Closed-Loop Steam Distribution

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THE UNIVERSITY of CHICAGO

University of Connecticut

GRAND VALLEY STATE UNIVERSITY

PENN STATE

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Penn

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Ohio State

Harvard

Carnegie Mellon
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Steam Basics

Cities With Central Steam

- New-York
- Philadelphia
- Boston
- Baltimore
- Washington DC
- Hartford
- Buffalo
- Rochester
- Minneapolis
- Milwaukee
- Denver
- Montreal
- Vancouver
- Pittsburg
- Saint-Louis
- Tulsa
- Kansas City
- San Francisco
- New Orleans
- Detroit
- Cambridge
- Los Angeles
- Houston
- San Antonio
- Austin
- Richmond
- San Diego
- Grand Rapids
Hydronic Vs Steam

Properties of Saturated Steam

Raising 1 lb. of WATER 1°F $\rightarrow$ 1 BTU of Energy

Raising 1 lb. of STEAM* 1°F $\rightarrow$ 970 BTU of Energy

*AT ATMOSPHERIC PRESSURE

<table>
<thead>
<tr>
<th>Pressure (psig)</th>
<th>Temp (°F)</th>
<th>Heat (BTU/lb)</th>
<th>Volume (ft³/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sensible</td>
<td>Latent</td>
</tr>
<tr>
<td>0</td>
<td>212</td>
<td>180</td>
<td>970</td>
</tr>
<tr>
<td>1</td>
<td>213</td>
<td>184</td>
<td>968</td>
</tr>
<tr>
<td>2</td>
<td>219</td>
<td>187</td>
<td>966</td>
</tr>
<tr>
<td>3</td>
<td>222</td>
<td>190</td>
<td>964</td>
</tr>
<tr>
<td>4</td>
<td>226</td>
<td>193</td>
<td>962</td>
</tr>
<tr>
<td>5</td>
<td>227</td>
<td>195</td>
<td>961</td>
</tr>
<tr>
<td>6</td>
<td>230</td>
<td>198</td>
<td>959</td>
</tr>
<tr>
<td>7</td>
<td>232</td>
<td>201</td>
<td>957</td>
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<td>8</td>
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<td>9</td>
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<td>206</td>
<td>954</td>
</tr>
<tr>
<td>10</td>
<td>239</td>
<td>208</td>
<td>953</td>
</tr>
<tr>
<td>11</td>
<td>241</td>
<td>211</td>
<td>950</td>
</tr>
<tr>
<td>12</td>
<td>244</td>
<td>212</td>
<td>948</td>
</tr>
<tr>
<td>13</td>
<td>247</td>
<td>215</td>
<td>946</td>
</tr>
<tr>
<td>14</td>
<td>250</td>
<td>217</td>
<td>944</td>
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<td>15</td>
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<td>944</td>
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<td>17</td>
<td>256</td>
<td>224</td>
<td>940</td>
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<td>260</td>
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<td>26</td>
<td>274</td>
<td>247</td>
<td>922</td>
</tr>
<tr>
<td>27</td>
<td>276</td>
<td>250</td>
<td>920</td>
</tr>
</tbody>
</table>
**Hydronic Vs Steam**

### Hydronic (212°F)

\[ 35,140,000 \frac{Btu}{hr} \times \frac{1}{180} \frac{lb}{Btu} \times \frac{1}{8.33} \frac{Gal}{lb} \times \frac{1}{60} \frac{hr}{min} = 391 \text{ GPM} \]

### Steam (100psi)

\[ 35,140,000 \frac{Btu}{hr} \times \frac{1}{1,190} \frac{lb}{Btu} \times \frac{1}{8.33} \frac{Gal}{lb} \times \frac{1}{60} \frac{hr}{min} = 59 \text{ GPM} \]

*Lower flow rate → Smaller pipes required*

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**Reduced Pump Energy**

**Hydronic**

- 90 HP

**Steam**

- 15 HP

The pumps represent 3% of the overall energy needed for the hydronic loop.
Hydronic Vs Steam

Conventional Method

Steam Method
Advantages of Closed-Loop Steam

\[ \dot{m}_{fs} = \frac{\dot{m}_c (h_c - h_{fc})}{h_{fg}} \quad R_{fs}(\%) = 100 \frac{\dot{m}_{fs}}{\dot{m}_c} \]

- \( \dot{m}_{fs} = \) mass flow rate of flash steam
- \( \dot{m}_c = \) mass flow rate of condensate
- \( h_c = \) enthalpy of condensate
- \( h_{fc} = \) enthalpy of flash condensate
- \( h_{fg} = \) latent heat of flash steam
- \( R_{fs} = \) flash steam ratio (%)
Advantages of Closed-Loop Steam

- No flash tank required → No Vent to roof
- Energy savings of 5-20%
- Safety and reliability
  - No steam safety valve needed
- Simplicity
- **No acid contamination**
  - Up to 6 times less corrosive on condensate piping
- Can use **high** or **low pressure steam**
Advantages of Closed-Loop Steam

- **Less make-up water** required
- **No PRV** required for steam
- **No condensate receiver pump** needed to return steam through loop
- **Smaller pipe size** due to higher energy content
- **Lower maintenance costs**
- **Few chemicals** and **fewer return lines** (with longer lifespan)
- **40%-60% smaller footprint**
- **Fully automated** control system
- **Digital Energy readouts**
- **No Noise**
Vertically-Flooded Design

- Vary % of shell flooded to avoid flash
- Can use low, medium, or high pressure steam
- No PRV downstream of boiler
- Acts as a Condensing Heat Exchanger

<table>
<thead>
<tr>
<th>Process</th>
<th>Pressure (psig)</th>
<th>BTU/h</th>
<th>Sensible (BTU/lb)</th>
<th>Latent (BTU/lb)</th>
<th>Total (BTU/lb)</th>
<th>lbs/h</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>6</td>
<td>4 000 000</td>
<td>-</td>
<td>959</td>
<td>959</td>
<td>4 171</td>
<td>-</td>
</tr>
<tr>
<td>Flooded</td>
<td>6</td>
<td>4 000 000</td>
<td>50</td>
<td>959</td>
<td>1 009</td>
<td>3 964</td>
<td>5,0%</td>
</tr>
<tr>
<td>Flooded</td>
<td>100</td>
<td>4 000 000</td>
<td>158</td>
<td>881</td>
<td>1 039</td>
<td>3 850</td>
<td>7,7%</td>
</tr>
</tbody>
</table>
• Uses latent and sensible heat of steam to heat liquid
• Oversized vertical shell & tube heat exchanger
• Flooded condensate subcooled to 200°F
• Level of condensate varied by control valve
  • Used to control temperature instead of throttling steam
• Improvements from comparable European models:
  • Steam can be any pressure
  • Control set-point of heated liquid outlet
Vertically-Flooded Design

Vertically Flooded Heat Exchangers

Heat Map Showing Tube Flooding to Avoid Flash
Make-Up Water Reduction

• Causes for make-up water to be added traditionally:
  • Boiler blow-down
  • Leaks
  • Flash steam

• Vertical heat exchanger eliminates flash
  • Condensate is subcooled below boiling point
  • Stays as a liquid
  • High pressure condensate eliminates need for condensate pump
Vertically-Flooded Design

Evaluation - Operating Cost Comparison: Exchanger with Full Load

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Vertically-Flooded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (psig)</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Energy Transferred (Mbtu/hr)</td>
<td>6.01</td>
<td>6.01</td>
</tr>
<tr>
<td>Steam Flow Rate (lbs/hr)</td>
<td>6,307</td>
<td>5,991</td>
</tr>
<tr>
<td>Percentage of Water Lost to Flash</td>
<td>2.85%</td>
<td>0%</td>
</tr>
<tr>
<td>Flash Loss Rate</td>
<td>180</td>
<td>-</td>
</tr>
<tr>
<td>Energy to Heat Condensate (Mbtu/hr)</td>
<td>0.38</td>
<td>0.44</td>
</tr>
<tr>
<td>Energy to Heat Make Up (Mbtu/hr)</td>
<td>0.04</td>
<td>-</td>
</tr>
<tr>
<td>Energy to Vaporize (Mbtu/hr)</td>
<td>5.86</td>
<td>5.57</td>
</tr>
<tr>
<td>Total (Mbtu/hr)</td>
<td>6.28</td>
<td>6.01</td>
</tr>
</tbody>
</table>

Savings

<table>
<thead>
<tr>
<th>Hours</th>
<th>Dollars $</th>
<th>Tons of CO₂ per Million BTUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,000</td>
<td>6,660.99</td>
<td>38.92</td>
</tr>
<tr>
<td>3,000</td>
<td>9,991.49</td>
<td>58.38</td>
</tr>
</tbody>
</table>

(0.05843 ton of CO₂ per Million BTUs)
Corrosion Prevention

• Traditional systems are 6.2 times more corrosive\(^1\)

• Deaerator uses low pressure steam to drive out dissolved gases

• Sensibly heats make-up water from 40°F to 205°F
  • Condensate reclamation reduces need for make-up water

• Cooler condensate reduces cavitation
  • Hot condensate cavitates as pump pulls it into the volute

• Lower make-up water requirement \(\rightarrow\) less chemicals for treatment \(\rightarrow\) cleaner steam running through pipes
  • Cuts surface blowdown in half
  • Delivers 97% quality steam (3% moisture)

1. Corrosion tests conducted independently at hospital in Montreal over 94 day period. Maxi-Therm has corrosion rate of 2.36 mills per year compared to 14.63 mills per year using conventional methods (both using alloy C1010 black iron)
Building Heat Application

- Can control liquid outlet temp to \( \pm 2^\circ F \) for building heat

- Building heat applications:
  - Heating water/ glycol
  - Hot oil or other heat transfer fluids
  - Wash stations
  - Emergency showers
  - Reactors, pasteurizers, jacketing
  - Booster heaters for kitchens
  - Heat recirculation water at 250°F (no bacteria)

- Can handle liquid flow between 35 and 850 usgpm (and can go above 2,000 usgpm if needed)

Domestic Hot Water Application

- Most facilities use over 50% of steam for hot water production
  - Service water
  - Domestic water
  - Reheat
  - Clean steam

- Can control liquid outlet temp to \( \pm 4^\circ F \) for domestic hot water

- Uses Vertically Flooded Heat Exchanger (VFHX)

- Smaller than conventional storage tank heaters
  - Can be wheeled through a doorway

- Smaller reservoir and higher temperatures
  - Stops growth of Legionella bacteria
Example in Practice: Vassar Hospital
### Example in Practice: Vassar Hospital

#### Flash Steam Loss Calc

<table>
<thead>
<tr>
<th>Flash Steam (lbs)</th>
<th>Make-Up Water (gal)</th>
<th>Flash Steam Heat Loss (Btu)</th>
<th>Additional Heat Vaporization (Btu)</th>
<th>Additional Gas to Heat Cond. (Btu)</th>
<th>Gas Consumed (Thers)</th>
<th>Cond. Flow Rate (GPM)</th>
<th>Pump Energy (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000,406</td>
<td>120,097</td>
<td>157,063,776</td>
<td>1,308,848,422</td>
<td>15,362,907</td>
<td>17,000</td>
<td>50,126</td>
<td>1,309</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flash Steam Loss Cost</th>
<th>Cost (in $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Savings:</td>
<td>$14,960</td>
</tr>
<tr>
<td>Water Savings:</td>
<td>$432</td>
</tr>
<tr>
<td>Chemical Savings:</td>
<td>$480</td>
</tr>
<tr>
<td>Electrical Savings:</td>
<td>$1,309</td>
</tr>
<tr>
<td><strong>Total Savings:</strong></td>
<td><strong>$15,873</strong></td>
</tr>
</tbody>
</table>

- Eliminating flash losses to the atmosphere **saves energy and money**
  - Less gas to reheat make-up water to usable temperature
  - Less make-up water lost to high-pressure water flashing to steam
  - Lower volume of water to chemically treat
  - Less pump energy to pull in make-up water
Effective designs have positive environmental impacts

- 705,000 SF
- 264 patient beds
- 16 ORs (~800 SF each)
- LEED 2009 Silver rating
- Fuel gas load: 90,000 CFH
- Heating density: 65 Btu/SF
Example in Practice: Vassar Hospital

**Heat Exchanger (Steam-Water) Schedule**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Service</th>
<th>EWT (°F)</th>
<th>LWT (°F)</th>
<th>GPM</th>
<th>Water Side (Tube)</th>
<th>Steam Side (Shell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main HVAC Heating</td>
<td>172</td>
<td>220</td>
<td>2,275</td>
<td>5</td>
<td>31,850</td>
</tr>
<tr>
<td>2</td>
<td>Domestic Water Heater</td>
<td>40</td>
<td>140</td>
<td>40</td>
<td>3</td>
<td>2,000</td>
</tr>
<tr>
<td>3</td>
<td>Non-Potable Hot Water Heater</td>
<td>40</td>
<td>140</td>
<td>30</td>
<td>2</td>
<td>1,500</td>
</tr>
<tr>
<td>4</td>
<td>Snow Melt</td>
<td>105</td>
<td>130</td>
<td>111</td>
<td>10</td>
<td>1,388</td>
</tr>
</tbody>
</table>

**Steam Boiler**

<table>
<thead>
<tr>
<th>Number</th>
<th>Operating Pressure</th>
<th>Pounds/ Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLR-1</td>
<td>85</td>
<td>24,150</td>
</tr>
<tr>
<td>BLR-2</td>
<td>85</td>
<td>24,150</td>
</tr>
<tr>
<td>BLR-3</td>
<td>85</td>
<td>24,150</td>
</tr>
</tbody>
</table>

**Clean Steam Generator Schedule (Steam to Steam)**

<table>
<thead>
<tr>
<th>Number</th>
<th>Service</th>
<th>Source Side (HPS)</th>
<th>Shell Side (Clean Steam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSIG</td>
<td>Pounds/Hour</td>
<td>PSIG</td>
</tr>
<tr>
<td>1</td>
<td>AHU Humidifiers</td>
<td>85</td>
<td>10832</td>
</tr>
</tbody>
</table>
What is Next?

**GenSet Replaces PRV**
- Potential Energy savings with a closed-loop steam system
- Self-contained, skid mounted
- No external oil lubrication needed
- Generator included

**Design Specs**
- **250 PSI to 10 PSI outlet**
  - 50 KW (2,500lbs./hr.) Office building
  - 100 KW (5,000lbs./hr.) Office building or large hotel
  - 400 KW (5,000lbs./hr.) Small campus or a small town

**GenSet Diagram**
- Small footprint, lightweight
- 5:1 turndown
- Small Footprint
- Easy annual maintenance (bearing and seals)
- Monitors electric grid and generator power for safe and easy use
What is Next?

Savings ($0.10/kW)

100 kW:

\[ 100 \text{ kW} \times 8,700 \text{ hrs/yr} \times 0.10/\text{kW} - 12,000 \text{ maintenance} = 75,000/\text{yr} \]

400 kW:

\[ 400 \text{ kW} \times 8,700 \text{ hrs/yr} \times 0.10/\text{kW} - 20,000 \text{ maintenance} = 328,000/\text{yr} \]

Return on Investment (ROI)

100 kW:

\[
\frac{\text{cost} + \text{installation} + \text{consultants} - \text{incentives}}{\text{savings}} = \frac{260,000 + 104,000 + 72,800 - 43,680}{75,000} = 5.24 \text{ years}
\]

400 kW:

\[
\frac{\text{cost} + \text{installation} + \text{consultants} - \text{incentives}}{\text{savings}} = \frac{450,000 + 180,000 + 126,000 - 75,600}{328,000} = 2.1 \text{ years}
\]
Thank you

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