Vacuum heating integration with District heating system

2015 IDEA conference,
Boston June 28 - July 1
The author gratefully acknowledges support from the following:

Heatinghelp.com - Dan Holohan, ConEd, NY – Edward Ecock, National Grid - Keith Miller
All Steamed Up - Frank “Steamhead” Wilsey
IDEA - Robert Thornton and Leonard A. Phillips
It is possible that in a few years from now we will be heating ..., by steam below atmospheric pressure, of such a low temperature that it gives all of the advantages of hot water without any of its disadvantages. “

A.G. King “Practical Steam and Hot Water Heating”, 1908

### Vacuum heating versus steam heating

<table>
<thead>
<tr>
<th>benefits</th>
<th>disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Additional equipment:</td>
</tr>
<tr>
<td>Wide operating temperatures interval (55 -100°C)</td>
<td>vacuum pump</td>
</tr>
<tr>
<td>Comfort</td>
<td>condensate pump</td>
</tr>
<tr>
<td>Safety</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Smaller pipes, reduced corrosion</td>
<td>Vulnerability to leaks</td>
</tr>
<tr>
<td>High speed of heat distribution ( &gt; 100 miles/hr)</td>
<td>Steam traps failures</td>
</tr>
</tbody>
</table>
Steam heating retrofit into vacuum
Peter Cooper Village by ITC, since 2006, 110 building NYC apartment complex, over 25,000 residents in 11,000 residential units.

Vacuum up to 20”Hg/steam temperature al low as 160°F

Outdoor air temperature sensor installed on the exterior of the building

28% savings of steam from ConEd
Empire State Building heating system

Installed
LEED® Gold

1931
2011

6800 radiators
6800 steam traps
24" riser,
14 miles of heavy piping,
118 expansion joints

3 psi steam from ConEd
3-4 to 0" Hg
Features of novel vacuum heating (NVH):

• deep vacuum – up 25- 28”Hg
• no steam traps and no hot condensate pumps
• lower capacity vacuum pumps employed for a short time
• small diameter copper/plastic tubing – leak tight, less corrosion
Schematic of NVH pilot

(2nd floor 2 family house, only 3 radiators out of 6 are shown)
NVH specific gear

Vacuum pump, 450W, 10,000 hours

Vacuum switch

Solenoid valve

Control's box
Obsolete and new boiler were tested with steam and vacuum systems.
Radiators heating in ~30 minutes after system cold start
Natural vacuum efficacy in NVH

April 5, 2014, daily average outside temperature 40.6°F,

vacuum created by the system – up to 25”Hg

vacuum pump pressure switch setting - 18-14”Hg (off/on)
Daily heating gas usage by the tested system vs outside average temperature

- old boiler + vacuum system
- old boiler + steam system
- new boiler + steam system
- new boiler + vacuum system
- Potential: tuned vacuum system
Heat Degree Days (HDD), monthly gas bills for 2nd floor apartment before and after retrofit of steam heating system into vacuum heating.
Heat Degree Days (HDD), $\text{ monthly gas bills for 1st and 2nd floor apartments before and after retrofit of steam heating system into vacuum heating on 2nd floor, no changes to the first floor (base for comparison)}$
Results summary:

NVH pilot was run since 2013 to heat the 2nd floor apartment of a two family house (2x1150 sq. ft):

- plumbing is small diameter copper/plastic tubing
- no steam traps and no condensate pump
- radiators operating temperature - from 65 to 85°C
- the only moving part - vacuum pump - maintains 14-18"Hg vacuum (pump is “on” for 1-1.5hr/day)
- system is able to bring vacuum up to 28"Hg after cooling

Fuel gas savings up to ~60%

- fuel savings ~30% from steam boiler upgrade only
- additional 20-30% from steam to vacuum system retrofit
What’s in a future …

New plumbing technologies:
  • welded plastic tubing – 60 years expectancy, leak tight at 45 psi@200°F
  • pressed joints for steel/copper tubing

Liquid crystal polymers for heat distribution grid, - heat deflection 230 - 290°C

Cast aluminum radiators at a fraction of cast iron/steel radiators cost

Smart building control systems
Questions?

Igor Zhadanovsky
izhadano@gmail.com
Q&A
addendum
NVH integration with district steam - single loop
NVH integration with district steam – separate loops
District heating exergetic efficiency: steam vs hot water

Without return  \[ Q/E = 1 - \frac{To}{(Ts - To)} \times \ln \left(\frac{Ts}{To}\right) \]

With return  \[ Q/E = 1 - \frac{To}{(Ts - Tr)} \times \ln \left(\frac{Ts}{Tr}\right) \]

To, Ts, Tr – heat sink, supply and return temperature deg. K, resp.

Göran Wall “EXERGY FLOWS IN INDUSTRIAL PROCESSES” p.37

<table>
<thead>
<tr>
<th></th>
<th>To</th>
<th>Ts</th>
<th>Tr</th>
<th>Q/E, %</th>
<th>difference Q/E, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without return</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot water</td>
<td>293</td>
<td>353</td>
<td></td>
<td>9.0</td>
<td>+42.2</td>
</tr>
<tr>
<td>Steam</td>
<td>293</td>
<td>383</td>
<td></td>
<td>12.8</td>
<td></td>
</tr>
<tr>
<td><strong>With return</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot water</td>
<td>293</td>
<td>353</td>
<td>313</td>
<td>11.9</td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>293</td>
<td>383</td>
<td>313</td>
<td>15.5</td>
<td>+30.3</td>
</tr>
</tbody>
</table>
Pumping hot water vs potential energy generation from steam

Exergy (available work): \[ W = [H - H_0] - To[S - S_0] \]

where \( H \) and \( H_0 \) – enthalpy of heating media and water at 140°F
\( S \) and \( S_0 \) – entropy of heating media and water at 140°F
\( To = 140 \) °F – temperature of water return

<table>
<thead>
<tr>
<th>Pressure, bars</th>
<th>Temperature, °F</th>
<th>Available Work using 140°F Heat Sink Temp.</th>
<th>Energy for hot water pumping ²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>F</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>248</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>248</td>
<td>8.8</td>
</tr>
<tr>
<td>Steam</td>
<td>2.5 bar</td>
<td>329</td>
<td>198.0</td>
</tr>
<tr>
<td></td>
<td>10.5 bar</td>
<td>374</td>
<td>273.3</td>
</tr>
</tbody>
</table>

1 Sussman. M. V. (Tufts University), "Availability (Exergy) Analysis". Mulliken House. P.O. Box 274, Lexington, MA 02155.
2 US Army Corps, ERDC/CERL TR-06-20, July 2006, p.131
Pumping “low exergy” hot water vs potential energy generation from steam

Exergy (available work): \[ W = [H - H_0] - T_0[S - S_0] \]
where \( H \) and \( H_0 \) – enthalpy of heating media and water at 140°F
\( S \) and \( S_0 \) – entropy of heating media and water at 140°F
\( T_0 = 140°F \) – temperature of water return

<table>
<thead>
<tr>
<th>Pressure, bars</th>
<th>Temperature, °F</th>
<th>Available Work using 140°F Heat Sink Temp.</th>
<th>Energy for hot water pumping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>F</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td>Btu/lb</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td>5.5</td>
<td>176</td>
<td>4.5</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>176</td>
<td>4.9</td>
</tr>
<tr>
<td>Steam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 bar</td>
<td></td>
<td>329</td>
<td>252.9</td>
</tr>
<tr>
<td>10.5 bar</td>
<td></td>
<td>374</td>
<td>323.8</td>
</tr>
</tbody>
</table>

1 Sussman. M. V. (Tufts University), "Availability (Exergy) Analysis". Mulliken House. P.O. Box 274, Lexington, MA 02155.
2 US Army Corps, ERDC/CERL TR-06-20, July 2006, p.131
Leaks history: steam vs hot water

**US Army Corps, ERDC/CERL TR-06-20 July 2006**


Table 2. **Leak history in the pipeline systems in Kiel**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam network</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High pressure</td>
<td>17</td>
<td>10</td>
<td>8</td>
<td>11</td>
<td>9</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Low pressure</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number of leakages</td>
<td>17</td>
<td>10</td>
<td>8</td>
<td>11</td>
<td>9</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Hot water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mettenhof</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>North/South</td>
<td>26</td>
<td>8</td>
<td>17</td>
<td>22</td>
<td>16</td>
<td>20</td>
<td>21</td>
</tr>
<tr>
<td>East</td>
<td>10</td>
<td>6</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Island network</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Number of leakages</td>
<td>39</td>
<td>14</td>
<td>23</td>
<td>27</td>
<td>26</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>Total</td>
<td>56</td>
<td>24</td>
<td>31</td>
<td>38</td>
<td>35</td>
<td>38</td>
<td>39</td>
</tr>
</tbody>
</table>
Heat loss from steam pipe vs diameter

0.59% per mile
24” pipe @ 20 psig

Margolis, A.
“Heat Distribution”
Proceedings of the Institution of Mechanical Engineers
June 1937 135: 359-382
Today’s steam heating systems retrofit options

into hot water

into VASH

Under floor plumbing - difficult and expensive

Plumbing through external walls - much easier