MAXIMIZING EFFICIENCY OF PUMP STATIONS FOR WATER AND WASTEWATER SYSTEMS

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October 13, 2014
Agenda

- A few Statistics
- Let's Start with the Intake
- Traditional Pump Selection
- Optimizing Pump Selection
- Are VFD's Really More Efficient?
- SCADA Tricks and Treats
- Predictive Maintenance for Improved Efficiency
- Conclusions
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Power Grid

Need for Highly Efficient Energy Generation in Wastewater Industry

- Water & wastewater services account for 30-50% of municipal energy use
- Largest single user of electricity
- Pumping systems consume an estimated 3% of all electricity used in the U.S. annually (Engle, 2008).
- 90% of energy cost at water treatment plants is pumping
- Typical electrical consumption of a WWTP is 575 to 1,205 kWh/MG. (EPA Region 1 Benchmarking Pilot)
- 20% of California’s energy requirements are associated with water

Typical Water Process
Energy Use Breakdown

Energy

- Distribution Pumping: 67%
- Raw Water Pumping: 11%
- Treatment Process: 9%
- In-plant Pumping: 2%
- Lighting & Building: 11%
Typical Wastewater Process
Energy Use Breakdown

Energy

- Treatment Process: 70%
- Influent Pumping: 16%
- Solids Disposal: 7%
- Lighting & Building: 7%
Fluid Transport Dominates National Energy Use as Well

- Pumps, 25%
- Compressed Air, 16%
- Fans, 14%
- Material Processing, 23%
- Material Handling, 12%
- Refrigeration, 7%
- Other, 4%

*Courtesy of A. Sdano - Fairbanks Morse*
Happenings at the National Level – Minimum Efficiency Standards

- HI, NGO’s and Department of Energy
- Currently in Negotiated Rulemaking
- Phase 1 Standards:
  - Inline Pumps
  - End Suction
  - Radial Split Vertical
  - Submersible Turbines
- Phase 2 Standards:
  - Circulators and Pool Pumps
- Currently, Solids handling, Split-case, and shafted turbines excluded.
Introduction

Why consider pumping system optimization?

a. Improve efficiency
b. Reduce operating costs
c. Reduce carbon footprint
d. Reduce maintenance costs
e. Improve reliability
f. Reduce inrush
g. Minimize number of start/stops
h. Reduce required power infrastructure
Resources for Pump Life Cycle Analysis


Executive Summary
Example LCC Analysis

- 15 year life cycle
- 500 HP pump
- $56,000 purchase
- $5,600/yr maintenance

1st Year = $82,100

- Purchase, 4%
- Energy, 88%
- Operations, 2%
- Maintenance, 6%
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Start by Evaluating Intake/Discharge Conditions

- HI 9.8 and HI 9.6.6
- Updated in 2012
HI 9.8 Intake Designs for Pumping Systems

- Circular Wet Wells
- Trench Type Wet Wells
- Confined Rectangular Wet Wells
Case Study – St. Louis, MO
Case Study (cont.)

Slide Gate Well

Min WL Elev @75 mgd 31.50

Max WL: Elev 43.75

46’-0” (1947 Tunnel Extension)
Case Study (cont.)

- Extensively researched through Physical Models.
- About ½ the excavation volume
- Allows close pump spacing
- Sloped walls to prevent Solids Deposition.
Case Study (cont.)

- CFD Modeling
  - Confirms flow regime to pumps
  - Sizes and locates antirotation baffles.
  - Sizes and locates hydrodynamic cones.
What About Existing Installations?

- Specially Designed Suction Elbows.
- Verify BF Valve Position
- Vaned Basket suction intakes
- Pump “cowcatchers” for shallow sump designs.
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Traditional Pump Selection

- Development of system flow characteristics
  a. Minimum rated plant flow
  b. Average (normal operating) plant flow
  c. Maximum rated plant flow

- Selection of Pump type
  a. Vertical turbine
  b. Horizontal centrifugal
  c. Solids handling (i.e. influent wastewater)
Traditional Pump Selection (cont.)

◆ Determine Total Dynamic Head (TDH)
  a. Varies depending on:
     1. Plant flow rate
     2. Age and condition of piping
     3. Temperature
     4. Flow splits or interconnects
     5. Downstream tank/basin level

◆ Select pump based on manufacturer’s available literature
Traditional Pump Selection (cont.)

Review Published Curves for:
- Design flow and total dynamic head
- Peak efficiency at rated design point
- Range of published curves

From American-Marsh Pumps Catalog, Curve dated August 1999
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Operating Regions: New Pump Selection Paradigm

- **Best Efficiency Point (BEP)**
  - The flow at which it is operating at its highest efficiency

- **Preferred operating region (POR)**
  - 70% - 120% of the BEP
  - Generally designed for 20 year life

- **The Allowable operating region (AOR)**
  - Region set by the manufacturer
  - Pump is able to operate in whilst conforming to predefined API 610 vibration limits.
Energy Efficient Pump Selection

- Efficiency curves with a wide range

![Diagram showing efficiency curves with an 80% efficiency band]

80% efficiency band

 Courtesy Fairbanks Morse 2003
System and Efficiency Curve

![Graph showing system and efficiency curve with flow (gpm) on the x-axis and total dynamic head / NPSHr (ft) on the y-axis. The graph includes lines for pump and efficiency, with a corresponding BEP marker.](image-url)
POR Operation: 1 Pump

Area Outside of POR Operation (TYP)
POR Operation: 2 Pump
POR Operation: 3 Pump

Area Outside of POR Operation (TYP)
AOR Operation: 3 Pump

Area Outside of POR Operation (TYP)
Pump Selection for Energy Efficiency

- Pump selection should recognize where the pump will normally operate.

- A balance between number of pumps and the potential for energy efficiency should be achieved.

- Future conditions should be considered.
Pump Selection Resources

• Pumping System Assessment Tool
  – Free from PumpSystemsMatter.org
  – Uses achievable pump performance data from HI standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.
  – Can compare/contrast pumps side by side.
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Variable Frequency Drives: The Good

Centrifugal Pump at Varying Speeds

- Full Speed Pump Curve
- Reduced Speed Curves
- Pump Rated Point (Example)

(Follows affinity laws)
VFD’s The Good...

- Greater Energy Efficiency:
  - Static Head < 70% of TDH
  - Good, Steep Pump Curves
  - Operations down to 50-60% speed
- True “Soft Start’’
- Reduced surge, less wear on rotating equipment.
- Power Factor Correction

\[
\text{Power factor} = \cos \theta = \frac{\text{kW}}{\text{kVA}}
\]

Useful work by Pump
Variable Frequency Drives – The Bad

- Steeper curves provide better turndown
- Slopes decrease on relatively flat curves during turndown
VFD’s – The Bad

- Acoustical Motor Noise
- Motor Heating/Energy Loss w/ Speed

<table>
<thead>
<tr>
<th>HP</th>
<th>Diver</th>
<th>Freq (Hz)</th>
<th>% Speed</th>
<th>% torque</th>
<th>Current</th>
<th>Temp Ride</th>
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<tr>
<td>50</td>
<td>Sine</td>
<td>60</td>
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<td>59.1</td>
<td>62</td>
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<tr>
<td>50</td>
<td>VFD</td>
<td>30</td>
<td>50</td>
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<td>6</td>
<td>10</td>
<td>62</td>
<td>45</td>
<td>66</td>
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</table>
### VFD’s.. The Ugly

- Problems with Bad Power
- Motor/Heat Loss at Full Speed

<table>
<thead>
<tr>
<th>HP</th>
<th>Diver</th>
<th>Freq (Hz)</th>
<th>% Speed</th>
<th>% torque</th>
<th>Current</th>
<th>Temp Rise</th>
</tr>
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<tr>
<td>50</td>
<td>Sine</td>
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<td>100</td>
<td>100</td>
<td>59.1</td>
<td>62</td>
</tr>
<tr>
<td>50</td>
<td>VFD</td>
<td>60</td>
<td>100</td>
<td>100</td>
<td>61.4</td>
<td>73</td>
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</tbody>
</table>
Hydraulic versus Electrical Efficiency

- Variable Frequency Drive
  - Power Factor – 0.96 (regardless of load)
  - Efficiency
    - Full Load – 96%
    - ½ Load – 90%

- Overall efficiency of motor and VFD
  - Cannot multiply the efficiency of the motor times the efficiency of the VFD
  - All VFDs notch or effect the motor efficiency
Overall System Efficiency Index (SEI) – Liptak, 1995

- SEI = (Pe x Me x Ve x Ue) x 10^{-6}
  - Pe = Pump Efficiency 90
  - Me = Motor Efficiency 94.7
  - Ve = Variable Speed Drive Efficiency 90
  - Ue = Utilization Efficiency head is changed
    - Ratio of (Q_a)(H_a)/(Q_d)(H_d)
    - Q_a = Actual Flowrate
    - H_a = Actual Head
    - Q_d = Design Flowrate
    - H_d = Design Head

- Provides relative comparisons
Comparison of Hydraulic and Actual Efficiencies

• Most applications we are changing head but not flows. Keep the flow the same. VFD system.
  – Pressure range 85 to 125 psi (wide range)
  – Percent speed = 82% (lowest)
  – Percent load = 55% (minimum load on Motor)
• Overall Efficiency (actual) = 73%
• Equivalent Hydraulic Efficiency for constant speed pump = 78%
  – Assuming full load
• This means that if the hydraulic efficiency was less than 78%, two pumps at lower speeds would be better than 1 pump running out on its curve
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- Predictive Maintenance for Improved Efficiency
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Finished Water Pump Optimization

◆ Goal: To develop operating strategy for pumps to optimize energy efficiency and reduce overall operating costs

◆ Solution:

a. Evaluate combined system curve to determine peak operating efficiencies

b. Select operating efficiency range based on system curve characteristics
Finished Water Pump Optimization (cont.)

Solution:

c. Plot efficiency lines and evaluate operating efficiency range

d. Verify sufficient overlap in operating efficiency range, if not, increase range and re-plot efficiency lines
Finished Water Pump Optimization (cont.)

1 pump running (82%-86% Efficiency)

Membrane Pumps

5 pumps running (82%-86% Efficiency)

5 pumps running (82% Efficiency)

5 pumps running
Best Efficiency Line (86%)
Finished Water Pump Optimization (cont.)

Solution:

d. Develop algorithm to control pumps based on desired output flow that accomplishes the following:

1. Operator decides the flowrate. The algorithm determines which pumps to run and how many based on the discharge pressure

2. Prevents pumps from running at pressures too low or too high for pump curve or system (to protect pumps and downstream piping)

3. Starts and stops pumps to maintain peak efficiency
Finished Water Pump Optimization (cont.)

4. May be overridden at any time by the operator to provide manual control

5. Allows for operational variability between seasons (peak pumping rates and discharge pressures different in summer vs. winter)

6. Protects pumps by not exceeding maximum number of starts per hour

7. The more pumps that are used in parallel, the stricter the tolerance for efficiency range
Finished Water Pump Optimization (cont.)

◆ Results:

a. Actual cost savings realized when operated in energy efficiency mode

b. Flexibility to operate in either energy efficiency mode or manual mode
Other Tricks of the Trade

- Time of Use Management
- Shift Competition Banner
- Real Time Pump Info

Energy Usage

<table>
<thead>
<tr>
<th>Shift</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage</td>
<td>305</td>
<td>250</td>
<td>300</td>
</tr>
</tbody>
</table>

Current Time: 6:41 AM
Current Period: Off-Peak 7.5¢

Carollo

Engineers... Working Wonders With Water™
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- **Predictive Maintenance for Improved Efficiency**
- Conclusions
HI Parameters for Condition Monitoring

◆ Hydraulic Institute (HI) indicators of various failure modes:
  - HI document does not require any monitoring be done
  - HI recommends user identify the need for implementing pump condition monitoring practices
HI Parameters for Condition Monitoring (cont.)

◆ HI’s 14 potential failure mode indicators:
  - Power
  - Temperature
  - Corrosion
  - Leak Detection
  - Pressure
  - Vibration
  - Lubrication Analysis
  - Shaft Position
  - Rate of Flow
  - Maint. Inspection
  - Speed (rpm)
  - Bearing Water Detection
  - Preinstall Hydrotest
  - Design Review
Case Study 1: In-Situ Testing @ Fayetteville, NC

- High Service Pump No. 4

**Design Conditions**

- Rated: 8,000 gpm at 400 Ft TDH
- 1,000 HP
- 85% Efficiency
In-Situ Testing @ Fayetteville, NC (cont.)

High Service Pump No. 4

- Actual observed head conditions different than design
  - Design head = 400 Ft
  - Actual head = 300 Ft
- Modifications to pump bowls during routine maintenance will allow for better operation under actual conditions
- Same pump (with new bowls) and motor provide 2% higher efficiency and more flow
In-Situ Testing @ Fayetteville, NC (cont.)

- High Service Pump No. 4

Actual Conditions

New Cond’s:
- 11,500 gpm at 300 Ft TDH
- 1,000 HP
- 87% Efficiency
In-Situ Testing @ Fayetteville, NC (cont.)

- High Service Pump No. 4
  - New system pressure conditions warranted pump modifications
  - In-situ testing prior to performing predictive maintenance allowed for modifications to coincide with maintenance
  - Overall energy savings will be realized by improved operation as well as prolonged service life
  - Time out of service minimized
Case Study 2 – Fayetteville, NC

◆ High Service Finished Water Pump
◆ 6,000 gpm
◆ 600 hp
## Case Study 2: Cont.

### WHAT IF ??? Assuming 10% Increase

<table>
<thead>
<tr>
<th>COMPARISON PUMP POWER COST CALCULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Cost per KWHR: $0.0516</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EXISTING PUMP DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Daily Flow: 2,643,333 gpd</td>
</tr>
<tr>
<td>Existing Pump Flow: 5,507 gpm</td>
</tr>
<tr>
<td>Existing Pump Total Head: 277 ft.</td>
</tr>
<tr>
<td>Existing Pump Efficiency: 72.00%</td>
</tr>
<tr>
<td>Existing Brake Horsepower: 534.15 HP</td>
</tr>
<tr>
<td>Existing Hours of Operation per Day: 8.00 hours</td>
</tr>
<tr>
<td>Annual Pumping Cost: $60,015.07</td>
</tr>
<tr>
<td>Pumping Cost / 1,000 gallons: $0.0622</td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>COMPARISON PUMP DATA</th>
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</thead>
<tbody>
<tr>
<td>Pump Flow: 5,507 gpm</td>
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<tr>
<td>Pump Total Head: 277 ft.</td>
</tr>
<tr>
<td>Pump Efficiency: 82.00%</td>
</tr>
</tbody>
</table>

### INCREASE PUMP EFFICIENCY

- **10%**

### Comparison Pump HP

- 469.01 HP

<table>
<thead>
<tr>
<th>Hours of Operation per Day</th>
<th>8.00 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Pumping Cost: $52,696.16</td>
<td></td>
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</table>

### Annual Savings if Efficiency is increased by **10%**

- $7,318.91

### Repair Cost

- $20,646.00

### Pay Back

- 2.8 Years
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- Recommendations
Recommendations

• Intake Design:
  – New Intakes conform to HI standards wherever possible.
  – Recommend CFD or similitude modeling (above 140 mgd)
  – Existing intakes use CFD as a tool to test changes.
  – Utilize special fittings in hard piped conditions.
  – Recognize this can be a huge energy efficiency hog.

• Pump selection for efficiency should examine the normal operating conditions as well as the design point
Recommendations (cont.)

• Recognize the Limitations in VFD’s
  – Make sure you have good power
  – Make sure that static head does not dominate (70% rule)
  – Make sure that number of VFD/s are balanced to the energy savings they provide.

• PLCs can handle complex math which allows for tailored energy efficiency algorithms

• Optimizing well drawdown is another area where energy savings can be recognized
Recommendations (cont.)

5. Comparing the pump curve to the original pump curve and well as comparisons with the operating point can show where efficiency gains are possible.

6. Attention to motors and motor efficiency can provide multiple benefits

7. An overall system understanding can lead to an integrated approach to energy efficiency that can be combined to yield significant reductions in energy use.

8. Set Goals: Frequent (twice per year) re-examination of overall efficiency expected versus actual conditions.