The 7 Most Common Myths About Heat Pipes

And the Truth About Designing Applications with Two Phase Cooling

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Overview

Over many decades, Boyd has led innovation of superior heat pipe and two phase thermal management solutions across many major industries from mobile and consumer electronics to NASA applications and next generation enterprise and 5G equipment. We've observed many misconceptions about heat pipes, how they work, and how to best utilize them in applications while working closely with engineering teams across leading major markets. This paper addresses the top 7 most common misconceptions, or "myths", about heat pipes that we've encountered with best practices for heat pipe utilization.

As electronics continue to become more powerful and require more functionality with greater reliability, excess heat remains a significant barrier to the development of better performing next generation applications and breakthrough innovation. Every industry, especially Mobile, Medical, Telecommunications, and IoT are developing new products and systems that must be lightweight, multi-functional, and able to manage high heat loads with high reliability. Engineers struggle to effectively handle the heat as consumers demand smaller, thinner, more powerful devices with more options, functionality, and capabilities.

Two phase cooling is rapidly evolving and gaining more popularity in solving these issues. Heat pipes are especially ideal to spread heat for faster dissipation, light weighting, higher reliability, and lifetime. But heat pipes most significant benefit is design flexibility and the ability to easily integrate them into thermal systems to vastly improve cooling efficiency and capacity.

For more information on the various two phase technologies, including heat pipes, vapor chambers, thermosiphons, and immersion cooling, view [Boyd's Guide to Two Phase Cooling.]

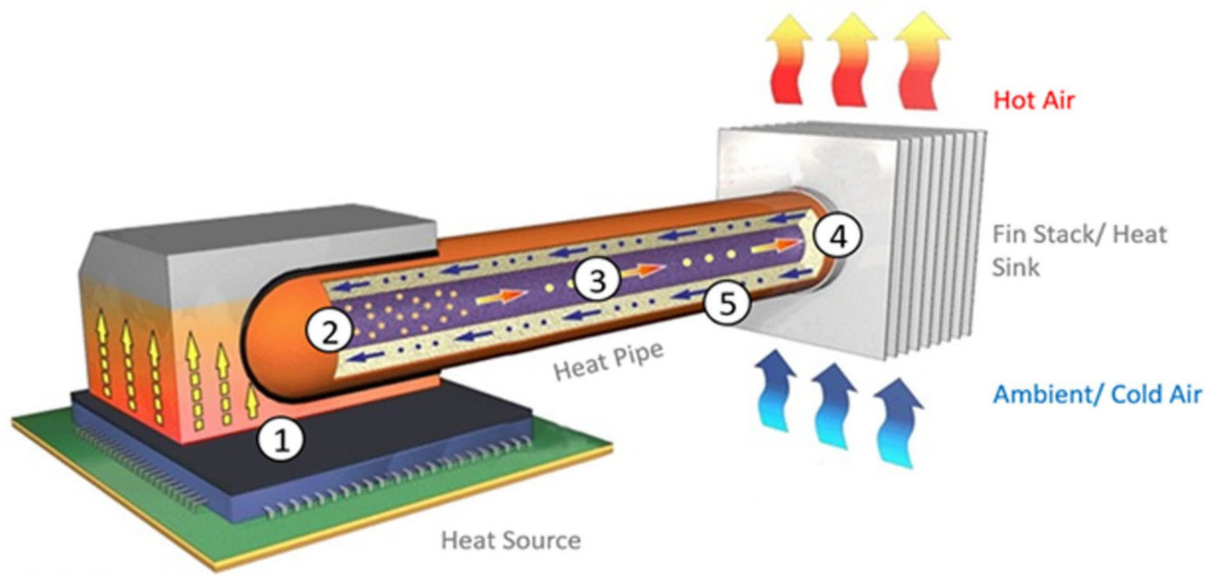
Multi-technology Heat Pipe Assembly

The addition of heat pipes to your solution or system can vastly improve its thermal performance for more efficient thermal management without adding active components that may be detrimental to application lifetimes, reliability, or accuracy.

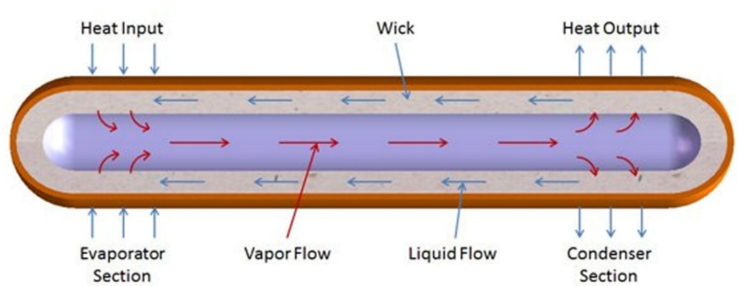
Active air cooling or liquid cooling can be large or cumbersome. Active air cooling comes with complications such as acoustics, weight, and vibration. Not all applications have infrastructure that supports liquid cooling systems. Two phase cooling is being leveraged to extend air cooling system performance, solves acoustic and vibration issues, and leverages existing cooling infrastructure.

HEAT PIPE BASICS

How Heat Pipes Work



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.



THE 7 MOST COMMON MYTHS ABOUT HEAT PIPES

Myth #1: If heat pipes break, they will get liquid on my electronics.

Truth: Heat pipes rarely, if ever, break. In the highly unlikely event that one was to break, the extremely small amount of liquid held in the pipe would be fully saturated into its wick and would not be able to drip or leak onto your electronics.

Heat pipes are inherently robust and are a purely passive system that does not have any moving parts to wear down over time. To "break" a well-manufactured heat pipe, you would need to cut the pipe open or put the pipe through an excessive amount of repeated bending or folding.

Heat pipes are charged with a vacuum while being filled ensuring the amount of fluid contained in the pipe is always in vapor form and therefore will not drip.

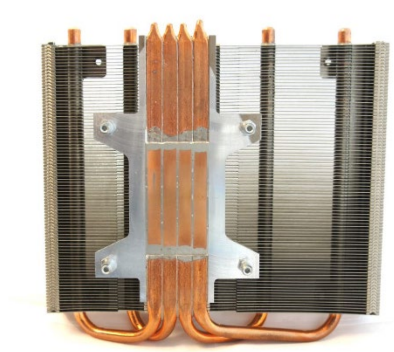
Their durability, increased reliability, and leak-free nature make heat pipes an ideal solution in markets such as Aerospace, Medical, Consumer Electronics, high power applications that require high reliability, and where leaks from traditional liquid solutions may be catastrophic.

Through decades of refining manufacturing techniques and engineering specifications, Boyd has developed consistently robust, high quality heat pipes. Boyd heat pipes are tested in thermal labs utilizing high temperature testing in accelerated life tests and other exhaustive reliability and performance testing to prove out design, seal, and welding quality.

Myth #2: Heat pipes are heavy.

Truth: Heat pipes can remove more weight than they add to an assembly.

Because they are typically made of copper, a heavier material, some believe that integrating heat pipes will add weight to their solution. Boyd engineers often utilize them with other cooling technologies to decrease the weight or volume of an overall solution as experts in heat pipe utilization and integration.



Heat Pipes utilized in an integrated solution to save space and weight.

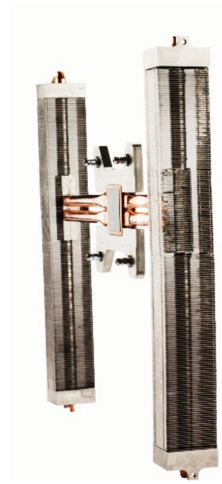
Although they are made of copper, heat pipes are hollow and can decrease the weight of your solution while improving thermal performance in a variety of ways. Heat pipes are often used to transfer heat to a cooler, remote, more open area of a device or assembly with greater access to airflow and space where a fan and light weight fin structures can be added to decrease the overall size and weight of your cooling solution.

Another common example is replacing a traditional copper spreader or larger heat sink with an aluminum heat sink base featuring embedded heat pipes. The high heat spreading efficiency of heat pipes evenly and rapidly distributes heat across a full heat sink, increasing heat sink efficiency, reducing heat sink size and the amount of material needed, thereby reducing the overall weight and cost of your solution.

Myth #3: Heat Pipes only work with the evaporator and condenser on the ends.

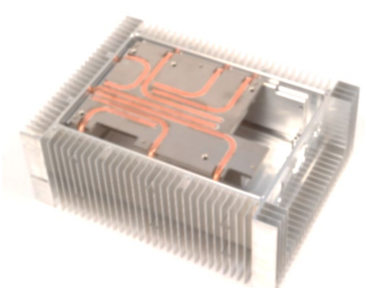
Truth: Heat pipes function along the entire length of the pipe and will consistently transfer heat from warmer regions to cooler regions regardless of their location along the pipe.

Heat pipes are often designed into thermal management assemblies to transport heat from the heat source at one end to the other end to dissipate safely and efficiently. This utilization is common, but it is not the only way to use heat pipes.



Heat Pipes transporting heat from the central heat source to be dissipated in fin stacks

Heat pipe wicking structure enables them to work in any orientation and typically runs the full length of the pipe interior. Heat inherently travels from hot to cold and this holds true with heat pipes. No matter where heat is placed along the pipe, heat will always travel away from the heat source(s) towards the condensation point(s) and back again through the wick. This increases design flexibility and heat pipe use options to enable more innovative and cost efficient thermal management.

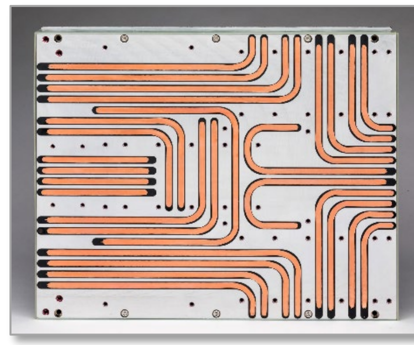


Embedded Heat Pipes for heat spreading

One such utilization is embedding heat pipes to spread heat rather than transfer it. When heat pipes are embedded in the base of a heat sink, the heat condenses along the entire length of the heat pipe rather than a set region. An example of this is integrating heat pipes into air cooled heat sinks to extend high power performance, mitigating the need for a liquid system when cooling high power IGBTs.

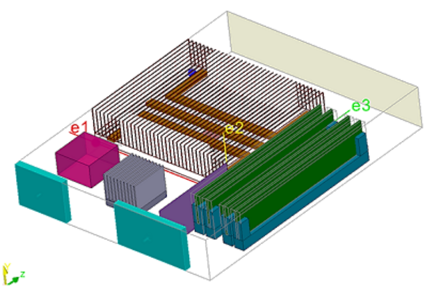
Myth #4: Heat pipes only spread heat in a straight line. If I want to spread heat along the whole base, I need a vapor chamber. *Truth: Heat pipes can be bent and used in a manner similar to a vapor chamber but with more structural integrity.*

When heat pipes were initially introduced and beginning to integrate with other technologies, they were embedded in straight lines. For more uniform heat spreading, engineers utilized vapor chambers. Vapor chambers, while effective for uniform heat spreading, have their own set of design challenges that may not be ideal for every application.



Embedded Heat Pipes for uniform heat spreading around several through holes.

Although a heat pipe only moves heat along its axis, this axis can be bent or used with multiple heat pipes to act effectively as a planar spreading mechanism similar to a vapor chamber. Heat pipes are less expensive and offer increased structural integrity and can be designed to mimic the function and performance of a vapor chamber. When embedded correctly, heat pipes can accommodate a significant amount of mounting force in applications where vapor chambers prove too delicate.



SmartCFD modeling

Boyd engineers have worked over several decades to perfect our heat pipe bending techniques and heat pipe capabilities, including development of flexible heat pipes. Boyd has compiled decades of empirical testing data that has even enabled us to develop a proprietary modeling software, SmartCFD, that can run more accurate simulations with bent or integrated heat pipes.

Myth #5: It has to be very hot for heat pipes to work.

Truth: Manufacturing techniques enable heat pipes to function even with small temperature differences.

Because heat pipes are dependent on evaporation and condensation to work, it is a common misconception that there must be a substantial temperature difference or high temperatures to benefit from using heat pipes. However, because heat pipes are charged with a vacuum prior to sealing, the fluid exists as both a liquid and a vapor at its saturation point. This is similar in principle to boiling a liquid at lower temperatures when at higher elevations with lower pressures. It takes much less heat for the molecules to be energized enough to change phase from a liquid to a vapor. Therefore, the temperature of the heat source does not need to reach the standard room temperature boiling point to cause the liquid to vapor phase change. In fact, only a few degrees difference is needed between the "hot" and "cold" areas of a heat pipe for it to function. This is one of the key benefits of utilizing heat pipes as it keeps the thermal resistance of your solution minimized.

Myth #6: Heat pipes cannot be used in freezing conditions.

Truth: Heat pipes can be developed to function in extremely rugged conditions such as freezing environments.

How a heat pipe operates in environmental conditions is dependent on materials and design. Although copper/water is the most popular combination; other materials can be used based on specialized requirements. Liquids such as ammonia, methanol, and acetone can all be combined with compatible metals to develop heat pipes that can function in temperatures well below -60°C.

Heat Pipes can be designed for cryogenic temperatures.

Even with copper and water, the solution can be designed to mitigate environmental conditions. By utilizing the proper thermal technologies and techniques, thermal solutions with integrated heat pipes can enable device functionality like cold start for applications in Telecom, Defense, and Transportation. With the correct design parameters, heat pipes can also withstand a large number of repeated freeze/thaw cycles without any failures.

Myth #7: Heat pipes are expensive.

Truth: Adding heat pipes can lower solution costs.

Copper's ductility enables heat pipes to be economically fabricated, reliably sealed, and easily bent and pressed into specific geometries. Boyd has refined manufacturing processes and heat pipe design techniques to produce extremely cost-effective copper/water high performance heat pipes. Heat pipes can enable cost reductions by allowing engineers to utilize aluminum and embedded heat pipes in applications that would otherwise require a copper base of fins. They can also eliminate the need of a fan or other components, saving on money and weight.

Boyd integrates heat pipe technology to create new solutions and retrofits that improve performance without incurring substantial design rework or system upgrades costs. We enable smaller, lighter solutions for greater application efficiency, reducing power and energy demand and costs. Heat pipe durability and reliability also reduce ongoing maintenance costs and downtime.

THE REALITY OF HEAT PIPES – OVERVIEW

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. Boyd has innovated and fabricated heat pipe solutions for more than five decades. Our experience allows us to design and fabricate effective and long-lasting cooling solutions that operate under the most demanding environmental conditions.

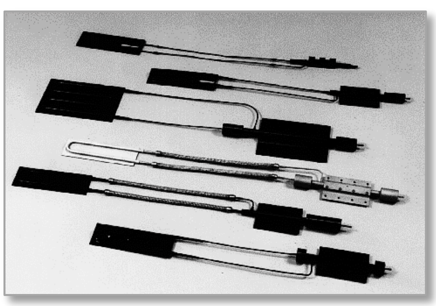
Aluminum die cast housing with stamped zipper fins and Heat Pipes

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 size, 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.

Heat Pipe Variations

- ***Alternate Materials & Fluids***
    - *Allow for Cryogenic Options, Extreme Temperature Changes, High Heat*
    - *For more information on alternate materials and fluids, read Boyd's Guide to Two Phase Cooling.*
- ***Flexible***
    - *Use of a bellows allows 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.*



Loop Heat Pipes

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**

THE REALITY OF HEAT PIPES – UTILIZATION AND BENEFITS

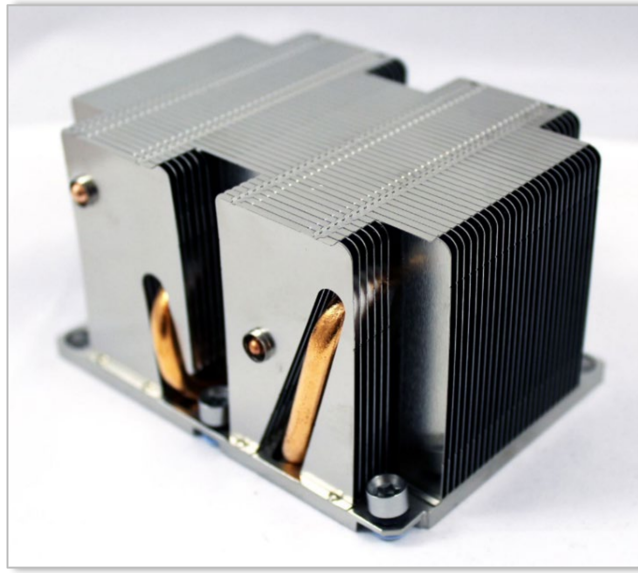
Passive

Heat pipe technology has no moving parts and operates on the laws of thermodynamics and capillary forces, making heat pipes silent, efficient, and extremely reliable with no inner wear and tear. This enables longer product lifetimes with no degradation in performance, improved acoustics and longer warranty periods due to lower temperatures.

Highly Efficient

Heat pipes have a conductivity of 10X – 200X that of solid thermally conductive materials such as copper, aluminum, and graphite. They transport heat faster than solid solutions as fluid and vapor move more heat while enabling more uniform temperatures.

For these reasons, heat pipes are often used to increase heat sink fin efficiency by transporting heat quickly from the base to the lesser utilized parts of the fin stack. This allows for maximum fin efficiency across the entire heat sink and enables the use of thinner fins.



Heat Sink integrated with heat pipes to optimize fin efficiency.

The high efficiency and efficacy of heat pipes enable lower, more regulated touch temperatures. Improved heat spreading also improves user safety and comfort and 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 even catching fire. They may lessen or eliminate the use of fans, mitigating acoustic and vibration issues.

Cost Efficient

Less weight, improved material usage, and improved performance also generate cost savings. Better cooling allows for smaller solutions and BOM savings or more room for more components and added functionality. Cost savings can be further augmented with advanced engineering and Design for Manufacture (DFM) techniques like those utilized at Boyd. Through effective thermal modeling, testing for optimal performance, and designing specifically for scalable manufacturing from prototypes to high volume, cost savings can be further improved and passed on to the end customer.

Increased Design Flexibility

The wicking structure allows heat pipes to operate in any orientation, including against gravity with the evaporator higher than the condenser and minimal effects on performance for most applications. This ability makes them ideal for mobile, portable, and consumer electronics that need to operate in various orientations including landscape, portrait, and inverted.

Heat Pipe Assemblies

In addition to multiple orientations, heat pipes offer increased design flexibility for unique and high tolerance geometries. They can be bent, flattened, and arranged to optimize heat transfer and flow. Utilizing alternate materials increases the level of customization, offering better performance and key market differentiation.

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 and advanced additive manufacturing practices to further improve cost savings, ease of manufacture, design flexibility, and overall thermal performance.

Key innovations include:

- Reaching an unprecedented level of wick customizations and performance-matching to highly specific or varying application and user requirements.
- Proprietary methods to enable 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 and materials as well as shorter lead times.
- 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.

Boyd's decades of two phase cooling innovation, integration, and mass production have been integral to the development of these technologies and their use across most major industries. 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 integrated two phase solutions, customizations, and other possibilities for better optimized cooling.

To receive more information regarding Heat Pipes, please visit www.boydcorp.com.

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