Pump Station Design
TAWWA / WEAT San Antonio Young Professionals Seminar - Design Fundamentals

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Agenda

- Hydraulic Theory / Terminology
- System and Pump Curves
- Pump Performance
- Pump Types (Water) and Selection
- Pump Station Design & Layout
Introduction

- **What is a pump?**
  - A machine that imparts kinetic and potential energy to a liquid to force a discharge from the machine.
  - A machine that moves a volume of liquid from a lower to higher elevation or energy level.
  - A machine that moves liquid along a pipeline.
Hydraulic Theory/Terminology Energy Equation

- General form:
  - \( E_T = E_p + E_v + E_z \)

- Conservation of energy
  - \( E_1 = E_2 \)

- Including losses & pumps:
  - \( E_{p1} + E_{v1} + E_{z1} + E_A = E_{p2} + E_{v2} + E_{z2} + E_f \)

- In terms of pressure head:
  - \( H_{p1} + H_{v1} + H_{z1} + H_A = H_{p2} + H_{v2} + H_{z2} + H_f \)
Hydraulic Theory/Terminology

- **Open to Atmosphere**
  - $H_{p1} = H_{p2} = 0$

- **For Large Reservoir**
  - $H_{v1} = H_{v2} = 0$

- **Simplified equation**
  - $H_{z1} - H_{f1} + H_A - H_{f2} = H_{z2}$
Hydraulic Theory/Terminology
Friction and Minor Losses

- Hazen-Williams:
  \[ H_f = \frac{(0.002083L \times (100/C)^{1.85} \times Q^{1.85})}{D^{4.87}} \]

- Darcy-Weisbach:
  \[ H_f = f \frac{L v^2}{2Dg} \]

- Minor Losses
  - Flow through valves, fittings, bends
  - Changes in flow path, direction, size
  - Minor losses are negligible in long pipelines
Hydraulic Theory/Terminology
Pumping Terms

- Static suction head / lift
- Head Terms
  - Discharge Head \( (H_A) \)
  - Static Head \( (H_z) \)
  - Pressure Head \( (H_p) \)
  - Velocity Head \( (H_v) \)
  - Friction Head \( (H_f) \)
- Energy Grade Line (EGL)
  - \( EGL = H_p + H_v + H_z + H_f \)
- Hydraulic Grade Line (HGL)
  - \( HGL = H_p + H_z + H_f = EGL - H_v \)
- Total Dynamic Head (TDH)
  - \( TDH = \text{Static} (H_z) + \text{Friction} (H_f) \)
System and Pump Curves
System Curve Determination

- Determine static head
- Determine pipe size and length
- Quantify friction and minor losses
- Plot sum of:
  - Static head
  - Friction head from piping and minor losses
System and Pump Curves
System Curve Generation

Plot: $H_z + H_f$ vs. $Q$

- $H_f$: Friction Head
- $H_z$: Static Head
- TDH: Total Dynamic Head

$H_f = \text{Friction Head}$
$H_z = \text{Static Head}$
$\text{TDH} = H_z + H_f$

Flow (mgd)

Head (feet)
System and Pump Curves
Multiple System Curves

Plot System Curves for each Static Head condition
System and Pump Curves
Pump and System Curves

- System ALWAYS runs at the intersection of the Pump and System Curves
System and Pump Curves
Pump and System Curves

1 - PUMP

2 - PUMPS IN PARALLEL

3 - PUMPS IN PARALLEL

Parallel Pumps
Add Q at given H

Flow (mgd)
Head (feet)

Maximum Static Head
Average Static Head
Minimum Static Head
1 Pump
2 Pumps
3 Pumps
System and Pump Curves
Pump and System Curves

2 - PUMPS IN SERIES

1 - PUMP

Series Pumps
Add H at Given Q

Maximum Static Head
Average Static Head
Minimum Static Head
1 Pump in Series
2 Pumps in Series
System and Pump Curves
Pump Curves & Performance

- Best Efficiency Point (BEP)
- Preferred Operating Region (POR): 80% to 110% of BEP is ideal
- Allowable Operating Region (AOR): 50% of BEP to runout is OK
- Brake Horsepower (BHP)
- Net Positive Suction Head (NPSH)
Pump Performance

- Water Horsepower
  \[ WHP = \frac{\gamma \times Q(cfs) \times H}{550} = \frac{Q(gpm) \times H}{3960} \]

- Brake HP (pump input)
  \[ BHP = \frac{Q(gpm) \times H}{3960 \times Ep} \]

- Total HP (wire-to-water)
  \[ THP = \frac{Q(gpm) \times H}{3960 \times Ep \times Em} \]

\( \gamma \) = Specific Weight of Water (62.4 lb/ft\(^3\))

\( Q \) = Flow in cfs or gpm

\( H \) = TDH (ft)

\( E_p \) = pump efficiency

\( E_m \) = motor efficiency

\( E_p \times E_m \) = wire-to-water efficiency

* If using VFD, wire-to-water efficiency = \( E_p \times E_m \times E_d \)
Pump Performance

- Cavitation
  - Formation of vapor bubbles
  - Drop below vapor pressure
  - Loss of capacity, noise, vibration damage to pump

- NPSH – TDH of fluid @ suction eye of pump
  - NPSHa – “Available”
  - \( \text{NPSHa} = H_{\text{bar}} + H_s - H_{\text{vap}} - H_f - H_m \)
  - NPSHr – “Required”
  - \( \text{NPSHa} > \text{NPSHr} \)
  - Insufficient NPSHa = Cavitation
Pump Performance
Variable Speed Pumping

Variable Frequency Drive (VFD)

- Affinity Laws (N – rpm)
  - Flow: \[
  \frac{Q_1}{Q_2} = \frac{N_1}{N_2}
  \]
  - Head: \[
  \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2
  \]
  - Power: \[
  \frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3
  \]
Variable Frequency Drive (VFD)

- **Advantages**
  - Match flow to demand
  - Fewer yet larger pumps
  - Reduced pressure surges
  - Potential for lower operating costs
  - Longer equipment life
  - Reduced inrush current
Disadvantages

- Higher capital / O&M costs
- Increased equipment, larger electrical room
- Less electrical efficiency
- Higher potential for vibration
- Heat dissipation
Common Pump Types
Water Pumps

- Horizontal Centrifugal End Suction
  - End suction, top discharge
  - Wide variety of sizes
  - Low cost
  - Most commonly manufactured pump
  - Many qualified manufacturers
Common Pump Types
Water Pumps

- Horizontal Centrifugal Split Case
  - Casing split axially
  - Rugged, heavy duty
  - High efficiencies
  - Easy to maintain
  - Large footprint
  - Bearings must be protected from dust
Common Pump Types
Water Pumps

- Vertical Turbine – Lineshaft
  - High head capability w/multiple stages
  - Tailor heads by adding bowls or stages
  - Installed in cans or sump
  - Small footprint
  - Tight shaft tolerances
Common Pump Types
Water Pumps

- Vertical Turbine – Submersible
  - Submersible motor mounted at well bottom
  - No shafting or bearings above the bowl assembly
  - Quiet operation
  - Practical at long depths
  - Frequent maintenance requires pulling unit
  - Long electric cables
Pump Selection

- Design and Peak Flows, Pressures
- Operating conditions & system head curves
- Select type, orientation & number of pumps
- Initial pump selection - consult w/manufacturers
- Match pump and system curves
- Efficiencies, Horsepower, NPSH
- Performance curve analysis, operating points
- Capacity and/or Head increase options
Pump Station Layout/Design
Types of Pump Stations - Water

- **Raw Water Intake**
  - Located at lake or river
  - Vertical configuration w/ sump or cans is typical

- **Booster Station**
  - Horizontal or vertical configuration
  - Installed along pipeline to boost pressure

- **High Service**
  - Horizontal or vertical configuration
  - Installed at WTP
  - Complicated hydraulics / system
Pump Station Layout/Design
Station and Site Design

- Sump, Wet Well & Can design
- Piping & Valve design
- Pump control system (motor, drive, valves)
- Power supply (main, standby)
- Instrumentation & SCADA
- HVAC & Ventilation
- Structural Design
- Architectural and Lighting
- Site Design, Access, O&M
References

- Pumping Station Design, 3rd Edition
  - by Sanks, Tchobanoglous, Bosserman
- Pump Handbook, 4th Edition
  - by Karassik, Messina, Cooper, Heald
- Hydraulic Institute Standards (HIS)
- AWWA
- ASTM
- ANSI
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Any Questions??

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