Boyd Two Phase Thermal Solution Guide

A Quick & Easy Reference to Two Phase Cooling Technologies

Overview

Over several decades, Boyd has been a leading innovator of two phase cooling with superior solutions for everything from consumer electronics to space applications. Boyd leveraged this experience and expertise to develop this Reference Guide to help you understand two phase technologies and find the right solution for your applications. This article covers the most popular two phase thermal solutions, integrations, and customizations as well as what to consider when selecting the best technology for your application. Utilizing heat pipes, vapor chambers, or thermosiphons can be the best way to optimize cooling with higher performance in more compact geometries for best total value.

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INTRODUCTION

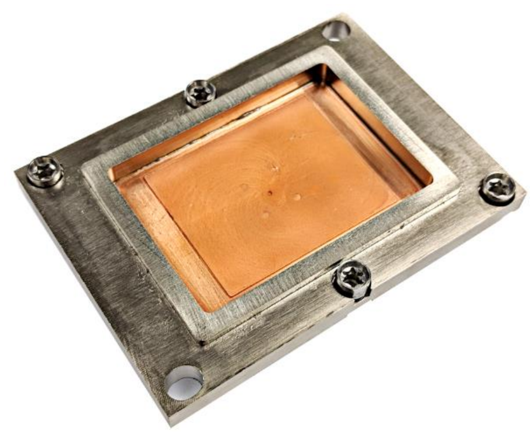
As electronic designs demand more power, functionality, speed, and reliability, heat remains one of the major barriers to maximize performance and realize major innovations. Every industry, especially Mobile, Medical, Telecommunications, and IoT, is developing new applications that are lightweight, multi-functional, and high power with increasing reliability standards. Engineers struggle to effectively handle excess heat as consumers demand smaller, thinner, more powerful devices with more options and capabilities.

Two phase cooling is rapidly gaining popularity to solve these issues. These technologies are especially ideal to spread heat for faster dissipation, reduce weight, increase reliability, and extend device lifetime, but their most significant advantage is design flexibility and how easy and efficiently they integrate in a system or device to vastly improve cooling efficiency and capacity. Active air cooling or liquid cooling systems are often too large, cumbersome, and come with inherent complications such as unwanted sound, heavy weight, and vibration. Two phase can replace active cooling components and systems, not only solving thermal challenges but also acoustic and vibration issues for enhanced reliability.

Multi-technology Heat Pipe Assemble

While many engineers are most familiar with heat pipes, two phase cooling in a linear and very flexible form factor, there are several major two phase technology types that manage more heat and feature unique benefits and features. Vapor chambers transfer heat in a planar geometry allowing for more uniform heat spreading. Thermosiphons do not use a wicking structure and can move more power by using gravity to return the fluid. Meanwhile, Immersion Cooling is gaining popularity in cooling high power components in markets such as data centers.

The following guide will touch on each of these technologies as well as the benefits and considerations when utilizing them to cool your applications.



Immersion Cooling Plate

TWO PHASE COOLING BASICS

PASSIVE

Two-phase products have no moving parts. They operate on the laws of thermodynamics and capillary forces, creating silent, efficient, and extremely reliable solutions with no wear and tear. This enables longer product lifetimes with no performance degradation, quieter devices, and longer potential warranty periods due to lower temperatures.

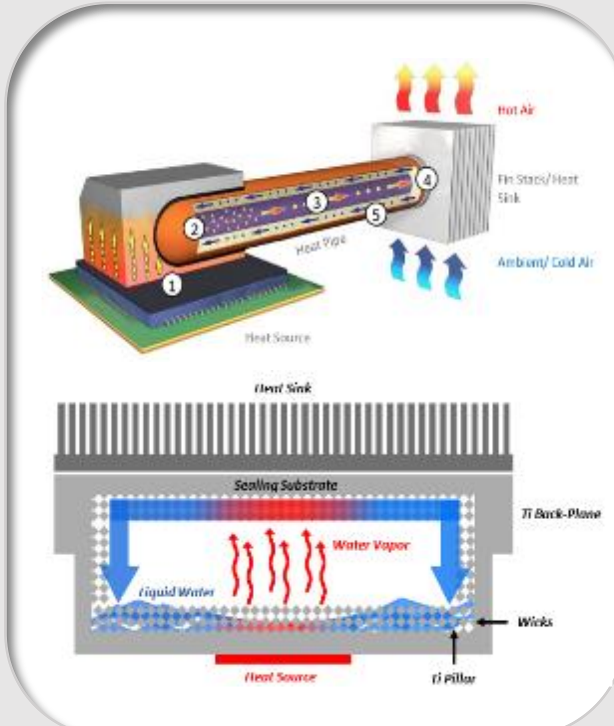
HIGHLY EFFICIENT

Heat pipes and vapor chambers have an effective thermal conductivity of 10X – 200X that of solid materials such as copper, aluminum, and graphite. They also tend to be much lighter and use less material than solid conductors. This enables solutions to transport more heat with less weight in the same volume, or, vice-versa, heat pipes can transport the same amount of heat in a much smaller weight and volume than solid solutions.

Vapor chambers are especially effective when used for planar, X-Y spreading while heat pipes are typically relegated to enhancing heat sink base spreading or increasing their fin efficiency. Spreading heat from single or multiple processors or chips over the increased surface area of a vapor chamber creates more uniform heat transfer, better efficiency, and improved cooling performance.

The high efficiency and efficacy of two phase technologies enable lower, more regulated touch temperatures. Efficient heat spreading also improves user safety and enhances comfort through lower touch temperatures, as well as decreases the likelihood of overheating if the device is left running constantly or for longer than average use times. This mitigates user complaints of device failure due to overheating or may even prevent fire. Two-phase products may lessen reliance on or eliminate the use of fans, meaning quieter, more comfortable devices with much less vibration issues.

How Two-Phase Cooling Works



1. *Heat enters the heat pipe or vapor chamber.*
2. *Small amount of fluid evaporates into a vapor.*
3. *Vapor carries the heat to the cooler part of the solution.*
4. *Vapor condenses back to a working fluid, releasing the heat.*
5. *Fluid is pulled back down the inner wick structure through capillary action.*
6. *Cycle repeats.*

COST EFFICIENT

Less weight, better material usage and improved performance also generate cost savings. Better cooling allows for smaller solutions and bill of material (BOM) savings or creates more available space for additional components and functionality. Cost savings can be further augmented with advanced engineering and Design for Manufacture (DFM) techniques like those utilized at Boyd. Further cost savings can be achieved through effective thermal modeling using Aavid SmartCFD and testing to optimize performance and design specifically for scalable manufacturing from concept to high volume. Thermosiphon technologies can possibly provide addition cost efficiency when the application is in a fixed orientation with respect to gravity.

INCREASED DESIGN FLEXIBILITY

Wicking structure allows vapor chambers and heat pipes to operate in any orientation, including against gravity with the evaporator higher than the condenser and minimal effect on performance. This ability makes heat pipes and vapor chambers ideal for mobile, portable, and consumer electronics that need to operate in various orientations including landscape, portrait and inverted. This also allows these devices to be used in other mobile applications such as automotive and eMobility where gravity may not be the only force acting on the system due to acceleration, deceleration, and cornering.

In addition to multiple orientations, these solutions offer increased design flexibility for unique and high tolerance geometries. While heat pipes can be bent, flattened, and arranged to optimize heat transfer and flow; vapor chambers can accommodate various device heights and through holes for mounting. Utilizing alternate materials, such as titanium or stainless steel, increases the level of customization, offering better mechanical or thermal performance and key market differentiation.


Heat Pipe Assemblies

As Boyd continues to innovate, our techniques have evolved to make the best use of design and materials to further enhance application performance and optimize size and weight. Boyd two-phase innovations incorporate new manufacturing processes including advanced additive manufacturing practices to further improve development times, cost savings, ease of manufacture, design flexibility, and overall thermal performance.

Key innovations include:

- Reaching an unprecedented level of wick customizations and performance optimization to highly specific or varying application and user requirements.
- Proprietary methods for enabling unique and complex geometries in a way that traditional methods could not produce easily or with the required level of cost efficiency.

- Advanced manufacturing techniques to integrate multiple geometries and features in a single process to reduce fabrication times. This enables cost savings in labor, materials, and assembly as well as shorter lead times.

- New and improved technologies such as Immersion Cooling Boiler Plates and Titanium Ultra-Thin Vapor Chambers.

- The consideration and optimization given to thermal management has become a key selling point for many of our customers marketing new technologies. Heat is one of the final barriers to end-user device innovation. Breakthroughs such as Ultra-Thin Titanium Vapor Chambers are a new tool that can help create a competitive advantage to those who employ them.

MAIN TYPES OF TWO PHASE COOLING

This table contains examples and general guidelines to utilizing two phase technologies. This is not a complete list. There are many variations and customizations that can make any one of these solutions ideal for most applications.

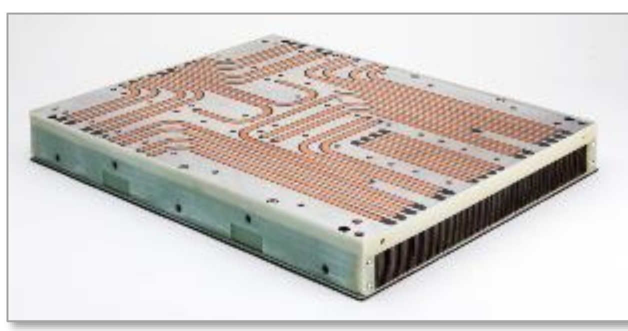
TECHNOLOGY	WHEN TO USE	WHEN NOT TO USE	KEY BENEFITS	KEY INDUSTRIES
Heat Pipes	Experiencing poor fin efficiency. Heat sink has enough overall convective cooling performance but experiences hot spots that need to be spread within the base. It is simpler to implement multiple heat pipes rather than a vapor chamber. Heat needs to be transported far from the heat source.	The distance between the heat source and area to dissipate the heat is short, ~<70mm. The heat source is a similar size to a heat sink base and fin efficiency is acceptable. The number of needed heat pipes are too high, and it is more efficient to use a vapor chamber.	Can be included into most heat sink types with little effort to augment or upgrade their performance. Are cost effective and meet performance needs while reducing weight or volume of the thermal solution.	Mobile Devices Gaming Enterprise applications in Server, Networking, & Telecom Industrial eMobility Medical
Vapor Chambers	Heat sink has enough cooling performance but has hot spots that make the heat sink base less effective. Design requirements warrant maximum spreading **performance** and does not allow enough heat pipes to be embedded physically or economically.	For bases that have an excessive number of thru holes and pockets. Adding heat pipes will meet the requirements.	Allows ideal heat spreading over the base of a heat sink making all fins attached to it as efficient as possible. Enables much higher effective thermal conductivities vs graphite. May allow heat spreading through an entire 3D volume when a 3D Vapor Chamber is used.	Mobile Devices including AR / VR Gaming Enterprise applications in Server, Networking, & Telecom Industrial eMobility

TECHNOLOGY	WHEN TO USE	WHEN NOT TO USE	KEY BENEFITS	KEY INDUSTRIES
Thermo-siphons	Power and distance between a heat source and the finned heat exchanger surface or condenser is such that heat pipes are not practical due to excessive number of heat pipes needed vs. 2 tubes of a thermosiphon. Power needs to be distributed over a 3D volume within a finned condenser more effectively than placing heat pipes in a fin stack. Orientation of the product is known and fixed with respect to gravity.	Heat source is above the condenser region with respect to gravity. If orientation may change, or other forces may act on the thermosiphon (not recommended for moving platforms such as automotive or aerospace).	Offers the ability to move heat over a longer distance than HPs or VCs, as long as gravity can be used to return the fluid. Allows solutions to use a combination of copper and aluminum to minimize weight and cost while still being able to leverage copper in high heat flux regions.	Enterprise (Server, Networking, & Outdoor Telecom Equipment) Industrial Power
Immersion Cooling	Direct liquid cooling is considered but plumbing to each component on each PCB is impractical. Air or liquid cooling does not maintain the same local ambient conditions at each chip (shadowing) leading to over design of the cooling solution. **When high heat flux components are used a proper boiling plate with applied BEC must be used.	Air cooling is sufficient. Facilities do not already have the infrastructure in place to contain the fluid. For small mobile devices.	Fluid allows constant local ambient conditions for all electronics. Allows cooling of components at lower heat fluxes with simple heat sinks or in some cases no heat sinks at all. Minimizes system thermal design with focus on a few high power or high heat flux components.	Enterprise Server, Cloud Data Center

CORE COOLING TECHNOLOGIES

HEAT PIPES

Heat pipe assemblies combine the proven reliability of passive two phase heat transport with a variety of other thermal management technologies to generate effective, long lasting cooling solutions. Aavid, Thermal Division of Boyd Corporation has innovated and fabricated heat pipe solutions for more than five decades. Our experience enables us to design and fabricate effective and long-lasting cooling solutions that operate under the most demanding environmental conditions.



Embedded Copper Heat Pipes

Ductile copper walls and wick enable bending or flattening to meet an application's thermal and geometric requirements. This can be used to reduce overall height, increase surface contact, or route heat pipes around keep-out areas like mounting hardware.

Heat pipes can be embedded in other technologies for faster heat spreading or utilized within a system to transport heat from the heat source to where it can safely dissipate. Copper-water heat pipes are often integrated into thermal management assemblies to improve effective conductivity and efficiency, improving overall system performance.

Heat Pipe Variations

- ***Alternate Materials & Fluids***
  - *Allow for Cryogenic Options, Extreme Temperature Changes, High Heat.*
- ***Flexible***
  - *Use of bellows allow frequent folding and movement with no degradation to heat pipe performance.*
- ***Ultra-Thin***
  - *Near flat heat pipes that allow for extremely low profile applications.*
- ***Loop Heat Pipes***
  - *Transport and control the direction of heat over long distances up to 23 meters.*

Typical Parameters for Copper-Water Heat Pipes

Length: *75mm – 500mm***
Diameter: *3mm-9.5mm***
Material: *High Purity Copper*
Fluid: *Water***

Typical Non-Operational Temperature Range:
-55° to 180°C (Water)

Wick

- *Sintered Copper Powder*
- *Axially Grooved*
- *Wire Mesh Screen*

Maximum Heat Flux: >300 W/cm^2

Lifespan: up to 20 years

**** Larger sizes and different working fluids are available based on application use**

VAPOR CHAMBERS

Vapor chambers leverage high heat transport capabilities of two phase cooling in a planar format, making vapor chamber assemblies ideal components for spreading high heat densities or heat loads across a larger surface. This enables increased and more uniform heat spreading, which is ideal when optimizing heat sink performance.

Boyd integrates vapor chambers into specialized air cooled heat sinks to improve heat distribution to each of the fins, improving the overall performance of the heat sink. Aavid, Thermal Division of Boyd is consistently innovating to develop and manufacture them in a variety of materials and working fluids. This includes our Ultra-Thin Copper-Water, Stainless Steel-Water, and Titanium-Water Vapor Chambers for high heat density, high strength cooling in applications such as PEM fuel cells and low profile Smartphones, consumer and mobile electronics.

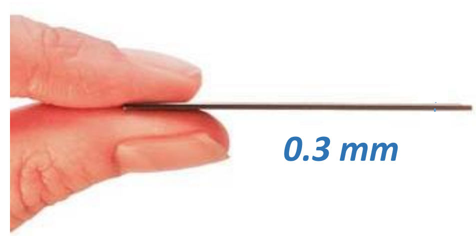
Custom Vapor Chamber

Additional Considerations & Benefits

- *More uniform heat spreading for cooler device temperatures.*
- *Reduces heat sink volume and overall thermal solution weight by using fins more effectively (or use the same volume to increase heat load/device performance).*
- *Reduce thermal solution complexity by using one vapor chamber as opposed to multiple heat pipes with complex bent geometries.*
- *Fins such as Zipper Fin or Folded Fin may be mounted directly to vapor chambers by soldering.*
- *Vapor chambers may also be inserted into pockets with an extruded or cast heat sink base by soldering or thermal epoxy.*
- *Ultrathin vapor chambers may be integrated within mobile devices by adhesive and in some cases welding to attach to mid-frame type structures.*

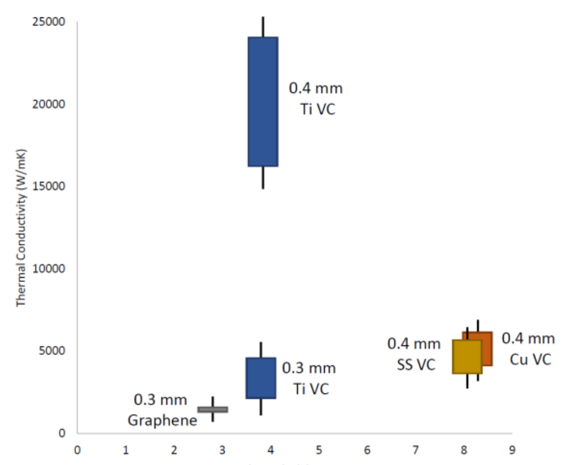
INNOVATION SPOTLIGHT: Boyd Ultra-Thin Titanium Vapor Chambers

One of Boyd's most recent innovations is the development of Ultra-Thin Titanium Vapor Chambers. Boyd's development of Titanium as well as Stainless Steel vapor chambers enables options for additional structural strength, reduced weight, and streamlined assembly which can accommodate inherent complexities for the growing matrix of mobile, wearable, and portable applications. They are thermally competitive with 0.3mm graphite solutions with increased design flexibility. Boyd's Ultra-Thin Titanium Vapor Chambers are also designed to increase uniformity for heat spreading and transfer, enabling these solutions to cool more efficiently.



Introducing Boyd's Ultra-Thin Titanium Vapor Chambers

The use of Titanium allows for even thinner solutions with maximum performance at a 0.30-0.5mm thickness, much thinner than even ultra-thin heat pipes that average at 1.0-1.5 mm.



Uniform, more efficient heat spreading in lower profile applications.

Titanium has also proven to have as much as 5-10x the specific strength (KN-m/kg) and yield strength (MPa) to similar structures comprised of copper. Additionally, titanium has a much lower coefficient of linear thermal expansion (CTE) than copper or aluminum. Titanium's increased mechanical strength enables engineers to design out traditional mechanical infrastructure, allowing the vapor chamber to function as a thermal and mechanical infrastructure solution for more available design space and better integration with other technologies like system components or EMI shielding to further optimize device performance and reduce costs.

This combined with Titanium Vapor Chambers' design flexibility and Boyd's ability to integrate a multitude of material and thermal technologies results in lower BOM and overall device costs while maintaining the highest performance and reliability in the market.

The evolution of the vapor chamber does not stop at design and improved materials for the envelope; Boyd vapor chamber innovations also include utilizing advanced working fluids. Although water is still the primary working fluid and highly effective, some applications, such as those used in aerospace and extreme environments, have requirements that make water unsuitable. This is especially true in environments with extreme temperatures or thermal cycling. It is imperative to match fluid and material properties to allow for proper functionality. Using incompatible materials can lead to corrosion, shorter lifetimes or loss of performance.

Sample Size: 100mm x 50 mm	**Total Weight (gr)**	**Thermal Conductivity (W/m.K)**
0.3 mm Stacked Graphene	2.8	1300
0.4 mm Copper VC Mesh Option A Mesh Option B	8.1	4000 ~ 6000 5700 ~ 8300
0.4 mm SS VC Mesh Option A Mesh Option B	8.2	3700 ~ 5700 5500 ~ 8100
0.4 mm Ti VC	3.9	16000 ~ 24000
0.3 mm Ti VC	3.8	2000 ~ 4500

Material	**Tensile Strength (Mpa)**	**Density (kg/m³)**	**Specific Strength (kNm/kg)**
Copper (Cu)	220	8960	24.5
Stainless Steel (SS)	505	7700	65.5
Titanium (Ti)	480	4500	106.6

THERMOSIPHONS

Thermosiphons offer higher power heat transportation versus heat pipes or vapor chambers, but as they are wickless, they need a known orientation with respect to gravity to operate. For additional cost savings, Boyd offers advanced engineering and streamlined manufacturing that enables one shot brazing. Boyd has also developed loop thermosiphon solutions that offer passive liquid cooling for more reliable high-power cooling. Thermosiphons are often more complete system level solutions as compared to heat pipes and vapor chambers, which are most often components integrated into a larger thermal system.

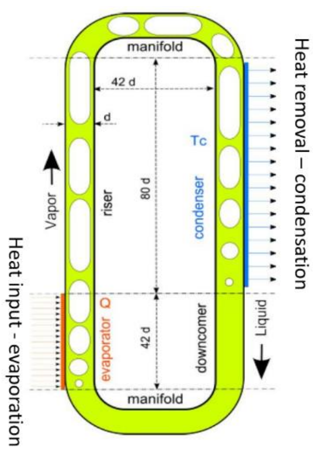
Thermosiphon for CPUs

Standard Specifications

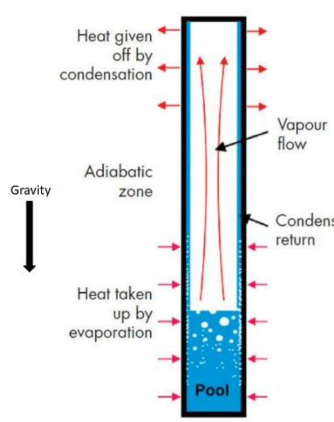
Materials: Copper, *Aluminum*
Working Fluids: *Most often dielectric refrigerants*

General Guidelines:
- *Consider basic thermal inputs, location and size of the heat source mounting base, volume used for fins, and gravity*

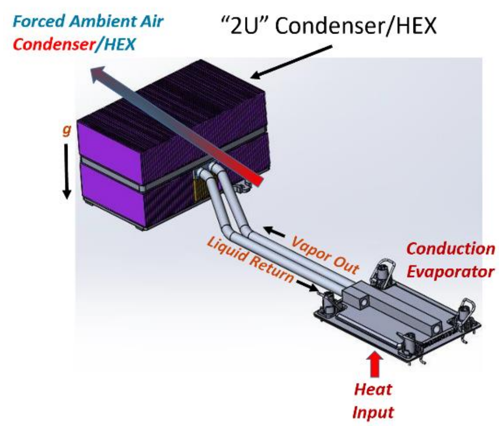
There are two main types of thermosiphons:
- Air to Air Heat Exchangers that reject heat from one air flow stream to another utilizing the thermosiphon working fluid.
- Remote heat ejection from a local component to ambient air using the thermosiphon working fluid to reject heat using a remote condenser.



Two-phase Loop Thermosiphon



Counter-flow Thermosyphon
(much like a heat pipe without the wick)



Example: Source to Air Thermosiphon for Enterprise

- Energy is transported from heat input zone to heat rejection zone at essentially constant temperature
- Large amounts of energy can be transported
- Zero moving parts in the fluid loop
- Numerous configurations are possible

- CPU heat evaporates the internal fluid
- The internal fluid vapor flows to the condenser by partial pressure difference
- Cold external air passes through the condenser - condensing the working fluid
- The liquid returns to the evaporator by gravity and the process repeats

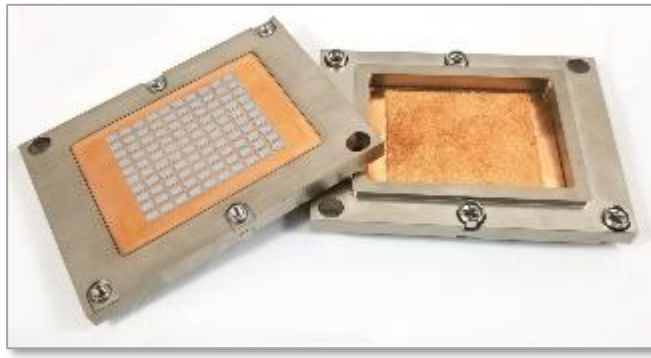
IMMERSION COOLING

Immersion cooling systems include a boiling plate attached to high heat flux devices such as CPU's and GPU's that are immersed in a dielectric fluid. These plates include a BEC (boiling enhancement coating) that initiates boiling of the fluid with a small temperature difference. The bubbles that boil up in the fluid bring the heat to the surface and reject the heat from the system when it condenses on a heat exchanger or cooling coil type condenser.

Boyd's Immersion Cooling Boiler Plates are extremely high performance, differentiated with a boiling enhancement coating (BEC) optimized with high boiling capacity and low temperature rise to ensure component temperatures are maintained below their maximum limits.

Materials: Copper for high heat flux and *Aluminum for lower heat flux components.*

Boyd offers standard and custom boiler plates.



Immersion Cooling Plates

DESIGN CONSIDERATIONS

Two phase solutions offer increased design flexibility and are extremely customizable. It is vital to consider your options when optimizing your solution.

WICKING STRUCTURES

In addition to sintering, wicking options include grooves and screen-mesh options. Grooves are extruded with the tube. Screens or mesh are rolled and inserted into the pipe along the interior wall.

Heat Pipe Wicks

Wick Structure	Operational Orientation Relative to Gravity	Power Density / Heat Flux Capabilities	Freeze Tolerance (Water Based Systems)
Wickless (i.e. Thermosiphons)	+90° to +5° *Orientation Sensitive*	*Up to 5 W/cm2* *Very Low Density*	*Not Freeze Tolerant*
Grooves	+90° to +0° *Orientation Sensitive*	*Up to 10 W/cm2* *Low Density*	*Not Freeze Tolerant*
Screen/Wire	+90° to -10° *Orientation Sensitive*	*Up to 15 W/cm2* *Medium Density*	*Not Freeze Tolerant*
Sintered Powder (Graded & Uniform Sintering Available)	+90° to -90° *Orientation Insensitive*	*Over 15 W/cm2 with 350 W/cm2 Achievable*	*Can be Designed for Freeze Tolerance*

Vapor Chamber Wick & Post Options


Sintered Powder Wick


Mesh Wick


Etched Wick

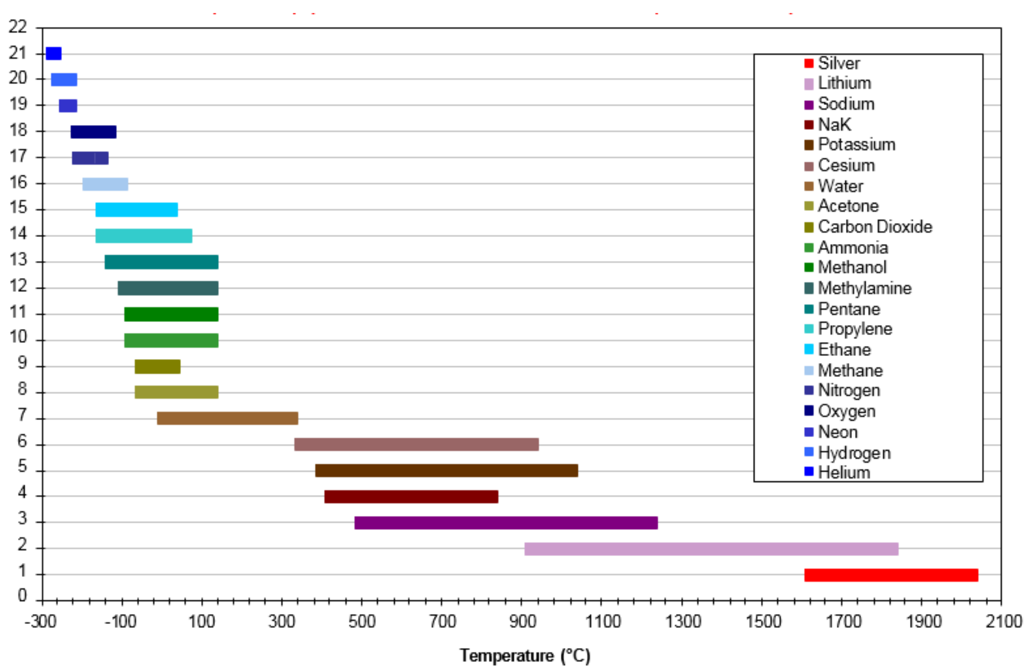

Stamped Posts


Cut & Sintered Posts


Etched Posts

WORKING FLUIDS

Water is typically the best choice working fluid due to its excellent heat of vaporization and working temperature range that are ideal for electronic cooling applications. For specialized applications requiring extremely low or high temperatures, other fluids may be considered. Each working fluid noted has a set of compatible materials that can be used for the outer walls of the heat pipe or vapor chamber.



Materials

Heat pipes and vapor chambers can be manufactured in a wide range of materials and alloys, although Copper is the most common. Copper is extremely compatible with water and several other fluids, highly conductive, and is easy to manufacture. If additional strength is required, stainless steel or titanium may be selected with the latter the best choice when weight reduction is desired.

Material	Tensile Strength (Mpa)	Density (kg/m^3)	Specific Strength (kNm/kg)
Copper (Cu)	220	8960	**24.5**
Stainless Steel (SS)	505	7700	**65.5**
Titanium (Ti)	480	4500	**106.6**

WHAT IS NEXT?

Boyd Corporation's decades of innovation expertise, experience, resources and unique approach to integrating multiple technologies into a streamlined product will continue to keep the company on the forefront of innovation and improved manufacturing. If you are ready to improve or retrofit your cooling solutions or are looking to tackle new challenges for the next generation, start by contacting Boyd Corporation to learn more about two phase solutions, customizations, and other possibilities for better optimized cooling.

To receive more information regarding Heat Pipes, Vapor Chambers, or other two-phase cooling of any type, please visit www.boydcorp.com.

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