Back to Basics: Pumping Systems

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AGENDA

- Closed loop heating and cooling piping systems
- Expansion Tanks
- Pumps
BASIC PUMPING LOOP

- Nice and simple – too simple?
- Constant energy draw of pump?
- Compatibility of source and load flow and temperatures
  - Too low/high boiler/chiller return temp
  - Too high radiant floor temp
  - Too low chilled beam temp
  - Too little chiller/boiler flow
DIRECT RETURN

- Simple, minimal pipe
- Extreme head differences will create balancing and control difficulties
- Eliminates extreme head differences
- Extra pipe – loop layouts are less extra than linear
REVERSE RETURN

- Loop Layout
This shows multiple riser low rise.

For single riser layouts, each floor can be RR with DR risers.

Can combine RR and DR for multiple loops/wings.

Minimizes pipe, maintains balance advantages.
OPTIONS TO REVERSE RETURN

- BRANCH DP CONTROLLERS
- AUTO FLOW VALVES
- PRESSURE INDEPENDENT CONTROL VALVES
- Variable flow through chiller/boiler – to a minimum. Bypass or 3-way valves to maintain min flow.
- Manifold the pumps to disassociate pump flow from chiller/boiler staging and provide easy redundancy
- Select chillers to allow both higher AND lower than normal flows
- Independent loops, not affected by each other
- Integrates different source and load needs
- Based on minimal pressure drop at decoupler
- Design load
- Lots of pumps – redundancy adds even more
- Part load - stage chillers and pumps to keep source flow greater than load flow
- Low DT syndrome forces multiple chillers to run even at plant load less than 1 chiller’s capacity.
- Pump energy
- Energy must balance
- Can set up for variable or constant source flow/DT
- Can set up for variable or constant load flow/DT
- High source DT, low load DT
- Different load supply temp than source supply temp
- Constant flow to load
- Load capacity changed via supply water temp
- Excellent for AHU preheat, 100% OA, or DOAS coil
  - Avoids oversizing
  - Helps destratification
  - Freeze protection
- Total pump HP is less than a single source pump
- Very small systems – cycle/modulate zone pumps
- Very large systems – Each zone is a building
- Total pump HP is less than a single source pump
- Very small systems – cycle/modulate zone pumps
- Very large systems – Each zone is a building
Miscellaneous Pipe Layouts

- **Single pipe loops**
  - Old school baseboard
  - Water source heat pumps
  - Process cooling

- **Two pipe changeover**
  - Either heat or cool through same piping, and usually same coils as well.
  - Changeover decision
  - Source equipment changeover

- **Three pipe systems**
  - Literally “old school” (was common in unit ventilator systems in schools). Also high rise terminal systems.
  - Huge energy waste just to save a pipe.
Expansion Tanks

- To limit the maximum pressure at weakest system component
- Maintain a minimum pressure to eliminate cavitation and boiling
- Provide a reference pressure (analogous to an electrical ground)
Expansion Tanks

Tank Pressure Related to System Pressure

- Point of no pressure change
- Reference pressure for automatic fill
- Isolates pump head from sensitive components

**A. Closed Tank Air/Water Interface**

\[ P_x = P_1 + \rho_w h \]

**B. Open Tank**

\[ P_x = P_a + \rho_w h \]

**C. Diaphragm Tank**

\[ P_x = P_1 - \rho_w h \]
Expansion Tanks

Effect of Expansion Tank Location

A

Pump Off

B

Pump Off

Pump On

Pump On

30 psi  30 psi

30 psi  40 psi

20 psi  30 psi

30 psi  20 psi
Expansion Tanks

- Usually at suction of pump, downstream of generating equipment
- Only one tank per system
  - Primary secondary
  - Campus
  - Additions
Expansion Tank Sizing

Information needed:

- $V_s =$ Volume of system
- $d_L =$ Density of fluid at lower temperature
- $d_H =$ Density of fluid at higher temperature
- $\alpha =$ Expansion coefficient of pipe
- $\Delta T =$ Expected fluid temp range
- $p_a =$ Atmospheric pressure
- $p_{L} =$ Minimum allowable pressure at tank = fill pressure
- $p_{H} =$ Maximum allowable pressure at tank
- Link to form
Expansion Tank Sizing

- **Closed (plain steel) tank:**
  - \[ V_t = V_s \frac{(dL/dH-1)-3\alpha\Delta T}{(P_a/P_L)-(P_a/P_H)} \]

- **Diaphragm/Bladder Tank:**
  - \[ V_t = V_s \frac{(dL/dH-1)-3\alpha\Delta T}{1-(P_L/P_H)} \]
  - Precharge pressure equals PL
  - Total expanded volume (upper term) must not exceed “acceptance volume”

- **All pressures are absolute (atm + gauge)**

- **MUST SPECIFY FILL/PRECHARGE (PL)**
# Expansion Tank Sizing

## Cator, Ruma Associates, Co.

### Expansion Tank Selection

<table>
<thead>
<tr>
<th>System Volume</th>
<th>Pipe Length (feet)</th>
<th>Size</th>
<th>Gallons/Feet</th>
<th>Volume (Gallons)</th>
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<td>1/2&quot;</td>
<td>0.016</td>
<td>0</td>
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<td>3/4&quot;</td>
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<td>0.130</td>
<td>43</td>
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<tr>
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<td>0.00</td>
<td>2-1/2&quot;</td>
<td>0.250</td>
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<td>100.00</td>
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<td></td>
<td>400.00</td>
<td>4&quot;</td>
<td>0.660</td>
<td>264</td>
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<td></td>
<td>0.00</td>
<td>5&quot;</td>
<td>1.060</td>
<td>0</td>
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<td>2.660</td>
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<td>0.00</td>
<td>24&quot;</td>
<td>24.20</td>
<td>0</td>
</tr>
</tbody>
</table>

### Boilers
- Total Volume Vs: 150

### Coils
- Total Volume Vs: 60

### Chillers
- Total Volume Vs: 0

### Unit Heaters
- Total Volume Vs: 0

### Baseboard Radiation
- Total Volume Vs: 0

### Miscellaneous Equipment
- Total Volume Vs: 50

### Safety Factor Future
- Total Volume Vs: 1.08

### VS Total Volume Vs: 692.1

### DL % Glycerol: 0%
### DH Density at Low Temperature: 63.43 lb/ft³
### DTH Density at High Temperature: 69.57 lb/ft³
### PA Atmospheric Pressure (At Altitude): 12 PSIA
### PH Highest Allowable Pressure (Absolute) at Tank Pressure: 15 PSIA
### PL Minimum (III) Pressure at Tank (to prevent boiling): 15 PSIA
### DT Temperature Difference - Lowest to Highest: 140 deg, F
### ALPHA Temperature: 6.56E-06
### VEX Acceptance Volume of Tank: 19.25 gallons

### Diaphragm/Bladder Tank Size
- VEX*(1 - PL/PH) = 33.65 gallons

### Plain Steel Tank Size
- VEX*(PA/PL - PA/P) = 42.14 gallons

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Expansion Tank.xls 5/5/2005 5:08 PM
Expansion Tank Sizing

- **Effect of Glycol:**
  - Expansion of plain water, 40°-180°
    - \( \frac{dL}{dH} - 1 \quad 62.42/60.57 - 1 = 0.0305 \)
  - Expansion of 30% Prop. Glycol, 40°-180°
    - \( \frac{dL}{dH} - 1 \quad 64.47/61.92 - 1 = 0.0401 \)
  - Glycol expands 1.35 times as much as water
Diaphragm Type Tank

Bladder Type Tank
Diaphragm Type Tank

![Diagram of diaphragm type tank models AX-80V, AX-100V, AX-120V, AX-144V, AX-180V, AX-200V, AX-240V.](image)

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Tank Volume</th>
<th>Accept. Volume</th>
<th>&quot;A&quot; Dim. (Height)</th>
<th>&quot;B&quot; Dim. (Dia.)</th>
<th>Sys. Taps. NPT (Ins.)</th>
<th>Shipping Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gals. Ltrs</td>
<td>Gals. Liters</td>
<td>Ins. mm</td>
<td>Ins. mm</td>
<td>Lbs. kg</td>
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<td>AX-60V</td>
<td>33.6 127.2</td>
<td>11.1 42.0</td>
<td>43 1092</td>
<td>16 413</td>
<td>1/2</td>
<td>145 66</td>
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<td>AX-80V</td>
<td>44.4 168.1</td>
<td>22.2 84.0</td>
<td>56 1422</td>
<td>16 413</td>
<td>3/4</td>
<td>201 91</td>
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<tr>
<td>AX-100V</td>
<td>55.7 211.8</td>
<td>22.2 84.0</td>
<td>69 1753</td>
<td>16 413</td>
<td>2 1/2</td>
<td>237 108</td>
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<tr>
<td>AX-120V</td>
<td>68.0 257.4</td>
<td>34.0 128.7</td>
<td>44 1124</td>
<td>24 610</td>
<td>1</td>
<td>285 129</td>
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<td>AX-144V</td>
<td>77.0 291.5</td>
<td>34.0 128.7</td>
<td>49 1248</td>
<td>24 610</td>
<td>1 1/4</td>
<td>299 136</td>
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<tr>
<td>AX-180V</td>
<td>90.0 340.7</td>
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<td>1 1/2</td>
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<tr>
<td>AX-200V</td>
<td>110.0 416.4</td>
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<td>1 3/4</td>
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<td>AX-240V</td>
<td>131.7 498.5</td>
<td>44.4 168.1</td>
<td>76 1946</td>
<td>24 610</td>
<td>1</td>
<td>401 182</td>
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</table>

NOTE: All Figures Above Are Nominal
Bladder Type Tank

<table>
<thead>
<tr>
<th>MODEL NUMBER</th>
<th>TANK VOLUME</th>
<th>&quot;A&quot; DIMENSION HEIGHT</th>
<th>&quot;B&quot; DIMENSION DIAMETER</th>
<th>SYSTEM COUPLING CONN.</th>
<th>SHIPPING WEIGHT</th>
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<tbody>
<tr>
<td></td>
<td>Gals.</td>
<td>Liters</td>
<td>Ins.</td>
<td>mm</td>
<td>Lbs.</td>
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<td>200-L</td>
<td>53</td>
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<td>500-L</td>
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<td>73 1/2</td>
<td>1867</td>
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<tr>
<td>1200-L</td>
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<td>2181</td>
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<td>1600</td>
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<td>2000</td>
<td>85 1/8</td>
<td>2162</td>
<td>48</td>
</tr>
</tbody>
</table>

NOTE: All figures above are nominal.
Effect of location in building – Mechanical room at bottom of building.

\[
\begin{align*}
\text{Pa} &= 12 \text{ psia} \\
\text{Pl} &= 5 \text{ psig} + 60 \times 0.433 + 12 = 43 \text{ psig} \\
\text{Ph} &= 45 \text{ psig} + 12 = 57 \text{ psig} \\
\text{ACCEPTANCE FACTOR} \\
\text{DIAPHRAGM TANK} - 1 - 43/57 &= 0.246 \\
\text{PLAIN STEEL} - 12/43 - 12/57 &= 0.07 \\
\text{PLAIN STEEL TANK IS 3.5 TIMES LARGER THAN DIAPHRAGM}
\end{align*}
\]
Expansion Tank Sizing

- Mechanical room on top

Pa = 12 psia
PL = 5 psig + 12 = 17 psig
PH = 45 psig + 12 = 57 psig

ACCEPTANCE FACTOR
DIAPHRAGM TANK - 1 - 17/57 = .70
PLAIN STEEL - 12/17 - 12/57 = .49
DIAPHRAGM AT BOTTOM IS 2.3 TIMES BIGGER THAN DIAPHRAGM AT TOP
PLAIN STEEL AT BOTTOM IS 7 TIMES BIGGER THAN PLAIN STEEL AT TOP
PLAIN STEEL AT TOP IS 1.4 TIMES BIGGER THAN DIAPHRAGM AT TOP
ENERGY ASPECTS OF PUMPS

- Always a parasitic loss in HVAC
  - Not doing the heat transfer, just getting it there.
- Better than air
  - Water has a much higher energy density
- BHP = \( \frac{\text{GPM} \times \text{Ft. Head}}{3960 \times \text{Pump Efficiency}} \)
- BTU/H = \( \frac{\text{GPM} \times 500 \times DT}{\text{Glycol affects the } 500} \)

<table>
<thead>
<tr>
<th>GPM FACTOR</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
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<tr>
<td>40 DEG</td>
<td>484</td>
<td>469</td>
<td>444</td>
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<tr>
<td>180 DEG</td>
<td>446</td>
<td>434</td>
<td>423</td>
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</table>
### Pump/Pipe Sizing Corrections - Glycol

#### Pressure Drop Correction Factor for Various Glycol/Water Percentages

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Percent Propylene Glycol</th>
<th>Percent Ethylene Glycol</th>
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<tbody>
<tr>
<td></td>
<td>30%</td>
<td>40%</td>
</tr>
<tr>
<td>35°F</td>
<td>1.56</td>
<td>1.78</td>
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<td>45°F</td>
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<td>1.07</td>
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<td>150°F</td>
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<td>1.01</td>
</tr>
<tr>
<td>170°F</td>
<td>0.93</td>
<td>0.97</td>
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</tbody>
</table>
Pump Selection

- System curve
- Best efficiency point
- Max impeller size
- Non-overloading
- VFD, constant, or ride the curve
- Future operation
- NPSH
PUMP SELECTION

TRIMMING IMPELLER CAUSES RECIRCULATION WITHIN THE VOLUTE, REDUCING EFFICIENCY.

OPERATING TO THE RIGHT SIDE OF CURVE CAUSES HYDRODYNAMIC STALL – UNPREDICTABLE

LOW NPSH CAUSES LOCALIZED PRESSURE BELOW VAPOR PRESSURE OF FLUID

■ IMPELLER – VOLUTE ARRANGEMENT

*Water is thrown off of the impeller due to centrifugal force.*
*Water is drawn into the eye.*
*Water is discharged from the volute.*
Pump Selection

- Usually only an issue with hot/open systems or suction lift.

- All pressures absolute (ATM + gauge)

- Vapor pressure
  - $90^\circ$ – .7 psi
  - $180^\circ$ – 7.5 psi
  - $200^\circ$ – 11.5 psi

**Net Positive Suction Head Available — NPSHA**

\[ \text{NPSHA} = h_p + h_z - h_{vpa} - h_f \]

- $h_p$: Head due to pressure
- $h_z$: Head due to elevation
- $h_{vpa}$: Vapor pressure at the suction point
- $h_f$: Friction head
Pump Selection

- NPSHA Examples

Condensate Return (200° atmospheric tank)

\[ h_p = 12 \text{ psia} = 27.7 \text{ft} \quad h_z = 4 \text{ ft} \]

\[ h_{vpa} = 11.5 \text{ psia} = 26.5 \text{ ft} \quad h_f = 2 \text{ ft} \]

\[ 27.7 + 4 - 26.5 - 2 = 3.2 \text{ ft} \]
Pump Selection

- NPSHA Examples

Cooling Tower

\[ h_p = 12 \text{ psia} = 27.7 \text{ ft} \]
\[ h_{vp} = 0.7 \text{ psia} = 1.6 \text{ ft} \]
\[ h_z = 4 \text{ ft} \]
\[ h_f = 5 \text{ ft} \]
\[ 27.7 + 4 - 1.6 - 5 = 25.1 \text{ ft} \]
Cavitation Example
Cavitation Example

- **Wort Cavitation**
Pump Selection

Flat – “Riding the curve” variable volume
Steep – VFD variable volume and constant volume

Flat Versus Steep Pump Curves

- Total Head in Feet
- Capacity in U.S. Gallons per Minute
Pump Selection

- Flattens curve (start with steep curve pumps)
- Provides 70% - 80% back-up.
- Check single pump operation for overloading and right end of curve operation
- Use two similar pumps
Pump Selection

Operating Conditions for Parallel Pump Installation

- Each Pump Operates at This Point — Both Pumps On
- System Operating Point — Both Pumps On
- Pumps and System Operating Point — Single Pump On
Open systems

- Static head
  - Remote sump cooling tower

- NPSH

- Don’t pump air
  - For cooling towers, “pumping gravel” sound is probably air, not cavitation.
Variable Speed Pumping in Constant Volume or Pressure applications
  - Use of VSP as throttling valve or control valve
  - Pressure is maintained by impeller speed, so if pressure at pump needs to stay constant regardless of flow, may not be much advantage to VSP.
    - Steep vs flat curves
  - Domestic Water Booster
    - If dominated by friction rather than lift, VFD is appropriate.
  - Steam Boiler Feed
    - Meet pressure relief setting per code at max speed, operate at lower speed to meet operating pressure.
  - Remote sump cooling tower
VFD WITH CONSTANT HEAD
FURTHER INFORMATION

- Manufacturer info (particularly high efficiency equipment)
- ASHRAE PDS
- GOOGLE