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# Feasibility study of an aluminum vapor chamber with radial grooved and sintered powders wick structures

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## HIGHLIGHTS

► We test Aluminum Acetone vapor chambers with radial grooved and sintered wicks.
► Optimal fluid charging ratio and thermal resistances are evaluated.
► Sintered vapor chamber has the better temperature uniformity.

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## ABSTRACT

Vapor chambers are used for spreading and heat transfer because of phase change phenomena. In general, vapor chambers are made of high-conductive metal, such as copper. Aluminum is abundant element, and has low cost. The advantage of aluminum is that it is light, bendable, and easy to shape. The authors studied the feasibility of an aluminum vapor chamber to provide more low cost devices. Aluminum alloy 6061 was used as the container material to fabricate the aluminum vapor chamber with the radial grooved wick and sintered aluminum powders wick. Two types of aluminum vapor chambers were fabricated, both of which had the same dimensions of 58 mm × 58 mm × 6 mm; the working fluid was acetone. This study compared various charging amounts, and evaluated thermal resistance and temperatures at the bottom of the heat sink. A comparison of the two types of wick designs revealed that the thermal resistance of sintered aluminum powders vapor chamber was more stable than radial grooved.



## 1. Introduction

Recently, electronic components are more highly concentrated and have higher total heat dissipation. High heat dissipation and high density of components cause heat to centralize on the components, which is called a hot spot. Hot spots can lead to an increase in the operating temperature of electronic components. The operating temperature exceeds the allowed temperature and causes failure or damage to the components. Consequently, heat removal and low operating temperature are crucial factors in electronic components. Heat pipes are popular heat transfer devices that have high heat transfer rates in cooling application. A heat pipe does not require a large size and can provide high thermal conductivity because of the phase change of working fluid. A heat pipe is excellent for one-directional heat transfer. Hot spot is an approximate two-dimensional problem that cannot be solved directly by using a heat pipe. This study designed a high transfer device based on the principle of heat pipe.

A heat spreader is used for heat removal, and high heat transfer coefficient is a priority. Hence, copper, which is a high-conductive material, is used as a heat spreader, and the two phase heat spreader is called a vapor chamber. A vapor chamber is a closed hollow object that is full of working fluid, with an inner vacuum pump. The purpose of vacuum pumping is to reduce the boiling point of the working fluid, which makes it easier to achieve the phase transition that allows heat to spread rapidly [1–4]. Vapor chambers as heat spreaders provide a higher heat transfer coefficient, and also enhance heat spreading. It is also used to homogenize the temperature and reduce heat centralization. The vapor chamber includes a container, a wick structure, and a vacuum space. From the literature and business information, the wick structure consists of metal mesh, sintered copper powder, or grooves on the container. The working fluid is inserted into the container and provides heat transfer by phase change. The liquid phase of working fluid is

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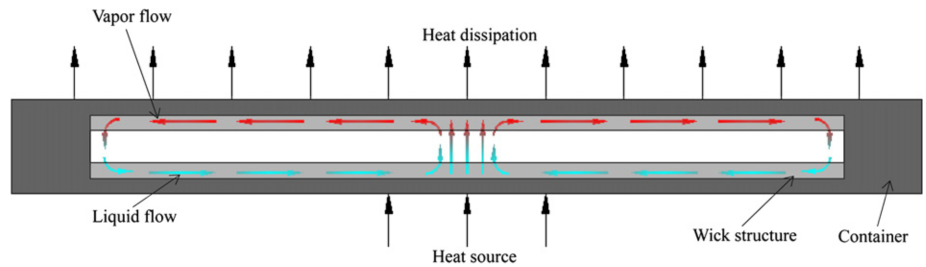


**Fig. 1.** Schematic diagram of a vapor chamber and the associated flow mechanism.

vaporized to vapor phase by absorbing heat on the evaporator, and the vapor subsequently moves to the condenser through the vapor core. The vapor phase of working fluid is condensed to liquid phase by releasing heat on the condenser, and the liquid subsequently returns to the evaporator through the wick structure. The wick structure ensures that the liquid phase of working fluid returns to the evaporator by capillary force. Therefore, the circulation of working fluid is ensured, and the heat transfer continues to circulate. The container must have excellent thermal conductivity and strength, and is usually made of silica, iron, stainless steel, nickel, aluminum, brass, copper, tungsten, or tantalum.

According to the literature, attempts were made to create the containers out of other materials, such as aluminum. In the 1980s, NASA Goddard Space Flight Center (GSFC) presented aluminum heat pipes [5]. The GSFC selected aluminum alloys, such as 6061 and 6063, as the container material of the heat pipes. The wick structure of axial grooves and containers were extruded in one process. Ammonia was chosen as the working fluid, and was compatible with aluminum at the operating temperature of unmanned spacecraft. The purity of ammonia was 99.99% because trace amounts of water in ammonia can lead to a reaction with the aluminum container and result in the formation of hydrogen gas, which is a non-condensable gas (NCG). An NCG can interfere with the flow of vapor and reduce the heat transfer efficiency. This was the first report of aluminum heat pipes.

Baehrle et al. (1998) [6] applied for a U.S. patent. This patent described aluminum heat pipes placed on the inside walls with a closed fluid-tight coating of a water-resistant nickel to ensure resistance against water as heat medium, or to ensure vacuum-tightness for long periods. Nickel was resistant against water in the containers, and was well-wettable by water. In addition, the coating nickel was compatible with the aluminum and did not form any corrosion. Take et al. (2000) [7] developed three types of grooved vapor chamber by a roll bonding process. The roll bonding process fabricated arch-shaped channels as wick structures in two aluminum plates (1100) with purity of 99%. R-123 and R-134a, as the working fluids, were inverted into the vapor chamber, and the optimal filling ratio and temperature drop between evaporator and condenser were evaluated.

Shimura et al. (2002) [8] used cyclopentane as working fluid to charge with aluminum flat heat pipes. Conventionally, heat pipes used freons, which included HCFCs and cyclopentanes, which are harmful to the global environment. The experiments consisted of evaluation of thermal resistance of aluminum–HCFC123 and aluminum–cyclopentane heat pipes, and long-term reliability. In horizontal working position, the aluminum–HCFC123 heat pipes and aluminum–cyclopentane heat pipes exhibited almost the same thermal resistance, and were superior to the aluminum plate, even at 14 W. For long-term reliability of aluminum–cyclopentane heat pipes, it was found that the performance reduction stopped at approximately 1000 h. Cao and Cao [9] attempted to manufacture heat spreaders using aluminum 6061, because of its superior machinability and high resistance to warpage with network design of wicks. Water and methanol were chosen as the working fluid, although it was not expected to be compatible with aluminum. Thermal resistance and the contact temperature were evaluated at various heat fluxes and filling ratios.

From these studies, the aluminum heat pipe was developed for application in the aerospace industry because of its temperature operation range and light weight. The rapid development of copper–water heat pipes interrupted research and development of aluminum heat pipes. Currently, the technology and research of

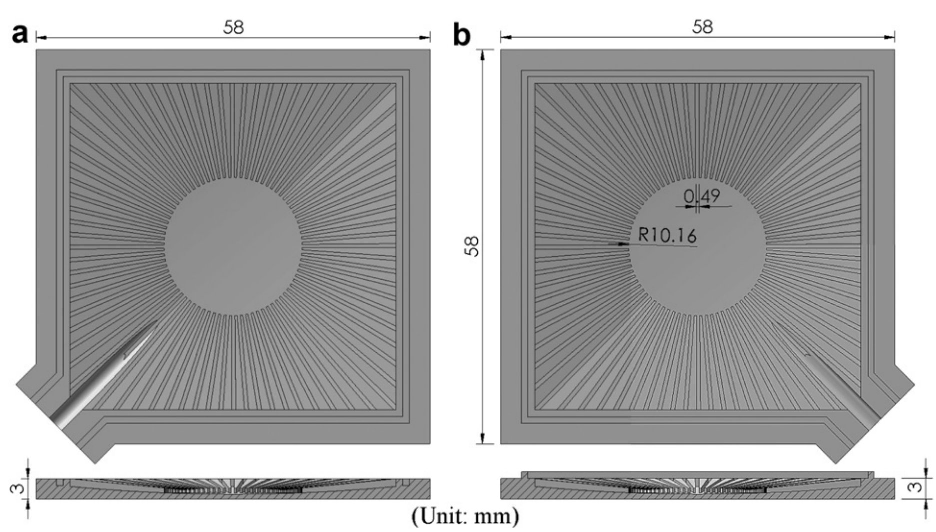


**Fig. 2.** Radial grooved vapor chamber. (a) Top plate (b) bottom plate.