylene	Aluminum, Stainless Steel, Nickel	LHPs below Ammonia Freezing point
-100	120	Pentane	Aluminum, Stainless Steel	

-80	**50**	R134a	Stainless Steel	Used in Energy Recovery
-65	**100**	Ammonia	Aluminum, Steel, Stainless Steel, Nickel	Copper, titanium are not compatible
-60	**~ 100 to 125**	Methanol	Copper, Stainless Steel	Gas observed with Ni at 125°C, Cu at 140°C. Aluminum and titanium are not compatible
-50	**~ 100**	Acetone	Aluminum, Stainless Steel	Decomposes at higher temperatures
-50	**280**	Toluene	Al 140°C, Steel, Stainless Steel, Titanium, Cu-NI	Gas generation at higher temperatures (ACT life test)
20	**280, short term to 300**	Water	Copper, Monel, Nickel, Titanium	Short term operation to 300°C. Aluminum, steels, stainless steels and nickel are not compatible

100	**350**	Naphthalene	Al, Steel, Stainless Steel, Titanium, Cu-Ni	380°C for short term. Freezes at 80°C
200	**300, short term to 350**	Dowtherm A/Therminol VP	Al, Steel, Stainless Steel, Titanium	Gas generation increases with temperature. Incompatible with Copper and Cu-Ni
200	**400**	$AlBr_3$	Hastelloys	Aluminum is not compatible. Freezes at 100°C
400	**600**	Cesium	Stainless Steel, Inconel, Haynes, Titanium	Upper limit set by where K is the better working fluid. Monel, Copper, and Copper-Nickel are not compatible
500	**700**	Potassium	Stainless Steel, Inconel, Haynes	Upper limit set where Na is the better fluid. Monel and Copper are not compatible
500	**800**	NaK	Stainless Steel, Inconel, Haynes	Upper limit set where Na is the better working fluid. Monel and

				Copper are not compatible
600	**1100**	Sodium	Stainless Steel, Inconel, Haynes	Upper limit set by Haynes 230 creep strength
1100	**1825**	Lithium	Tungsten, Niobium. Molybdenum, TZM	Lithium not compatible with superalloys. Refractory metals react with air

Table 2.

Return to Working Fluids…

Return to Heat Pipe Materials, Working Fluids, and Compatibility…