Vapor Envelope^{TM} Vapor Chamber | Whitepaper

Unlock Your Computing Product’s Thermal Limitation

Minco has developed a new product that we call a Vapor Envelope^{TM} vapor chamber, an evolution thinner and lighter than traditional heat spreaders, allowing for a significant performance improvement over a typical vapor chamber-heat sink assembly of the same space.

Product Outline

The Vapor Envelope^{TM} vapor chamber’s creation comes as rigid vapor chambers have seemingly maxed out their potential. Thermal management remains one of the critical hurdles for continued advancements in electronic technologies. Mobile devices, autonomous vehicles, edge computing, and servers all demand continual improvements in size, weight, and power while still confronting increasing thermal requirements. Heat pipes and standard vapor chambers have taken the lead in CPU and ASIC cooling, but they suffer from weight and size limitations. In a market where each generation of device is expected to be smaller

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and lighter than its predecessor, manufacturers are looking for the latest advancement in thermal management.

Minco's Vapor Envelope™ vapor chamber functions in the same way as other vapor chambers, but in a distinctly different form. It possesses a unique combination of size, weight, and power capability that we feel will be beneficial for thermal management systems in certain electronic applications. The distinctly different form also enables customization of the product size for an industry disrupting lower non-recurring engineering cost. We created a prototype manufacturing work-cell for our baseline product construction.

The following pages detail the genesis of the Vapor Envelope™ vapor chamber project and some fundamental comparisons with other thermal management technologies.

You'll also learn about a major test we conducted that provided our most recent results**: a Vapor Envelope™/heat sink assembly enables 20% higher power than a standard vapor chamber/heat sink combination in the same amount of space.**

Key Features & Benefits

The Vapor Envelope's unique architecture makes it ideal for heat spreading:

- Ultra-Thin Vapor Chamber
- Ultra-sonic welded seam = Low Tooling Cost, Fast Protos, Flexible Design
- 0.04" (1mm) Thickness
- ≥ 4" (11cm) Radial Isothermal Heat Spreading
- Specific Area: 1.3 gm/sq." of Surface
- Non-Rigid (Micro-Pliable)
- Max. Heat Flux: > 160 W/cm^2
- Operating Range: 10 to 100°C
- Maximum Size: 7" x 9"
- Thin and Light = Weight Savings
- Made from a material combination known for its reliability

Vapor Envelope™ Vapor Chamber Architecture

Combining proven technology with patented improvements

Vapor Envelope™ vapor chamber takes highly concentrated heat and rapidly spreads it out over a larger area where it can then be dissipated from your device. It functions in essentially the same manner as a heat pipe: A phase change fluid–in this case, purified water–contained in a hermetically sealed vessel changes from a liquid to a vapor when it absorbs heat from a localized heat source. The vapor then moves rapidly to cooler, lower-pressure areas of the vessel where it condenses back to a liquid. At the moment it changes phases, it releases its latent heat.

For heat spreading applications, the goal is to move heat to the farthest extremities of a heat sink configuration with the minimal amount of thermal resistance. This enables optimal performance of cooling fins in dissipating heat into the environment. One indication of how well a heat spreader is working is the temperature uniformity of its surface while under load. The ultimate indicator is the temperature of your heat source under similar boundary and interface conditions.

Origins of the Product

This product is based on work carried out by the University of Colorado-Boulder as a participant in a DARPA funded program on thermal management.

The University of Colorado-Boulder developed a demonstrator with desirable performance in a unique form factor. However, their design only had a 60-day life span and was not compatible with low pressure environments. Minco developed and patented a way to hermetically seal the package, provide structural compatibility with low pressure environments, and implement a novel and advantageous charging configuration.

Minco’s Innovations

Since then, Minco has developed its understanding of the charging process and thermal characterization and is now introducing this distinctively beneficial product to the market. We are aware of multiple potential product applications but have been focusing first on heat spreading to enhance convective cooling applications.

Central to the success of this project was to find a way to seal the edges of the pressurized envelope. Minco's engineers developed and patented a process to use ultrasonic welders to ensure a bond strong enough to resist low pressure environments and to ensure a long product life. A method for fusing the assembly internally was also developed.

Another innovation involved designing a charging method that does not leave a vulnerable charging tube sticking out of the product, as in standard vapor chambers. In all, three patents were awarded to Minco for innovations relating to this product.

Minco Engineering estimates Vapor Envelopes have a lifespan exceeding 10 years, long enough to play a role in the lifecycle of a PC or server.

Fundamental Technology Comparison

Comparing the Vapor Envelope™ Vapor Chamber with Legacy Heat Spreaders

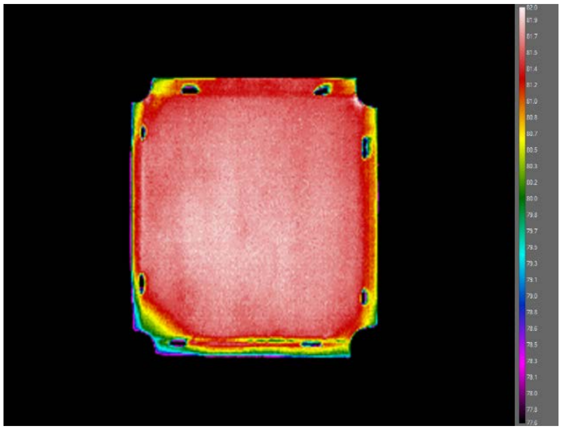
Our first comparison utilizes infrared imaging to illustrate the high-performance heat spreading of a Vapor Envelope™ vapor chamber compared to a highly conductive solid copper heat spreader. Our second comparison looks at the weight comparison of a typical generic vapor chamber and a Vapor Envelope™ vapor chamber.

Vapor Envelope™ vapor chamber Compared to Solid Copper

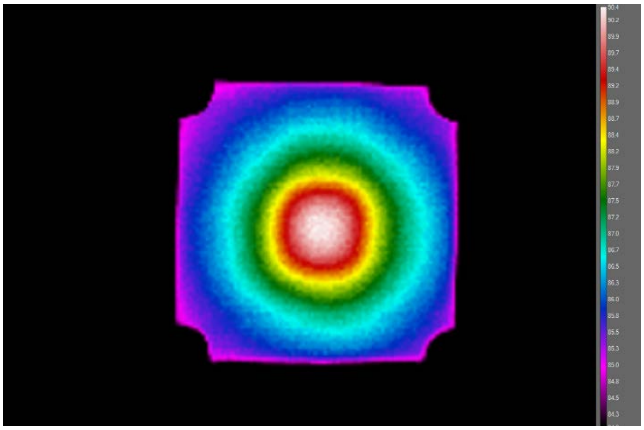
Thermal Conductivity (k)	W/m K
Silver	428
Copper	413
Aluminum	237
Nickel	106
Stainless Steel	14.4

Solid copper is much more thermally conductive than most any other material (see table). Because vapor chambers do not transfer heat through conduction, but through two-phase physics, they can have an effective thermal conductivity much higher than metals. However, their effective thermal conductivity changes with various boundary factors.

The images below show infrared images of a Vapor Envelope™ vapor chamber (left) and a solid piece of high-conductivity copper of the same dimensions (right) with a one-inch square heater contacting the bottoms. They are both in a room ambient, still-air environment with 10 watts applied to the heater. The images show that the Vapor Envelope™ vapor chamber is in an isothermal state while the copper piece has a roughly 5˚C thermal gradient across it.

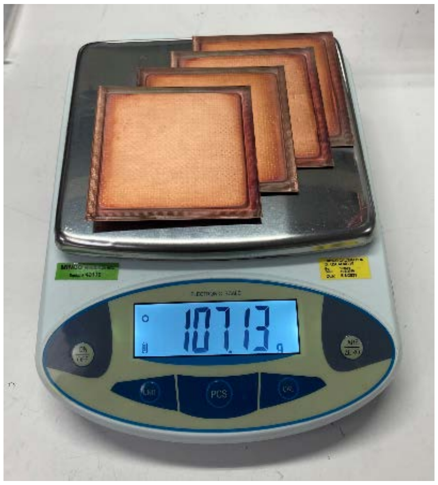


Vapor Envelope™ vapor chamber



Vapor Envelope™ Vapor Chamber Compared to a Typical Vapor Chamber

Typical vapor chambers are 3mm thick. Minco's baseline Vapor Envelope™ vapor chamber is only 1mm thick. This is possible because Minco uses extremely thin 0.1mm thick copper foil to form its hermetic



envelope. Not only does this result in a thinner overall package, but it results in greatly reduced weight per area of heat spreading. We call this ratio of weight-to-spreader-surface-area “Specific Area”.

Specific Area and Heat Density

As the picture above shows, a baseline Vapor Envelope™ vapor chamber has four times better Specific Area than a typical vapor chamber. Or to put another way, the typical vapor chamber has four times greater weight-cost than a Vapor Envelope™.

The better Specific Area and the thinner package are a result of the thinner walls, not a smaller interior chamber. Therefore, we are not stifling the internal wicking or vapor flow that enable the rapid heat transfer, even at high heat densities. The wicking structure has demonstrated the capacity to handle a 160-watt heat load with a 1-centimeter square interface without drying out.

Our primary takeaway from these tests was that the Vapor Envelope™ vapor chamber offers heat spreading comparable to vapor chambers and better than heat pipes at a much lower volume. Our next test was to prove that a Vapor Envelope™-heatsink assembly could outperform a vapor chamber-heatsink assembly with an identical volume.

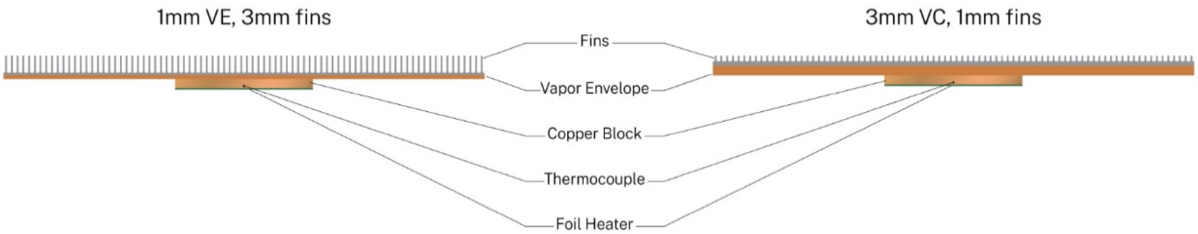
Case Study

Substituting a Vapor Envelope™ Vapor Chamber for a Standard Vapor Chamber

In a world where each generation of electronics demands continued technological improvements, the difference between a standard 3mm vapor chamber and a 1mm thick Vapor Envelope™ vapor chamber could make all the difference in an application.

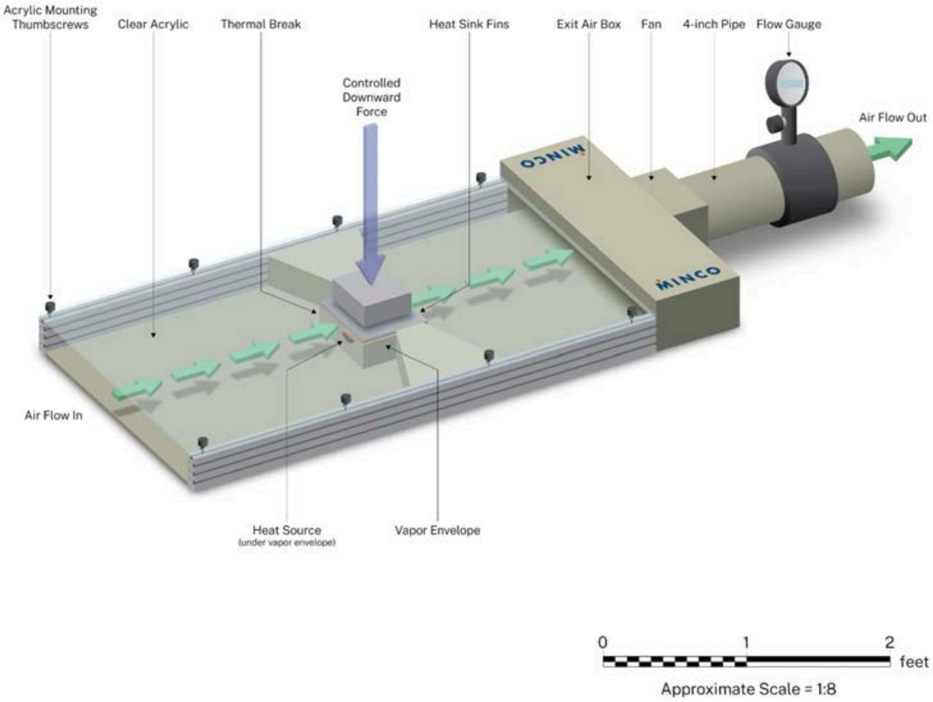
In order to prove our thesis, Minco engineers built two assemblies. The first was our Vapor Envelope™ vapor chamber (VE) with a 5mm-thick, anodized-aluminum heat sink attached to the top with a thermal interface material in between. The assembly was attached to a simulated CPU consisting of a ¼” copper block with a foil heater attached to the underside and a temperature sensor monitoring its temperature. The heat sink consisted of a 2mm-thick base plate with 3mm tall fins.

The second assembly was composed of a standard 3mm-thick vapor chamber (VC) with a 3mm-thick heat sink mounted on top with a thermal interface material in between. The heat sink consisted of a 2mm-thick base plate and 1mm tall fins. It had an identical copper block standing in as the CPU.



The assemblies were tested in an apparatus consisting of an enclosure (see below) with restricted inlets and outlets, and a box fan that draws air across the fins of a heat sink.

First, each system was operated under identical conditions, with 13-watt and 50-watt heat inputs. The copper block’s operating temperature was monitored. Next, each system was operated on the same boundary conditions, and heat input was adjusted to achieve the target operating temperature of 70˚C, which is based on desirable CPU/ASIC operating temperatures.

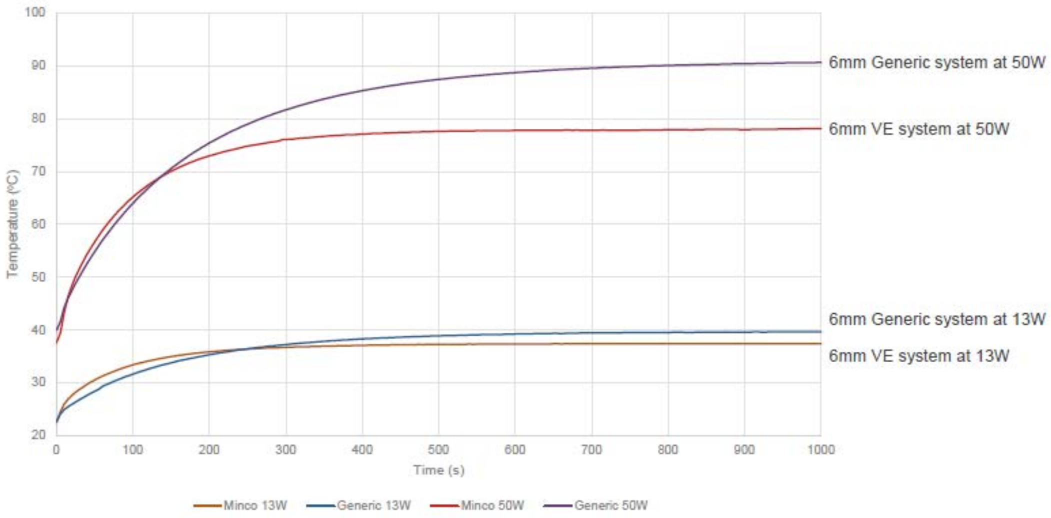


Case Study Results

Enabling 20% higher processor power than generic vapor chambers

The charts below detail the results of the tests. The Vapor Envelope™ vapor chamber assembly showed superior characteristics as compared to the standard vapor chamber. In circumstances where volume matters – such as a blade server – the ability to spread heat efficiently becomes paramount.

Systems Operating Temperature at Same Powers



When both systems were operated at 50 watts heat input, the simulated CPU operated at a roughly 12˚C lower temperature for the Vapor Envelope™ vapor chamber system.

Spreader	Trial	Power	Average Power
Vapor Envelope™	1	41.6	41.6
	2	41.6	
	3	41.6	
Generic Vapor Chamber	1	34.5	34.5
	2	34.5	
	3	34.5	

When both systems were tuned to operate at 70˚C the Vapor Envelope™ vapor chamber system was able to input 41.6 watts of average power – a 20% power increase compared to the standard vapor chamber system's 34.5 watts.

Technology Recap

Minco's patented build process allows the creation of 1mm vapor chambers

Minco's Vapor Envelope™ vapor chamber technology moves far beyond the results of the DARPA study. By providing superior heat spreading for its volume, the Vapor Envelope™ vapor chamber allows more room for fins in space-constrained applications.

Here are some key data points to consider:

- Vapor Envelope™ vapor chamber combines heat spreader technology with a patented welding process to create a 1mm-thin pressure vessel.
- The heat-spreading characteristics of the Vapor Envelope™ vapor chamber compares favorably with full-sized vapor chambers but at a third the volume.
- When combined with a heat sink, a Vapor Envelope™ vapor chamber offers superior characteristics to a vapor chamber assembly of similar volume.
- Wick structure and phase transition fluid is sealed inside the pressure vessel to make for a long-lasting product – Minco estimates a 10+ year lifespan. Because of this reliability, they can be sealed inside enclosures like laptop cases.
- Vapor Envelope™ vapor chamber operates at orientations of 0° to 90° relative to horizontal as well as in low-pressure environments.
- Operating temperatures range from 10 to 100°C. Maximum heat flux: >160 W/cm². Minco is able to adjust heat transport distance and thermal conductivity by modifying the thickness of the pressure vessel.
- >4” (11cm) radial isothermal heat spreading, making for a current size limit of 7” x 9”.
- Copper pressure vessel can be nickel-plated for corrosion protection and redundant hermetic sealing.

Advantages of Foil Over Plate

The thinness of the copper foil, as well as that of the full Vapor Envelope™ vapor chamber, offer numerous advantages over heavier vapor chambers:

- Vapor Envelope™ vapor chamber can be quickly and inexpensively created in a variety of shapes and custom configurations to suit each project. Heat spreaders made from copper plate are much more expensive to customize.
- Vapor Envelope™ vapor chamber foil makeup lends them a slight pliability, possibly easing installation in the final product.
- The Vapor Envelope™ vapor chamber foil construction lends itself to efficient charging, which simplifies manufacturing.
- Copper is the standard for water-based heat pipes. When manufacturing Vapor Envelope™ vapor chamber, Minco uses the same materials as a heat pipe and the pricing compares favorably.

Trade-Offs

The Vapor Envelope™ vapor chamber’s unique combination of size, weight and power capability does not come without trade-offs. The foil wall of a Vapor Envelope™ vapor chamber can be easily penetrated with a pen knife; the envelope should be protected within an enclosure for practically all applications.

Also, we currently have a stated limit to our isothermal heat spreading to a radial distance of 4”. Keep in mind that the amount of area covered by a 4” radius (8” diameter) would provide sufficient heat dissipation area for many applications.

Next Steps

Contact Minco to learn more about this exciting technology

We are currently in the process of introducing the Vapor Envelope™ vapor chamber to the Thermal Management industry.

In addition to our in-house initiatives, we're looking for partners interested in developing applications for the technology.

To learn more about Vapor Envelope™ vapor chamber technology, we recommend you reference the DARPA study, "Two-Phase Thermal Ground Planes: Technology Development and Parametric Results" by Bar-Cohen, Matin, Jankowski, and Sharar. In addition, the white paper "Measuring the Thermal Resistance of a Vapor Envelope™" by Russell H. Strehlow, Research and Technology Program Manager, is available by contacting Minco.

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