U. S. Department of Energy
Energy Savings Assessment (ESA)

Overview of the Pumping System
Assessment Tool (PSAT)

Date: February 12, 2007
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Motor-driven equipment is a dominant electricity consumer

Industrial motor systems:
- are the *single largest electrical end use* category in the American economy
- account for 25% of all U.S. electrical sales
Pumps are the largest industrial user of motor-driven electrical energy.

Fluid handling equipment, including pumps, fans, and compressors, account for over 60% of industrial motor-driven energy.
BestPractices encourages a three-tiered prescreening and assessment approach

- Initial prescreening based on size, run time, and pump type
- Secondary prescreening to narrow the focus to systems where significant energy reduction opportunities are more likely
- Opportunity assessment and quantification of potential savings
The bulk of motor-driven energy is used by a relatively small part of the population.
Primary prescreening

- All plant motor systems
  - Filter 1: Seldom used, small loads
  - Filter 2: Big centrifugal loads that run a lot
  - Big loads that run a lot
- Policies and practices
  - Moderate priority
- Big centrifugal loads that run a lot
Pump energy basics is fundamental to secondary prescreening

\[ E = \frac{Q \cdot H \cdot T \cdot sg}{5308 \cdot \eta_{\text{pump}} \cdot \eta_{\text{motor}} \cdot \eta_{\text{drive}}} \]

- **E**: energy, kilowatt-hours
- **Q**: flow rate, gpm
- **H**: head, ft
- **T**: time, hours
- **sg**: specific gravity, dimensionless
- **5308**: Units conversion constant
- **\( \eta_{\text{pump}} \)**: pump efficiency, fraction
- **\( \eta_{\text{motor}} \)**: motor efficiency, fraction
- **\( \eta_{\text{drive}} \)**: drive efficiency, fraction
Five basic causes of less than optimal pumping system operation

- Installed *components* are inherently inefficient at the normal operating conditions
- The installed *components* have degraded in service
- More flow is being provided than the *system* requires
- More head is being provided than the *system* requires
- The equipment is being run when not required by the *system*
Secondary prescreening

All plant motor systems

Filter 1
Seldom used, small loads

Filter 2
Big loads that run a lot
Non-centrifugal, ASD loads

Policies and practices

Symptom or experienced-based segregation

Big centrifugal loads that run a lot

Moderate priority

Highest Priority
Some symptoms of interest

• Throttle valve-controlled systems
• Bypass (recirculation) line normally open
• Multiple parallel pump system with same number of pumps always operating
• Constant pump operation in a batch environment or frequent cycle batch operation in a continuous process
• Cavitation noise (at pump or elsewhere in the system)
• High system maintenance
• Systems that have undergone change in function
Pumping System Assessment Tool (PSAT)

• An opportunity quantification tool
• Relies on field measured (or estimated) fluid and electrical performance data
• Uses achievable pump efficiency algorithms from the Hydraulic Institute
• Motor performance (efficiency, current, power factor) curves developed from average motor data available in MotorMaster+ (supplemented by manufacturer data for larger size, slower speed motors)
A matter of focus

- PSAT is based on component performance
- It can be used to evaluate component-level performance
- But it can also be used to evaluate system-level conditions
An example system

Motor data: 80.5 amps, 2300 V

Measured fluid data
F1 = 6050 gpm
L1 = 12 ft above ground
P2 = 75.5 psig (5 ft above ground)
**Head calculation**

PSAT includes a pump head calculator to support user-measured pressure, flow data.

<table>
<thead>
<tr>
<th>Type of measurement configuration</th>
<th>Suction tank elevation, gas space pressure, and discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>K_s</strong> represents all suction losses from the tank to the pump</td>
<td><strong>K_d</strong> represents all discharge losses from the pump to gauge <strong>P_d</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suction pipe diameter (ID), inches</th>
<th>19.500</th>
<th>Discharge pipe diameter (ID), inches</th>
<th>15.500</th>
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</thead>
<tbody>
<tr>
<td>Suction tank gas overpressure (P_g), psig</td>
<td>0.00</td>
<td>Discharge gauge pressure (P_d), psig</td>
<td>75.50</td>
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<tr>
<td>Suction tank fluid surface elevation (Z_s), feet</td>
<td>12.00</td>
<td>Discharge gauge elevation (Z_d), feet</td>
<td>5.00</td>
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<td>Suction line loss coefficients, K_s</td>
<td>0.50</td>
<td>Discharge line loss coefficients, K_d</td>
<td>2.50</td>
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<tr>
<td>Fluid specific gravity</td>
<td>0.990</td>
<td>Flow rate, gpm</td>
<td>6050</td>
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</table>

<table>
<thead>
<tr>
<th>Differential elevation head, ft</th>
<th>-7.00</th>
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</thead>
<tbody>
<tr>
<td>Differential pressure head, ft</td>
<td>176.17</td>
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<tr>
<td>Differential velocity head, ft</td>
<td>1.64</td>
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<tr>
<td>Estimated suction friction head, ft</td>
<td>0.33</td>
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<tr>
<td>Estimated discharge friction head, ft</td>
<td>4.11</td>
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<tr>
<td>Pump head, ft</td>
<td>175.25</td>
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Component-based analysis

Inputs

Pump, fluid data
- Fixed pump specific speed? Yes/No
- Speed, rpm: 1185
- Drive: Direct drive
- # stages: 1
- Specific gravity: 0.990
- Fluid viscosity (cS): 1.00

Motor ratings
- Motor hp: 350
- Existing motor class: Standard efficiency
- rpm: 1185
- Rated voltage: 2300
- Nameplate FLA: 83.0
- Motor size margin, %: 15

Duty, cost rate
- Operating fraction: 1.000
- Electricity cost, cents/kwhr: 3.900

Required or measured data
- Simple system curve utility: Head calc
- Flowrate, gpm: 6050
- Head, ft: 175.3
- Load estimation method: Current
- Motor voltage: 2300
- Motor amps: 80.5

Results

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Optimal</th>
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<tbody>
<tr>
<td>Pump efficiency, %</td>
<td>78.2</td>
<td>87.3</td>
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<tr>
<td>Motor rated power, hp</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Motor shaft power, hp</td>
<td>339.0</td>
<td>303.7</td>
</tr>
<tr>
<td>Pump shaft power, hp</td>
<td>339.0</td>
<td>303.7</td>
</tr>
<tr>
<td>Motor efficiency, %</td>
<td>94.5</td>
<td>95.6</td>
</tr>
<tr>
<td>Motor power factor, %</td>
<td>83.4</td>
<td>83.8</td>
</tr>
<tr>
<td>Motor current, amps</td>
<td>80.5</td>
<td>71.0</td>
</tr>
<tr>
<td>Motor power, kWe</td>
<td>267.5</td>
<td>237.0</td>
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<tr>
<td>Annual energy, MWhr</td>
<td>2343.7</td>
<td>2075.8</td>
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<tr>
<td>Annual cost, $1,000</td>
<td>91.4</td>
<td>81.0</td>
</tr>
<tr>
<td>Annual savings potential, $1,000</td>
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<td>10.4</td>
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<tr>
<td>Optimization rating</td>
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<td>88.6</td>
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Input sections 1-3

Basic design, operating profile and cost inputs

Pump, fluid design information

Motor design information

Operating profile, electric cost rate

<table>
<thead>
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<th>Pump, fluid data</th>
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<tr>
<td>Fixed pump specific speed? Yes/No</td>
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<tr>
<td>Drive Direct drive</td>
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<tr>
<td># stages 1</td>
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<tr>
<td>Specific gravity 0.990</td>
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<td>Fluid viscosity (cS) 1.00</td>
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<table>
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<tr>
<th>Motor ratings</th>
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<tr>
<td>Motor hp 350</td>
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<tr>
<td>Existing motor class Standard efficiency</td>
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<tr>
<td>rpm 1185</td>
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<tr>
<td>Rated voltage 2300</td>
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<tr>
<td>Nameplate FLA 83.0</td>
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<td>Motor size margin, % 15</td>
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</table>

<table>
<thead>
<tr>
<th>Duty, cost rate</th>
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<tr>
<td>Operating fraction 1.000</td>
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</table>
Input section 4

Accurate performance data is essential

![Required or measured data chart]

- Simple system curve utility
- Head calc
- Flowrate, gpm: 6050
- Head, ft: 175.3
- Load estimation method: Current
- Motor voltage: 2300
- Motor amps: 80.5

{fluid}
{electrical}
Alternate forms of electrical data input

Either motor current or power can be used to estimate the motor shaft load.
Results: optimization rating

The optimization rating is akin to an exam grade of how well the existing operation compares with optimal.

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\[
\frac{237.0 \times 100}{267.5} = 88.6
\]
## Results: cost, savings potential

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Annual energy costs for the existing and optimal cases are tabulated, and the potential cost savings is listed.
A system-level perspective

Delivered to Tank 2

71.3 ft friction loss across control valve

F2 = 2800 gpm
F1 = 6050 gpm

Required flow rate: 2800 gpm sent to Tank 2
Required head = Pump head: 175.3 ft
- valve loss: 71.3 ft
= 104.0 ft
A system-level perspective

PSAT analysis using the required fluid data

Optimal equipment sized to meet the required conditions could save over $68,000/year.
PSAT does not identify solutions; some options

- Trimmed impeller
- Reduced speed motor
- Adjustable speed drive
- Different pump

Other factors, such as load variability, extent of system head that is static, and pump details (curve, impeller size, etc.) would be needed to evaluate alternative solutions.
Two types of PSAT "Help"

Pop-up help for screen item under the mouse cursor:

<table>
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<tr>
<th>Parameter</th>
<th>Value1</th>
<th>Value2</th>
</tr>
</thead>
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</tr>
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Annual savings potential, $1,000: 10.4
Optimization rating: 88.6

Background info selection menu:

- Prescreening - IMPORTANT
- General background
- System measured conditions vs. actual requirements
- Sources of system losses
- Pump efficiency discussion
- Motor efficiency discussion
A demo of the tool use
Example system

Suction line size: 14-inch sch. 40 CS (13.1" ID)
Discharge (except reducers at valve V1): 12-inch sch. 40 CS (11.9" ID)
Fluid: water at 70°F
Valve V1 is 8-inch v-port ball
Cost of electricity is 5 cents/kWh
Motor is 460-Volt, 250-hp, 1780 rpm, nameplate efficiency = 95.8%
All pressure gauges at 5 ft above ground
Pump is single stage end suction
Both tanks are open to atmosphere

Table 1. Measured operating data

<table>
<thead>
<tr>
<th>Condition</th>
<th>Q, gpm</th>
<th>P1, psig</th>
<th>P2, psig</th>
<th>P3, psig</th>
<th>Motor kW</th>
<th>% of time at Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2000</td>
<td>90</td>
<td>52</td>
<td>50</td>
<td>135</td>
<td>50%</td>
</tr>
<tr>
<td>B</td>
<td>3160</td>
<td>75</td>
<td>66</td>
<td>61</td>
<td>150</td>
<td>40%</td>
</tr>
</tbody>
</table>
We'll do PSAT calculations for Condition A

• Calculate pump head
• Annual energy cost
• Potential savings
• Develop a system curve with artificial control valve losses eliminated
• Take a look at some of the background information and data
Important note about loss coefficients

The loss coefficients used here apply to the velocity head in the line size represented by the suction and discharge pipe diameters at the points of pressure measurement.

If the loss elements are in different size lines than the points of pressure measurement, they need to be appropriately scaled. The appropriate scaling factor is proportional to the 4th power of the diameter ratio. For example, if the discharge pressure is measured in a 12-inch header, and there is a 6-inch check valve with a nominal loss coefficient of 2 (applied to the 6-inch valve size), the K factor to use for the valve would be $2 \times (12/6)$ to the 4th power, or 32. The reason for this 4th power scaling is that the velocity varies with the square of the pipe diameter, and the velocity head is proportional to the velocity squared.
**Important note about loss coefficients**

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Note that the two system curves plotted here are not matched to the two pump data sets from the main PSAT panel. Instead, they are intended to allow the user to evaluate the effects of modifying the characteristics of the system and/or the operating flow rate would have on the potential energy savings.
Other options for the side-by-side comparison

- Same pump, different operating conditions
- Same pump, different times - such as in periodic performance testing/trending
- Parallel pumps
- Old pump/new pump
- etc., etc.
A valve loss estimating tool is included with PSAT

Based on standard valve equations (ISA 75.01)
Software download (free) and training links

www.eere.energy.gov/industry/bestpractices/software.html

Software Tools
BestPractices has a varied and expanding software collection. Much of the software can be accessed here. A few packages must be ordered from the EERE Information Center via e-mail or by calling 1-877-EERE-INF (877-337-3463).

With the right know-how, you can use these powerful tools to help identify and analyze energy system savings opportunities in your plant. While the tools are accessible here for download, you are also encouraged to attend a training workshop to enhance your knowledge and take full advantage of opportunities identified in the software programs. For some tools, advanced training is also available to help you further increase your expertise. Find out more about training. You can get help on software installation and operation from the EERE Information Center at 1-877-EERE-INF (877-337-3463) or email to eereic@ee.doe.gov.

DOE Industry Tools
- AIRMaster+
- Chilled Water System Analysis Tool (CWSAT)
- Combined Heat and Power Application Tool (CHP)
- Fan System Assessment Tool (FSAT)
- MotorMaster+ 4.0
- MotorMaster+ International
- NOx and Energy Assessment Tool (NxEAT)
- Plant Energy Profiler for the Chemical Industry (ChemPEP Tool)
- Process Heating Assessment and Survey Tool (PHAST)
- Pumping System Assessment Tool 2004 (PSAT)
- Steam System Tool Suite

PSAT Introduction
There are two PSAT workshops: End-user and Specialist.

Pumping Systems Field Monitoring and Application of the Pumping System Assessment Tool (PSAT)

A BestPractices Workshop

PSAT Introduction
PSAT specialists are listed on the DOE web site
www.eere.energy.gov/industry/bestpractices/psat.html

Qualified BestPractices PSAT Specialists: by Last Name
* indicates Qualified BestPractices Instructor

<table>
<thead>
<tr>
<th>Name</th>
<th>E-Mail</th>
<th>Phone</th>
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<tr>
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<tr>
<td>Adams, Bill</td>
<td><a href="mailto:wadams@flowserve.com">wadams@flowserve.com</a></td>
<td>269-226-6203</td>
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<tr>
<td>Ahlen, Arne</td>
<td><a href="mailto:aahlen@apiweb.com">aahlen@apiweb.com</a></td>
<td>404-872-8807 ext. 205</td>
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<tr>
<td>Ahlgren, Roy‡</td>
<td><a href="mailto:roy.ahlgren@itt.com">roy.ahlgren@itt.com</a></td>
<td>847-966-3700</td>
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<td>Allen, Jim</td>
<td><a href="mailto:jallens@flowserve.com">jallens@flowserve.com</a></td>
<td>757-495-8021</td>
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<tr>
<td>Anderson, Kent</td>
<td><a href="mailto:andersonka@schofield.army.mil">andersonka@schofield.army.mil</a></td>
<td>808-656-1410 ext. 1108</td>
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<td><a href="mailto:lbell@flowserve.com">lbell@flowserve.com</a></td>
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<td>315-568-7339</td>
</tr>
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