HPC Cooling: Liquids and Systems

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HPC Needs

• Fastest processors
  – Have high power dissipation, 300W+

• Fast, abundant interconnect, low error rates
  – Requires short connections driving high density requirement

• 2-3kW per baseboard requirement
  – Low power CPUs enables higher packing density, not lower power
• Eight Xeon Phi 5100s in an 8U blade
• 2kW approx.
The Air Problem

• Air’s physical properties not suitable
• Water can carry 3,500 times more heat per unit volume
• Refrigerant, 3.1M times with phase change
### Popular Cooling Liquids

<table>
<thead>
<tr>
<th></th>
<th>Novec 7000</th>
<th>R134a</th>
<th>Therminol XP (oil)</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point @ 1 atmosphere (°C)</td>
<td>34</td>
<td>-26.6</td>
<td>358</td>
<td>100</td>
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<tr>
<td>Latent Heat of Vaporization (kJ/kg)</td>
<td>142</td>
<td>216</td>
<td>214</td>
<td>2256</td>
</tr>
<tr>
<td>Specific Heat (kJ·kg⁻¹·K⁻¹)</td>
<td>1.30</td>
<td>1.34</td>
<td>1.68</td>
<td>4.19</td>
</tr>
<tr>
<td>Liquid Density (kg/m³)</td>
<td>1400</td>
<td>1206</td>
<td>875</td>
<td>998</td>
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<tr>
<td>Coefficient of Expansion K⁻¹</td>
<td>0.00219</td>
<td>0.00369</td>
<td>0.00096</td>
<td>0.00021</td>
</tr>
<tr>
<td>Thermal Conductivity (W·m⁻¹·K⁻¹)</td>
<td>0.075</td>
<td>0.092</td>
<td>0.1249</td>
<td>0.58</td>
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<tr>
<td>Vapor Pressure (kPa)</td>
<td>64.6</td>
<td>350</td>
<td>0.012</td>
<td>2.34</td>
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<tr>
<td>Kinematic Viscosity mm²/s (cSt)</td>
<td>0.32</td>
<td>0.17</td>
<td>47.70</td>
<td>1.00</td>
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<tr>
<td>GWP</td>
<td>370</td>
<td>1300</td>
<td>0</td>
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</tbody>
</table>
Water

Positives
• Abundant, cheap
• Best specific heat
• Moderate viscosity, limits pump energy required
• Non flammable
• Non toxic
• 0 GWP

Negatives
• Universal solvent
• Electrically conductive
• Not isothermal
• Low conductivity
• Turbulent flow required to break boundary layer
• Coefficient of expansion too low for good convective performance
• Water to the chip coolers must be separated from the enterprise water to avoid fouling
Systems: Water to Chip

• 40-50kW per rack
• Highly effective for some chips
  – Rest need air cooling
• Liquid connectors needed
  – Can leak
  – Pay large premium for quality
• Service techs may need extra training
Therminol (Oil)

**Positives**
- Low cost
- Good specific heat
- Electrical insulator
- Non toxic
- 0 GWP

**Negatives**
- High viscosity requires increased pump energy
- Limited life
- Not fire resistant, protective devices recommended
- Not isothermal
- Low conductivity
- Turbulent flow required to break boundary layer
Oil Bath

Oil Filled Bath

- Light mineral oil is forced through multiple servers by jets on a manifold
- Convective forces insufficient
• Simple concept
• 40-50kW per bath
• Serviceability issues:
  – Systems must drain before removing to avoid slip/fall hazards
Novec 7000

Positives

• Can be used in single or two phase systems
• Isothermal
• Electrically non conductive
• Low viscosity, low pumping energy
• High coefficient of expansion supports convection
• Non flammable

Negatives

• Very Expensive
• Low thermal conductivity
• Turbulent flow required to break boundary layer
• Heat flux limit (15W/cm²)
• Possible toxicity at high concentrations
• 370 GWP
• 1 motherboard per module
• All components on board cooled
Circulating Coolant Bath

• Compact and efficient
• 30-40 kW per cabinet
• Front I/O only
• Requires liquid proof electrical connectors
• Requires quick connects for serviceability
• Technicians may require additional training
- Motherboard per module
- All components on board cooled
- HX built into side of module
- External heat exchanger needed to avoid fouling
Water Cooled Bath

- Board in pod immersed in Novec-like fluid
- Fluid is cooled by water loop embedded in module
- 1&2 phase operation
- 20kW per rack
- Front I/O only
- Requires quick connects for serviceability
- Technicians may require additional training

Iceotope
Positives

- Isothermal
- Electrically non conductive
- Low viscosity, low pumping energy
- High coefficient of expansion supports convection
- Non flammable
- Widely available & understood

Negatives

- Low thermal conductivity
- Possible toxicity at high concentrations
- 1300 GWP*

* R1234YF with GWP of 6 is future replacement
Cold Plate

- Two motherboards per blade
- All components on board cooled
- 2 phase operation
- Cold plates are fixed in chassis
Cold Plate with Refrigerant

- 2000kW per rack
- Heat brought to a single plane
- Passed to cold plate via special thermal interface
- Abundant front & rear connectivity
- No quick connects
- No additional training required
<table>
<thead>
<tr>
<th>Company</th>
<th>Water to Server</th>
<th>Water in Data Room</th>
<th>Dielectric Bath</th>
<th>Refrig to Rack</th>
<th>Single Cold Plate</th>
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Summary

• Liquid cooled systems
  – Provide High Density
  – Very efficient cooling of powerful processors
  – Go anywhere
  – Improve reliability
    • Avoid Quick Connects

• Chillers not required

256 Xeon node 80kW system in a utility room

0/128 server failures in 10 months
• 2 rows of 16 cold plates for motherboard cooling
  – >1200W/plate, 2.4KW/blade**
• 4 plates for activeplane cooling
  – 500W per plate
• Interoperable with Liebert XD refrigerant based cooling system
Chassis Front

- PDU
- Dual Server Blade
- Cold Plates
Chassis Rear

- Exit manifold
- Switch 1
- Switch 2
- Coolant inlet manifold
- Switch Cold plates
• 16 PCIe 2.0 x 4 to servers
• 8 PCIe x4 to external switches
• 16 x 1GbE from servers, 2 external ports
• Due to low CPU to refrigerant thermal resistance, 30C water provides sufficient cooling
• One Liebert XDP can cool 2-3 racks