What You Don’t Know You Don’t Know About (Hot) Water
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Goal of this Session:

• Identify at least 5 things you didn’t know you didn’t know about (hot) water
• Any specific topics you want me to address?
• Are you ready?
1. Water Heaters Have Air Filters

- Well, not all of them, but a very large and growing percentage

- Atmospheric Gas-fired Storage Heaters
  - Flammable Vapor Ignition Resistance (FVIR)
    - Closed combustion chamber, screen with tiny air holes, easily clogged with dust and lint
    - Large particle screen surrounds the bottom of the heater

- Electric Heat Pump Water Heaters
  - Filter on the inlet side of the air path through the heat pump coils.

- Filters need to be cleaned regularly!
2. Fixed vs. Variable Orifices

• Fixed Orifice:
  – High pressure: High flow rate
  – Low pressure: Low flow rate
  – Before 2000, practically all fixture fittings and appliances

• Pressure Compensating Aerators
  – Adjusts flow rate to compensate for available pressure
  – Almost the same flow rate for all pressures above 20-25 psi
  – Ramped up from 2000-2012 for showerheads
  – Today more than 90% and many faucet aerators
Pressure Compensating Aerators - 2

Flow Rate at the Rated Pressure:
- 2.2 gpm for faucets
- 2.5 gpm for showers

Rated Pressure:
- 60 psi for faucets
- 80 psi for showers
Pressure Compensating Aerators - 3

Flow Rate at Rated Pressure: 2.0 gpm
Flow Rate at ½ Rated Pressure: 1.4 gpm (0.7*Rated Flow Rated

Rated Pressure: 60 psi for faucets 80 psi for showers
A pressure compensating flow regulator maintains a constant flow regardless of variations in line pressure thereby optimizing system performance and comfort of use at all pressures.

Source: Neoperl’s website for this and the pressure-flow diagrams
3. (Hot) Water Flow in Buildings

• What percent of the time does water flow through the meter into the building?
  – Most normal condition is off – zero flow!
    • Depending on occupancy, more than 96% of the time
  – 2\textsuperscript{nd} most normal is 1 fixture fitting or appliance
    • Probably cold, say a toilet
    • Of the remaining 4%, this happens more than 3.9% of the time
      • Hot water is roughly half of this.
  – Flows greater than 3 gpm occur less than 0.1% of the time
3. (Hot) Water Flow in Buildings (cont.)

• Pipe sizing rules were written down in the 1940s
  – Pressure and temperature balanced shower valves became widely available in the 1980s
  – Pressure compensating orifices became widely available in the 2010s
• These two devices mitigate many of this issues that occurred with peak flow rates
  – Relatively constant, safe flow rates for showers and faucets
  – Little impact on the fill rates for toilets, tubs and machines.
• Let’s use these technologies to help with revising the rules for pipe sizing.
4. Time-to-Tap and Volume-until-Hot

• More water than is in a pipe comes out of it before hot water arrives. How much more?
  – Carl Hiller measured this in the early 2000s for 3/8 to 3/4 inch copper, CPVC and PEX piping
  – Zhang recently reviewed the data and has found that for flow rates of 0.5 to 2 gpm in 3/4 inch pipe, 1.5-2.5 times the pipe volume comes out before hot water (>105°F) comes out the other end. Roughly 2:1.

• Conclusion: if you want hot water to arrive within 10 seconds, make sure there is no more than 5 seconds of volume in the pipe between the source of hot water and the use.
How Long Should We Wait?

<table>
<thead>
<tr>
<th>Volume in the Pipe (ounces)</th>
<th>Minimum Time-to-Tap (seconds) at Selected Flow Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25 gpm</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>16</td>
<td>30</td>
</tr>
<tr>
<td>24</td>
<td>45</td>
</tr>
<tr>
<td>32</td>
<td>60</td>
</tr>
<tr>
<td>64</td>
<td>120</td>
</tr>
<tr>
<td>128</td>
<td>240</td>
</tr>
</tbody>
</table>

Cut the volume in half to get these times!

ASPE Time-to-Tap Performance Criteria

- **Acceptable Performance**: 1 – 10 seconds
- **Marginal Performance**: 11 – 30 seconds
- **Unacceptable Performance**: 31+ seconds

5. Pressure Drop Through Pipe and Fittings

• Many materials and types of fittings
• Calculations vs. measured data
• Are the data we use representative of present day materials and fittings?

From the current ASHRAE Fundamentals Pipe Sizing chapter
• Hegberg (1995) and Rahmeyer (1999a, 1999b) discuss the origins of some of the data shown in Tables 4 and Table 5.
• The Hydraulic Institute (1990) data appear to have come from Freeman (1941), work that was actually performed in 1895.
• The work of Giesecke (1926) and Giesecke and Badgett (1931, 1932a, 1932b may not be representative of current materials.
Pipe from ¼ inch to ¾ inch Nominal
Pipe from $\frac{1}{4}$ inch to $\frac{3}{4}$ inch Nominal
90 Degree Elbows
Pressure Drop - 1

• Elbows widely spaced and close together
• Velocities from 1-12 feet per second
• So far, we have not yet measured any published numbers
  – Are our measurements higher or lower than what is published? Yes!
  – Do our numbers have the same trends as what is published? No!
• It matters if we want to right-size piping systems.
Pressure Drop - 2

• Is there a minimum radius of curvature through which there is no additional pressure drop other than that due to the length of the bend?

• Wouldn’t that be the most water, pressure, energy and time efficient bend?

• Ask me about the Swoop®
6. Viscosity of Hot and Cold Water

- What is the viscosity of hot water compared to cold water?
  - Is the difference small or large?
  - Cold water is 1.8-3.2 times more viscous than hot water for a wide range of temperatures typically found in buildings!

- It is almost as though there are 2 different fluids moving through the same pipe.
  - Slippery hot water and sluggish cold water.
  - This helps explain much of the extra volume and time to get hot water from the source to the use.
## Dynamic viscosity of water at various temperatures

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Temperature (°F)</th>
<th>Viscosity (mPa·s)</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>50</td>
<td>1.308</td>
<td>50:122 = 1.308/0.5471 = 2.39</td>
</tr>
<tr>
<td>20</td>
<td>68</td>
<td>1.002</td>
<td>50:140 = 1.308/0.4658 = 2.81</td>
</tr>
<tr>
<td>30</td>
<td>86</td>
<td>0.7978</td>
<td>50:158 = 1.308/0.4044 = 3.23</td>
</tr>
<tr>
<td>40</td>
<td>104</td>
<td>0.6531</td>
<td>68:122 = 1.002/0.5471 = 1.83</td>
</tr>
<tr>
<td>50</td>
<td>122</td>
<td>0.5471</td>
<td>68:140 = 1.002/0.4658 = 2.15</td>
</tr>
<tr>
<td>60</td>
<td>140</td>
<td>0.4658</td>
<td>68:158 = 1.002/0.4044 = 2.48</td>
</tr>
<tr>
<td>70</td>
<td>158</td>
<td>0.4044</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>176</td>
<td>0.3550</td>
<td></td>
</tr>
</tbody>
</table>
7. Converting Volume to Height

Most of us are between 5’– 7’ tall. This means we are roughly equal to:

- 1/8” pipe: 1 shot of liquor (1 ounce)
- 1/4” pipe: A “double” of liquor (2 ounces)
- 3/8” pipe: 1 glass of wine (4-6 ounces)
- 1/2” pipe: 1 cup of water (8 ounces)
- 3/4” pipe: 1 pint of beer (16 ounces)
- 1” pipe: 1 bottle of wine (750 ml)
# Length of Pipe that Holds 8 oz of Water

<table>
<thead>
<tr>
<th></th>
<th>3/8&quot; CTS</th>
<th>1/2&quot; CTS</th>
<th>3/4&quot; CTS</th>
<th>1&quot; CTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;K&quot; copper</td>
<td>9.48</td>
<td>5.52</td>
<td>2.76</td>
<td>1.55</td>
</tr>
<tr>
<td>&quot;L&quot; copper</td>
<td>7.92</td>
<td>5.16</td>
<td>2.49</td>
<td>1.46</td>
</tr>
<tr>
<td>&quot;M&quot; copper</td>
<td>7.57</td>
<td>4.73</td>
<td>2.33</td>
<td>1.38</td>
</tr>
<tr>
<td>CPVC</td>
<td>N/A</td>
<td>6.41</td>
<td>3.00</td>
<td>1.81</td>
</tr>
<tr>
<td>PEX</td>
<td>12.09</td>
<td>6.62</td>
<td>3.34</td>
<td>2.02</td>
</tr>
</tbody>
</table>
Questions?
Given human nature, it is our job to provide the infrastructure that supports efficient behaviors.