WHITE PAPER

SPRAYCOOL®

Mechanics of SprayCool Direct Spray

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ABSTRACT

As power densities of embedded electronics increase, cooling becomes a challenge especially in harsh environments. Liquid cooling is accepted as an alternative cooling method for an increasing number of applications. Direct spray is a particularly efficient form of liquid cooling that has recently been included on several manned and unmanned military platforms. The article will focus on the mechanics of direct spray and the benefits derived from a two-phase cooling approach.

BACKGROUND

For decades military platforms have included electronics for avionics, vehicle controls, radios, radar, sonar and fire control. From a computational standpoint most of these systems could be accomplished with relatively low power devices. There have always been higher performance electronics for applications such as radar processing, Intelligence, Surveillance, and Reconnaissance (ISR) processing, and mission computing; however, high performance electronics were relegated to stationary, benign environments. Due to bandwidth limitations of secure communications between command centers and front line troops, trends to include these computationally intense applications on vehicles and aircraft exist. From airborne platforms such as U-2 Dragon Lady and Global Hawk operating up to 70,000 feet and -65°C to a surface-to-air missile launcher mounted on a 5-ton truck called Medium Extended Air Defense System (MEADS) in a scorching +60°C desert, the military is deploying incredible performance in harsh environments. To fit on these military vehicles, the size, weight and power (SWaP) of the electronic systems are minimized to extend the range of airborne platforms or allow ground vehicle transport with a wider range of operation. Direct spray systems from SprayCool® are enabling these programs with minimal SWaP budgets and harsh environmental requirements to use lower cost, high performance embedded electronics.

COOLING SYSTEM ARCHITECTURE

In practice, direct spray systems operate similarly independent of shape, size, or application. Figure 1 diagrams the common components found in direct spray enclosures. For all systems there are three fundamental functions of a cooling system: Heat acquisition, heat transport and heat rejection. Heat acquisition is accomplished by spraying a fine mist of non-conductive and non-corrosive coolant with atomizers (orifices) directly onto electronics or within a cold plate. As the coolant vaporizes, heat is transferred from the electronics to the fluid-vapor mixture. Transport occurs when the coolant vapor condenses on the enclosure walls collecting in the reservoir. System components are often connected by drip-less "quick disconnect" fluid connectors for ease of maintenance or reconfiguration. Finally, heat rejection is accomplished via the heat exchanger that rejects the thermal load to ambient air or platform fluid. Several fluid options for heat rejection on military vehicles include Polyalphaolefin (PAO), fuel, engine bleed air, an Ethylene Glycol and Water (EGW) mixture, or ram air. Heaters are also used to heat the electronics at cold ambient temperatures.

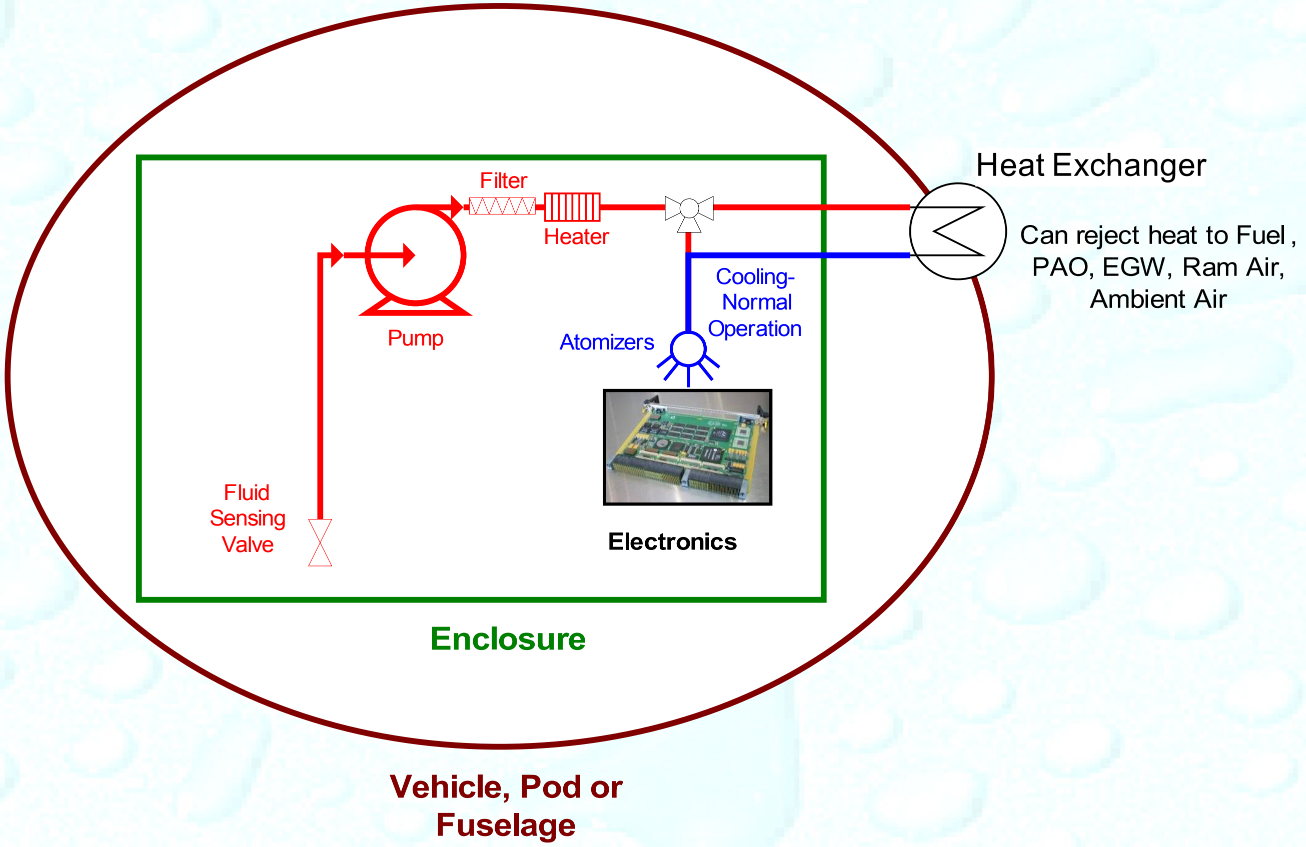

Figure 1 System diagram of direct spray enclosure

Filtration is built into the enclosure, pump and coolant delivery system to remove organic and chemical contamination. For mobile applications, valves are placed in the corners of the units to sense fluid and open when sufficient fluid is present. A controller is employed to operate the cooling system and provide cooling system status, user diagnostics, and warnings/shutdown notifications. Lastly, direct spray enclosures support cPCI, VME, VXS and VPX electronics in either conduction or lower cost air-cooled variants.

THERMAL CHARACTERISTICS

Direct spray enclosures apply fluid directly on the electronics by pumping fluid from the reservoir to the electronics. By wetting the electronics directly, energy is transferred between heat generating components and the fluid via forced convection (sensible heat), evaporation and nucleation (latent heat). The goal is to maximize the phase change from fluid to vapor because of the exceptional heat transfer capacity afforded by the latent heat of vaporization. Figure 2 illustrates the differences in heat transfer capacity of a given single phase liquid, boiling and direct spray. Noticeably, direct spray outperforms boiling at higher temperature differences between the component surface and saturated fluid. This is primarily due to direct spray droplet velocity that reduces the boundary layer on component surfaces and breaks up bubbles created by nucleation. Cooling with single phase liquid has significantly less heat transfer capacity than either boiling or direct spray because there is no phase change.

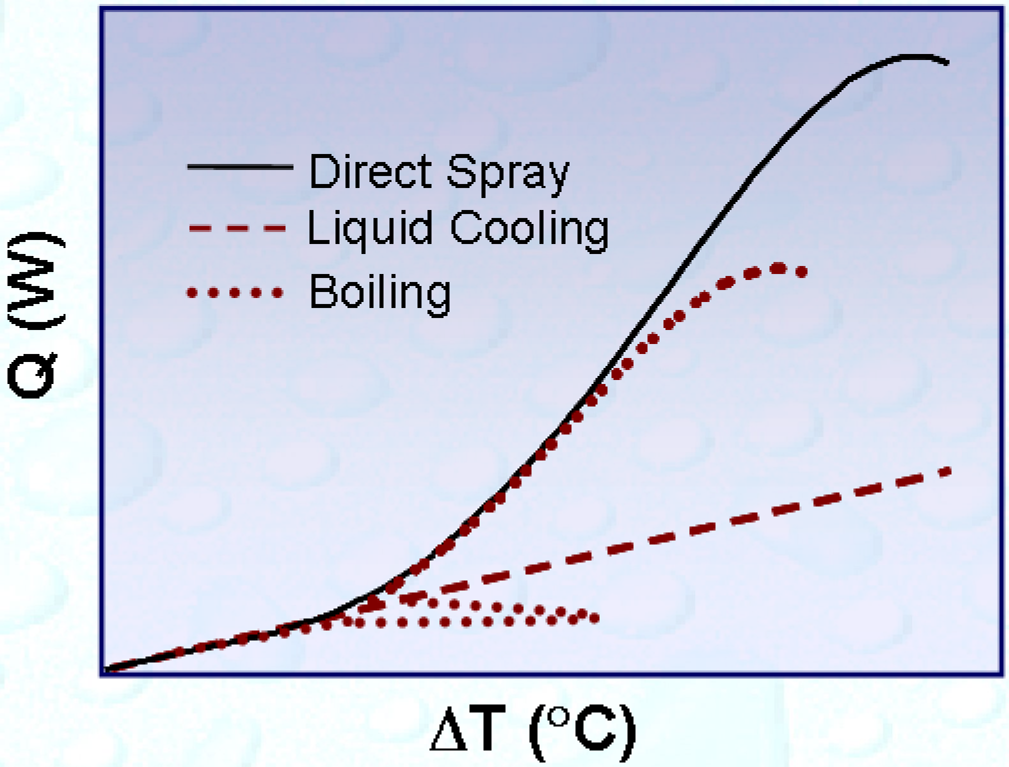

Figure 2 Comparison of heat transfer modes of a given liquid

Fluid selection is critical in direct spray enclosures for multiple reasons: Boiling point, thermal properties, material compatibility, inertness, handling, safety and of course dielectric properties. Perfluorocarbon fluids have been used for over 50 years in electronics applications and are commonly employed in electronics cooling today. 3M's Fluorinert brand fluids offer several options for boiling points that coincide with ideal component temperatures, such as FC-72, and FC-84. Another brand with similar properties is Performance Fluid (PF) -5060 and PF-5070, also from 3M.

In a direct spray card cage, the method for delivering spray varies depending the heat flux, total power and physical size of the components of interest. Transverse spray is most common and is accomplished by delivering fluid from card cage manifolds that include both card guides and atomizers. The fluid is sprayed between cards from the card edge. For higher heat densities, angled or top down spray can improve heat transfer coefficients (h) as shown in Figure 3.

Figure 3 Heat transfer coefficients based on angle of spray

Variations to flow rate, fluid temperature and discharge pressure at the system level affect local heat transfer coefficients, especially on high power devices. For this reason, the card cage can be tuned for hot spots and total heat load of the electronics in context of pump curves and heat exchanger performance. The interdependence of all components within the system cannot be overstated. Tuning does require expertise, but is readily accomplished by those familiar with the process.

To compare and contrast the cooling capability of direct spray to that of other cooling methods, Figure 4 describes a 1cm^2 device that is 30°C higher than the heat transfer fluid (be it air or liquid). Typical heat transfer coefficients on the left side of the graphic determine the amount of power removed from the component (Q) shown on the right side. The differences in cooling capacity are easily explained with fluid properties. The specific heat of air and perfluorocarbon are very similar at 1 kJ/kg-°C and 1.1 kJ/kg-°C, respectively. However, when changing phase, the latent heat of FC-72 is 87.9 kJ/kg contributing to significant heat transfer rates. It is noteworthy that a 30°C temperature difference is difficult to achieve with liquid immersion as bubbles from vapor generation prevent fluid contact with the component surface resulting in a ‘dry out’ condition.

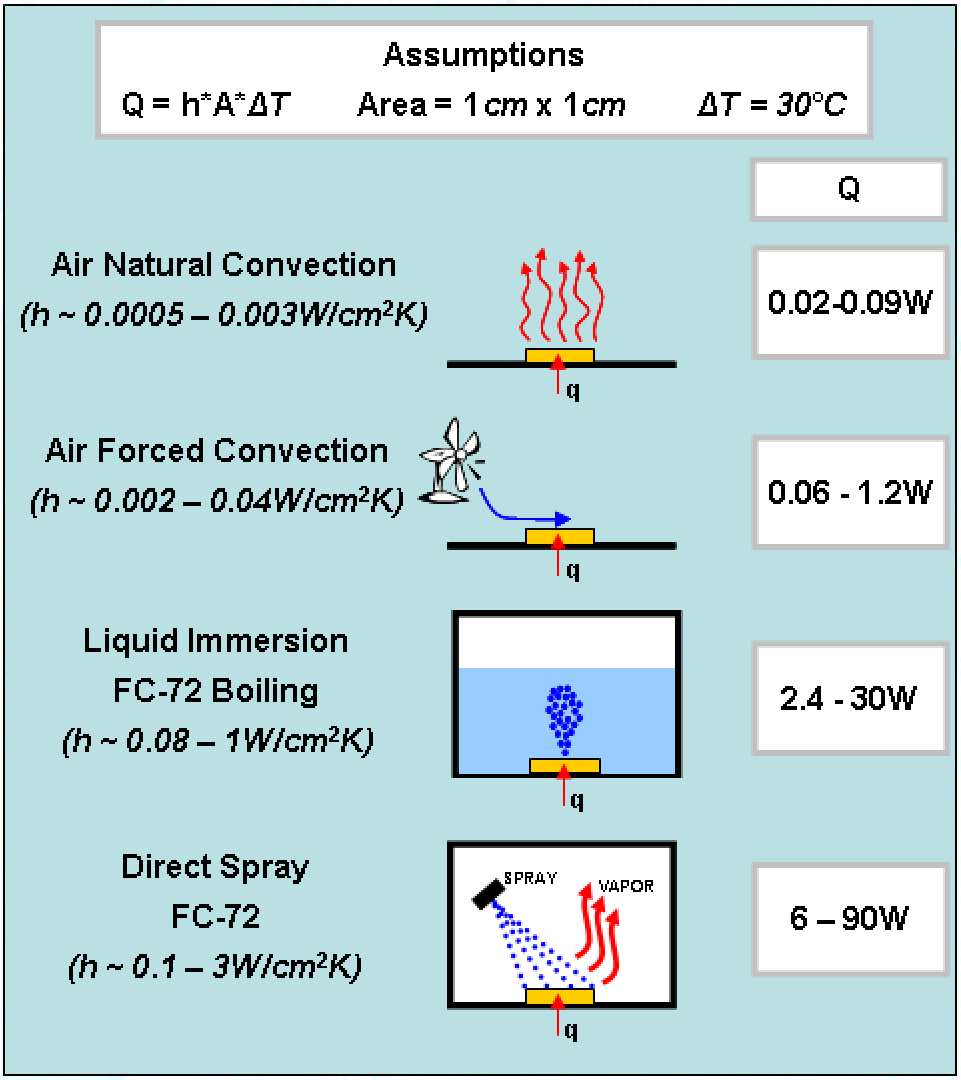

Figure 4 Comparison of cooling methods

A resistance model is appropriate to quantify differences between conduction cooling and direct spray. Typical values for conduction resistance values for spreader-to-wedgelock range from 0.3 to 0.5°C/W compared to direct spray resistances of 0.1 to 0.3°C/W for similar areas. Figure 5 qualifies the resistances associated with each interface found in sealed enclosures used to cool electronics. Not only are the individual resistance values lower in direct spray, there are fewer of them. The resultant temperature difference between heat source and ultimate heat sink (such as ambient air) is 10-15°C higher with conduction than direct spray. This means the end user has the ability to either run at higher ambient temperatures, higher power devices, or both without impacting component reliability.

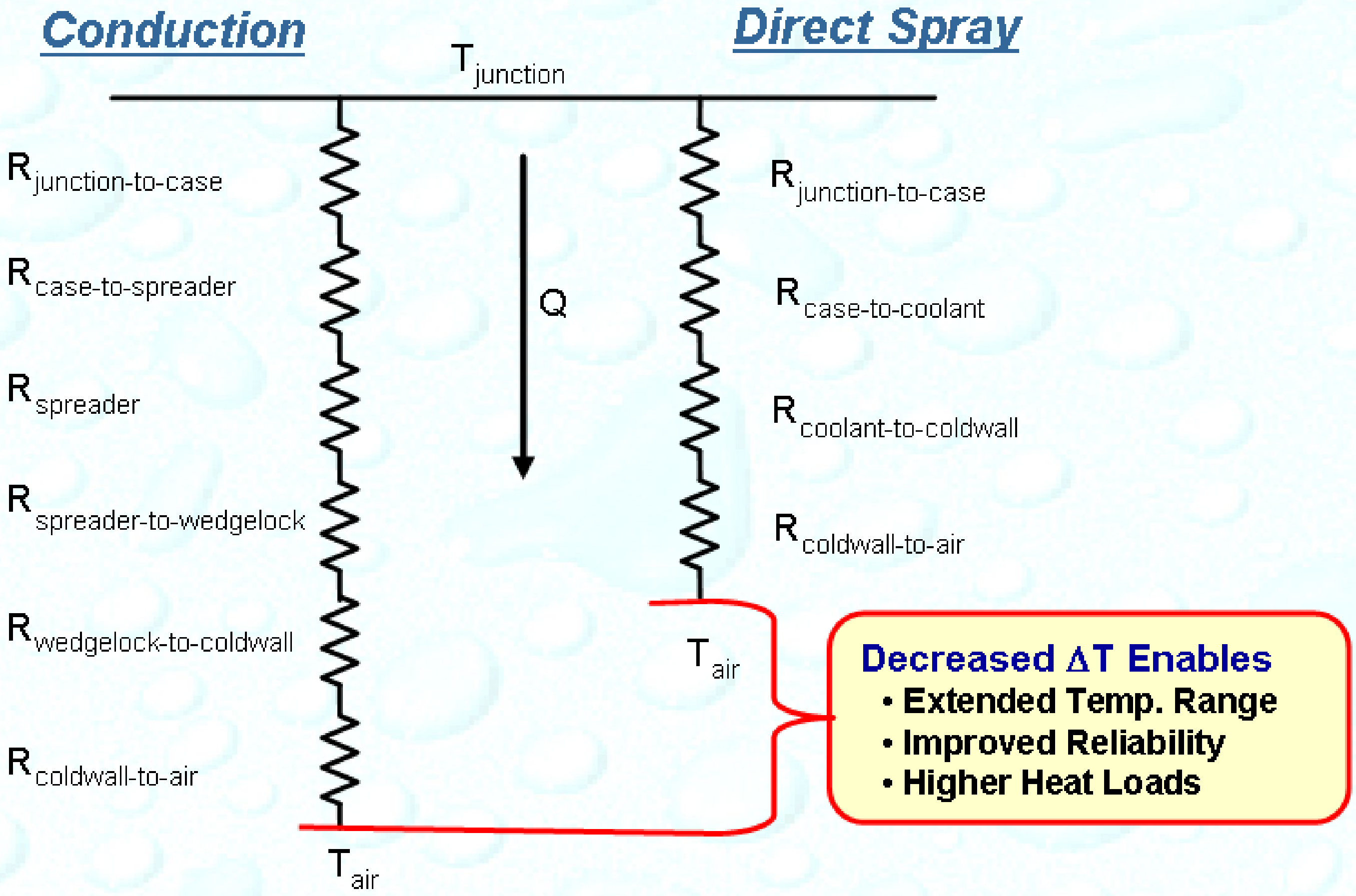

Figure 5 Qualitative thermal resistance models for conduction and direct spray

ALTERNATIVE COOLING APPROACHES

Air-cooled and conduction-cooled enclosures have long been the favored solutions for good reason: These enclosures traditionally kept destructive things away from electronics like dust, sand, salt water, EMI, etc. As the demand for higher performance electronics in harsh environments increases, the role of the enclosure gets more complex. Now enclosures must not only protect electronics from external contamination, but face increasing challenges in preventing internal overheating.

Heat transfer rates and thermal resistances of a given cooling solution have a direct impact on the available options for fielding electronics in harsh military environments. If sufficient conditioned (air conditioned and/or pressurized) space exists, air-cooled enclosures are a logical choice. When electronics must reside in unconditioned (especially high altitude) environments, conduction and air-cooled systems are limited in total slot count and constrained to 20-75 Watts/slot for 6U systems.

As power densities for 6U VPX range from 50-200 Watts/slot, liquid cooling has emerged as an essential supplement to electronics cooling products. The search for fluids that are both non-conductive and possess high sensible heat transfer rates is ongoing. For now, single phase liquid cooling most often employs conductive fluids such as EGW or PAO that create contamination and corrosion risks. Furthermore, without latent heat of vaporization, required flow rates drive operational system pressures up to 100 psig, negatively affecting SWaP and making all fluid connections more susceptible to leaks. Fluid connections have been developed to address leaks at these pressures, but such highly reliable interfaces are costly. By utilizing non-conductive, non-corrosive fluids in low pressure systems (20 psig for fluid distribution, 8 psig for enclosure) with the flexibility to use air-cooled or conduction-cooled boards in the same chassis, direct spray enclosures offer an alternative for environmentally isolating electronics up to 500 Watts/slot.