Cooling Datacenters with Liquids

Herb Zien
July 2014
Today virtually all datacenters circulate conditioned air around the data processing room and through the racks to cool IT equipment. Separate hot and cold aisles are maintained in a desperate attempt to conserve energy. In most installations cold air is forced up through holes in the floor. Humidity control is critical to avoid condensation on IT equipment if too high or electrostatic discharge if too low.

None of this makes sense. Air is a thermal insulator and has an extremely low heat capacity. Was it fourth grade science class where the principle that hot air rises and cold air drops was passed along? In engineering school they teach that fan energy increases as the cube of the volume of air circulated, which means that doubling the airflow requires eight times the energy. It should come as no surprise that using fans to fight gravity with brute force accounts for more than 10% of the total energy used in a datacenter.

Cooling with air creates problems beyond wasting energy. Contact between air and electronics leads to oxidation and corrosion. Pollutants in the air can cause additional damage. Fans can fail, affecting reliability. OSHA regulations require earplugs in some datacenters due to excessive fan noise. Additionally, in some high density computing applications, heat generation at the device level is bumping up against the thermodynamic limit of how much can be dissipated by circulating air.

When asked, most engineers admit that cooling datacenters with a liquid makes sense, but express concern about equipment cost and ready access for maintenance. These are the problems that must be solved before liquid cooling technologies will be widely adopted.

**LiquidCool Solutions**

LiquidCool Solutions has solved the cost and maintenance problems that stand in the way of widespread acceptance of liquid cooling.

LCS has developed and owns an IP portfolio comprising 17 issued and 21 pending patents, which are licensed to electronic device manufacturers. LiquidCool Solutions combines a sealed enclosure and standard-size rack, a cost-effective approach that places special emphasis on scalability and rack management. A specially engineered yet inexpensive dielectric liquid is used to remove heat from all components without any moving parts in the chassis.
Maintainability is a key consideration. There will not be any maintenance cost associated with chillers, direct expansion units, CRACs, CRAHs or air handlers, because none of this equipment is required with LCS cooling technology. Additionally there will be less maintenance in the racks, because most root causes of IT equipment failure are eliminated:

- Dramatic reduction in thermal fluctuations, which drive solder joint failures
- Much lower operating temperatures for the board and components
- No oxidation/corrosion of electrical contacts
- No fretting corrosion of electrical contacts induced by structural vibration
- No fans, pumps or other moving parts within the device enclosure
- No exposure to electrostatic discharge events
- No sensitivity to ambient particulate, humidity, or temperature conditions

When access to a board for upgrades is desired an IT device can be removed from a rack, drained, opened, serviced, reassembled, refilled, and reinstalled within a 15 minute turnaround window. If a spare is available the swap out procedure takes less than two minutes, and the insertion/removal process in the rack is dry because the quick disconnect fluid couplings are dripless.
Other Approaches to Liquid Cooling

Three competing technologies have emerged to cool electronic equipment with liquids: cold plates, in-row cooling and direct contact by a dielectric fluid.

**Cold Plates**, originally designed to enable gamers to overclock their machines, target the hottest or highest power density components in servers, namely the processors. Device fans, facility fans and other cooling infrastructure are still required to cool other components that are not equipped with cold plates. Additionally cold plates are not an effective way to cool switches, which do not have point sources of heat. Cooling efficiency for cold plate systems can be 50% better than air.

**In-Row Cooling** essentially is an attempt to make the room around the IT equipment smaller, but they still require all of the elements of a complete datacenter air conditioning system. Cooling efficiency for in-row systems can be 60% better than air.

**Direct Contact** means that electronics are totally immersed in a non-conducting dielectric fluid, thereby decoupling electronics from the room and eliminating fans. A closed cycle is used to dissipate heat. Some direct contact systems are single phase where the dielectric fluid remains a liquid throughout the heat dissipation cycle. In others a two-phase system is used where the fluid boils and is then condensed. Cooling efficiency for direct contact system can be more than 90% better than air.

**Cold Plates**

Companies that offer cold plate technology include Asetek, Clustered Systems, CoolIT Systems and Cray.

**Asetek** manufactures sealed-loop liquid coolers for the computer industry. The company’s products serve the gaming, workstation, performance PC and, most recently, the datacenter market. The vast majority of Asetek’s current business involves the sale of aftermarket cold plate kits for PCs:
Asetek’s server product, ISAC, is an adaptation of its PC kit, which uses water to cool high heat flux components such as CPUs and GPUs. Other heat generating components inside a server are cooled via a water-to-air heat exchanger. Fans within the ISAC enclosure circulate the air within the server and through a radiator. Then water transports the heat to a cooling distribution unit called RackCDU, which mounts on the rear of a standard server rack.

**Chilldyne's** Cool-Flo system is a patented, direct-to-chip liquid cooling system that delivers water at a low flow rate by utilizing a proprietary negative pressure pump. That way the water does not short out the electronics when there is a leak.

**Clustered Systems** develops and markets high performance cooling systems for servers, storage systems and related applications. The company also designs, sells and licenses adapters to enable standard volume servers to be used with racks made to Clustered System specifications.

Instead of cold plates inside each server, Clustered Systems attaches an external cold plate to each server in the rack. Heat risers, which extend to the external cold plate, are used to transfer heat from the hottest components including CPUs. The remaining components in the server are cooled by convection. The cooling fluid in the cold plate is a refrigerant that does not damage electronics when there is a leak.
**CoolIT Systems** markets Rack Direct Contact Liquid Cooling kits, a cold plate system similar to Asetek’s. For datacenters CoolIT offerd rack mounted cooling distribution units that integrate with its cold plate system. Asetek and CoolIT Systems are currently litigating patent infringement claims against each other.

**Cray** markets the CS300-LC, which uses warm water instead of chilled water to reduce operating costs. Cold plates are used to directly cool the processors, removing about 80% of the heat in a high performance server; the remaining 20% is removed by fans. Leak detection and remote monitoring equipment is built into the system to let operators know when water leaks out of the kit.
In-Row Cooling
Companies that offer in-row cooling technology include HP, IBM, Opengate Data Systems, and Rittal.

HP offers the Apollo 8000 system, which includes custom servers, racks and cooling distribution units. Water-cooled heat exchangers mounted on rack sidewalls operate at sub-atmospheric pressure to limit damage when a leak occurs. Sealed heat pipes in the servers are used to transfer heat from electronic components to thermal contact plates mounted along the server chassis walls, where it is transferred to the rack-mounted heat exchangers.

IBM has an extensive patent portfolio related to liquid cooling technology including cool rear doors. IBM’s Rear Door Heat eXchanger brings cooling capacity to areas around server racks. About half of the heat generated by the servers is removed by chilled water that circulates through the Rear Door Heat eXchanger, and the rest is transferred to the hot aisle by fans.
**Opengate** provides rack- and row-based heat containment systems to minimize power consumption while maintaining target temperature for datacenters. Its technology focuses on cabinet-level containment systems that eliminate the hot aisle by removing waste heat from servers through a chimney system that brings air directly into an overhead air chamber.

![Opengate Data Systems Chimney System](image)

**Rittal** manufactures Liquid Cooling Packages that incorporate water-to-air heat exchangers and fans in a small cabinet surrounding a standard rack. The LCPs can be designed into new datacenter construction or retrofitted to expand the efficiency of existing facilities.

![Rittal LCP](image)
Direct Contact

In addition to LiquidCool Solutions four companies offer direct contact cooling solutions: Allied Control, Green Revolution Cooling, Iceotope and SGI.

**Allied Control** uses a two-phase (evaporative) immersion cooled system. Electronic components are submerged in a bath of Novec, an expensive hydrofluoroether dielectric. Boiling occurs on the surface of the heat generating devices and vapor passively rises to the top of the enclosure, where it condenses on water-cooled coils and falls back into the tank. While this form of immersion cooling is effective at removing heat from ultra-high power components, it presents technical challenges. Novec is a volatile fluid, so care must be taken to minimize the amount of fluid escaping from the enclosure and ensure that excessive pressure does not build up during the phase change process.

**Green Revolution Cooling** has developed a liquid cooling enclosure for datacenter racks. The product comes standard with tank, rack, cooling system and control system. The firm’s CarnotJet Dielectric Fluid Submersion Cooling System resembles a rack tipped over on its back, with modified servers inserted vertically into slots in the tank. Each 42U tank is filled with roughly 250 gallons of standard white oil. Practical concerns are floor space requirements, scalability and the long term reliability of the coolant.
Iceotope servers include off-the-shelf motherboards, which are mounted inside sealed hot-swappable cartridges that are flooded with a primary refrigerant, Novec. Unlike Allied Control, which boils and condenses Novec, it remains a liquid in Iceotope’s system. To take the heat out of the Novec there is a secondary circuit with water snaking through a channel inside one wall of the cartridge. As suggested by the illustration Iceotope’s two circuit technology, requiring both Novec and water, is expensive and the water circuit complicates equipment maintenance.

Iceotope Server

SGI technology is similar to Allied Control’s, a two-phase immersion cooled system. Electronic components are submerged in a bath of Novec. Boiling occurs on the surface of heat generating components and vapor passively rises to the top of the enclosure, where it condenses on water-cooled coils and drips back into the tank. Novec is very expensive, and replacing escaped vapor might be a concern.
Summarizing the characteristics of commercially available liquid cooling technologies:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Water</th>
<th>Fans</th>
<th>Rack Based</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiquidCool Solutions</td>
<td>Total immersion in dielectric</td>
<td>No</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>Allied Control</td>
<td>Total immersion in refrigerant</td>
<td>Yes</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Asetek</td>
<td>Cold plate</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>Childyne</td>
<td>Cold Plate w/ vacuum</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>CoolIT Systems</td>
<td>Cold plate</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>Clustered Systems</td>
<td>Cold plate</td>
<td>No</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Cray</td>
<td>Cold plate</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>Green Revolution</td>
<td>Total immersion in dielectric</td>
<td>No</td>
<td>No</td>
<td>Low</td>
</tr>
<tr>
<td>HP</td>
<td>Heat pipe to water wall</td>
<td>Yes</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>IBM</td>
<td>Cold rear door</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>Iceotope</td>
<td>Total immersion in dielectric</td>
<td>No</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>OpenGate</td>
<td>Cold ceiling</td>
<td>No</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Rittal</td>
<td>Cold wall</td>
<td>No</td>
<td>No</td>
<td>Medium</td>
</tr>
<tr>
<td>SGI</td>
<td>Total immersion in refrigerant</td>
<td>Yes</td>
<td>No</td>
<td>High</td>
</tr>
</tbody>
</table>
**LiquidCool Solutions** offers significant benefits over air cooling and every other approach to liquid cooling:

**Saves Energy**
- Device power-to-cool can be reduced by up to 98% vs. air-cooled devices
- Waste heat easily can be recovered for other uses

**Saves space**
- Greater IT device density in each rack because there is no need for air circulation
- Higher rack density because there is no need for hot aisles

**Enhances Reliability**
- Sealed fluid circuits prevent failures from corrosion and contamination
- Liquid submersion reduces thermal fatigue due to fluctuating temperatures
- IT equipment can be easily accessed for upgrades

**Cools High Power Density Electronics**
- Core Coolant™ dielectric liquid is a low-cost, highly effective cooling medium
- Lower operating temperatures result in lower leakage current
- All internal components are kept within normal operating temperature ranges

**Suitable for Harsh Environment Deployment**

**Operates Silently** - Fan noise is eliminated

**Easy to Maintain** – IT devices in racks can be hot swapped in less than two minutes

**Scalable** – Technology accommodates anything from one server to hundreds of racks

**Upgrades** - The cooling system can easily accommodate increased heat loads from future generations of IT devices. Only the motherboard needs to be exchanged as technology advances

**Pick Your Supplier** - LCS does not manufacture IT equipment, but licenses its patented technology to established manufacturers

LCS technology saves energy and space, enhances reliability, cools high-density electronics, operates silently and simplifies upgrades. Capital, operating and maintenance costs are lower. It is not necessary to switch suppliers.

There are no excuses left. The time has come to switch to LCS!