MINISTRY OF
INDUSTRY AND TRADE

EU - VIET NAM SUSTAINABLE ENERGY
TRANSITION PROGRAMME (SETP)

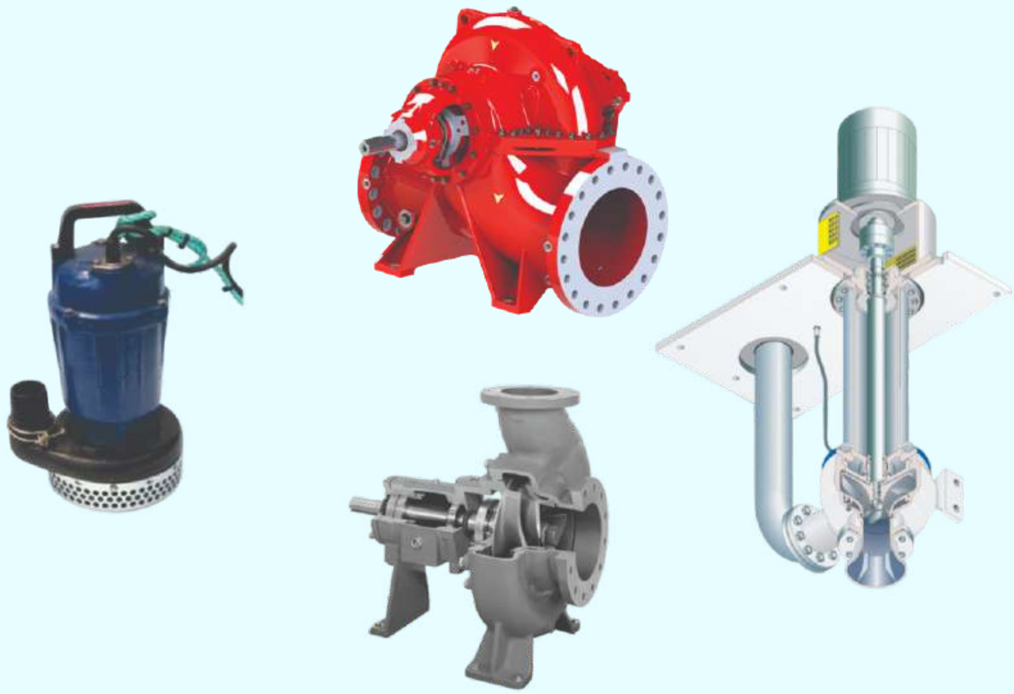
Global Gateway
Funded by
the European Union

UNIDO
UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Project “Accelerating energy efficiency (EE) in large industries through energy management system, system optimisation and the promotion and adoption off EE in SMEs” (IEEP)

TRAINING PROGRAMME
PUMP SYSTEMS OPTIMISATION

Ha Noi, 10 - 11/07/2025



AGENDA

Training on Pump System Optimisation (PSO)
10-11 July 2025

At Adonis Hotel - 55 Quang Trung Street, Hai Ba Trung District, Ha Noi

Day 1: 10 July 2025

Time	Contents	Speakers
8.00-8.30	Registration and welcome	
8.30-8.40	Opening speech	Representative of UNIDO Project Office
8.40-9.00	Introduction	Lecturer
9.00-10.00	**Session 1: Organizing the pump system assessment** - Understanding the assessment process - Defining objectives, scope, and strategy	Lecturer
10.00-10.15	**Tea-break**	
10.15-12.00	**Session 1 (continued):** - Identifying operating conditions and loading to define data collection periods - Reviewing prior audits - Determining energy and operating costs	Lecturer
12.00-13.15	**Lunch at the hotel**	
13.15-15.00	**Session 2: Conducting the assessment** - Planning measurements - Measuring performance and operational data - Establishing baselines	Lecturer
15.00-15.15	**Tea-break**	

15.15-16.45	**Session 2 (continued):** - Identifying and analyzing improvement opportunities - Evaluating system-wide impacts - Implementation factors - Defining assessment targets for gaps	Lecturer

Day 2: 11 July 2025

Time	Contents	Speakers
8.00-8.30	Registration	
8.30-9.30	Q&A and recap of Day 1	Lecturer
9.30-10.00	**Session 3: Data analysis** - Establishing baselines - Conducting technical analysis - Forecasting	Lecturer
10.00-10.15	**Tea-break**	
10.15-12.00	**Session 3 (continued):** - Quantifying performance improvement opportunities - Financial analysis - Defining acceptable economic criteria - Identifying specific opportunities	Lecturer
12.00-13.15	**Lunch at the hotel**	All the class
13.15-15.00	**Session 4: Reporting findings** - Drafting preliminary recommendations - Synthesizing data and preparing report - Describing calculation methods	Lecturer

15.00-15.15	**Tea-break**	
15.15-16.30	**Session 4 (continued):** - Developing actionable recommendations - Preparing optimization projects for management decision-making - Final presentation of recommendations	Lecturer
16:30 – 16:45	Course evaluation and feedback	UNIDO Project Office

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Accelerating energy efficiency (EE) in large industries through energy management system, System optimisation and the promotion and adoption of EE in SMEs -(IEEP project)

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

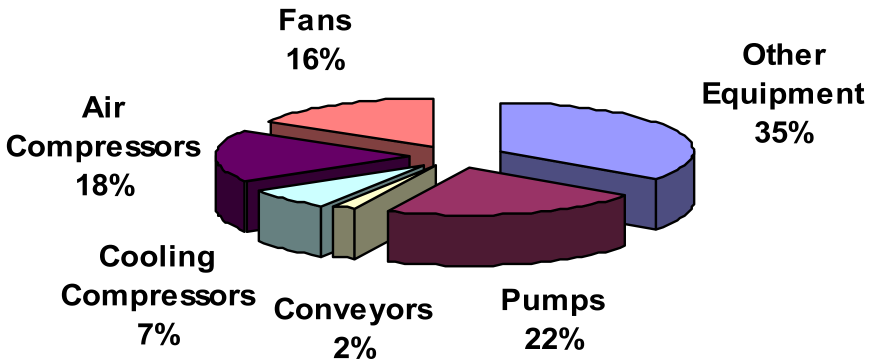
Two Day
End User Pump Systems Optimization Training

Day One

Facilitated by: Harry Rosen

Pump System Optimization

Pump systems account for 22% of the world's electric motor energy demand



What is Pump System Optimization?

- Pump system optimization is a systematic approach to evaluate high energy use pumps to identify energy savings opportunities.

- After prescreening pump systems, potential savings of the selected pumps are determined by measuring, pressure, flow and power in the field. This data is combined with pump system operational data to determine an energy use baseline and the true system requirements.

- The DOE - PSAT software tool can be used to provide a preliminary savings analysis. If there is a good opportunity, a more advanced analysis can be performed to determine the most cost effective improvement for pump system optimization.

Prescreening

The DOE Best Practices Program encourages a three tiered prescreening and assessment approach that includes:

- Initial prescreening based on size, run time and pump type.
- Secondary prescreening to narrow the focus to systems where significant energy saving opportunities are more likely.
- Evaluating the opportunities and quantifying the potential savings.

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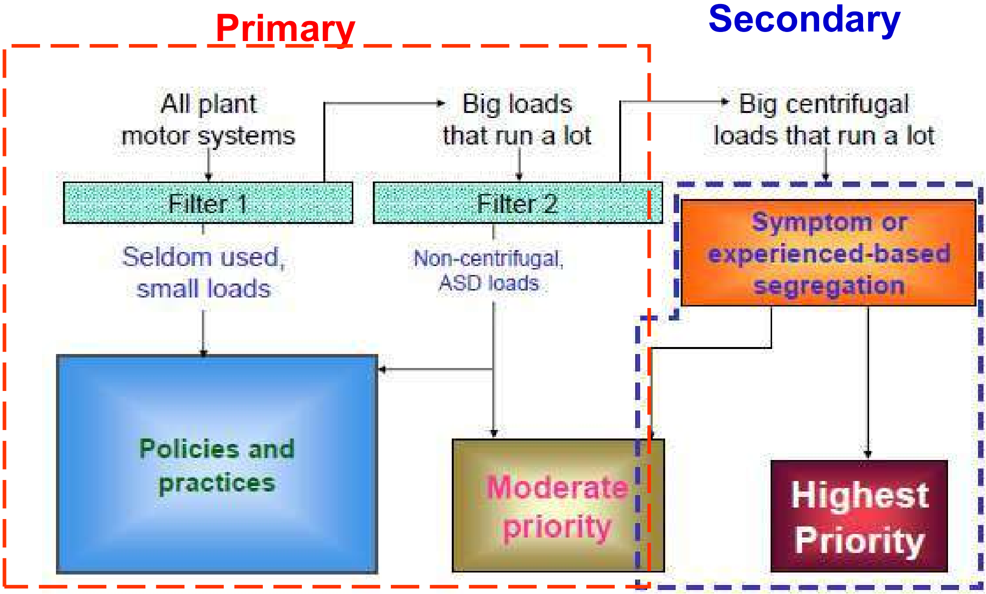
Primary & Secondary Prescreening



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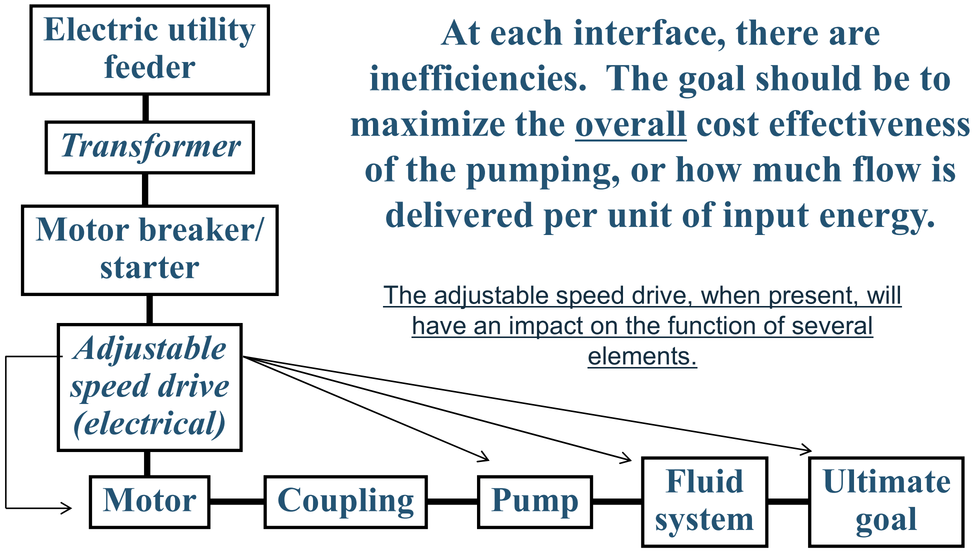
The System



At each interface, there are inefficiencies. The goal should be to maximize the overall cost effectiveness of the pumping, or how much flow is delivered per unit of input energy.

The adjustable speed drive, when present, will have an impact on the function of several elements.

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Power Train & System Components

- **Utility system** - Line losses
- **Transformer** – Efficiencies
- **Breaker/starter** - Types
- **Adjustable speed drive** – advantages & dis-advantages
- **Motor** – Efficiency class and nameplate data
- **Couplings** – Types, advantages & dis-advantages
- **Pump** – Type and application
- **System** – Components and inter relationships
- **Ultimate goal** – System requirement

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It is essential to understand the ultimate goal of the fluid system in order be able to optimize it

- Understand **why** the system exists
- Understand what the pump & system is trying to **do**
- Have clearly defined criteria for what's **really** needed
- Understand what's negotiable and what's not

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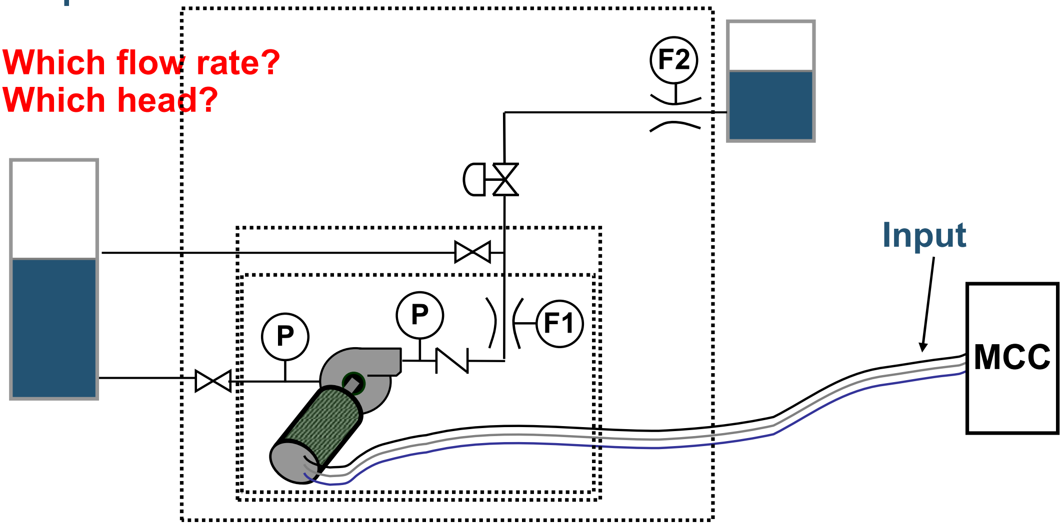
Defining the system

Output = Flow rate * head *constant

Which flow rate?
Which head?



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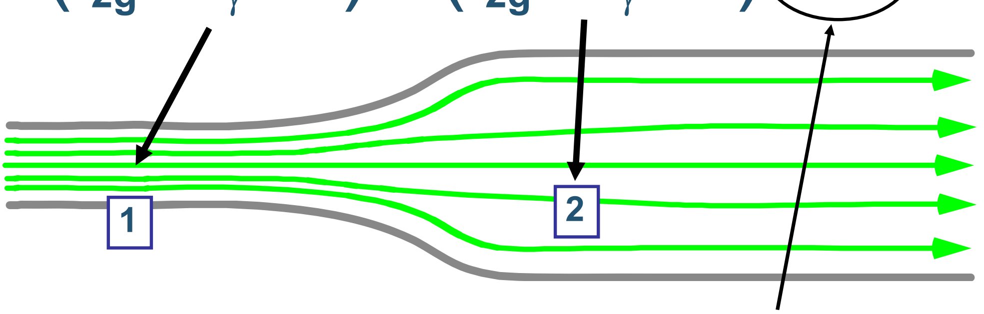
Pump System Fluid Relationships

Bernoulli equation + accounting for friction

$$\left(\frac{V_1^2}{2g} + \frac{P_1}{\gamma} + Z_1\right) = \left(\frac{V_2^2}{2g} + \frac{P_2}{\gamma} + Z_2\right) + H_f$$



Hydraulic energy at point 2 is lower than at point 1 because of the friction loss, so we balance the equation by adding it here

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The ability for pumps to move water is based on the energy contained in a mass of water

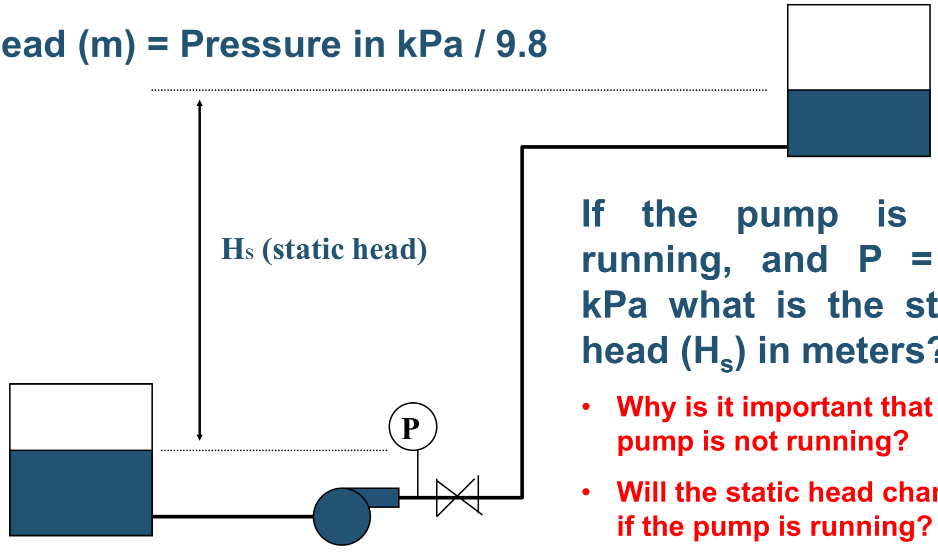
- Pump output is measured in meters of head. The three common terms used to express this energy in water is:
  - Elevation / Pressure Head (Static Head or H_s)
  - Velocity Head (H_v)
  - Head loss due to Frictional Losses (H_f)

Total Head (TDH) = $H_s + H_v + H_f$

- This means that the head created by the pump is used to **overcome friction, lift the fluid** and to create **kinetic energy** in the fluid

Using a simple pump system, what is the elevation / pressure head (or static head)?

Head (m) = Pressure in kPa / 9.8



If the pump is not running, and P = 98 kPa what is the static head (H_s) in meters?

- **Why is it important that the pump is not running?**
- **Will the static head change if the pump is running?**

Velocity head

Velocity head (H_v) is the amount of energy required to cause the water to move at a given velocity. This is represented by the following relationship:

$H_v = V^2/2g$ V = the velocity in meters/second

g = the acceleration due to gravity (9.8 m/sec^2)

To determine velocity, the following equation can be used:

$V = Q/A$ Q = flow in m^3/sec

A = the area of the pipe in m^2

Velocity head is usually below 0.5 m and can often be considered minimal for many water pumping systems

Head loss due to piping frictional losses

- Frictional Head loss (H_f) is the loss of energy due to the friction of the piping materials and is expressed in meters of head. This can be determined theoretically (Darcy-Weissbach equation)
- H_f can be determined more accurately in the field using actual pressure measurements

The equation below is very useful to understand what parameters influence *frictional* losses in piping:

H_f = pressure drop due to friction
f = Darcy friction factor
L = pipe length
d = pipe diameter
$\frac{V^2}{2g}$ = velocity head

$$H_f = f \cdot \frac{L}{d} \cdot \frac{V^2}{2g}$$

Pipe Diameter vs Pipe Friction loss

$$H_f = f \cdot \frac{L}{d} \cdot \frac{V^2}{2g}$$

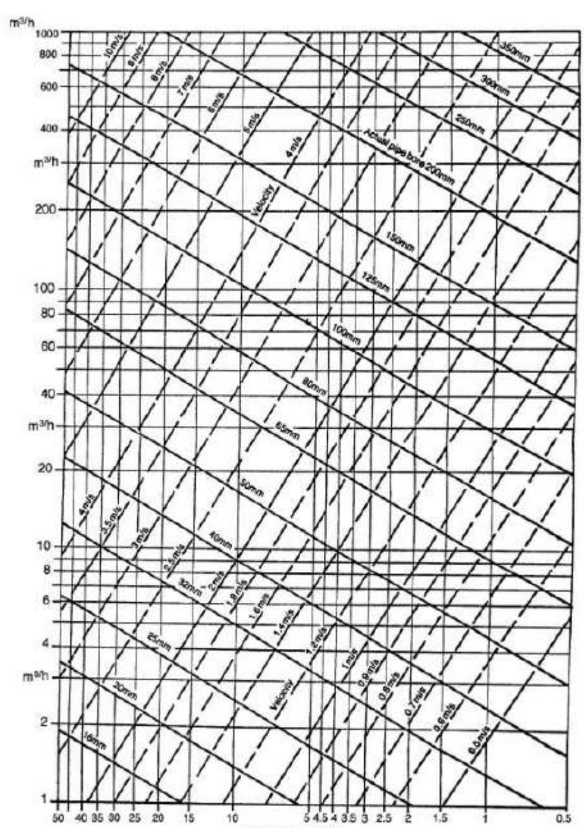
$$V = \frac{Q}{A} = \frac{Q}{\pi D^2/4}$$

$V \approx 1 / D^2$

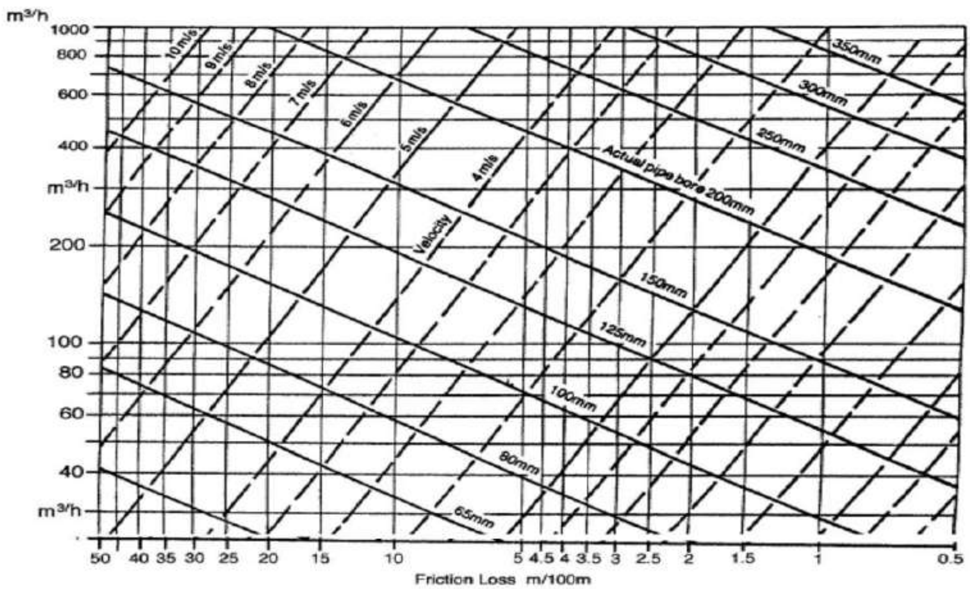
$V^2 \approx 1 / D^4$

$Hf \approx 1/ D^5$

Pipe Diameter vs Pipe Friction loss



Pipe Diameter vs Pipe Friction loss



Sources of friction for piping components

- Valves
- Elbows
- Tees
- Reducers/expanders
- Expansion joints
- Tank inlets/outlets

$$H_f = K \cdot \frac{V^2}{2g}$$

K = Loss coefficient

$\frac{V^2}{2g}$ = velocity head

For pipe components, frictional losses have generally been estimated based on the velocity head.

K is a function of size, and for valves, the valve type, and valve % open.

Some typical K values for miscellaneous pipe components:

Component	Component K
90˚ elbow, standard	0.2 - 0.3
90˚ elbow, long radius	< 0.1 - 0.3
Square-edged inlet (from tank)	0.5
Discharge into tank	1
Check valve	2
Gate valve (full open)	0.03 - 0.2
Globe valve (full open)	3 - 8
Butterfly valve (full open)	0.5 - 2
Ball valve (full open)	0.04 - 0.1

System Curves

System head curve for all frictional system

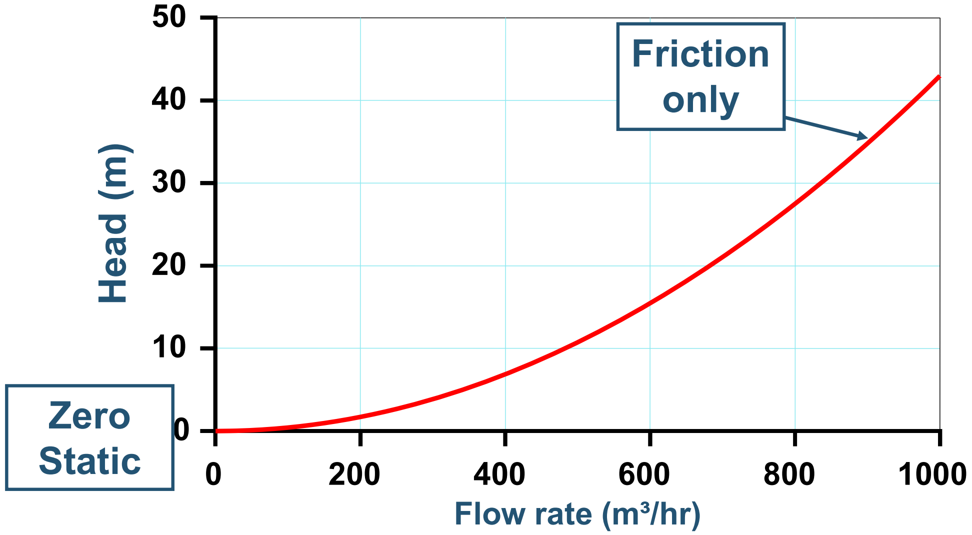
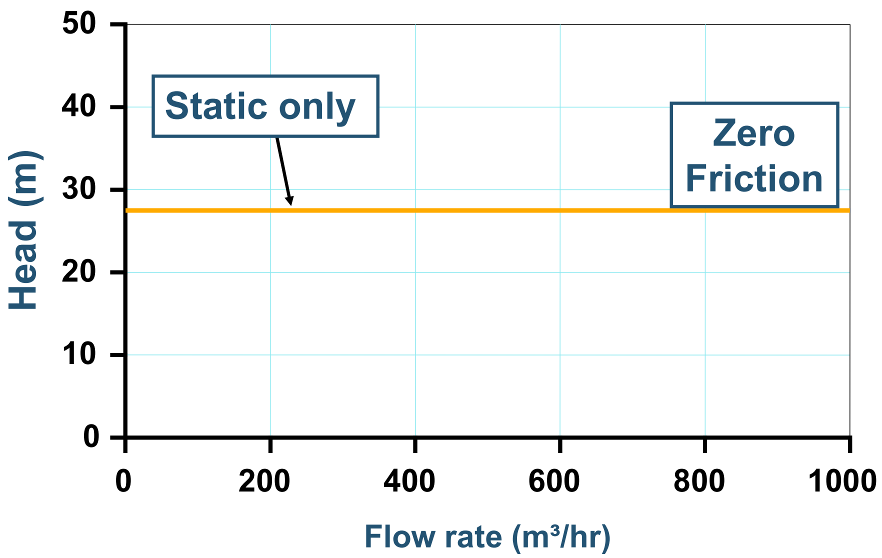


Figure Courtesy of Oak Ridge National Laboratory

System head curve for all static system



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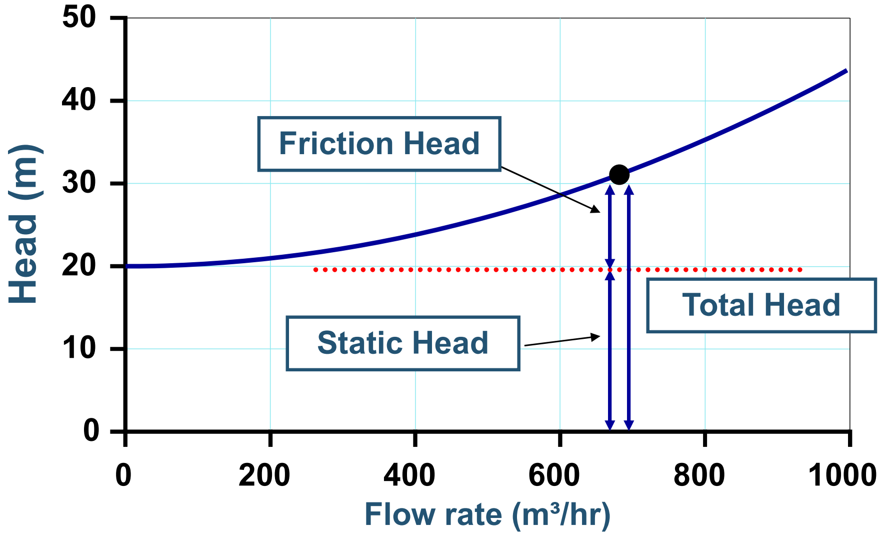
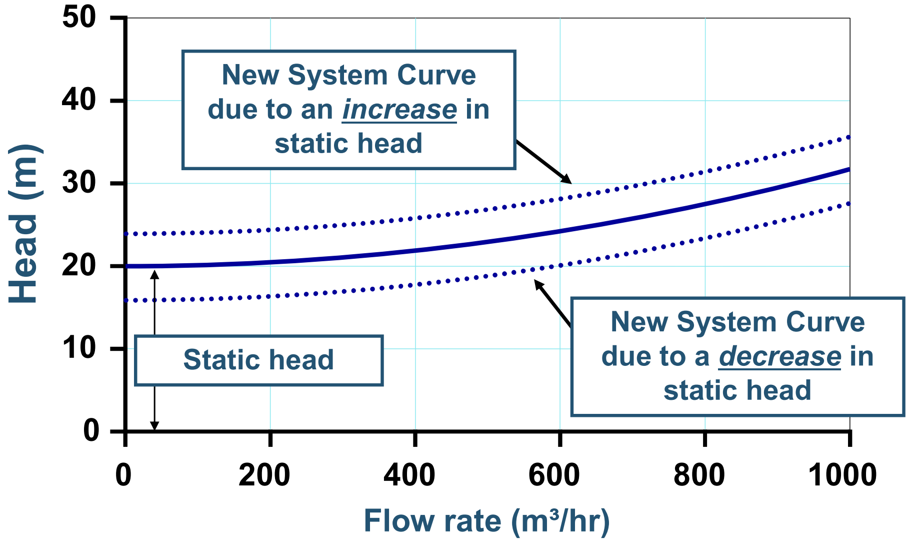
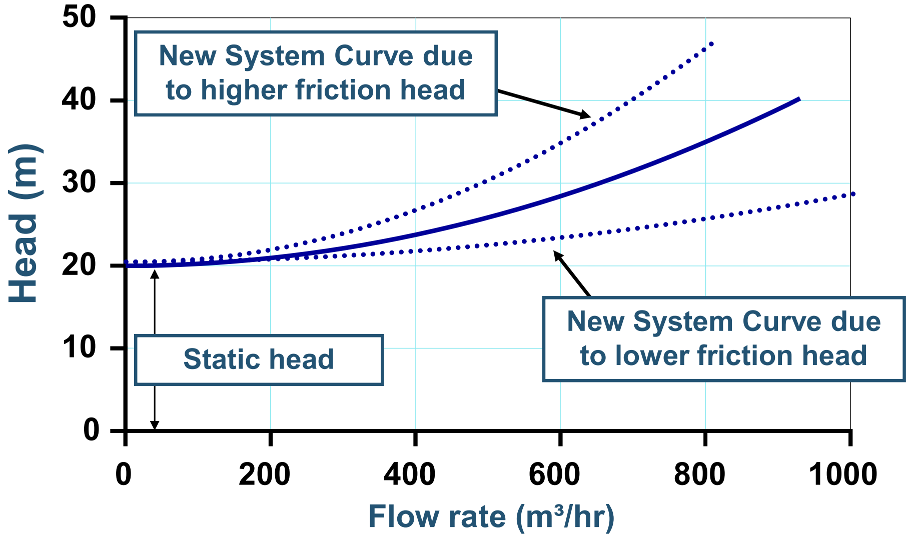
System head curve for combined static and frictional system



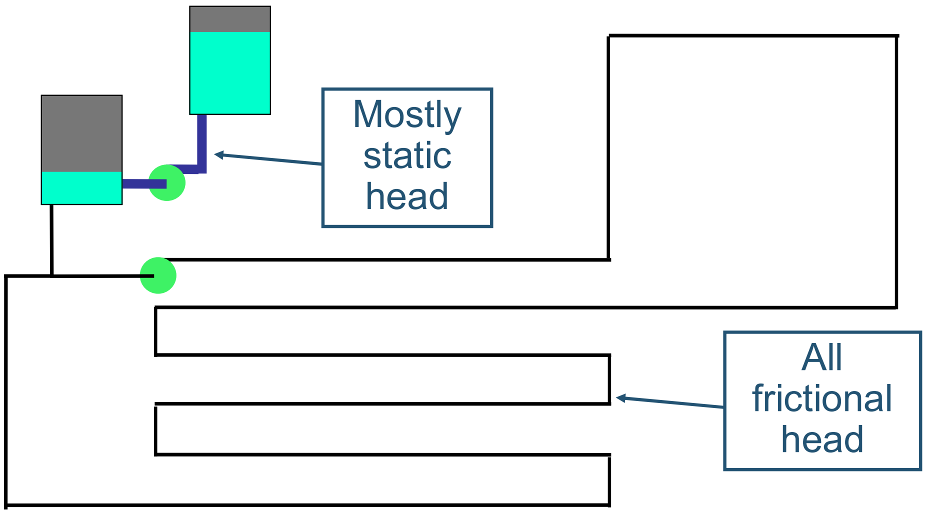
The effect on the system head curve when the static head changes



The effect on the system head curve when system friction changes

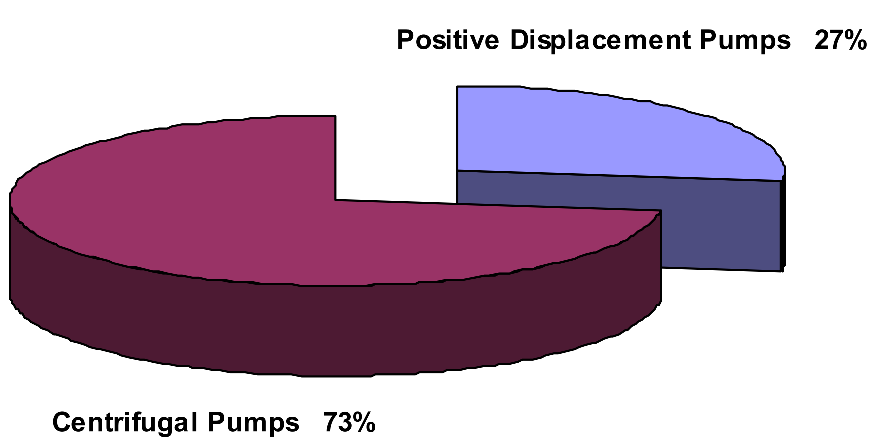


Two types of pump systems



Pump Types

Centrifugal pump systems account for 73% of pump system energy consumption



Pump types

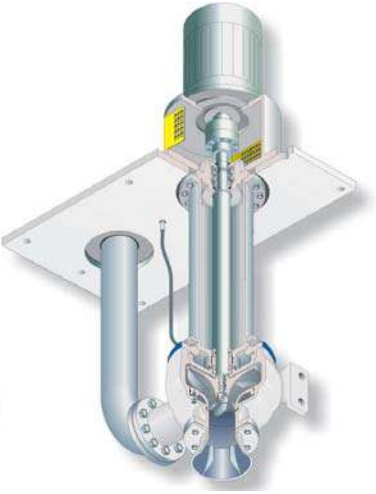
- **Pump Types**
  - **Roto-Dynamic Pumps (Centrifugal)**
    - Split Case
    - Vertical Turbine
    - Special Pumps
      - Jet Pumps
      - Vortex Pumps
      - Regenerative turbines
  - **Displacement Pumps**
    - Reciprocating
      - Piston
      - Diaphragm
    - Rotary
      - Peristaltic
      - Progressive Cavity
      - Multiple Gear-Lobe

Centrifugal Pump Types

Split Case

Submersible

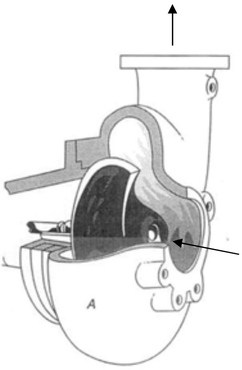
End Suction



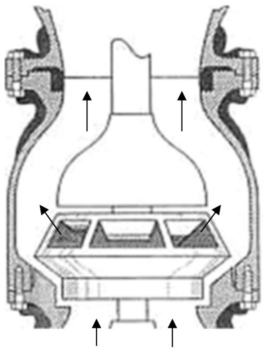
Vertical line shaft

Centrifugal pump flow

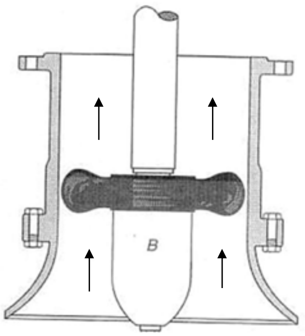
Common centrifugal pump flow configurations:



Radial Flow



Mixed Flow



Axial Flow

Centrifugal Impellers

Centrifugal impeller types:

Semi-Open

Open

Closed

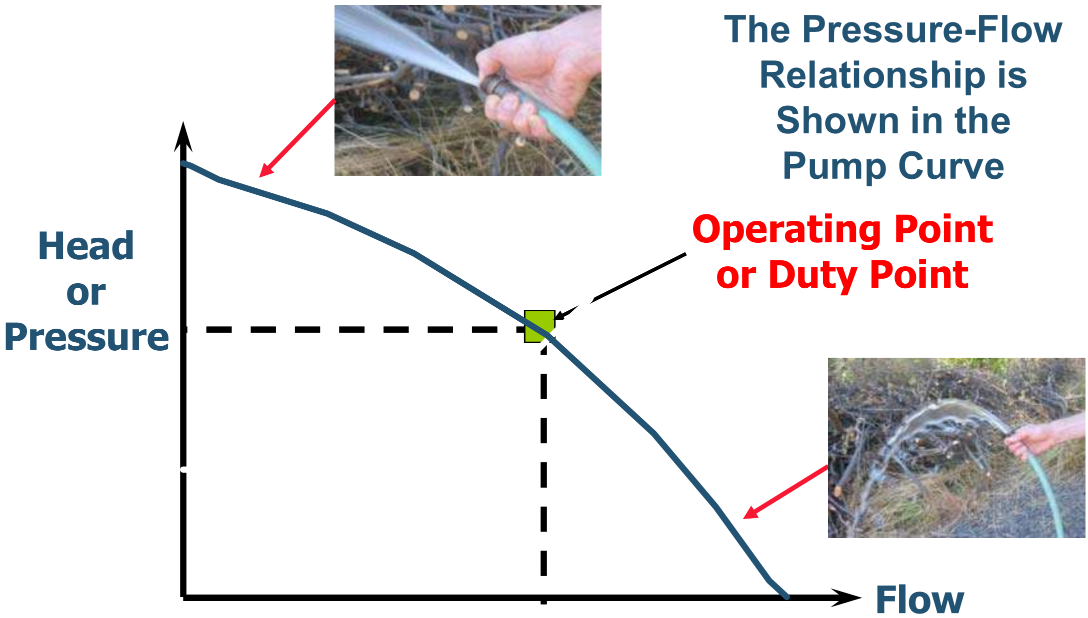
Pump Performance Characteristics

The Pressure-Flow Relationship

- A pump adds **energy** to a fluid
- Pumping increases pressure(energy) in the fluid
- Pumps deliver: ***high pressure / low flow*** or ***high flow / low pressure*** (and everything in between)
- Reliability and energy use are highly dependent on **Operating Point** of the pump

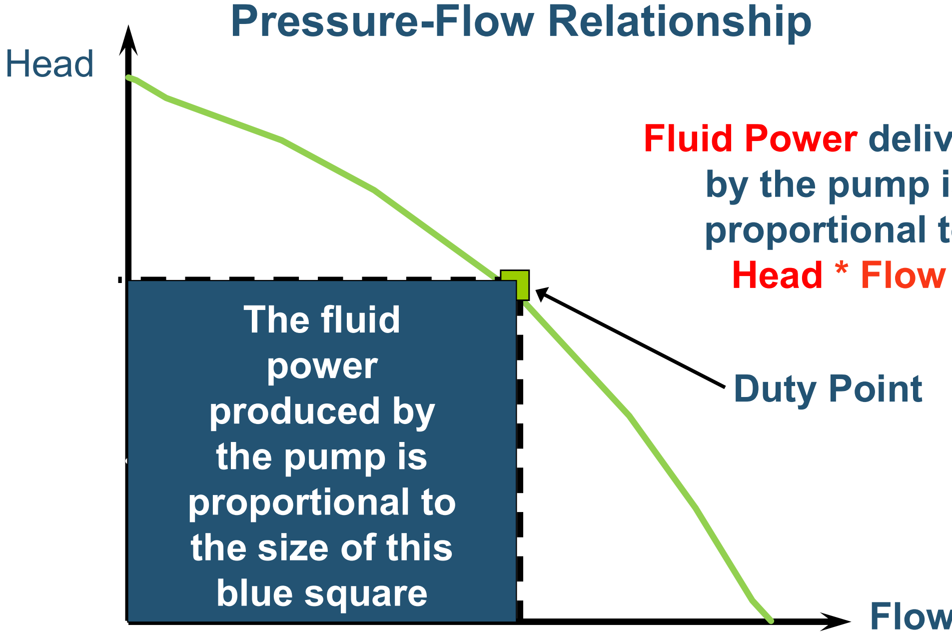
Pumping Pressure-Flow Relationship

The Pressure-Flow Relationship is Shown in the Pump Curve

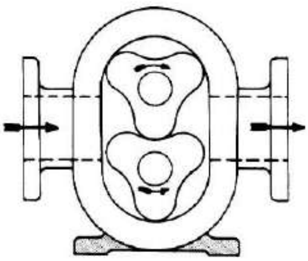


Fluid Power Output of a pump Pressure-Flow Relationship

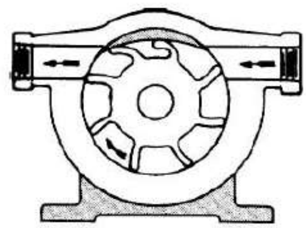
Fluid Power delivered by the pump is proportional to **Head * Flow**



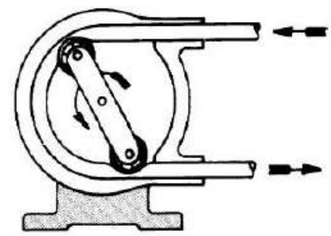
Examples of displacement pump types



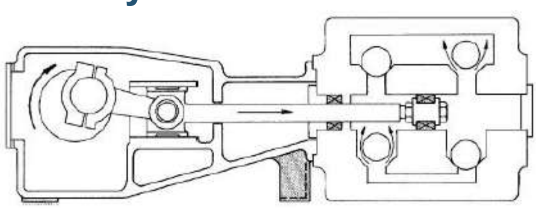
Rotary Lobe



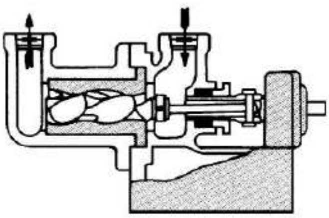
Flexible Vane



Flexible Tube



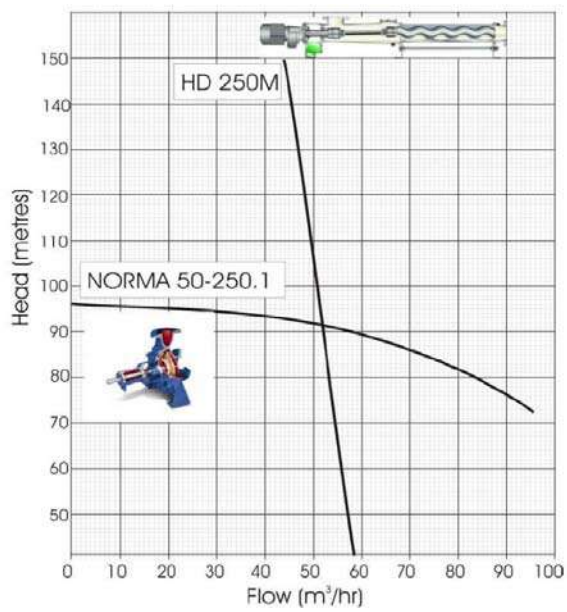
Horizontal Piston



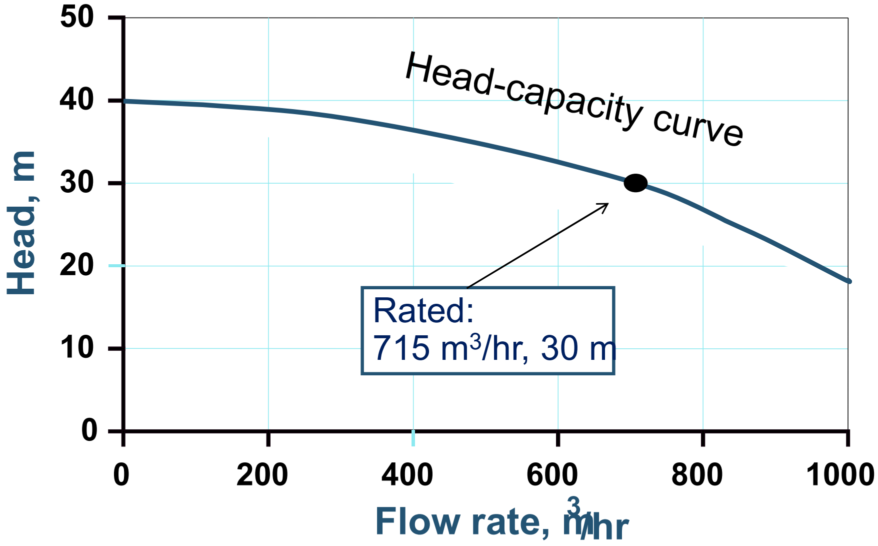
Screw Pump

Centrifugal Pumps vs Positive Displacement Pumps

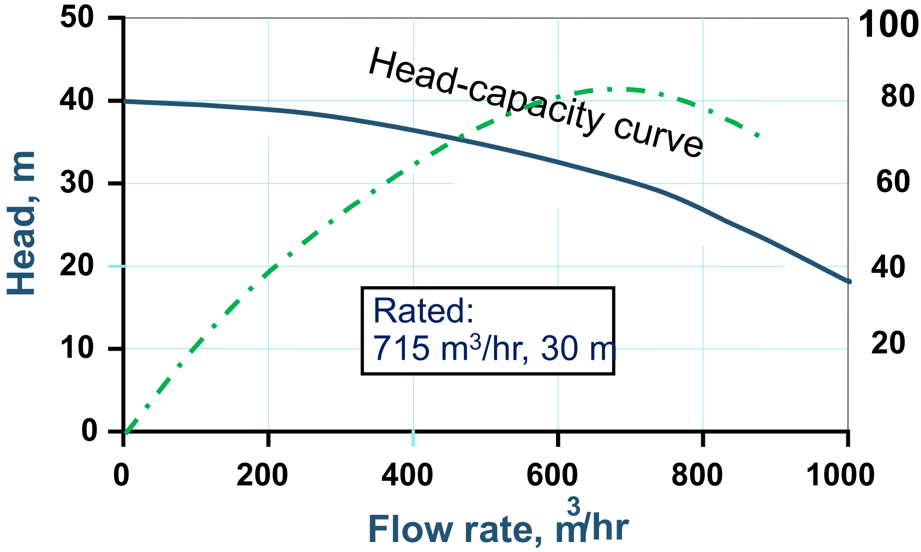
Positive Displacement pump curve superimposed on the same set of axes as Centrifugal pumps



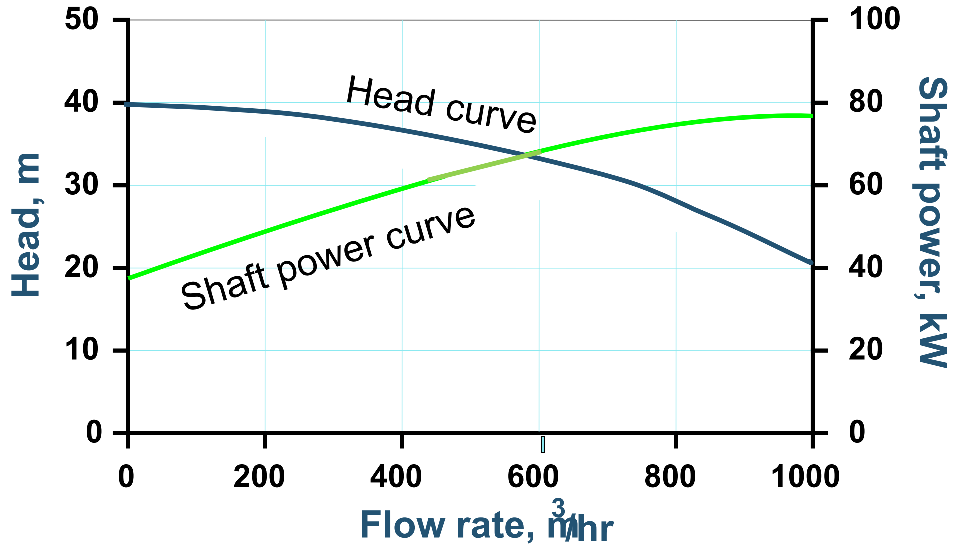
Nameplate data applies to one particular operating point



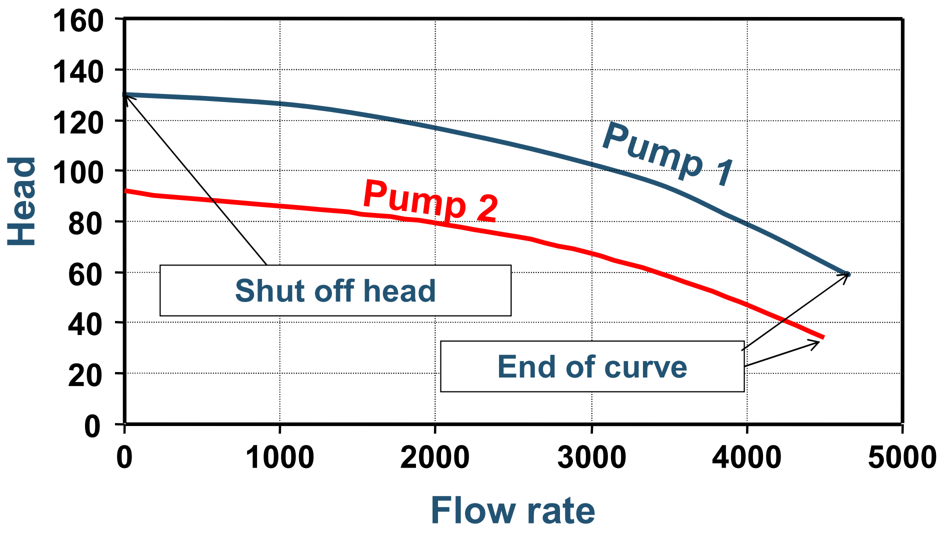
Efficiency added to the pump curve



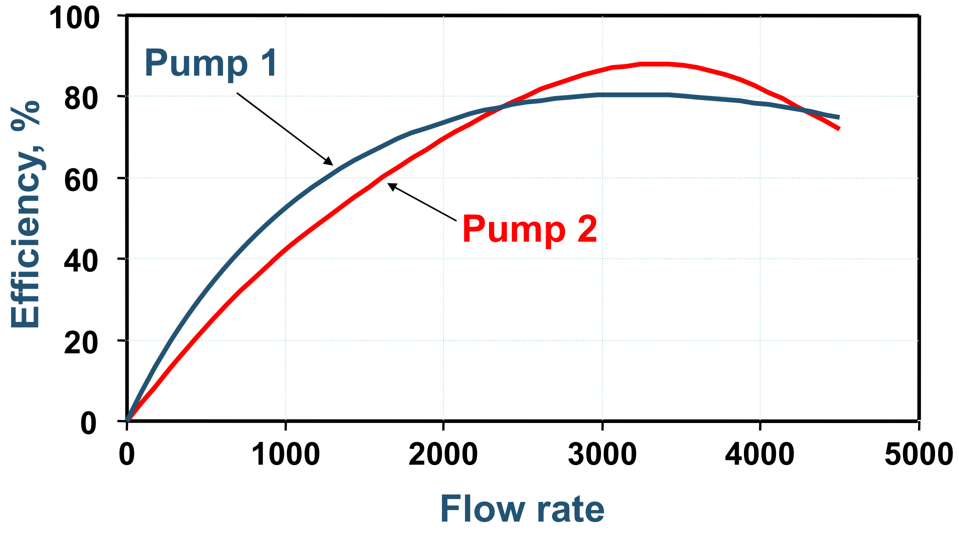
Another characteristic curve of interest is the shaft power as a function of flow rate



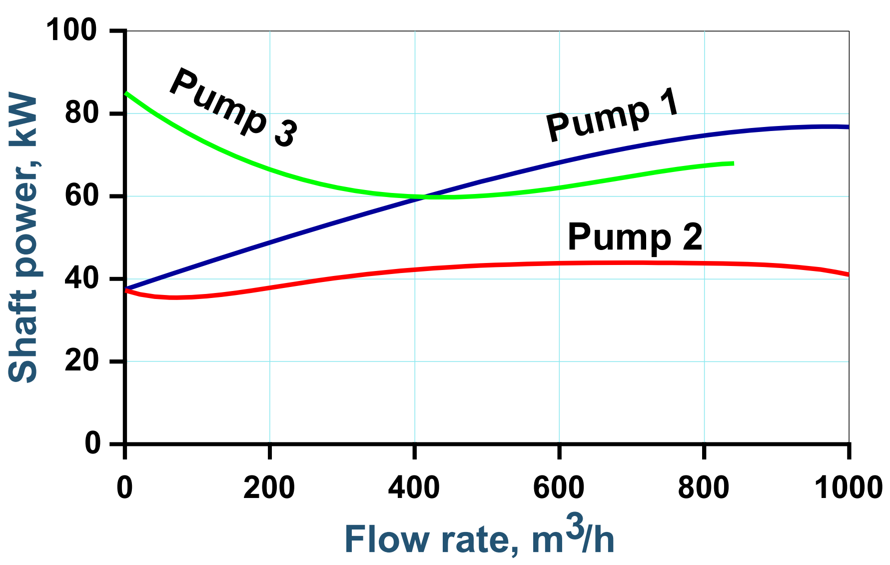
Pump curve shapes vary: Head curves for two pump designs



And finally, efficiency curves for the two pumps



Different motor loads for different types of centrifugal pumps



Affinity Laws

Pump **Affinity Laws** can be used to predict pump curves for different speeds and impeller diameters

Speed

$$\left(\frac{Q_1}{Q_2}\right) = \left(\frac{N_1}{N_2}\right)^1$$

$$\left(\frac{H_1}{H_2}\right) = \left(\frac{N_1}{N_2}\right)^2$$

$$\left(\frac{P_1}{P_2}\right) = \left(\frac{N_1}{N_2}\right)^3$$

Diameter

$$\left(\frac{Q_1}{Q_2}\right) = \left(\frac{D_1}{D_2}\right)^1$$

$$\left(\frac{H_1}{H_2}\right) = \left(\frac{D_1}{D_2}\right)^2$$

$$\left(\frac{P_1}{P_2}\right) = \left(\frac{D_1}{D_2}\right)^3$$

Q = flow rate; H = head; P = power; N = speed; D = diameter

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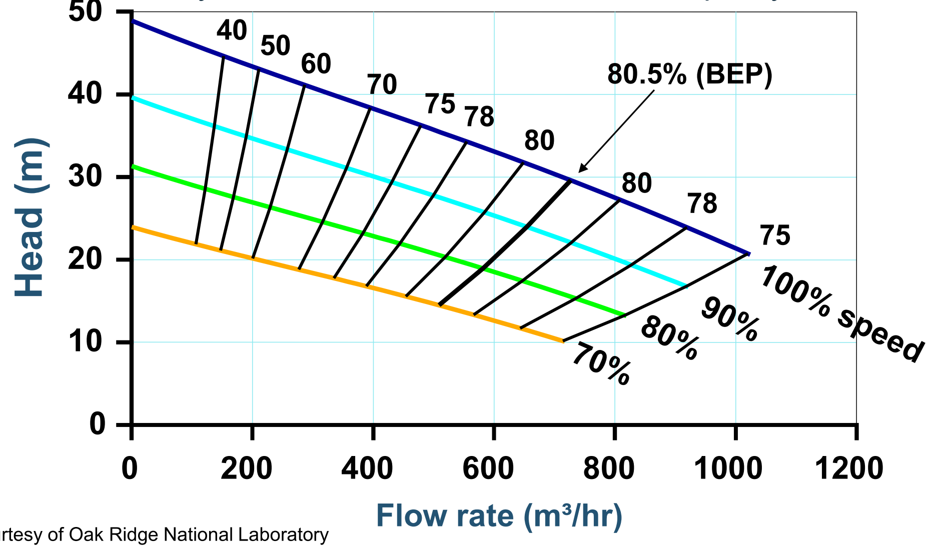
For speed changes, the efficiency lines follow the affinity laws

Iso-efficiency lines can be overlaid onto head-capacity curves



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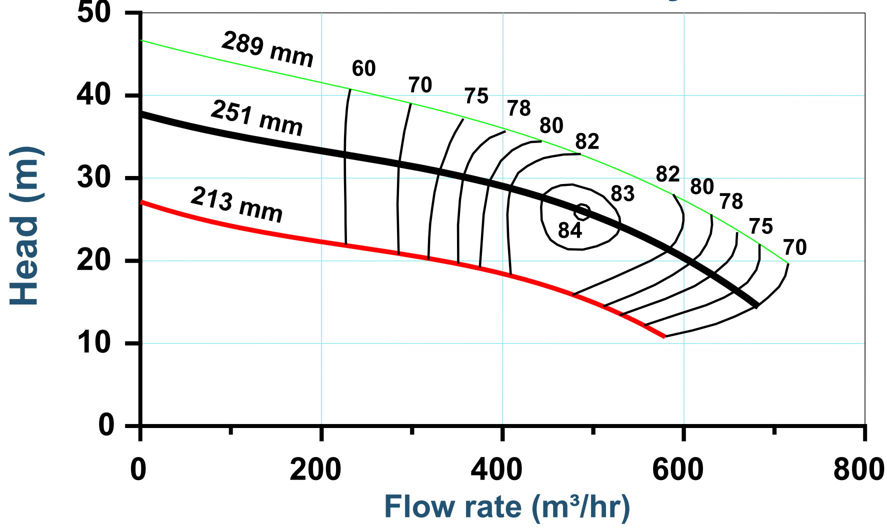
For multiple impeller diameters, the efficiency lines *do not* follow the affinity laws



(In most cases the 251mm impeller would be the largest)

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Considerations for Affinity Laws

- It's fine to use the affinity laws to explore the possibilities with impeller trimming for better pump and system matching, but don't get carried away. Get **actual** performance curves from the manufacturer, especially if the trim change being considered is large.

- The affinity laws will generally ***not tell you*** where on the curve the pump will operate or give you correct estimates of possible energy savings, *except for systems* ***without static head***

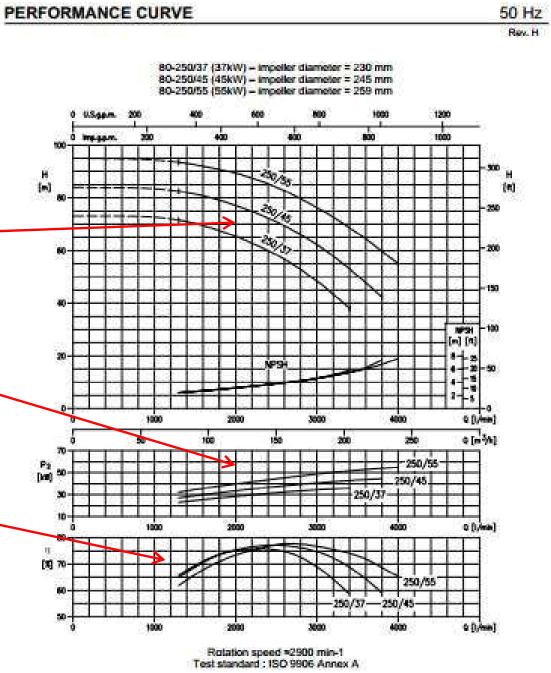
Pump Selection

Manufacturers set of pump curves

Performance curves for different impeller sizes

Power curves for different impeller sizes

Efficiency curves for different impeller sizes



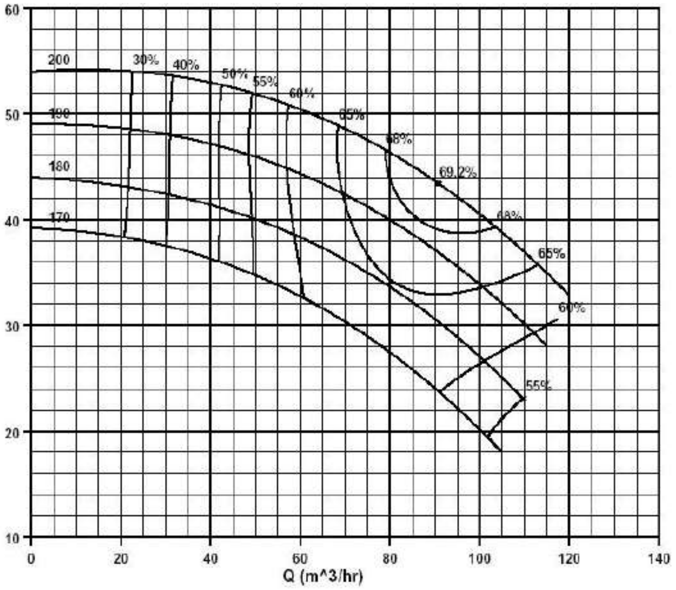
Affinity Laws : Impeller Trims

- ✓ Family of pump curves with varying impeller diameters and constant pump speed.

- ✓ $$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$$

$$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2$$

$$\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^3$$



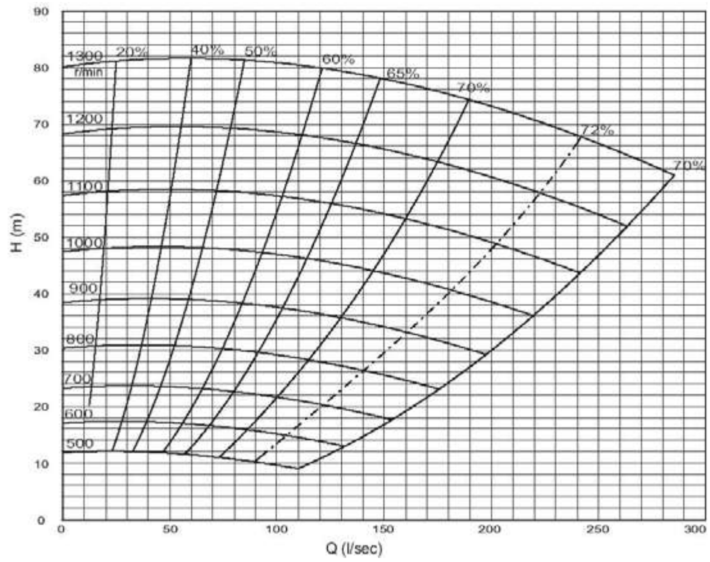
Affinity Laws : Variable Speed Pumps

Family of pump curves with varying pump speed and constant impeller diameter.

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$



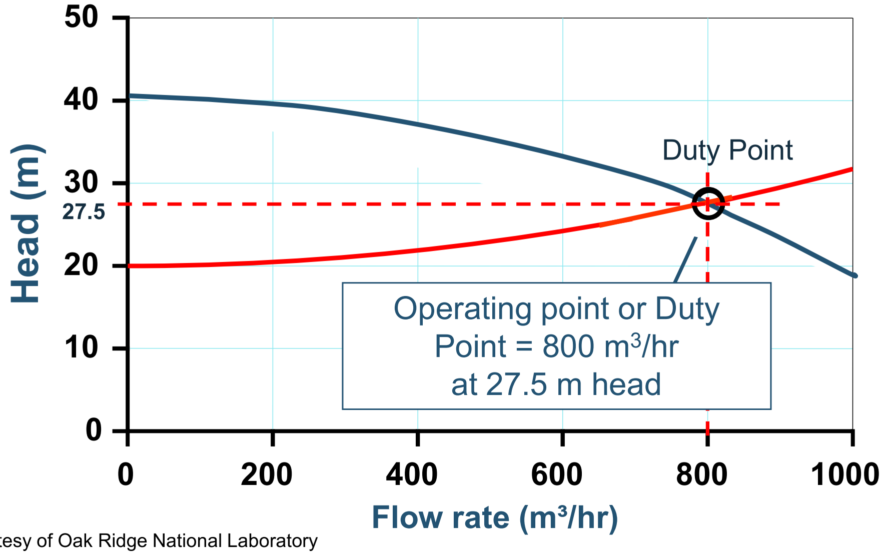
Pump Systems

Now let's hook a pump up to a system

Pump Operating Point

The pump will **always** operate where the system and pump curves intersect since at that point we have balance between what the system demands and what the pump can deliver

The intersection between the pump and system head capacity curves defines the operating point



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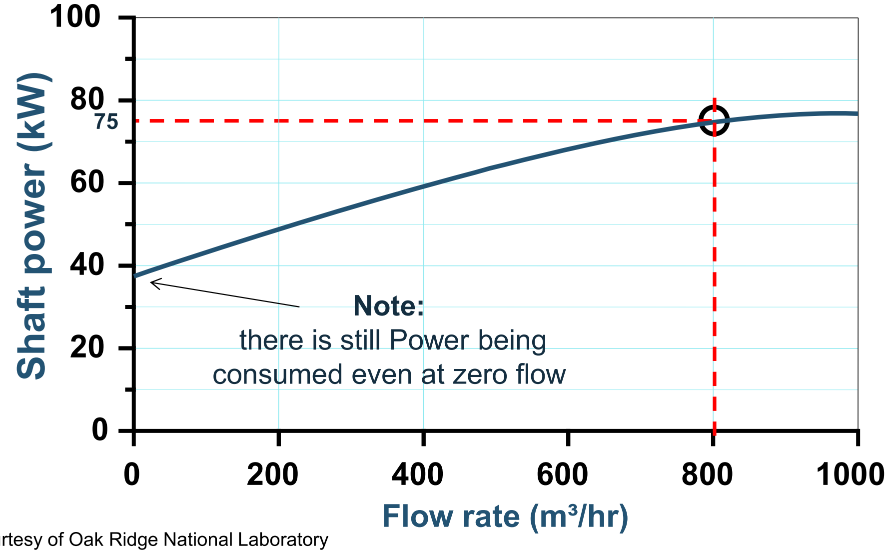
The *shaft power* curve for this pump indicates that the power at 800 m3/hr is about 75 kW



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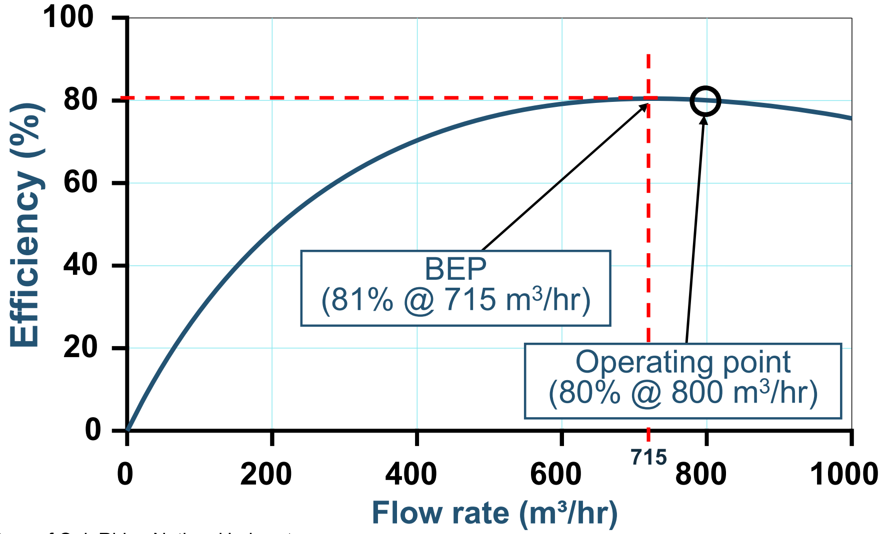
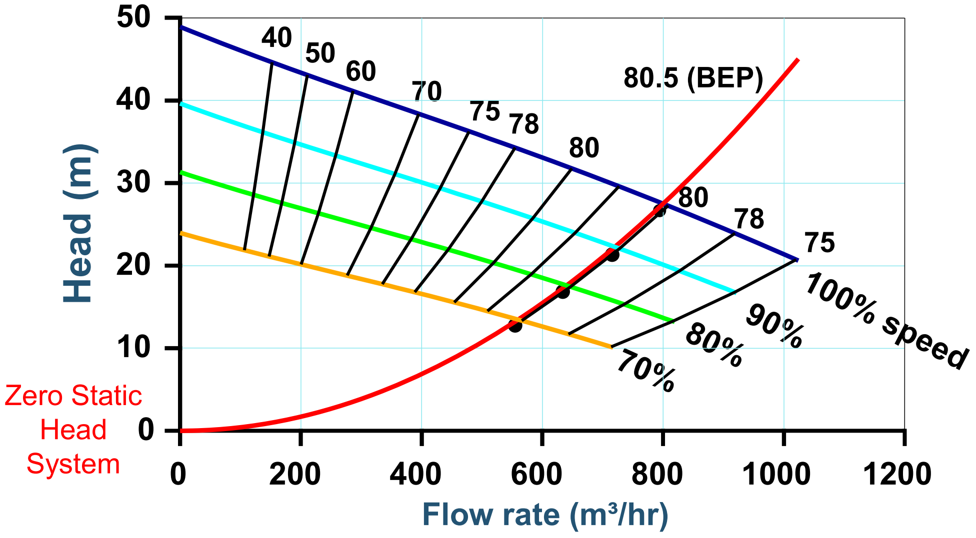
The operating point at slightly greater than the pump best efficiency point (BEP) flow rate



Slide Courtesy of Oak Ridge National Laboratory

Operating a pump at a reduced flow rate, with three different system curves

Change in speed for the All Frictional system results in maintenance of constant pump efficiency



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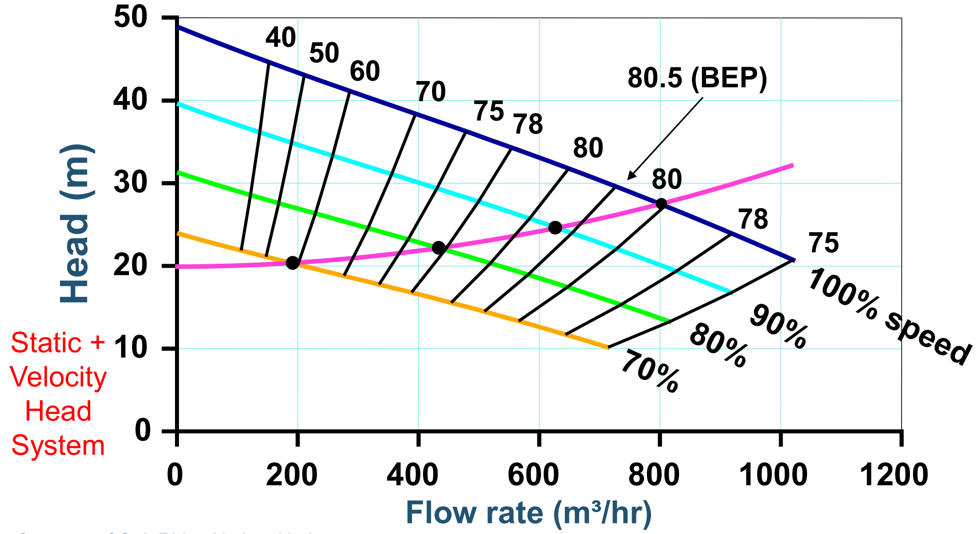
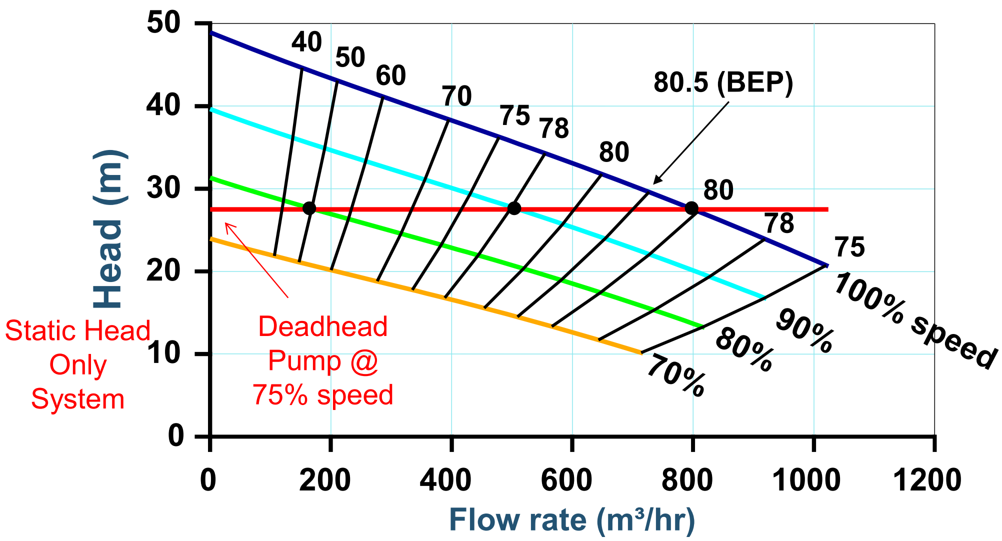
In a system with Static & Velocity head, pump efficiency does not remain fixed as speed changes



Slide Courtesy of Oak Ridge National Laboratory

In a system with *ONLY* Static Head, the effect is even more dramatic



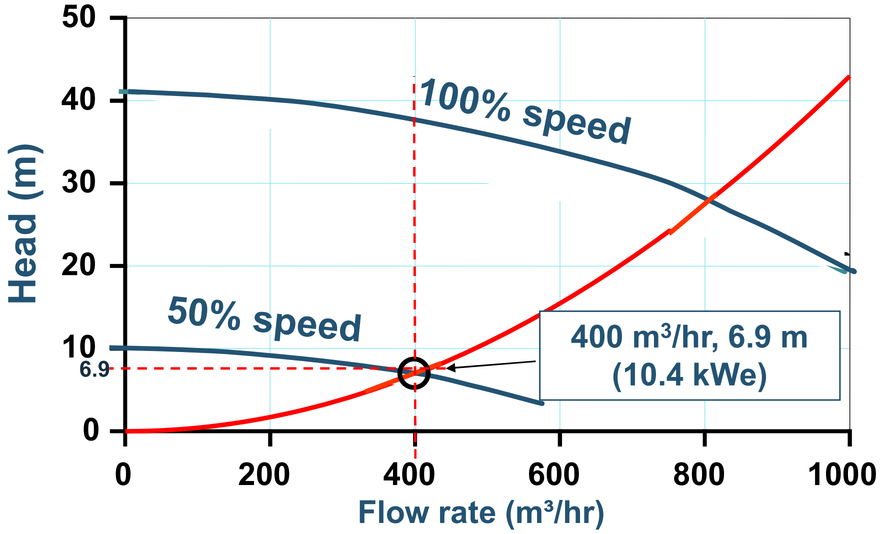
Slide Courtesy of Oak Ridge National Laboratory

Let's pick a second flow condition for our system:

Flow = 400 m³/hr

(half the original requirement)

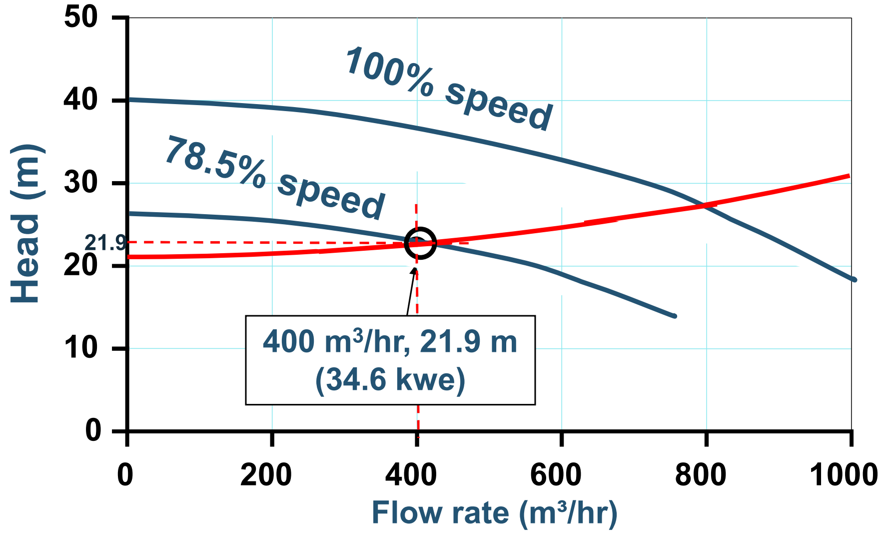
To develop 400 m³/hr in the *all Frictional* system speed is reduced to 50% of the original



Note:
Efficiency remains constant for zero static system

Slide Courtesy of Oak Ridge National Laboratory

To develop 400 m3/hr in the *mixed Static/Frictional* system, speed is reduced to 78.5% of the original



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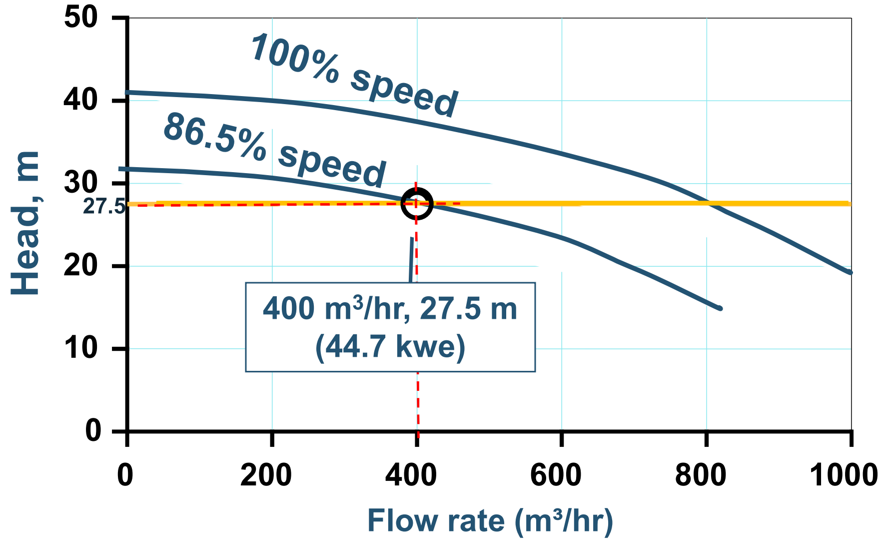
To develop 400 m³/hr in the *all Static Head* system speed is reduced to 86.5% of the original



Slide Courtesy of Oak Ridge National Laboratory

Specific Energy Es

- The amount of energy needed to pump one unit volume through the system.

- The Specific Energy varies with flow-rate.

Some Basic Equations

Fluid Power = Head (m) x Flow (m^3/sec) x specific gravity x 9.8

$$\frac{Energy\ used}{Pumped\ Volume} = Specific\ Energy$$

$$E_s = \frac{P_{in} \cdot Time}{V} = \frac{P_{in}}{Q}$$

The power and ratio of volume per unit energy or energy per unit volume

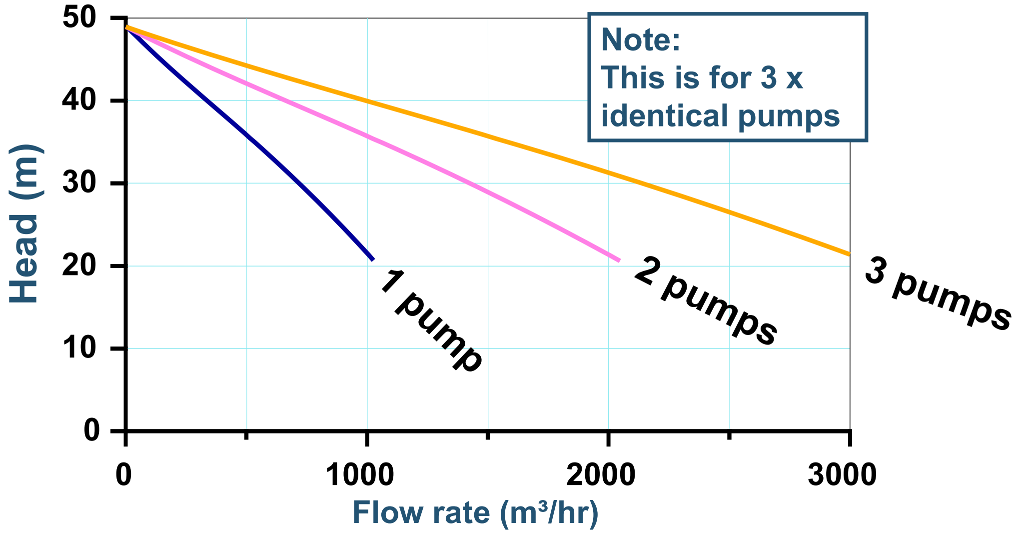
Static Head (m)	m^3/h	Speed (%)	Power (kW)	m^3/kWh	Es= kWh/m^3
0	800	100	79.5	10.1	0.099
0	400	50.0	10.4	38.5	0.026
20	800	100	79.5	10.1	0.099
20	400	78.5	34.6	11.6	0.087
27.5	800	100	79.5	10.1	**0.099**
27.5	400	86.5	44.7	8.9	**0.112**

Note: 1) the power values for the 800 m^3/hr assume the motor being driven directly (ASD bypassed)
2) The **increase** in **kWh/m^3** at 27.5 m

Pump Combinations

Parallel & Series

Parallel pumps can help adapt to changing system requirements and provide redundancy



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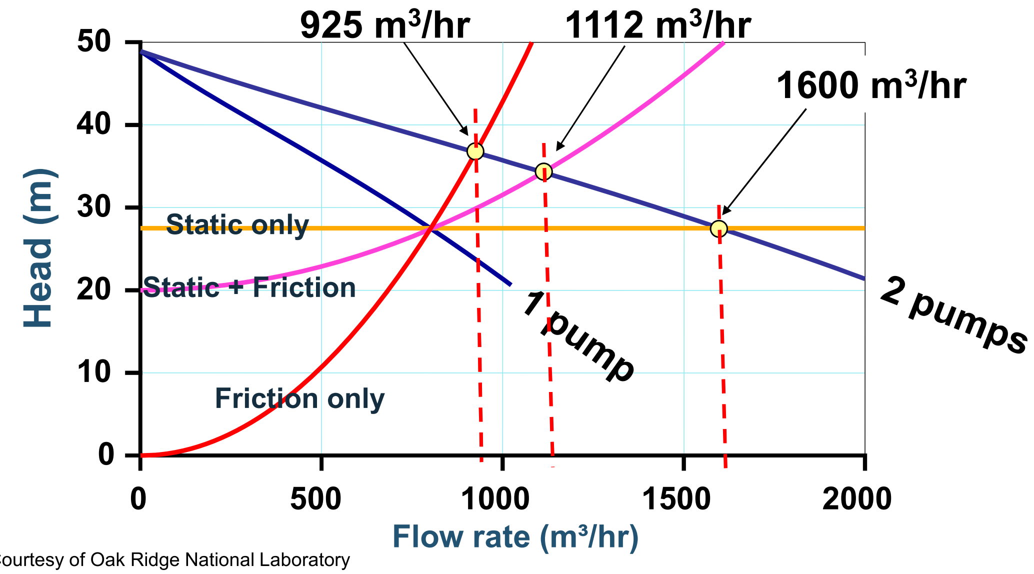
The effect of turning on a parallel pump also depends on the *nature* of the system



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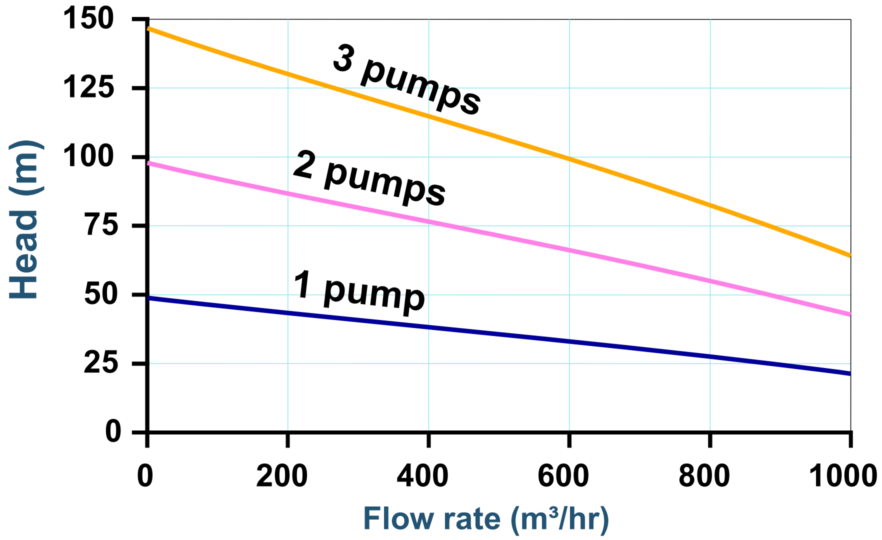
Identical pumps in series; add head at a given flow rate to estimate overall performance



Slide Courtesy of Oak Ridge National Laboratory

Pump affinity laws can be used to predict pump curves for different speeds and impeller diameters

Speed

$$\left(\frac{Q_1}{Q_2}\right) = \left(\frac{N_1}{N_2}\right)^1$$

$$\left(\frac{H_1}{H_2}\right) = \left(\frac{N_1}{N_2}\right)^2$$

$$\left(\frac{P_1}{P_2}\right) = \left(\frac{N_1}{N_2}\right)^3$$

Diameter

$$\left(\frac{Q_1}{Q_2}\right) = \left(\frac{D_1}{D_2}\right)^1$$

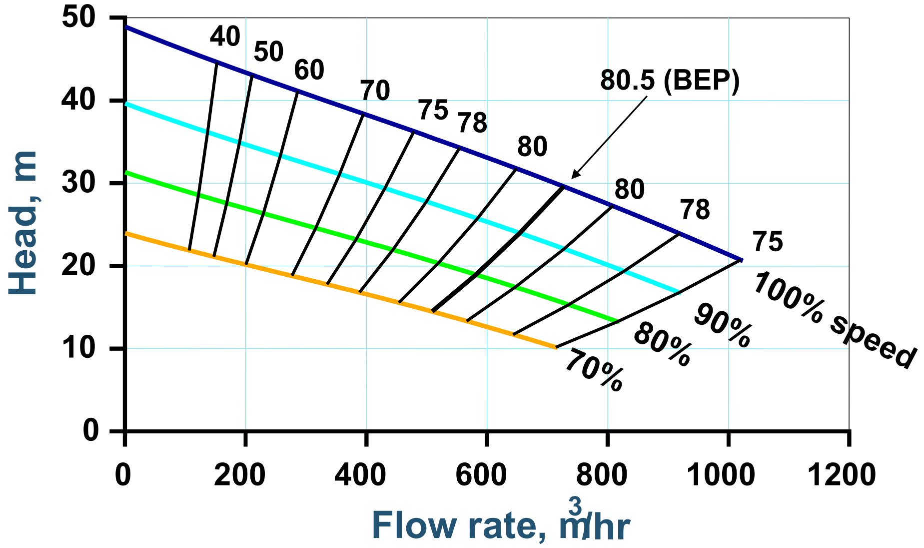
$$\left(\frac{H_1}{H_2}\right) = \left(\frac{D_1}{D_2}\right)^2$$

$$\left(\frac{P_1}{P_2}\right) = \left(\frac{D_1}{D_2}\right)^3$$

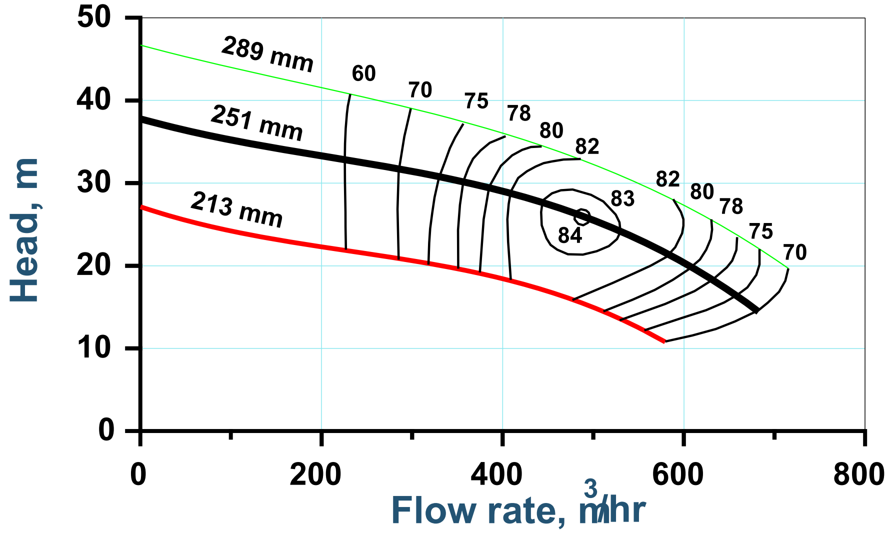
Q = flow rate H = head P = power N = speed D = diameter

For speed changes, the efficiency lines follow the affinity laws

Iso-efficiency lines can be overlaid onto head-capacity curves



For multiple impeller diameters, the efficiency lines do not follow the affinity laws



(In most cases the 251mm impeller would be the largest)

Considerations for Affinity Laws

- It's fine to use the affinity laws to explore the possibilities with impeller trimming for better pump and system matching, but don't get carried away. Get actual performance curves from the manufacturer, especially if the trim change being considered is large.

- The affinity laws will generally not tell you where on the curve the pump will operate or give you correct estimates of possible energy savings, except for systems without static head

System Demand

(Some system requirements vary in time)

Examples:

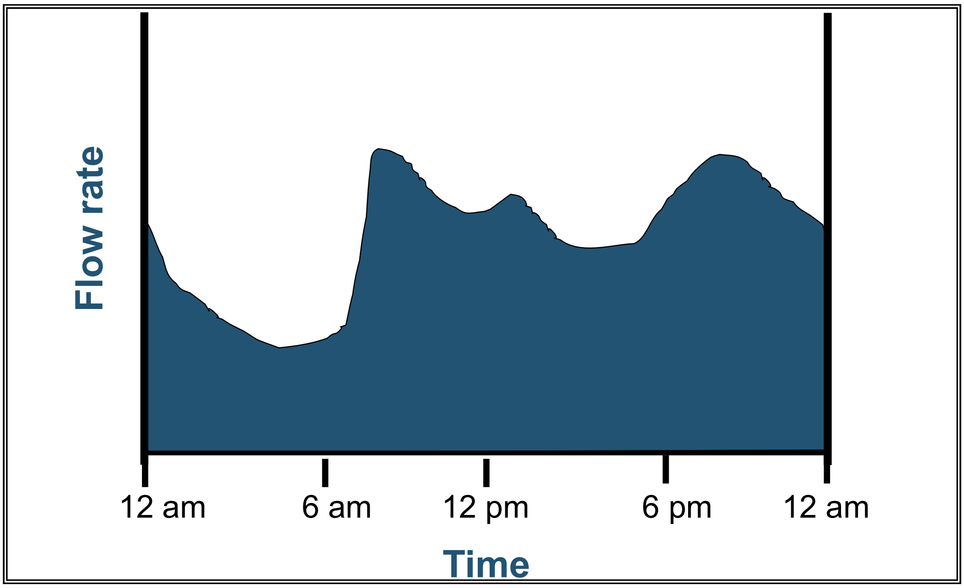
- Seasonal loads (chilled water, associated tower water, etc).
- Industrial processes with variable output
- Potable and waste-water, large daily variations

Design parameters vs. actual operating conditions

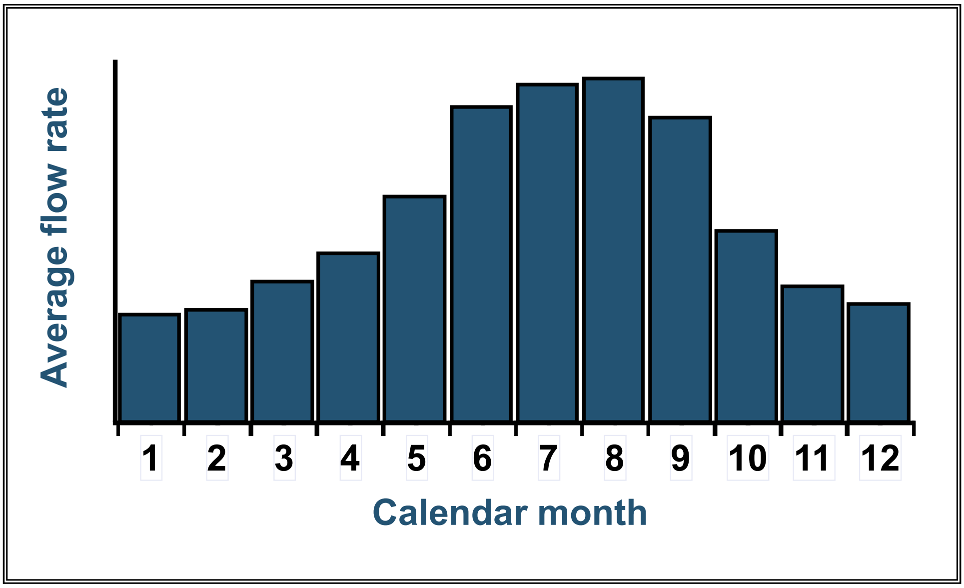
- Centrifugal pumps and fans are typically designed to handle peak flow/volume requirements that typically occur for only short periods.

- As a result, they frequently operate at reduced flows/volumes, often by being throttled.

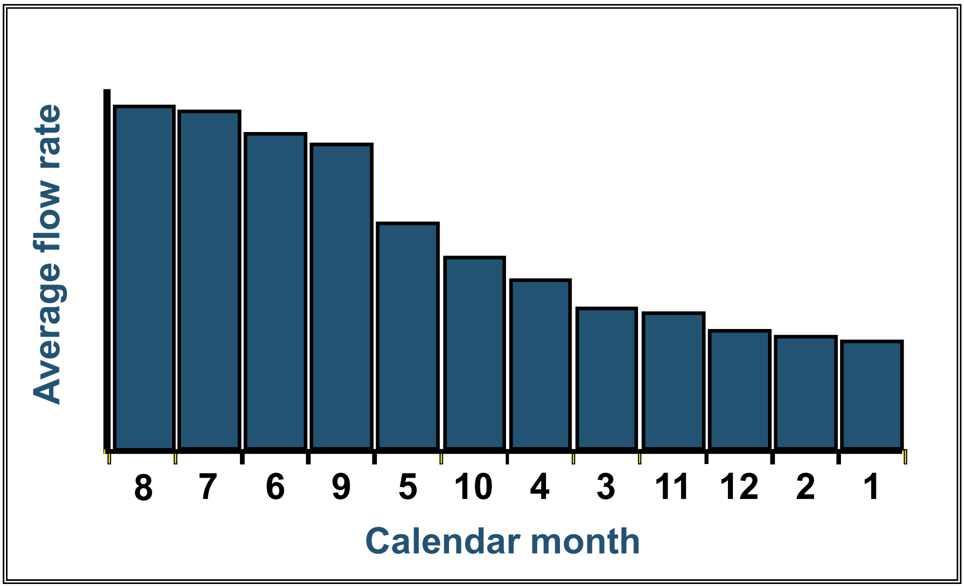
Daily flow fluctuation example



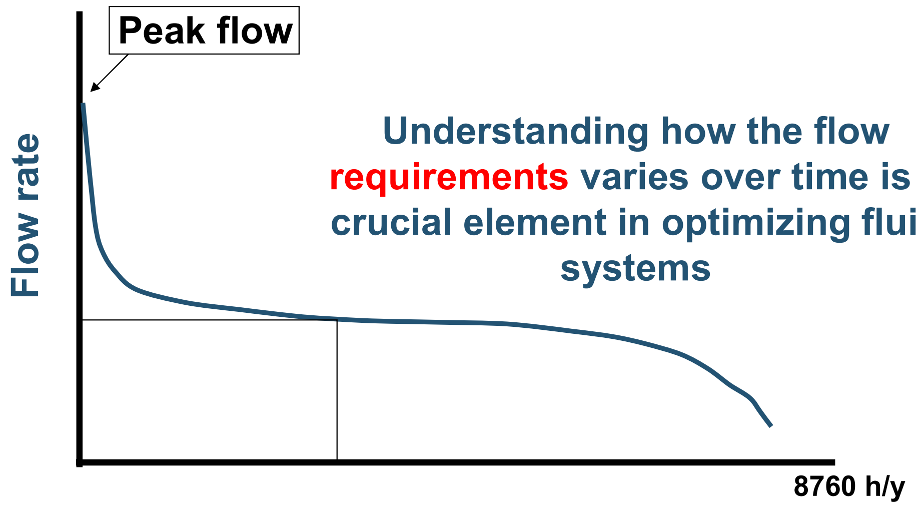
Annual flow fluctuation example



We can sort the months by flow rate:

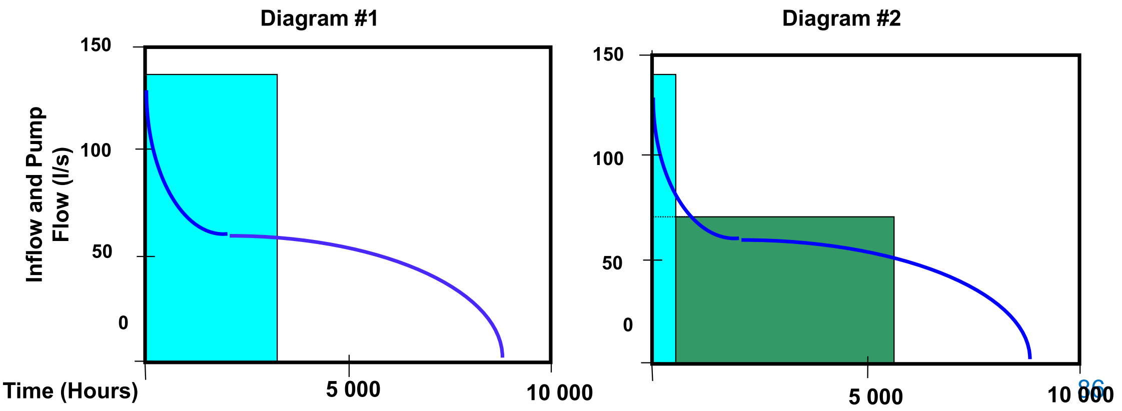


By tracking flow rate over time, a "flow duration" curve is developed



Using smaller pumps to handle low flows

- Diagram #1 shows a pump operating for 2 500 hours per year at a flow rate of 130 l/s – total flow is represented by the area under the curve.
- Diagram #2 shows the same total flow pumped by two pumps. The 130 l/s pump only operates 200 hours per year and a smaller pump rated for 70 l/s operates for 5 000 hours



Control Methods

Flow Control in Pumping Systems

There are a variety of process and control types:

Process Types:

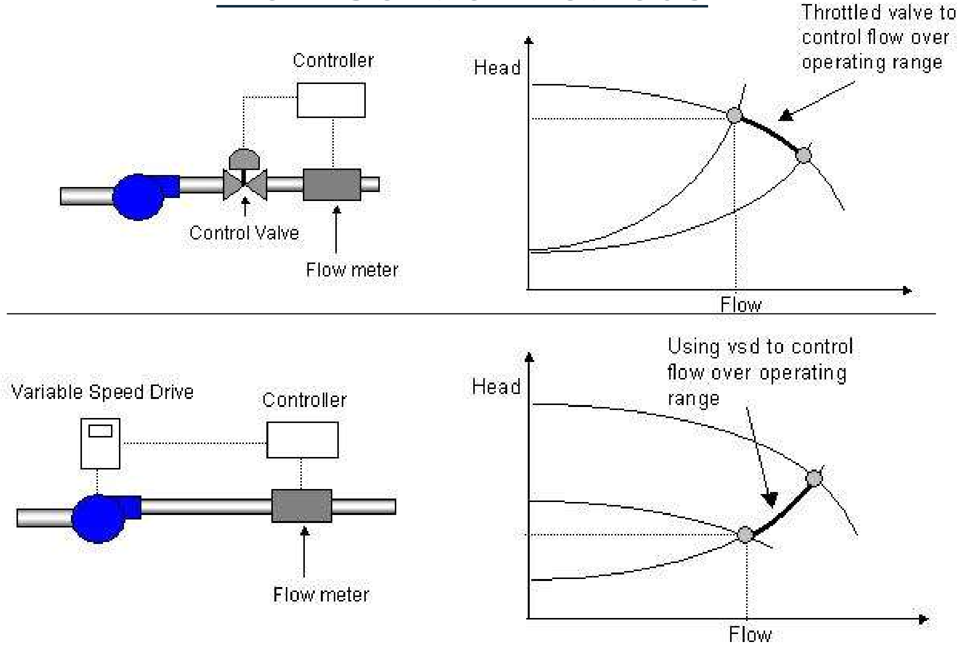
- Continuous
- Batch
- Combination

Can be either steady or variable flow

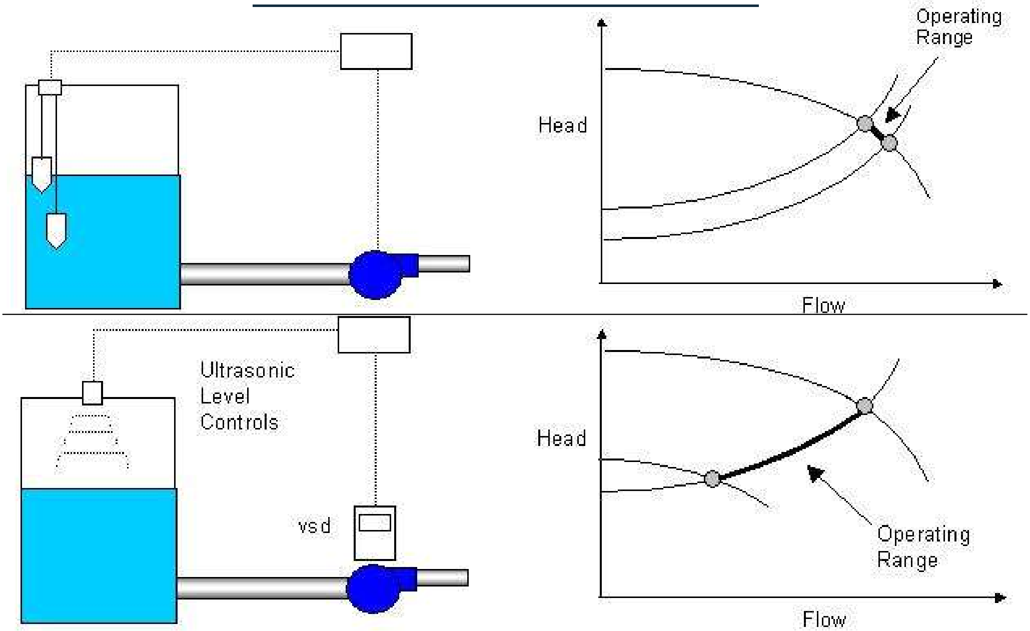
Control Strategies:

- On/off
- Valve throttling
- Bypassing
- Variable speed drive
- Combinations

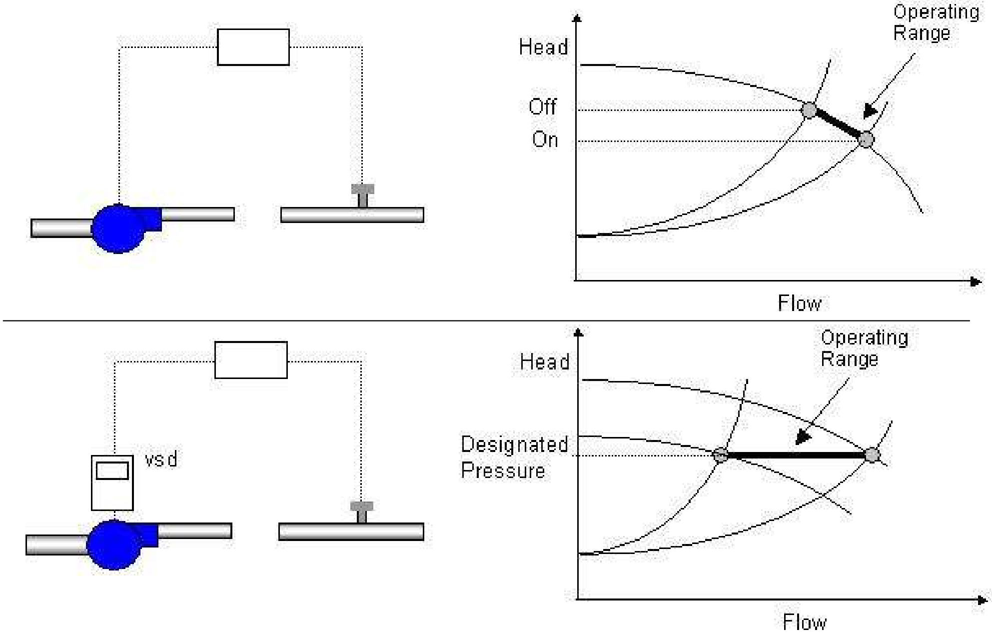
Flow Control Methods



Level Control Methods

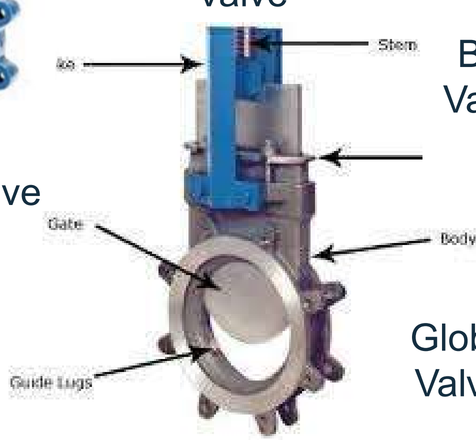


Pressure control methods

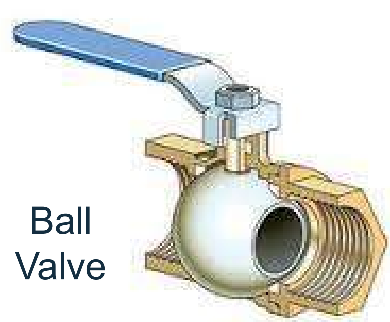


Butterfly Valve

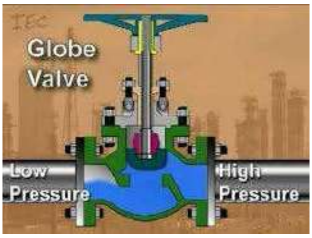
Gate Valve



Ball Valve



Globe Valve



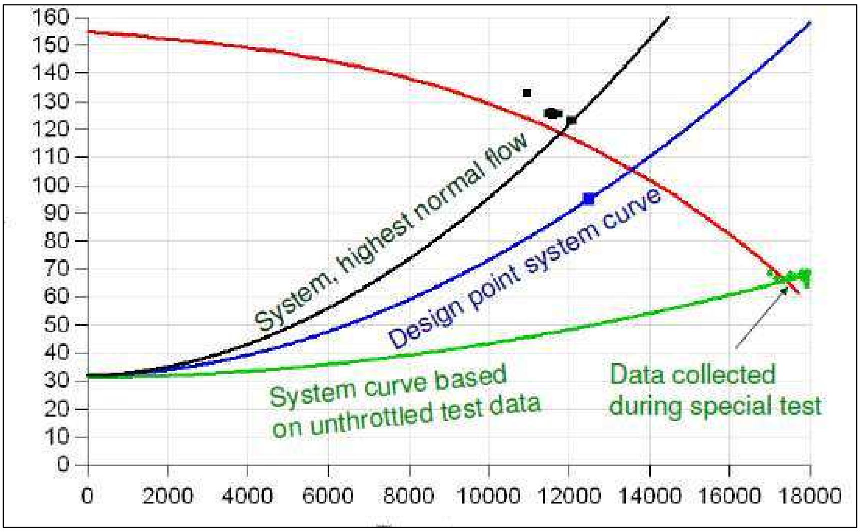
Flow Control in Pumping Systems

We will look at two options to achieve flow control in pumping systems:

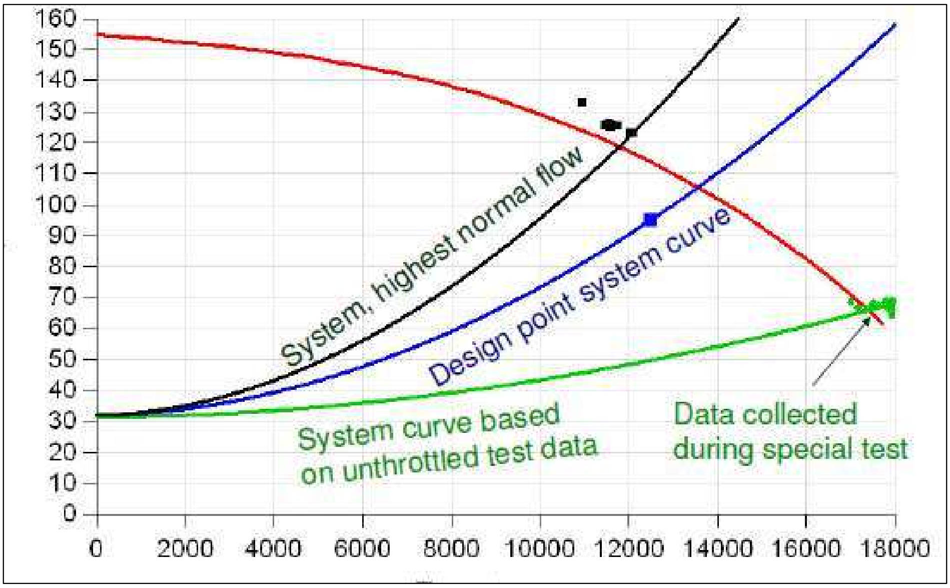
- Change the **system curve** (usually done by valve throttling);

- Change the **pump curve** by
  - changing the pump speed (by using a VSD or changing the motor)
  - trimming the impeller or
  - downsizing the pump/motor.

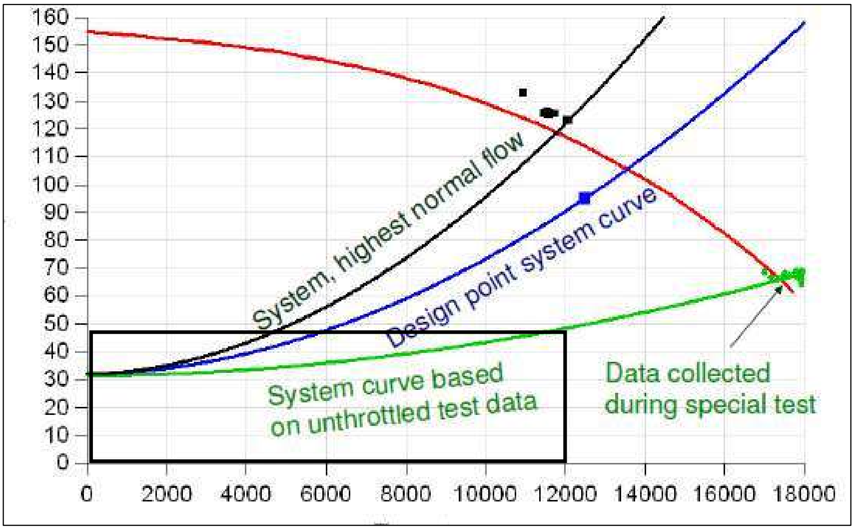
Measured data at two operating points, Max flow and with Un-throttled system



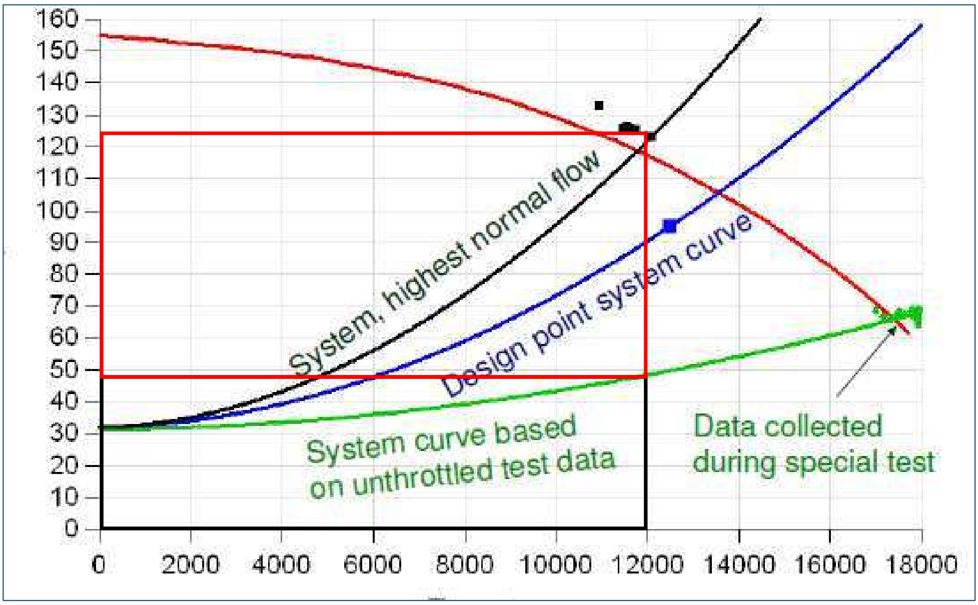
The Square is proportional to fluid power delivered during normal operation



Necessary fluid power needed to deliver the same flow if valve is opened



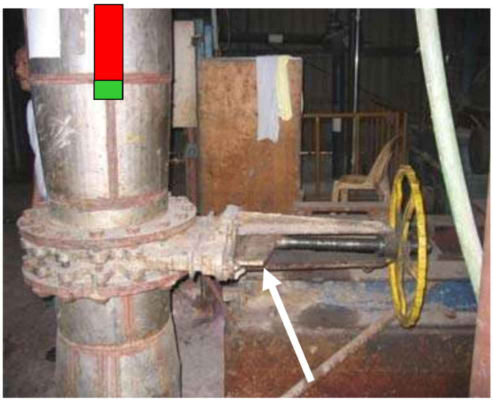
Delivered Fluid power is 270% of needed !



Result of test

- The pump is delivering 2.7 times more fluid power than needed
- The difference in delivered fluid power dwarfs any differences due to pump efficiency that could be obtained by changing pumps
- Thus there is more to be gained from looking at the system than at the components in this case

And you think this doesn't happen?



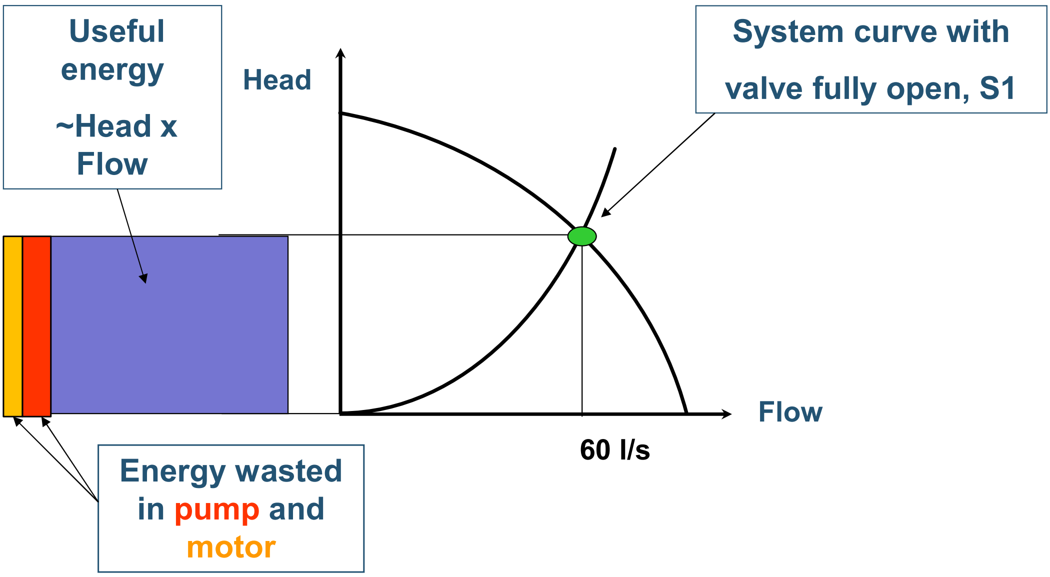
Paper Mill Pump

Flow Control in Pumping Systems

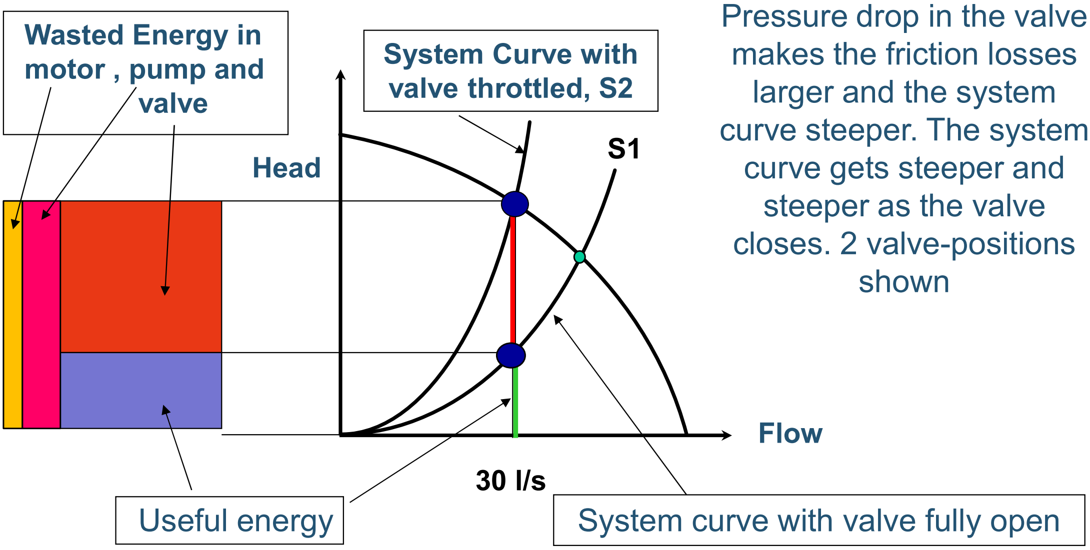
We will look at two options to achieve flow control in pumping systems:

- Change the system curve (usually done by valve throttling);
- Change the **pump curve** by
  - changing the pump speed (by using a VSD or changing the motor)
  - trimming the impeller or
  - downsizing the pump/motor.

Pump System Energy Representation

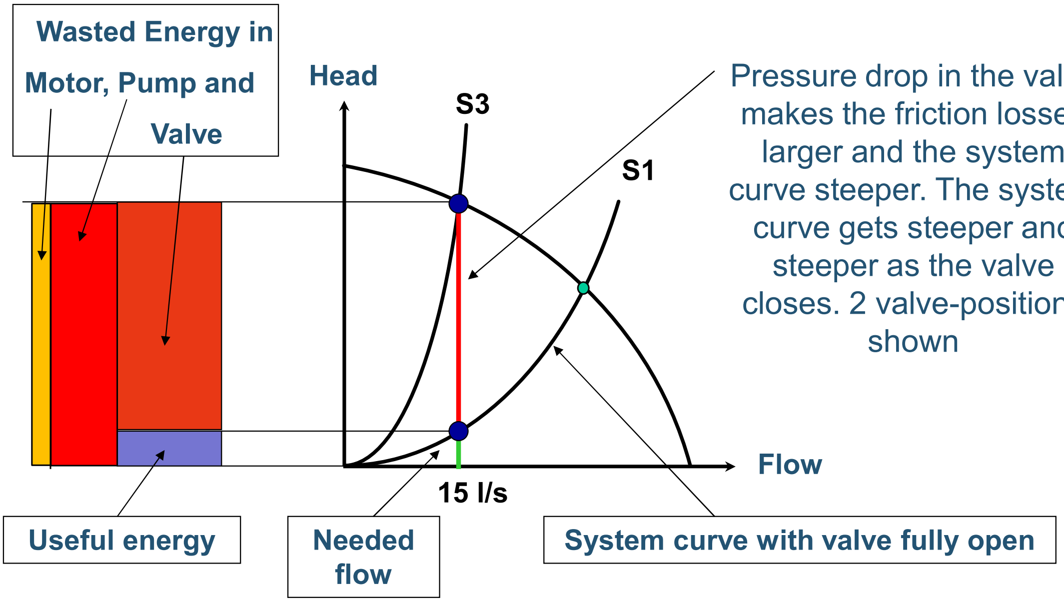


Throttling: Duty Point Moves to Left on the Pump Curve



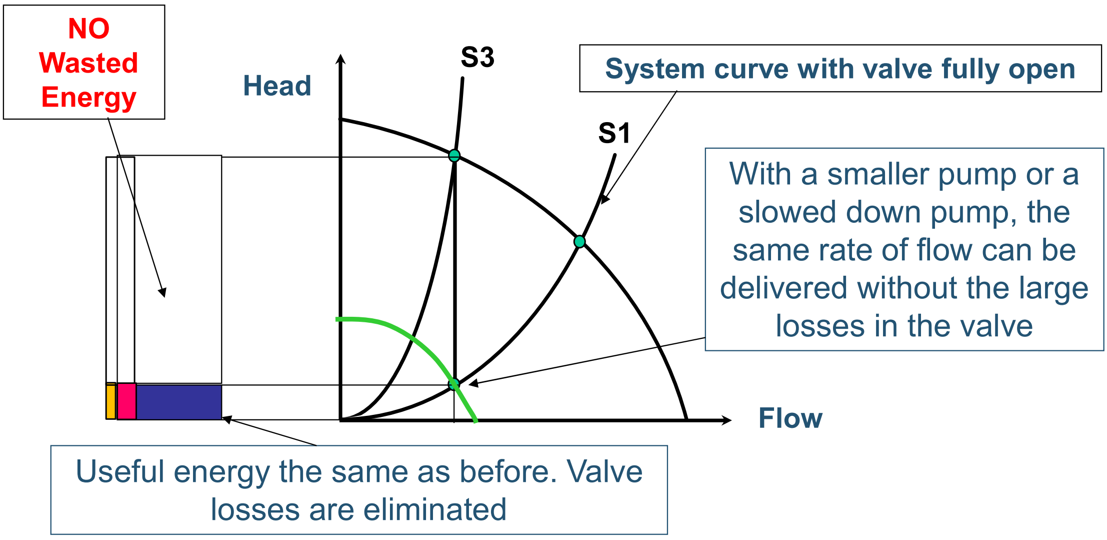
Pressure drop in the valve makes the friction losses larger and the system curve steeper. The system curve gets steeper and steeper as the valve closes. 2 valve-positions shown

Throttling: Duty Point Moves to Left on the Pump Curve



How a VSD saves energy

The pump curve changes, *not* the system curve



Why duties vary from optimal

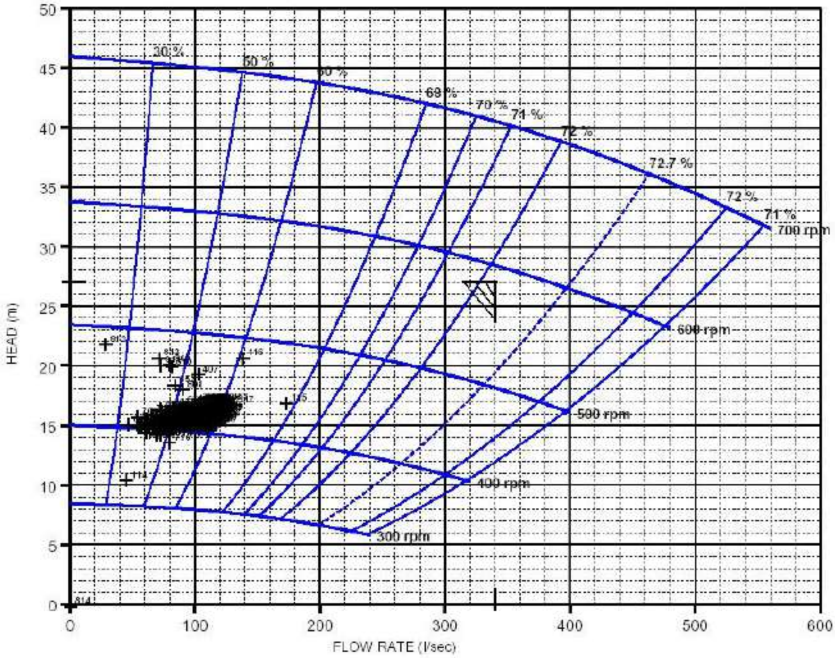
- Incorrect system data and assumptions
- Safety factors added
- New system components
- Increased duty
- Changing suction head
- Dynamic process conditions
- System and pump wear
- Flow control

Assumptions and Safety Factors

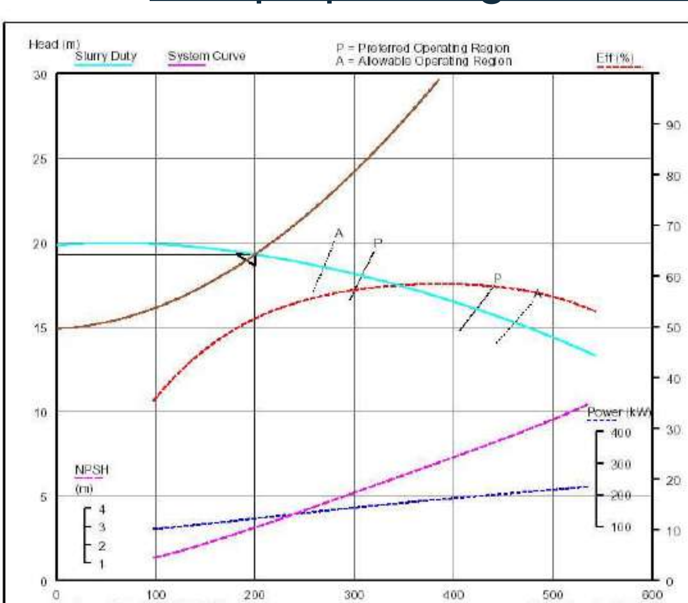
✓ Case Study - Oversized Mill Circuit Pump

- 120,000 TPM → 240,000 TPM
- Flow rate 140 l/s → 280 l/s plus safety factor
- Head (at above flow) → 24 m plus safety factor
- Power absorbed 180 kW → 281 kW
  - 2 safety factors, 25% each
- Motor Size 315 kW

Pump operating far left of BEP



Pump operating far left of BEP

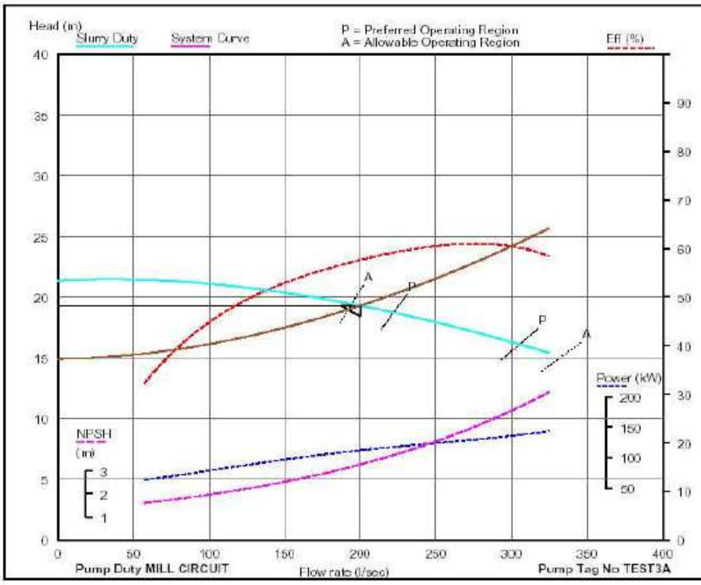


Required Flow	200 l/sec
Total Head (TDH)	19.3 m
Head Ratio	0.76
Efficiency Ratio	0.76
Suction Head	5 m
Seal Type	Expeller - Back
Max suct press	27.62 kPa
No of Stages	1
SG	1.710
Pump Size	14/12F-AH-M
Pump Range	AH
Pump Speed	379 RPM
Efficiency	51.70 %
BEP	58.39 %
Q BEP	52 %
Power Absorbed	125.2 kW
Motor Size	160 kW
Service Factor	1.28
Impeller Part No	FAM12147
No of Vanes	5
Impeller Diameter	965 mm
Tip Speed	19.17 m/s
Maximum Speed	700 RPM
% of Max Speed	0.541
Customer	TAS SA
Quote Ref	APAPP01A
Customer Contact	HARRY ROSEN
DATE	25/05/2006

For more information visit us at www.warman.co.za

Alternative pump selection

Compare duty for 14/12 vs 12/10



TAS online

TAS PumpMonitor
Tel +2711 326 0891
Fax +2711 326 0488
www.tasonline.co.za

Required Flow	200 l/sec
Total Head (TDH)	19.3 m
Head Ratio	0.76
Efficiency Ratio	0.76
Suction Head	5 m
Seal Type	Expellor - Back
Max suct press	55.04 kPa
No of Stages	1
SG	1.71
Pump Size	12/10F-AH-M
Pump Range	AH
Pump Speed	512 RPM
Efficiency	57.68 %
BEP	61.03 %
Q BEP	72 %
Power Absorbed	112.2 kW
Motor Size	160 kW
Service Factor	1.43
Impeller Part No	FAM10147
No of Vanes	5
Impeller Diameter	762 mm
Tip Speed	20.45 m/s
Maximum Speed	900 RPM
% of Max Speed	0.569
Customer	TAS SA
Quote Ref	APAPP01A_ALT
Customer Contact	HARRY ROSEN
DATE	25/05/2006

Replace with Smaller Pump Size

✓ Projected Savings：

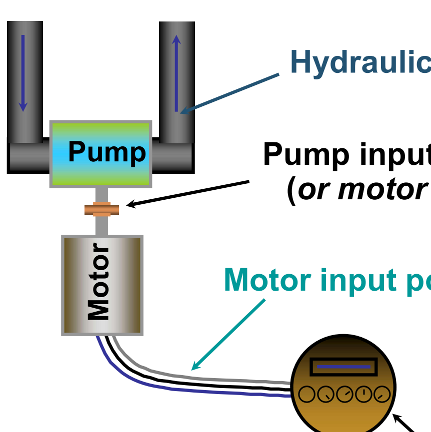
- Duty savings 35%, 40 kW
- 85% utilisation, 6970 hrs/year
- Total power savings 278,800 kW.hrs

✓ Process Advantages：

- Better control achievable
- Improved plant stability and overall system efficiency
- Head ratio far left of BEP unstable – slurry system

Pump System Energy Use

From the water or hydraulic power, to kW delivered by the MCC



Hydraulic power $= \dfrac{\text{l/s} \cdot \text{m} \cdot \text{relative density}}{102}$

Pump input power (kW) (*or motor output*) $= \dfrac{\text{Hydraulic power}}{\text{Pump efficiency}}$

Motor input power (kWe) $= \dfrac{\text{Motor output power}}{\text{Motor efficiency}}$

And finally, the cost of running the motor =

Motor input power x operating hours x per unit electricity cost

Expanding the equation…

$$kW = \frac{\text{Flow (l/s)} \times \text{Total Head (m)} \times \text{Relative Density}}{102 \times \eta p \times \eta m \times \eta vfd}$$

Flow
Total Head

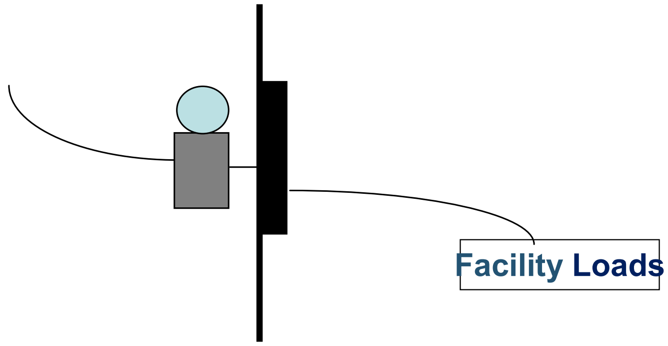
System-level Opportunities

ηp = pump efficiency
ηm = motor efficiency
ηvfd = VFD efficiency

Component-level Opportunities

kWh = kW x Hours

Looking at Both Sides of the Meter



Energy Supply **Energy Load Side**

The Utility Side:
How is Electric Energy Billed?

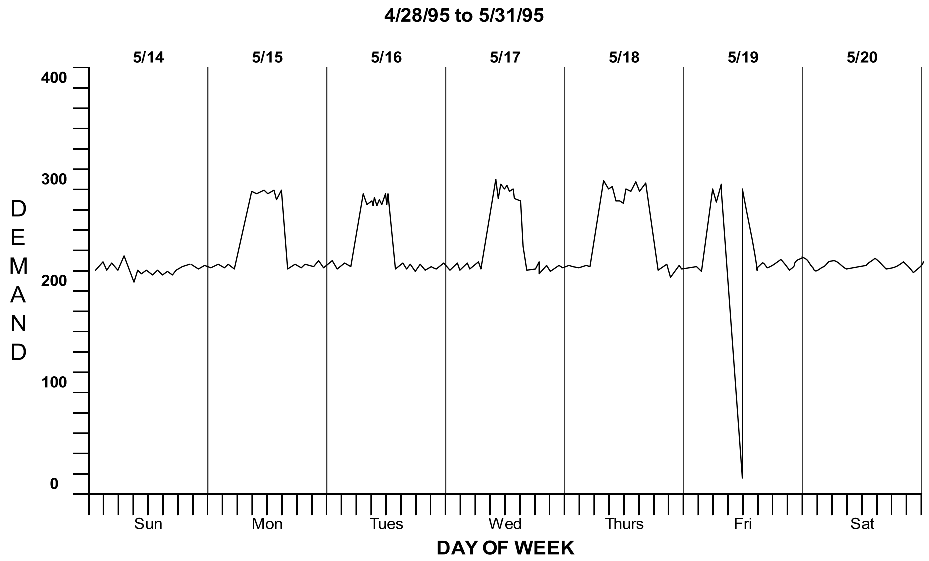
The two areas that make up the majority of energy charges for a commercial facility are:

- Consumption (kWh): Based on kilowatt-hour use that measures energy use over time
- Demand (kVA): Based on the highest average kilowatt level reached by a facility over a 15 or 30 minute period during the monthly billing period

What Are Demand Charges?

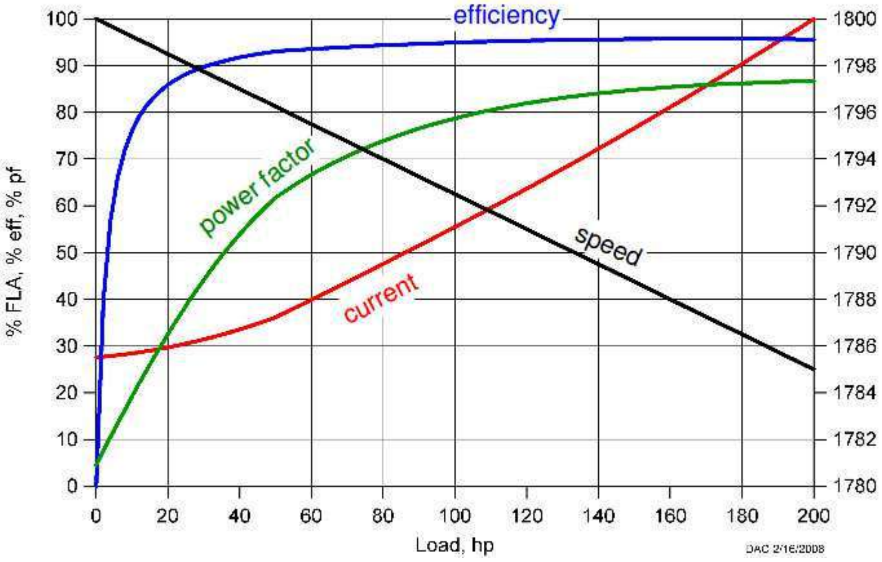
- Demand charges relate to the utility's costs in having the capacity to serve its customers. Generally recovers the capital investment made by the utility based upon system peaks.
- Typically measured in 15 or 30 minute intervals. A high demand charge can be carried forward for 11 months

Sample Facility Demand Profile

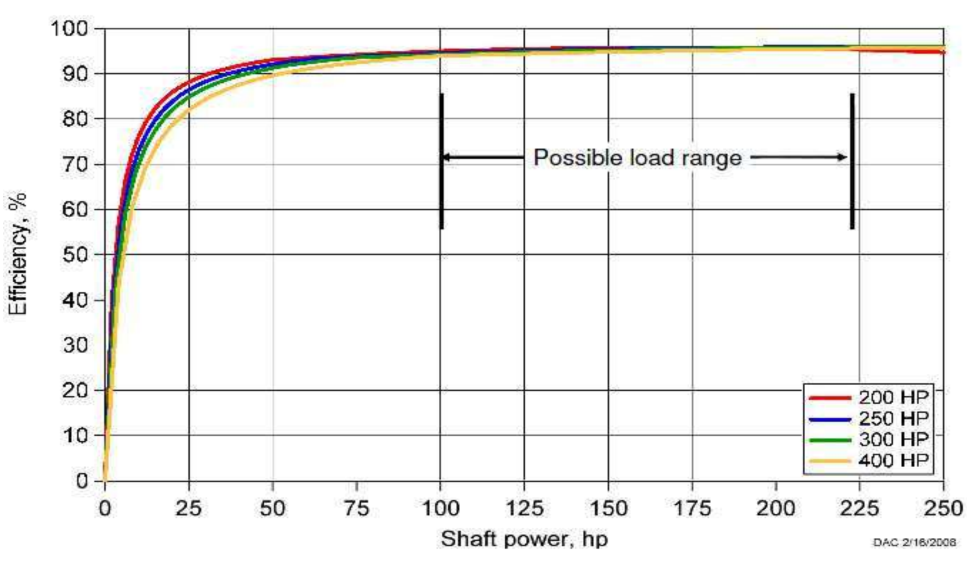


Motor Considerations

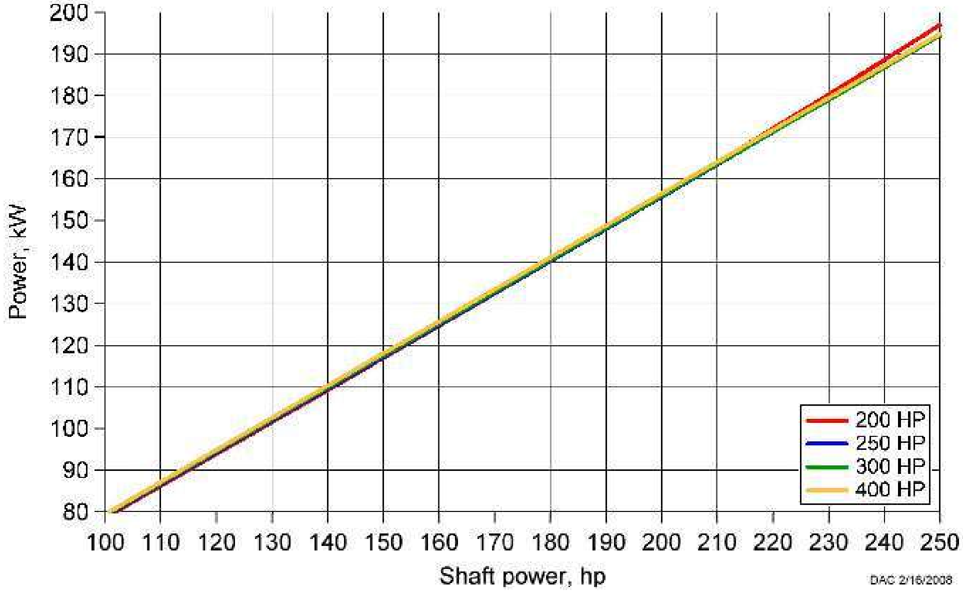
Typical high efficiency motor curves (150 kW, 4-Pole)



Effect of an oversized motor (virtually nothing)



The difference in power consumption for oversized motors is trivial



MINISTRY OF INDUSTRY AND TRADE
EU - VIET NAM SUSTAINABLE ENERGY TRANSITION PROGRAMME (SETP)
Accelerating energy efficiency (EE) in large industries through energy management system, System optimisation and the promotion and adoption of EE in SMEs -(IEEP project)
Global Gateway
Funded by the European Union
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Two Day End User Pump Systems Optimization Training

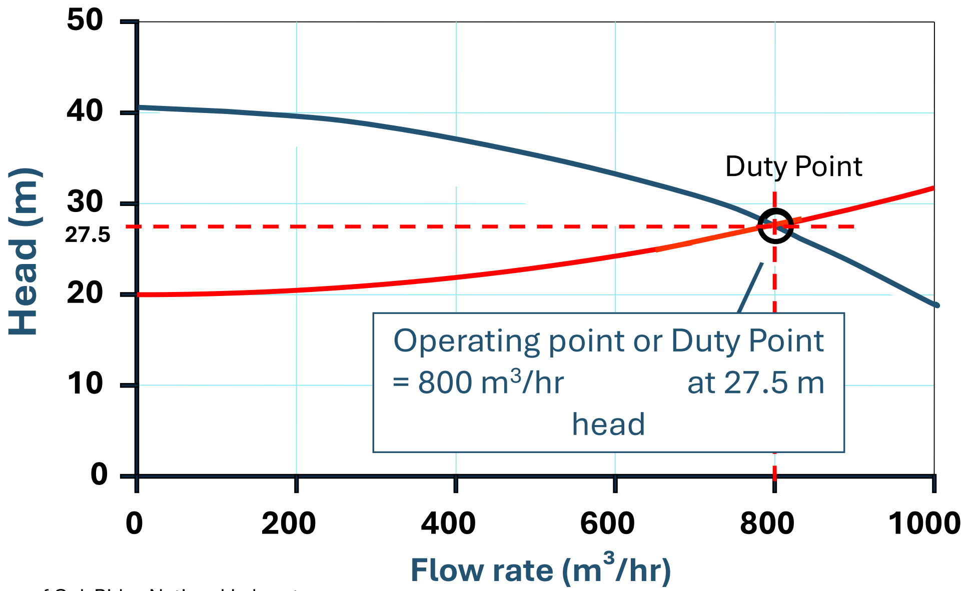
Day Two

Facilitated by: Harry Rosen

Pump Operating Point

The pump will **always** operate where the system and pump curves intersect since at that point we have balance between what the system demands and what the pump can deliver

The intersection between the pump and system head capacity curves defines the operating point



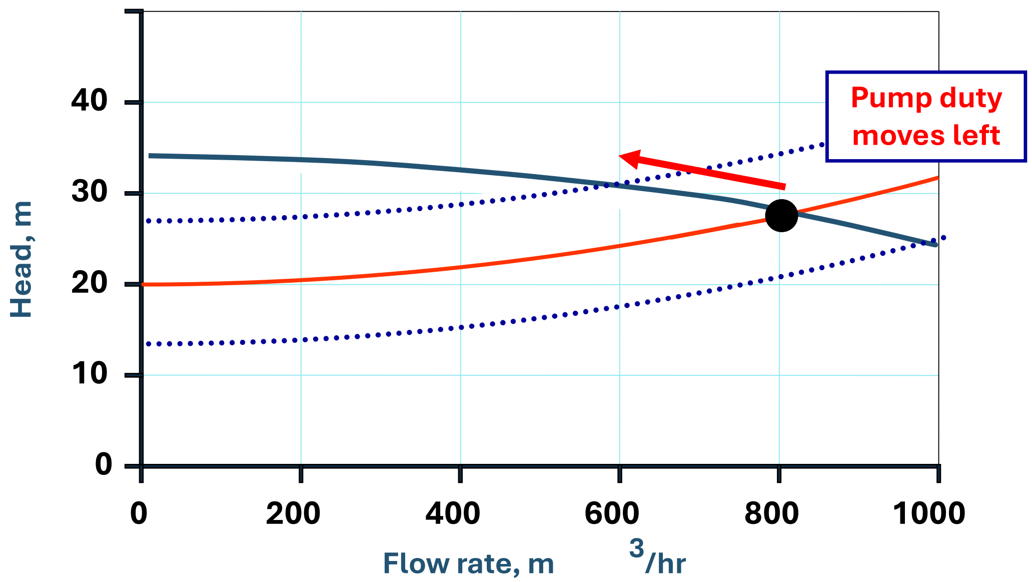
Slide Courtesy of Oak Ridge National Laboratory

Why duties vary from optimal

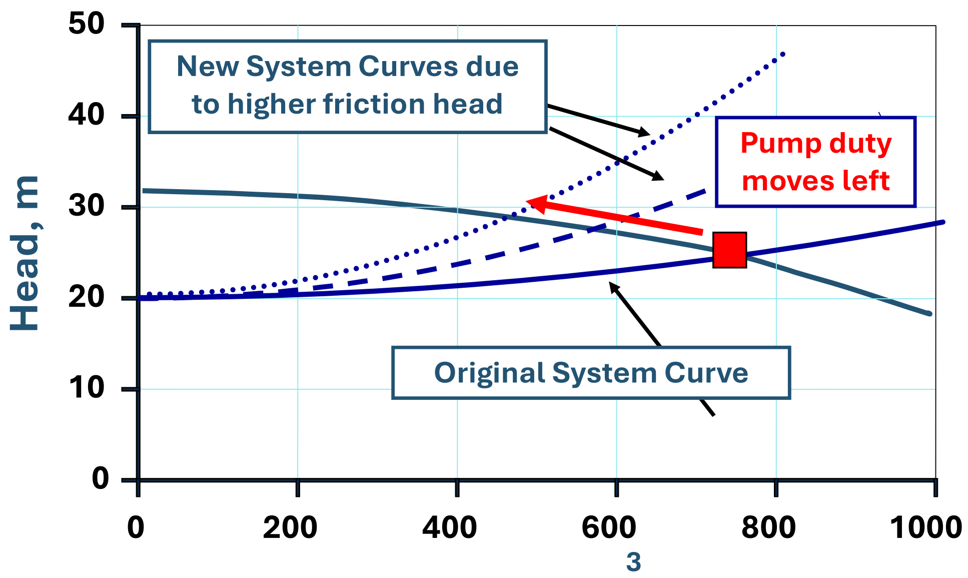
- Incorrect system data and assumptions
- Safety factors added
- New system components
- Increased duty
- Changing suction head
- Dynamic process conditions
- System and pump wear
- Flow control

Changing Static Head

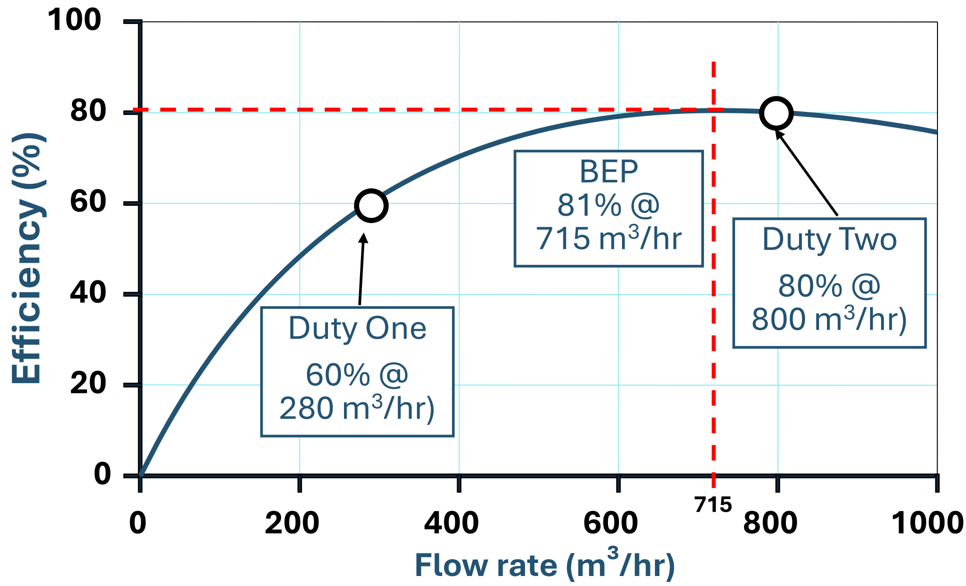
Changing static head has major effect on pump operation



Varying Friction Head



Pump Efficiency is a function of the operating point



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Pump Reliability is a function of operating point

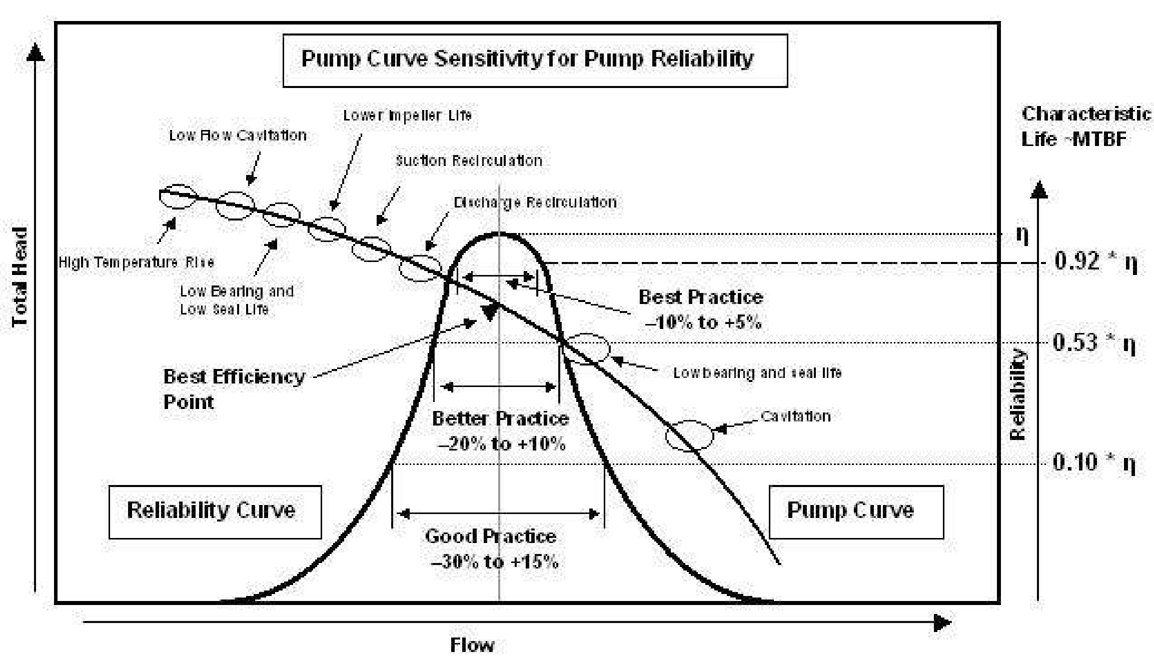


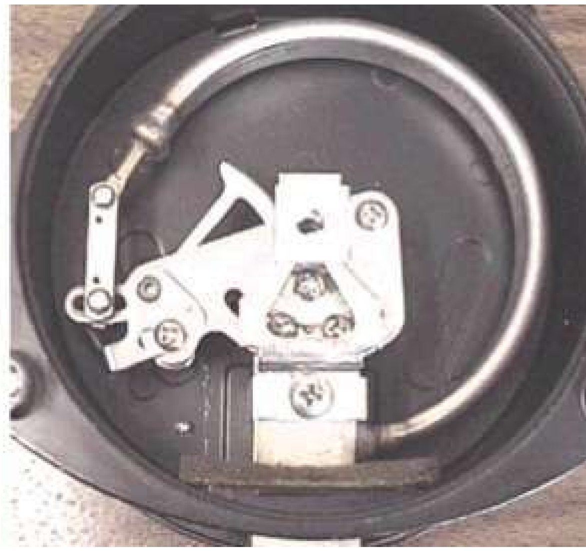
Figure Courtesy of P. Barringer.

Where is the Pump Operating Point?

Measuring pump test data in the field

Measuring Pressure and Head

The C-type Bourdon tube is by far the most common industrial pressure gauge



Slide Courtesy of Oak Ridge National Laboratory

Some practical considerations

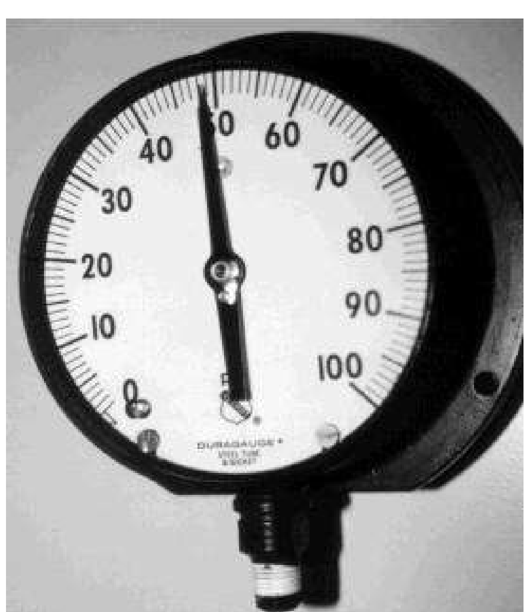
- Service environment, history
  - Water hammer
  - Calibration
- Instrument range
  - Accuracy
  - Overpressure capability
- Physical location, Setup
  - Process connection point
  - Accounting for sensing element elevation
  - Proper instrument line fill & vent

Slide Courtesy of Oak Ridge National Laboratory

What do you think the system pressure is? (note the angle from which the picture is taken)

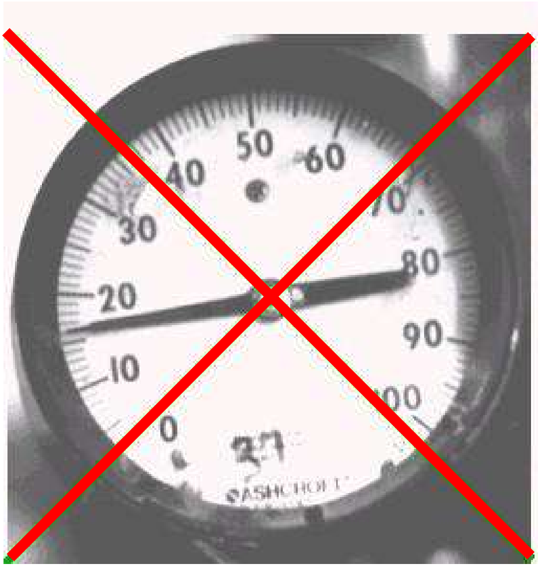
Slide Courtesy of Oak Ridge National Laboratory

Would a little larger picture change your mind?



Slide Courtesy of Oak Ridge National Laboratory

The use of portable, temporary instrumentation is advisable when accurate data is needed



Slide Courtesy of Oak Ridge National Laboratory

There are a variety of flow meter types

- Differential pressure - orifice, venturi, nozzle, elbow
- Velocity - Magnetic, ultrasonic, turbine, vortex shedding, variable area (rotameter), pitot tube
- Open flow - Weir
- Positive displacement - gear, nutating disc
- Mass

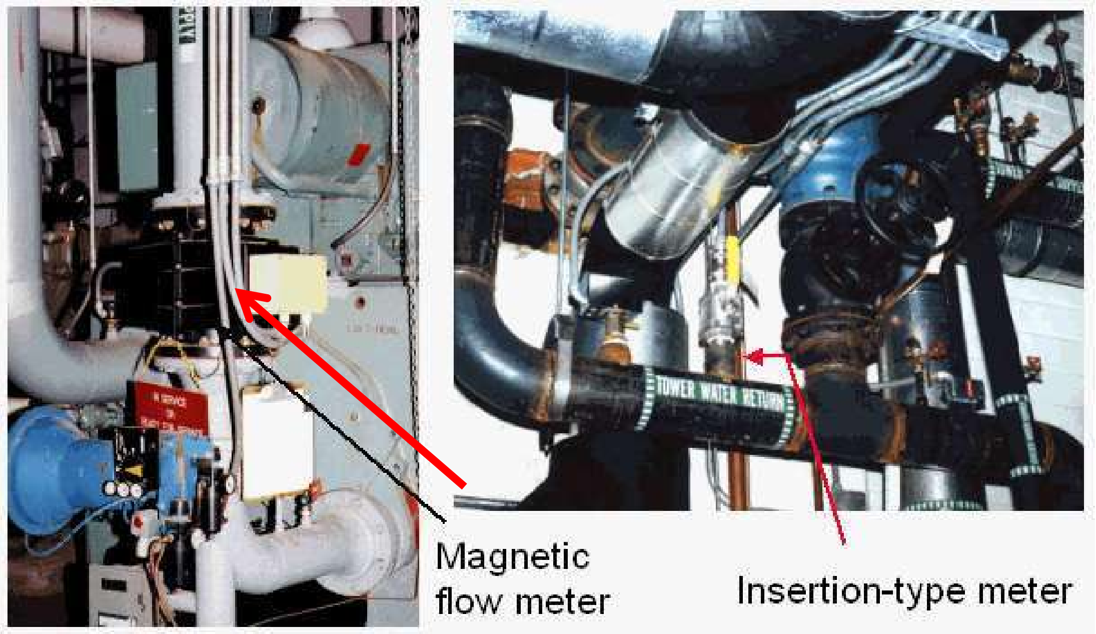
Slide Courtesy of Oak Ridge National Laboratory

Some important flow meter considerations

- Proper flow profile and installation
- Range
- Calibration
- Wear
- Corrosion, scale, foreign material
- Sensing line issues (similar to pressure)

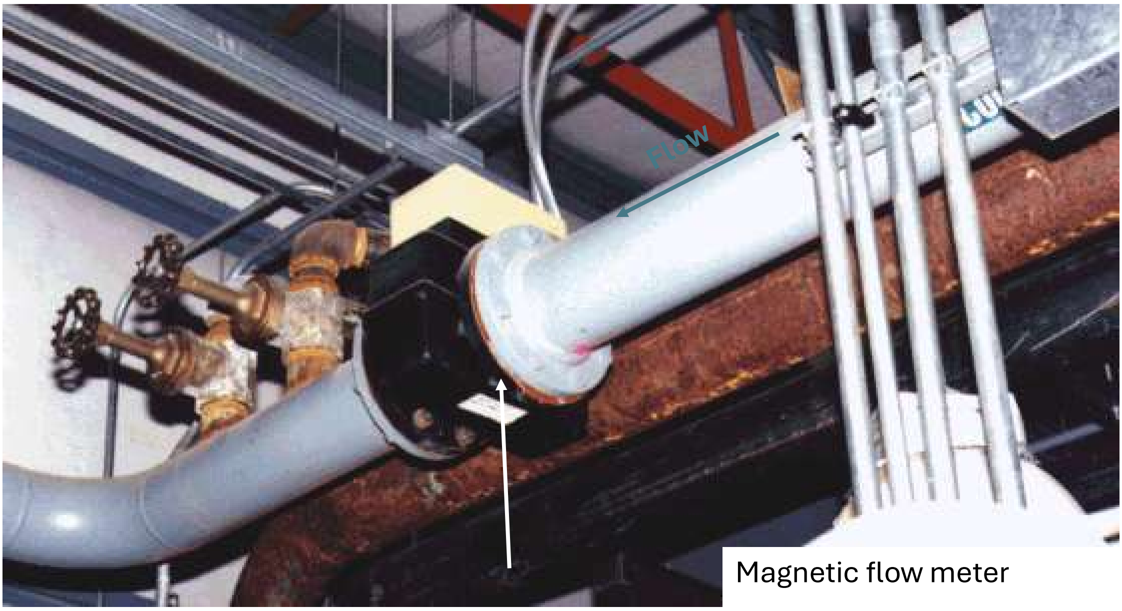
Slide Courtesy of Oak Ridge National Laboratory

Some all too often found field configurations...



Slide Courtesy of Oak Ridge National Laboratory

A better configuration

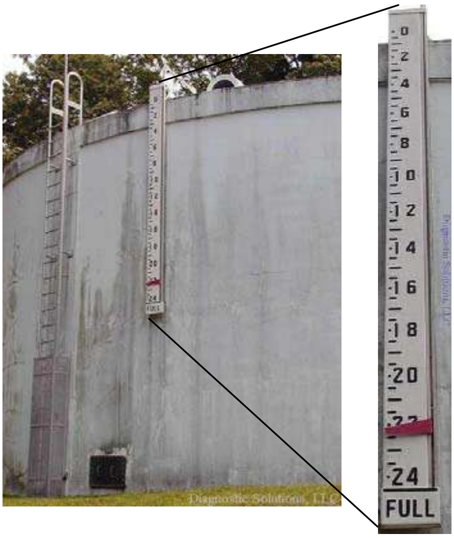


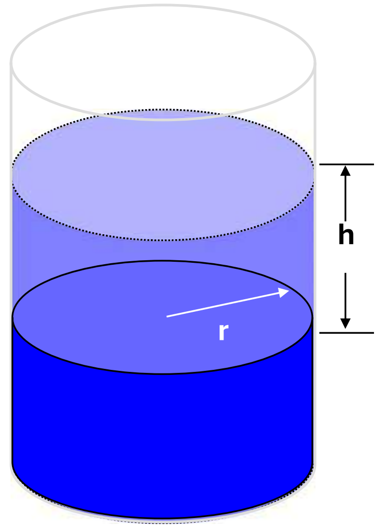
Slide Courtesy of Oak Ridge National Laboratory

Portable ultrasonic flow meter

Slide Courtesy of Oak Ridge National Laboratory

Special test example - tank drain or fill
(also a standard way to calibrate flow meters)





$$Q = \frac{\pi r^2 h}{t}$$

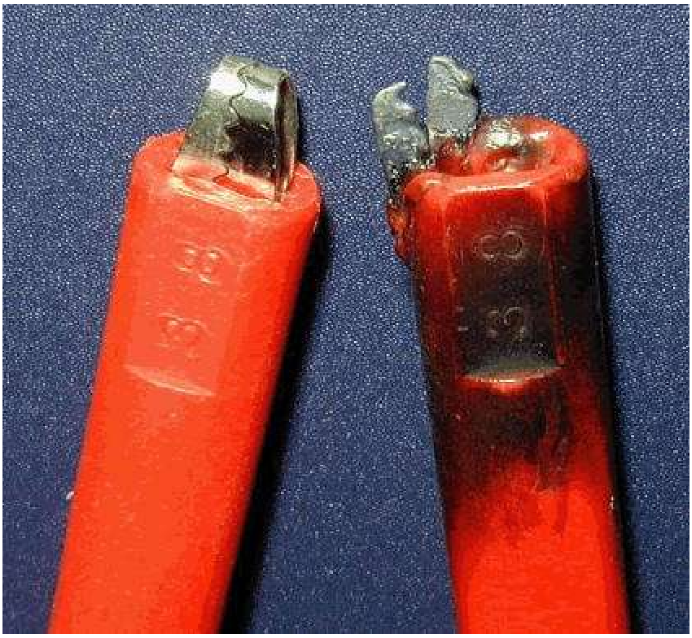
Slide Courtesy of Oak Ridge National Laboratory

Electrical measurements:
Instruments and considerations

The most important consideration in electrical measurements:

SAFETY

These two alligator clips used to look alike...



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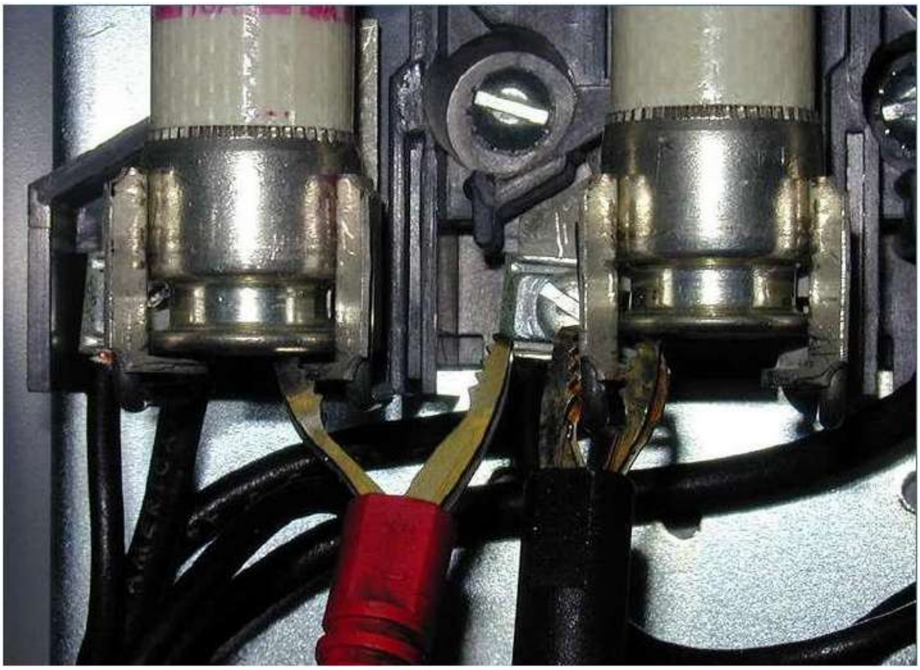
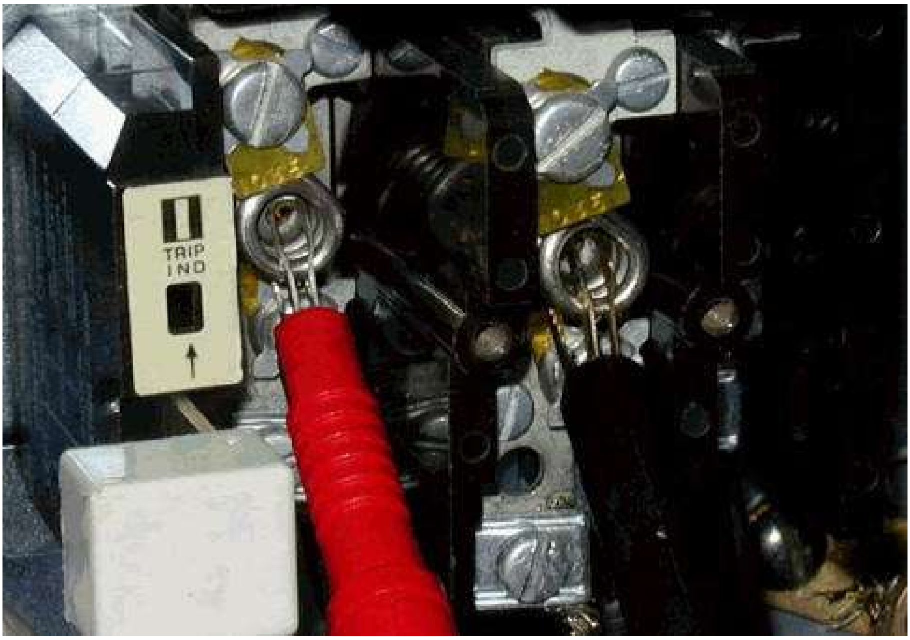
How it happened



A better alternative - starter terminals



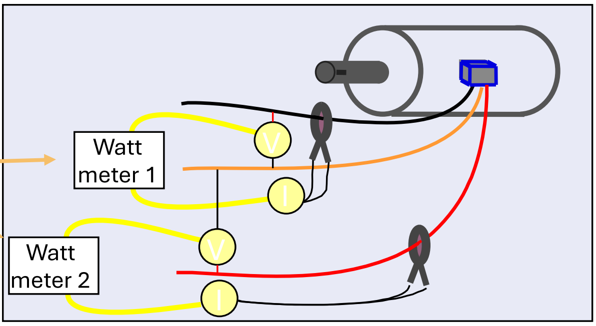
Slide Courtesy of Oak Ridge National Laboratory

Fundamental electrical power relationships: Three phase power

Balanced 3-phase power: $P = 3 \cdot \sqrt{I_{rms}} \cdot V_{rms} \cdot$ power factor

For balanced *or* unbalanced conditions, the two watt-meter method can be used:

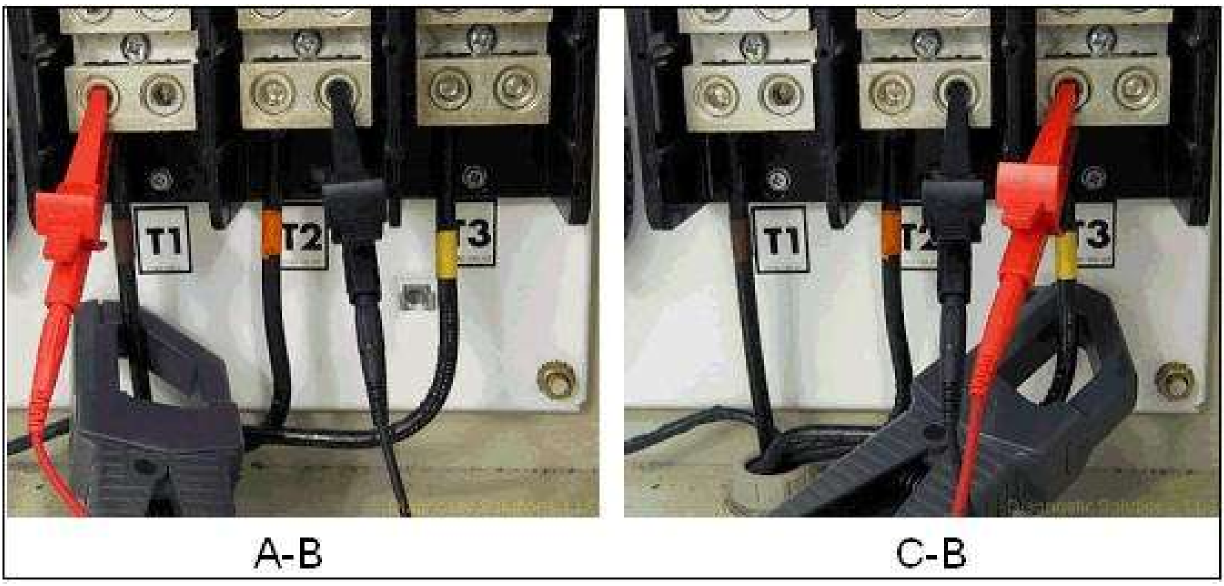
$$\begin{array}{r} P_1 \\ + \; P_2 \\ \hline P_{tot} \end{array}$$



Note: the V_{rms} above is line to line voltage

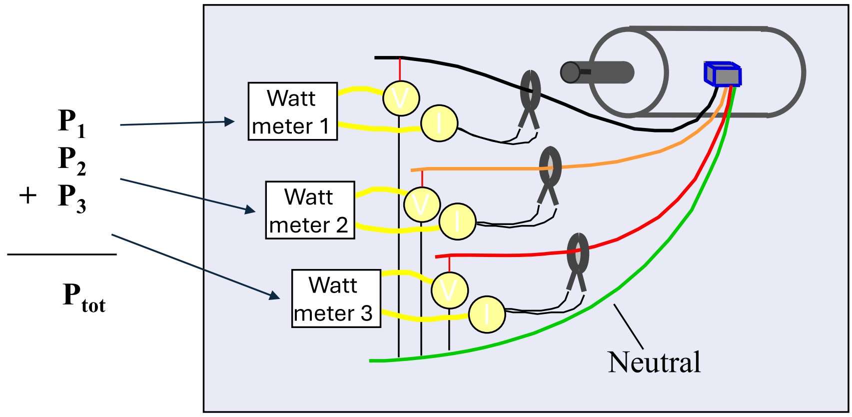
Slide Courtesy of Oak Ridge National Laboratory

The two watt-meter method being applied



Slide Courtesy of Oak Ridge National Laboratory

An alternative method of measuring power in three-phase circuits with a neutral



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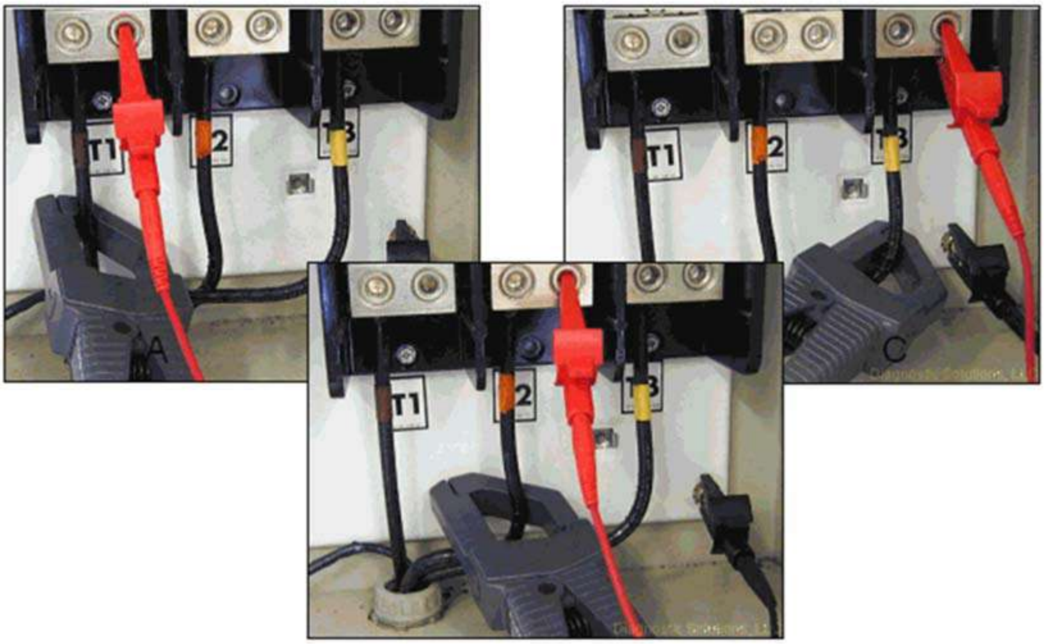
The three watt-meter method being applied

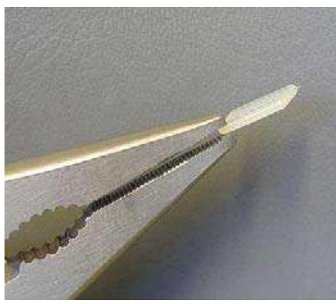


Slide Courtesy of Oak Ridge National Laboratory

A caution about current measurements: CT jaw closure is critical

Jaws fully closed - 114.2 amps

Piece of tie wrap
< 0.05 in thick



<0.05 inch gap: 78.5 amps

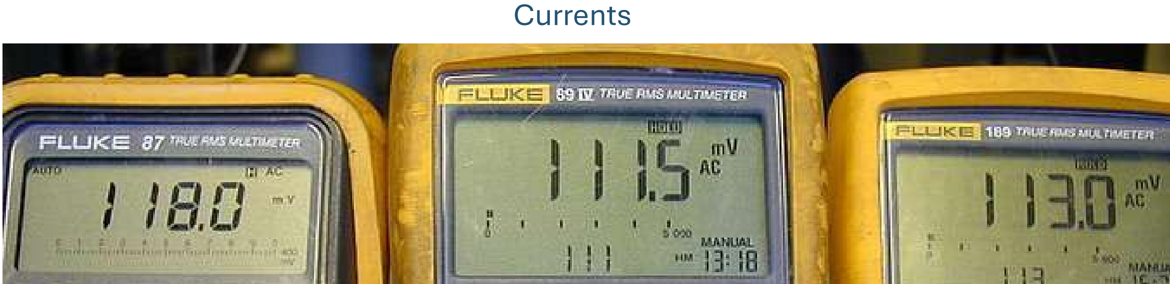
Note: CT scaling is 1 mV/amp

Slide Courtesy of Oak Ridge National Laboratory

If possible, measure all three phases

Phase-to-phase voltages

Currents



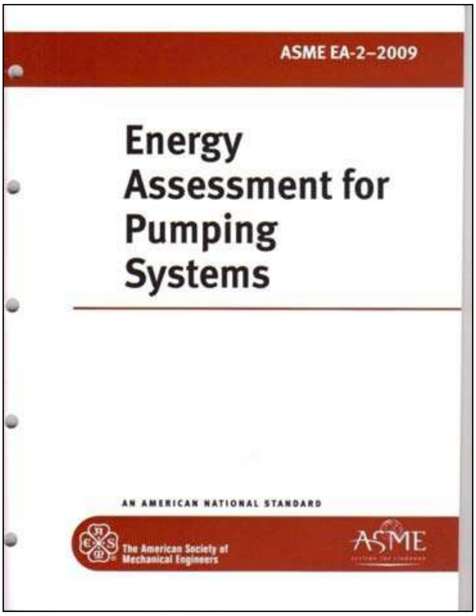
<0.9% voltage unbalance => 3.3% current unbalance

Slide Courtesy of Oak Ridge National Laboratory

ASME EA-2-2009

Energy Assessment Standard for Pumping Systems

ASME Pump Assessment Standard & Guidance Document

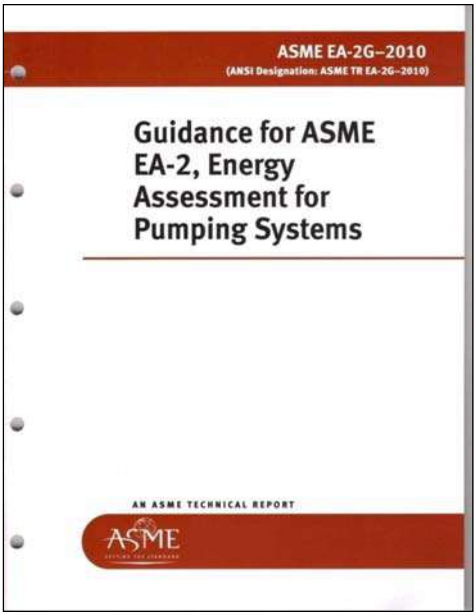

ASME EA-2–2009

Energy Assessment for Pumping Systems

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

ASME


ASME EA-2G–2010

(ANSI Designation: ASME TR EA-2G–2010)

Guidance for ASME EA-2, Energy Assessment for Pumping Systems

AN ASME TECHNICAL REPORT

ASME

ASME Standard

Introduction

Difference Between ASME Pump Standard & Guidance Document

Standard EA-2-2009

- Provides a common understanding of what should be included in a pump system assessment to replace the lack of a standardization for pump systems previously evaluated as part of an energy evaluation, audit, survey or energy study.
- Defines specific requirements that must be performed for different assessment levels.

Guidance Document EA-2G-2010

- Provides technical background and application details to help the user apply the standard.
- Includes rational for the technical requirements, application notes, alternative approaches, tips, techniques and examples.

Objectives of the Pump Standard/Guidance Document

- Provide a step by step approach to perform a pump system energy assessment.
- Identify energy assessment levels and the effort required for each type of assessment
- Emphasize the importance of taking a systems approach
- Review equipment data that should be collected for pump system evaluations.
- Become familiar with solutions for pump system optimization.
- Present the results in a suitable format.

Standard/Guidance Document Sections

ASME EA-2-2009 Energy Assessment Pump Systems Sections:

1. *Scope & Introduction*
2. *Definitions*
3. *References*
4. *Organizing the Assessment*
5. *Conducting the Assessment*
6. *Analyzing the Data*
7. *Reporting & Documentation*

Areas to be discussed

ASME Standard

Chapter 4:

Organizing the Assessment

Chapter 4: Organizing the Assessment

Before Arriving on Site

4.1 Identification and Responsibilities of Assessment Team Members

- Authorized Manager - accepts overall responsibility for funding and decision making (often times not present during assessment)
- Assessment Team Leader - familiar with operations and maintenance of pump systems to be reviewed and able to organize resources to evaluate pumps.
- Pump System Expert - qualified to perform the assessment activities, data analysis and report preparation.

4.2 Facility Management Support

- Written support should be provided by facility management to commit the resources needed. Develop written agreement/purchase order before arriving on site that *clearly defines Goals and Scope of Assessment*.

Chapter 4: Organizing the Assessment

Before Arriving on Site and at the Kick-Off Meeting

4.4 Access to Resources and Information

- Review access to equipment areas
- Discuss needed personnel to conduct assessment (electrician, engineers, operations staff)
- Determine access to data such as drawings, manuals, utility bill data, computer monitoring and control data

4.5 Assessment Goals & Scope

- Overall goals and assessment scope should be reviewed
- (This was defined before arriving on site – but should be reviewed with all meeting attendees)

Chapter 4: Organizing the Assessment

4.6 Initial Data Collection and Evaluation

Before Arriving on Site

Work with facility to identify pump systems that will be reviewed

Pump System Screening Questions					
System Name/ ID	Paper Machines 411 and 412				
	Pump ID				
	Pump #401	Pump #605	Pump #333	Pump #210	Pump #422
Estimated annual operating hours	7600	7600	7600	7600	7600
Motor rated hp	75	125	150	100	150
Is system throttle valve-controlled?	yes	yes	yes	yes	yes
Is the pump bypassing to regulate flow/pressure?	no	no	no	no	no
Multiple parallel pumps with same # normally operating?	yes	yes	yes	yes	yes
Distributed cooling system with multiple unregulated loads?	no	no	no	no	no
Constant pump operation in batch process?	constant	constant	constant	constant	constant
Frequent cycle batch operation in continuous process?	no	no	no	no	no
Cavitation noise at pump or elsewhere in system?	no	no	no	no	no
High system maintenance without obvious causes?	no	no	no	no	yes
Has system function or demand changed over time with no pump change?	no	no	no	no	no
Is flow metered?	yes	yes	yes	yes	yes

Chapter 4: Organizing the Assessment

4.6 Initial Data Collection and Evaluation

Before Arriving on Site

Obtain energy use and cost data to determine unit costs

SAVE ENERGY NOW PRE-ASSESSMENT SURVEY FORM

Step 2: Plant's Energy Consumption & Production Overview

Current Year	2010						
Month	Monthly Site Electricity Consumption (MWH)	Total Monthly Electricity Cost ($)	Monthly Natural Gas Consumption (MMBtu)	Total Monthly Natural Gas Cost ($)	Monthly Steam Consumption (MMBtu)	Total Monthly Steam Cost ($)	Monthly Heavy Fuel Oil Consumption (MMBtu)
January	6.57	$445,924	17,448	$120,466	78,698	$451,885	
February	6.39	$456,088	16,635	$147,556	72,787	$447,478	
March	6.86	$466,007	17,809	$123,209	73,095	$437,502	
April	5.65	$459,013	14,379	$143,309	49,906	$373,967	
May	7.41	$513,624	19,652	$121,629	54,454	$375,194	
June	7.88	$545,731	20,353	$161,600	53,877	$379,361	
July	7.32	$527,183	16,738	$143,719	52,889	$379,405	
August	7.49	$530,737	19,189		50,424	$364,642	
September							
October							
November							
December							
Grand Total	55.58	$3,944,308	142,201.80	$961,488	486,129	$3,209,434	0

Example of Eskom Consumption Report

Customer Account Number	Year	Month Number	Month	Notified Maximum Demand	Actual kVA Maximum Demand	Peak Consumption Total	Standard Consumption Total	Offpeak Consumption Total	Consumption	Rate Description
8018806098	2008	2	FEBRUARY	200	146.74	8,752.00	22,902.00	6,918.00	38,572.00	Ruraflex Interval
8018806098	2008	3	MARCH	200	148.83	4,426.00	11,148.00	2,143.00	17,717.00	Ruraflex Interval
8018806098	2008	4	APRIL	200	148.36	6,737.00	16,058.00	4,562.00	27,357.00	Ruraflex Interval
8018806098	2008	5	MAY	200	147.12	6,838.00	16,284.00	5,407.00	28,529.00	Ruraflex Interval
8018806098	2008	6	JUNE	200	196.19	8,150.00	19,135.00	4,707.00	31,992.00	Ruraflex Interval
8018806098	2008	7	JULY	200	195.96	10,353.00	26,121.00	8,761.00	45,235.00	Ruraflex Interval
8018806098	2008	8	AUGUST	200	194.72	10,401.00	25,334.00	9,135.00	44,870.00	Ruraflex Interval
8018806098	2008	9	SEPTEMBER	200	194.72	9,242.00	29,930.00	10,164.00	49,336.00	Ruraflex Interval
8018806098	2008	10	OCTOBER	200	197.95	14,224.00	37,719.00	33,796.00	85,739.00	Ruraflex Interval
8018806098	2008	11	NOVEMBER	200	200.18	7,746.00	20,908.00	22,120.00	50,774.00	Ruraflex Interval
8018806098	2008	12	DECEMBER	200	131.94	7,546.00	19,919.00	9,478.00	36,943.00	Ruraflex Interval
8018806098	2009	1	JANUARY	200	128.62	4,438.00	12,307.00	6,214.00	22,959.00	Ruraflex Interval
8018806098	2009	2	FEBRUARY	200	133.7	6,811.00	17,550.00	9,347.00	33,708.00	Ruraflex Interval
8018806098	2009	3	MARCH	200	131.42	4,097.00	9,999.00	4,201.00	18,297.00	Ruraflex Interval
8018806098	2009	4	APRIL	200	169.89	8,406.00	20,991.00	9,481.00	38,878.00	Ruraflex Interval
8018806098	2009	5	MAY	200	149.34	7,243.00	19,979.00	13,661.00	40,883.00	Ruraflex Interval
8018806098	2009	6	JUNE	200	143.79	8,283.00	20,775.00	12,429.00	41,487.00	Ruraflex Interval

Chapter 4: Organizing the Assessment

<u>**As Part of Initial Plant Tour**</u>

4.6.4 Systems Data

- Define the system (s) functions and boundaries
- Identify high energy use equipment
- Identify control methods
- Identify inefficient devices
- Initial measurement of key operating parameters

4.7 Site Specific Goals

- Based on preliminary data collection – develop a measurement plan that takes into account the three evaluation levels (to be discussed) and goals that are consistent with scope of work

Be flexible – there may be other energy savings opportunities that are discovered during the pump evaluation process that can be reviewed

Chapter 4: Organizing the Assessment

Identify existing conditions that are associated with inefficient pumping system operation such as:

- Pumping systems where significant throttling takes place
- Pumping systems with recirculation of flow used as a control scheme
- Pumping systems with large flow or pressure variations
- Multiple pumping systems where the number of operated pumps is not adjusted in response to changing conditions
- Systems serving multiple end uses where a minor user sets the pressure requirements.
- Cavitating pumps and/or valves
- High vibration and/or noisy pumps, motors or piping
- Pumps with high maintenance requirements
- Systems for which the functional requirements have changed with time, but the pumps have not.
- Motor issues: Oversizing, reduced efficiency due to rewinding etc.

Chapter 4: Organizing the Assessment

Initial Data Collection and Evaluation

Paper Mill Spray Pump Example:

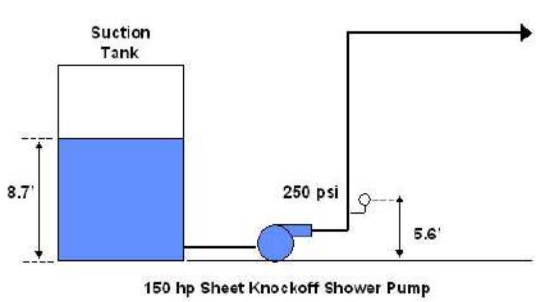
- Spray Pump was identified by staff to have potential because it was 150 hp (112 kW) and operated full time.
- However there was no apparent throttling, no re-circulation or any other energy saving symptoms.

- Normally we would move on to the next pump, but there was an existing pressure tap (reading 250 psi) and straight pipe for a flow measurement.

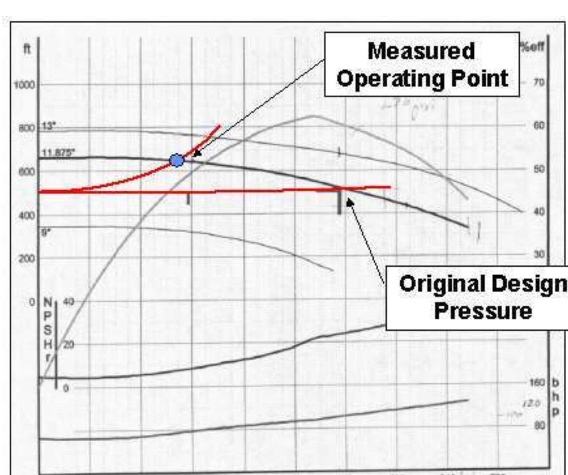
Chapter 4: Organizing the Assessment

Paper Mill Spray Pump Example:

- Walk down of system did not reveal any specific opportunity
- However compared to original design point, measured flow and pressure was operating high up on the curve.



62.4 kW x 8700 hours x $0.07/kWh = $38,000 energy cost/year



Chapter 4: Organizing the Assessment

4.8 Develop a plan of action & schedule activities

- Review information that has been collected
- Prioritize pump systems that will be reviewed in more detail (assessment levels to be discussed)
- Identify control methods
- Identify inefficient devices
- Initial measurement of key operating parameters
- Define schedule for activities (staff interviews, electrician time, meetings)

4.9 Goal Check

- Ensure Action Plan meets assessment goals

The Action Plan should include pump system sketches that can be presented on a white board, a sketch pad or handouts

ASME Standard

Chapter 5:

Conducting the Assessment

Pumping System Assessment Standard

5. CONDUCTING THE ASSESSMENT

5.1 Introduction

5.2 Assessment Levels

5.3 Walk Through

5.4 Understanding System Requirements

5.5 Determining System Boundaries and System Demand

5.6 Information Needed to Assess the Efficiency of a Pump System

5.7 Data Collection Methodology

5.8 Cross Validation

5.9 Wrap-up Meeting and Presentation of Initial Findings and Recommendations

Assessment Levels

- ***<u>Level #1</u>***

  Prescreening and gathering preliminary data *(qualitative effort)* to identify potential energy savings potential

- ***<u>Level #2</u>***

  Measurement based *quantitative* evaluation to determine energy savings. This assessment is based on “snapshot” measurements that cover a limited amount of time.

- ***<u>Level #3</u>***

  For systems where conditions vary over time. This requires more extensive *quantitative* data collection effort to develop a system load profile.

Pumping System Assessment Level

Activities	Level 1 Assessment	Level 2 Assessment	Level 3 Assessment
Prescreening opportunities	Req.	n/a	n/a
Walk through	Opt.	Req.	Req.
Identify systems with potential saving opportunities	Req.	Req.	Req.
Evaluate systems with potential saving opportunities	Opt.	Req.	Req.
Snapshot type measurement of flow, head and power data	Opt.	Req.	n/a
Measurement / data logging of systems with flow conditions that vary over time *	n/a	n/a	Req.

*** Verify and use data from plant historical information where applicable**

Level 1 Assessments

- Level 1 includes gathering system information for all pumping systems within the scope of the assessment.
- Pre-screening includes listing pump systems in the facility:
  - Motor nameplate power (may establish a minimum size)
  - Hours of operation
  - Pump function
  - Control methods

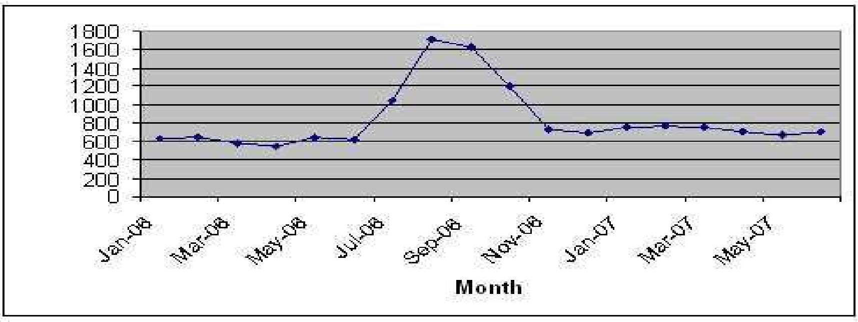
- Determine if changes will affect other systems and constrain optimization options.
- Collect Level 1 required data.

Level 2 Assessments

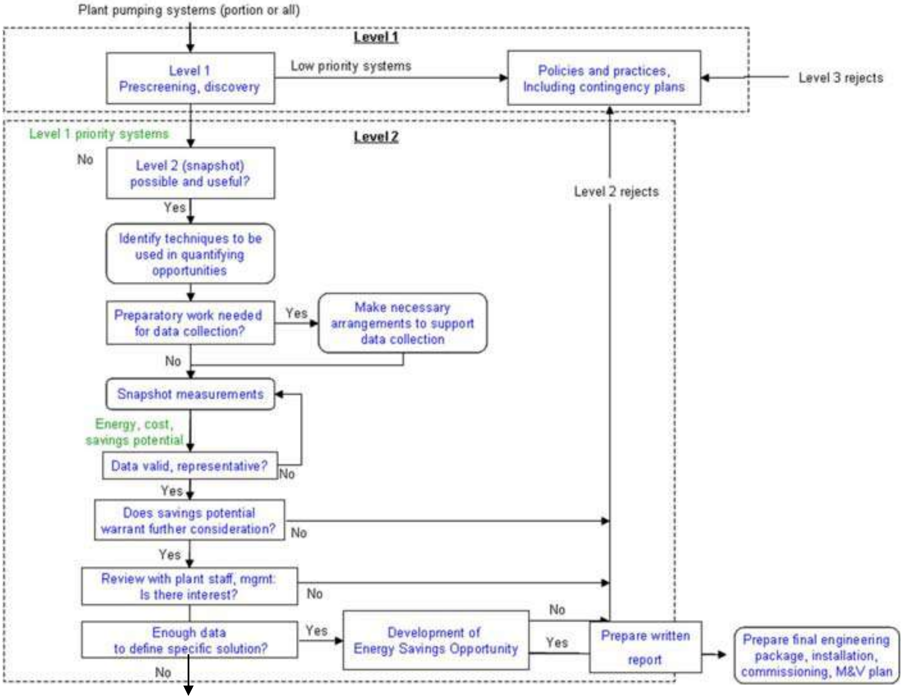
- Level 2 assessment performed using measurements of system variables from digital or paper records (operating logs, trend charts, DCS screens, etc.) or portable measuring instruments.
- Measurements taken over a limited time frame and provide a snapshot of the operating conditions.
- Observed data is representative and changes in operating conditions are small.
- Use data collected to calculate savings.

Level 3 Assessments

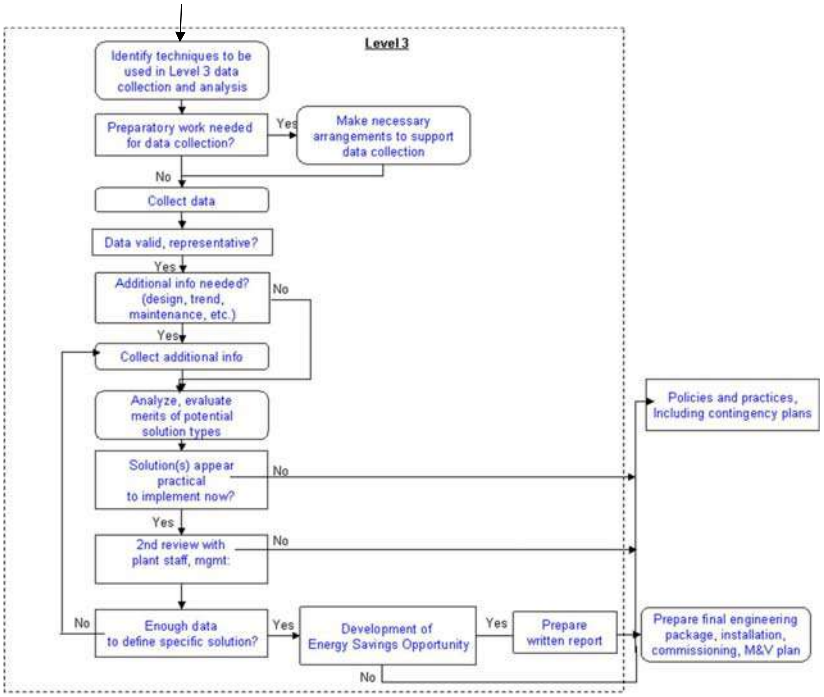
- Level 3 assessments performed on systems where operating conditions vary substantially over time, complicating the analysis.
- System performance is measured over a sufficient period of time to capture all operating conditions.
  - May use historical information from the facility's information system (DCS historian).
  - May need to connect transmitters of measured variables to data logger.



Pumping System Assessment Standard



Pumping System Assessment Standard



System Walk Through

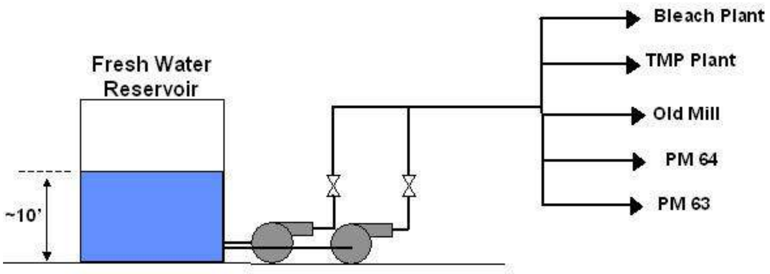
- Level 2 and 3 systems are visually inspected after pre-screening.
- Systems are traced from start to finish to ensure information reflects the actual system configuration.
- It is ideal to have an up-to-date Piping (or Process) and Instrumentation Diagram (P&ID) or a Process Flow Diagram (PFD)
- Key items to look for:
  - Measurements of flow, pressure, current, motor power
  - Control valve positions
  - Flow control methods

Assessment Levels – Example 1

What Assessment Level Applies?

Example #1:

Two water pumps operate in parallel. During the walk through the pump expert asks if the smaller pump could be turned off. After the operator deactivates the pump, there is no change in flow or pressure and the existing MCC power sub meter displays the before and after kW value.



What questions should you ask?

Assessment Example #1: Questions/Data Collection

<u>Example #1 - Sample Questions</u>

1. **How often do the pumps operate (annual hours)?**
2. **What was the reason that two pumps were put on line?**
   It is important to understand the reason behind the original decision – it might be a critical system where redundancy is extremely important.
3. **How reliable is the existing instrumentation?**
   Could flow be verified using another system flow meter, pump down test, pump curve or is there enough straight pipe for a portable flow meter?

Assessment Levels – Example #2

<u>Example #2:</u>

A paper stock pump with a 2300 V motor has a throttled discharge valve that varies from 25% open to 100% open (controlled by DCS) and a bypass valve that circulates flow back to the suction tank continuously. There is no flow meter, but there is a pressure tap on the pump discharge.

- What Assessment Level applies?
- What questions should you ask to develop a measurement plan?

Example #2: Measurement Plan Questions

<u>**Example #2 - Sample Questions**</u>

1. Is there an amperage meter on the MCC?

Although we can't measure kW with a portable meter, if there is an amperage meter (and voltage and power factor may also be available)- kW can be calculated. PSAT does a good job estimating power factor and calculating kW from amperage data.

2. Do you have a pressure gauge/flow measurement somewhere downstream?

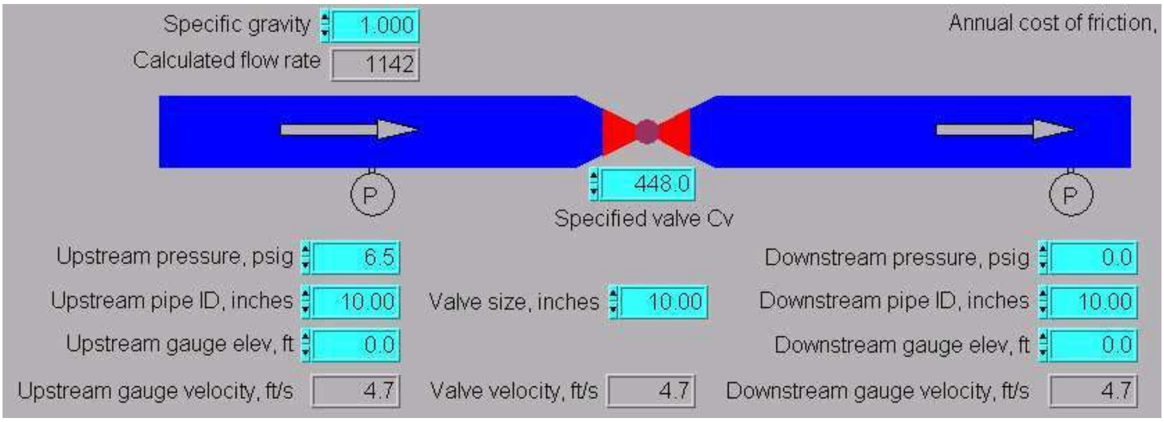
Since it is paper stock it will be difficult to get a reading with a portable ultrasonic flow meter, However, if there are minimal restrictions between the pump and a pressure gauge downstream, pressure near the pump could be estimated to see what the loss is across the valve – and a pump curve could help estimate flow.

Example #2: Measurement Plan Questions

<u>**Example #2 - Questions**</u>

3. Can they provide Cv values for the throttled valves?

With pressure on both sides of the valve and a Cv value, the PSAT valve tool can also be used to estimate flow. This can be done for the re-circulation bypass valve as well.



Example #2: Measurement Plan Questions

Example #2 - Questions

4. **Do you have hourly historical DCS data over the last 12 months that can be dumped into an Excel file?**

Since energy saving calculations depend on how often the pump flow is restricted (and bypassed). Getting DCS data for valve positions may be the only way to develop the operating profile.

Interval	Hours	Valve Position	Flow	Pressure Data	kW	kWh
1		0-20%				
2		20-40%				
3		40-60%				
4		60 to 80%				
5		80 to100%				

Establish System Requirements

- Must determine system requirements of Level 2 and 3 systems.
  - System needs must be met after optimization is implemented.
  - Normal operating conditions, minimum and maximum conditions must be considered.
- System requirements change over plant lifetime.
  - Change in flow rates due to changes in process or new loads added to the system.
- Plant engineers and operators are good sources of information.
- If records not available, observe system operation over a period of time to establish system requirements.

Establish System Boundaries

- Must determine system boundaries for Level 2 and 3 systems prior to taking measurements and doing calculations.
- System boundaries encompass:
  - Pump and driver, including power supply system (motor and VFD, if used)
  - Piping, valves, fittings, tanks, heat exchangers, boilers, etc.
- Assessment considers the overall efficiency by comparing the power needed to fulfill system requirements to the input power.

Field Data Collection

Collect Equipment and Fluid Data

- **Driver information (the ASME standard focuses on motor-driven pumps)**

  Motor nameplate: type, voltage, frequency, full load amps, rated horsepower, speed, efficiency, power factor, service factor.

- **Pump**

  Type, number of stages, speed, flow and head design point, impeller diameter, pump curve, maintenance records, presence of cavitation.

- **Fluid Properties**

  Temperature, viscosity, density or specific gravity, presence of solids

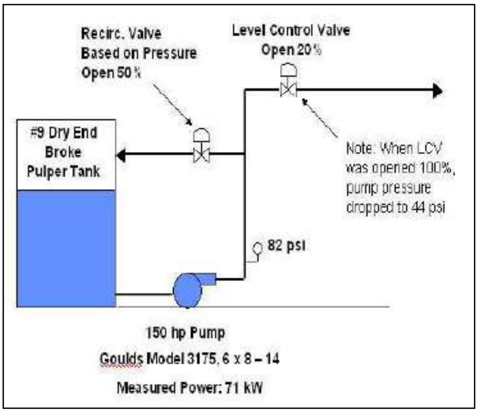
Equipment Data Collection Form

Tester		Date		Time	
Facility		System		Parallel Pumps Running:	

PUMP NAMEPLATE	ID / SET				
Pump Style	-				
Nameplate Pump Speed	RPM				
Number of Stages	-				
MOTOR NAMEPLATE					
Power	HP				
Full Load Speed	RPM				
Full Load Efficiency	%				
Rated Voltage	VOLTS				
Full Load Current	AMPS				
PUMP, FLUID DATA	Units				
Pump Rotational Speed	RPM				
Flow Rate	GPM				
Specific Gravity	-				
Suction Pressure	PSIG				
Suction Elevation	FT				
Suction Pipe Nom. Size	IN				
Discharge Pressure	PSIG				
Discharge Elevation	FT				
Discharge Pipe Nom. Size	IN				
ELECTRICAL DATA	Units				
Motor Rotational Speed	RPM				
kW A-B __ or A-GR __	kW				
kW C-B __ or B-GR __	kW				
kW C-GR __	kW				
Power Total	kW				

Collect System Data

- **Data gathered using installed plant instrumentation or portable instruments:**
  - Motor power or voltage and current
  - Pump flow rate, suction and discharge pressure
  - Flow rates to system loads
  - Pressures at system loads
  - Fluid temperature, density, and viscosity
- **Additional System Data:**
  - Static head
  - Operating hours
  - Pump control method:



VSD; Throttled valve; By-pass or recirculation; On/off; Parallel pumps; Uncontrolled

Collecting Pump Data & Field Measurements

Choose Assessment level

- Determine if data collected is a representative snapshot or if the system needs to be evaluated over a longer period of time or if historical process control data is available.
- Pressure measurements should be taken with calibrated, reliable gauges or transmitters.
- Flow measurements should be taken with properly installed, calibrated meters.
  - If using portable flow meters, confirm measurement at alternative locations
  - May use dP across a component and component curve

Data Collection Tips and Cross Validation

- Motor input power
  - Preferably measure power directly with a power meter
  - Can calculate motor input power using measured voltage and current, and estimating the power factor
- Cross-validation
  - Flow rate, pressure, and power measurements may not be available but can be determined using cross-validation
- Use pump differential pressure (total head) and pump curve to estimate flow rate
- Use motor input power and efficiency to calculate shaft horsepower, then use pump curve to estimate flow rate
- Use valve position, flow rate, and Cv data to estimate dP
- Measure drawdown and fill times to estimate flow rate

Develop a simplified flow diagram

- Capture the critical elements of the system
- How do you do that?
  - Review P&ID and piping isometrics
  - Talk with operators
  - Walk the system down (nice to have a P&ID when you do)

Slide Courtesy of Oak Ridge National Laboratory

Next...get a copy of the pump curve

Three types of pump curves

- Generic curve for pump model - usually from a manufacturers catalog
- Certified factory curve – where the pump was tested at the factory
- Field certified curve – where the pump was tested after installed in the field.

Getting a certified factory test curve for the specific pump you're buying should be encouraged as a standard practice for pumps above 50 kW; a field certified curve should be pursued for pumps above 150 kW

Centrifugal pump curve with different impeller trims

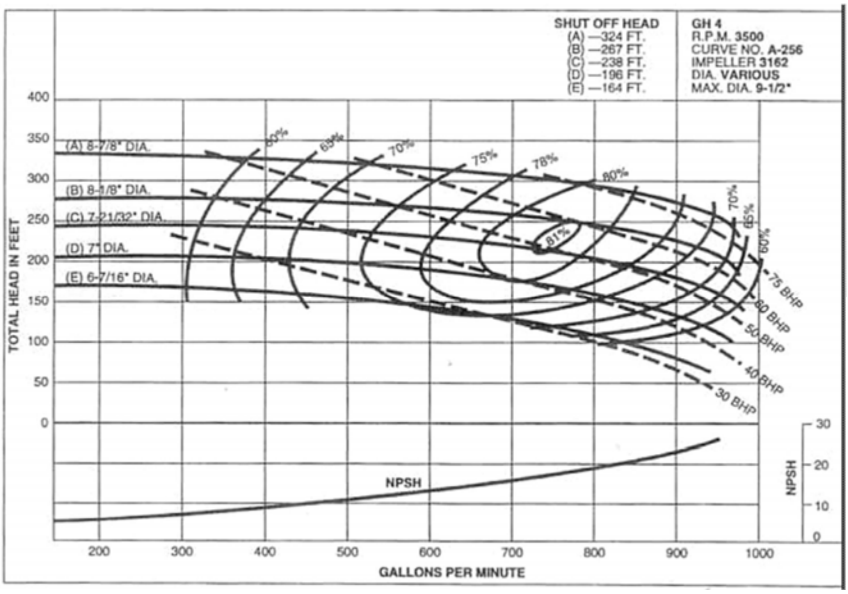
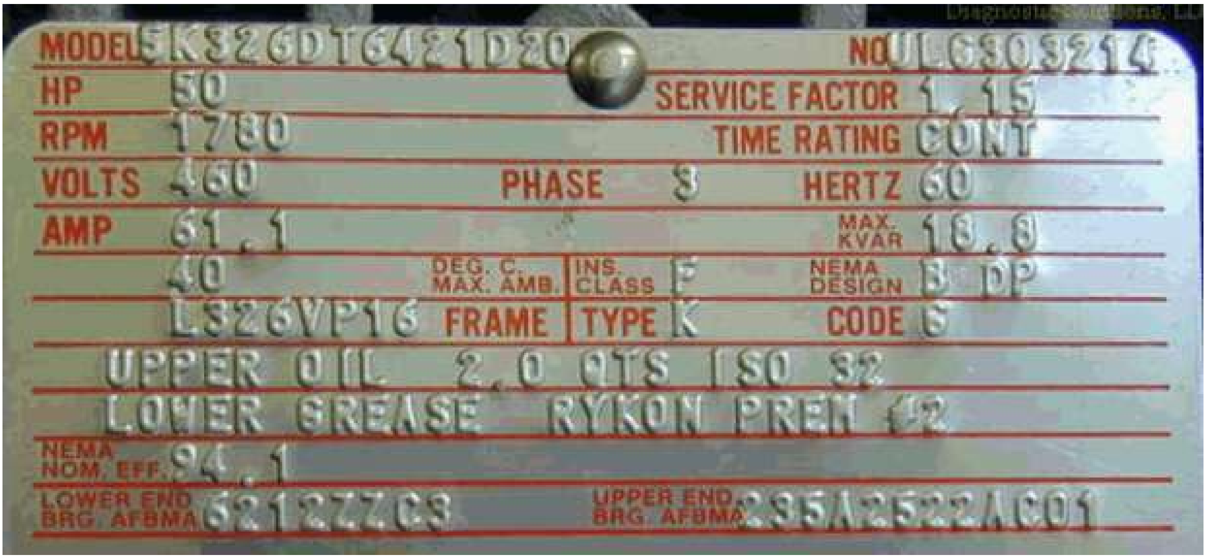


Figure Courtesy of ACR Publications

A motor nameplate



Slide Courtesy of Oak Ridge National Laboratory

Pump nameplate data

- Nameplate speed here (1800 rpm) is NOT consistent with flow rate and head, it is the *nominal* synchronous speed

Slide Courtesy of Oak Ridge National Laboratory

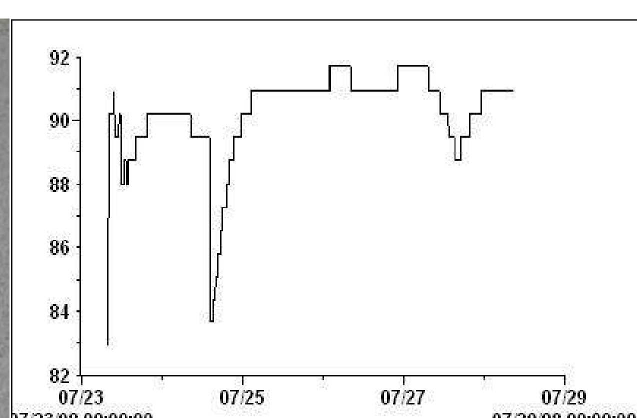
Data Logging

Data Loggers

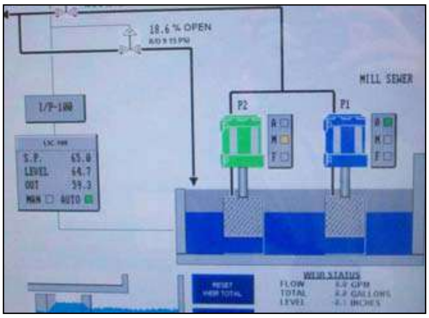
- Data loggers can provide more insight on how a pump system operates over an hour, a day or several weeks
- Simple Data Loggers such as on/off loggers or small programmable data loggers are helpful to evaluate pump cycle times and power variations (a laptop is needed to program the units)
- Many flow and power meters also have data logging features that can be used

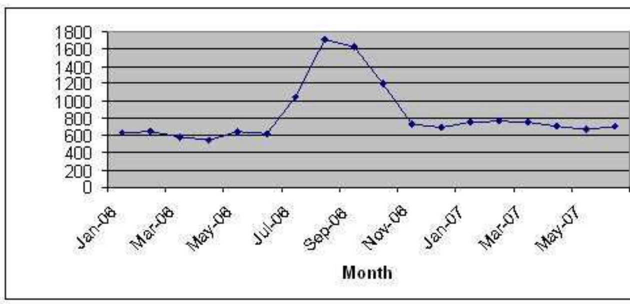
Multi-Channel Data Loggers

- Some data loggers can be used to log amperage, temperature or other types of data depending on the sensor attached. The data logger below is set up with an amp CT



SCADA/DCS trending to determine how process conditions change over a full 12 months





Introduction to the PSAT Program

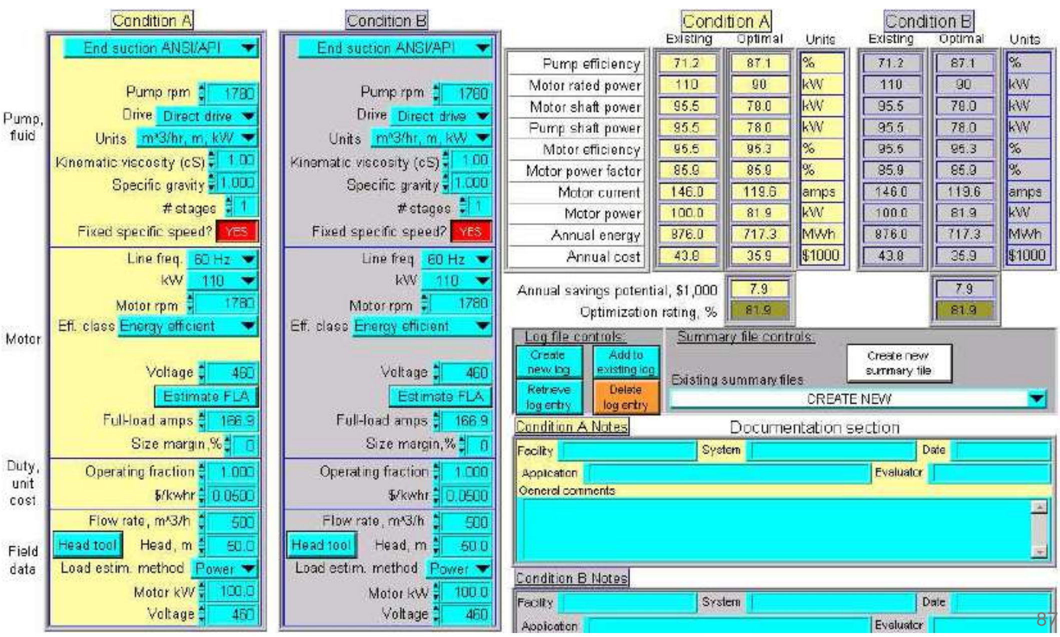
An introduction to the Pumping System Assessment Tool (PSAT)

- Goal: to assist pump users in identifying pumping systems that are the most likely candidates for energy and cost savings
- Requires field measurements or estimates of flow rate, pressure, and motor power or current
- Uses pump and motor performance data from Hydraulic Institute standard ANSI/HI-1.3 and MotorMaster+ to estimate existing, achievable performance

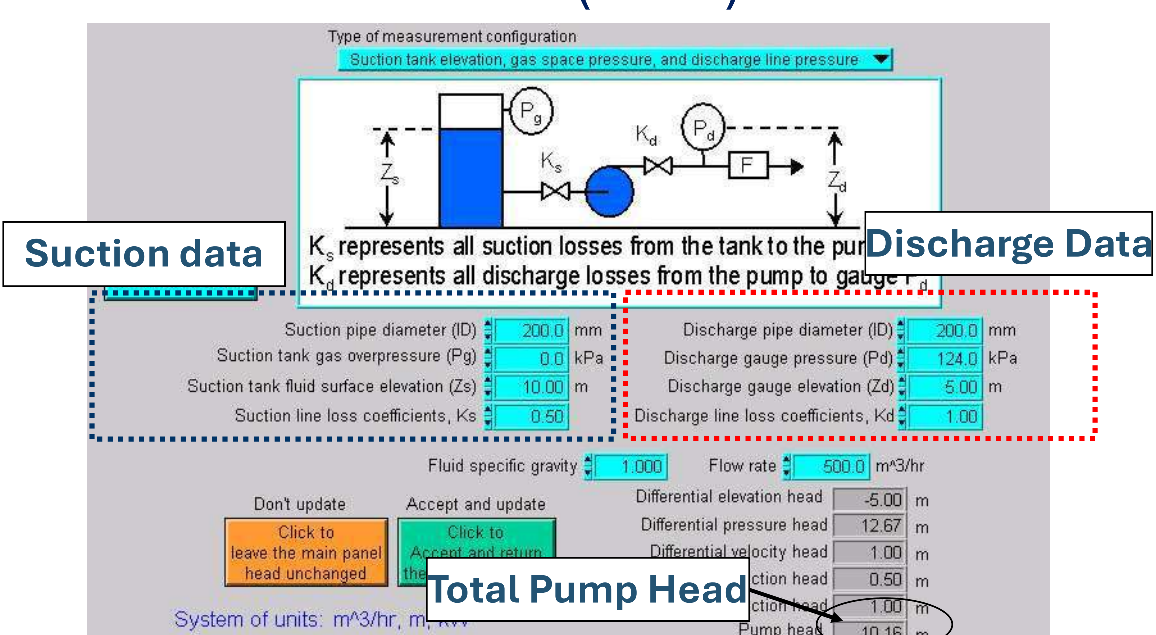
PSAT Can be used both as a component tool and as a system tool

- For a given operating point, PSAT searches for the highest pump efficiency possible at that point
- It also searches for the highest motor efficiency available to drive the found pump at that point
- It calculates the cost of operating at the point in terms of kWh used and $
- PSAT can also be used as a system tool if the minimum flow and pressure needed for the process are entered instead of current head and flow

An introduction to the Pumping System Assessment Tool (PSAT)



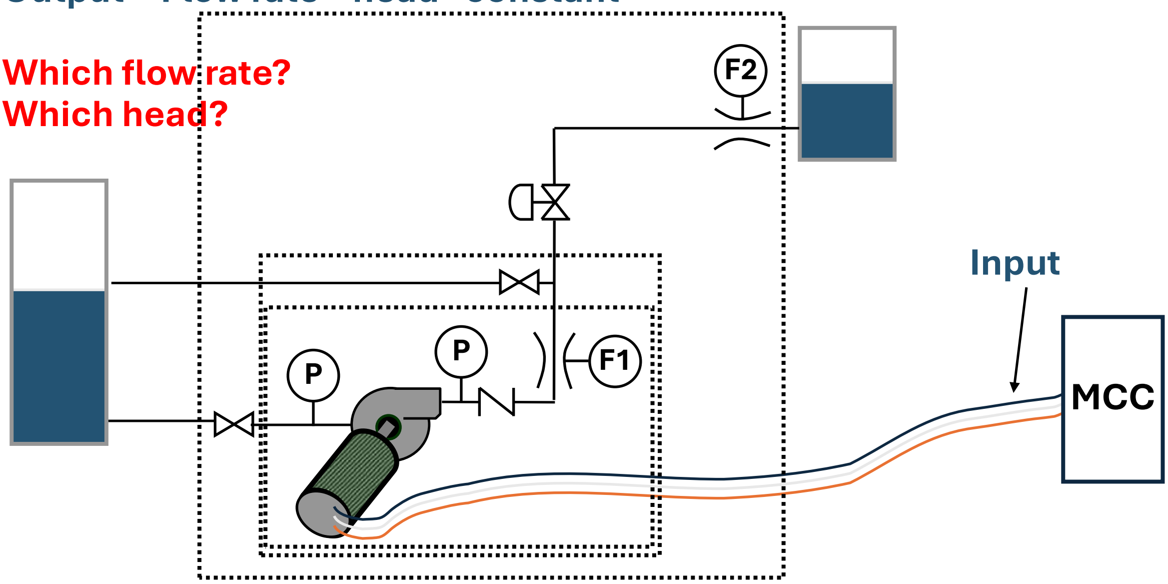
An introduction to the Pumping System Assessment Tool (PSAT) Head Tool



Defining the system

Output = Flow rate * head *constant

Which flow rate?
Which head?



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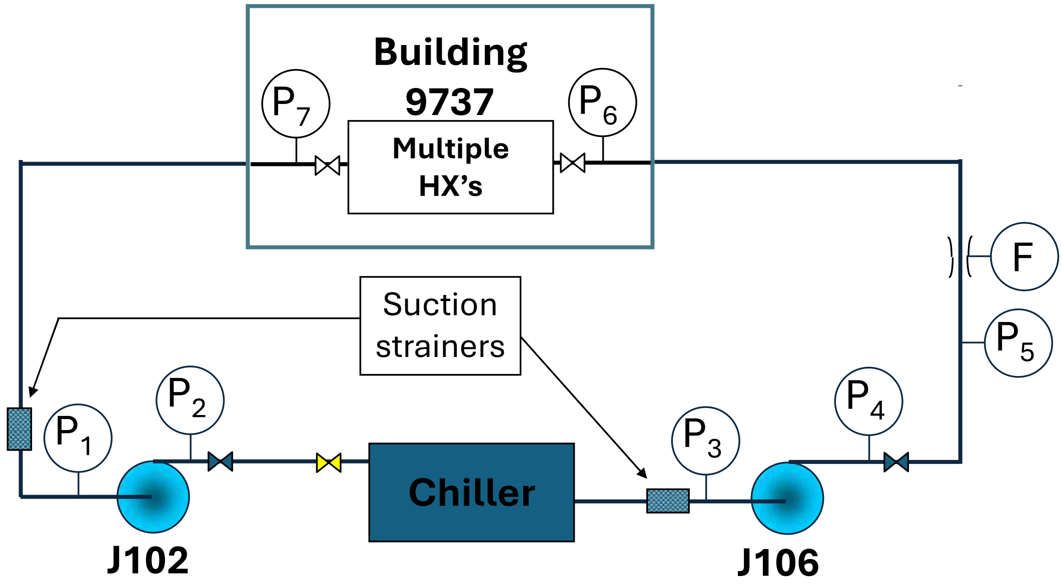
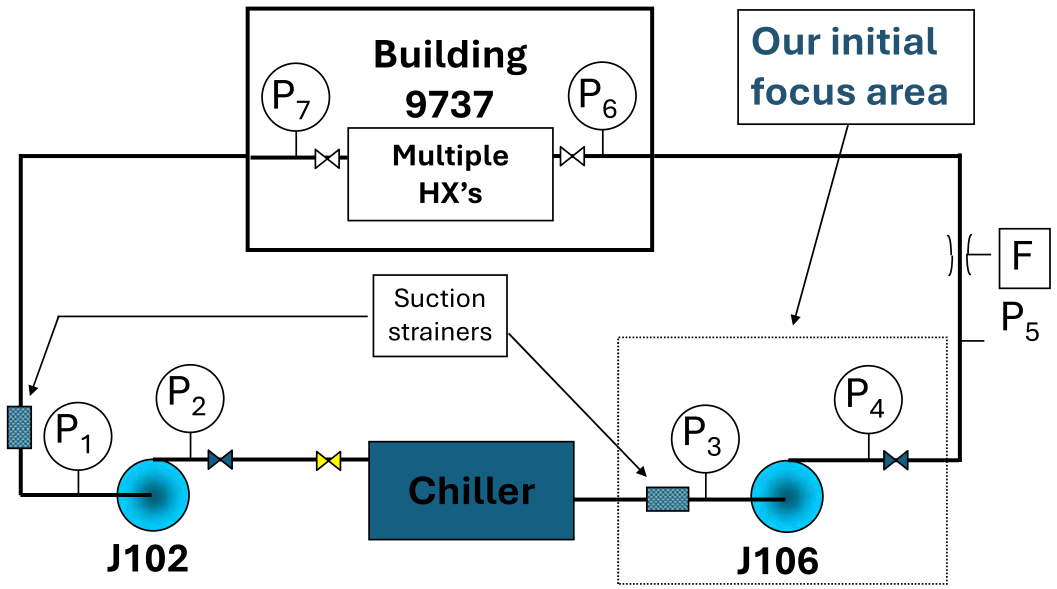
To illustrate, let's consider a real-world chilled water pumping application



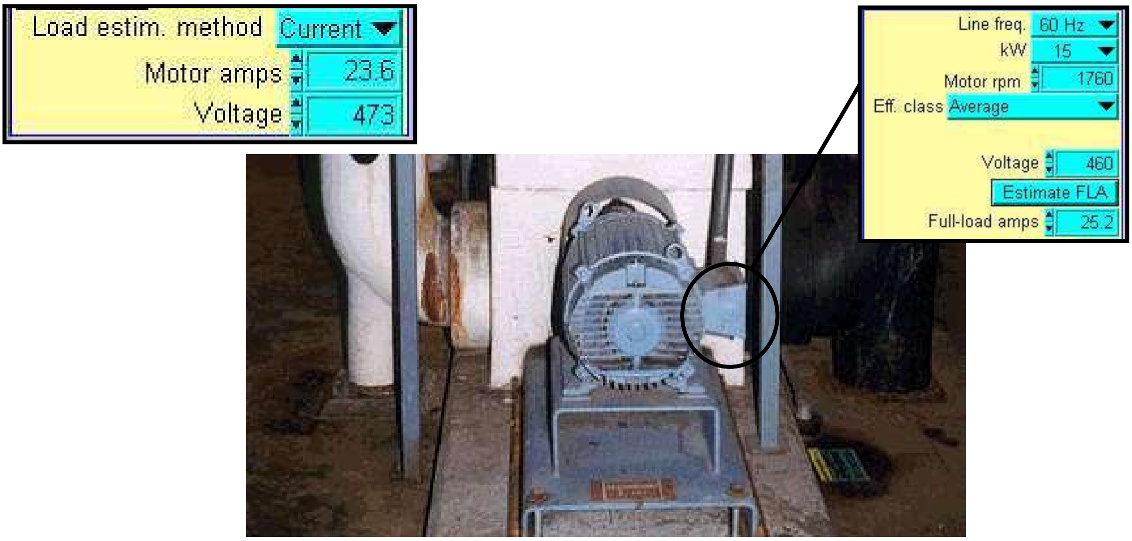
We're only going to look at a part of the system: the part surrounding secondary pump J106



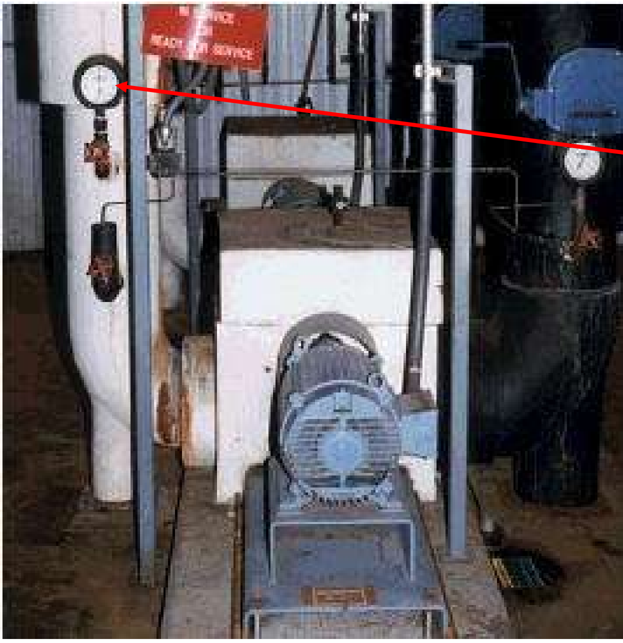
Starting at the J106 motor

Measured electrical data

Nameplate data



Pump data: 35.2 meters head, 102 m^3/hr



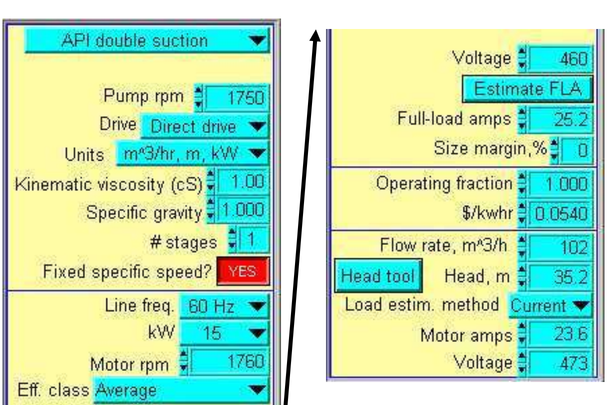
Suction gauge: 216.5 kPa

Discharge gauge: 557.1 kPa

Gauge elev. difference: .43 m

Total pump head: 35.2 m

The combined pump and motor are about 97% of optimal for this size, class of equipment



	Existing	Optimal	Units
Pump efficiency	67.9	69.0	%
Motor rated power	15	15	kW
Motor shaft power	14.4	14.2	kW
Pump shaft power	14.4	14.2	kW
Motor efficiency	90.7	92.5	%
Motor power factor	82.0	83.0	%
Motor current	23.6	22.5	amps
Motor power	15.9	15.3	kW
Annual energy	138.9	134.0	MWh
Annual cost	7.5	7.2	$1000
Annual savings potential, $1,000		0.3	
Optimization rating, %		96.5	

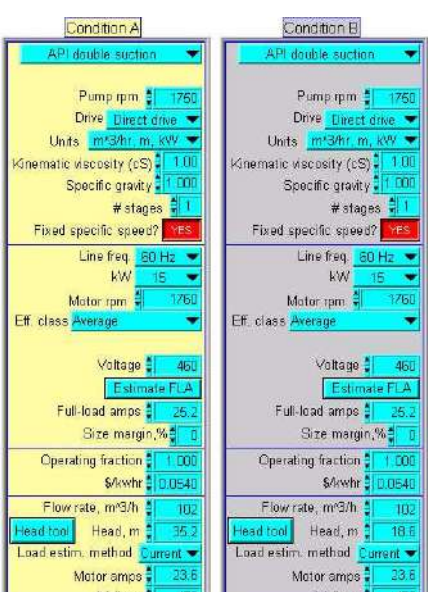
But supply and demand are unbalanced

There is > 158 kPa pressure drop across the throttled valve; the downstream pressure was measured to be 379.2 kPa (3 meters above floor)

Suction gauge:	216.5 kPa
Discharge gauge:	379.2 kPa
Gauge elev. difference:	2.0 m
Total pump head:	**18.6 m**

This is the ***net*** required head

Applying PSAT to the REQUIREMENTS - the picture of opportunity is quite different



	Condition A			Condition B		
	Existing	Optimal	Units	Existing	Optimal	Units
Pump efficiency	67.9	69.0	%	35.9	71.9	%
Motor rated power	15	15	kW	15	7.5	kW
Motor shaft power	14.4	14.2	kW	14.4	7.2	kW
Pump shaft power	14.4	14.2	kW	14.4	7.2	kW
Motor efficiency	90.7	92.5	%	90.7	90.8	%
Motor power factor	82.0	83.0	%	82.0	82.5	%
Motor current	23.6	22.5	amps	23.6	11.7	amps
Motor power	15.9	15.3	kW	15.9	7.9	kW
Annual energy	138.9	134.0	MWh	138.9	69.3	MWh
Annual cost	7.5	7.2	$1000	7.5	3.7	$1000
Annual savings potential, $1,000		0.3			3.8	
Optimization rating, %		96.5			49.8	

An important consideration: Demand and Supply - in the engineering domain

- There is often a difference between what the pump is providing the system and what the system really needs

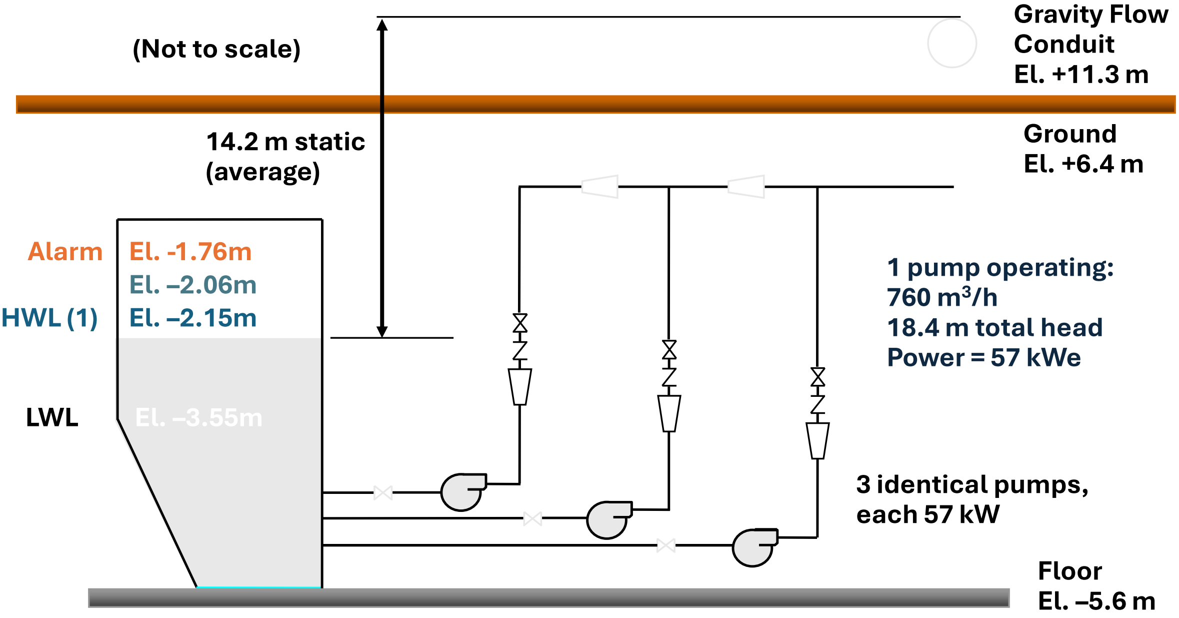
- Try to think in terms of demand, not supply

PSAT Case Studies

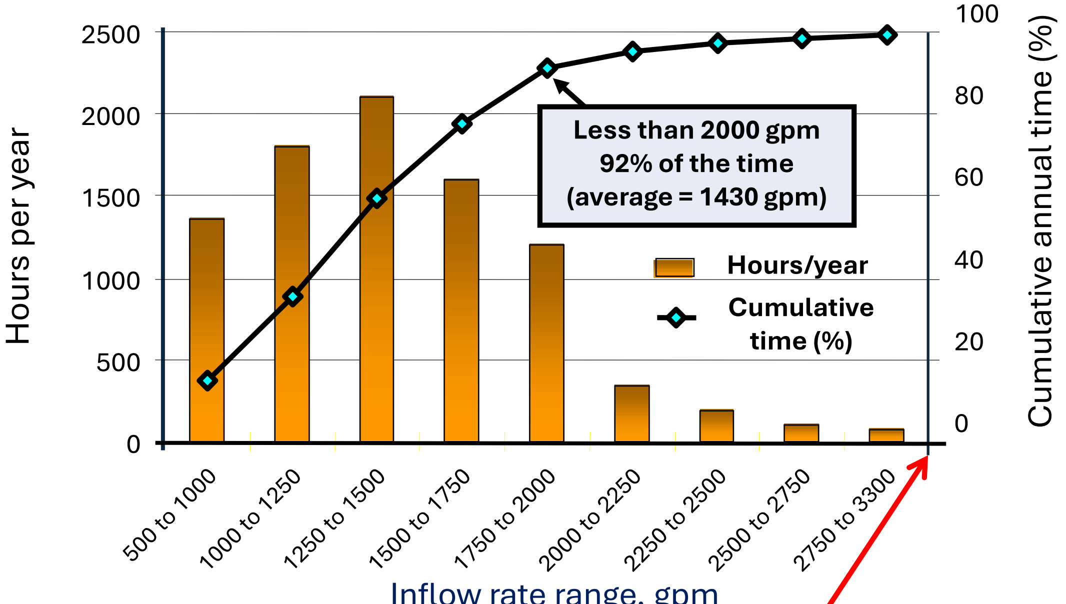
Case study example 1:

Welches Point Wastewater Lift Station (Milford, Connecticut)

The Welches Point Lift Station cycles pump(s) on/off (run 43% of time) to control wet well level

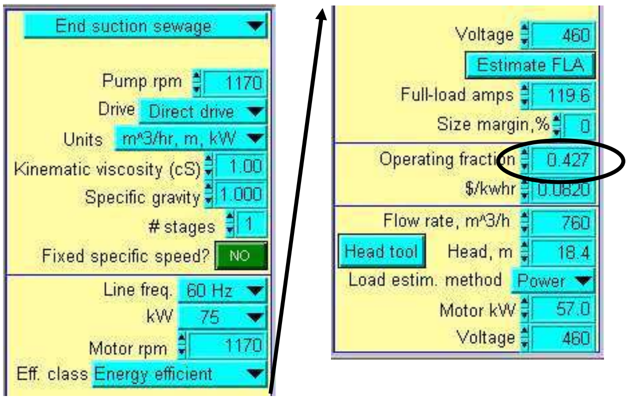


The pump design capability greatly exceeds the normal operational requirement



NOTE: Average pump flow rate = 3 350 gpm

Putting the box around the pump and motor for the existing flow and head condition

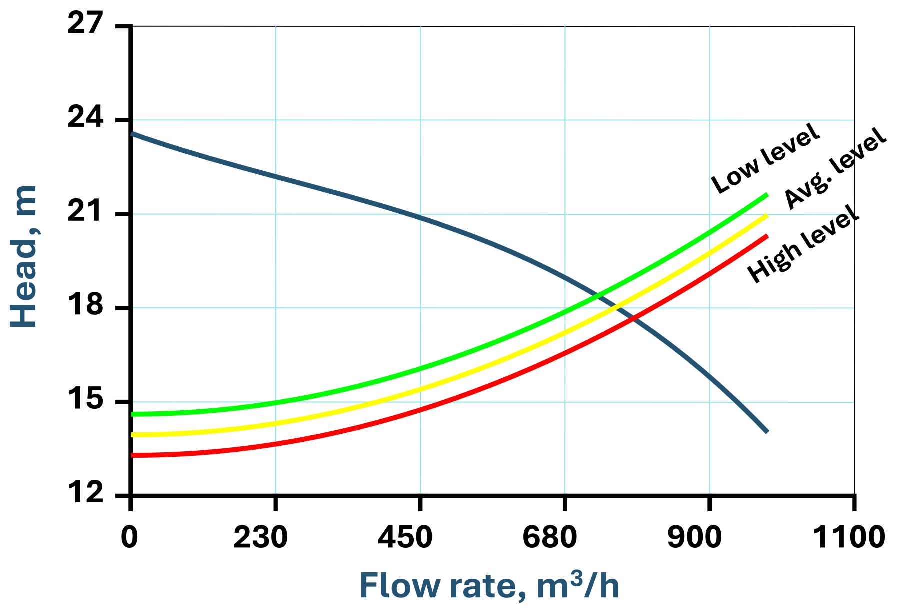


	Existing	Optimal	Units
Pump efficiency	70.4	83.2	%
Motor rated power	75	55	kW
Motor shaft power	54.0	45.7	kW
Pump shaft power	54.0	45.7	kW
Motor efficiency	94.8	94.6	%
Motor power factor	80.3	82.0	%
Motor current	89.1	73.9	amps
Motor power	57.0	48.3	kW
Annual energy	213.2	180.7	MWh
Annual cost	17.5	14.8	$1000

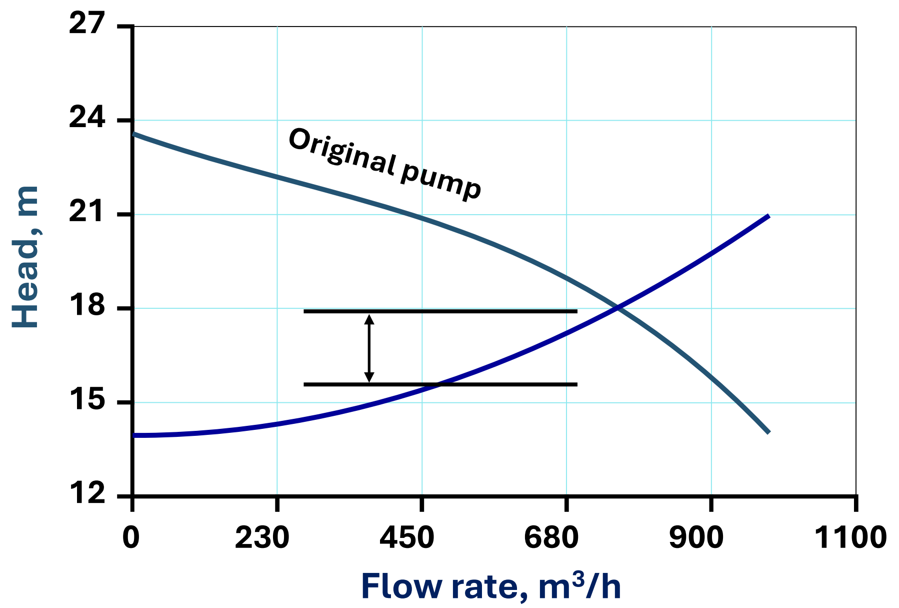
Annual savings potential, $1,000	2.7
Optimization rating, %	84.8

The efficiency is not all that bad

Existing pump and system head-capacity curves



Excessive frictional head losses occur when higher than necessary flow rates occur

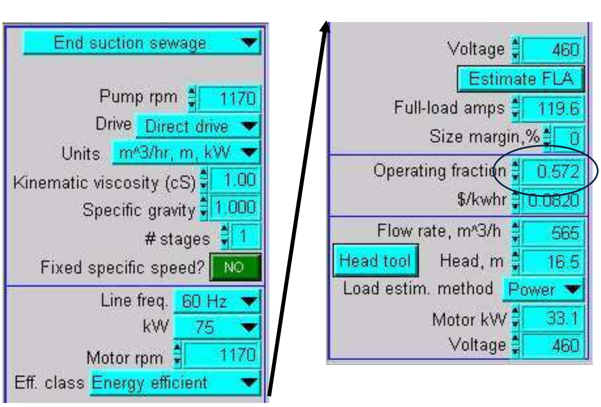


The station processes 2.84 million m^3 of water/year; What if we pumped at lower flow rates?

Average operating hours and head at different flow rates:

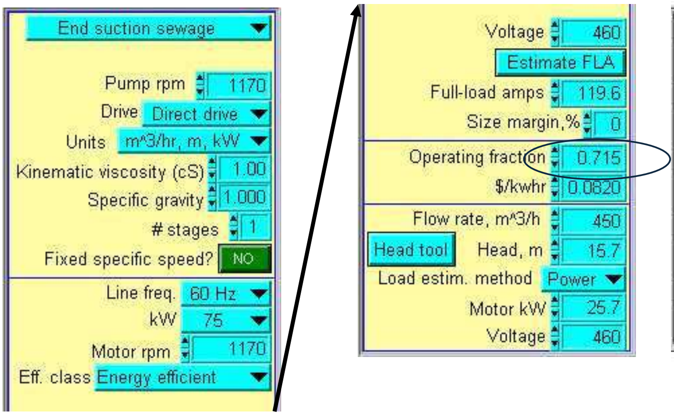
Flow Rate	Hours / Year	% of time on	Head (m)
760 m3/h	3,741	0.427	18.4m
565 m3/h	5,013	0.572	16.5m
450 m3/h	6,267	0.715	15.7m
340 m3/h	8,356	0.954	15.0m

Optimized pump at 565 m^3/h



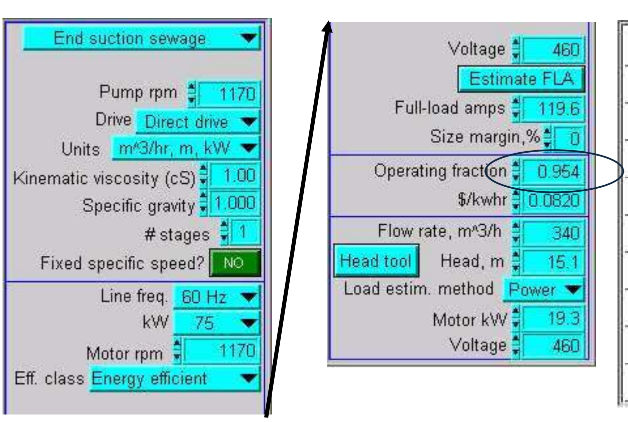
	Existing	Optimal	Units
Pump efficiency	81.7	81.7	%
Motor rated power	75	37	kW
Motor shaft power	31.0	31.0	kW
Pump shaft power	31.0	31.0	kW
Motor efficiency	93.8	94.1	%
Motor power factor	67.1	82.3	%
Motor current	61.9	50.3	amps
Motor power	33.1	33.0	kW
Annual energy	165.9	165.3	MWh
Annual cost	13.6	13.6	$1000
		0.0	
		99.7	

Optimized pump at 450 m^3/h



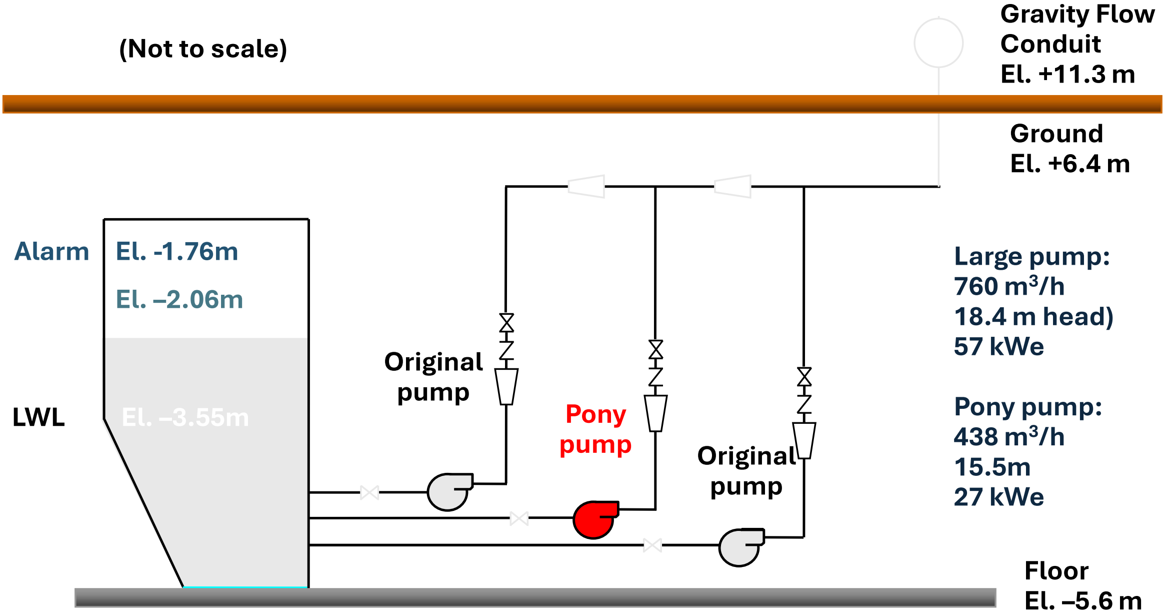
	Existing	Optimal	Units
Pump efficiency	80.5	80.4	%
Motor rated power	75	26	kW
Motor shaft power	23.9	23.9	kW
Pump shaft power	23.9	23.9	kW
Motor efficiency	92.9	93.3	%
Motor power factor	59.0	83.0	%
Motor current	54.7	38.7	amps
Motor power	25.7	25.6	kW
Annual energy	161.0	160.4	MWh
Annual cost	13.2	13.2	$1000
Annual savings potential, $1,000		0.0	
Optimization rating, %		99.7	

Optimized pump at 340 m^3/h

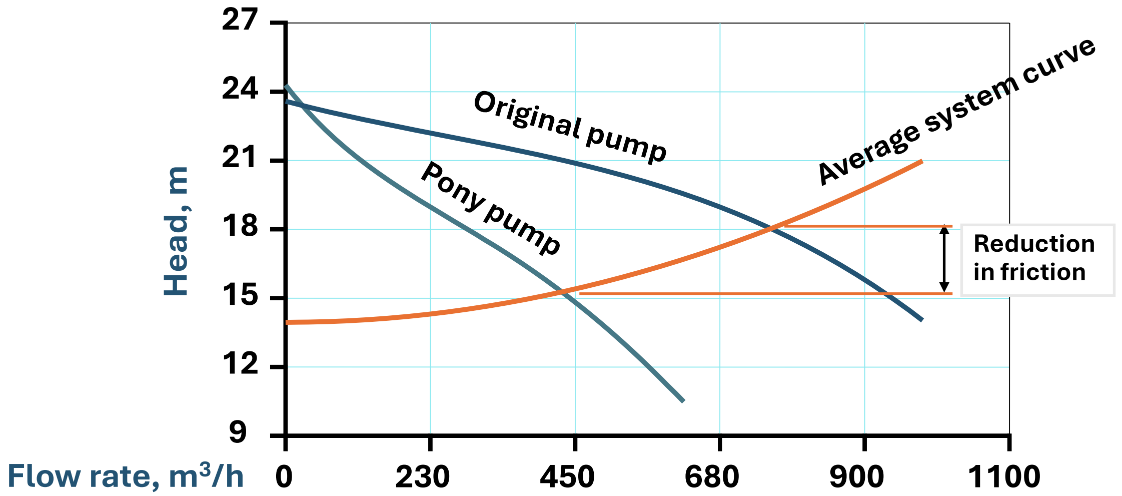


	Existing	Optimal	Units
Pump efficiency	79.0	78.7	%
Motor rated power	75	18.5	kW
Motor shaft power	17.7	17.8	kW
Pump shaft power	17.7	17.8	kW
Motor efficiency	91.5	92.5	%
Motor power factor	49.3	82.7	%
Motor current	49.1	29.1	amps
Motor power	19.3	19.2	kW
Annual energy	161.3	160.5	MWh
Annual cost	13.2	13.2	$1000
		0.1	
		99.5	

Lift station after replacing one large pump with a smaller pump

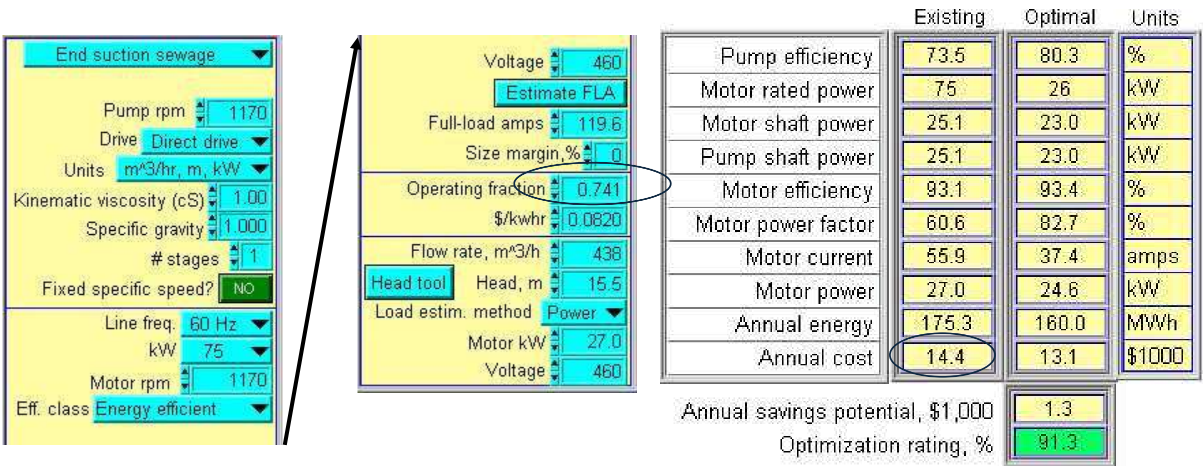


The pony pump operates efficiently at lower flow rate, eliminating 2/3 of the frictional losses



Note: The sizing of the original pump, the availability of adequate spare capacity, and nature of the system made use of a variable speed drive less attractive for this particular system.

After making the design change:



Pump Installation

A 438 m^3/hr (1 928 gallons/minute) pump replaced a 795 m^3/hr (3 500 gpm) conventional pump in a 3-pump sewage lift station

Case Study 2:

Demineralized Water System at OAK RIDGE

Now we will change from a static head dominated system to an all frictional head system

Application:

- Demineralized water pumps used for process cooling
- Original pump and motor design (4 parallel pumps):

840 m^3/hr @ 89 m head, 1 785 rpm pump

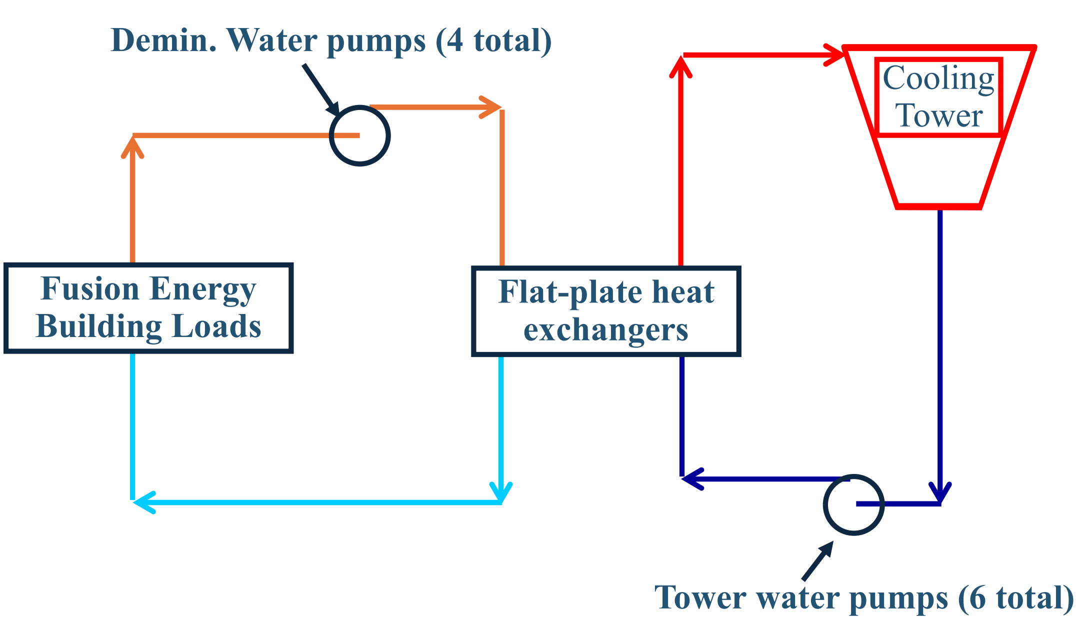
261 kW , 2 300 V, 1 785 rpm motor

Current system requirements:

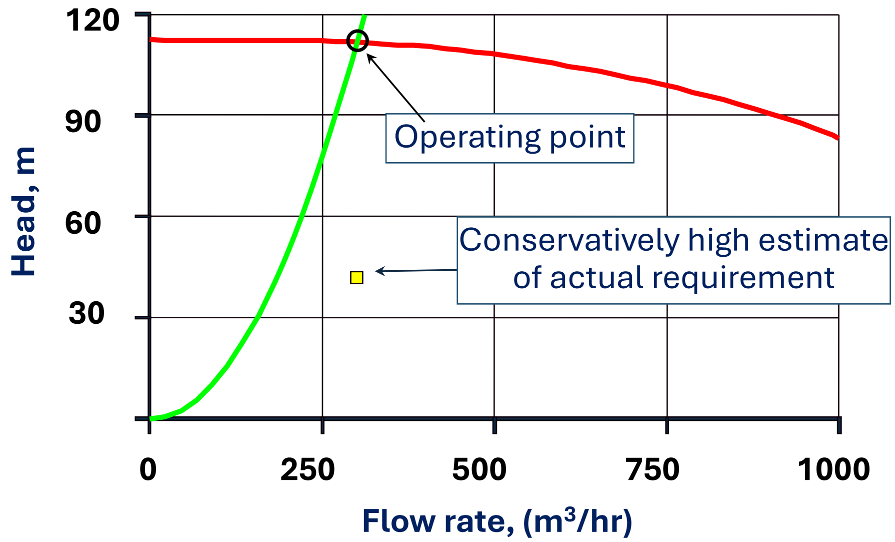
272 m^3/h @ 43 m head (conservatively high)

Demineralized and tower water pumping station for the Fusion Energy complex

Simplified flow diagram

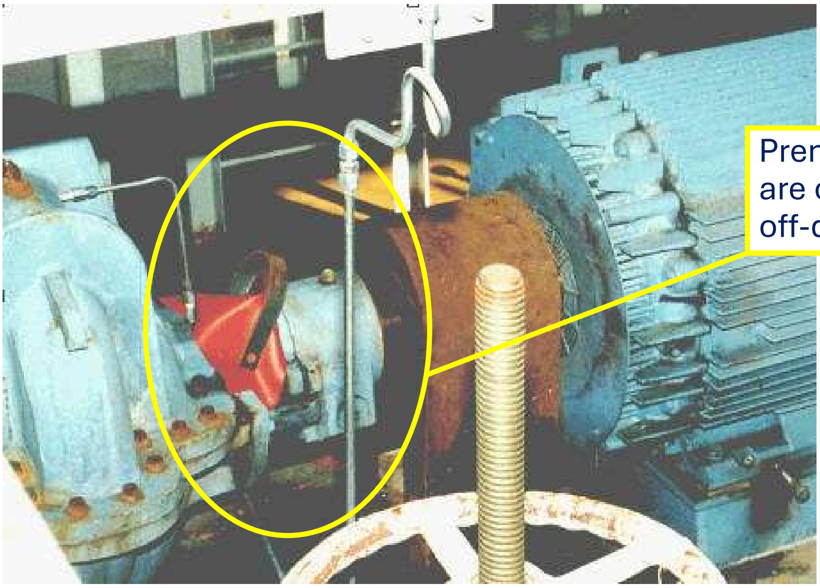


Even a conservative estimate clearly showed the effects of throttling/bypass losses



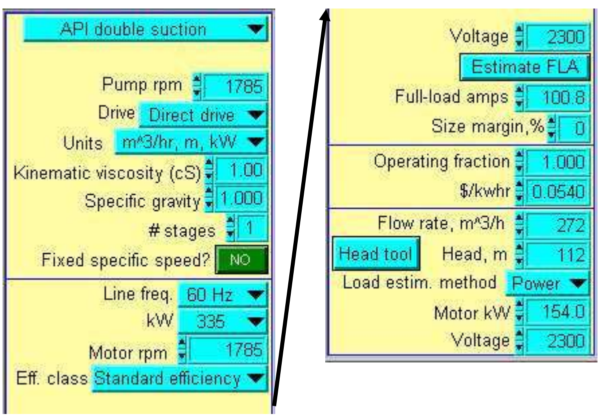
Bottom line: we were producing significantly more head than necessary

Off-design operation of pumps will result in increased operating AND maintenance costs



Premature seal failures are one consequence of off-design operation

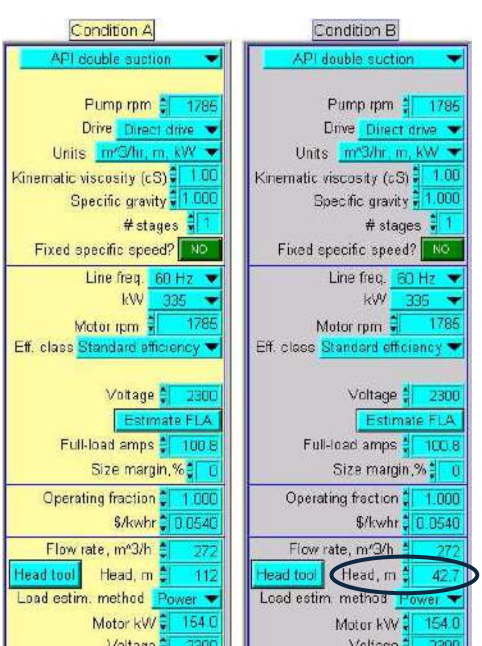
Applying the PSAT tool to the measured conditions showed significant potential savings



	Existing	Optimal	Units
Pump efficiency	57.3	80.2	%
Motor rated power	335	110	kW
Motor shaft power	144.6	103.4	kW
Pump shaft power	144.6	103.4	kW
Motor efficiency	93.9	95.5	%
Motor power factor	78.0	86.4	%
Motor current	49.5	31.4	amps
Motor power	154.0	108.2	kW
Annual energy	1349.0	948.2	MWh
Annual cost	72.8	51.2	$1000
Annual savings potential, $1,000		21.6	
Optimization rating, %		70.3	

Potential annual savings is about $22 000

Using required head estimate instead of the actual operating head could yield much greater savings



	Condition A			Condition B		
	Existing	Optimal	Units	Existing	Optimal	Units
Pump efficiency	57.3	80.2	%	21.9	80.2	%
Motor rated power	335	110	kW	335	45	kW
Motor shaft power	144.6	103.4	kW	144.6	39.4	kW
Pump shaft power	144.6	103.4	kW	144.6	39.4	kW
Motor efficiency	93.9	95.5	%	93.9	94.4	%
Motor power factor	78.0	86.4	%	78.0	85.2	%
Motor current	49.5	31.4	amps	49.5	12.3	amps
Motor power	154.0	108.2	kW	154.0	41.8	kW
Annual energy	1349.0	948.2	MWh	1349.0	365.9	MWh
Annual cost	72.8	51.2	$1000	72.8	19.8	$1000
Annual savings potential, $1,000		21.6			53.1	
Optimization rating, %		70.3			[illegible]	

Potential annual savings ~ $53 000

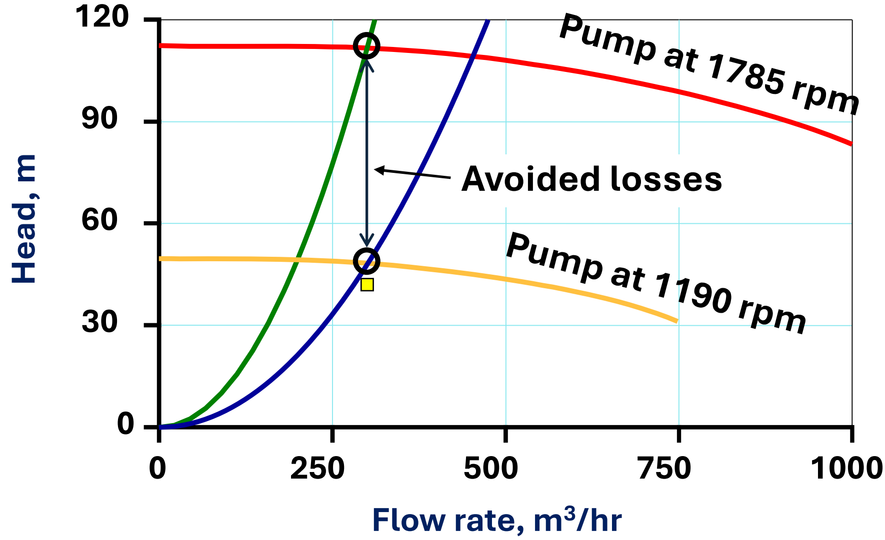
We considered some options

- Trim the pump impeller
- Get a new, smaller pump
- Add a variable speed drive

But what we finally decided was a little unconventional

A 93 kW, 6-pole (1190 rpm) motor was installed on an existing demineralized water pump

Operation of the pump at reduced speed eliminated much of the throttling losses



About $43 000 annual savings achieved by using the slower speed motor

	Condition A	Condition B
	API double suction	API double suction
Pump rpm	1785	1785
Drive	Direct drive	Direct drive
Units	m^3/hr, m, kW	m^3/hr, m, kW
Kinematic viscosity (cS)	1.00	1.00
Specific gravity	1.000	1.000
# stages	1	1
Fixed specific speed?	NO	NO
Line freq.	60 Hz	60 Hz
kW	335	335
Motor rpm	1785	1785
Eff. class	Standard efficiency	Standard efficiency
Voltage	2300	2300
Estimate FLA		
Full-load amps	100.8	100.8
Size margin, %	0	0
Operating fraction	1.000	1.000
$/kwhr	0.0540	0.0540
Flow rate, m^3/h	272	272
Head tool / Head, m	112	42.7
Load estim. method	Power	Power
Motor kW	154.0	62.0
Voltage	2300	2300

	Condition A Existing	Condition A Optimal	Units	Condition B Existing	Condition B Optimal	Units
Pump efficiency	57.3	80.2	%	56.5	80.2	%
Motor rated power	335	110	kW	335	45	kW
Motor shaft power	144.6	103.4	kW	55.9	39.4	kW
Pump shaft power	144.6	103.4	kW	55.9	39.4	kW
Motor efficiency	93.9	95.5	%	90.1	94.4	%
Motor power factor	78.0	86.4	%	49.2	85.2	%
Motor current	49.5	31.4	amps	31.6	12.3	amps
Motor power	154.0	108.2	kW	62.0	41.8	kW
Annual energy	1349.0	948.2	MWh	543.1	365.9	MWh
Annual cost	72.8	51.2	$1000	29.3	19.8	$1000
Annual savings potential, $1,000		21.6			9.6	
Optimization rating, %		70.3			67.4	

Potential additional savings ~ $10 000

Dollar and energy savings:

- Annual electricity cost reduction from this change exceeds 50 000 USD (other changes made to the system)
- Reduction in annual electrical energy is > 900 000 kWh
- The motor capital cost was 12 000 USD
- Capital cost repaid in about 3 months

There were some important tangential benefits

- Seal face speed is reduced, seal life thereby extended
- Pump is more hydraulically stable, which means fewer maintenance problems are expected
- Noise levels are reduced - both in the pump house and in the main Fusion building (hearing protection is no longer required)

Case Study 3:

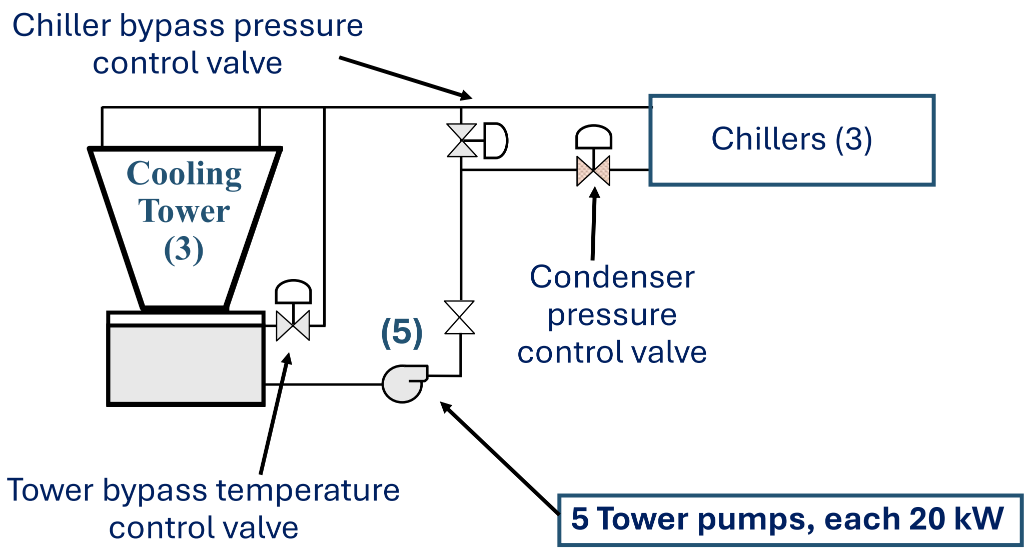
Cooling Tower Water Pump System

Multiple parallel pumps:
An outstanding idea…

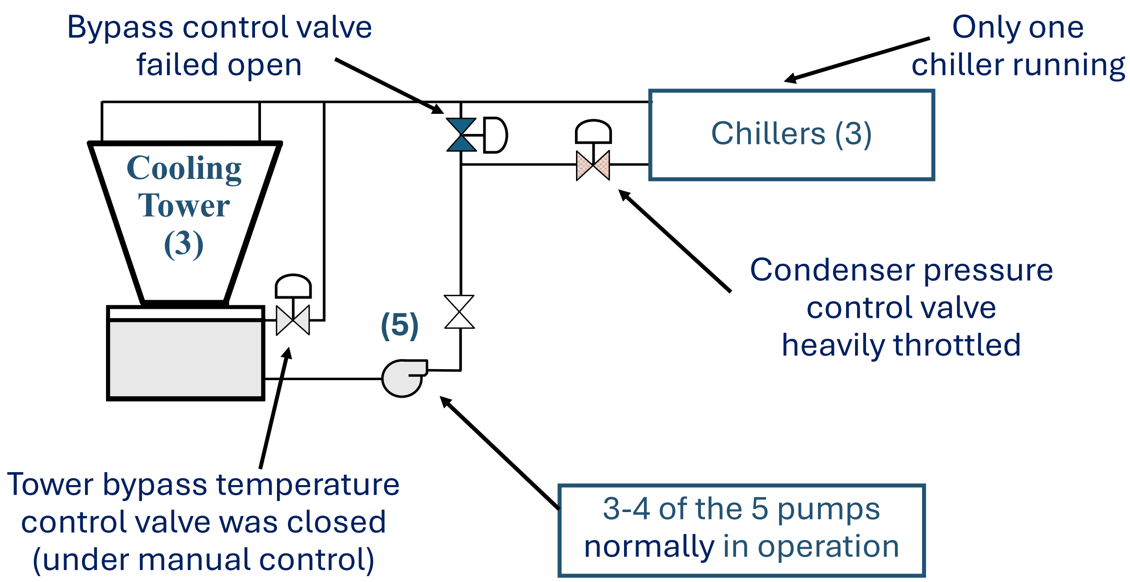
WHEN PROPERLY USED OPERATIONALLY

There is often a temptation to run more pumps than are really needed, defeating the very reason for having multiple pumps.

Simplified flow diagram of the tower water portion of the chilled water system



As found conditions: One chiller in operation, but 3 or 4 tower pumps running

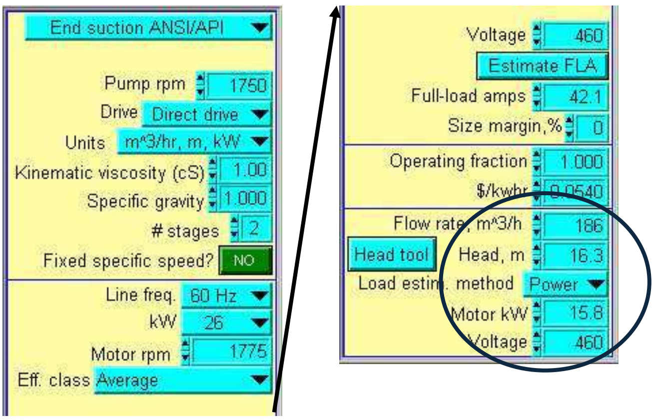


Initial corrective actions were simple

- Repaired diaphragm in failed open bypass valve, eliminating bypass flow
- Turned off all but one or two tower pumps (depending on time of the year)
- Savings: about 30 kWe ($14 000 per year)

A further look revealed additional energy reduction opportunities

Measured performance with only one original pump running (box around the pump & motor)



	Existing	Optimal	Units
Pump efficiency	56.9	83.6	%
Motor rated power	26	11	kW
Motor shaft power	14.5	9.9	kW
Pump shaft power	14.5	9.9	kW
Motor efficiency	91.7	92.0	%
Motor power factor	76.9	82.2	%
Motor current	25.8	16.4	amps
Motor power	15.8	10.7	kW
Annual energy	138.4	93.9	MWh
Annual cost	7.5	5.1	$1000
Annual savings potential, $1,000		2.4	
Optimization rating, %		67.9	

Potential annual savings ~ $2 500

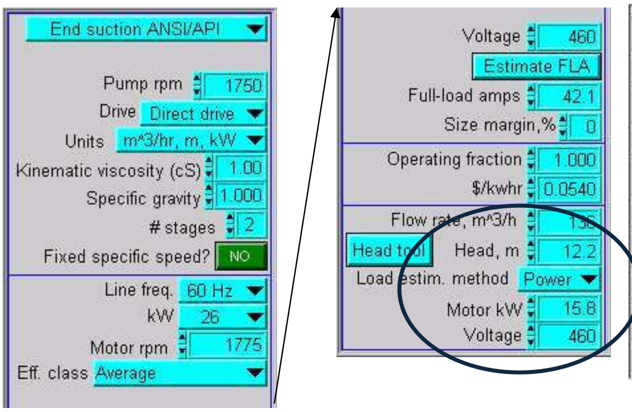
Stepping back
Consider what is really required

A general rule of thumb for chillers:

3 gpm tower water flow per ton of cooling

(6° C rise in tower water for an 80% efficient chiller)

Estimated chiller needs, based on the 3 gpm per ton rule of thumb



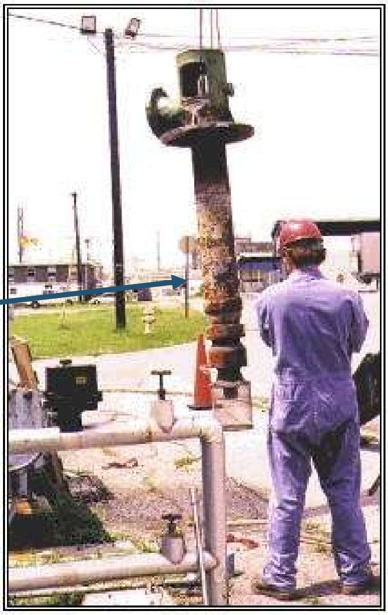
	Existing	Optimal	Units
Pump efficiency	31.1	82.0	%
Motor rated power	26	6	kW
Motor shaft power	14.5	5.5	kW
Pump shaft power	14.5	5.5	kW
Motor efficiency	91.7	90.3	%
Motor power factor	76.9	82.2	%
Motor current	25.8	9.3	amps
Motor power	15.8	6.1	kW
Annual energy	138.4	53.4	MWh
Annual cost	7.5	2.9	$1000
		4.6	
		38.6	

Potential annual savings ~ $4 600

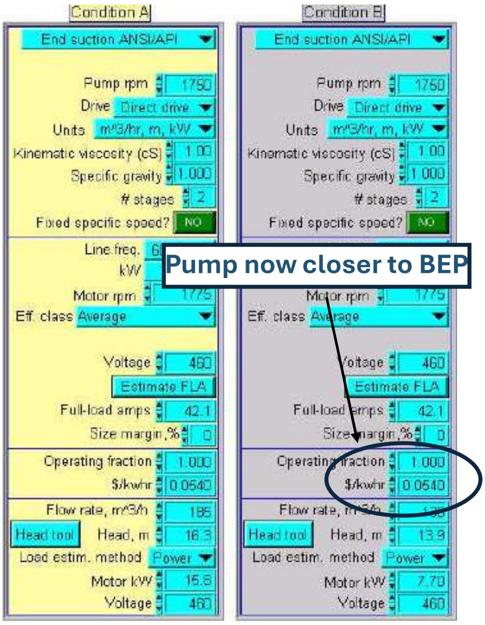
A great opportunity, but…

NO CAPITAL FUNDS

Turning maintenance problems into energy savings…



One stage was removed from two of the tower pumps (a maintenance convenience)



	Condition A Existing	Condition A Optimal	Units	Condition B Existing	Condition B Optimal	Units
Pump efficiency	56.6	83.6	%	76.3	82.0	%
Motor rated power	26	11	kW	26	7.5	kW
Motor shaft power	14.5	9.8	kW	6.7	6.3	kW
Pump shaft power	14.5	9.8	kW	6.7	6.3	kW
Motor efficiency	91.7	92.0	%	87.5	91.1	%
Motor power factor	76.9	82.1	%	56.7	80.8	%
Motor current	25.8	16.3	amps	17.1	10.7	amps
Motor power	15.8	10.7	kW	7.7	6.9	kW
Annual energy	138.4	93.4	MWh	67.5	60.3	MWh
Annual cost	7.5	5.0	$1000	3.6	3.3	$1000
Annual savings potential, $1,000		2.4			0.4	
Optimization rating, %		67.5			89.4	

Achieved annual savings of about $4 000 per pump-year

Sample Problem

Sample Problem

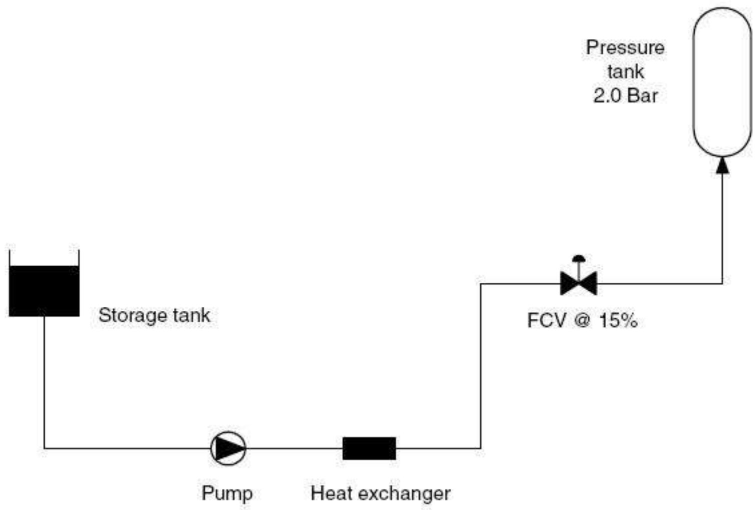
System with a Problem Control Valve

In this example the LCC analysis for the piping system is directed at a control valve. The system is a single pump circuit that transports a process fluid containing some solids from a storage tank to a pressurized tank. A heat exchanger heats the fluid, and a control valve regulates the rate of flow into the pressurized tank to 80 m^3/h (350 USgpm).

The plant engineer is experiencing problems with a control valve that fails as a result of erosion caused by cavitation. The valve fails every 10 to 12 months at a cost of 4000 Euro or USD per repair. A change to the control valve is being considered to replace the existing valve with one that can resist cavitation.

Before changing out the control valve again, the project engineer wanted to look at other options and perform a LCC analysis on alternative solutions.

Sample Problem



Sketch of pumping system in which the control valve fails
Storage tank, Pump, Heat exchanger, FCV @ 15%, Pressure tank 2.0 Bar

Sample Problem

How the system operates:

- The first step is to determine how the system is currently operating and to determine why the control valve fails, then to see what can be done to correct the problem.
- The control valve currently operates between 15 to 20 percent open and with considerable cavitation noise from the valve. It appears the valve was not sized properly for the application. After reviewing the original design calculations, it was discovered that the pump was sized for 110 m3/h instead of 80 m3/h resulting in a larger pressure drop across the control valve than originally intended.
- As a result of the large differential pressure at the operating rate of flow, and the fact that the valve is showing cavitation damage with regular intervals, it is determined that the control valve is not suitable for this process.

Sample Problem

The following four options are suggested:

A. A new control valve can be installed to accommodate the high pressure differential.

B. The pump impeller can be trimmed so that the pump does not develop as much head, resulting in a lower pressure drop across the current valve.

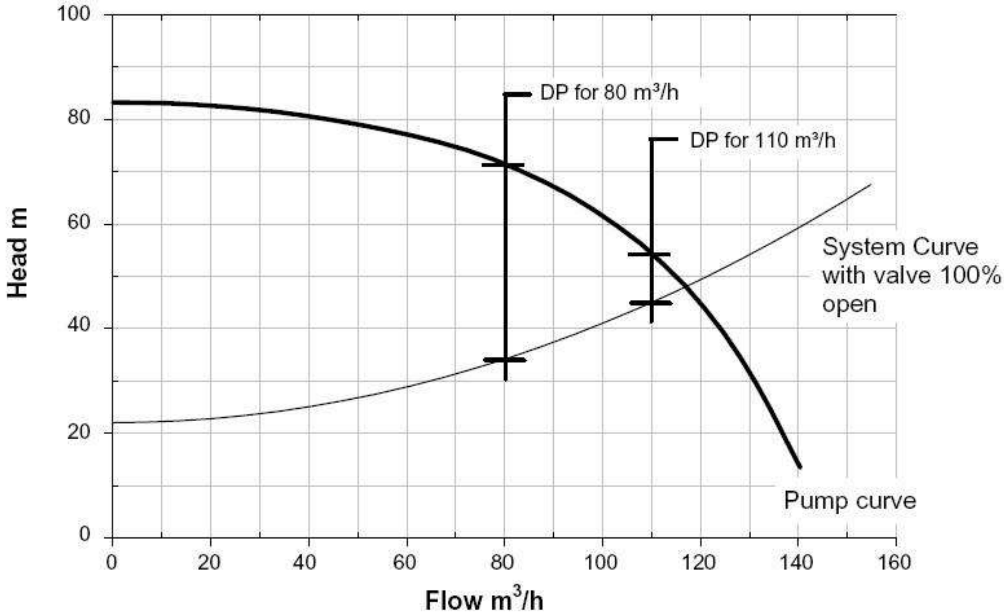
C. An adjustable speed drive (such as a variable speed drive - VSD) can be installed, and the flow control valve removed. The VSD can vary the pump speed and thus achieve the desired process flow.

D. The system can be left as it is, with a yearly repair of the flow control valve to be expected.

Option Costs

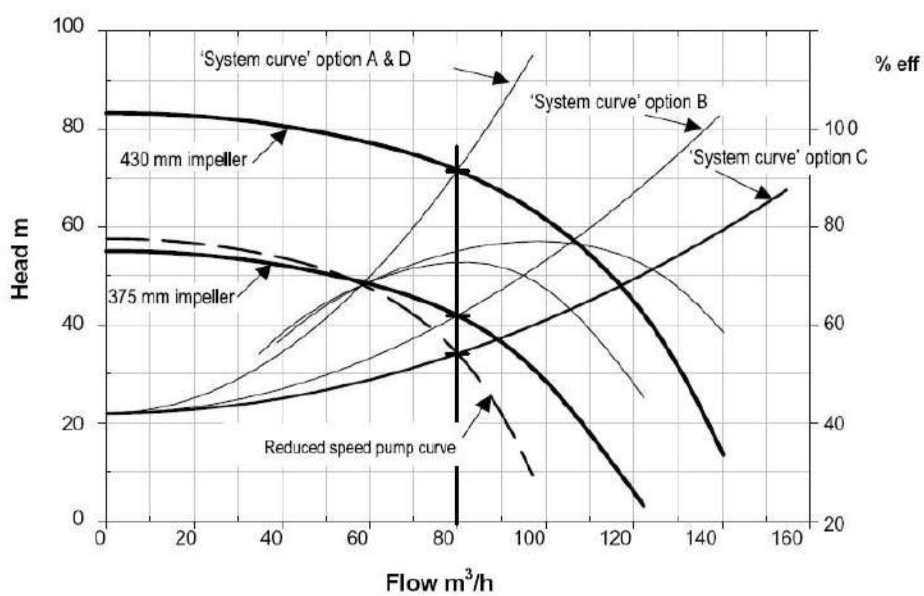
- The cost of a new control valve that is properly sized is $5 000
- It costs $2 250 to trim the impeller including the cost to disassemble and reassemble the pump
- A 30 kW VSD costs $20 000, and an additional $1500 to install. The VSD will cost $500 to maintain each year but will not need any repairs over the project's 8-year life
- The option to leave the system unchanged will result in a yearly cost of $4 000 for repairs to the cavitating flow control valve
- The process operates at 80 m^3/h for 6000 hr/year. The energy cost is $0.08 per kWh and the motor efficiency is 90 percent

Sample Problem



Pump and System curves

Sample Problem - Options



Pump and System curves for impeller trimming, variable speed operation, and different system curves

Sample Problem - Comparison

- When operating at 71.1m head, the total annual energy cost is $11 088
- By trimming the impeller to 375 mm, the pump's total head is reduced to 42 m at 80 m³/h. This drop in pressure reduces the differential pressure across the control valve to less than 10 m, which better matches the valve's original design point, so there will not be any additional cost due to control valve failures
- The resulting annual energy cost with the smaller impeller is $6 720
- By installing the VSD, the pump's total head is reduced even further to 34.4m at 80 m³/h. The resulting annual energy cost with the reduced speed is $5 568

Cost Comparison

Table: Cost comparison for Options A through D in the system with a failing control valve.

Cost	Change Control Valve (A)	Trim Impeller (B)	VSD (C)	Repair Control Valve (D)
Pump Cost Data				
Impeller Diameter	430mm	375mm	430mm	430mm
Pump Head	71.1m	42.0m	34.4m	71.1m
Pump Efficiency	75.1%	72.7%	77%	75.1%
Rate of flow	80m3/h	80m3/h	80m3/h	80m3/h
Power Consumed	23.1kW	14.0kW	11.6kW	23.1kW
Power Cost / yr	$ 11,088	$ 6,720	$ 5,568	$ 11,088
New Valve	$ 5,000	0	0	0
Modify Impeller	0	$ 2,250	0	0
VSD	0	0	$ 20,000	0
Installation of VSD	0	0	$1,500	0
Valve repair/year	0	0	$ 500	$ 4000

Sample Problem

- **What benefits do you see in the different solutions?**
- **Which would you recommend and why?**

Key Take-Away

- My key take-away about identifying and qualifying pump system optimization opportunities is:
- After participating in this training, I believe that there ___ [is] ___ [is not] potential in my facility for pump optimization.

Thank you!

Have a pleasant evening

DISCLAIMER

This document was developed within the framework of the project “Accelerating energy efficiency in large industries through energy management systems, system optimization and the promotion and adoption of energy efficiency in small and medium-sized enterprises (IEEP)”, funded by the European Union (EU), managed by the Ministry of Industry and Trade (MOIT), and implemented by the United Nations Industrial Development Organization (UNIDO). The content of this document is the sole responsibility of the Project and does not necessarily reflect the views of any individual or organization.