Immersion Cooling: Emerging Technologies for High Density Computing

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Abstract: The following white paper is part of a quarterly series developed by Willdan Energy Solutions. The intent of the series is to provide the intelligence we have collected through implementation of data center energy efficiency programs nationally. We seek to identify technologies and strategies that can become actionable items in utility-run data center programs. This quarter's white paper focuses on the emerging technology of immersion cooling. This technique submerges computing hardware in a fluid that, unlike water, does not conduct electricity. Products utilizing this technology are in the early stages of commercialization and lack long-term data regarding cost, reliability, and serviceability. However, immersion cooling offers excellent energy efficiency for high density data centers and the ability to achieve efficiency in warm climates.

Servers Immersed in Mineral Oil

Data centers most often use air as the cooling medium. Legacy raised floor cooling systems utilize chillers, cooling towers, pumps, and computer room air conditioning/ handling (CRAC/H) units to provide cool air to each server node. Though this configuration is robust and well-known, it presents a few significant limitations. It involves several heat transfer processes, and thus has inherent inefficiencies. One way to address this is through "free cooling" which provides cool, filtered outside air directly to the server racks. CPU temperature specifications have risen significantly in recent years, allowing facilities to utilize free cooling year-round in cooler climates.

Air, however, has a low density which means large volumetric flow rates and high temperature differentials are required to cool servers. As the power density of a data center increases, more air must be supplied for cooling which requires increasing the raised floor plenum pressure. At power densities around 150-200 W/sqft, it becomes impractical to use a raised floor cooling system.[1] In-rack/in-row cooling systems are available which move the air-to-water heat exchangers to the racks themselves, essentially bypassing the raised floor distribution system. This approach still uses air as a heat transfer medium and requires chilled water be pumped to each rack increasing the cost of plumbing and the risk of leaks.

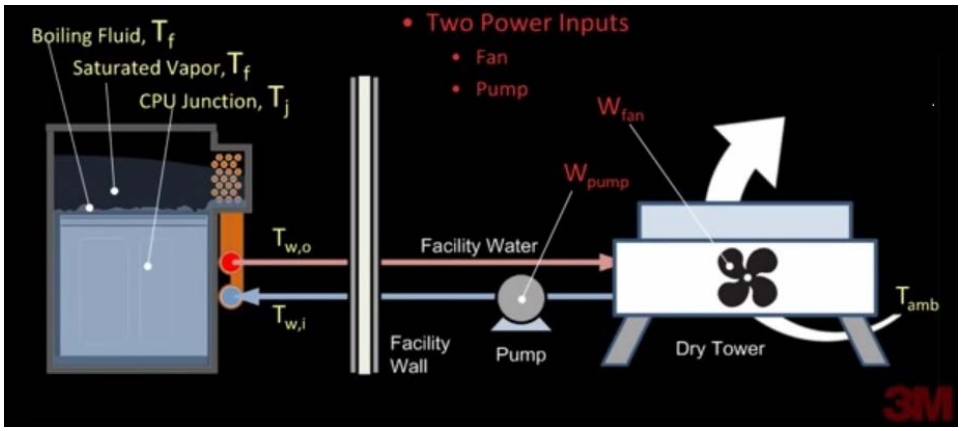
Liquid cooling is physically the most efficient means to cool a microprocessor. It has long

been used in the world of supercomputers, often using water pumped through heat exchangers that are themselves in direct contact with the CPU. The growth of internet applications, cloud computing, and high performance computing have driven high density server deployments and increased interest in this cooling technique beyond the supercomputer niche.

Sealed Module Immersion Cooling Rack by Iceotope™

In response, several firms have developed new immersion cooling technologies that submerge servers in a bath of dielectric fluid and provide heat removal to the fluid bath through a facility water loop. Dielectric fluids do not conduct electricity and are not harmful to electronic equipment. In September 2012, Intel announced immersion cooling to be safe for servers after a year of testing.[2] Fluids used in this application are typically mineral oil or engineered fluoroplastic liquids with optimized boiling points for the most even and effective heat transfer. These new cooling fluids are non-ozone depleting and exempt from the US Environmental Protection Agency's list of Volatile Organic Compounds.[3]

Two system configurations are in use today: open bath immersion, and sealed module immersion. Open bath systems simply submerge several servers in a bath of cooling fluid at atmospheric pressure to reduce plumbing costs and leakage risks as well as minimize pumping energy. Sealed module systems protect the server from the environment, thus opening possibilities to house data centers in environments typically considered unsuitable.



Open Bath Immersion Cooling System Schematic by 3M™

Advantages:

1. Energy Efficiency: Eliminates the need for chillers, chilled water distribution, distribution fans, raised floor plenums, and server fans.
2. Density: Offers ability to cool highly dense computing facilities. Increased packing density offers more bandwidth which is important for high performance computing applications.
3. Higher water temperatures (e.g. 122 ^{o}F for one manufacturer)[4] mean free cooling can be used year-round in any location.
4. Higher water temperatures are suitable for heat recovery applications including comfort heating, absorption chillers, and desalination.
5. Open bath immersion configuration offers simplicity of design.
6. Sealed module configuration offers protection of the equipment from the surrounding environment.

Disadvantages:

1. Likely not the most practical approach for lower density applications.
2. Due to its status as an emerging technology, very little data are available regarding first cost, ownership cost, reliability, and serviceability.
3. Engineered dielectric fluids are costly ($70 per gallon according to one source).
4. Commodity servers are not yet designed specifically for immersion cooling applications.

Comparison

The table below lists a high level comparison of energy savings. Note that exact energy savings will depend on the actual project under consideration.

IT Load (kW)	New Construction Baseline PUE[A]	Immersion Cooling PUE[B]	Annual Hours of Operation	Energy Savings (kWh) over baseline
1,000	1.5	1.05	8,760	3,942,000
2,000	1.5	1.05	8,760	7,884,000
3,000	1.5	1.05	8,760	11,826,000
4,000	1.5	1.05	8,760	15,768,000

A. Energy Efficiency Baselines for Data Centers: Statewide Customized New Construction and Customized Retrofit Incentive Programs

B. Manufacturer claimed PUE: http://www.grcooling.com/liquid-cooling-retrofit-savings/

Sources:

1. *Barroso, Luiz, and Urs Holzle. "The Datacenter as a Computer: An Introduction to the Design of Warehouse-Scale Machines." Synthesis Lectures on Computer Architecture. (2009): 44. Web. 6 Mar. 2014.*
2. *Miller, Rich. "Intel Embraces Submerging Servers in Oil." Data Center Knowledge. N.p., 04 09 2012. Web. 6 Mar. 2014.*
3. *Pfanner, Eric. "Liquid-Cooled Supercomputers, to Trim the Power Bill." the New York Times 11 Feb 2014, n. pag. Web. 6 Mar. 2014.*
4. *Miller, Rich. "Iceotope Gets $10 Million Funding, Partners With Schneider." Data Center Knowledge. N.p., 14 Jan 2014. Web. 6 Mar. 2014.*