Hydraulic Considerations in Pumping System Design

VWEA Wastewater Operations Education Conference
Roanoke Virginia
July 14, 2016
Agenda

• Basics of Hydraulics and Pump Operation
• Pumping System Design Process
  • Types of Pumps
  • System Curve Development
  • Pump Station Layout
  • Pump Selection Considerations
  • Hydraulic Concerns
• Case Studies
• Summary
• Questions
Abbreviations and Acronyms

- **BEP** – best efficiency point
- **BHP** – brake horsepower
- **fps** or **ft/sec** – feet per second (velocity)
- **FM** – force main
- **gpm** – gallons per minute (flow)
- **H** – Head (feet)
- **HP** – horsepower
- **n** – rotational speed
- **NPSH\textsubscript{A}** – net positive suction head available
- **NPSH\textsubscript{R}** – net positive suction head required
- **psi** – pounds per square inch (pressure)
- **Q** – Flow Rate (gpm, mgd, cfs…)
- **rpm** – revolutions per minute
- **TDH** – total dynamic head
Basics of Pump Operation

• A pump lifts fluid from one elevation to another

• Work is needed to lift fluid

• Work is independent of type
  • Human Power
  • Animal Power
  • Wind Power
  • Steam Power
  • Electrical Power

• Pump can lift continuously or in increments

• Take-away:
  • Higher lift requires more work
  • Higher flow requires more work
  • Faster work requires more power
Pressure Head (Head)

- Pumps deliver fluid against pressure
- Pressure = Force / Area (psi)
- Head (feet) is commonly used to express pump operating pressure
- A 2.31 foot high column of water exerts a pressure equal to 1 psi
  - i.e. Car tires ~ 35 psi = 81 feet of head
Closed Conduit Flow (Q)

- Volume of fluid passing per time (gpm, mgd, cfs…)
- $Q \text{ (cfs)} = \text{Area (ft}^2\text{)} \times \text{Velocity (fps)}$
- For a given flow, the smaller the conduit the larger the velocity.
- Higher velocity translates into increased frictional headloss
Total Dynamic Head (TDH)

- TDH is the total amount of head a pump must operate against to deliver wastewater to a desired location

- TDH = Static Head + Head Loss (HL)

- Static Head – exists when pump is on or off

- Head Loss – exists only when fluid is pumped
Static Head

For free surfaces:

- Static Head = Discharge Tank WSEL – Suction Tank WSEL
- Static Discharge Head = Discharge Tank WSEL – Pump CL
- Static Suction Head = Suction Tank WSEL – Pump CL
Dynamic Head (Head Loss)

• Energy dissipated due to friction and turbulence during pump operation

• Major Losses (Friction Losses)
  • Due to friction between pumped water and inner surface of piping
  • \( H_f = 3.02 \ L \ D^{-1.167} \ (V/C_h)^{1.85} \) (Hazen-Williams Formula)
    where:
    • \( L \) is length of pipe (feet)
    • \( D \) is diameter of pipe (square feet)
    • \( V \) is mean velocity (fps)
    • \( C_h \) is Hazen-Williams friction coefficient (new up to 140 and old as low as 80)

• Minor Losses
  • Due to turbulence at bends, fittings, valves, etc.
  • \( H_f = K \ (V^2/2G) \) (Headloss factor times velocity head)
Net Positive Suction Head (NPSH)

- $NPSH_A = \text{Atmos. Head} + \text{Static Suction Head} - \text{Suction HL}$
  - Standard atmospheric pressure = 14.7 psi (34 ft. head)

- Net Positive Suction Head Required ($NPSH_R$)
  - Furnished by pump manufacturer – pump specific
  - Increases with pump flow

- $NPSH_A < NPSH_R \rightarrow \text{Cavitation}$
  - Typically occurs in systems with static lift
  - Could occur in flooded suction scenario with extremely long lengths of suction piping

- Insufficient submergence can lead to vortexing
Work & Power

- **Work**
  - A force does work when it acts on a body over a distance
  - Units of foot pound (ft-lb)
  - Wastewater pumps do work to move the wastewater

- **Power**
  - Rate of work done (ft-lb/s)
  - Wastewater pumps most often do work by using electric motors
  - Motors are commonly rated by horsepower (hp)
  - 1 unit of hp is equal to 550 ft-lbs/s
The Pumping System Design Process

- Collect information
- Determine type of pump to be used
- Develop station layout
- Develop system curves
- Select pumps that match the system curves
- Write your specification
- Coordinate
- Finalize the design
Collect Information

• What – type of fluid is to be pumped?
  • Fluid properties: density, viscosity, solids content, temperature

• From where to where?
  • System characteristics: friction and minor losses, suction lift, static head, other pumps operating simultaneously

• How much – what are design flowrates?
Determine Type of Pump

- Flow and head requirements
- Type of fluid, solids content
- Site conditions
  - Footprint and headroom constraints
  - Subgrade conditions
  - Elevation constraints
    - Suction and discharge inverts
    - Suction head available

More than one type may work - what’s best for the specific application and owner preference?
Types of Pumps

• Kinetic (Rotodynamic) Pumps
  • Energy is imparted to the fluid by a rotating impeller which increases the flow velocity and converts to a pressure increase upon exit.
  • Can be safely operated under closed valve conditions (for short periods of time).
  • Three Types:
    • Radial-flow pumps (Centrifugal Pump) - higher pressures and lower flow rates than axial-flow pumps.
    • Axial-flow pumps - lower pressures and higher flow rates than radial-flow pumps.
    • Mixed-flow pumps – A compromise between radial and axial-flow pumps - operate at higher pressures than axial-flow pumps while delivering higher discharges than radial-flow pumps.

• Positive Displacement (PD) Pumps
  • PD pumps physically displace fluid
  • Closing a valve downstream can lead to continual pressure build up and failure of pipeline
Positive Displacement Pumps

HP Reciprocating Triplex Pump

Progressing Cavity Pump
Progressing Cavity Pumps

- Flowrate fixed to speed
- Capable of pumping highly viscous stream
- Commonly used in sludge and slurry pumping applications
- Operates at high pressures
- Must avoid running pump dry
- Provide safety features on discharge
Centrifugal Pump

A centrifugal pump lifts fluid from one elevation to another by continuously adding kinetic energy (accelerating the fluid) using a rotating impeller.
Common Types of Centrifugal Pumps for Water and Wastewater

- Horizontal Split Case Pumps
- Vertical Turbine Pumps
- End Suction Pumps
  - Closed impeller
  - Non-Clog pumps
  - Submersible non-clog pumps
Horizontal Split Case

Applications

• Water treatment:
  • Raw Water
  • High service pumping
  • Transfer pumping

• Wastewater treatment:
  • Reuse filter feed
  • Reuse distribution
  • Treated effluent pumps

Characteristics

• Wide flow range
• Heads to ~500 ft. for single stage, higher for two-stage
• High efficiency (85-95%)
• Ease of maintenance
• Flat curve

Configurations

• Horizontal motor
• Vertical motor
• Single or two stage
• Dual diesel / electric drive
Vertical Turbine

Applications

• Water treatment:
  • Raw water pumps
  • Groundwater pumps (submersible)
  • Membrane feed pump
  • Filter backwash pump
  • High service pumps
  • Transfer pumps

• Wastewater treatment:
  • Reuse filter feed
  • Reuse distribution pumps
  • Treated effluent pumps
  • VTSH (vertical turbine solids-handling)

Characteristics

• Wide flow range
• Wide head range – add stages for higher head
• Steep curve
• Very compact footprint
• Prone to vibration
• Difficult to service

Configurations

• Can-type
• Wetwell-mounted
• Submersible
End Suction

Applications

- Water treatment:
  - Booster Pumping
  - Filter Backwash
  - Membrane Feed
  - Chemical Feed
  - Raw water

- Wastewater treatment (non-clog impellers):
  - Sewage lift stations
  - Raw sewage pumps

Characteristics

- Low to Medium flow
- High head - add stages
- Curve shape varies

Configurations

- Vertical - save space or to mount motor above flood elevation
- Horizontal - provides good access and saves head room
- Close-coupled (single pump/motor shaft)
- Direct coupled (motor shaft connected to the pump shaft by a shaft coupling)
- V-belt drive
- Extended shaft
- Submersible
End Suction Pumps – Wastewater

- Heads to ~250 ft. for a single stage
- Best efficiencies 70-75%
- Impeller options:

  Channel Impeller  
  (enclosed, 1-3 vanes)  
  Sewage lift station  
  typical application

  Semi-Open Impeller

  Vortex Impeller  
  (recessed impeller)

  Grit and sludge pumping  
  typical applications

Solids handling performance improves

Hydraulic efficiency increases
Pump Type Selection Example – Griffith RWPS

Selected horizontal split-case pumps – why?

- Had available land area and suction head
- Rock subgrade
- Suitable curve shape
- Owner preference
- Ease of maintenance
Centrifugal Pump Summary

• Larger impellers - Greater flow and head

• Greater Speed – Greater flow and head

• Larger, slower impellers are more efficient but cost more

• Pumps in parallel - more flow at same head

• Pumps in series - higher head at same flow

• Generally, power increases as flow increases to run out

• Best efficiency point (BEP) is at max of efficiency curve
Centrifugal Pumps - Points to Watch

- Rotational speeds $\leq 1,800$ rpm
  - Non-clog in particular

- Flooded suction - no priming needed

- Curve shall continually rise to shut off

- Steeper pump curves are best for VFDs

- Duty point to be $\sim 75\% Q_{\text{max}}$, close to BEP

- Aim for efficiencies $> 75\%$ single stage

- Size motor HP for “run out” or maximum power NOT duty point
Station Layout - Where to Start?

- Resources
  - Hydraulic Institute (HI) Standards, other references

- Consider constraints – site, budget, etc.

- Collect/develop information needed to create system curves
  - Elevations of suction, pump room floor, high points, discharge

- For retrofits, survey/measure existing elevations, test existing pumps for flow and pressure
  - Develop piping system layout, list of minor losses
Station Layout Considerations

• Provide sufficient work space between pumps

• Use largest pump and motor dimensions (now or future)

• Allow for expansion

• Think through process of installing/removing pumps and valves
  • Size crane and openings for heaviest / largest single item in the station
  • Ensure crane can reach everything it needs to lift
  • Consider need for portable hoists or truck access, etc. when selecting pump spacing, sizing hallways

• Involve operations and maintenance staff early
Layout - Hydraulic Institute Standards

- American National Design Standards for Pump Intake and Centrifugal Pumps

- Wetwells - different designs for clear and solids-bearing liquids
  - Provide steady, uniform flow with minimal flow disturbances
  - Keep solids entrained

- Piped intakes – recommended piping configurations, velocity limits

- Canned vertical turbine pumps – geometry and velocity specifications

- No flow disturbing fittings within 5 pipe diameters of suction
  - Long-radius bends and full-port valves are not considered flow disturbing
Points to Watch – Suction and Discharge Piping

- Suction pipe velocities ≤ 6 ft/s
- Delivery pipe velocities ≤ 8 ft/s
- Avoid applying forces (especially unbalanced ones) to pumps via piping and valves
  - Provide pipe supports
  - No horizontal bends near pumps
- Use long radius elbows for vertical suction bends
- Avoid creating high points
  - On suction, use eccentric reducers with flat side up
  - Continuously rising discharge pipe alignment
- Provide isolation valves
- Include restrained flexible couplings
- Pipe/flanges rated for worst case pressures, including surge / test pressures
Developing System Curve

There will be several system curves for a given application.

Total Head, $H_T$

FLOW RATE, $Q$

System Curve

Friction Head

Static Head = $z_{disch} - z_{suction}$

Friction Head

Total Head

Use real elevations on $y$-axis, not TDH of pump.
Example Pump Station

Force Main Conditions: Hazen-Williams C: 120
Flow Scenario: ADF (mgd) 0.875 Peak (mgd) 2.5

Number of Pumps: 1
Total Static Head: 102.42

Coefficients for Flow Units:
- Flow Unit: GPM
- Frac Q
- Sum K
- Kf
- Km

A. Suction - 10" inside PS

Minor Losses in Pipe Reach -- Pump 1

- Slightly rounded entrance: 0.23
- Gate valve: 0.19
- 90° elbow: 0.3
- 10x5" reducer: 0.25
- 90° elbow: 0.3

A. Subtotal: 1.27

Define Pipe System

<table>
<thead>
<tr>
<th>Pipe Reach (in.)</th>
<th>Diameter (feet)</th>
<th>H&amp;W C</th>
<th>Frac Q</th>
<th>Sum K</th>
<th>Kf</th>
<th>Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>11</td>
<td>120</td>
<td>1</td>
<td>1.27</td>
<td>2.231E-07</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>12</td>
<td>120</td>
<td>1</td>
<td>5.54</td>
<td>7.214E-07</td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>9</td>
<td>120</td>
<td>1</td>
<td>2.24</td>
<td>0.000E+00</td>
</tr>
<tr>
<td>D</td>
<td>14</td>
<td>2949</td>
<td>120</td>
<td>1</td>
<td>6.85</td>
<td>1.162E-05</td>
</tr>
<tr>
<td>E</td>
<td>14</td>
<td>2625</td>
<td>120</td>
<td>1</td>
<td>2.2</td>
<td>1.034E-05</td>
</tr>
</tbody>
</table>

System Curve

<table>
<thead>
<tr>
<th>Flow (gpm)</th>
<th>TDH (ft)</th>
<th>NPSHa</th>
<th>Friction Losses</th>
<th>Kf*Q^1.85</th>
<th>Km*Q^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>296.42</td>
<td>33.99</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>297.03</td>
<td>33.97</td>
<td>0.34</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>298.73</td>
<td>33.89</td>
<td>1.24</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td>301.45</td>
<td>33.76</td>
<td>2.62</td>
<td>2.42</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>305.17</td>
<td>33.58</td>
<td>4.46</td>
<td>4.30</td>
<td></td>
</tr>
<tr>
<td>1250</td>
<td>309.87</td>
<td>33.36</td>
<td>6.73</td>
<td>6.72</td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td>315.53</td>
<td>33.08</td>
<td>9.44</td>
<td>9.67</td>
<td></td>
</tr>
<tr>
<td>1750</td>
<td>322.13</td>
<td>32.76</td>
<td>12.55</td>
<td>13.17</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>329.68</td>
<td>32.39</td>
<td>16.07</td>
<td>17.20</td>
<td></td>
</tr>
</tbody>
</table>

System Head (single FM)
The Pump Curve

- TOTAL HEAD, $H_T$
- FLOW RATE, $Q$

- Pump Curve
- System Curve
- Efficiency Curve
- BHP Curve
- NPSH$_R$ Curve

1. Operating Point
2. Shut-Off Head Point
3. Best Efficiency Point (BEP)
4. Run-Out Point
One duty point does NOT define a pump curve. A flat pump curve is very sensitive to system curve changes.
System Curve Considerations

System losses can increase significantly over time.
Pump Curve

Curve efficiencies are typical. For guaranteed values, contact Fairbanks Morse or your local distributor. Las eficiencias en curvas son típicas. Para valores garantizados contacte a Fairbanks Morse o a su distribuidor local.

Company: Hazen and Sawyer
Name: 6/24/2010
Fairbanks Morse Pump, 60 Hz
Catalog: Fairbanks Morse Centrifugal, 60, Vers 3
Size: 5’5413
Dia: 11.625 in
Speed: 1780 rpm
Curve: 130504A
Impeller: T5C1A
“Droopy” Pump Curves

Normal pump curve compared to “droopy” curve. Pump curves shall continuously rise to shut off.

Two potential Operating Points – unstable

System Curve
Curves – Pumps in Parallel

Pump Curves for two equal capacity pumps

System Curve
Curves – Pumps in Series

Pump Curve for two equal pump impellers in series

System Curve

TOTAL HEAD, $H_T$

FLOW RATE, $Q$

First stage or pump

Second stage or pump
Curves – Pumps with Variable Frequency Drives (VFD)

Pump Curves at different speeds

System Curve 1

System Curve 2

TOTAL HEAD, $H_T$

FLOW RATE, $Q$
Affinity Laws - Variable Speed

\[ Q_2 = Q_1 \times \frac{N_2}{N_1} \quad H_2 = H_1 \times \left[ \frac{N_2}{N_1} \right]^2 \]

<table>
<thead>
<tr>
<th>Manufacturer Pump Curves</th>
<th>Adjusted Pump Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goulds 3316 6x8-17</strong></td>
<td><strong>95.0 % Speed</strong></td>
</tr>
<tr>
<td><strong>1786 Curve Speed</strong></td>
<td><strong>90.0 % Speed</strong></td>
</tr>
<tr>
<td>Max Impeller 17.00</td>
<td><strong>85.0 % Speed</strong></td>
</tr>
<tr>
<td><strong>14.25 Curve Impeller</strong></td>
<td><strong>80.6 % Speed</strong></td>
</tr>
<tr>
<td><strong>14.25 Curve Impeller</strong></td>
<td><strong>75.0 % Speed</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>gpm</th>
<th>TDH</th>
<th>Efficiency</th>
<th>gpm</th>
<th>TDH</th>
<th>gpm</th>
<th>TDH</th>
<th>gpm</th>
<th>TDH</th>
<th>gpm</th>
<th>TDH</th>
<th>gpm</th>
<th>TDH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,560</td>
<td>397</td>
<td>69</td>
<td>1,482</td>
<td>358</td>
<td>1,404</td>
<td>322</td>
<td>1,326</td>
<td>287</td>
<td>1,257</td>
<td>258</td>
<td>1,170</td>
<td>223</td>
</tr>
<tr>
<td>1,500</td>
<td>412</td>
<td>71</td>
<td>1,425</td>
<td>372</td>
<td>1,350</td>
<td>334</td>
<td>1,275</td>
<td>298</td>
<td>1,209</td>
<td>268</td>
<td>1,125</td>
<td>232</td>
</tr>
<tr>
<td>1,400</td>
<td>437</td>
<td>74</td>
<td>1,330</td>
<td>394</td>
<td>1,260</td>
<td>354</td>
<td>1,190</td>
<td>316</td>
<td>1,128</td>
<td>284</td>
<td>1,050</td>
<td>246</td>
</tr>
<tr>
<td>1,300</td>
<td>457</td>
<td>76</td>
<td>1,235</td>
<td>412</td>
<td>1,170</td>
<td>370</td>
<td>1,105</td>
<td>330</td>
<td>1,048</td>
<td>297</td>
<td>975</td>
<td>257</td>
</tr>
<tr>
<td>1,200</td>
<td>477</td>
<td>76</td>
<td>1,140</td>
<td>430</td>
<td>1,080</td>
<td>386</td>
<td>1,020</td>
<td>345</td>
<td>967</td>
<td>310</td>
<td>900</td>
<td>268</td>
</tr>
<tr>
<td>1,100</td>
<td>492</td>
<td>76</td>
<td>1,045</td>
<td>444</td>
<td>990</td>
<td>399</td>
<td>935</td>
<td>355</td>
<td>887</td>
<td>320</td>
<td>825</td>
<td>277</td>
</tr>
<tr>
<td>1,000</td>
<td>507</td>
<td>75</td>
<td>950</td>
<td>458</td>
<td>900</td>
<td>411</td>
<td>850</td>
<td>366</td>
<td>806</td>
<td>329</td>
<td>750</td>
<td>285</td>
</tr>
<tr>
<td>900</td>
<td>520</td>
<td>73</td>
<td>855</td>
<td>469</td>
<td>810</td>
<td>421</td>
<td>765</td>
<td>376</td>
<td>725</td>
<td>338</td>
<td>675</td>
<td>293</td>
</tr>
<tr>
<td>800</td>
<td>532</td>
<td>70</td>
<td>760</td>
<td>480</td>
<td>720</td>
<td>431</td>
<td>680</td>
<td>384</td>
<td>645</td>
<td>346</td>
<td>600</td>
<td>299</td>
</tr>
<tr>
<td>700</td>
<td>542</td>
<td>66</td>
<td>665</td>
<td>489</td>
<td>630</td>
<td>439</td>
<td>595</td>
<td>392</td>
<td>564</td>
<td>352</td>
<td>525</td>
<td>305</td>
</tr>
<tr>
<td>600</td>
<td>552</td>
<td>62</td>
<td>570</td>
<td>498</td>
<td>540</td>
<td>447</td>
<td>510</td>
<td>399</td>
<td>484</td>
<td>359</td>
<td>450</td>
<td>311</td>
</tr>
<tr>
<td>500</td>
<td>560</td>
<td>56</td>
<td>475</td>
<td>505</td>
<td>450</td>
<td>454</td>
<td>425</td>
<td>405</td>
<td>403</td>
<td>364</td>
<td>375</td>
<td>315</td>
</tr>
<tr>
<td>400</td>
<td>567</td>
<td>49</td>
<td>380</td>
<td>512</td>
<td>360</td>
<td>459</td>
<td>340</td>
<td>410</td>
<td>322</td>
<td>368</td>
<td>300</td>
<td>319</td>
</tr>
<tr>
<td>300</td>
<td>572</td>
<td>40</td>
<td>285</td>
<td>516</td>
<td>270</td>
<td>463</td>
<td>255</td>
<td>413</td>
<td>242</td>
<td>372</td>
<td>225</td>
<td>322</td>
</tr>
<tr>
<td>200</td>
<td>577</td>
<td>30</td>
<td>190</td>
<td>521</td>
<td>180</td>
<td>467</td>
<td>170</td>
<td>417</td>
<td>161</td>
<td>375</td>
<td>150</td>
<td>325</td>
</tr>
<tr>
<td>100</td>
<td>582</td>
<td>18</td>
<td>95</td>
<td>525</td>
<td>90</td>
<td>471</td>
<td>85</td>
<td>420</td>
<td>81</td>
<td>378</td>
<td>75</td>
<td>327</td>
</tr>
<tr>
<td>0</td>
<td>587</td>
<td>-</td>
<td>0</td>
<td>530</td>
<td>0</td>
<td>475</td>
<td>0</td>
<td>424</td>
<td>0</td>
<td>381</td>
<td>0</td>
<td>330</td>
</tr>
</tbody>
</table>
Preferred Operating Range

TOTAL HEAD, $H_T$

FLOW RATE, $Q$

70% of BEP

120% of BEP

BEP

POR

Pump Curve
Allowable Operating Range

TOTAL HEAD, $H_T$

FLOW RATE, $Q$

Pump Curve

50% of BEP

1

BEP

125% of BEP

AOR
Operating Outside of POR/AOR

- Several issues occur when operating outside these ranges:
  - Recirculation
  - Excessive Noise
  - Excessive Vibration
  - Cavitation
  - Pump Damage
Cavitation Issues

- Results when liquid is subject to rapid changes of pressure that cause the formation of cavities where pressure is relatively low

- The formation and collapse of cavities or gas pockets can cause mechanical damage to impeller

- Accompanied by loud noises

- Caused by insufficient NPSH
Net Positive Suction Head (NPSH) – Avoiding Cavitation

- **NPSH$_A$** – Total suction head available at the pump inlet
  \[ \text{NPSH}_A = h_{atm} + h_{ss} + h_{vs} - h_l - h_{vap} \]
  Where:
  - \( h_{atm} \) = atmospheric pressure head (~34 ft)
  - \( h_{ss} \) = static suction head
  - \( h_{vs} \) = suction velocity head \( (v^2/2g) \)
  - \( h_l \) = headloss (friction + minor losses) in suction piping
  - \( h_{vap} \) = vapor pressure head of liquid being pumped (table lookup based on pressure, temp – Ex. 1.18 ft. for water at 1 atm and 80° F)

- **NPSH$_R$** – net positive suction head required, as published by manufacturer
  - Defined by HI as the NPSH that causes the total head of the pump (or 1$^{st}$ stage of pump if multi-stage) to be reduced by 3% at a specific rate of flow

- NPSH Margin \( (\text{NPSH}_A / \text{NPSH}_R) \) – 1.1 to 2.0 (ANSI/HI)
Example of $\frac{NPSH_A}{NPSH_R}$

Example Pumping Station
Single Pump Operating

$NPSH_A / NPSH_R = \frac{36}{22} = 1.6$
Correcting NPSH Problems

• Increase wetwell level or supply pressure

• Lower pump elevation

• Reduce headloss in suction piping
  • Check for blockages in pipe
  • Ensure that valves are operating correctly
  • Increase diameter of suction piping
  • Use long-radius bends

• Select (or run at) a lower speed pump

• Choose pump with larger suction diameter
Water Hammer

- Also known as hydraulic shock or surge

- An oscillation in pressure resulting from a rapid increase or decrease in flow (stopping pump, closing valve)

- Causes serious mechanical damage and loud noises

- Surge valves can help minimize water hammer
Water Hammer

Joukowsky head change:

\[ \Delta h = \frac{c}{g} \times \Delta v \]

where \( c \) = wave propagation speed in pipe material
\( g \) = acceleration due to gravity
\( \Delta v \) = change in flow velocity

- Occurs most often due to power failure (pump trip)
- Mitigation methods: surge tanks, damped check valves, surge relief valves, air inlet (vacuum relief) valves
Case Study – Flow Equalization Basin

- Prestressed Concrete Ground Storage Tank
- Pumped Influent, Gravity Drain
- Varying Water Levels Pose Hydraulic Challenges
Case Study – Flow Equalization Basin

- Pumps off curve at full and reduced speed when WSE is low.
Case Study – Flow Equalization Basin

Addition of a standpipe changes effective WSE seen by pump
Case Study – DC Water Blue Plains FADF FIP System

• (10) 100 MGD Vertical Turbine Pumps
  • Magnetic Drives limit to 90% turndown
  • Insufficient Submergence
  • Pumps, motors and mag drives at end of life

• Slamming of check valves
  • Undersized air and vacuum valves

• Proposed System:
  • (10) 70 MGD Constant Speed Pumps
  • (2) 50 MGD Pumps (VFD’s)
  • Premium Efficiency Motors
  • New Medium Voltage Electrical Facility

• Increase in Forebay WSE
  • Floating Datum Concept

• Refine Control Strategy
FIP System – Energy Savings

- Replacement Pumps, Motors and Controllers
- Proposed Control Strategy
  - Trial by locking Mag Drives at 100% with FIP 11 and 12 as trim pumps
- Operational Changes:
  - Discharge to FIC – WSE at 26'
  - Increase Forebay WSE – Floating Datum concept
  - Datum a function of influent flow and headloss

<table>
<thead>
<tr>
<th>Flow Condition</th>
<th>FADU Phase 2 Basis of Design</th>
<th>FIP Alternative Analysis Basis of Design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FIP Q (mgd)</td>
<td>Recycle Flow (mgd)</td>
</tr>
<tr>
<td>Peak Influent</td>
<td>740</td>
<td>110</td>
</tr>
<tr>
<td>Average Influent</td>
<td>370</td>
<td>20</td>
</tr>
<tr>
<td>Minimum Influent Flow</td>
<td>180</td>
<td>0</td>
</tr>
</tbody>
</table>

- Energy savings of approx. $160,000 / year
Case Study – DC Water Blue Plains RWWPS2

• (9) 100 MGD Split Case Centrifugal Pumps
• Rehabilitate for 20 year design life
  • On site repairs
  • Off site rehabilitation
  • Allowance for unanticipated work
  • Motor replacement
  • Controller replacement

• Rehabilitate Discharge Siphons
  • Design point correction
  • Energy Savings

• Refine Control Strategy
RWWPS 2 - Discharge Siphon Improvements

- Rehabilitation of pumps and operation of the wet well at a higher WSE alleviates need for vacuum priming system

- Restore siphon operations – 12” vent
  - Discharge check valve
  - Vacuum breaking valve

- Corrects the pumps primary operating point

- Provides for energy savings
  - 4’ high point
  - PCS data shows ADF of 165 MGD
  - Wire to water efficiency of 70%
  - Energy cost $0.09/kWh
  - Approximately $100,000 / year in consumption
Summary – Pump and System Curves

• There will be several system curves – explore all boundaries – low and high flow / elevations, existing and future C-factors

• Use real elevations for system curves (not pump TDH)

• Avoid flat pump curves if VFDs to be used

• Use affinity laws to explore speed impacts

• Duty point to be ~75% \( Q_{\text{max}} \), close to BEP

• Aim for efficiencies > 75% single stage
Summary - Centrifugal Pump Selection

- Single duty point is insufficient to specify pump
- Give secondary points for VFD reduced speed curves
- No droopy curves – unstable operation - “shall continuously rise to shut off”
- Size motors for Run Out / Maximum HP
- Make sure pump motors are inverter-rated if using VFDs
- Pump motors can be noisy and generate heat (VFDs too)
Summary - Good Hydraulic Design

• Develop system curves early
• Get real data – measure, survey, test
• Follow HI Standards
• The best flow path is a smooth one
• Don’t forget NPSH – no cavitation!
• Consider surge pressure in design
• Consider the full range of possible operating conditions, now and future
• Provide flexibility and expandability
• Work with vendors and O&M staff
• Iterative process
Acknowledgements / Useful Web Sites

- Hydraulic Institute Standards – www.pumps.org

- Books: Pumping Station Design – Sanks, Perry’s Chemical Engineers’ Handbook, Cameron Hydraulic Data, etc.

- Other useful websites:
  - www.pump-zone.com
  - www.pumped101.com
  - www.mcallynstitute.com
  - www.pumpcalcs.com
  - www.eere.energy.gov

- Hazen colleagues - Brian Porter, Bryan Lisk and Ellen Hall, among others
Questions?

Tad Rogers, PE, CCCA, ENV-SP
Richmond, VA
(804) 605-8525
grogers@hazenandsawyer.com