Pump Systems Optimisation
User Training

(Egypt Edition – Sep 2021)

Presented by:

Albert Williams & Siraj Williams

Welcome

- Name
- Organisation
- Energy management experience
- What do you expect to learn over these few days?

Acknowledgements

- UNIDO, Vienna
- US DOE
- Oak Ridge National Laboratory
- Dr G Hovstadius
- Barry Platt
- Siraj Williams

Contents of this Course

Agenda: Day 1

PSO User Day 1			
TIME	**DESCRIPTION**	**SLIDES**	**PERSON**
09:00 – 09:30	Welcome and registration		TI
09:30 – 11:15	1. Pump System Optimisation 2. The Systems Approach 3. Pump Types 4. Pump System Fluid Relationships		AW AW SW SW
11:15 – 11:45	TEA		
11:45 – 13:45	5. Pump Performance Characteristics 6. Pump System Energy Use		AW AW
13:45 – 14:45	LUNCH		
14:45 – 16:45	7. Introduction to PSAT / Measur 8. Case studies		SW SW
16:45 – 17:00	SUMMARY OF DAY 1		

Agenda: Day 2

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PSO User Day 2			
TIME	**DESCRIPTION**	**SLIDES**	**PERSON**
09:30 – 11:15	9. Valve Tool 10. ASME standards • Organising the assessment • Conducting the assessment		AW AW SW SW
11:15 – 11:45	TEA		
11:45 – 13:45	11. Data Collection & Analysis • Data gathering • Measuring Flow, Pressure, Power • Analysing the data		AW AW SW SW
13:45 – 14:45	LUNCH		
14:45 – 16:45	12. Example: Systems analysis 13. Class Test		AW SW
16:45 – 17:00	SUMMARY OF DAY 2		

01. Pump System Optimisation

Pump Basics

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What is Pump System Optimization?

- Pump system optimization is a systematic approach to evaluate high energy use pumps and 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.

Initiating a Project

- Requires Financial Justification
- Consider Life Cycle Costs
- LCC considerations
- Purchase costs
- Installation & Commissioning costs
- Energy costs
- Other operating costs
- Maintenance costs
- Down time costs
- Decommissioning costs
- Environmental costs

Comparing Life Cycle Costs

Vehicle vs Pump & Motor System

Item	Motor Car	Pump & Motor
Initial energy cost rate	$ 0.50 /litre	$ 0.12 /kWh
Energy inflation rate	10% /yr	10% /yr
Operating extent	32 000 km/yr	7 000 h/yr (80%)

Common assumptions

- Discount rate = 8%
- Non-energy inflation rate = 4%
- Lifetime = 5 years

Life Cycle Cost - Vehicle

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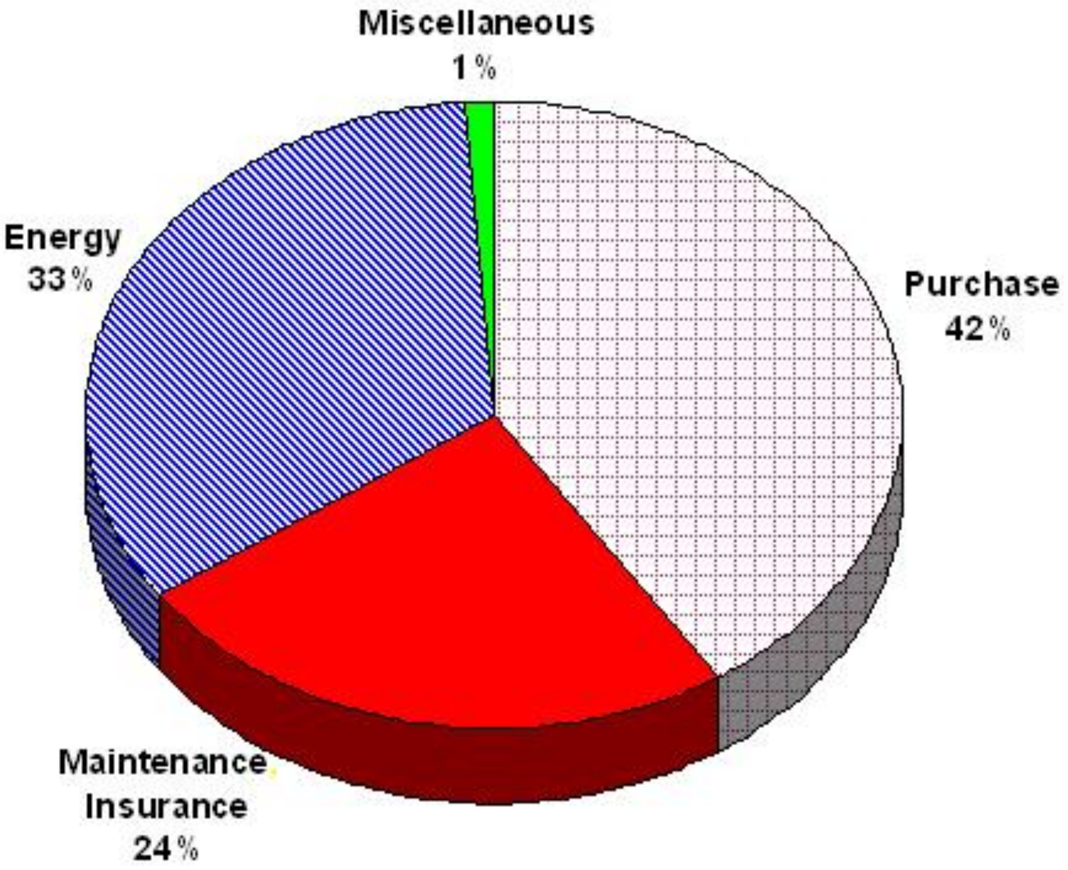
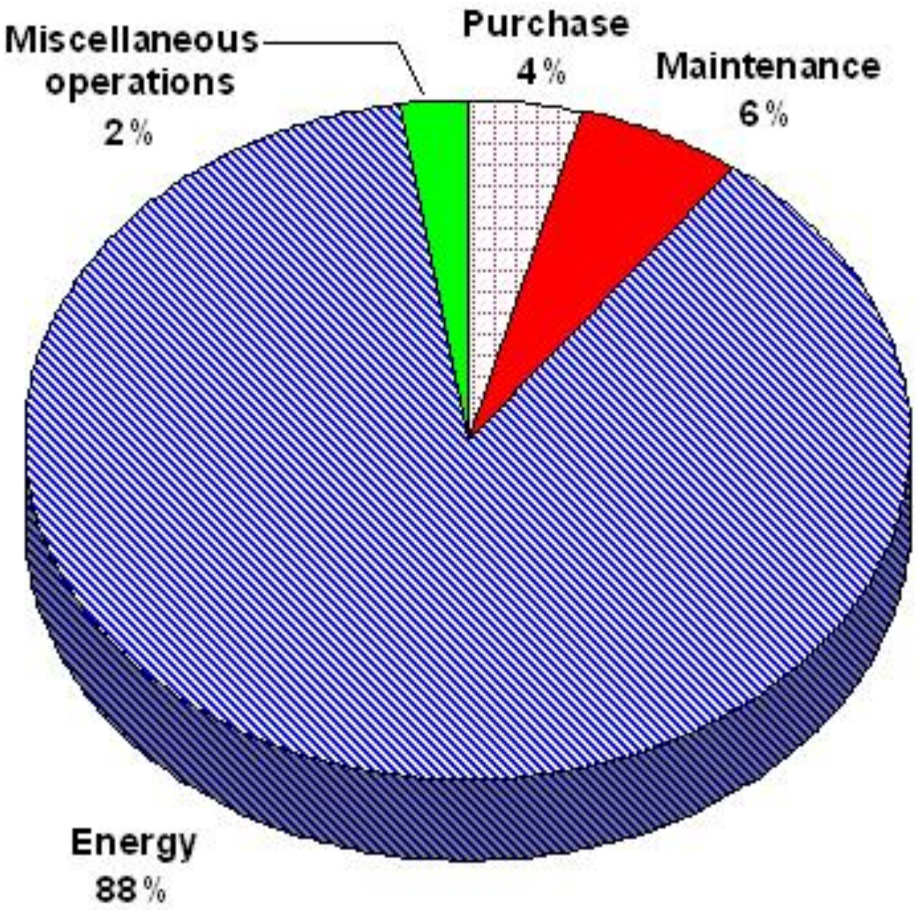


- $10 000 purchase
- 10 km/l
- 32 000 km/yr

1st year energy cost:
$1 600

Life Cycle Cost – 200kW Pump and Motor



- $10 000 initial cost
- $1 500 /yr maintenance

First year energy cost

= 100kW x 7 000hrs x $ 0.12/kWh

= $84 000

(motor drawing 50% of FLA)

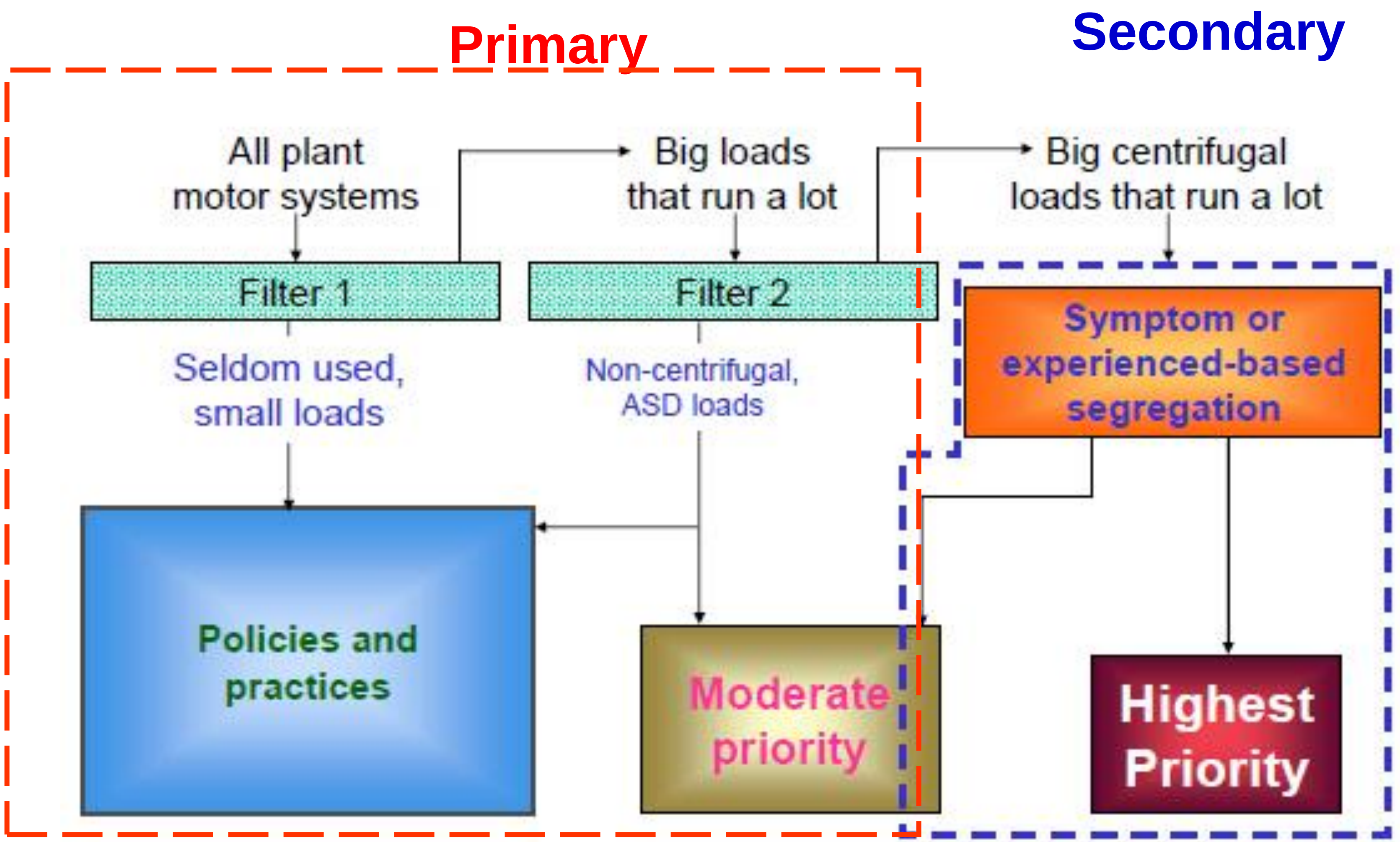
Prescreening

The US 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.

Slide Courtesy of Oak Ridge National Laboratory

Primary & Secondary Prescreening



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02. The Systems Approach

Pump Basics

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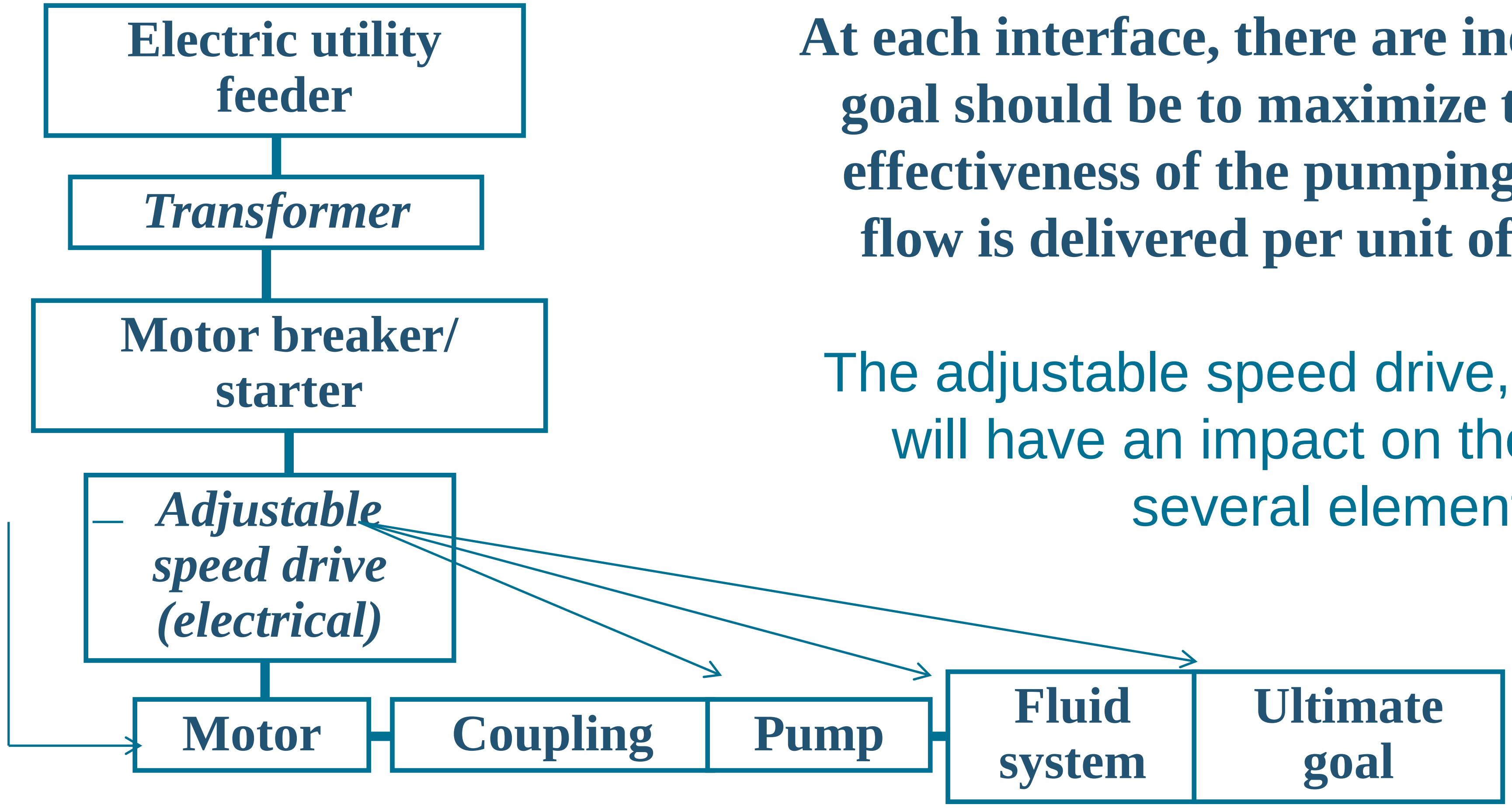
Systems Approach



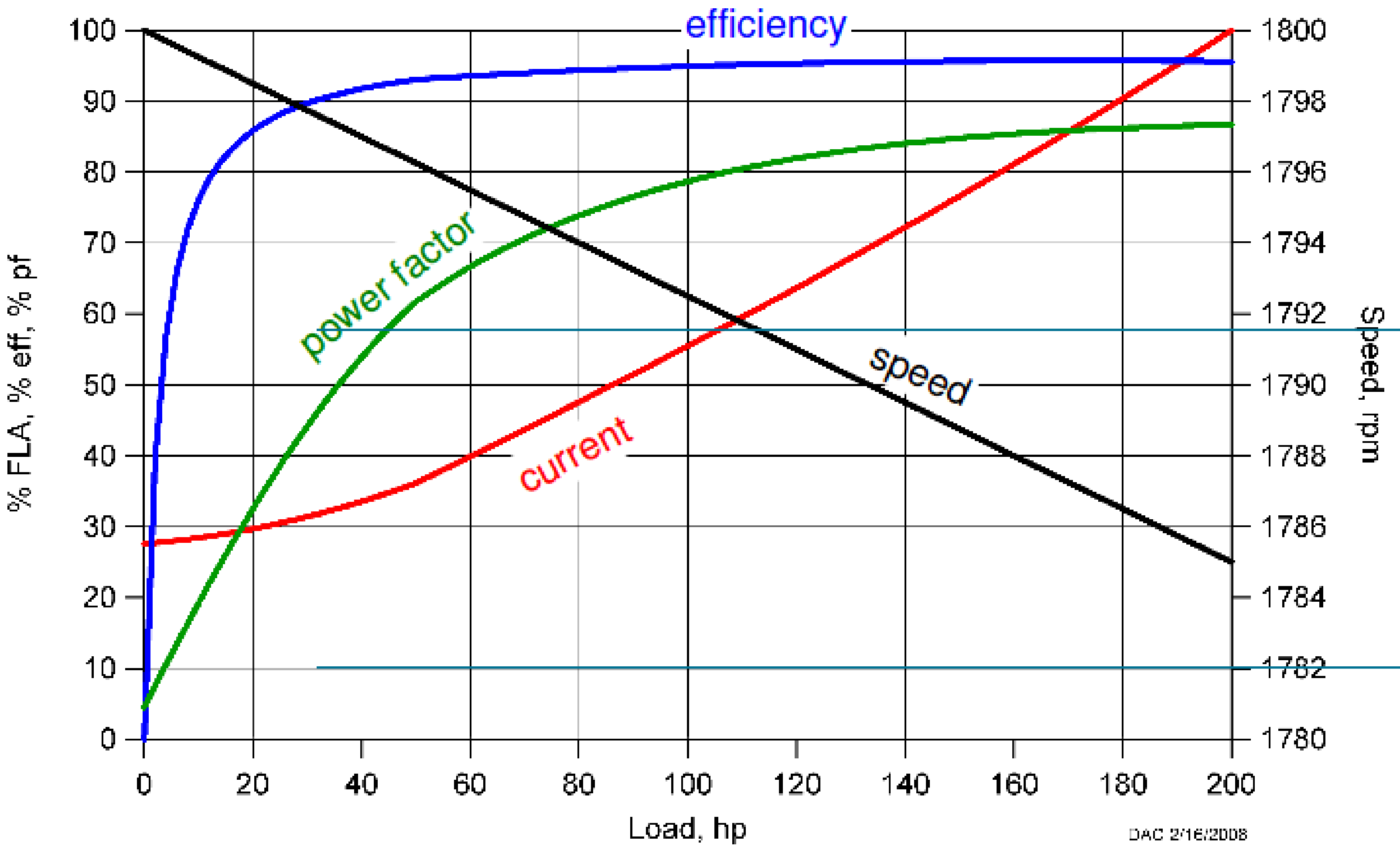
At each interface, there are inefficiencies. The goal should be to maximize the overall cost effectiveness of the pumping, or how much flow is delivered per unit of input energy.

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

Power Train Components

- Utility system - Line losses (minimal)
- Transformer – Typically efficient
- Breaker/starter - Negligible losses
- Adjustable speed drive - To be discussed (briefly)
- Motor - To be discussed (briefly)
- Coupling - Losses should be minimal
- Pump - To be discussed
- System - To be discussed
- Ultimate goal - To be discussed

Typical High Efficiency Motor Curves



150 kW (200hp)
4-Pole

Pump Losses

- Pump efficiencies can (and do) on the other hand vary a lot:
  From 0 to about 85%

- The pump efficiency depends strongly on where the pump is operated on its performance curve

What is the purpose of the system?

It is essential to understand the ultimate goal of the fluid system to optimize it.

- Understand ***why*** the system exists
- Have clearly defined criteria for ***what's really needed***
- Understand ***what's negotiable and what's not***

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Fluid Power Output – Pressure Flow Relationship

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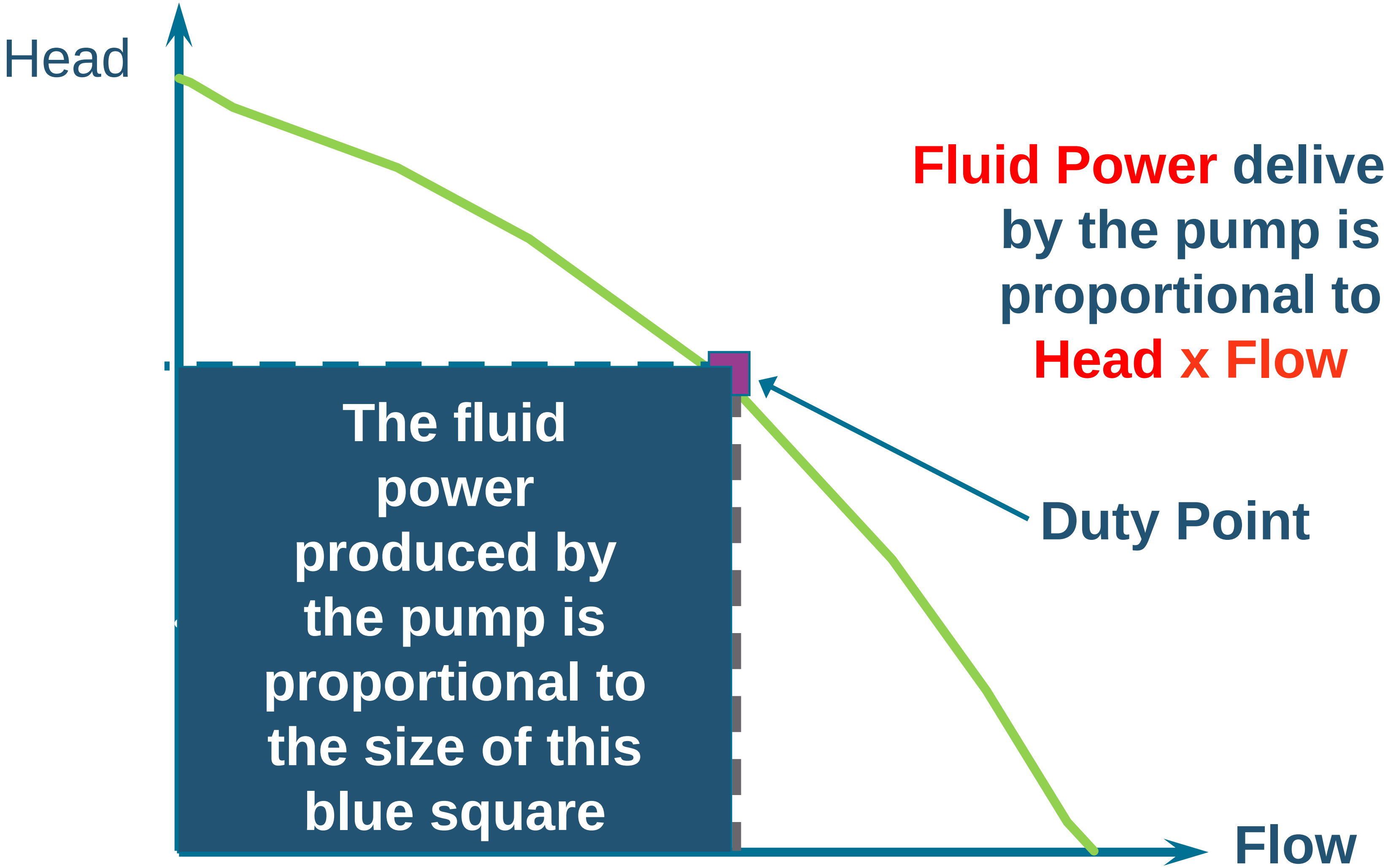
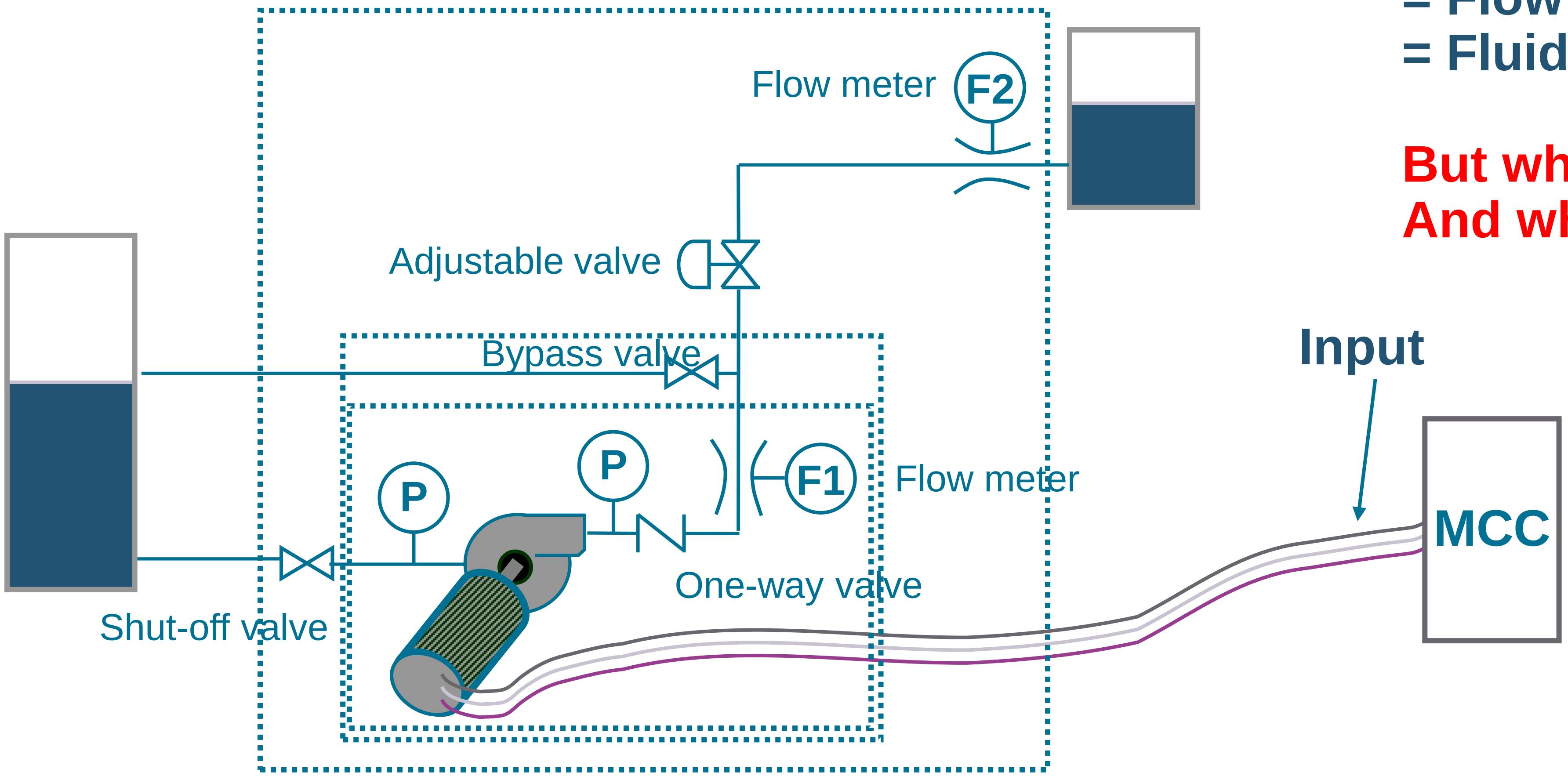


Fluid Power delivered by the pump is proportional to Head x Flow

Defining the System



Output:
= Flow Rate x Head x Constant
= Fluid Power

But which flow rate?
And which head?

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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

System Demand

Some system requirements will vary in time

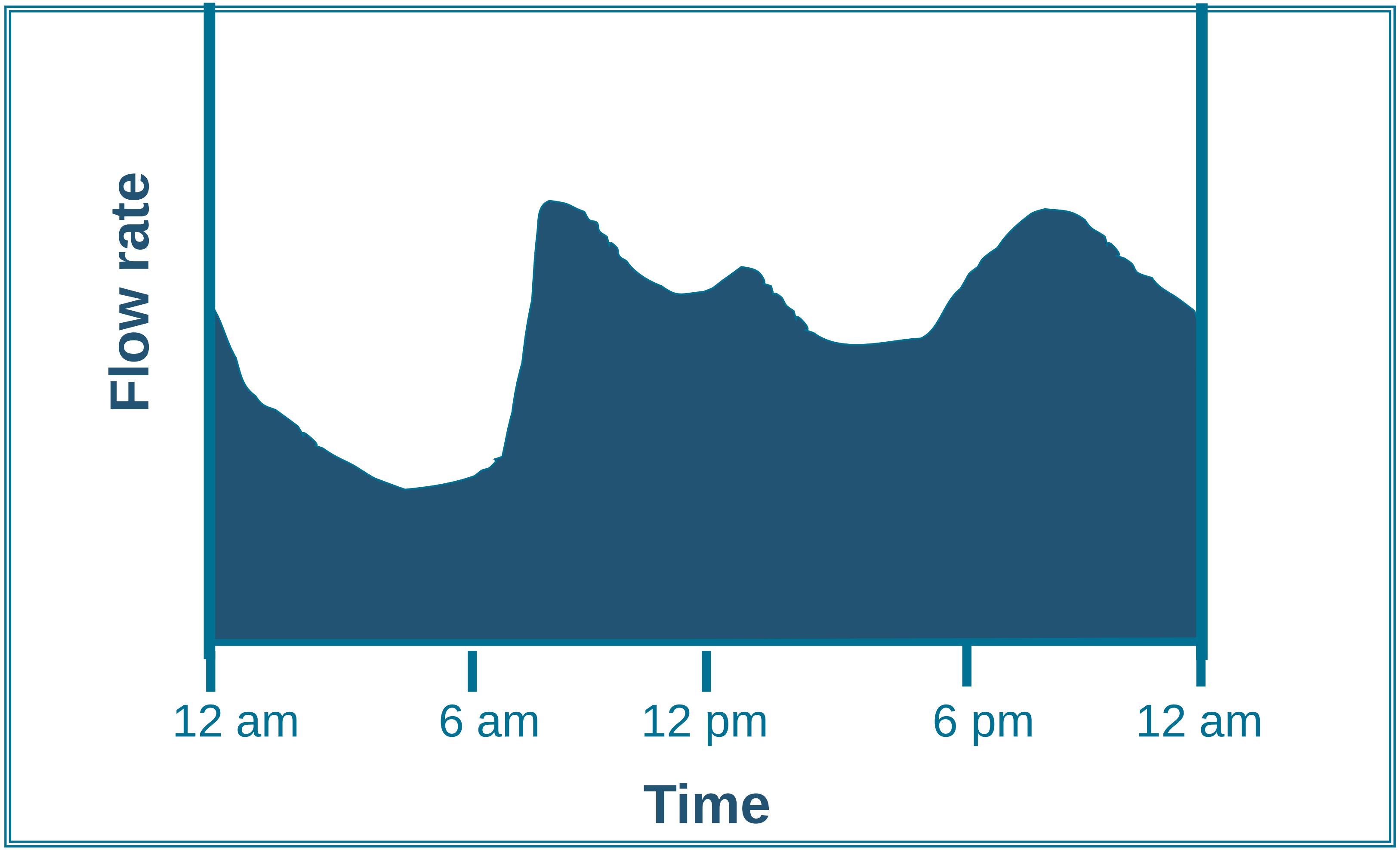
- Seasonal loads (chilled water, associated tower water, etc).
- Industrial processes with variable output
- Potable and waste water, large daily variations

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

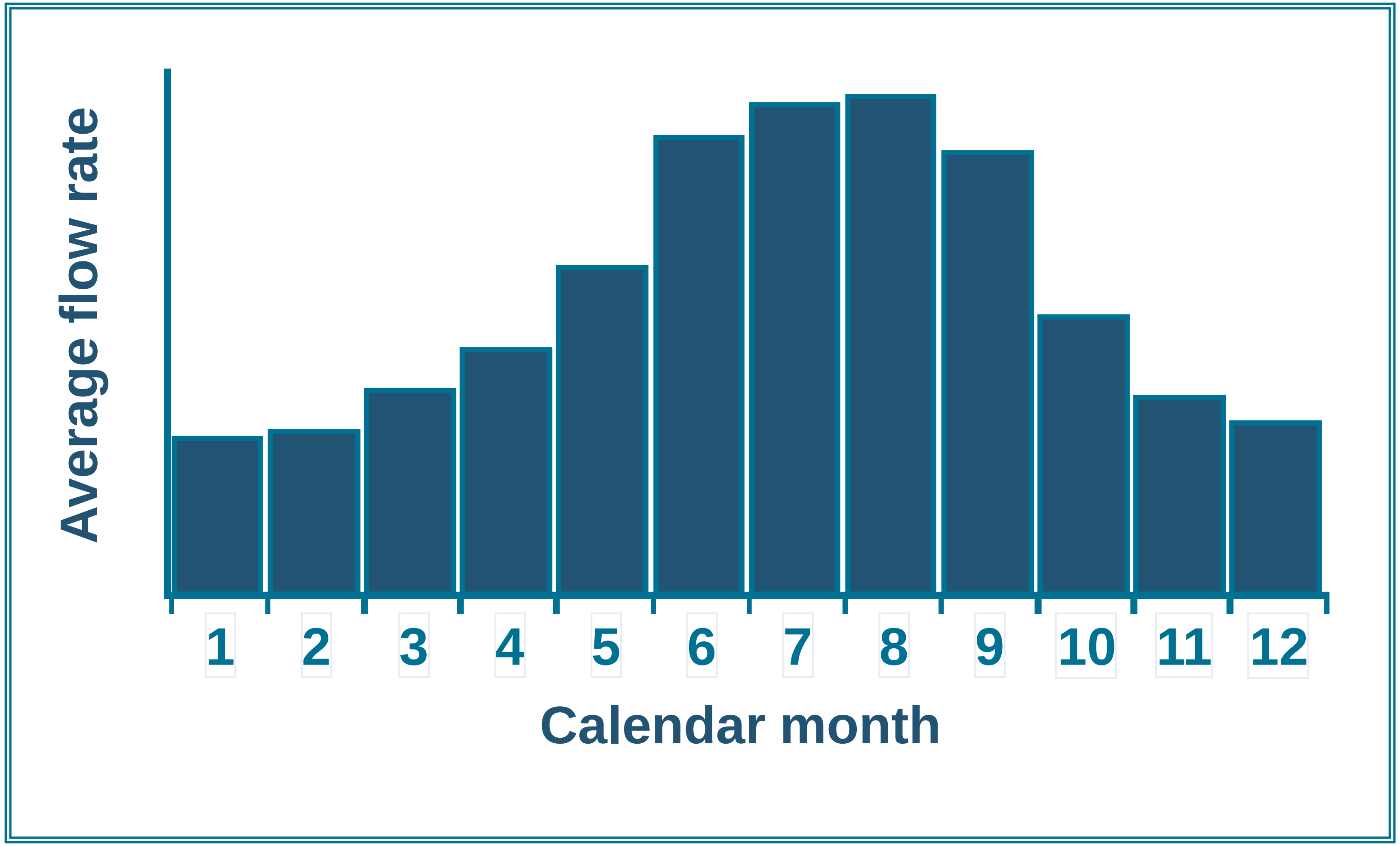
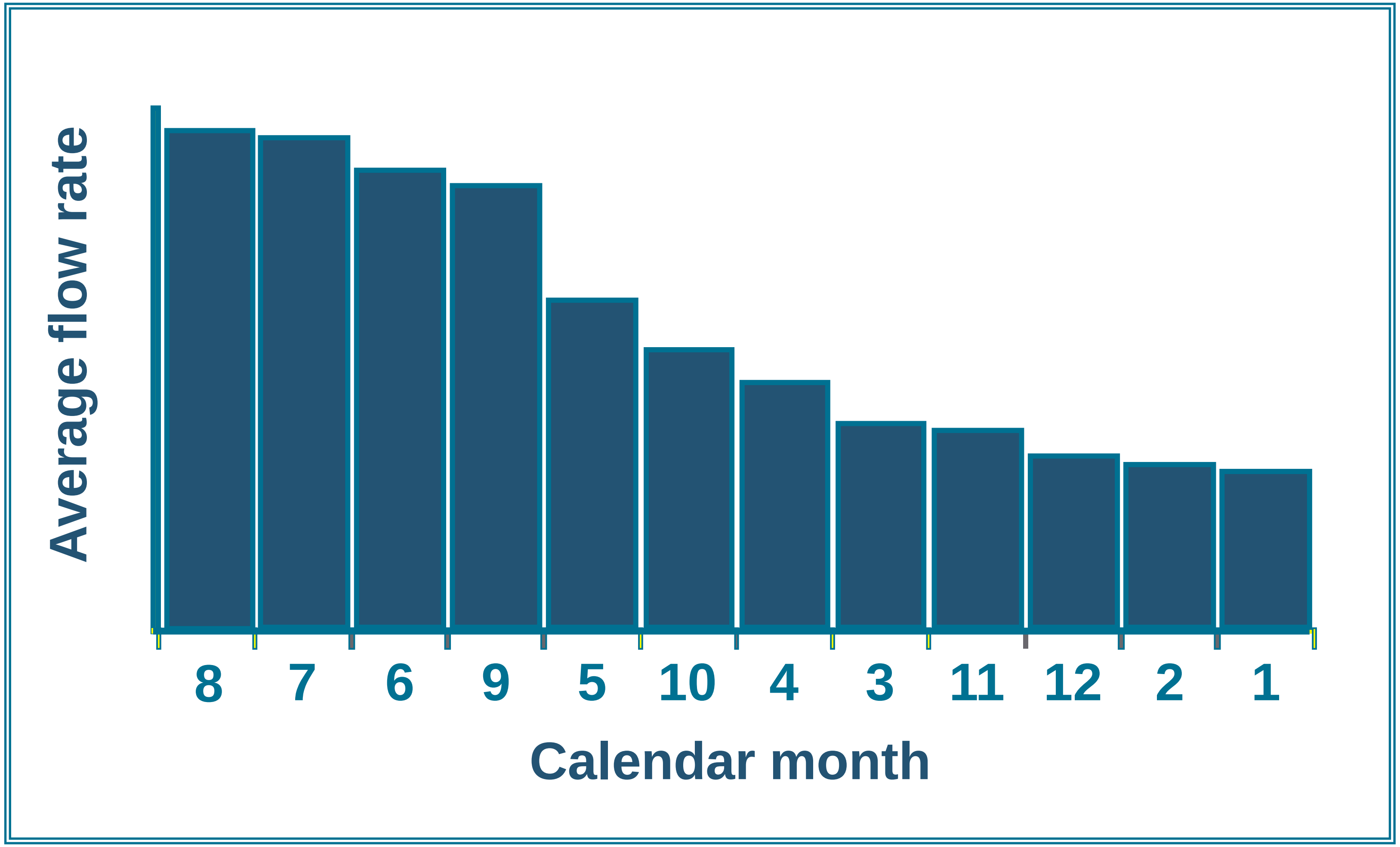
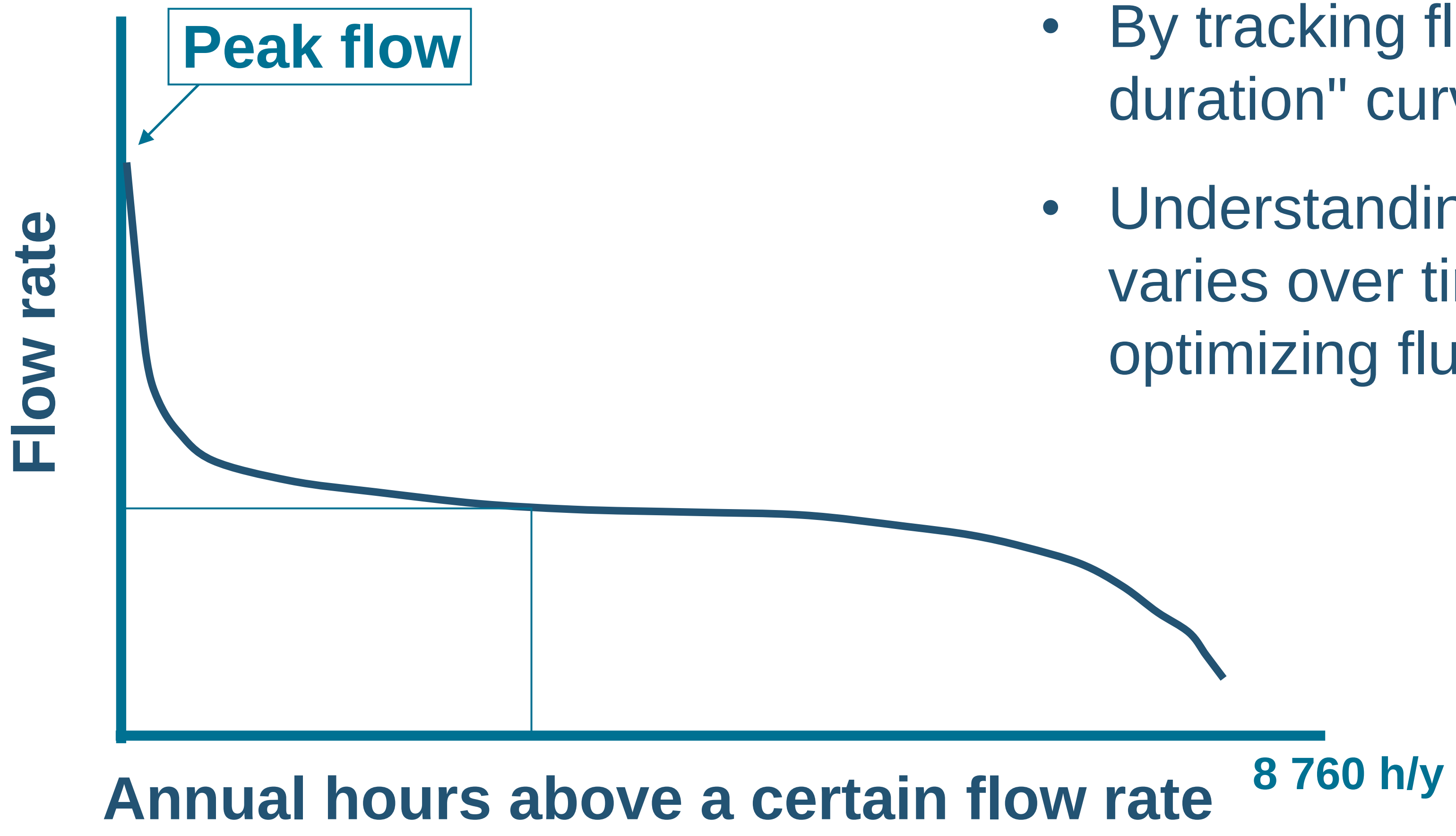


Figure Courtesy of Oak Ridge National Laboratory

Sorting the months by flow rate…



Flow Duration Curve



- By tracking flow rate over time, a "flow duration" curve is developed
- Understanding how the flow requirements varies over time is a crucial element in optimizing fluid systems

Using Smaller Pumps to Handle Low Flows

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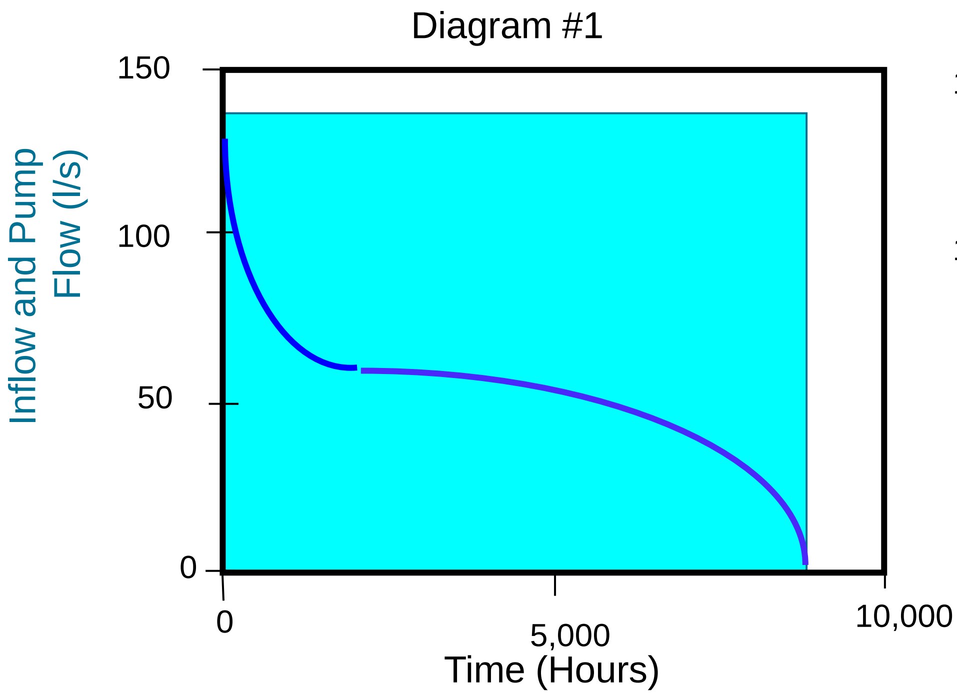
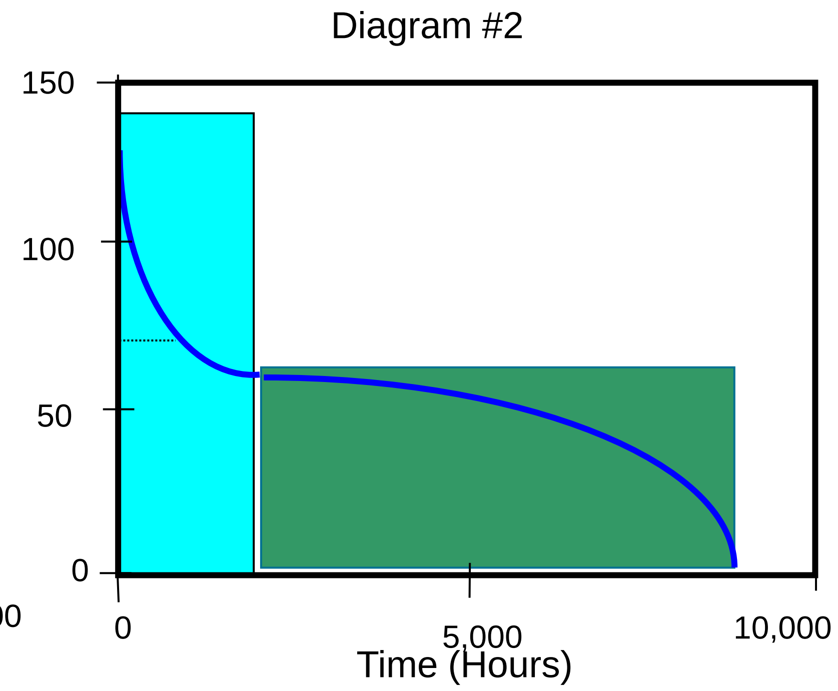
- **Diagram #1** shows a large pump operating for 8,760 hours per year at a flow rate of 140 l/s – total flow is represented by the area under the curve.

- **Diagram #2** shows the same total flow pumped by two pumps.
- The 140 l/s pump only operates 2,000 hours per year and a smaller pump rated for 60 l/s operates for 6,760 hours





03. Pump Types

Pump Basics

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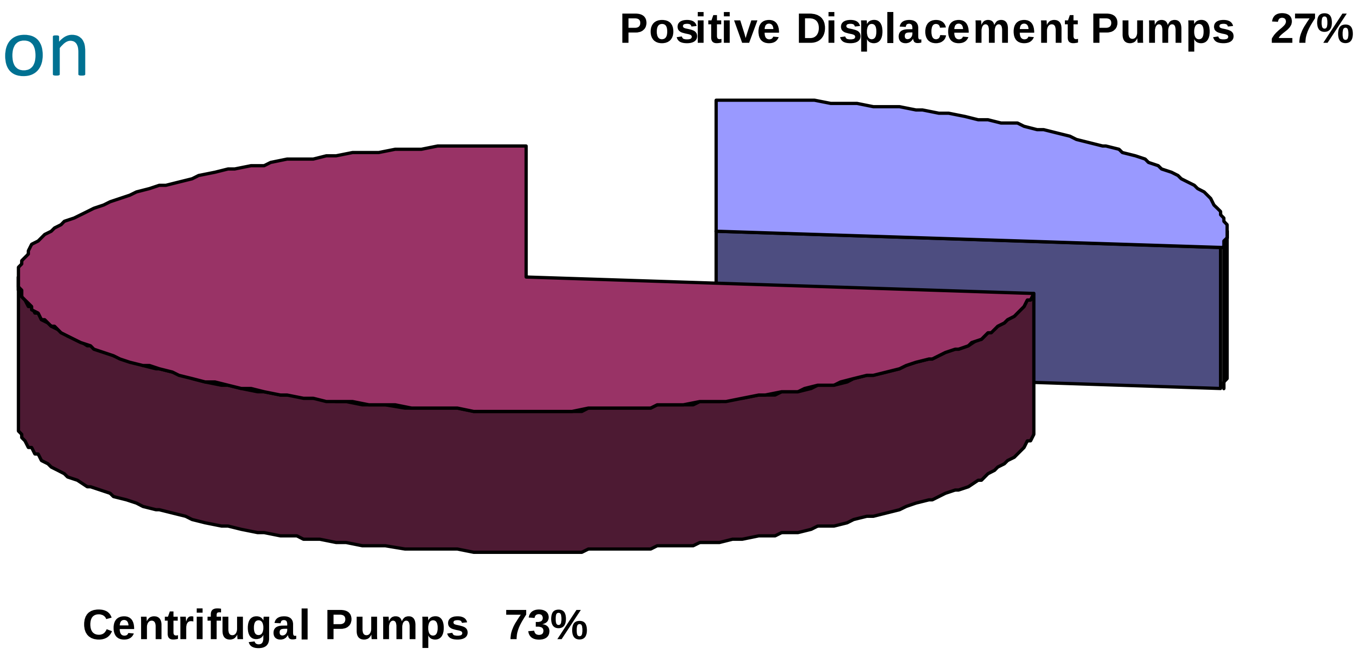
Pump Types

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

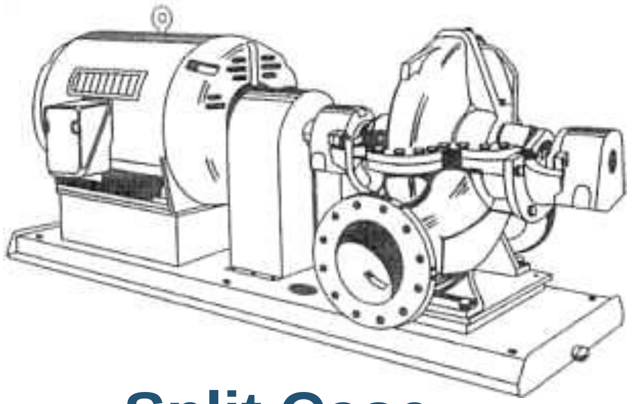


Data based on European Commission Save Study on Variable Speed Drives

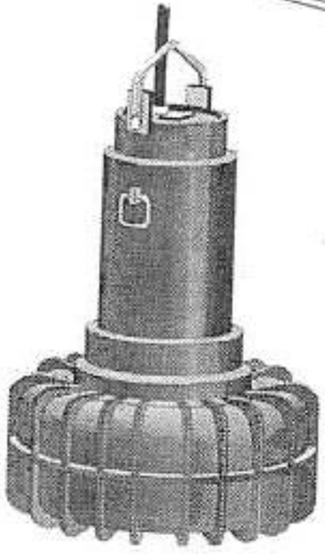
Pump Types

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

Examples: Centrifugal Pumps



Split Case



Submersible

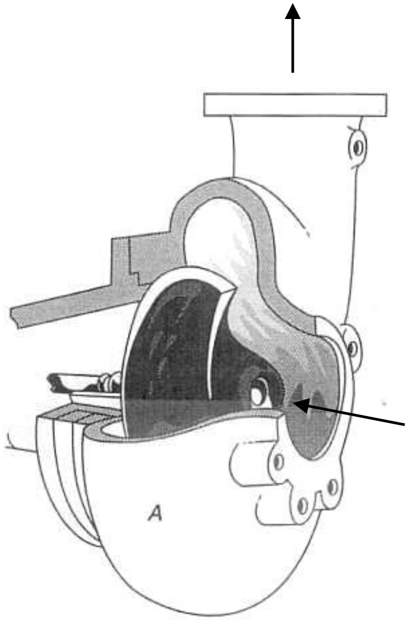
End Suction

Vertical, close coupled

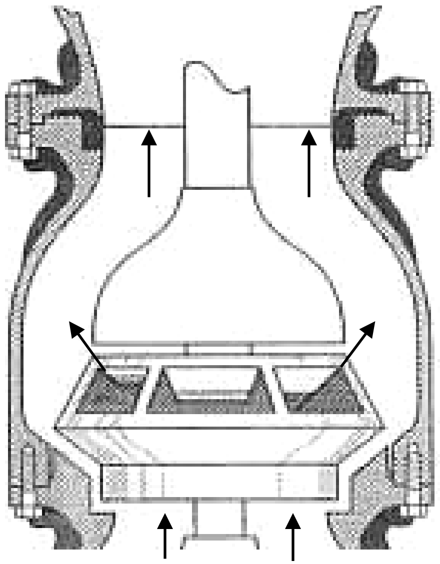
Figures courtesy of ACR Publications

Centrifugal Pump Flow

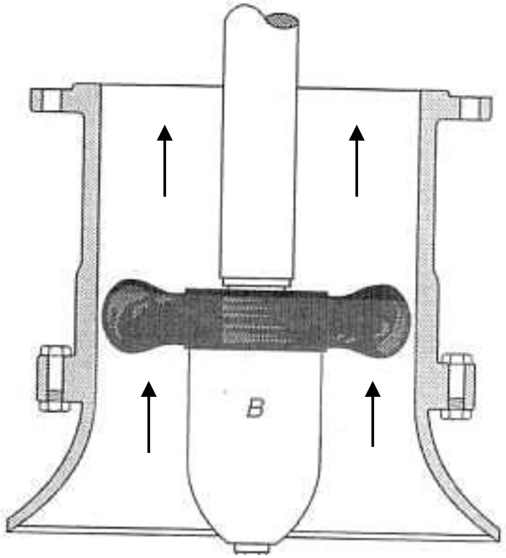
Common centrifugal pump flow configurations:



Radial Flow



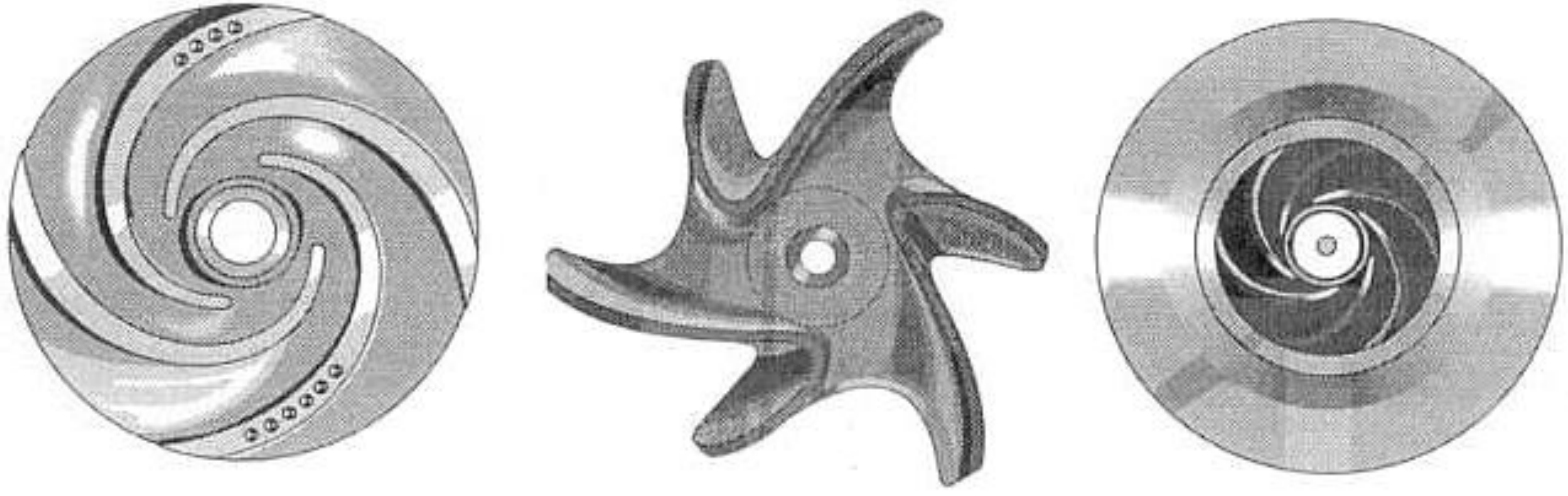
Mixed Flow



Axial Flow

Figures courtesy of ACR Publications

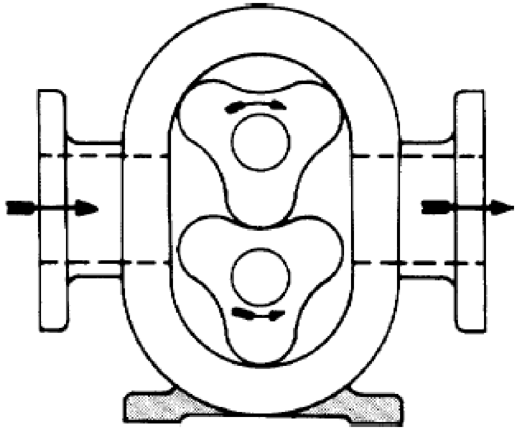
Centrifugal impeller types:



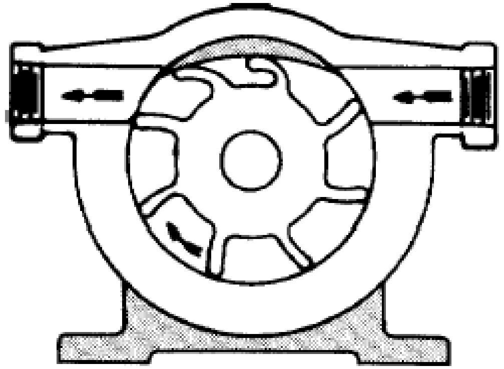
Semi-open **Open** **Closed**

Figures courtesy of ACR Publications

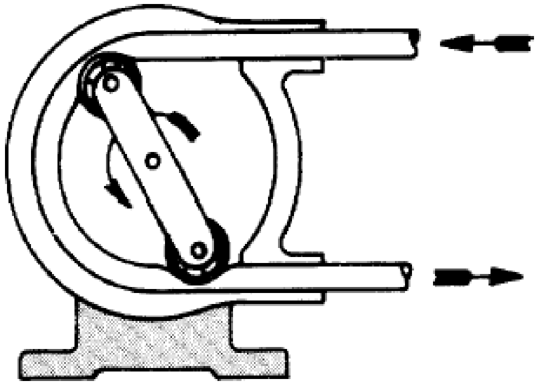
Examples: Displacement Pumps



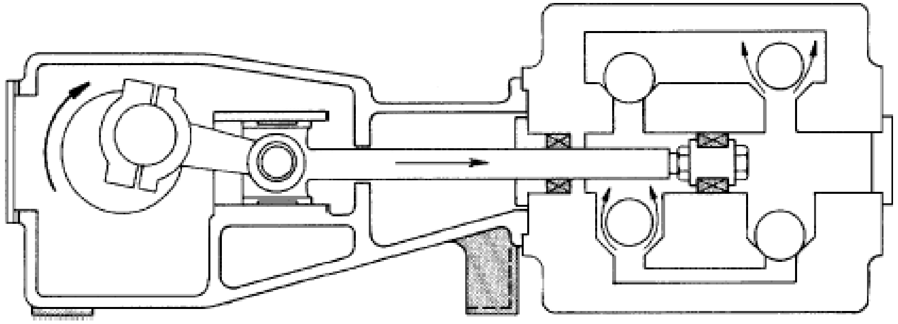
Rotary Lobe



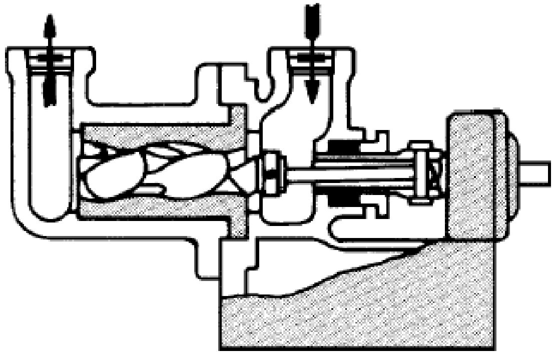
Flexible Vane



Flexible Tube



Horizontal Piston



Screw Pump

Figures courtesy of Hydraulic Institute

04. Pump System Fluid Relationships

Pump Basics

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Pumping Effort (Output)

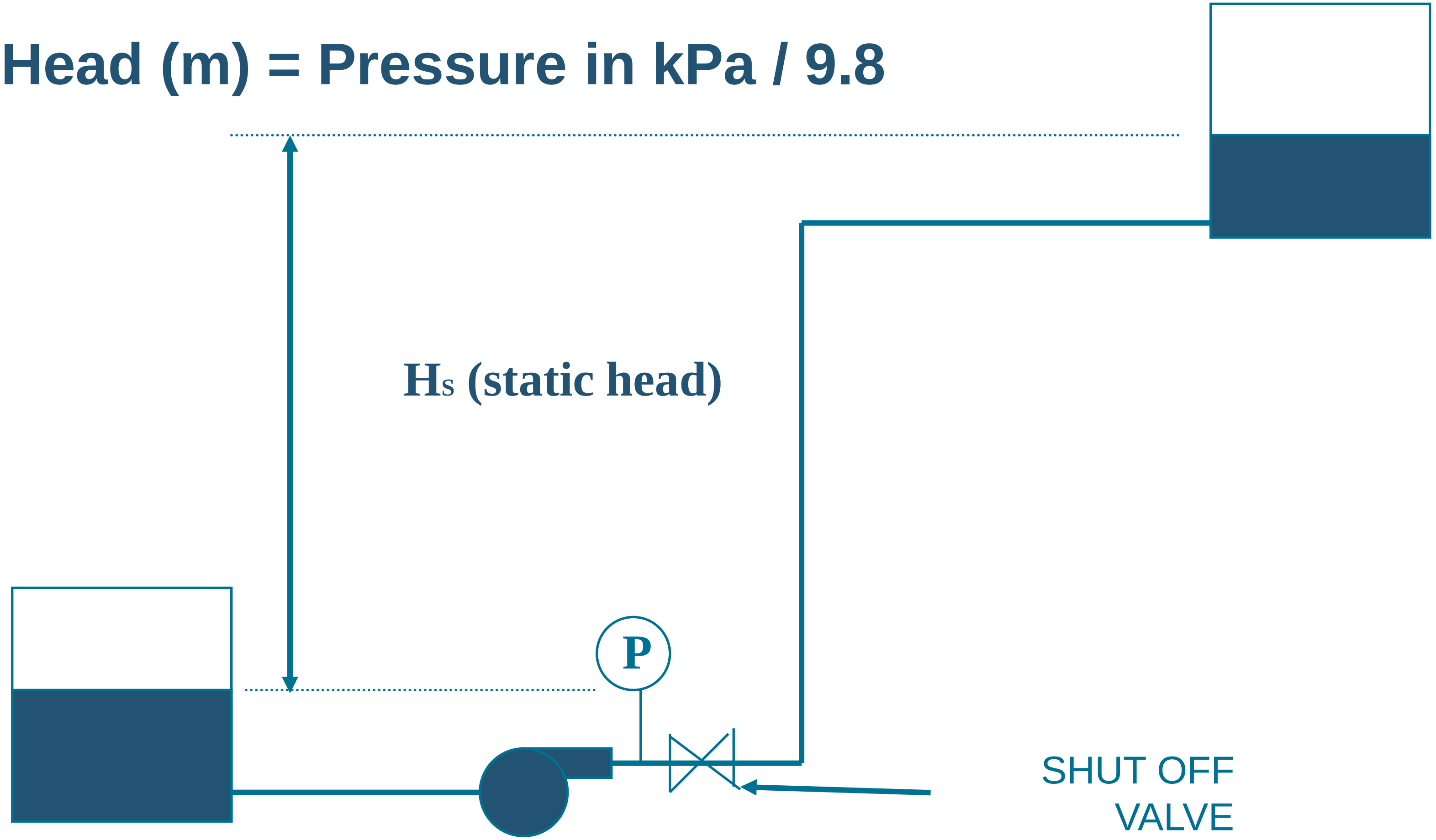
- The ability for pumps to move water is based on the energy contained in a mass of water
- Pump output is measured in meters of head. The three common terms used to express this energy in water is:

  - Elevation / Pressure Head (Static Head or H_s) → Lift the fluid
  - Velocity Head (H_v) → Create kinetic energy
  - Head loss due to Frictional Losses (H_f) → overcome friction

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

Static Head

Head (m) = Pressure in kPa / 9.8



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 = Velocity in meters/second

g = 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 cross sectional Area of the inside 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 using:

The Darcy Weisbach Equation

or

The Hazen-Williams Equation

- H_f can be determined more accurately in the field using actual pressure measurements

Estimating Pipe Friction Loss

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- Pipe friction loss estimates are usually based on an equation referred to as Darcy-Weisbach
- This equation is very useful to understand what parameters influence frictional losses in piping

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

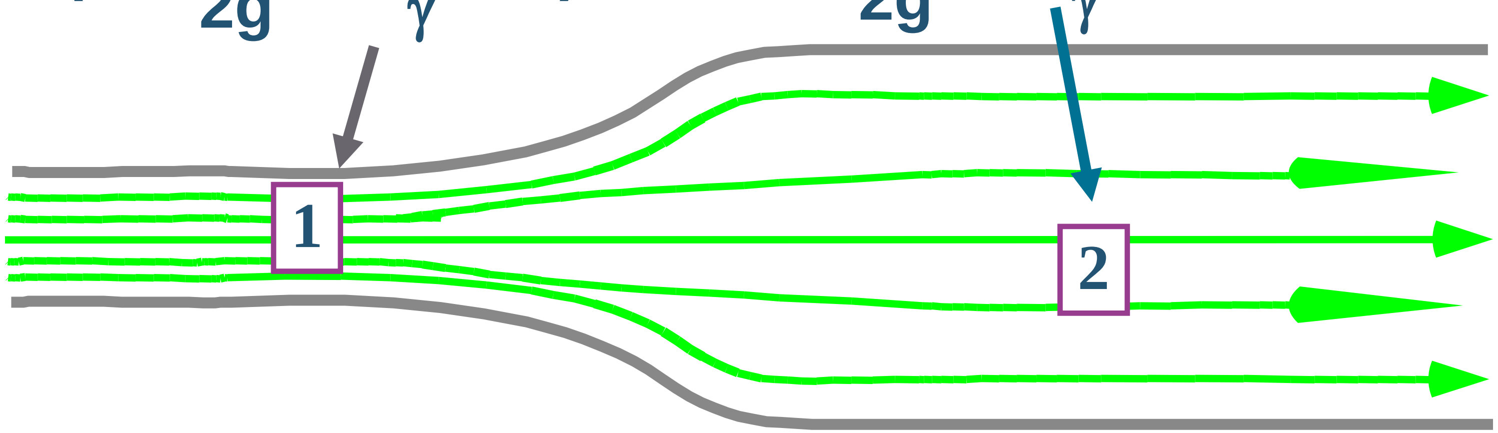
H_f = pressure drop due to friction (ft or m)
f = Darcy friction factor
L = pipe length (ft or m)
d = pipe diameter (ft or m)
$\frac{V^2}{2g}$ = velocity head (ft or m)

Slide Courtesy of Oak Ridge National Laboratory

Bernoulli's Principle

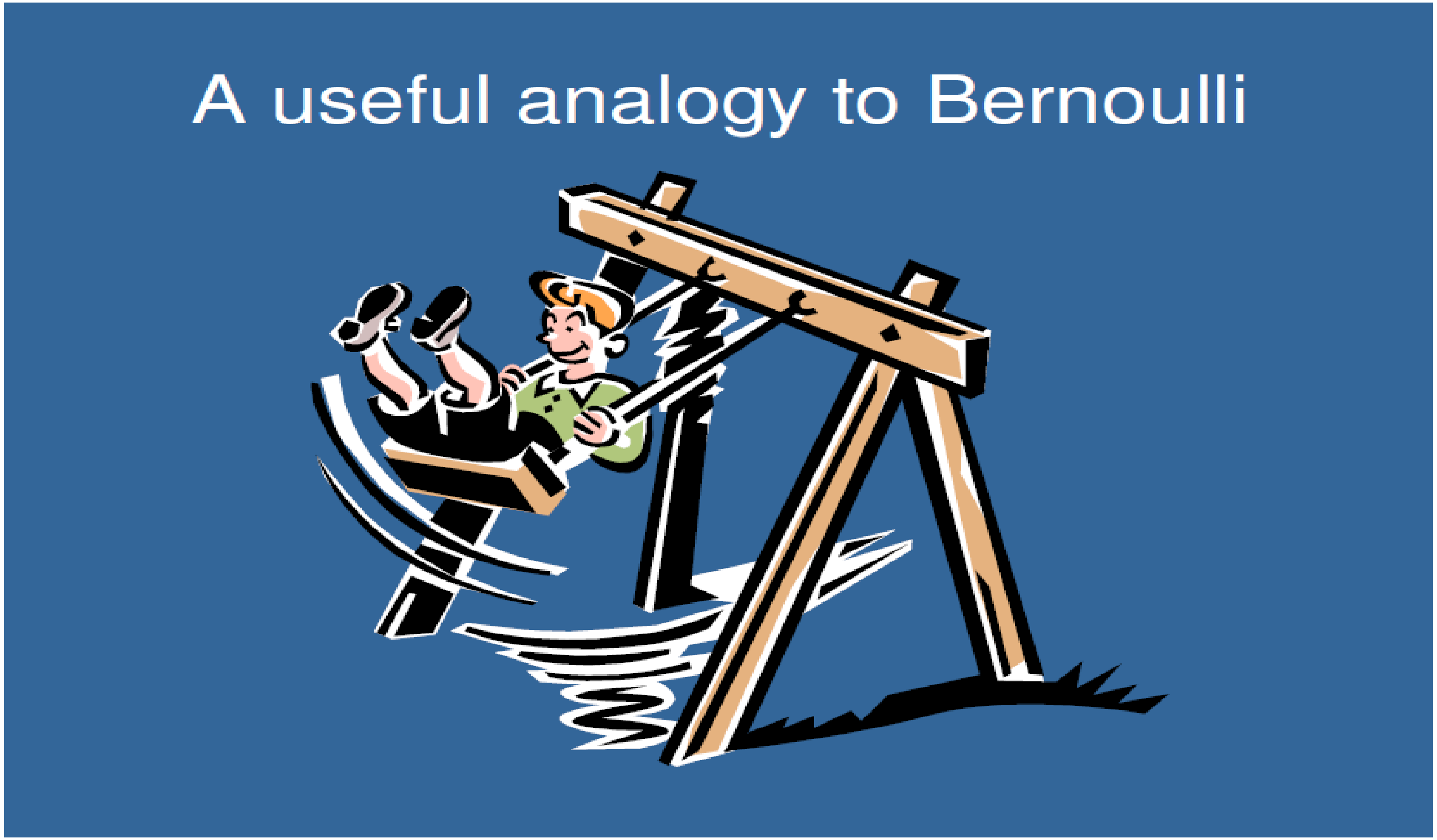
Total energy is constant along a frictionless streamline

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



P = pressure
V = velocity
γ = fluid specific weight
g = gravitational acceleration
Z = elevation head

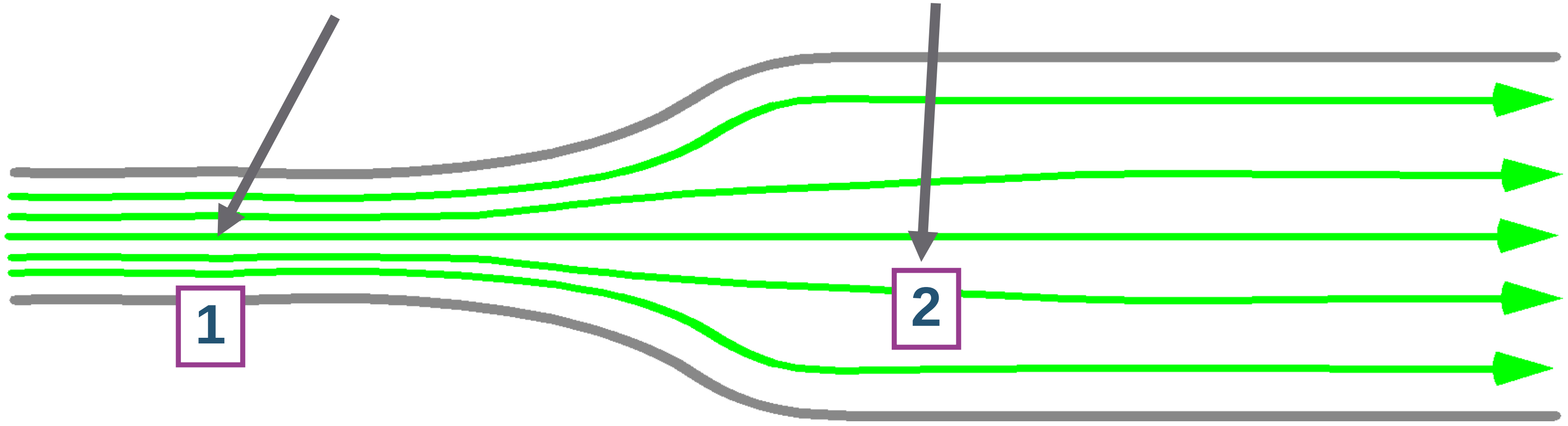
So, what does the Bernoulli equation say?



Bernoulli Equation (Modified to include friction)

We can slightly modify the Bernoulli equation to account 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

Slide Courtesy of Oak Ridge National Laboratory

Sources of Friction for Piping Components?

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

In other words, almost everything that the pumped fluid passes through, as well as the fluid itself

Piping Frictional Losses

- Piping component frictional losses are also primarily dependent on experimental data
- For pipe components, frictional losses have generally been estimated based on the velocity head.

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

K = loss coefficient
(K is a function of size, and for valves, the valve type, and valve % open)

$$\frac{V^2}{2g} = \text{Velocity head}$$

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

Slide Courtesy of Oak Ridge National Laboratory

Specific Gravity / Relative Density

- Specific gravity is the relationship of the weight of a fluid referenced to the weight of water at 16.7 °C.

- For purposes of evaluating water pumping systems, a specific gravity of 1.0 can be used at a temperature range of 0 °C to 26 °C . However, if water temperature increases, the specific gravity will decrease and decrease pump power.

- If a fluid other than water is being evaluated, specific gravity of the fluid must be included in pump calculations.

- If relative density is used instead of density the power will be expressed in kW

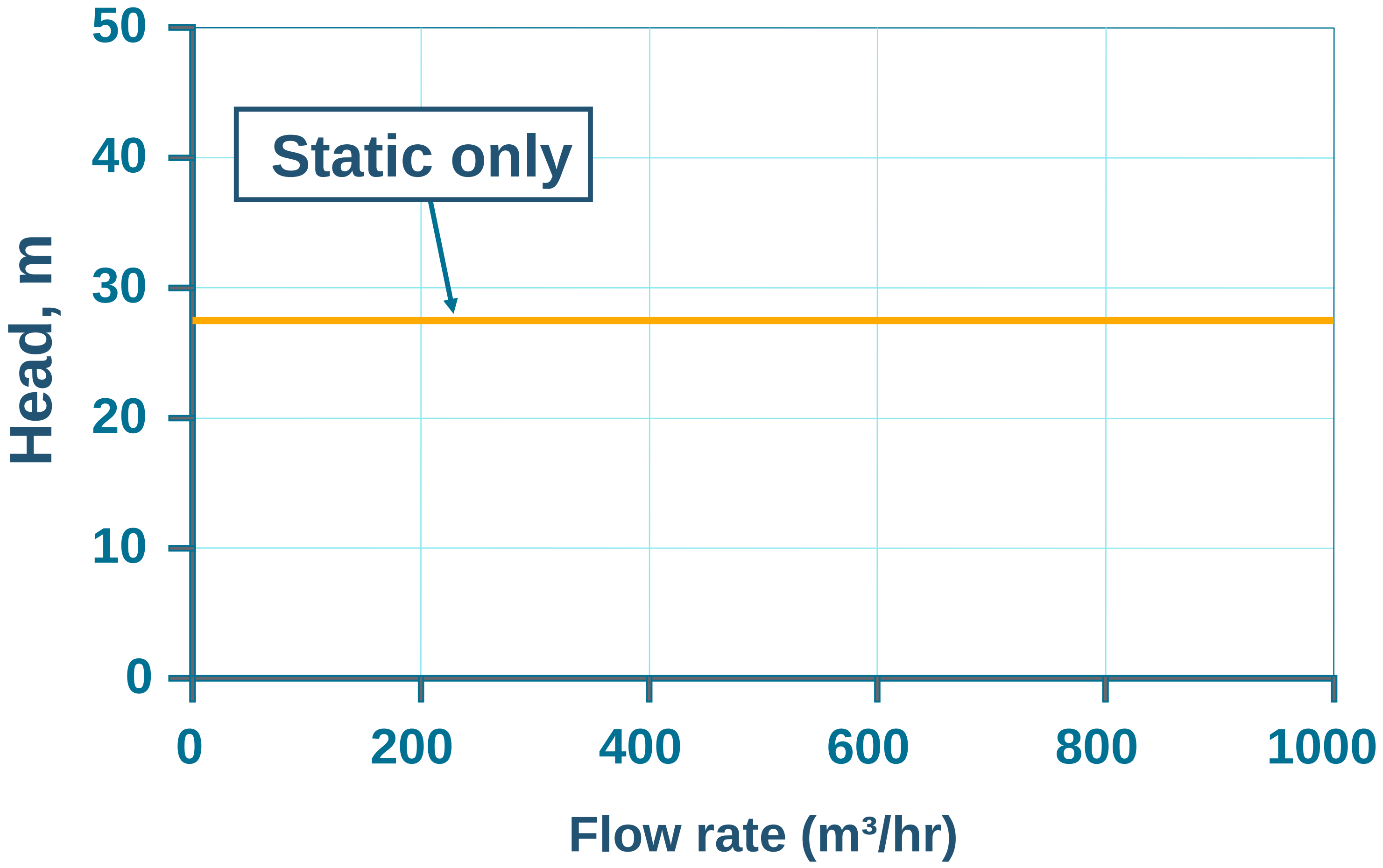
System Curves

What is included in the system?

Everything that comes into contact with the fluid being pumped

- Pipes
- Valves
- Bends
- ‘T’s
- Etc.

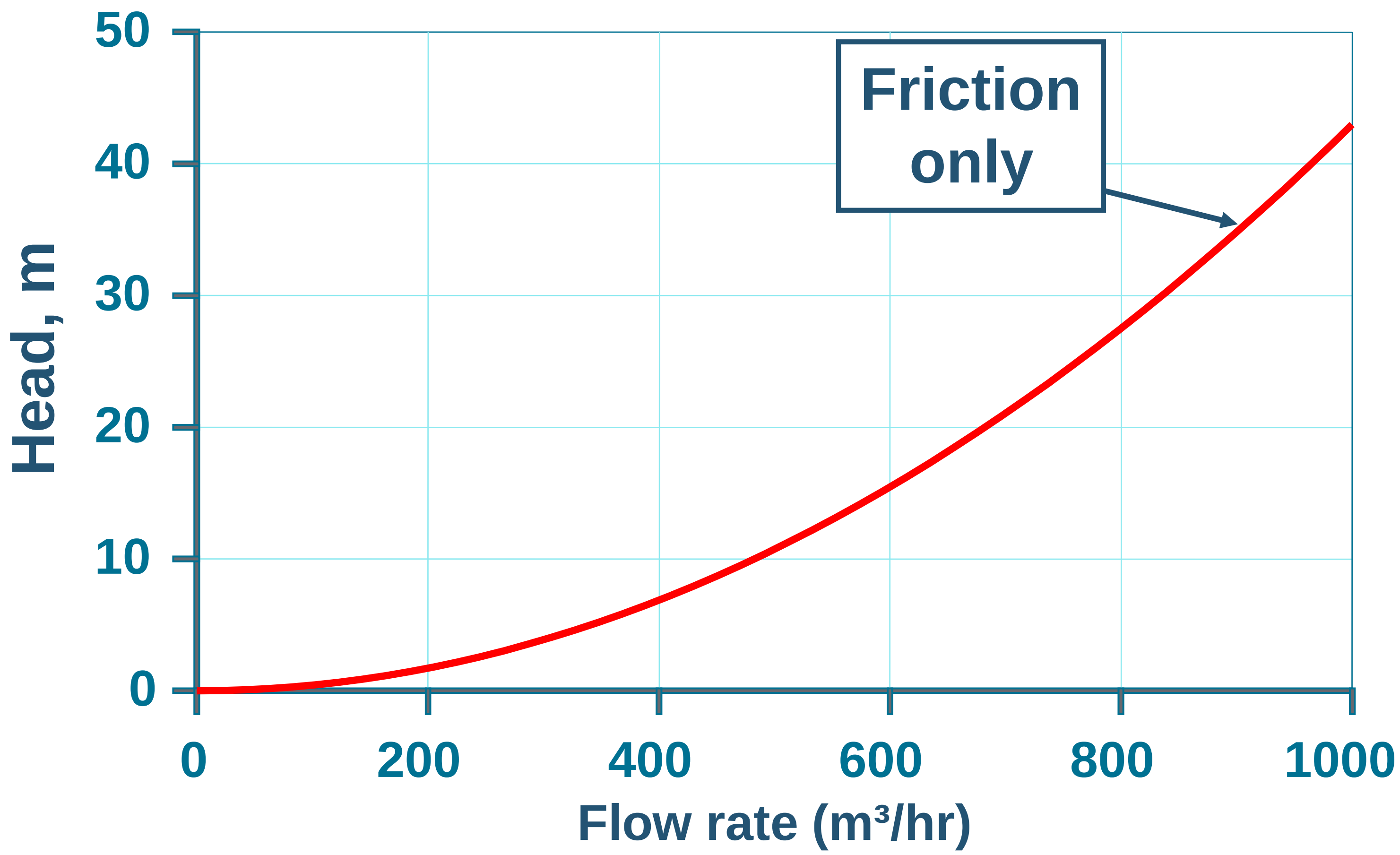
System Head Curve: All Static System



Lifting action only

Figure Courtesy of Oak Ridge National Laboratory

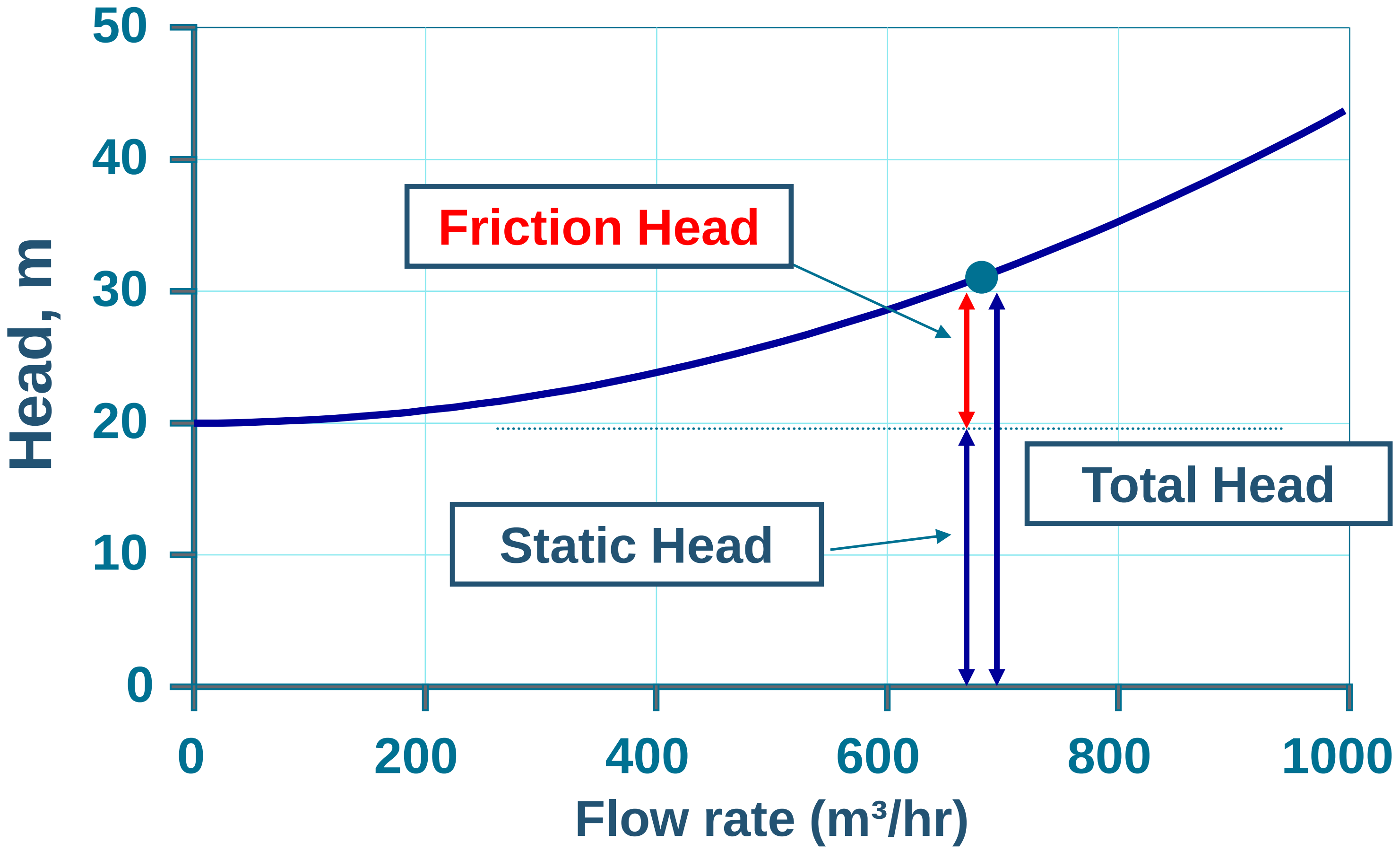
System Head Curve: All Frictional System



Moving action only

Figure Courtesy of Oak Ridge National Laboratory

System Head Curve: Combined Static and Frictional System



Moving & lifting

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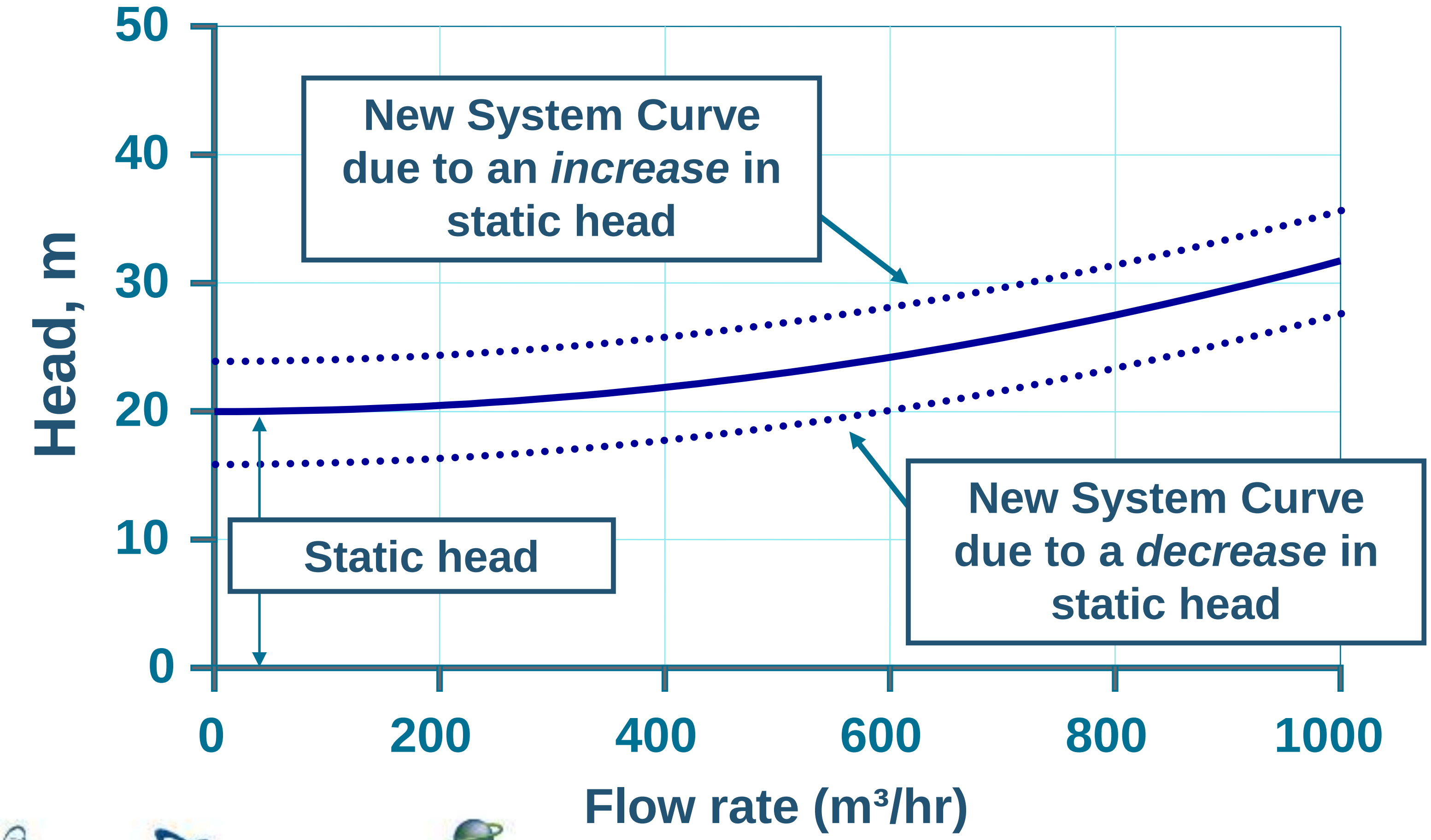
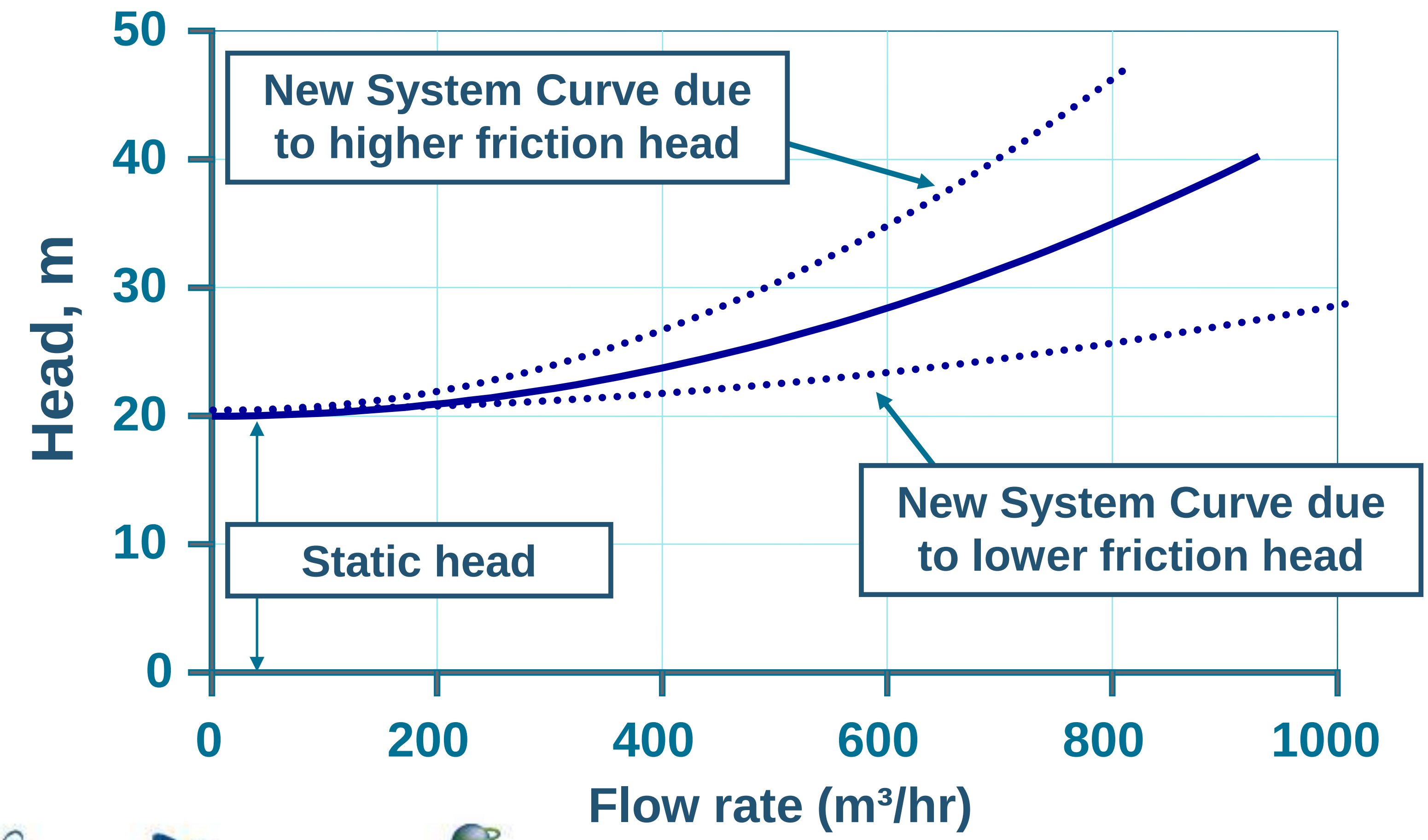
The effect on the system head curve when the static head changes



System Effects: Changes in Friction Head

The effect on the system head curve when system friction changes



Two Types of Pump Systems

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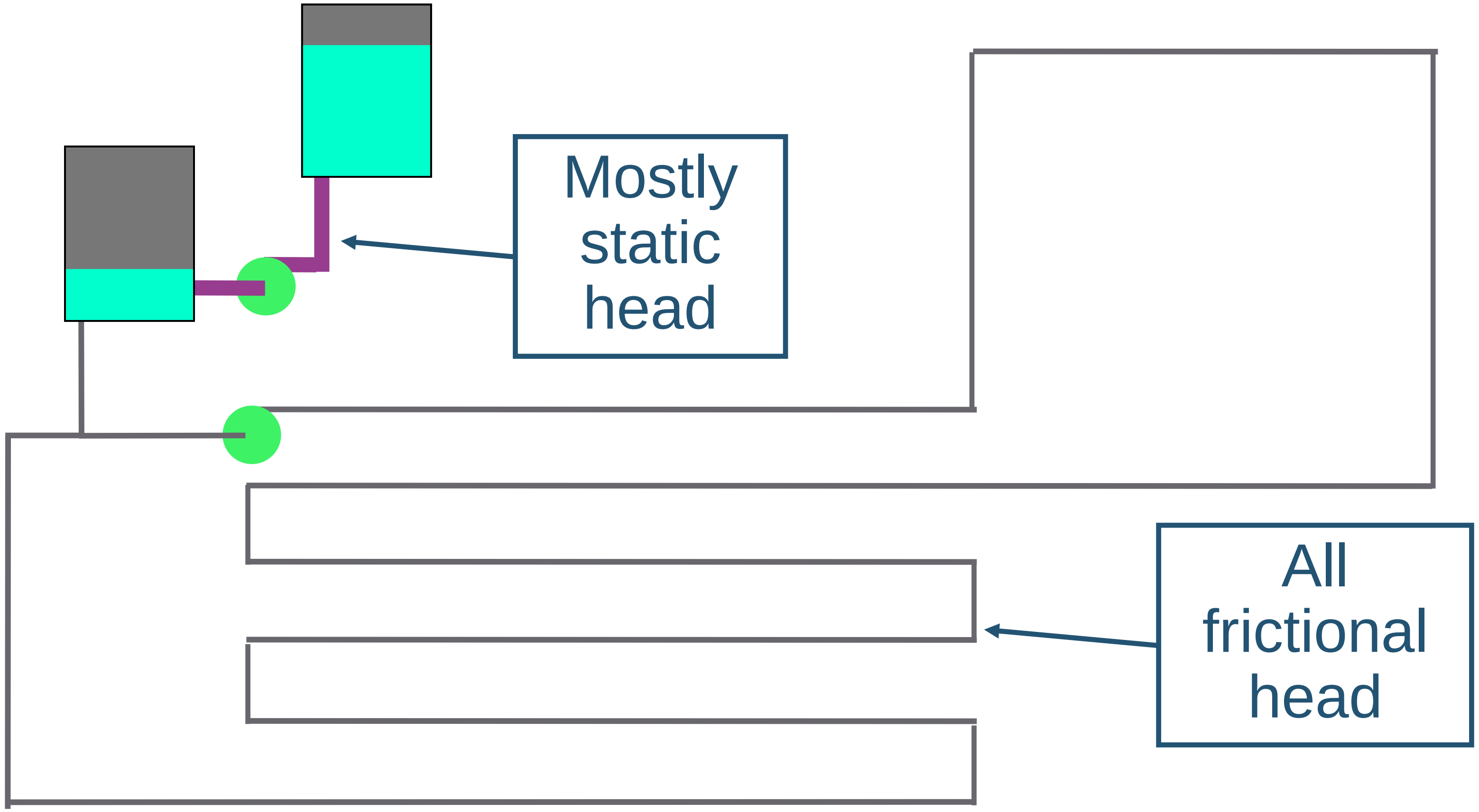

Figure Courtesy of Oak Ridge National Laboratory

Reducing Friction Losses With “Pigs”

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THE RESULTS. . .

Restored Flow: It is not uncommon to double flow (and more) in old lines.
Reduced Pumping Costs: Power saving can be dramatic in large lines.
Cleaner Product: Impurities such as Red Water can be eliminated.
Pleased Customers: Due to good results and minimum service downtime.

In the case of removing heavy buildups from pipes a "progres-sive" pigging method is used which maximizes cleaning safety.

Sources: http://www.pipepigs.com/services.htm
http://www.pipepigs.com/images/pigsmain.jpg

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05. Pump Performance Characteristics

Pump Basics

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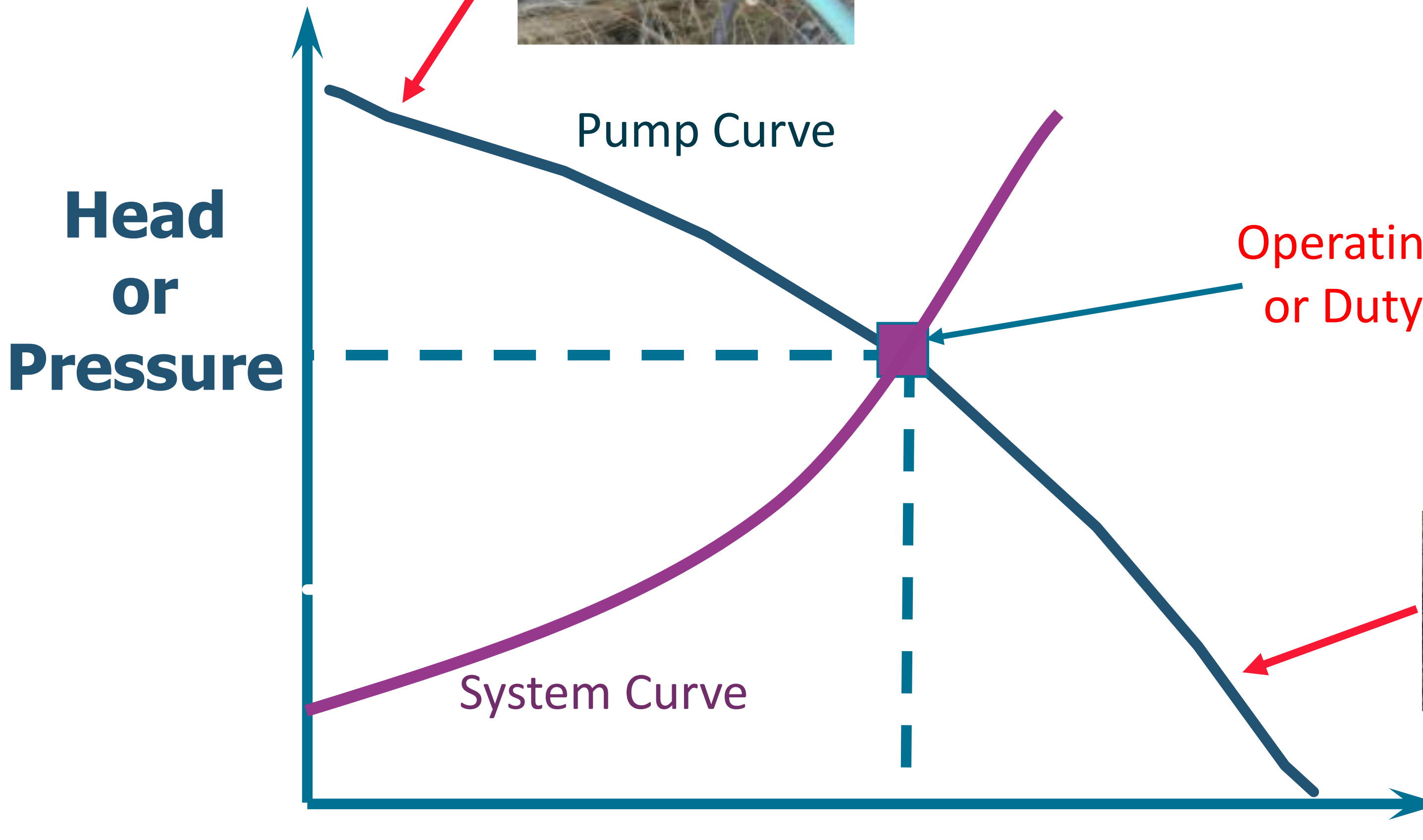
Pressure Flow Relationship

- 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

Pressure Flow Relationship

High Pressure
Low Flow



How do we vary the operating point?

Low Pressure
High Flow

Pressure Flow Relationship

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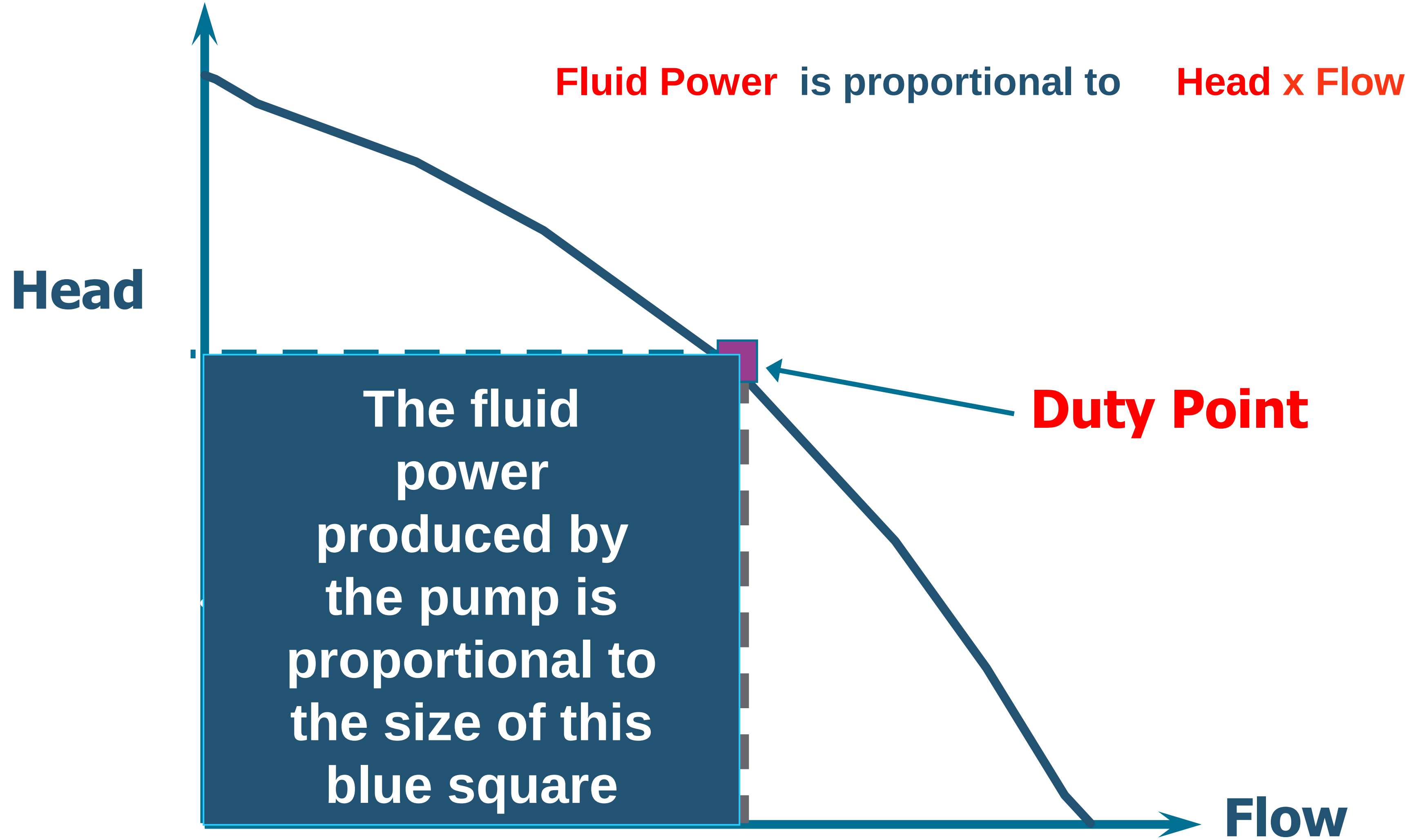

Important Fundamental Relationships

$$\text{Fluid Power (kW)} = \frac{\text{Flow rate (l/s)} \times \text{Head (m)} \times \text{Rel. Density}}{102}$$

$$\text{Fluid Energy (kWh)} = \text{Fluid Power} \times \text{operating time}$$

Reduce the run time
Reduce the flow rate
Reduce the head

} **Reduce energy use, cost**

Nameplate Operating Point

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Nameplate data applies to one particular operating point

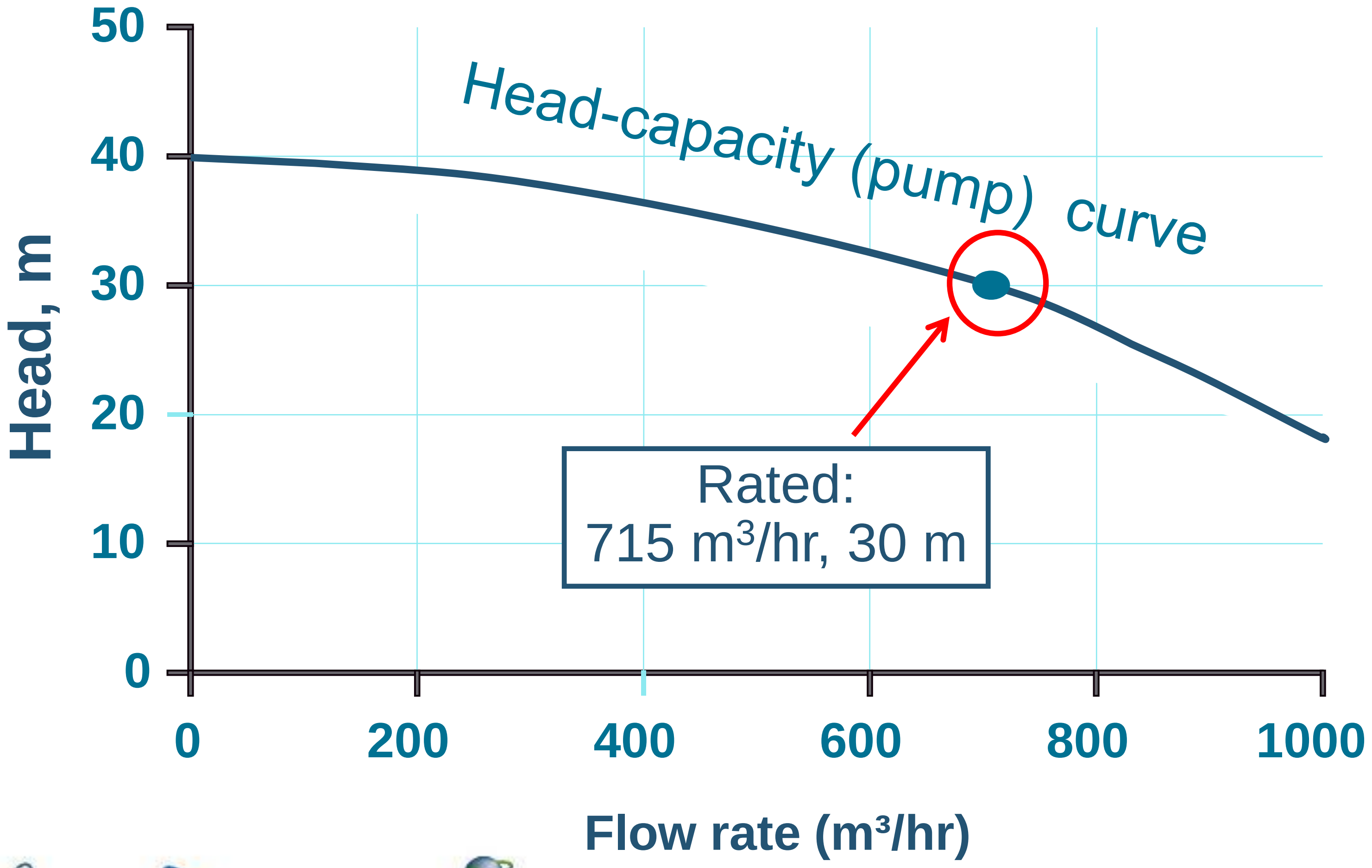


Figure Courtesy of Oak Ridge National Laboratory

Pump Efficiency Curve

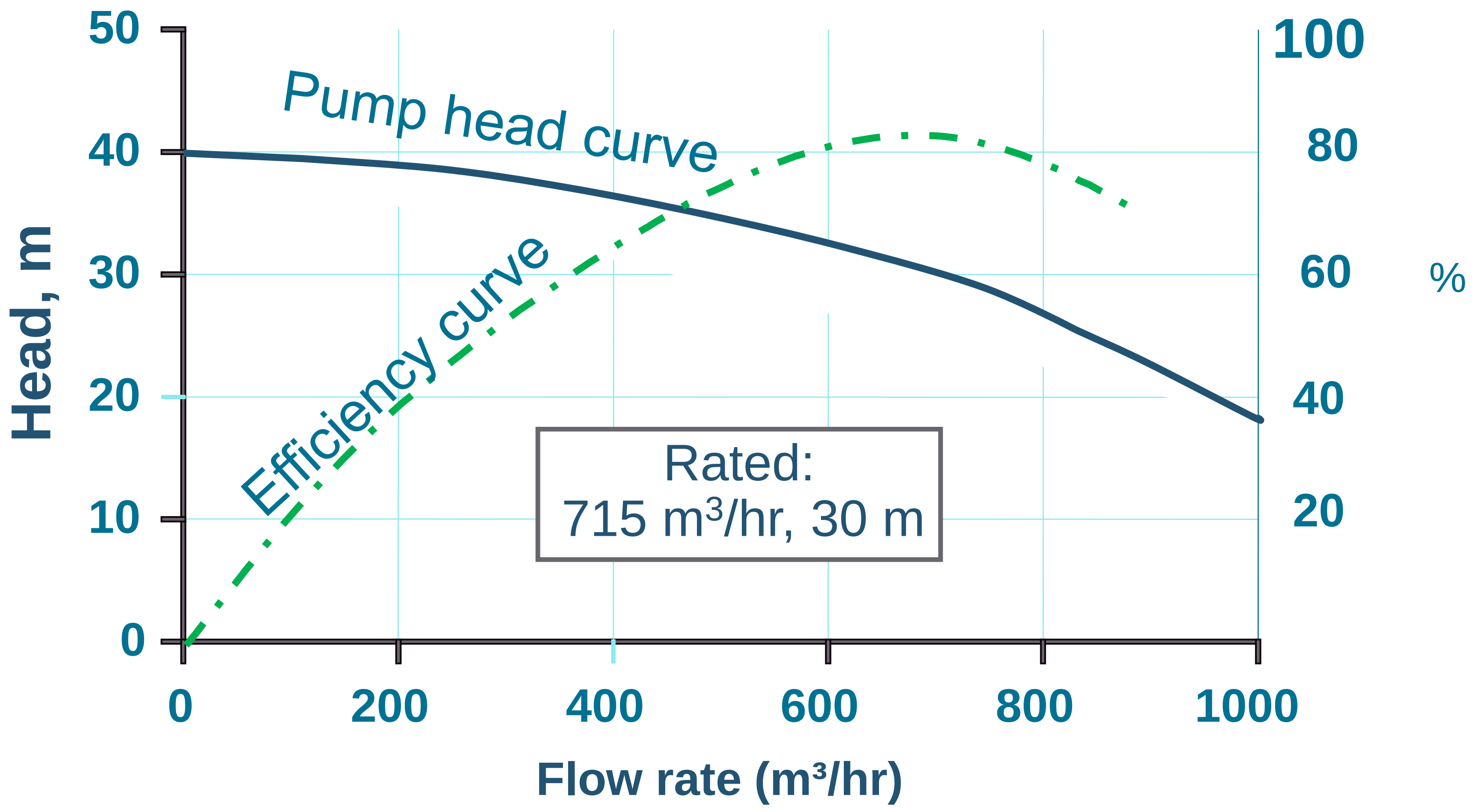
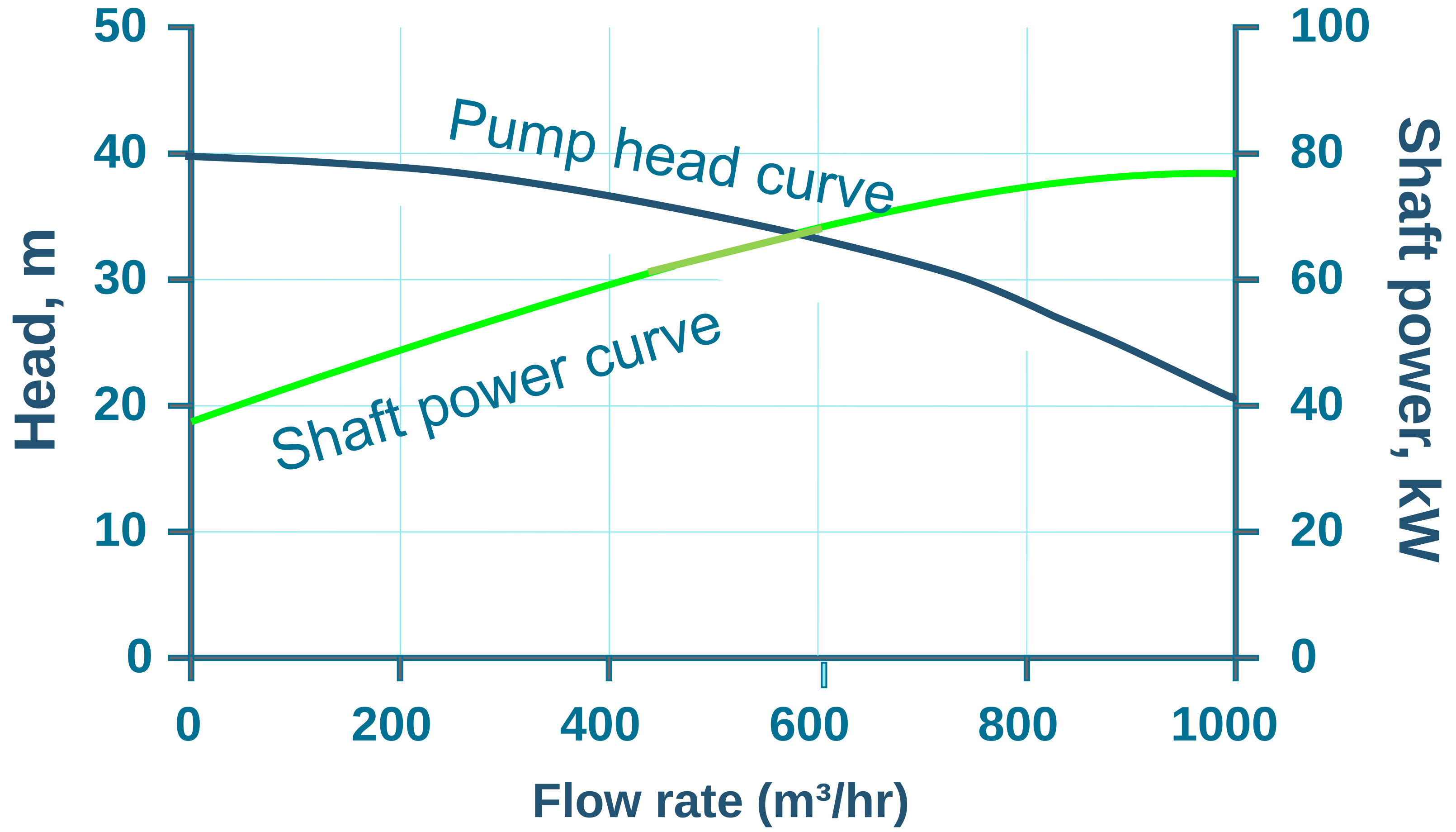


Figure Courtesy of Oak Ridge National Laboratory

Shaft Power as a Function of Flow Rate



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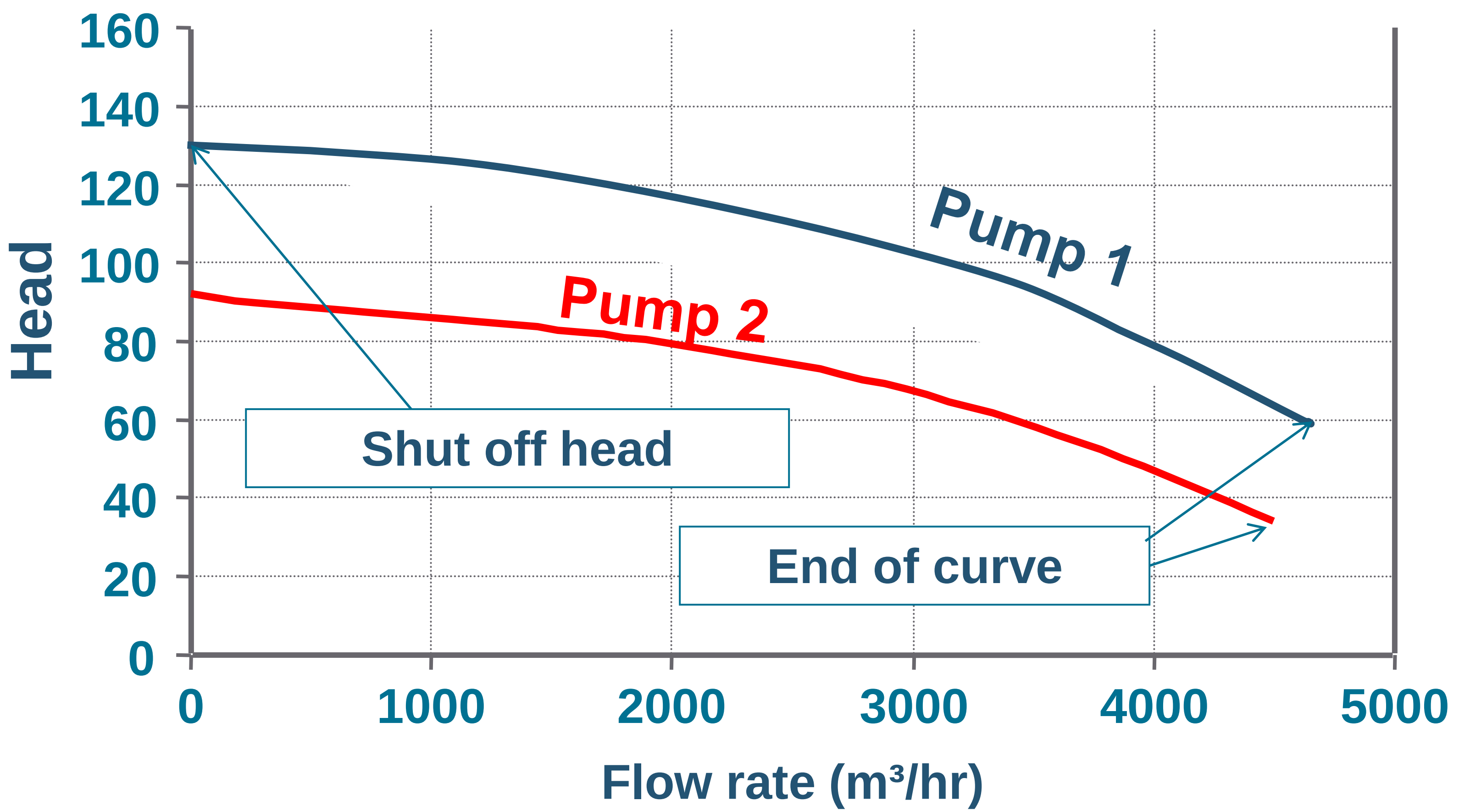
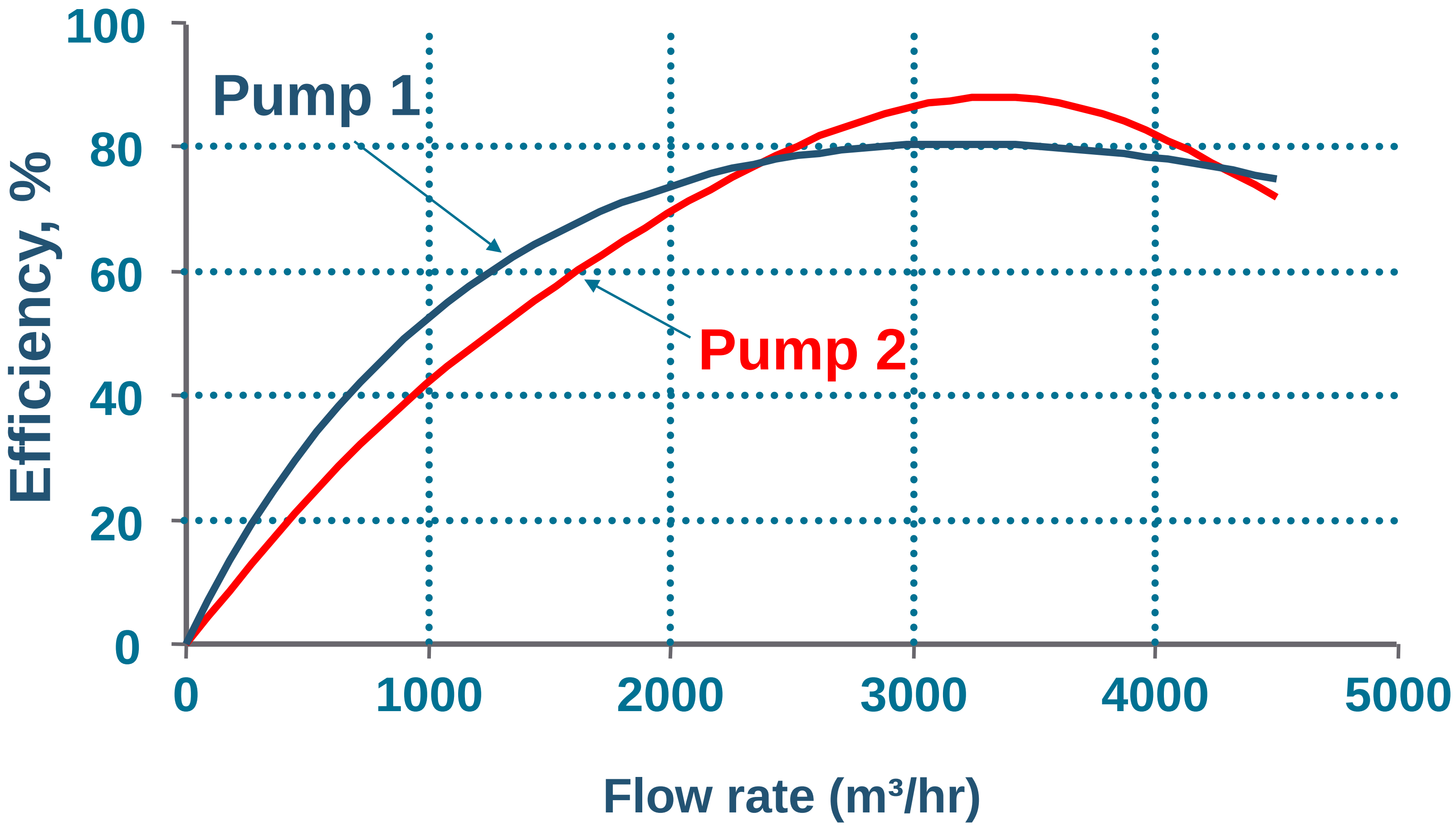
Pump Curve Shapes Vary



Efficiency Curves Vary



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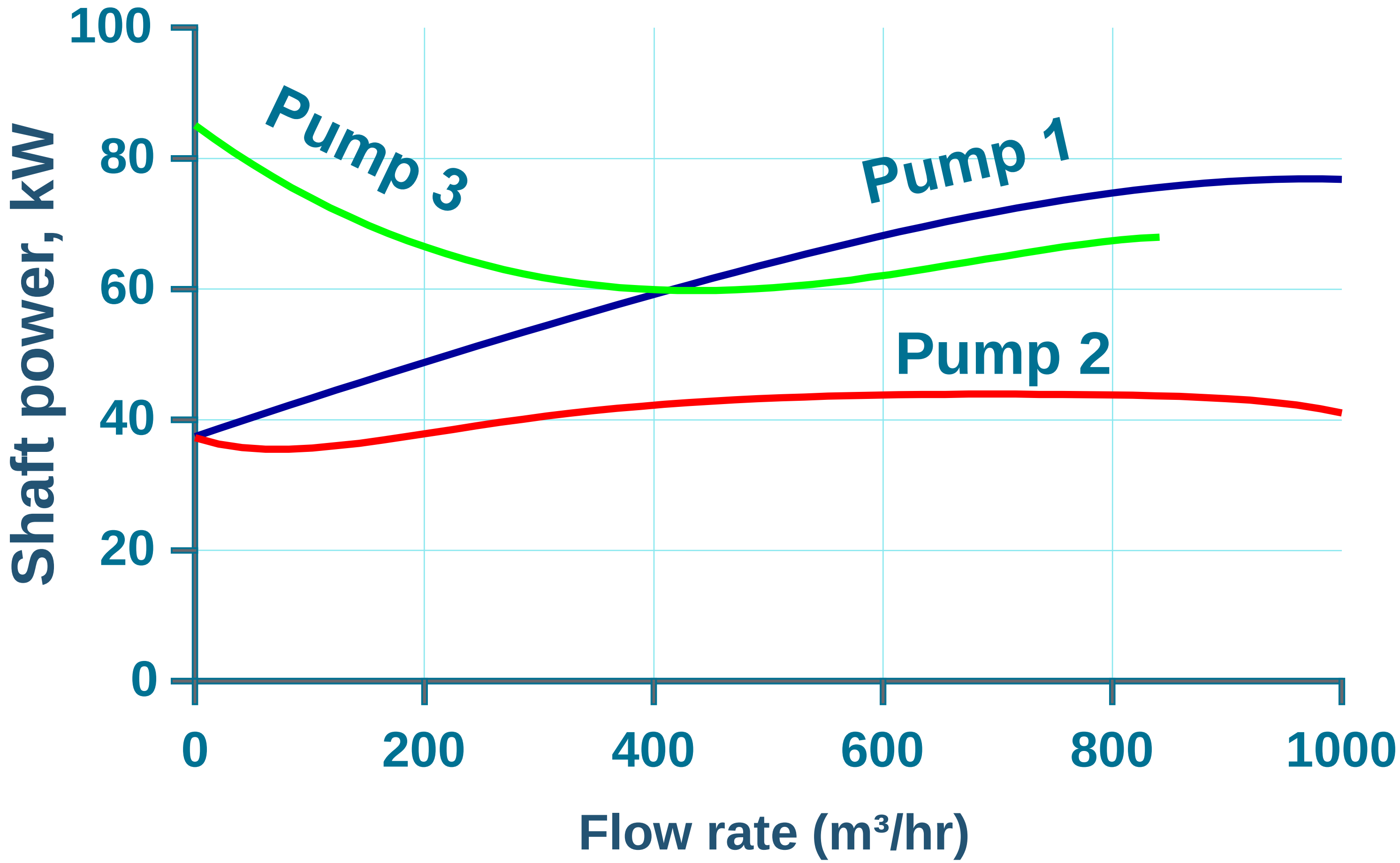
Example: for different types of centrifugal pumps



Note:
There is still power even with zero flow

Slide Courtesy of Oak Ridge National Laboratory

Affinity Laws

Affinity Laws for Centrifugal Pumps

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Relation between

- Pump Speed (N),
- Impeller Diameter (D)
- Flow (Q)
- Head (H)
- Power (P)

- Changes to centrifugal pump performance is governed by the Affinity Laws.
- These laws show how performance is affected when the pump speed is changed, or when the impeller diameter is changed.

For changes in speed

$$Q_{new} = Qold * \left(\frac{N_{new}}{N_{old}}\right)$$

$$H_{new} = H_{old} * \left(\frac{N_{new}}{N_{old}}\right)^2$$

$$P_{new} = P_{old} * \left(\frac{N_{new}}{N_{old}}\right)^3$$

For changes in diameter

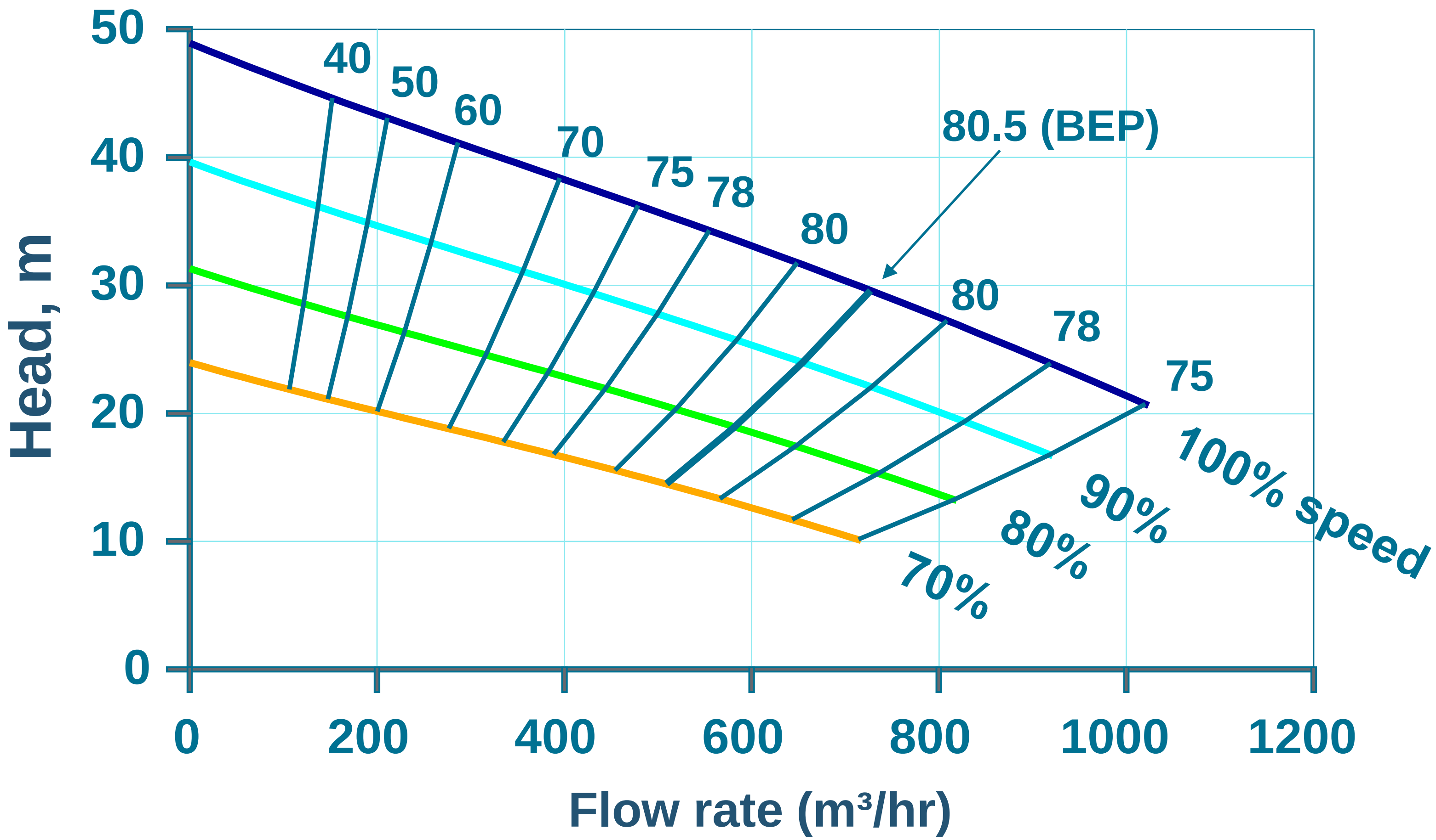
$$Q_{new} = Qold * \left(\frac{D_{new}}{D_{old}}\right)$$

$$H_{new} = H_{old} * \left(\frac{D_{new}}{D_{old}}\right)^2$$

$$P_{new} = P_{old} * \left(\frac{D_{new}}{D_{old}}\right)^3$$

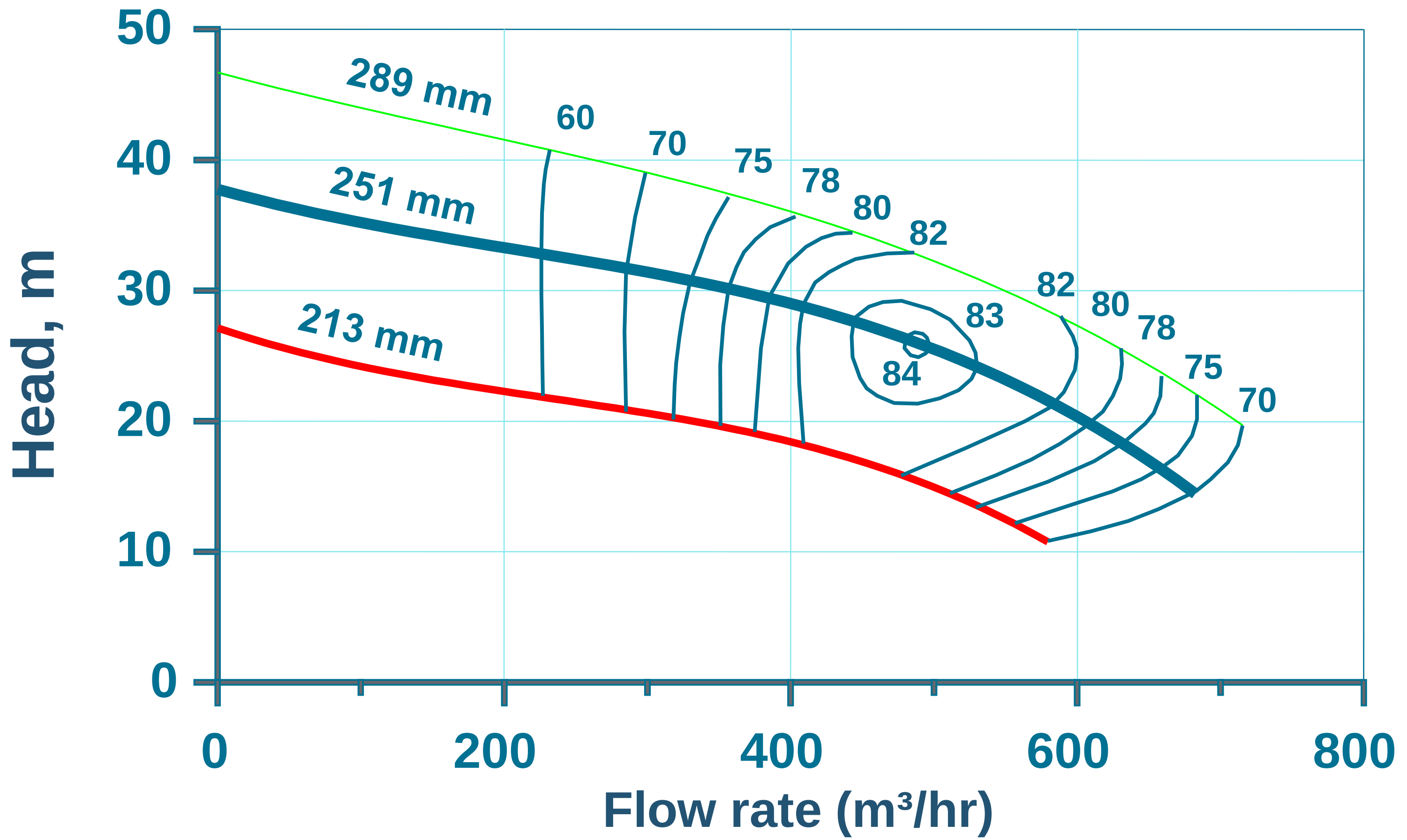
Changes in Speed

- For speed changes, the efficiency lines follow the affinity laws
- Iso-efficiency lines can be overlaid onto head-capacity curves



Change in Impeller Diameter

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



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

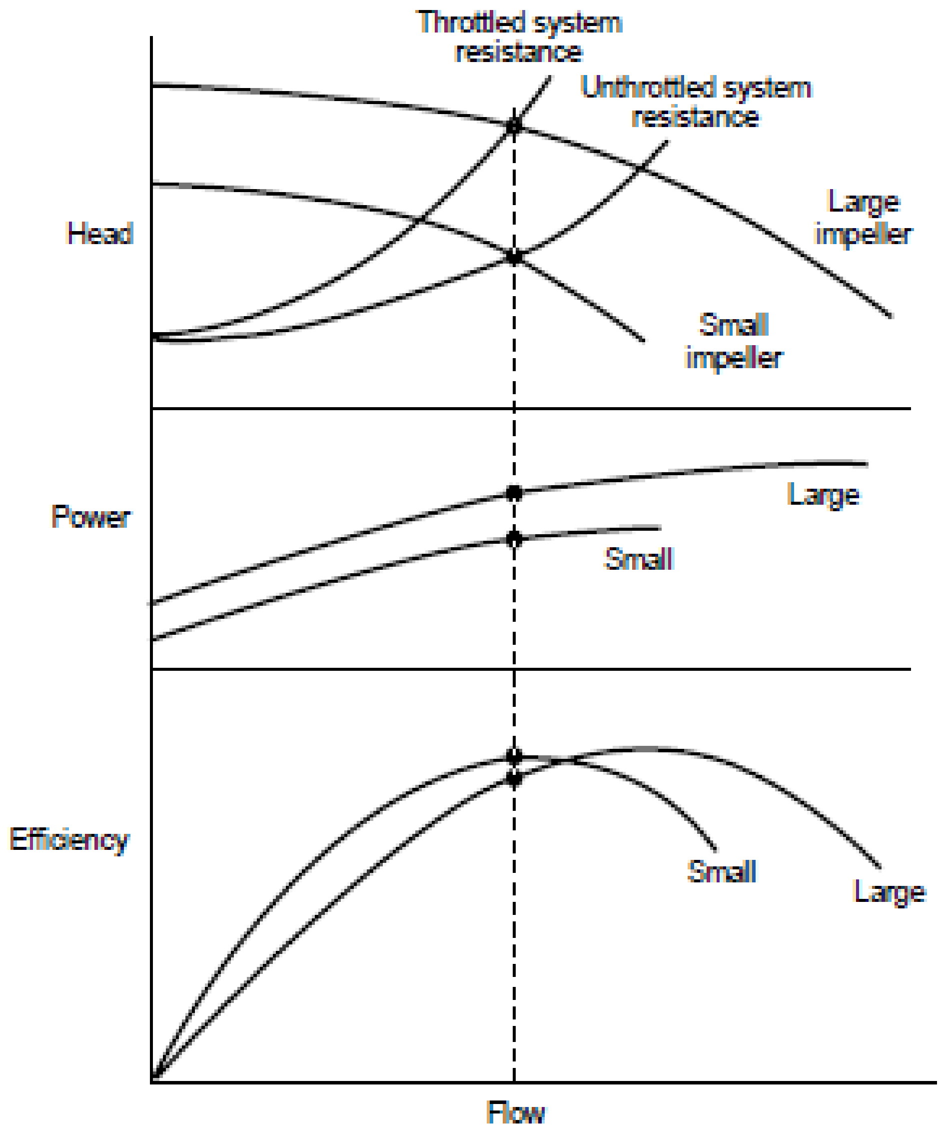
Slide Courtesy of Oak Ridge National Laboratory

Impeller Trimming

- Pump impeller will be most efficient close to maximum diameter.

- A smaller impeller will be less efficient, but the system energy savings will be large.

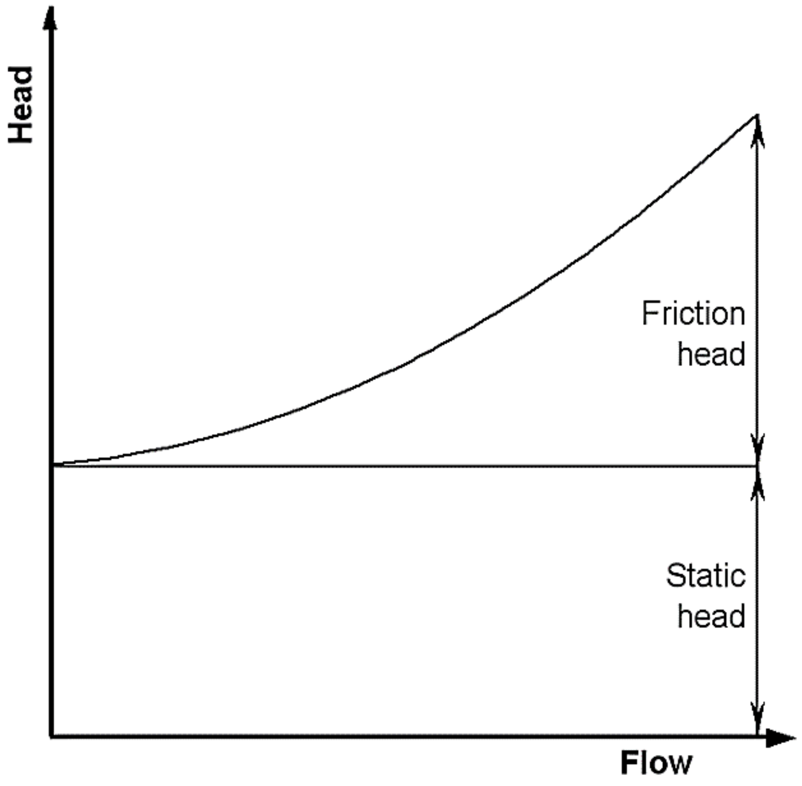
- Replacing or trimming an impeller is an option, usually for fixed load applications

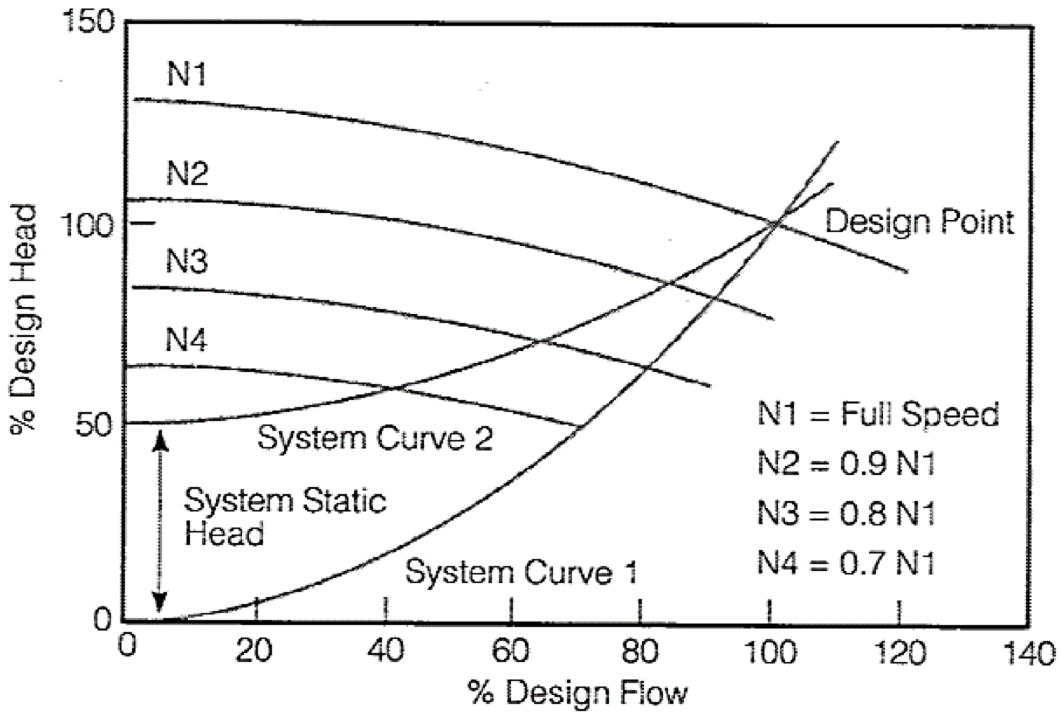


Affinity Laws Applicable to Friction Losses

Affinity laws only apply to the friction losses.

Static losses are constant at different speeds.





Therefore, systems with low static head tend to be better candidates for VSDs and thus for energy savings.

Fluid Flow Control Methods

1. **On Off Control** — Fluid flow is controlled by switching pumps on and off . This often requires a multi pump arrangement.

2. **Bypass Lines** — Bypass allow the fluid to flow around or past the production or system component, when the fluid flow is not required.

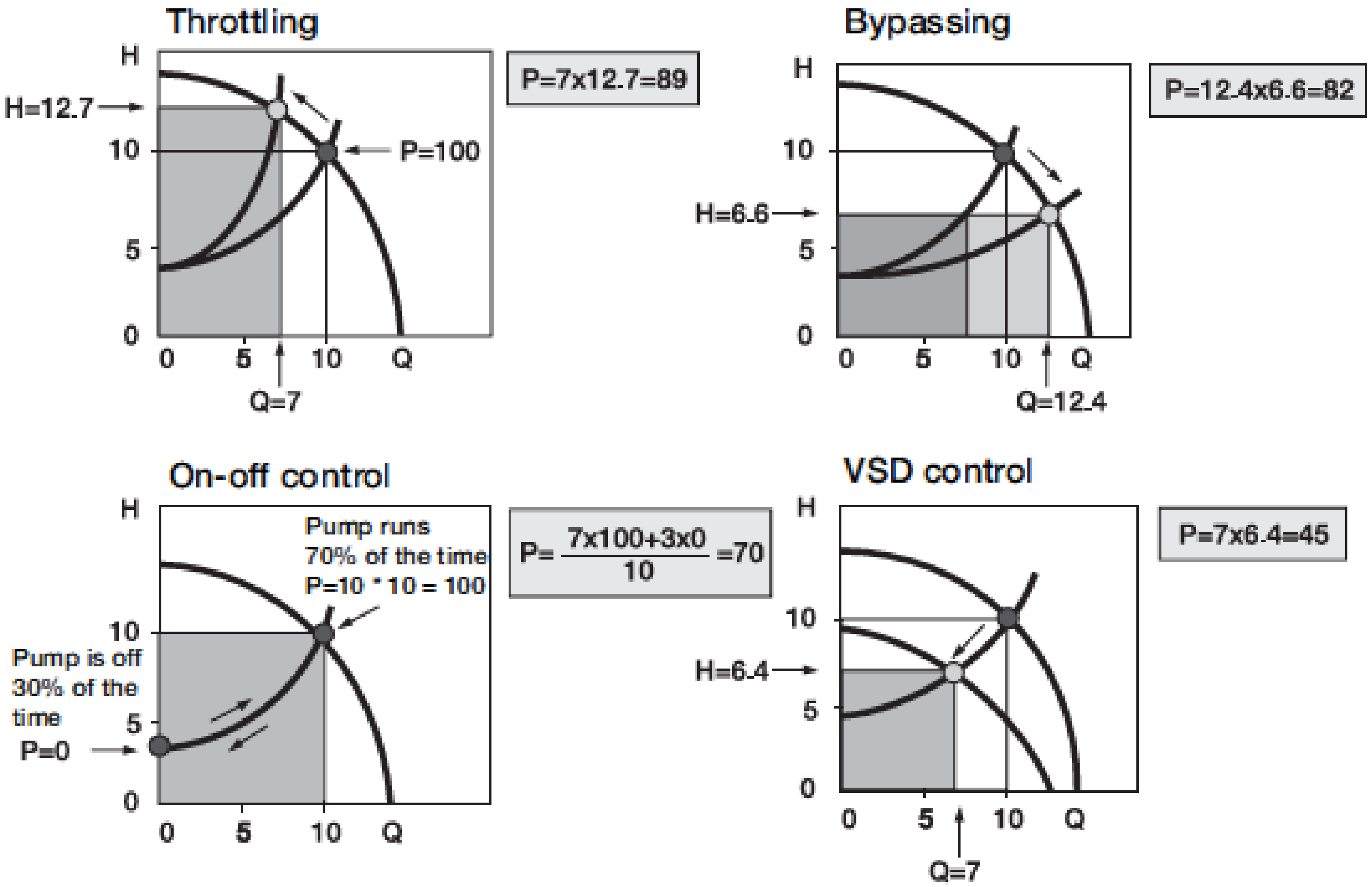
3. **Throttle Valves** — A throttle valve restricts the fluid flow so that less fluid can flow through the pump, and also creating a pressure drop across the valve

4. **Multispeed Pumps** — Pumps that have been fitted two speed motors that can switch between speeds depending on the fluid flow required.

5. **Impeller Trimming** — For specific process speed requirements the pump impeller may be trimmed in order to redefine the operating point of the pump more efficiently

6. **Fan Speed Control** — Fluid flow is controlled by the actual speed of the pump and includes:
   1) Mechanical (Gears, Belts, Fluid Couplings)
   2) Electrical (Variable speed drives (VSDs)

Comparison of Pump Control Methods



Relative power consumption on an average flow rate of 70% with different control methods

Control	Energy
Throttling	89
By Passing	82
On-Off control	70
VSD control	45

Considerations for Affinity Laws

- It is 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 + System

Pump Operating Point

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Very Important

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.

Operating Point

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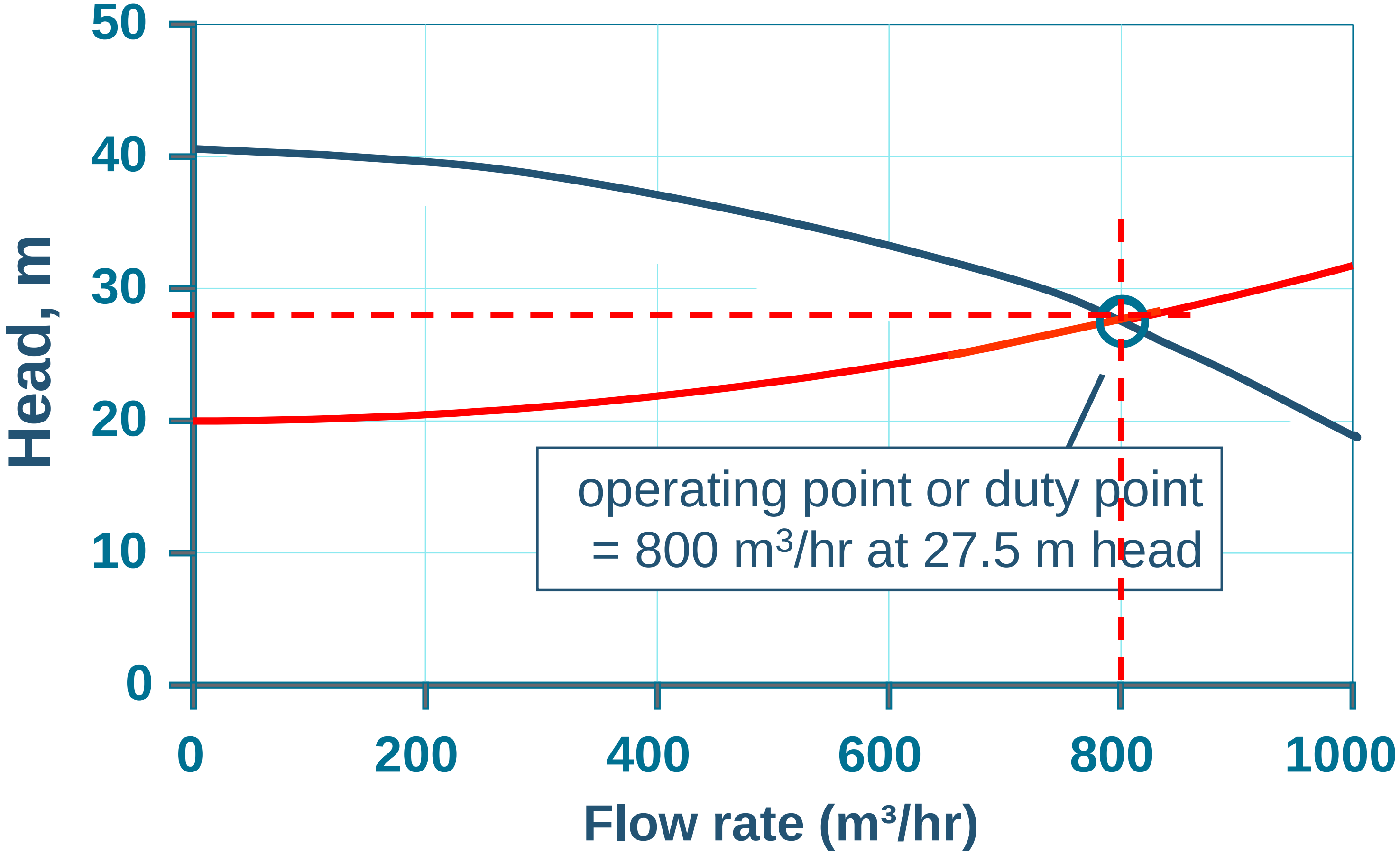
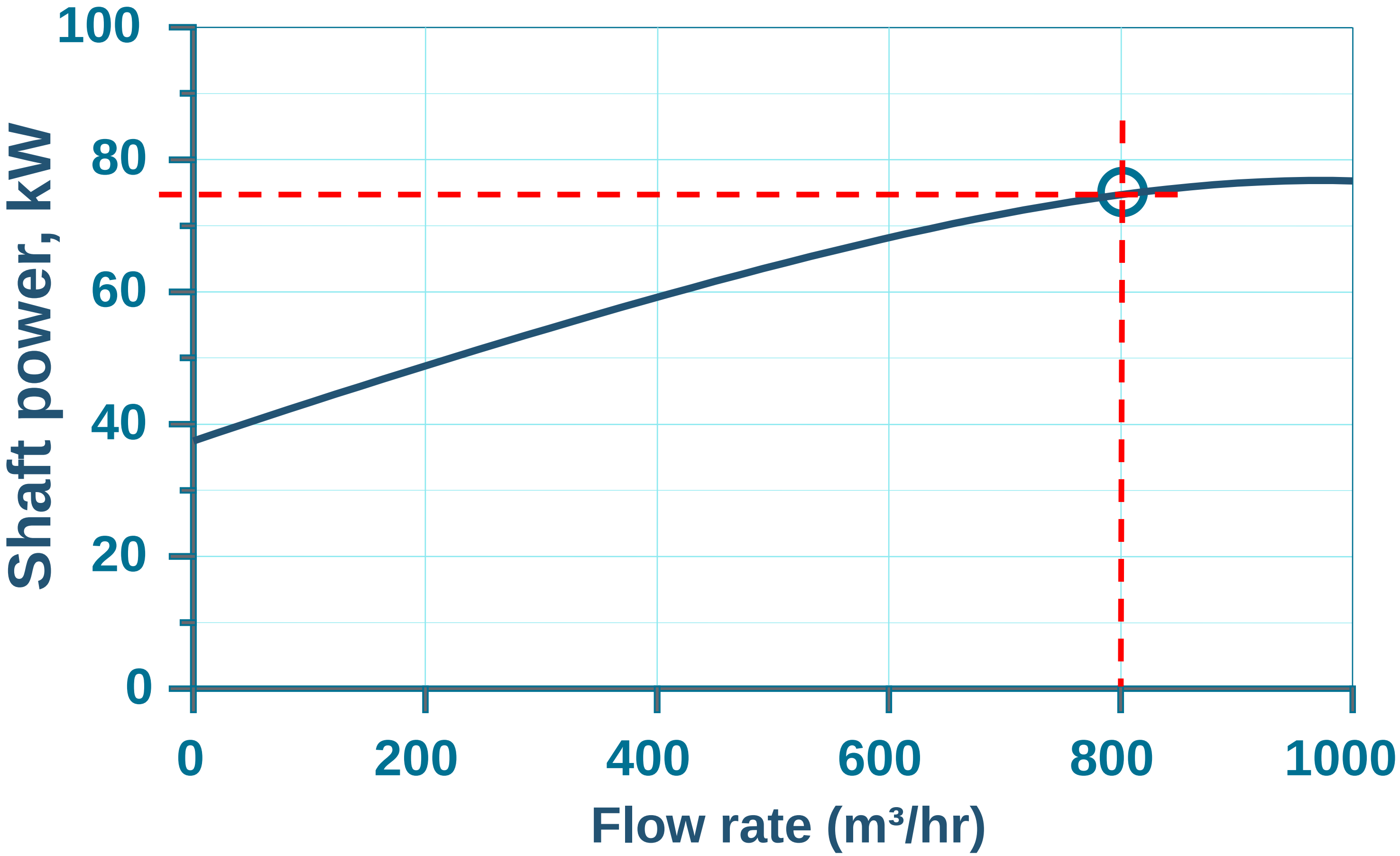
- The intersection between the pump and system head capacity curves defines the operating point



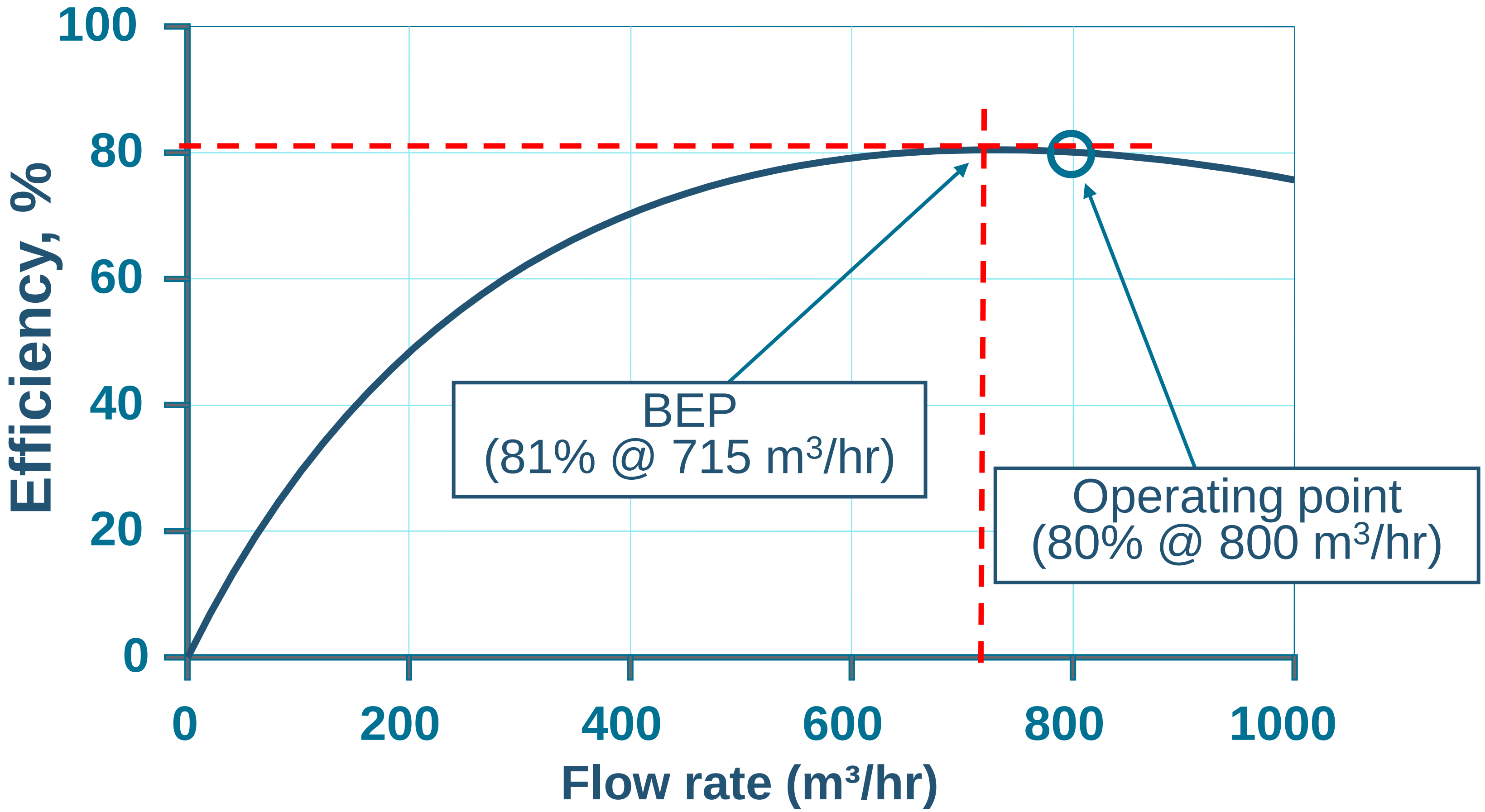
Shaft Power Curve

- The shaft power curve for this pump indicates that the power at 800 m^3/hr is about 75 kW



Best Efficiency Point

- The operating point at slightly greater than the pump Best Efficiency Point(BEP) flow rate



Operating a pump…

- at a reduced flow rate
- with three different system curves

Change in Speed: All Frictional System

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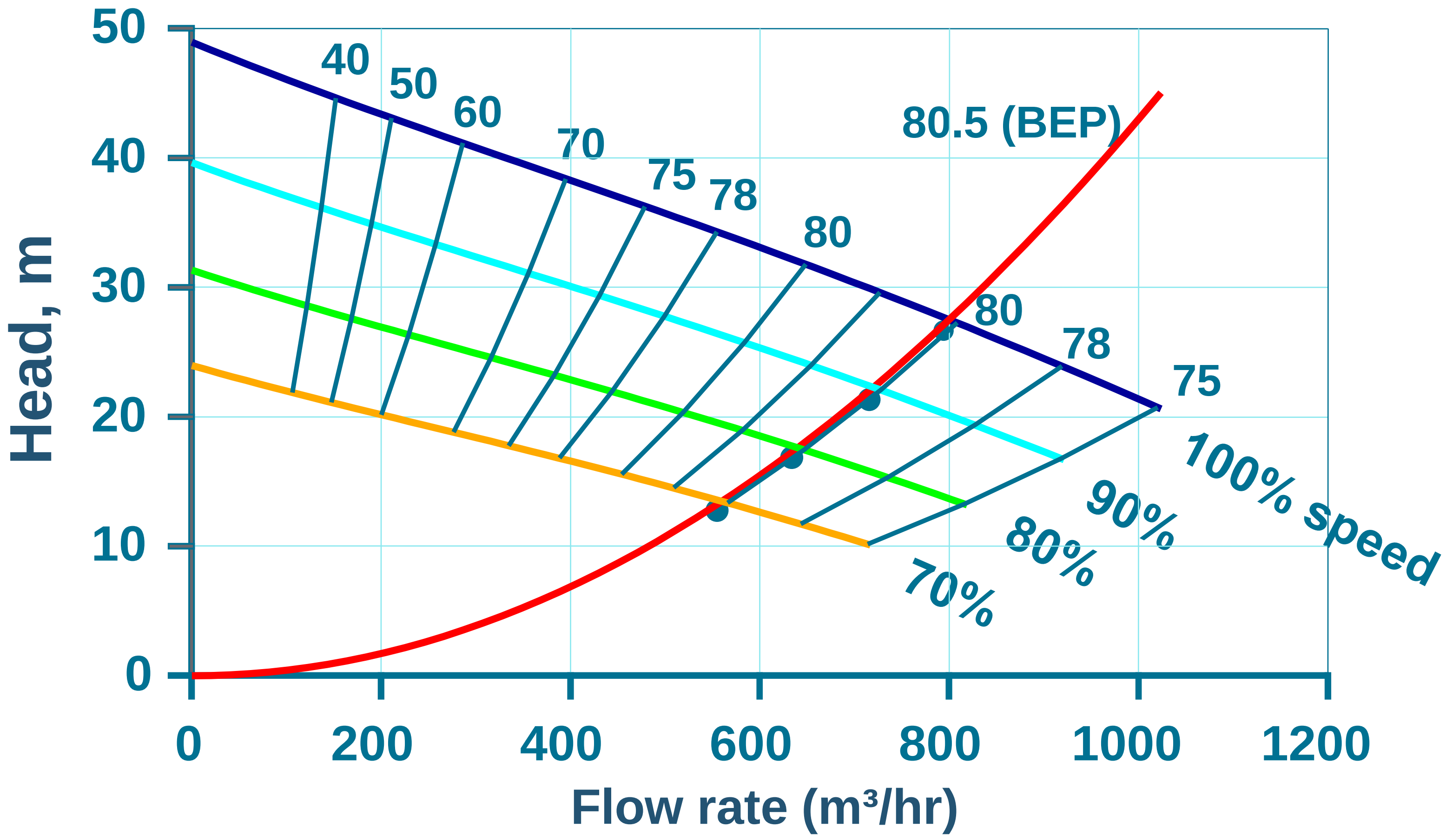
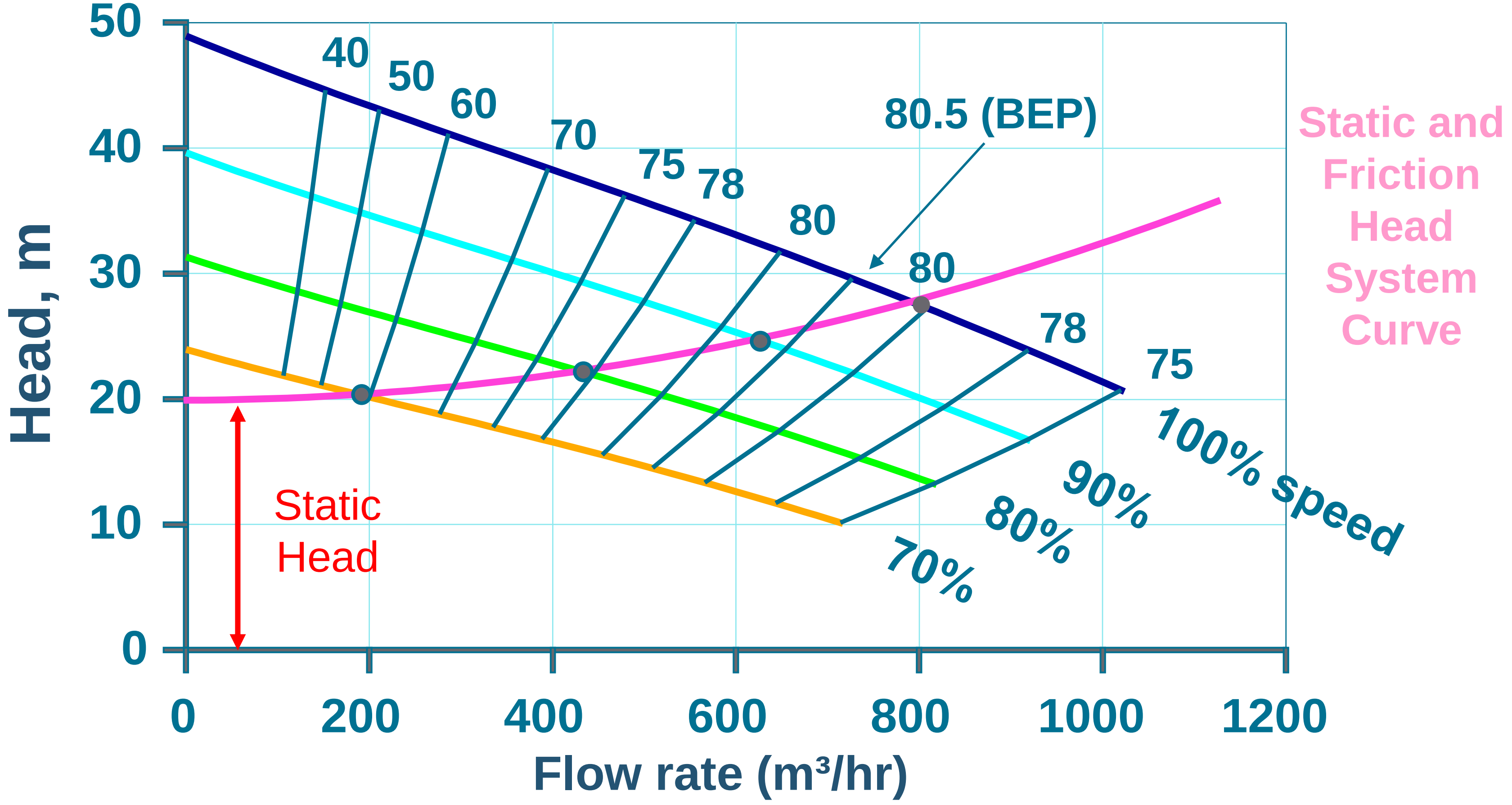
- Change in speed for the all frictional system results in maintenance of constant pump efficiency



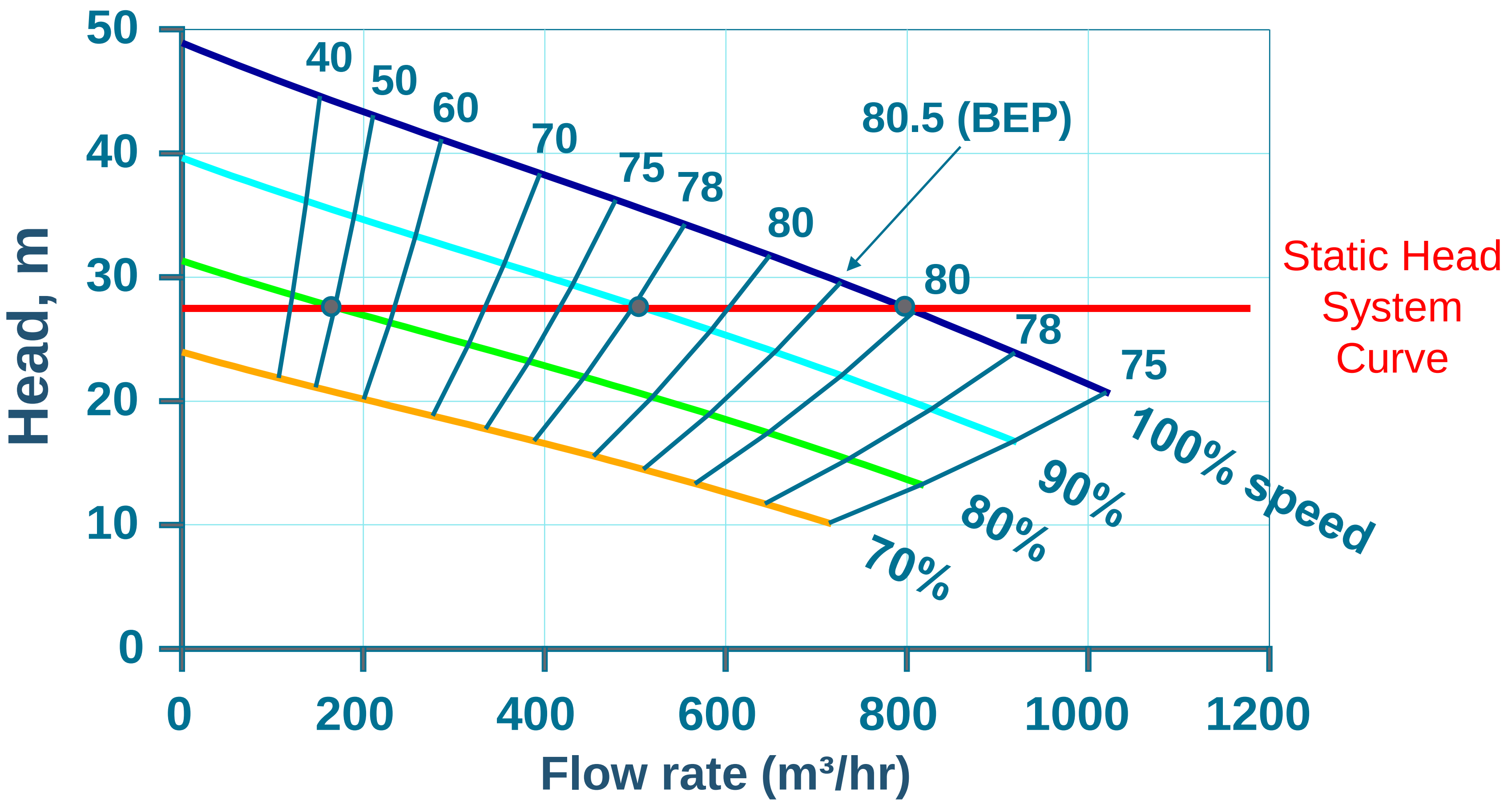
Change in Speed: Static & Frictional System

- In a system with static head, pump efficiency does not remain fixed as speed changes



Change in Speed: All Static System

- In a system with Only Static Head, the effect is even more dramatic



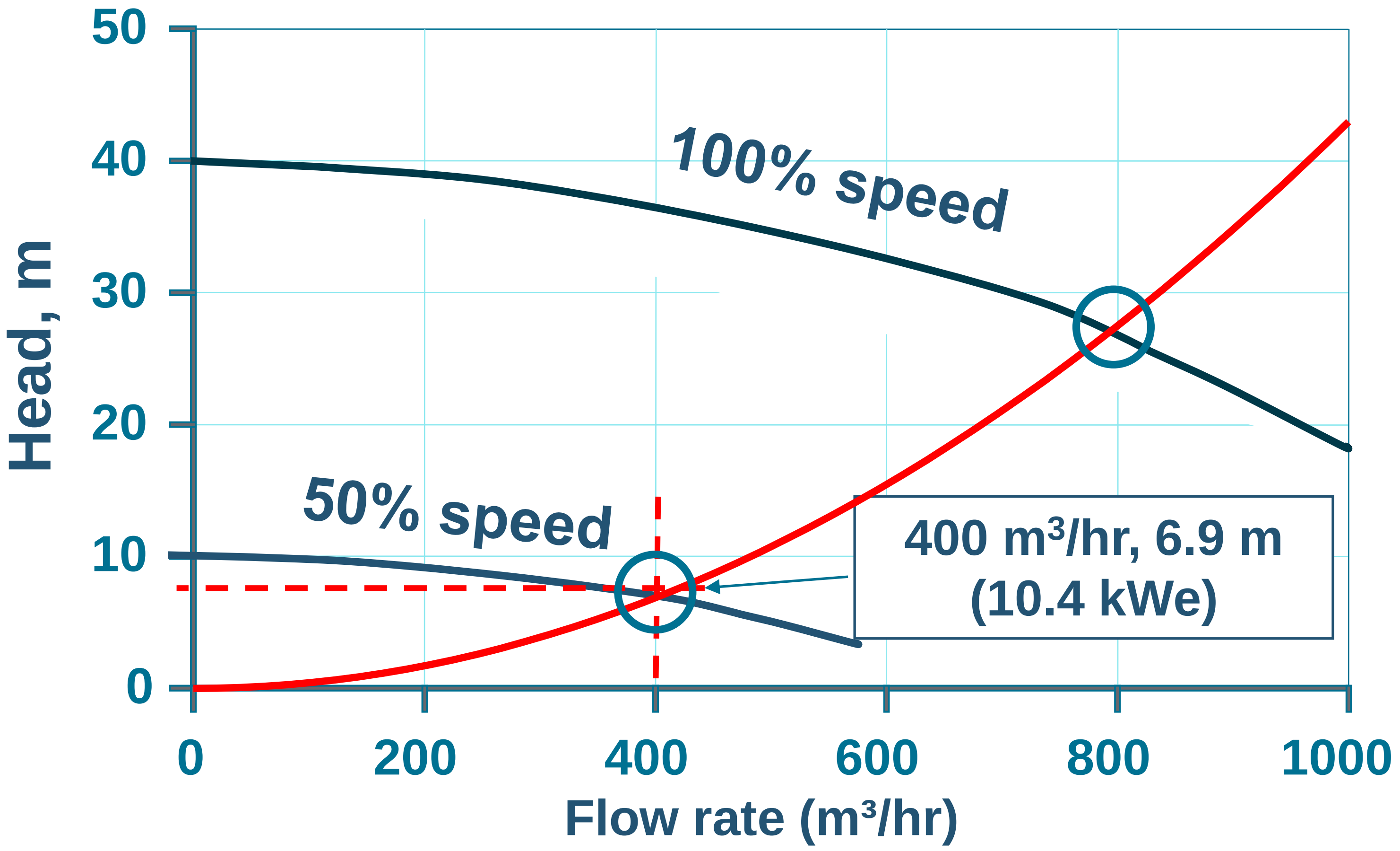
Slide Courtesy of Oak Ridge National Laboratory

Operating a pump…

- With 50% flow, 400 m^3/hr (half the original requirement)

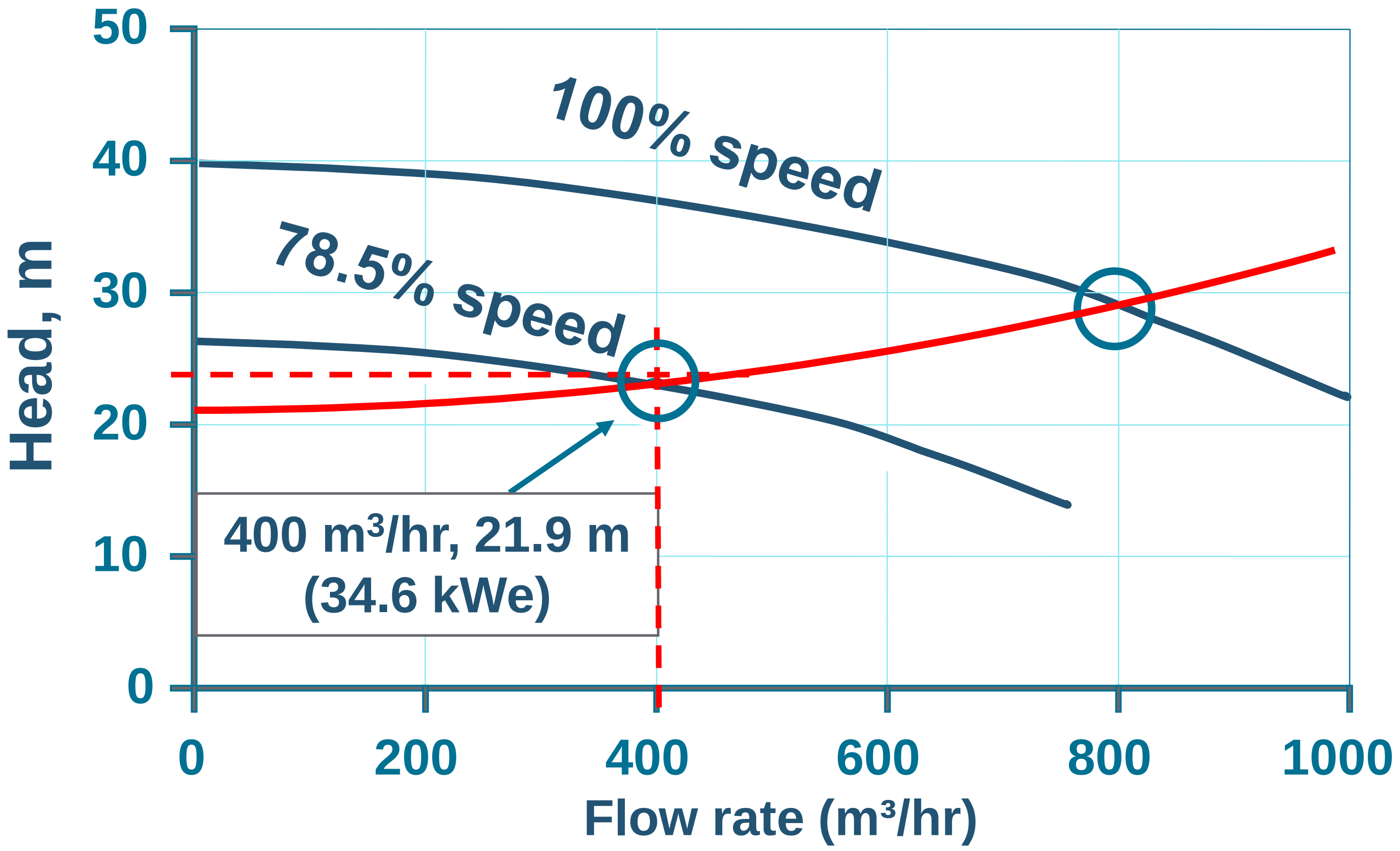
Half Speed: All Frictional System

- To develop 400m^3/hr in the all frictional system speed is reduced to 50% of the original



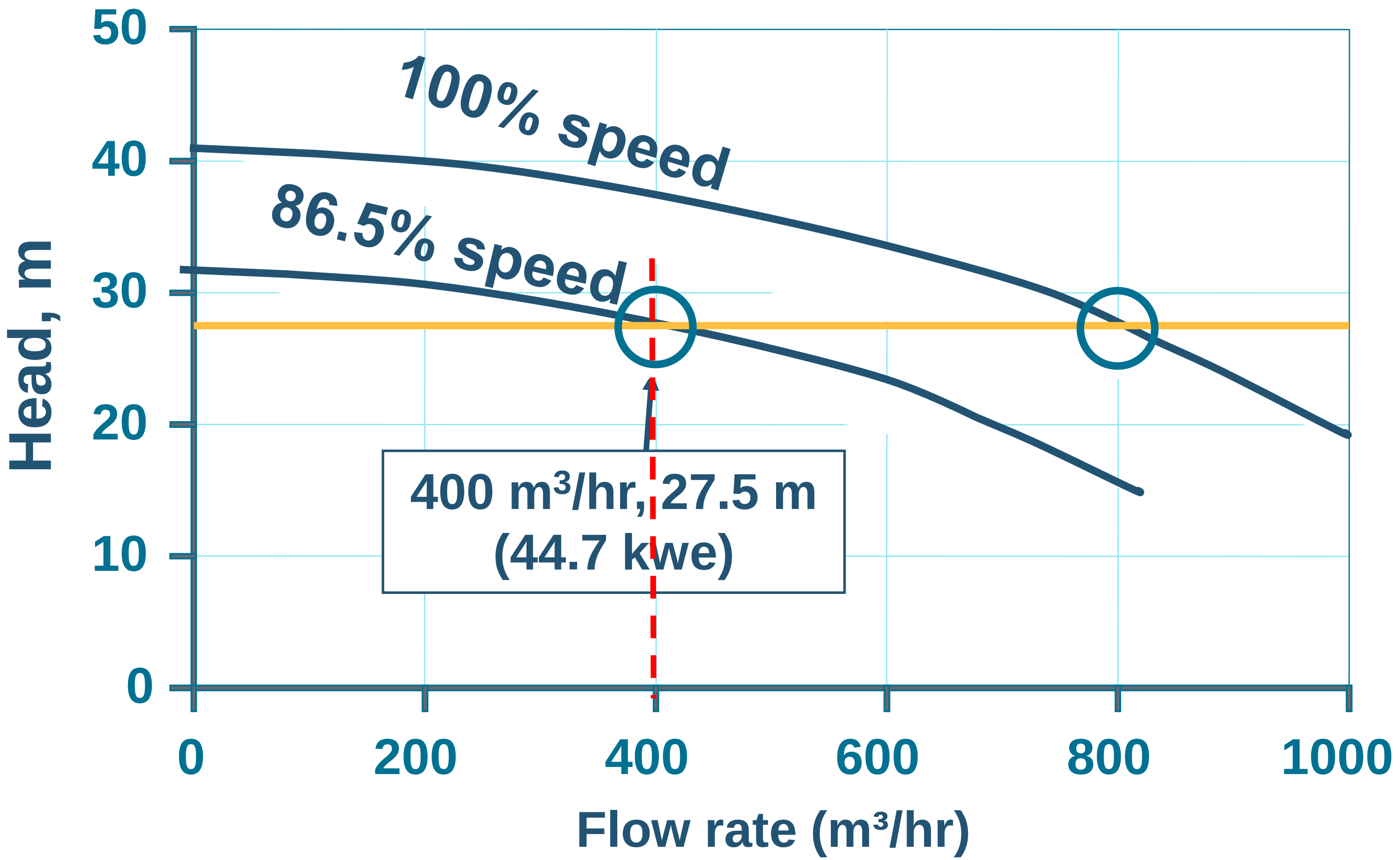
Half Speed: Static & Frictional System

- To develop 400 m^3/hr in the mixed static / frictional system, speed is reduced to 78.5% of the original



Half Speed: All Static System

- To develop 400 m³/hr in the all static head system speed is reduced to 86.5% of the original



NPSH (Net Positive Suction Head) and CAVITATION

Cavitation – Properties of a Liquid

- Boiling point of any liquid proportional to temperature and pressure

  (At sea level, water boils at 100 ˚C)

- As pressure drops, so does the temperature at which the liquid will boil

  (At Higher altitude – lower atmospheric pressure water boils at a lower temperature)

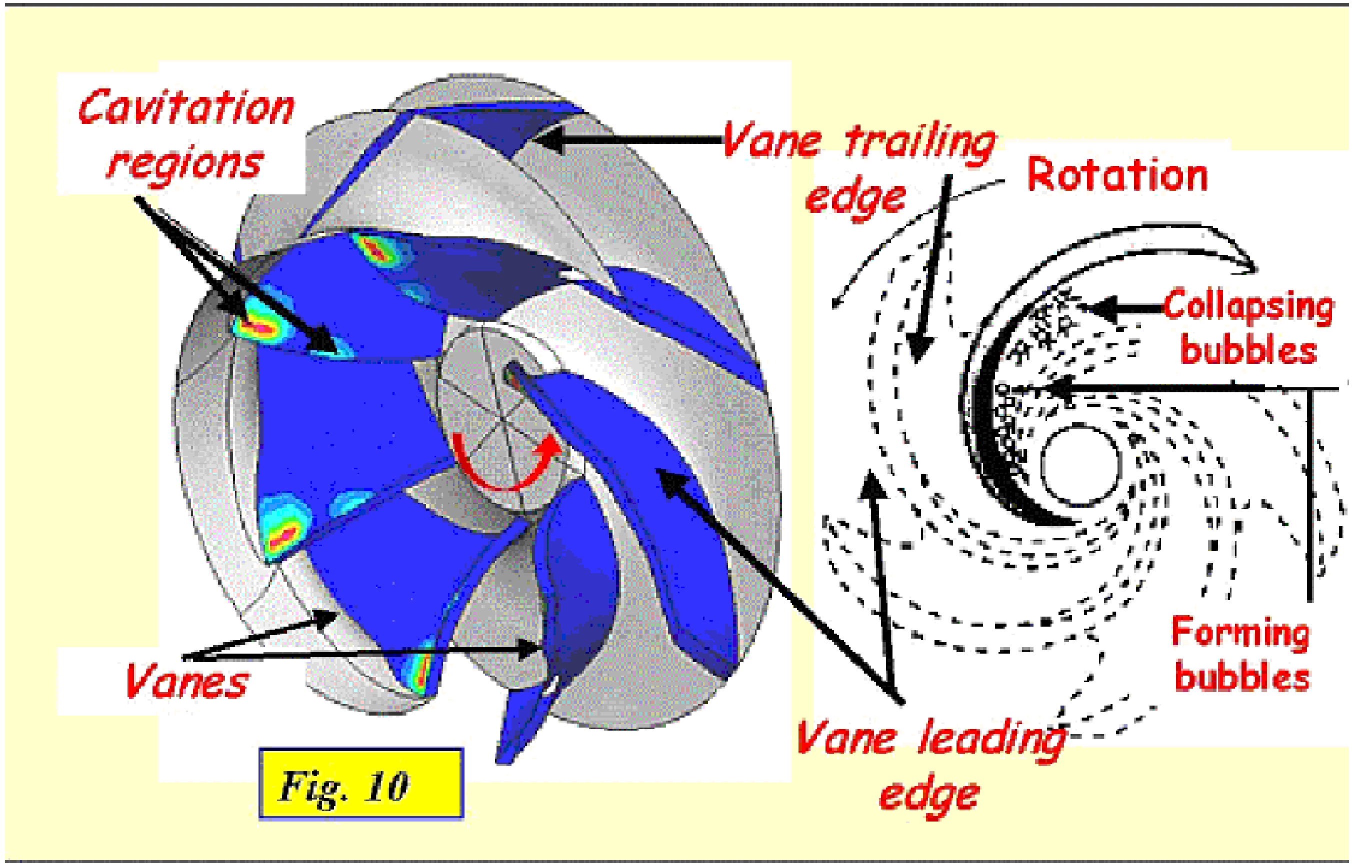
- An area of **<u>low pressure</u>** is always present at the impeller eye
- If the pressure is low enough the liquid will boil at room temperature

Cavitation - Theory

- When the pressure at the impeller eye is low enough, it causes the liquid to flash and form bubbles of vapour in the liquid.
- When the liquid/vapour bubble travels further into the impeller the pressure increases and the vapour bubbles start to collapse.
- This phenomenon of bubbles forming and collapsing is called cavitation.
- Cavitation is harmful to pump operation because it reduces the pump's performance and can cause structural damage to the impeller vanes.

Cavitation

Impeller cavitation regions



www.cheresources.com

Cavitation Damage

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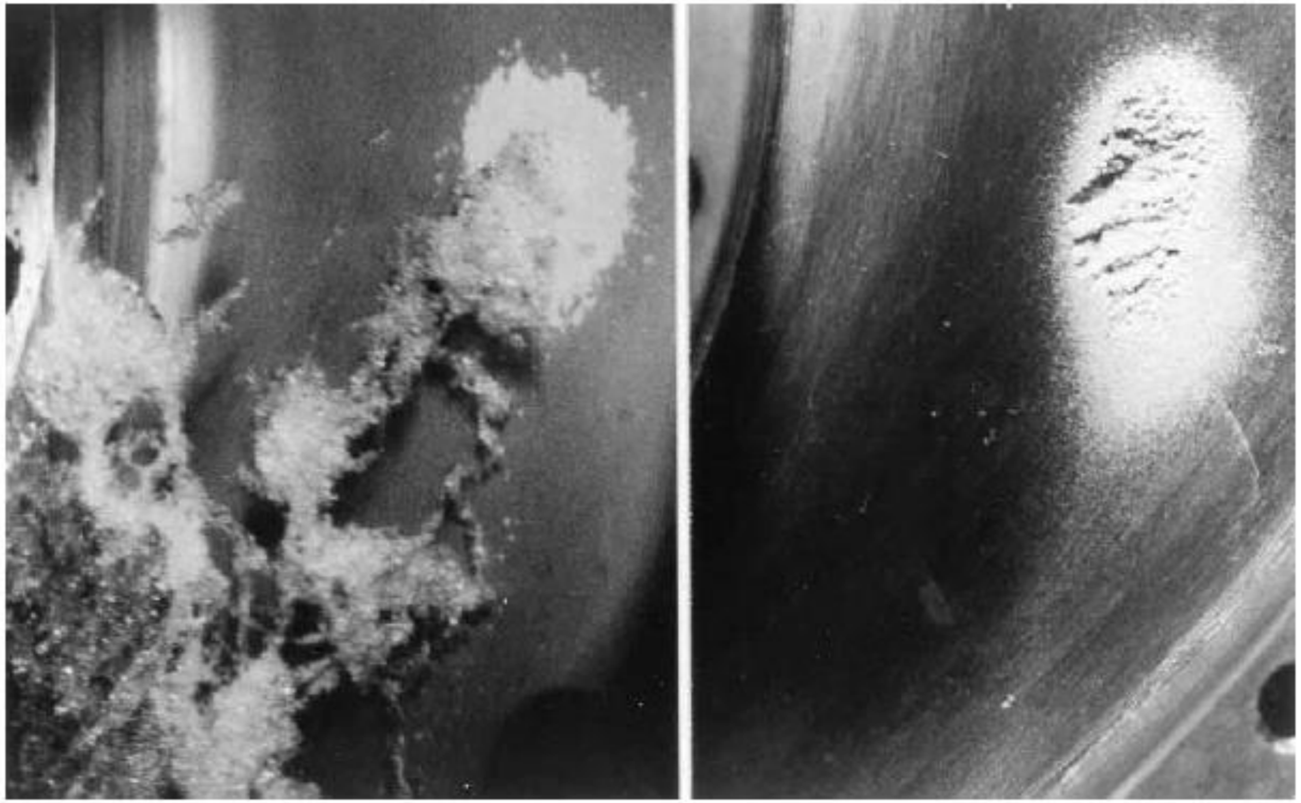
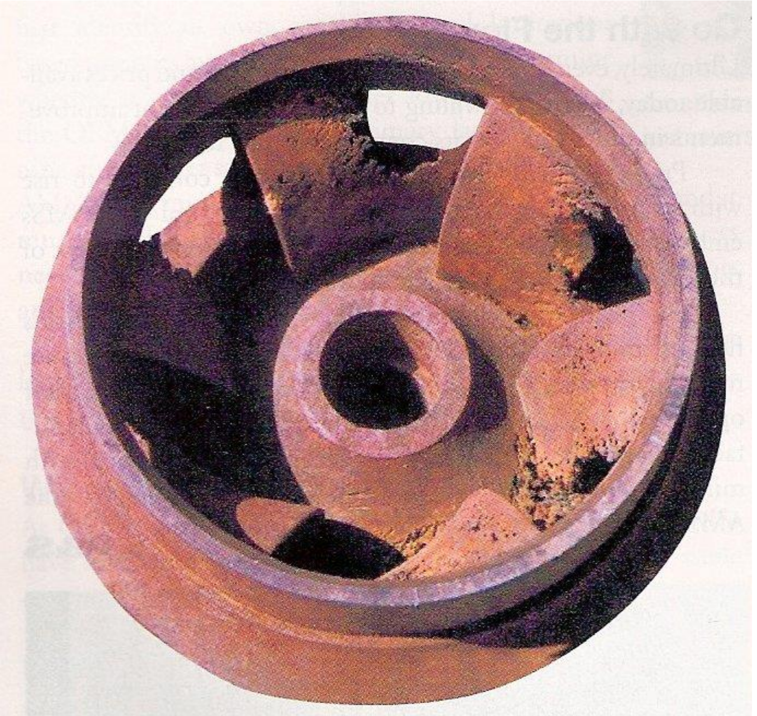


Cavitation Bubbles and Cavitation Damage

Cavitation Damage



Cavitation Damage

Waste water lift station

Cavitation Damage

$NPSH_a$ should be greater than $NPSH_r$

- Centrifugal pumps cannot suck
- Centrifugal pumps require a positive suction pressure

  - The pump manufacturer will indicate at what inlet pressure the outlet pressure has fallen 3%.
  - This is called the Net Positive Suction Head Required. (NPSHr)
  - At that pressure cavitation is already taking place.
  - The available pressure NPSHa has to be higher than the NPSHr in order to avoid cavitation.

NPSH Required - (NPSHr)

- Centrifugal pumps require enough pressure on the suction side of the pump to prevent flashing in the impeller eye.
- This flashing reduces the pump’s performance and can damage the impeller.
- The amount of pressure required for a specific pump is determined during the design of the impeller and is confirmed by testing during performance tests.

NPSH Required - (NPSHr)

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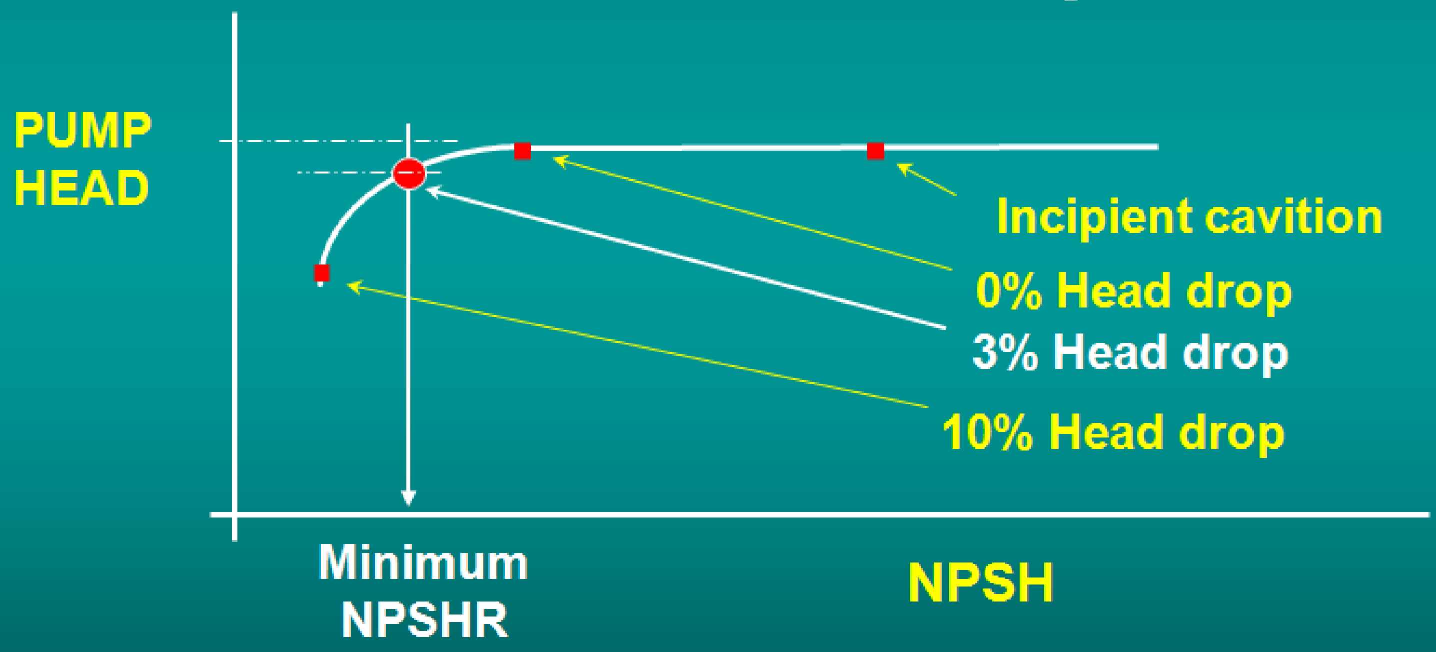
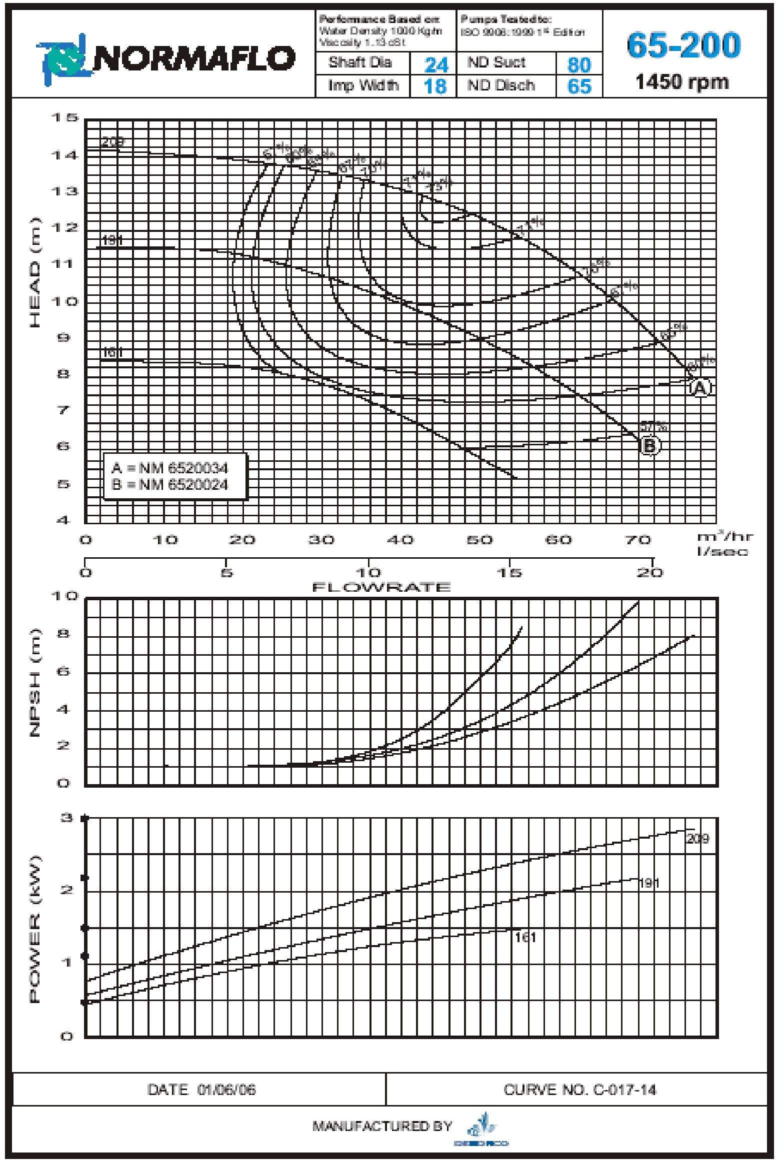
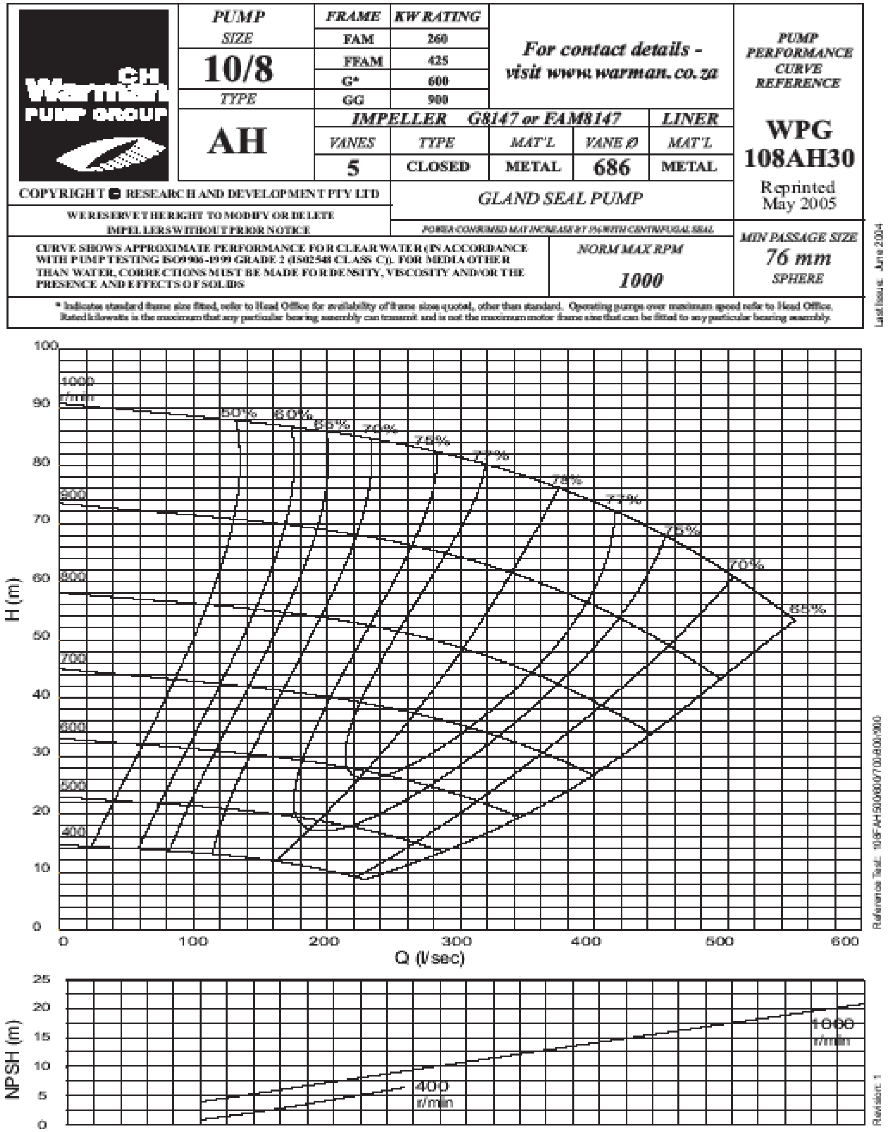


- Test result for one constant flow
- NPSHR increases with flow.

Typical set of OEM Curves



Typical OEM Curves for Speed Regulation of Slurry Pump



NPSH Available - ($NPSH_a$)

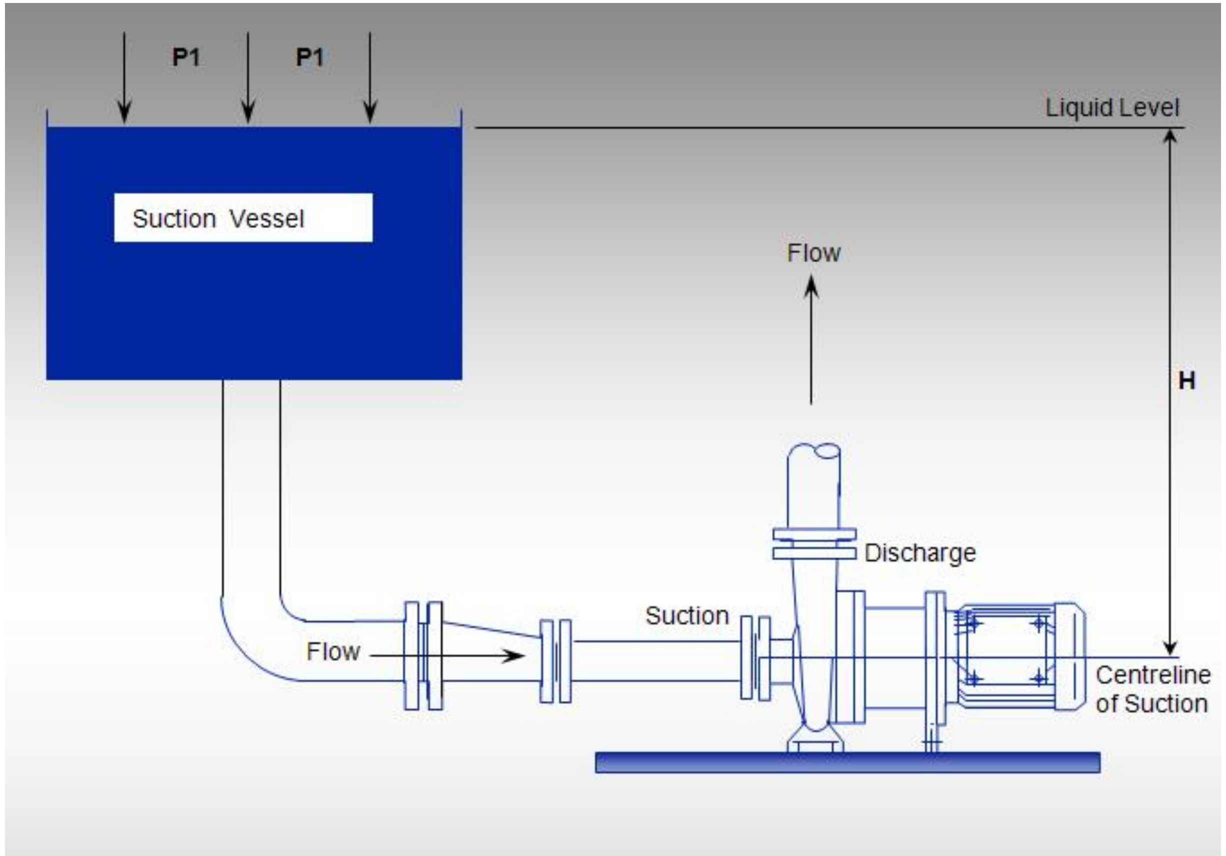
- The available pressure at the suction of the pump is called Net Positive Suction Head available

$$NPSH_a = H_a +- H_z - H_f + H_v - H_{vap}$$

- Ha – Atmospheric pressure
  - Absolute pressure
  - Includes tank pressure if a sealed tank
  - Dependant on altitude

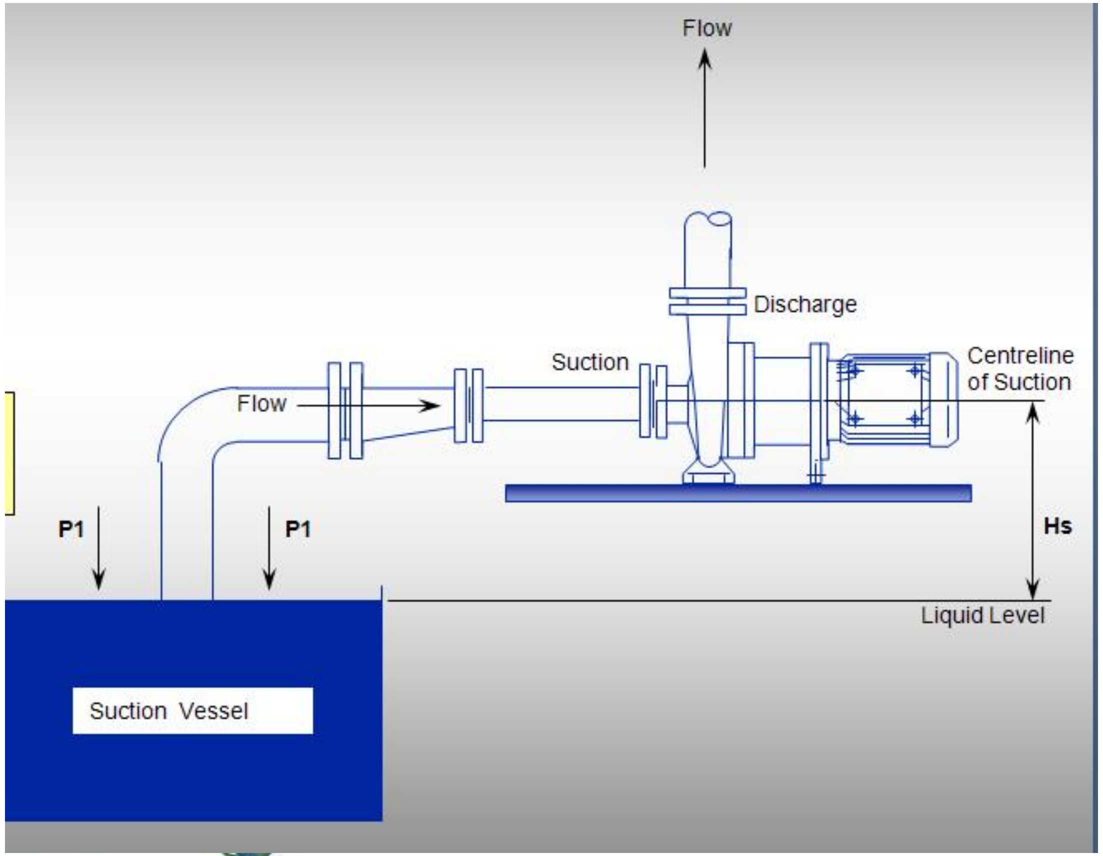
NPSH Available (Hz)

Hz – Vertical height between water level and pump centreline – positive suction head



NPSH Available (Hz)

Hz/ (Hs in Fig.) – Vertical height between water level and pump centreline – suction lift



NPSH Available (H_f and H_v)

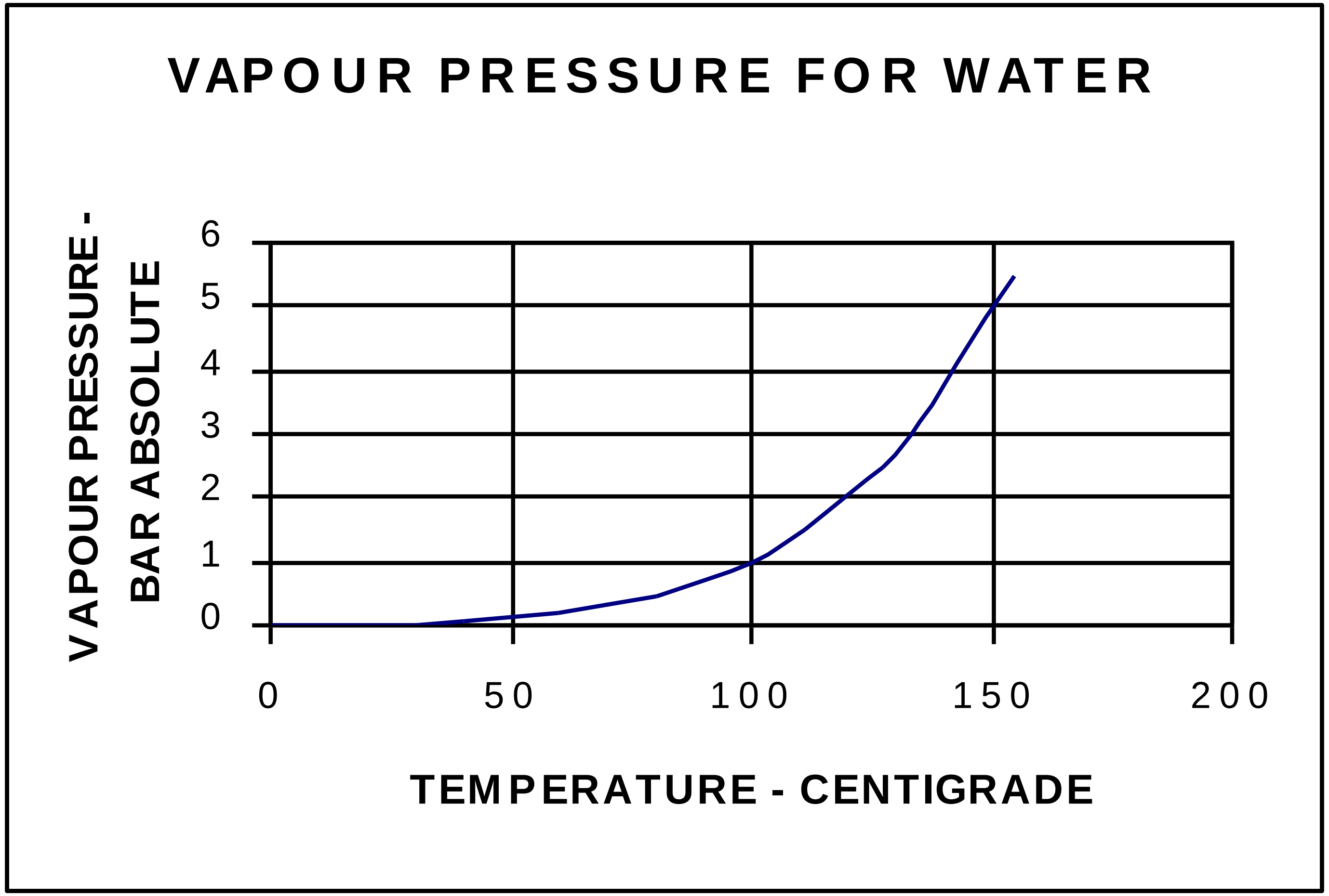
- **H_f** – friction loss through the suction pipe and fittings
  - Always negative
  - Adversely affected by valves, strainers, narrow pipes

- **H_v** – Velocity head at pump suction
  - Kinetic energy of the water = $V^2/2g$
  - Generally Negligible and can be ignored
    - Normal suction 1m/s Hv = 0.05m
    - 2m/s (bad suction design), Hv = 0.2m

NPSH Available (Hvap)

Hvap – Vapour pressure of water

- Pressure required to keep water in its liquid state
- Varies with temperature



Cavitation Symptoms

- The pump sounds like it is pumping rocks!
- High vacuum reading on suction line
- Low discharge pressure
- High flow rate

Cavitation Remedies

To increase NPSH available in the system:

- Unblock suction line (remove debris in pipe, clean strainer, clean out suction tank)
- Increase suction line diameter
- Raise liquid level or lower the pump
- Move pump closer to tank
- Fully open suction line valve
- Use a booster pump
- Sub-cool the liquid

Cavitation Remedies

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To reduce NPSH required by the pump:

- Move duty point left on curve
- Use oversize pump
- Run pump at slower speed
- Use a double suction impeller (two eyes)
- Use a larger impeller eye diameter (higher suction specific speed impeller). Lower inlet velocity due to increased area for the same flow.
- Use an inducer (special type of impeller)

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Pump reliability is a function of operating point

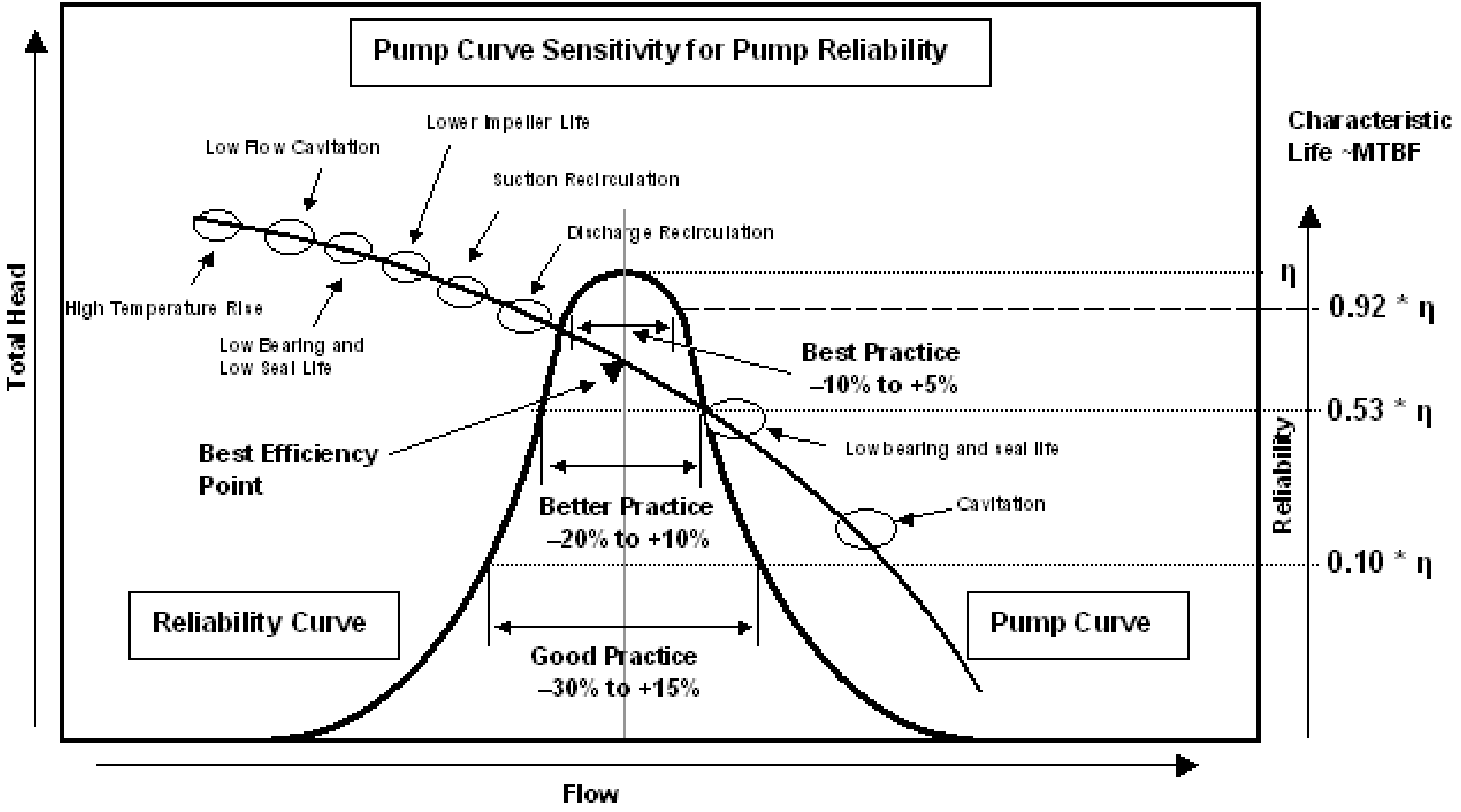


Figure Courtesy of P. Barringer.

Pumps in Parallel & Series

Parallel and Series Pumps

Parallel pumps - **sum** the **flow** rates at a given head

(to add flow, add pumps in parallel)

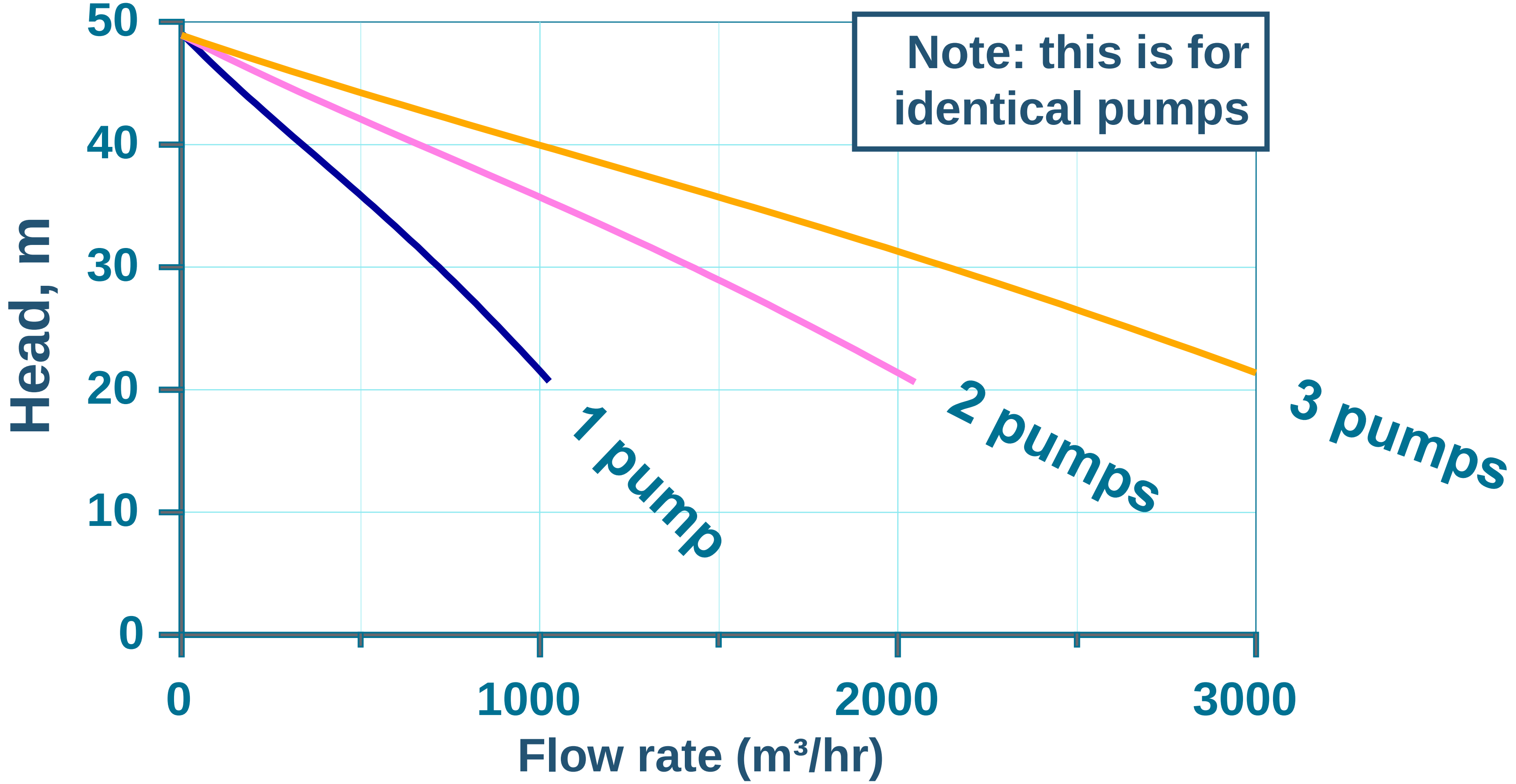
Series pumps - **sum** the **heads** at a given flow rate

(to add pressure, add pumps in series)

Parallel and series pumping "laws", like the pump affinity laws apply to the Pump Curves only

Parallel Pumps

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



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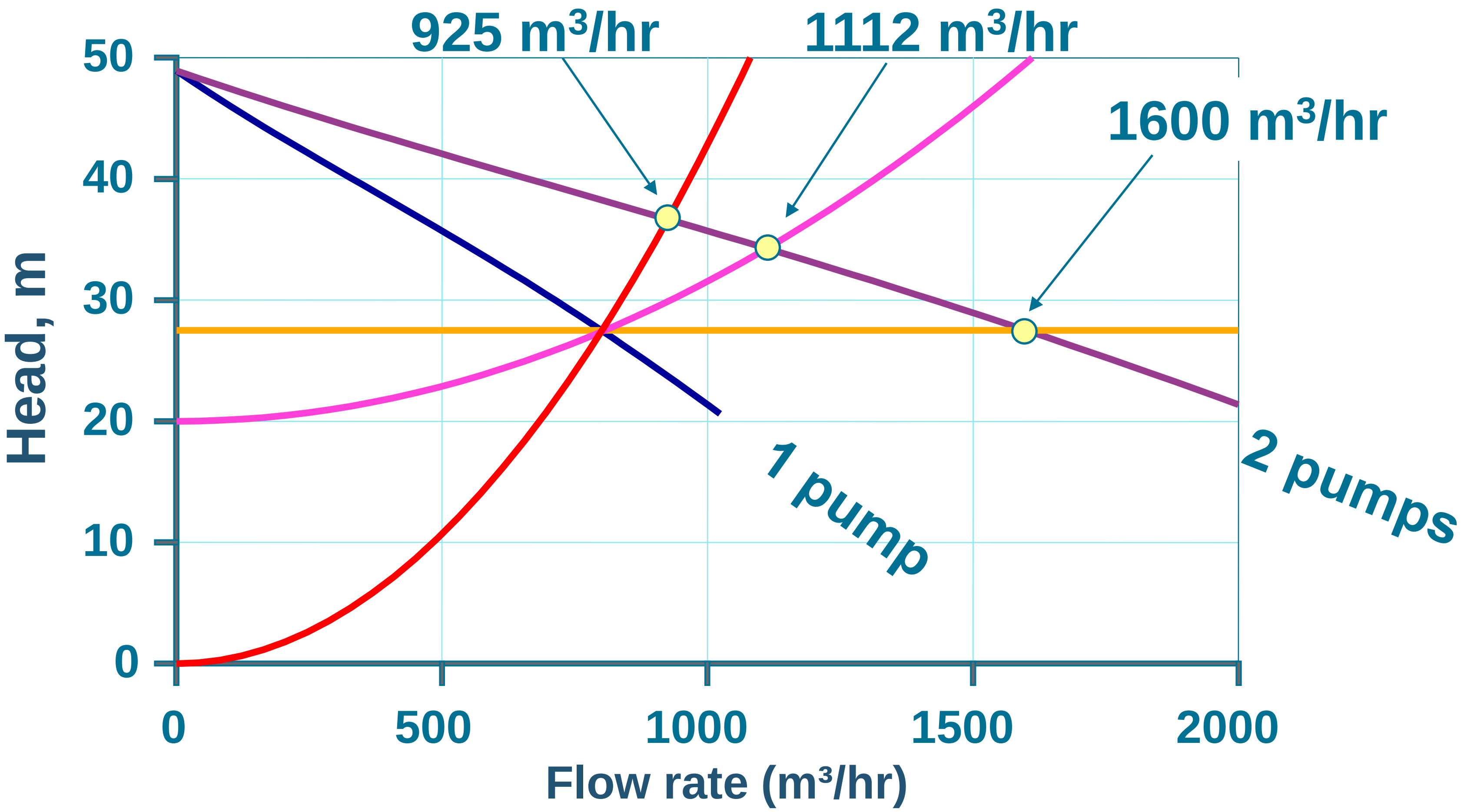
Parallel Pumps for Different Systems

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

- Static only
- Friction only
- Static & friction



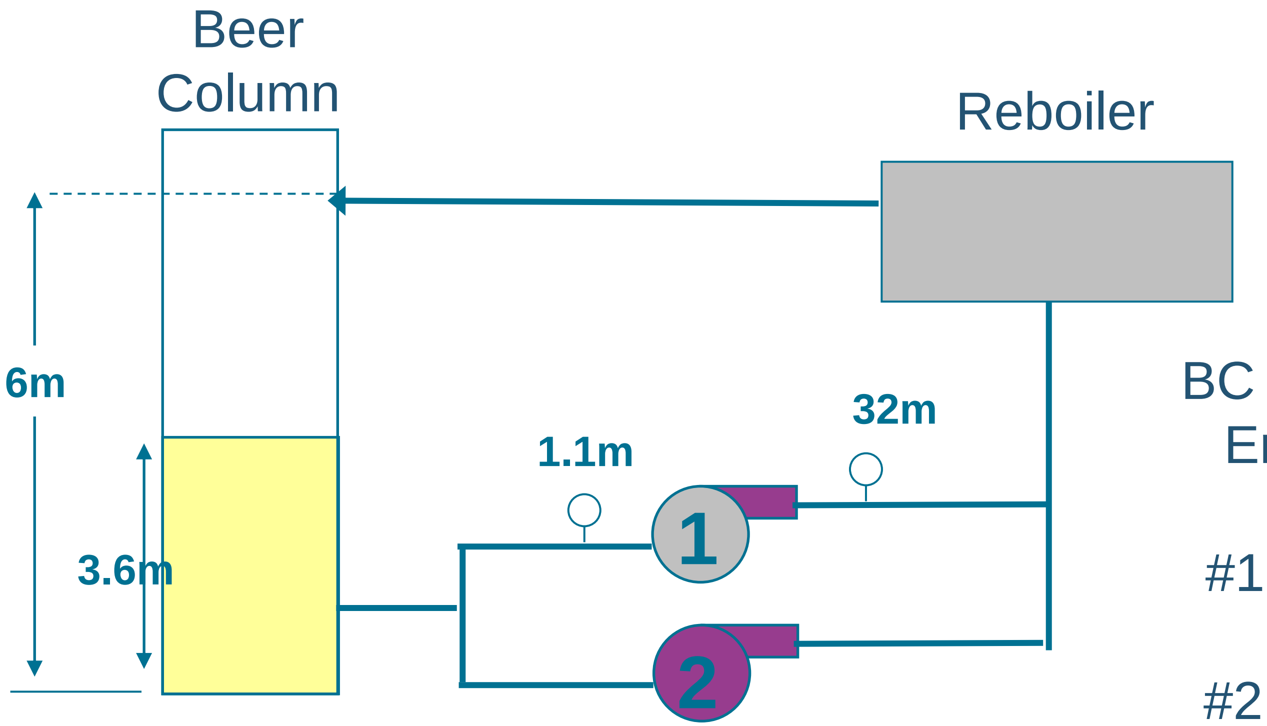
Pumps in Parallel

Multiple pumps in parallel

Pumps in Parallel

Case Study at Reboiler in an Ethanol Plant

Reboiler Pumps #1 and #2



BC Boiler Pump Energy Use:

#1 (119.6 kW)

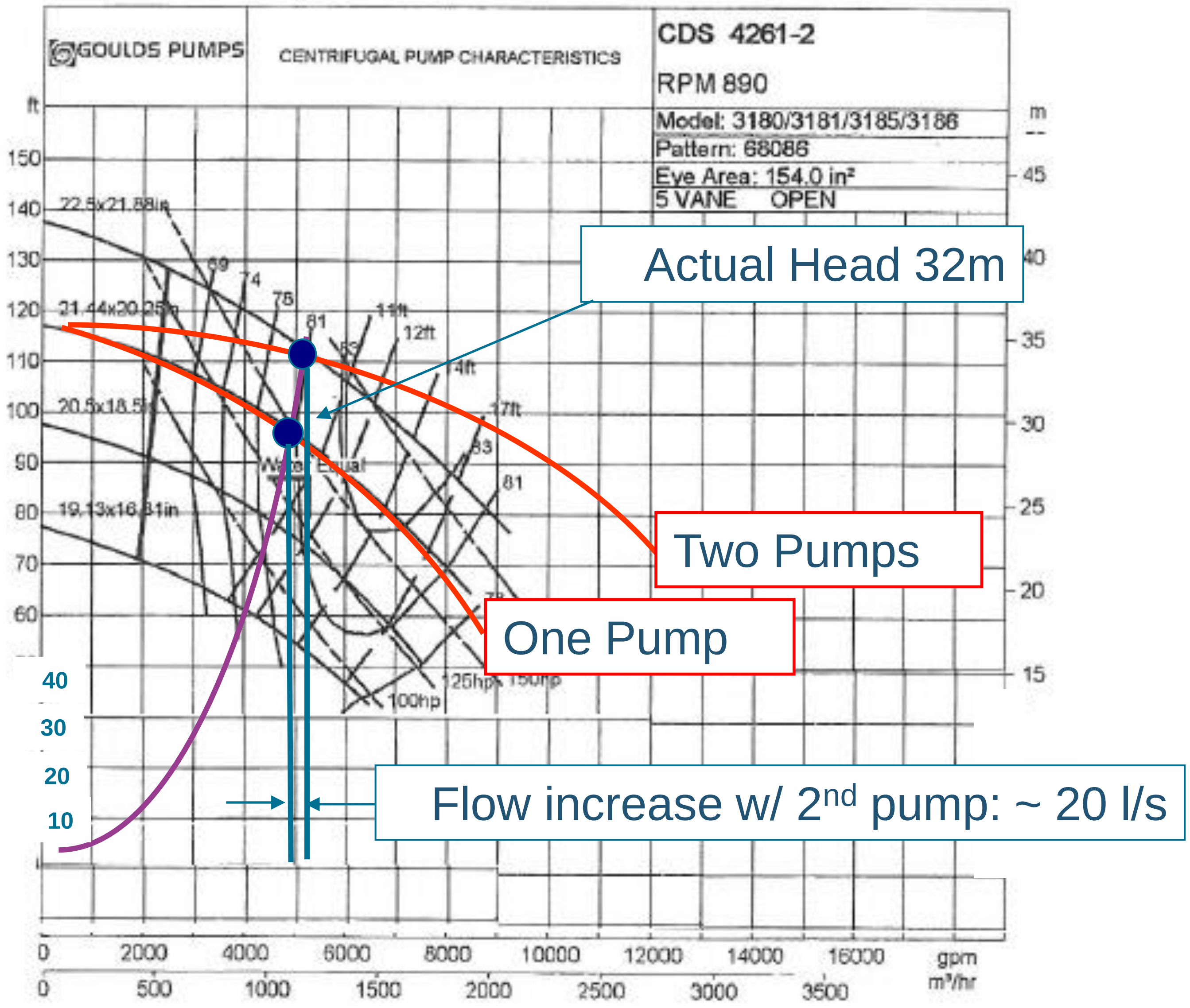
#2 (120.4 kW)

Energy Cost for Pump #2 : 120.4 kW x 8500 hours =

1,023,400 kWh @ $ 0.12/kWh = $ 122 808/ year

Reboiler Pump Curves

Operating two pumps instead of one only increases flow by 6% in this case, *but increases system annual energy costs by $ 122 808*



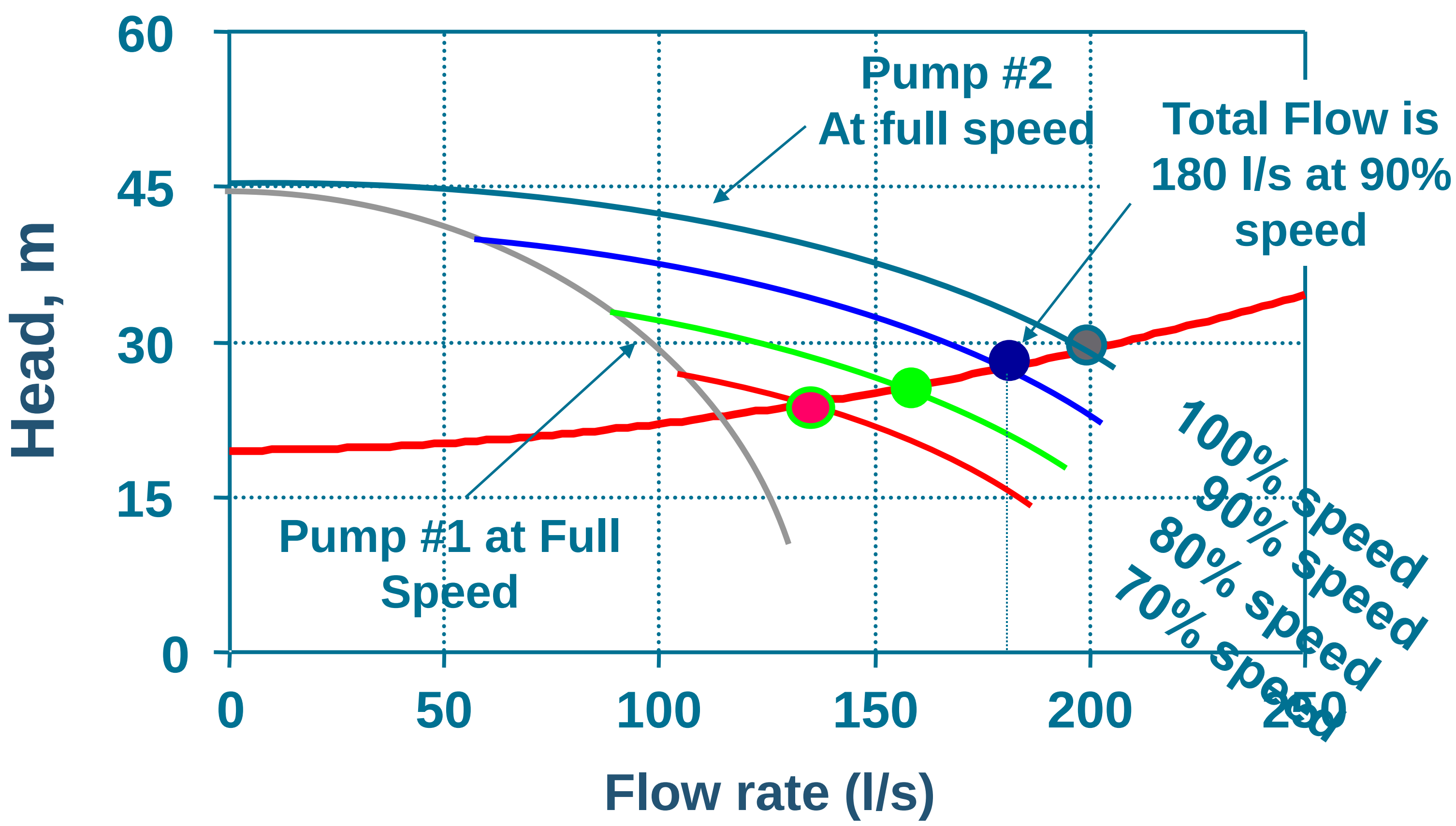
Operating Pumps in Parallel

Using a variable speed drive with 2 pumps in parallel

- With one full speed pump and one pump on VFD, the full speed pump might dead head the speed controlled pump if the speed is reduced too much.
- In systems with static head this can also happen if both pumps are on speed control.
- The same phenomena occurs with two identical pumps if one is more worn than the other and as a result has a lower shut off head.

Be careful of installing VSD's with multiple pumps

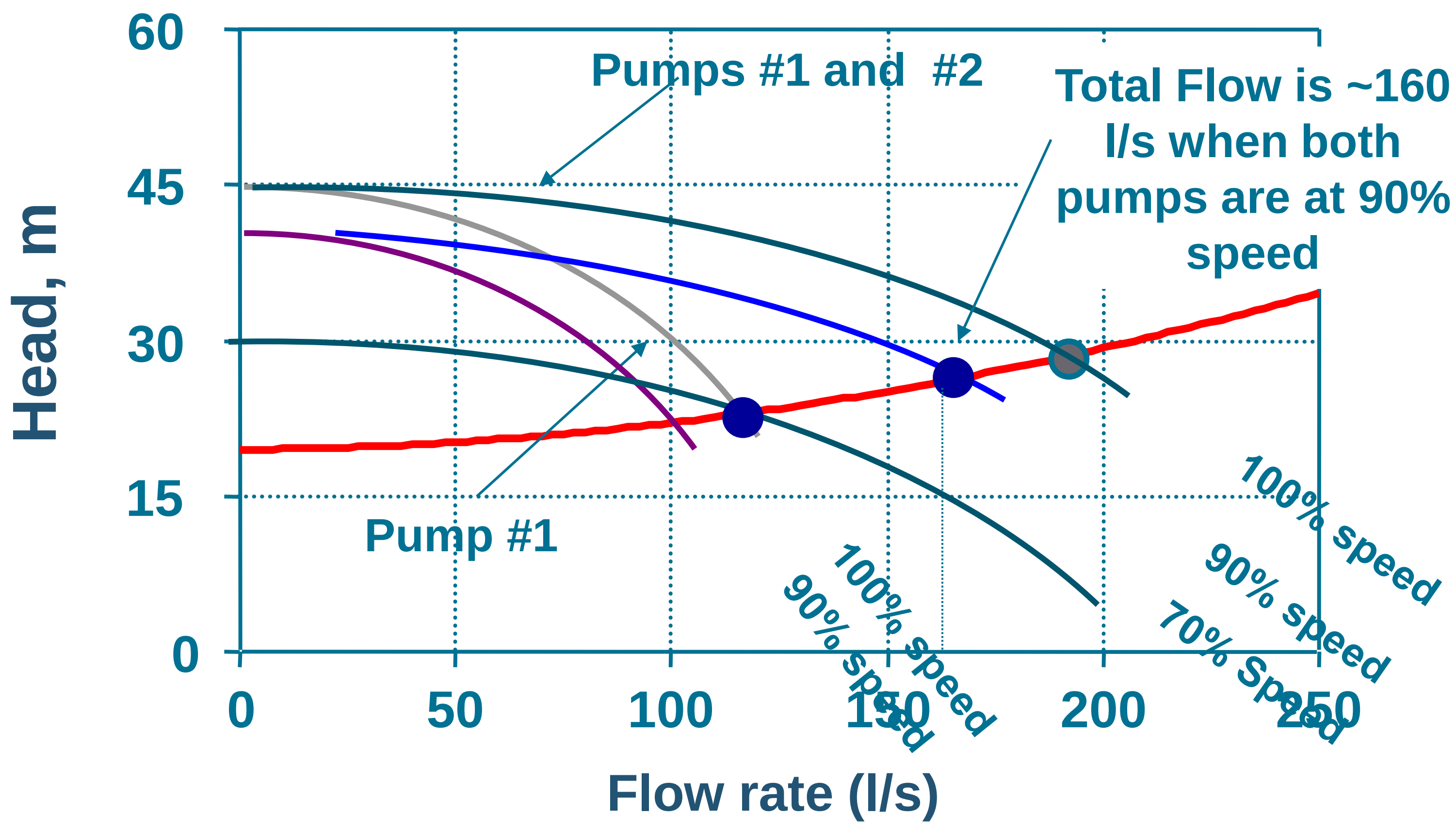
One pump at full speed and one with a variable speed drive



Pump 2 risks getting dead headed

Operating Pumps in Parallel

Both pumps equipped with variable speed drives

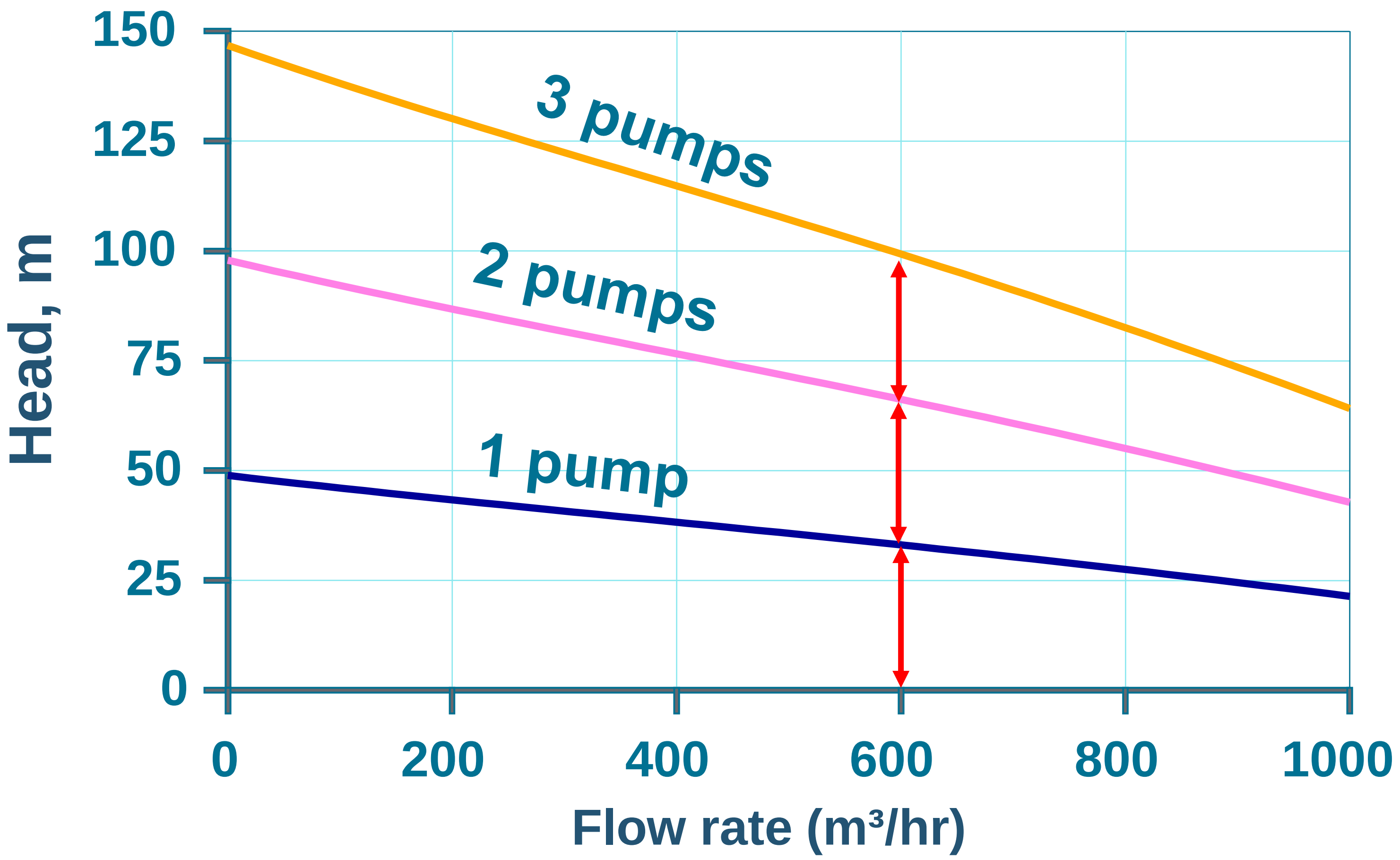


Pumps in Series

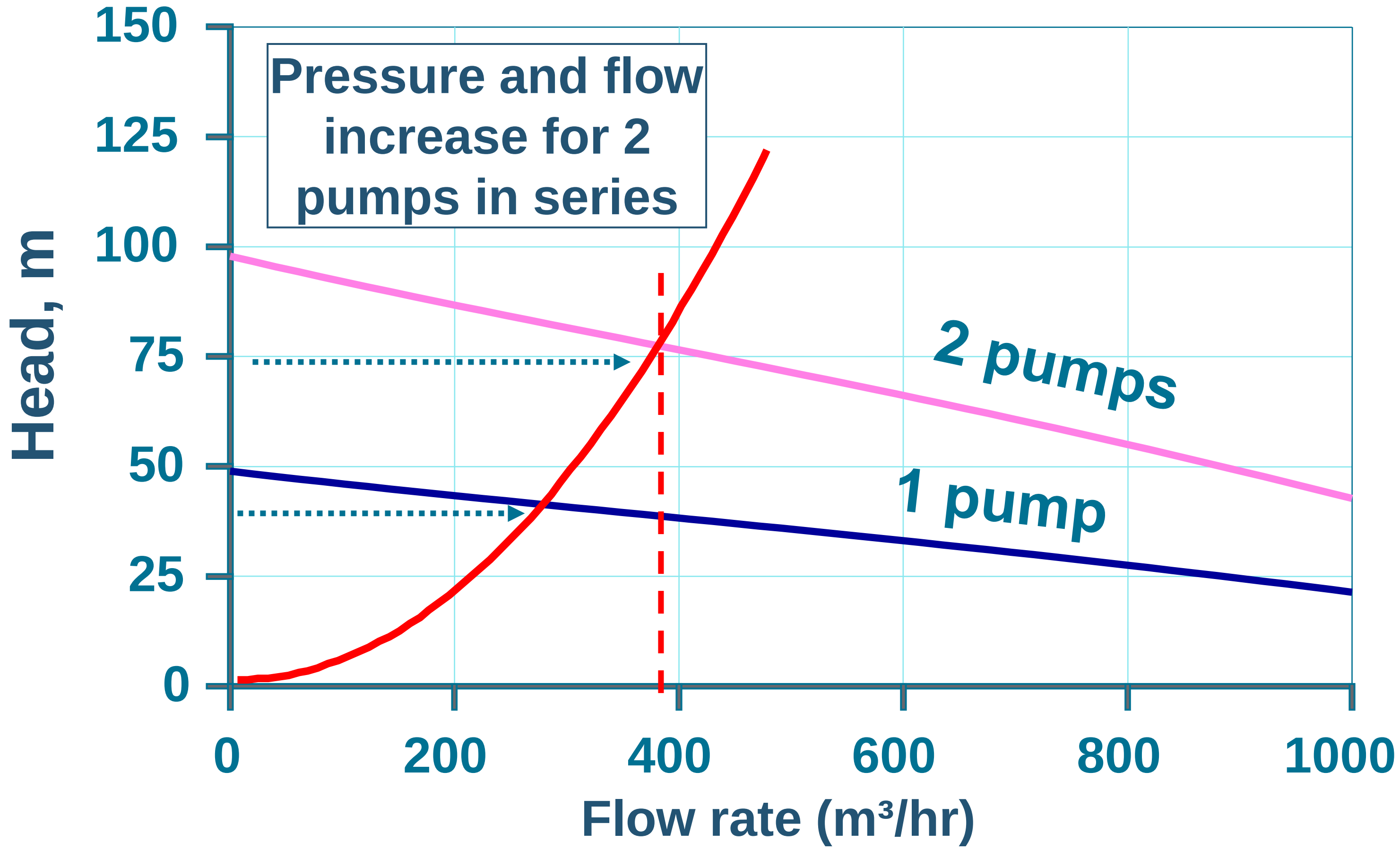
Pumps in Series

For identical pumps in series:

- Add heads of each pump together at the given flow rate to estimate overall performance



System Curve & Two identical Pumps in Series



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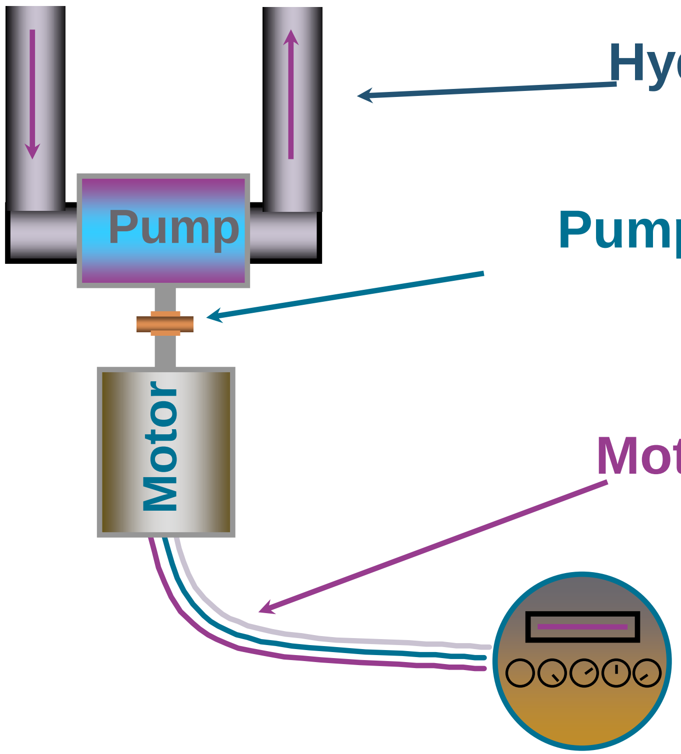
06. Pump Systems Energy Use

Pump Basics

Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

Power Used by a Pump



$$\text{Hydraulic power } (kW_{hyd}) = \frac{\text{l/s} \times \text{m} \times \text{relative density}}{102}$$

$$\text{Pump input power } (kW_{mech}) = \frac{\text{Hydraulic power}}{\text{Pump efficiency}}$$

(*or motor output*)

$$\text{Motor input power } (kW_{elec}) = \frac{\text{Motor output power}}{\text{Motor efficiency}}$$

Motor Operating Cost = Motor input power x Operating hours x per unit electricity cost

Some Basic Equations

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$$\text{Fluid Power} = \frac{\text{Head (m)} \times \text{Flow (l/sec)} \times \text{specific gravity}}{102}$$

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

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

Power = kW

Expanding the equation…

$$kW_{elec} = \frac{\text{Flow (l/s) x Total Head (m) x Relative Density}}{102 \times \eta_p \times \eta_m \times \eta_{vsd}}$$

Flow
Total Head
} **System-level Opportunities**

η_p = pump efficiency
η_m = motor efficiency
η_{vsd} = VSD efficiency
} **Component-level Opportunities**

kWh = kW x Hours

Specific Energy (E_s)

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- The amount of energy needed to pump one unit volume through the system
- The Specific Energy varies with flow-rate
- A good way of comparing pump system performance

    ie. how much bang for your buck

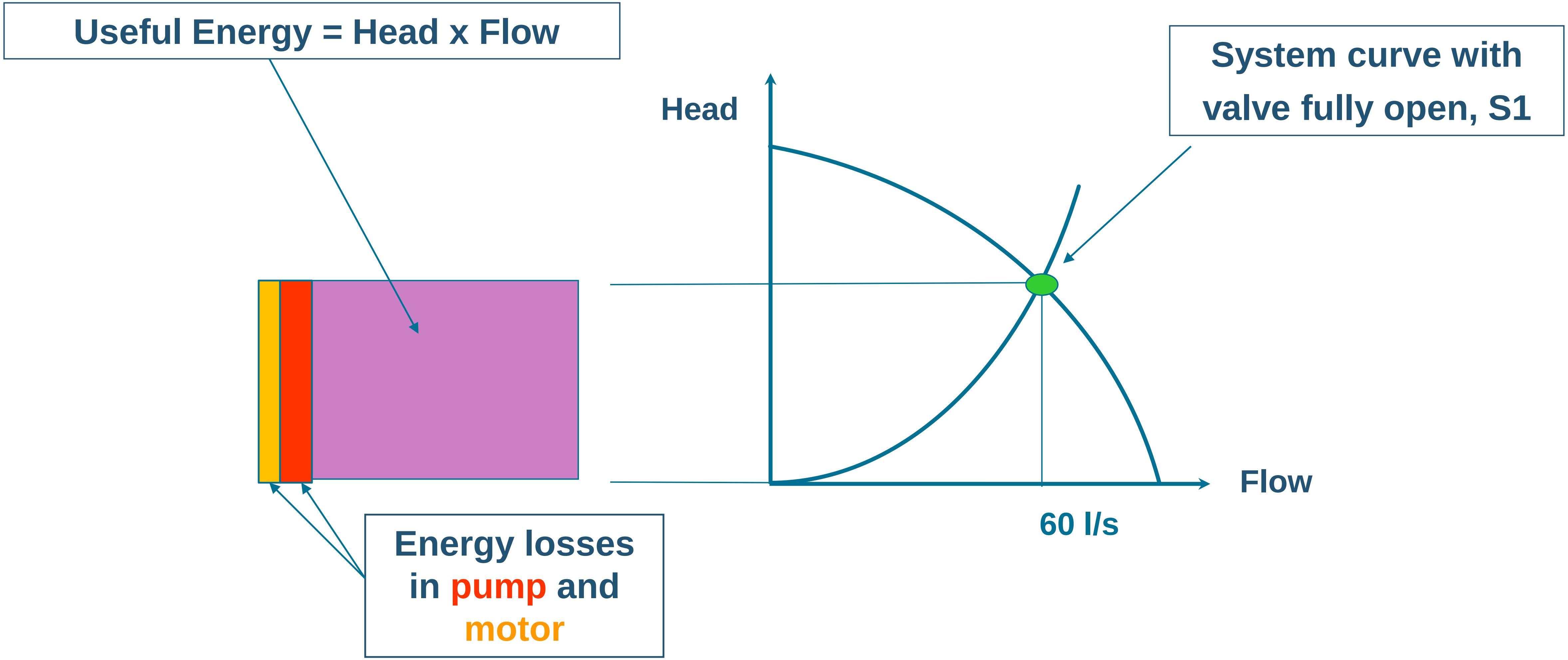
Specific Energy Ratios

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

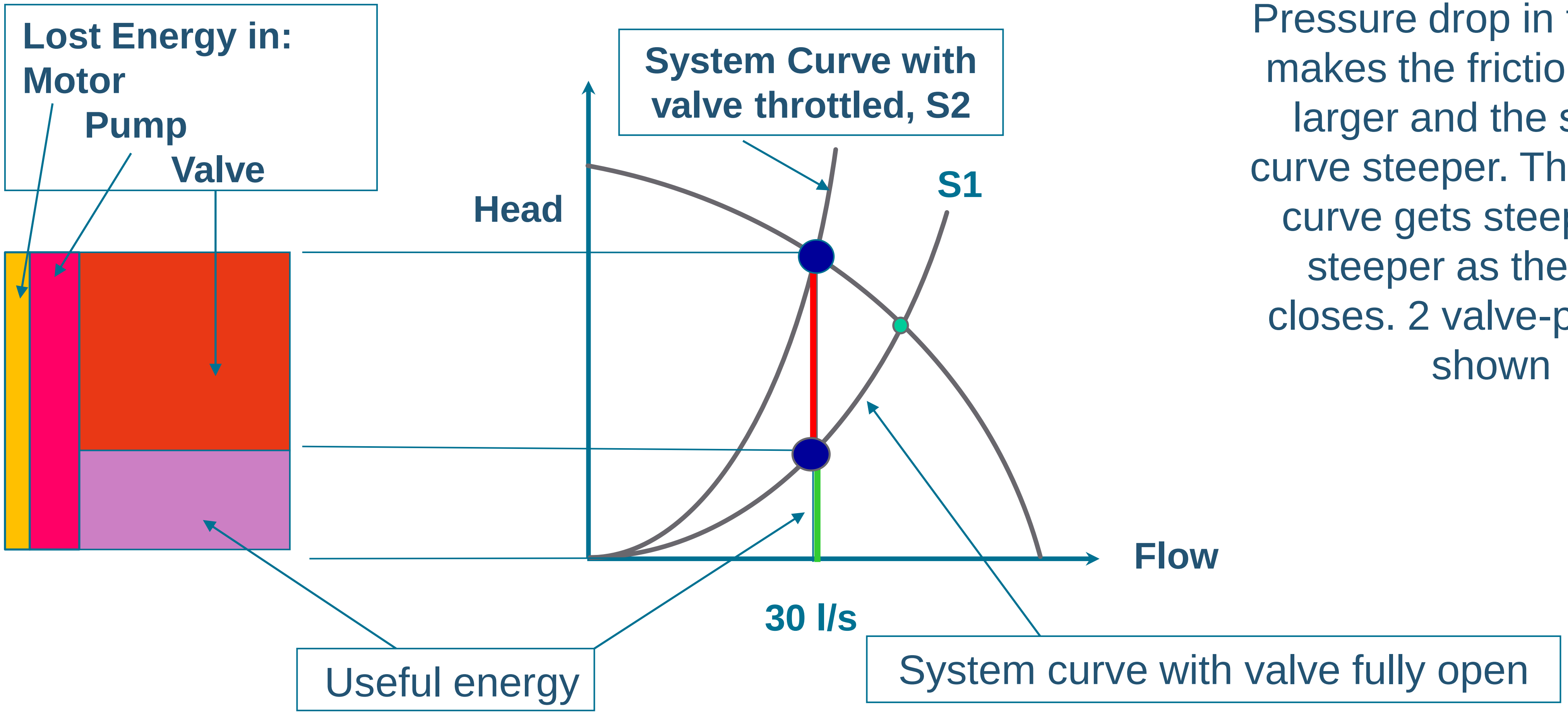
Static Head (m)	m^3/h	Speed (%)	Power (kW)	m^3/kWh	Es= kWh/m^3
0	800	100	79.5	10.1	0.099
0	400	50.0	10.4	38.5	0.026
20	800	100	79.5	10.1	0.099
20	400	78.5	34.6	11.6	0.087
27.5	800	100	79.5	10.1	**0.099**
27.5	400	86.5	44.7	8.9	**0.112**

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 System Energy Representation

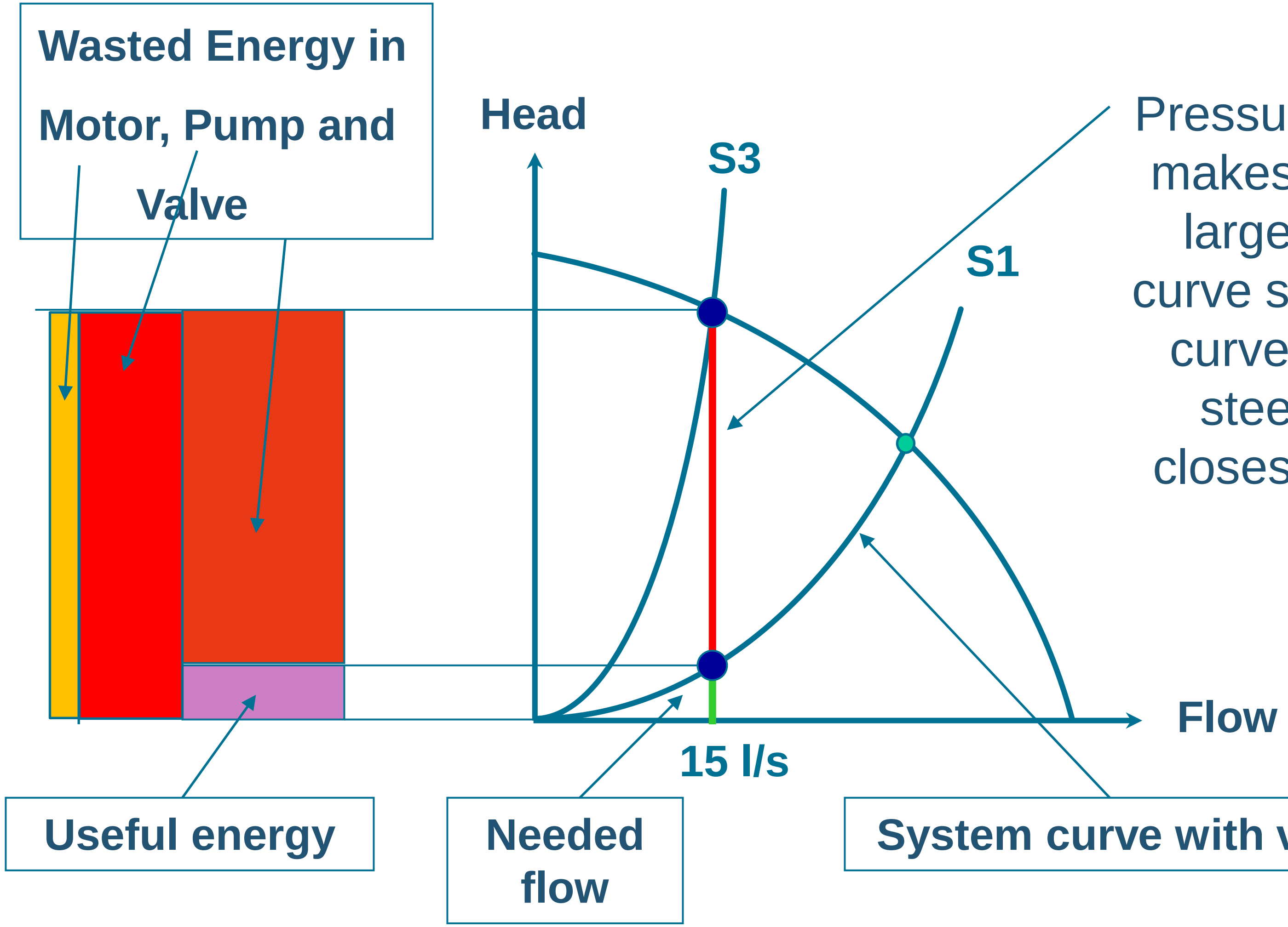


Throttling: Duty Point Moves to Left on the Pump Curve



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



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

How does a VSD save energy?

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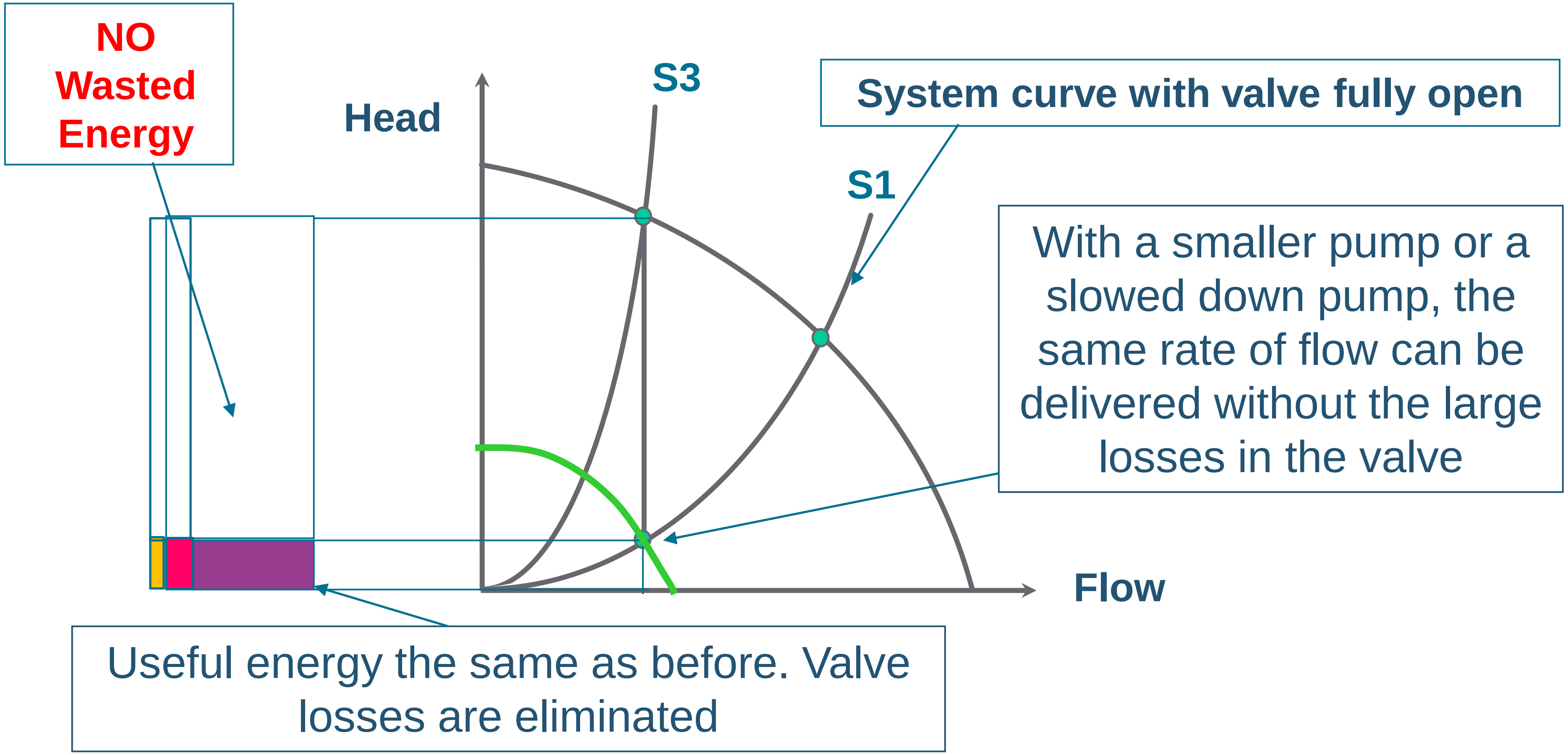
The pump curve changes, not the system curve



Why systems and not components?

- The following slides show test results from a throttled system at a paper plant

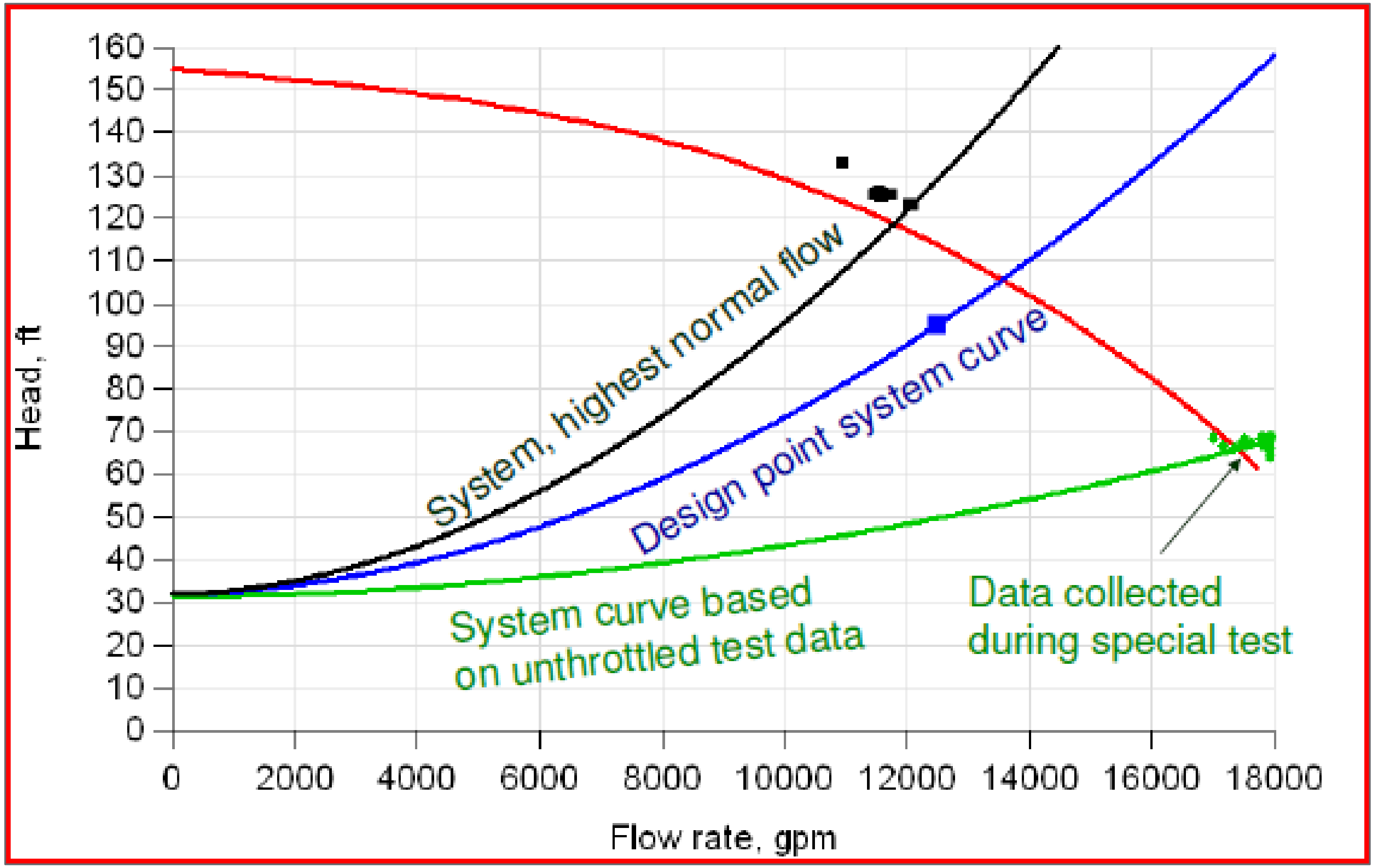
- The different system curves refer to design, normal operation and un-throttled operation

<u>Only Delivered Fluid Power is considered</u>

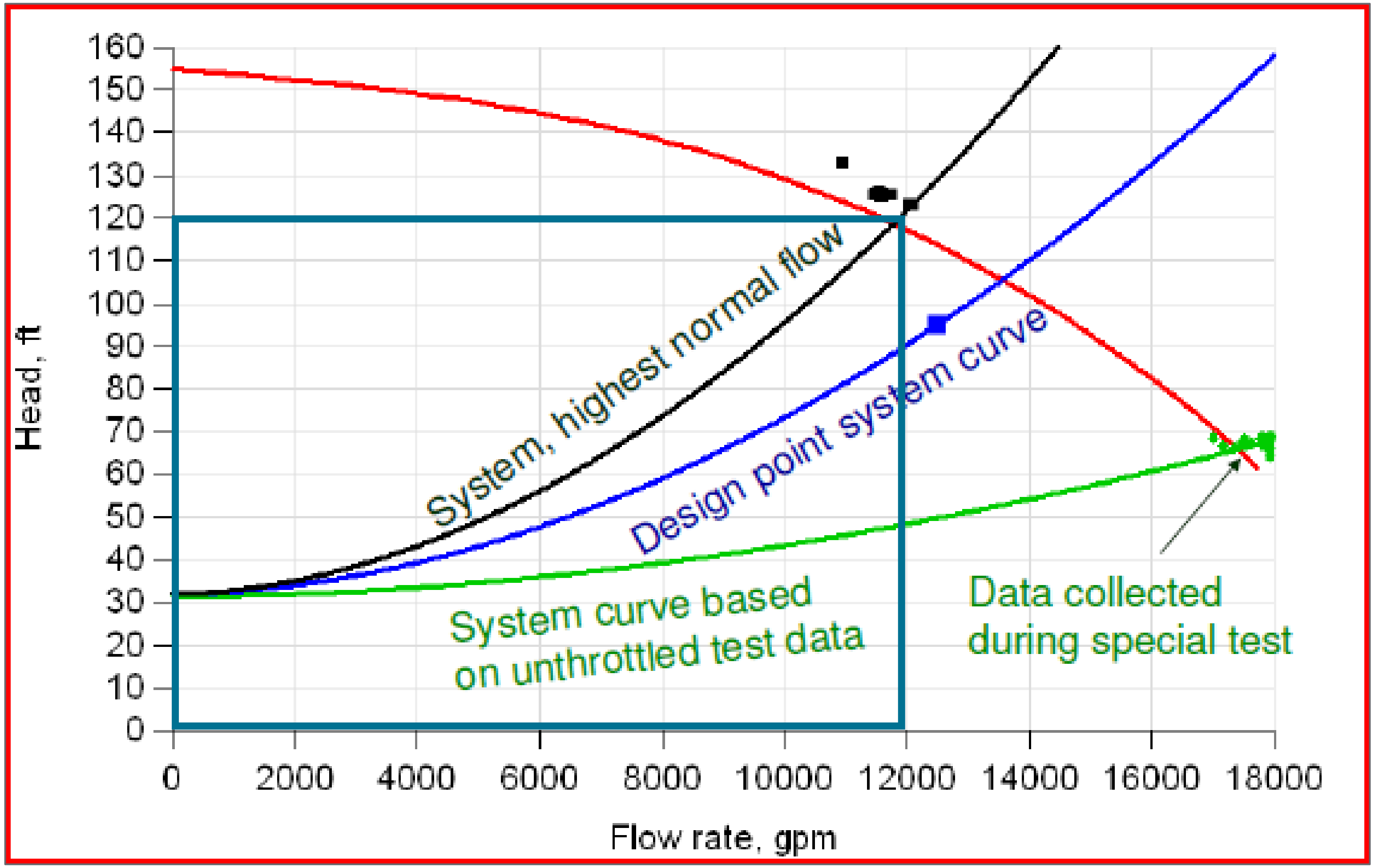
The Case for Systems Optimisation

Measured data at two operating points:

- Max operating flow
- Max unthrottled flow

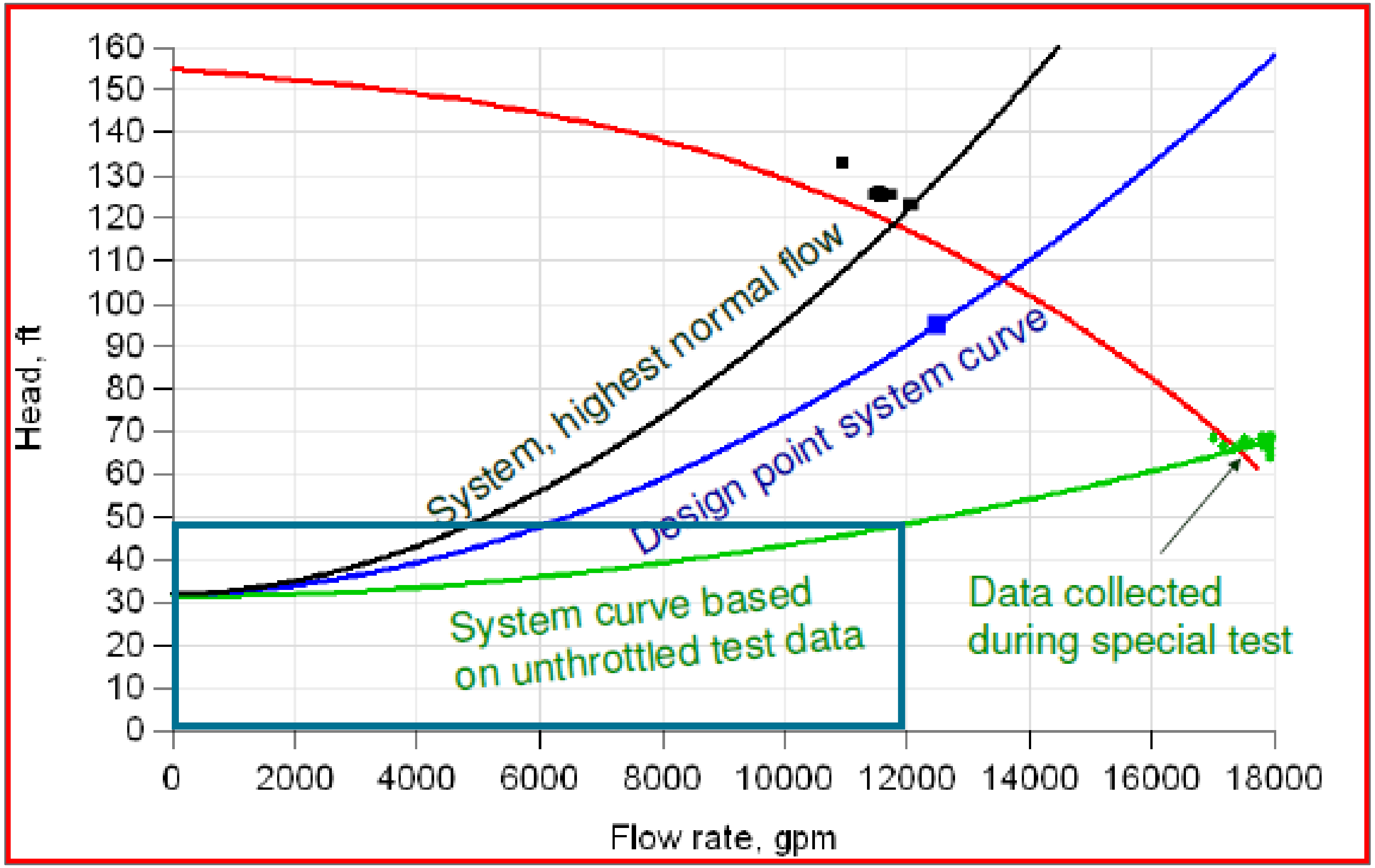


The rectangular area represents the power required during max operating flow



The Case for Systems Optimisation

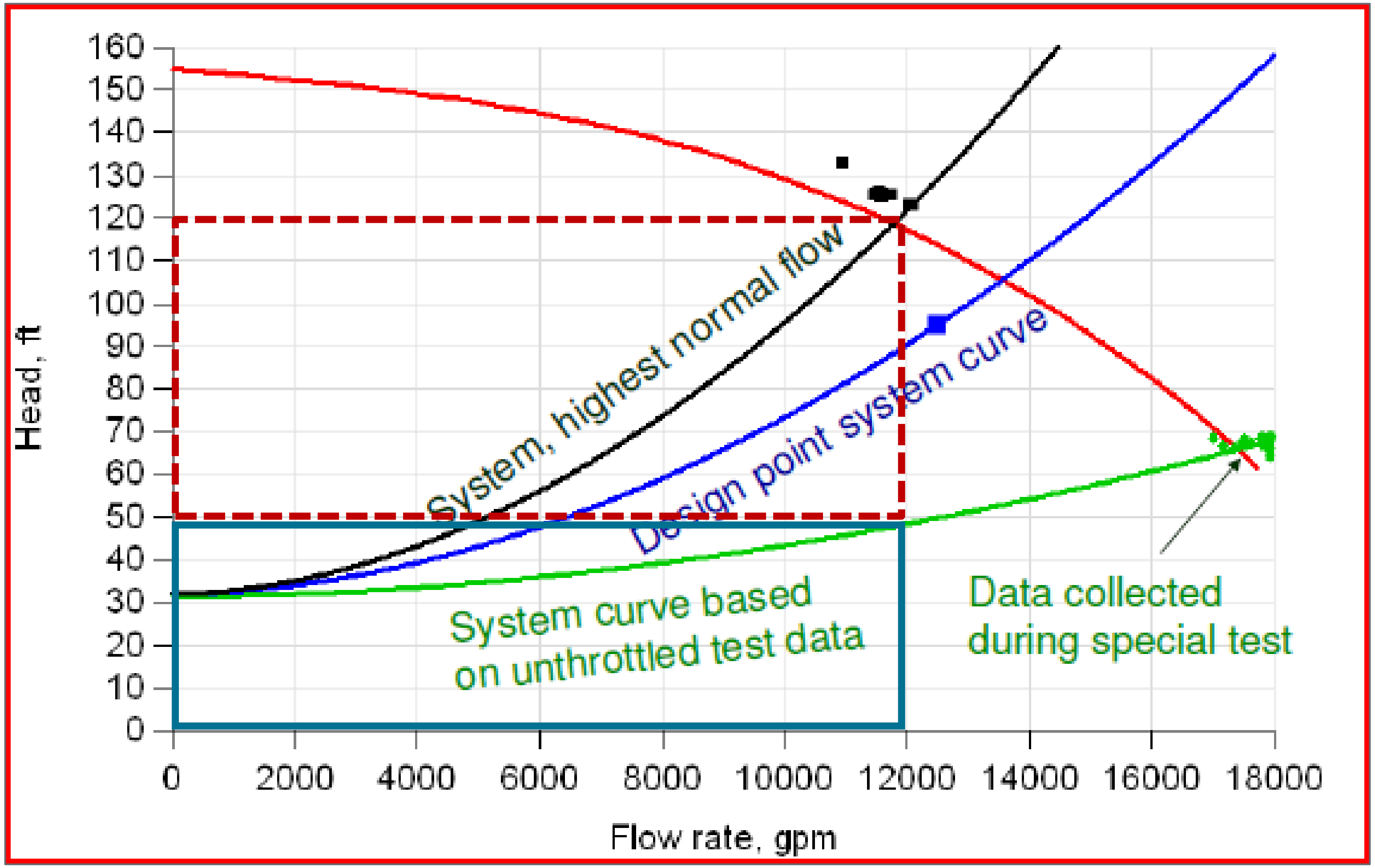
This rectangular area represents the actual fluid power required during max operating flow if the throttle valve was fully open



The Case for Systems Optimisation

The red area represents the wasted power

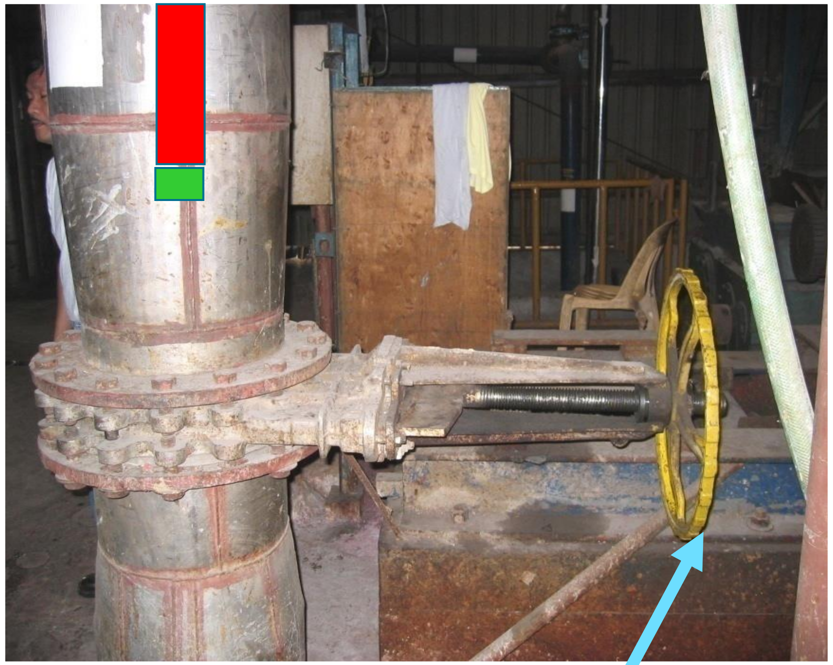
The actual delivered power is 270% more than required because the use of the throttle valve



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?



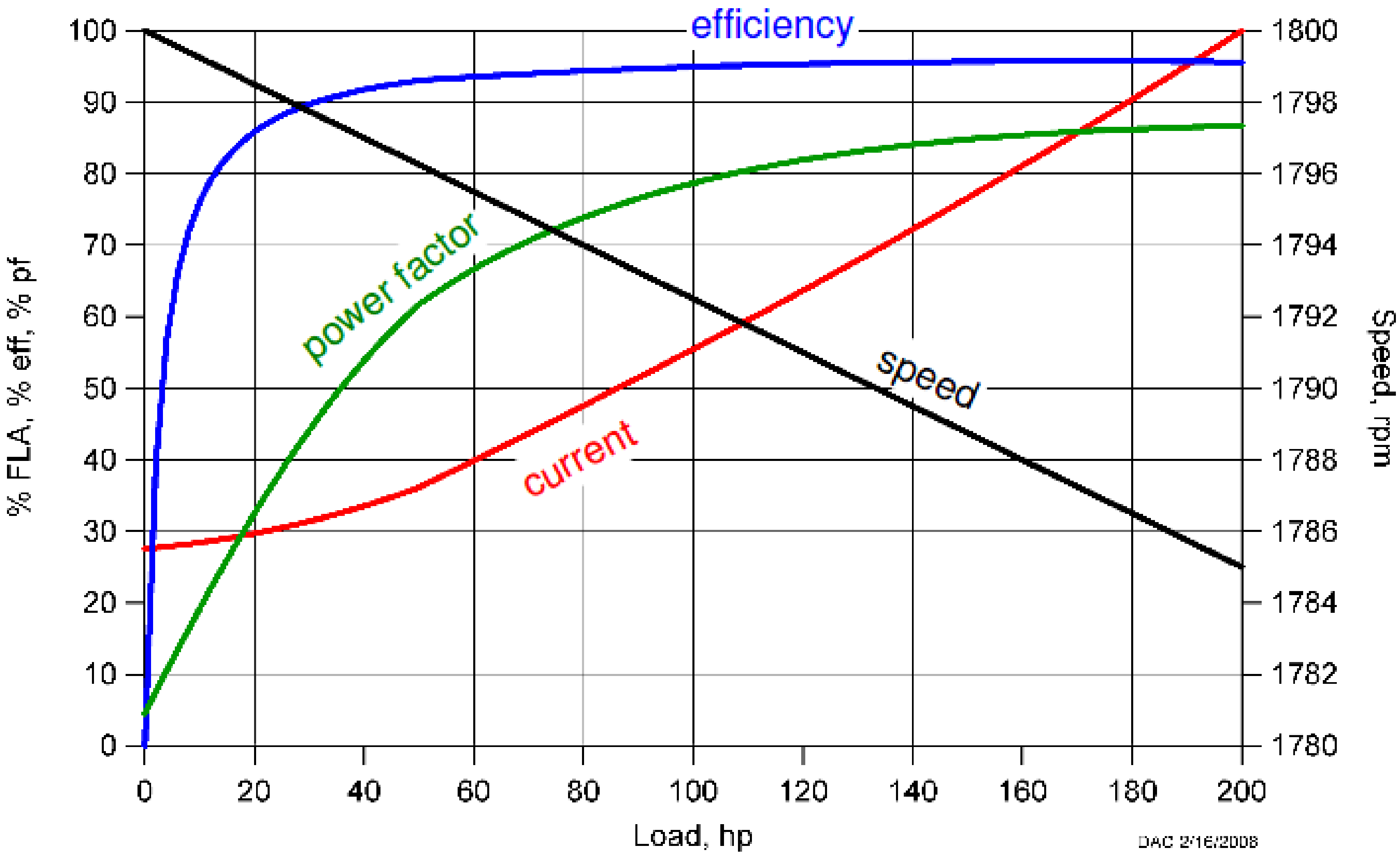
Gate valve throttled on next floor up so can't be seen from the pump floor

Paper Mill Pump

Motor Considerations

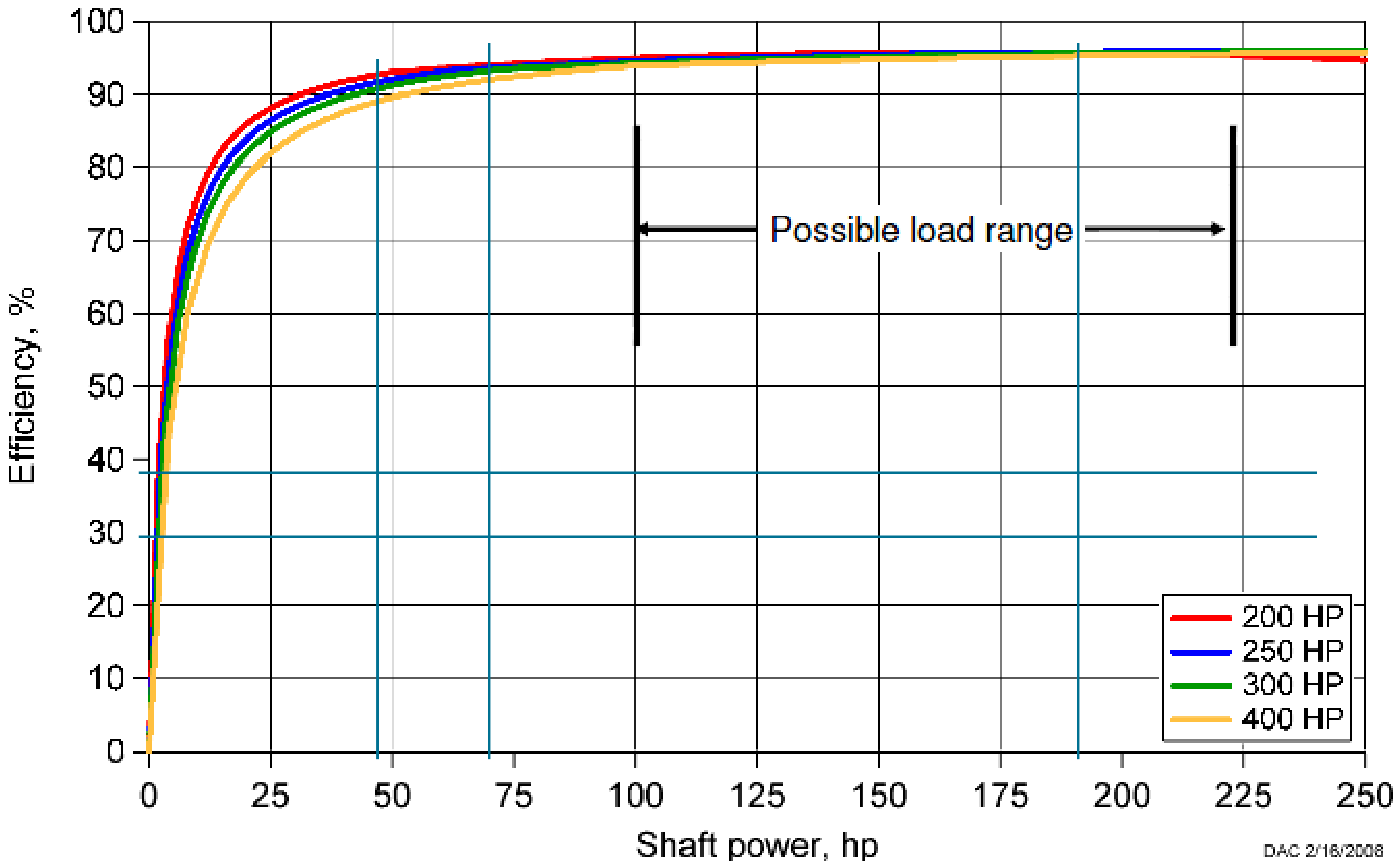
Typical High Efficiency Motor Curves

150 kW (200hp), 4-Pole



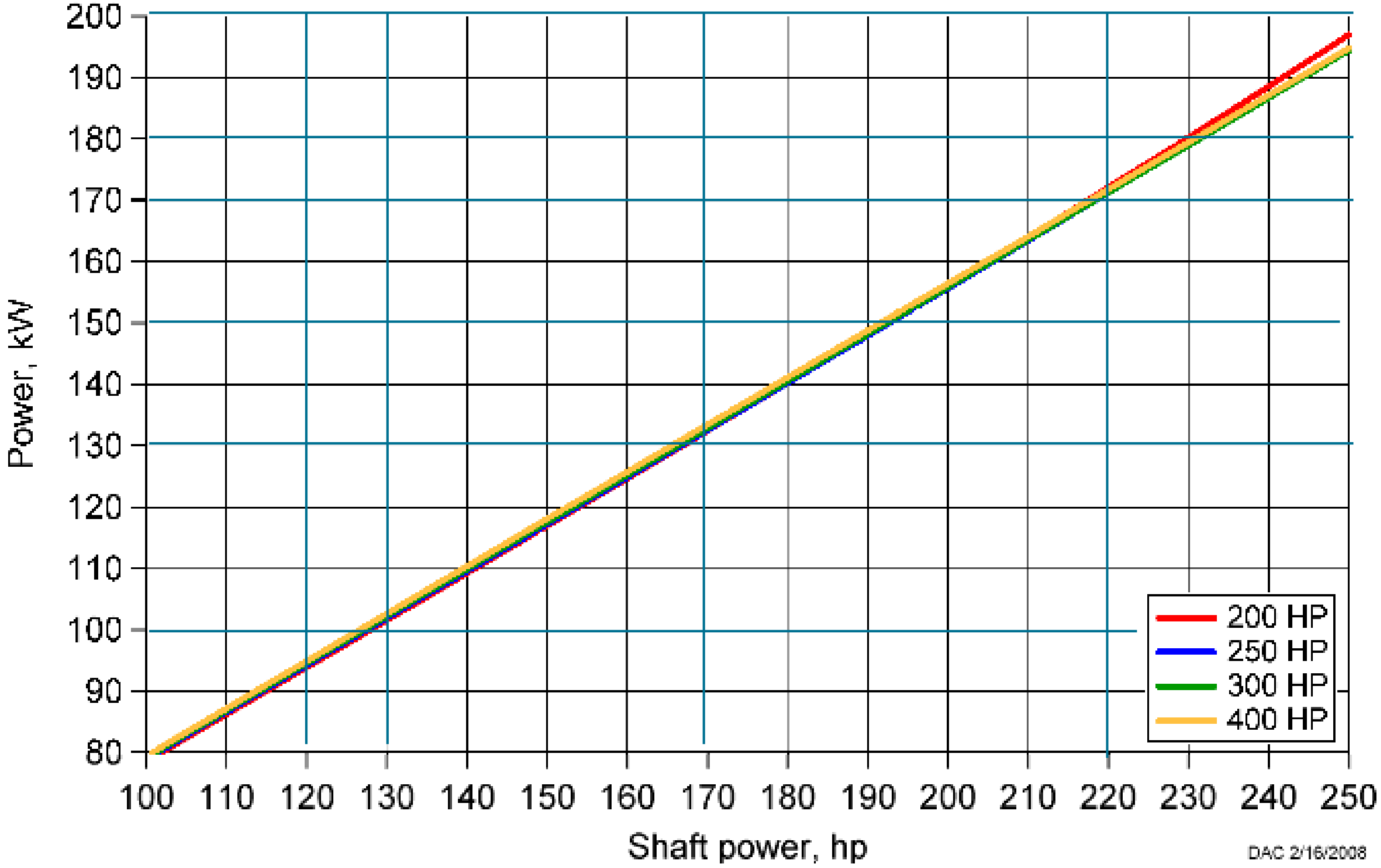
Effect of an Oversized Motor

Virtually negligible for loads above 50%



Effect of Oversized Motors

The difference in power consumption for oversized motors is minimal



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07. Introduction to MEASUR (PSAT)

Pump Systems Software

Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

Introduction to MEASUR (PSAT)

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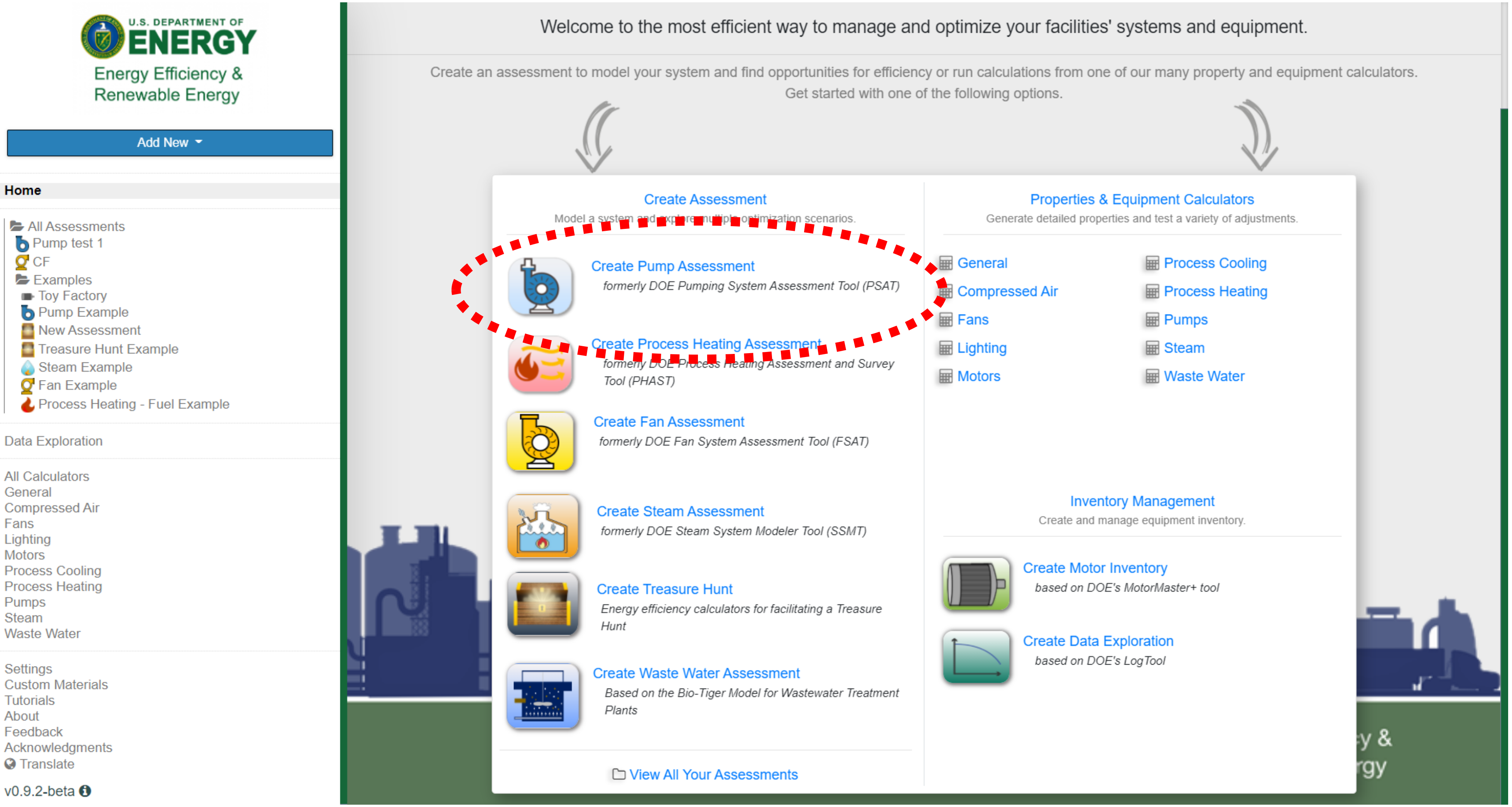
- New integrated software tool developed by the US DOE (Department of Energy)

- Contains the legacy software:
  - PSAT (Pumps)
  - FSAT (Fans)
  - SSAT (Steam)
  - PHAST (Process Heat)

- New features include:
  - Waste water assessment
  - Motor inventory
  - Report generation

UNIDO | Ministry of Trade & Industry | Egypt National Cleaner Production Centre | مركز تحديث الصناعة INDUSTRIAL MODERNISATION CENTRE | gef www.theGEF.org

Using PSAT in the MEASUR Application Software



Source: US DOE

Pump 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 Motor-Master+ to estimate existing, achievable performance

How to Use PSAT

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

Introduction to PSAT: Input Fields

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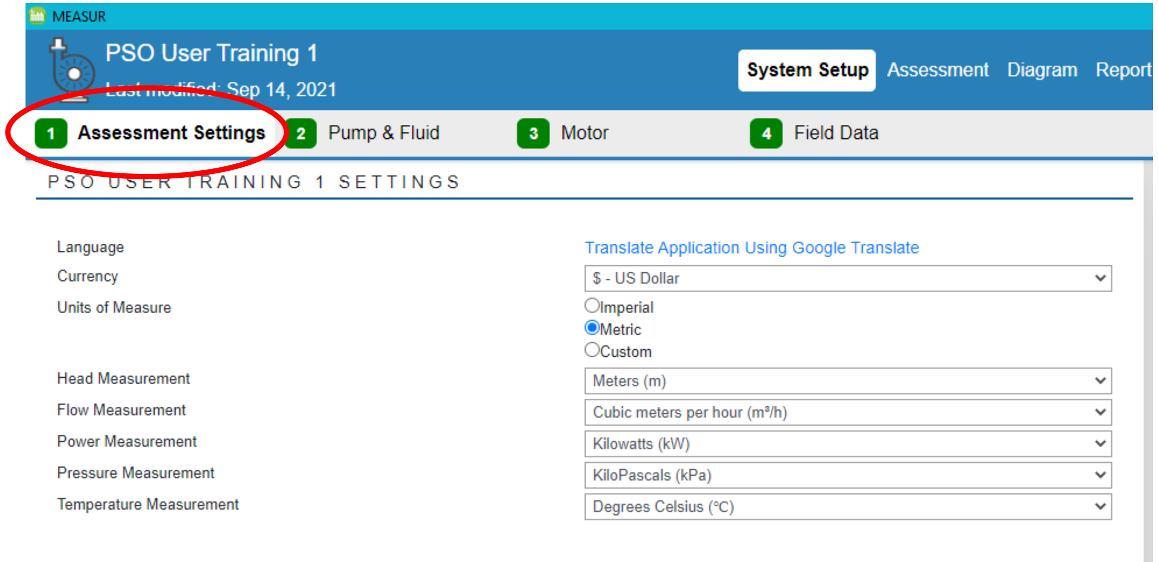

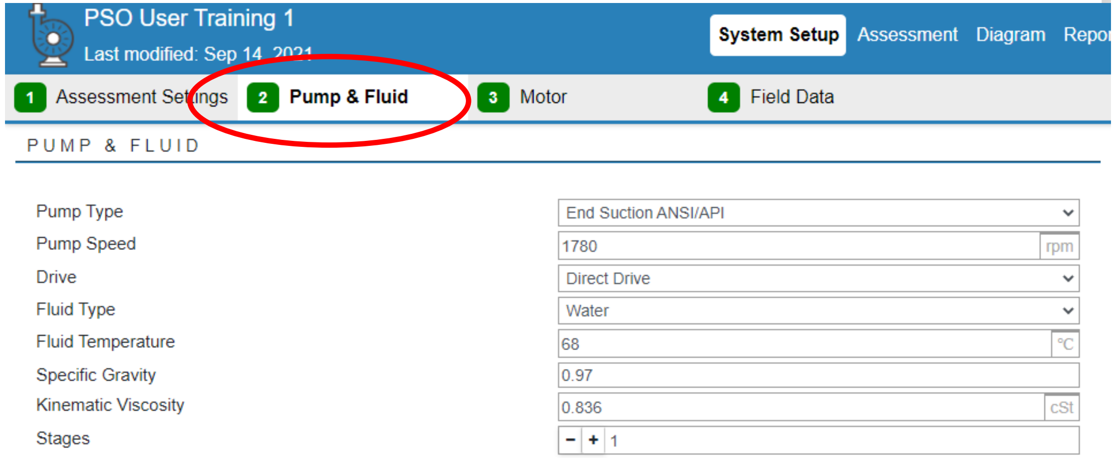

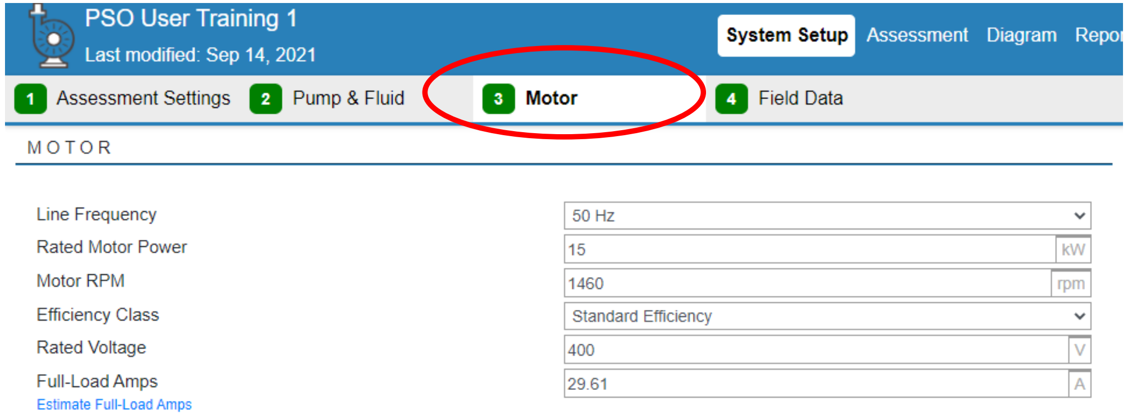

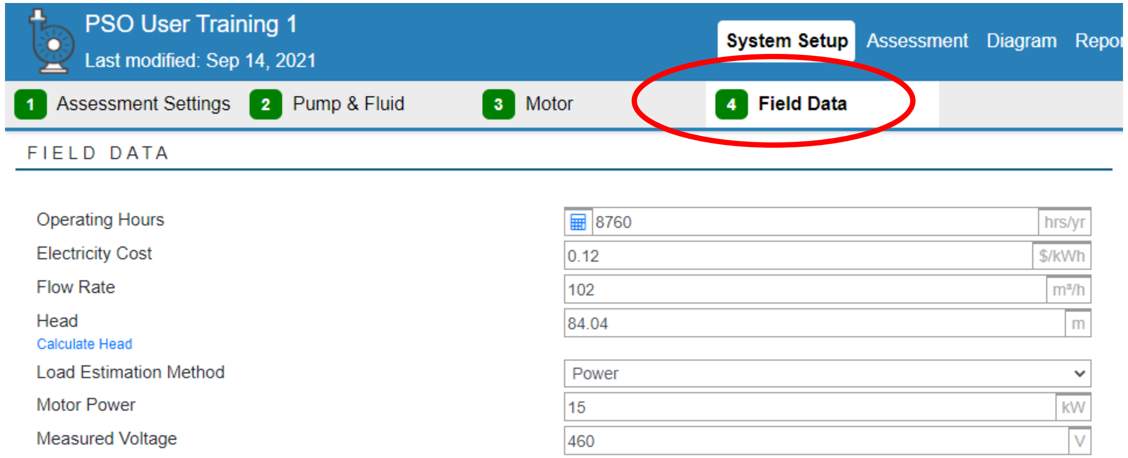

Introduction to PSAT: Output Result

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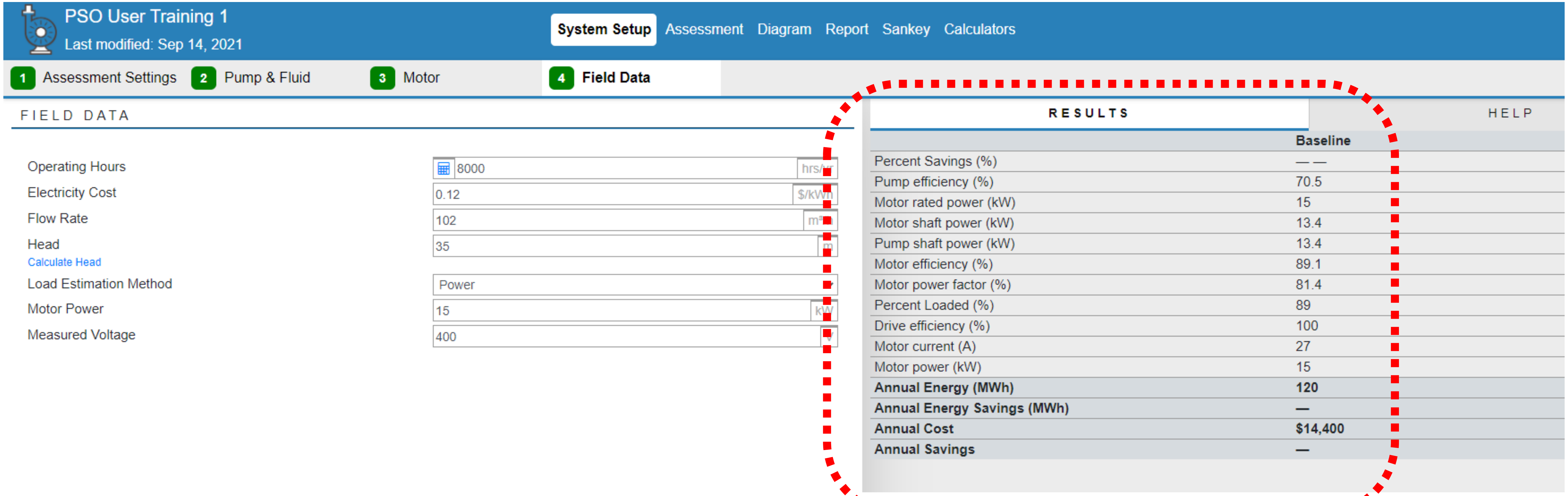
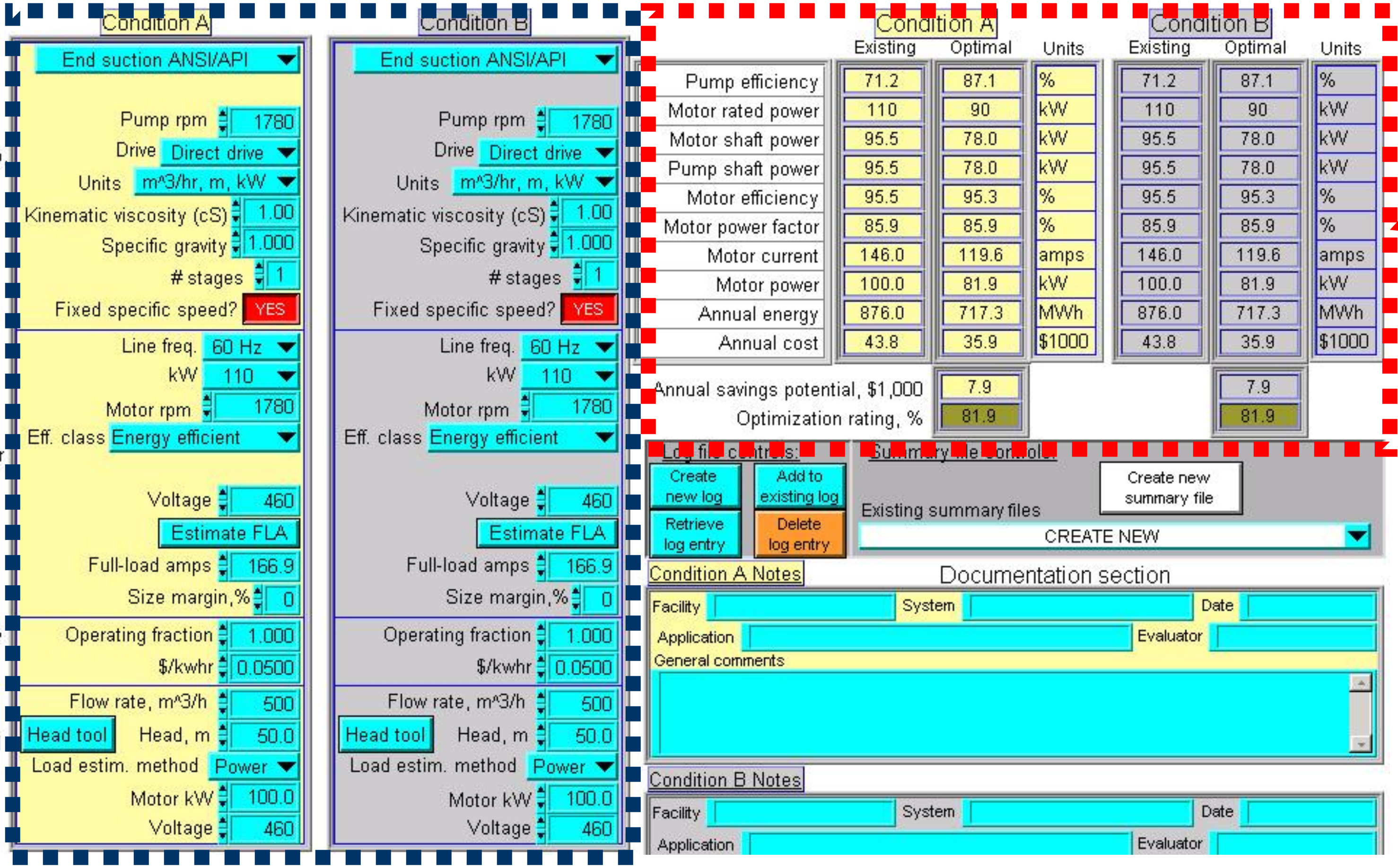
- Results from initial output provide the baseline energy consumption.
- Next step is to add in saving opportunities and evaluate energy savings against the baseline



Introduction to PSAT: Legacy Software

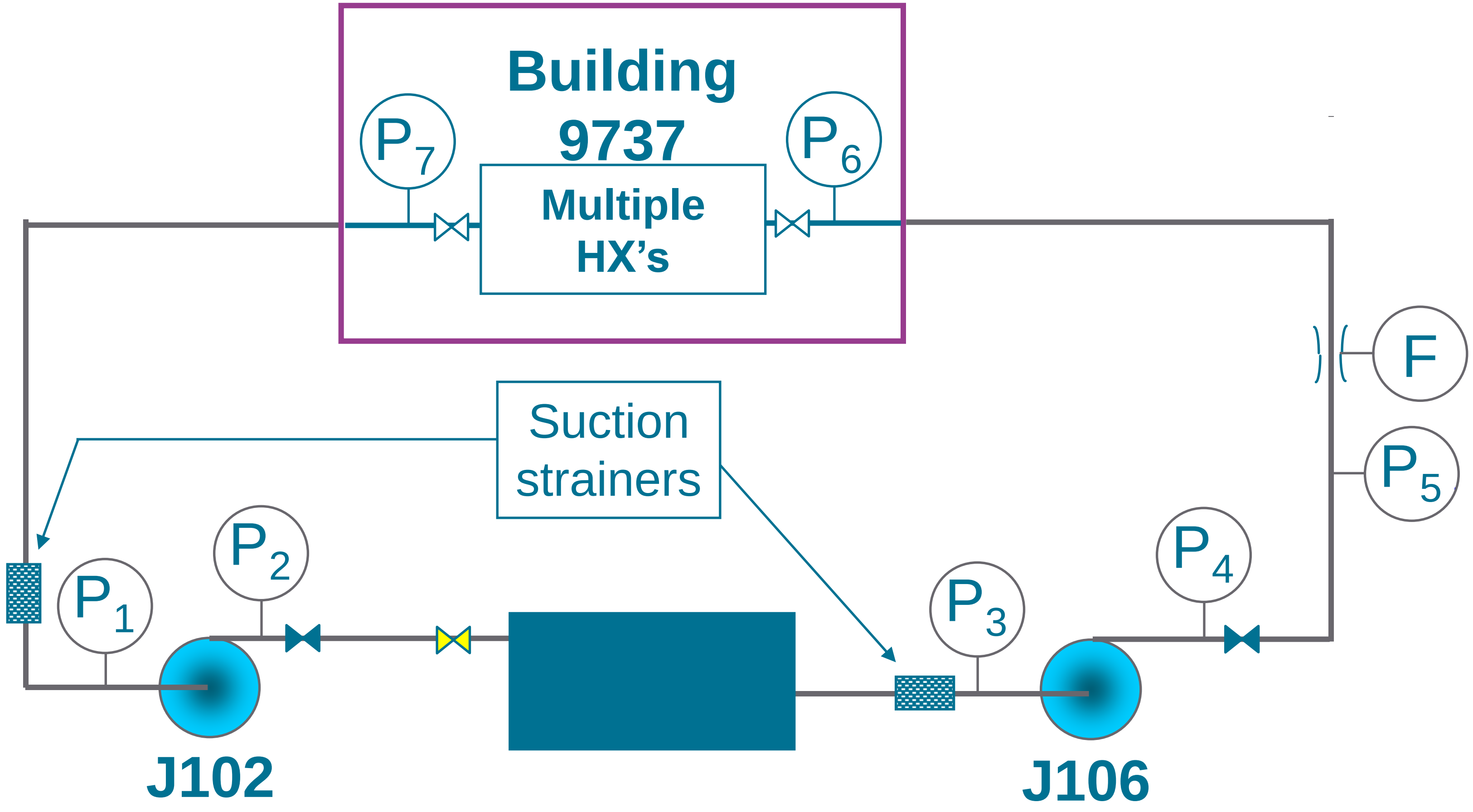
Input data

Results



Introduction to PSAT: Example

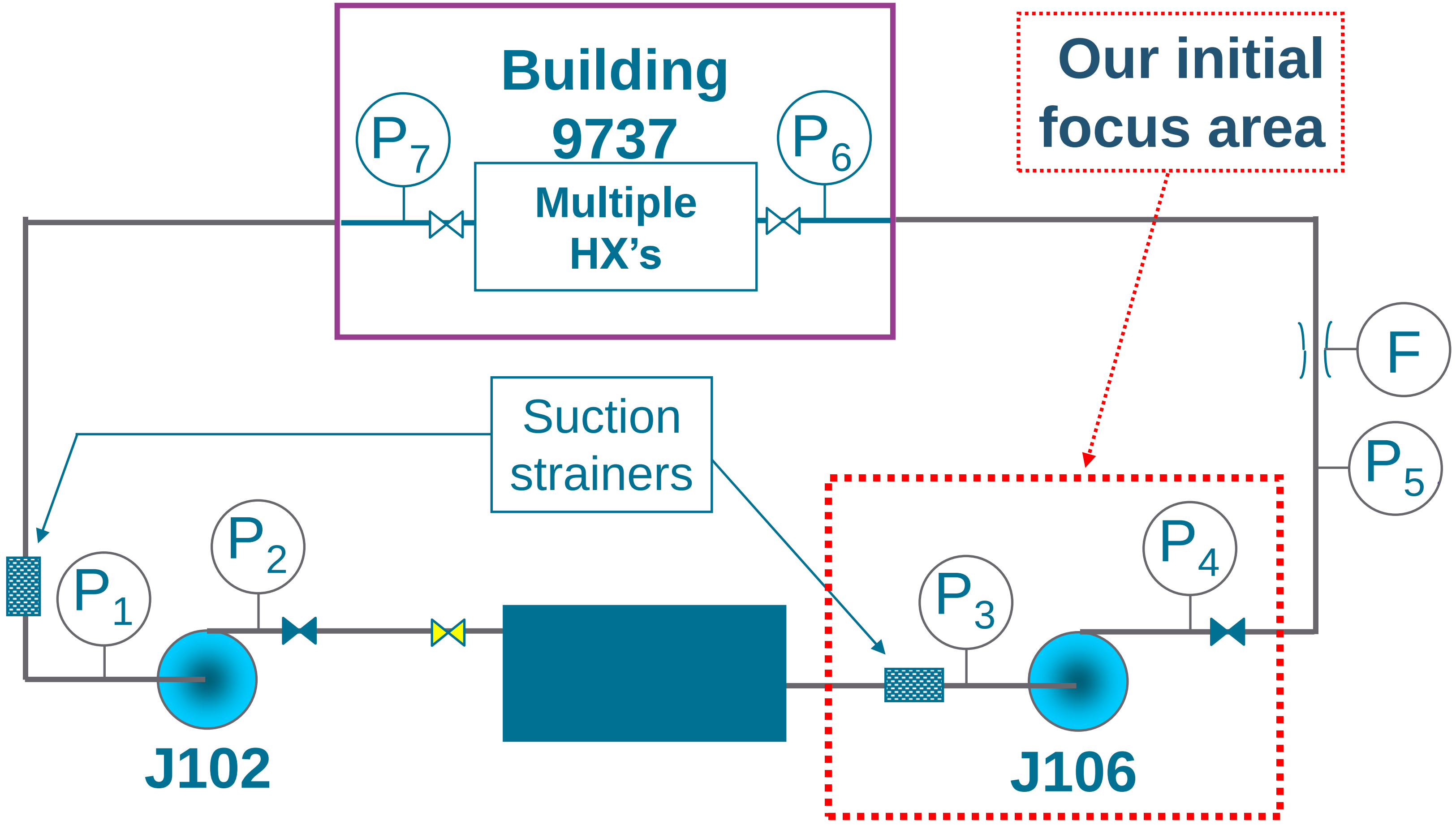
To illustrate, let's consider a real-world chilled water pumping application



Introduction to PSAT: Example

Initial Focus Area:

The part surrounding secondary pump J106



Slide Courtesy of Oak Ridge National Laboratory

Pump Data

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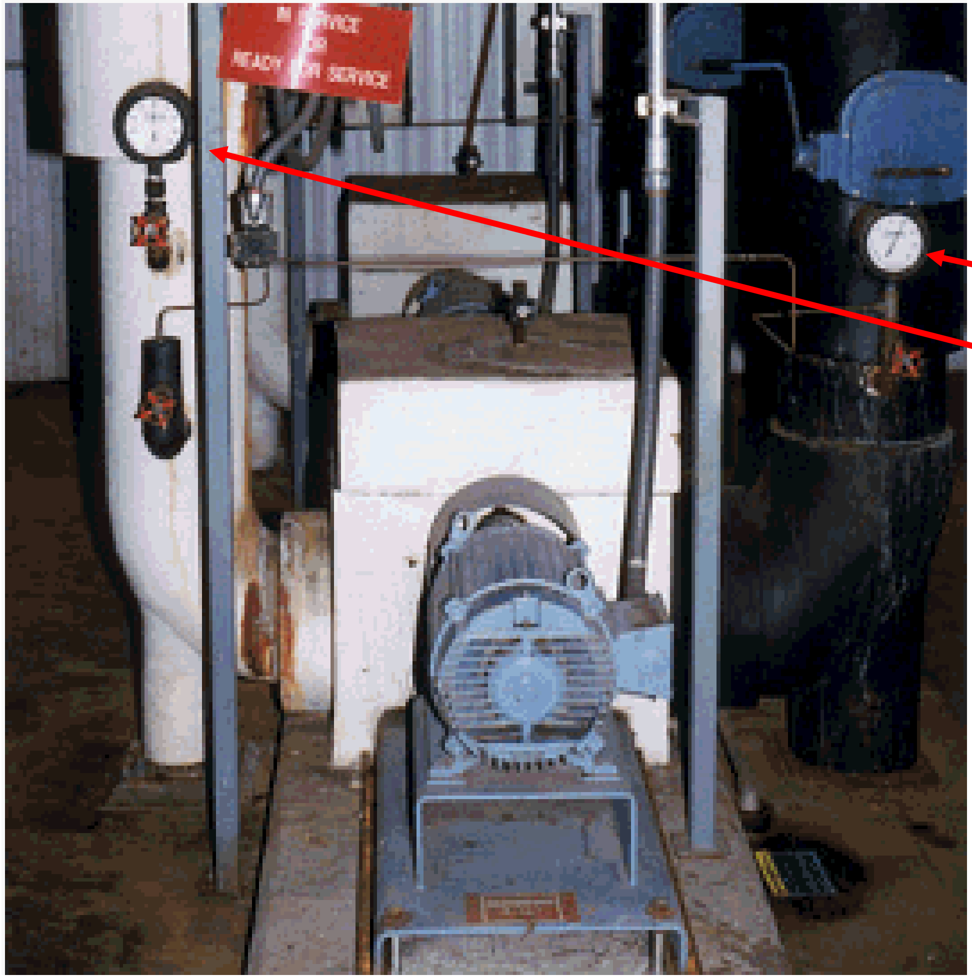


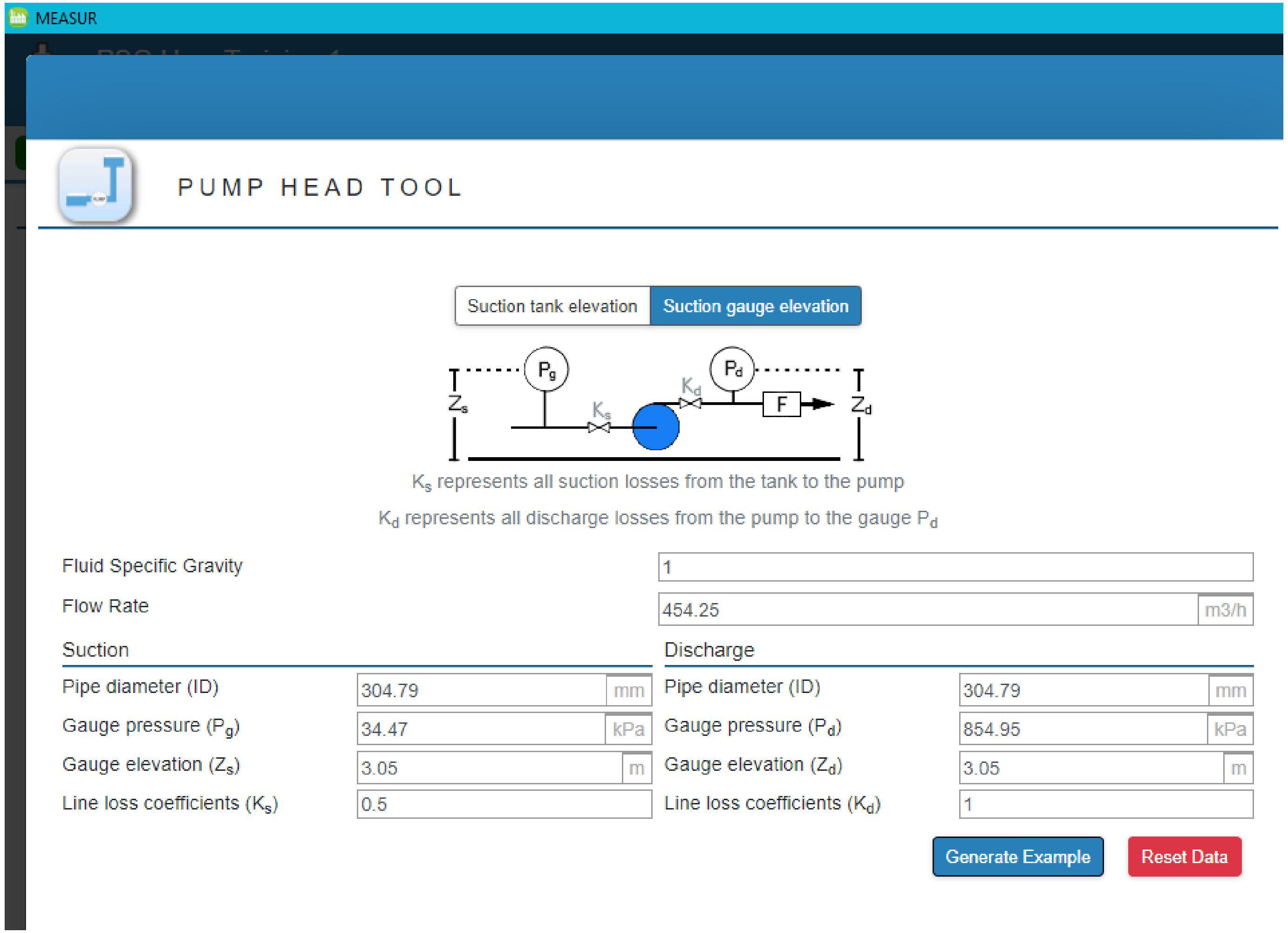
Photo Courtesy of Oak Ridge National Laboratory

Observed:

- Suspect Pressure 216 kPa
- Discharge Pressure 557 kPa
- Gauge elevation 0.43 m

- Total head 35.2 m
- Flow rate 102 m^3/h

Using PSAT Head Tool



INPUTS

- Suction Pressure 2.16 kPa
- Suction Diameter 50 mm
- Gauge elevation 0.43 m

- Discharge Pressure 2.16 kPa
- Discharge Diameter 50 mm
- Gauge elevation 0.43 m

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PSAT Head Tool – Legacy Software

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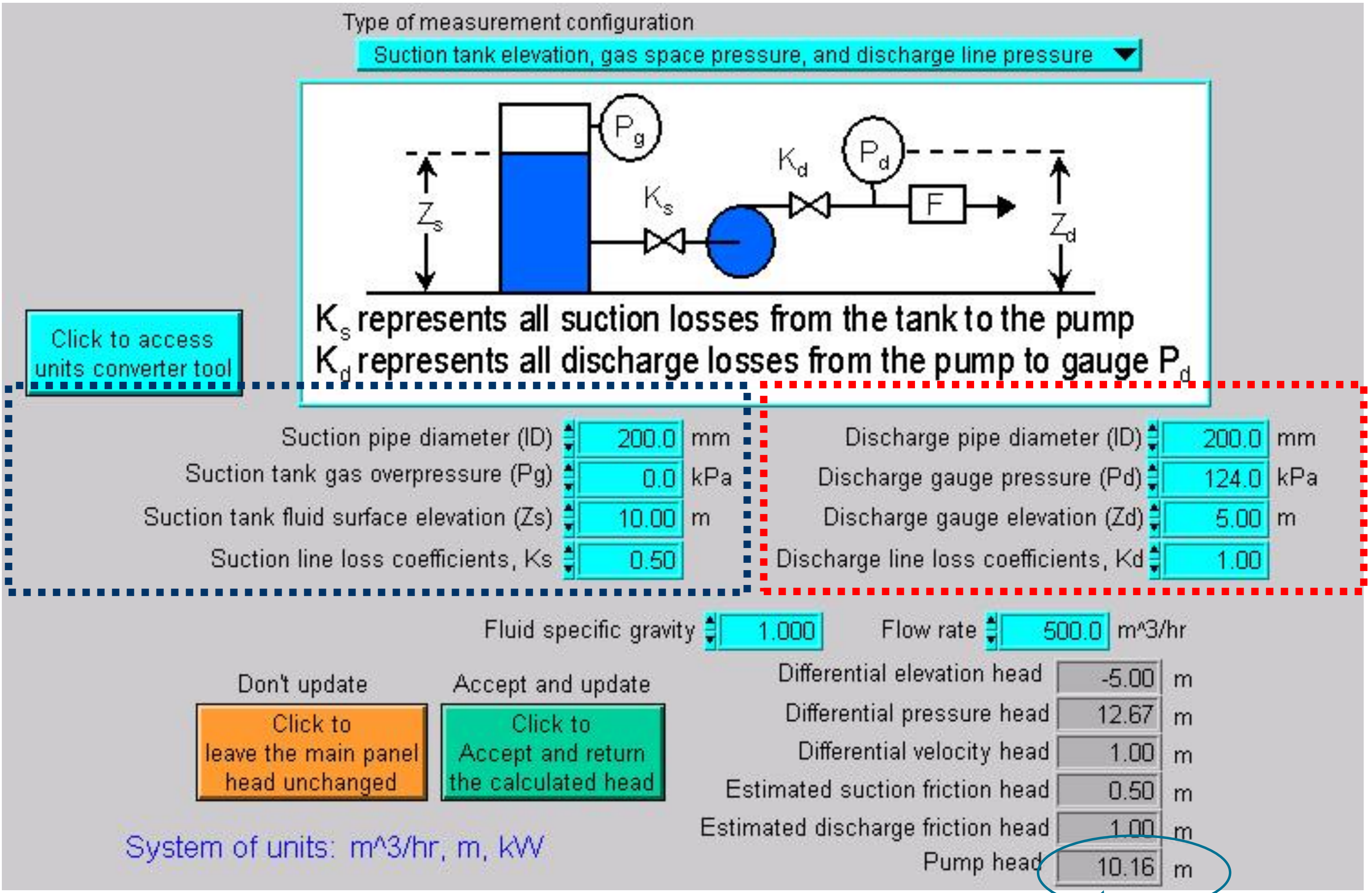
Suction Data



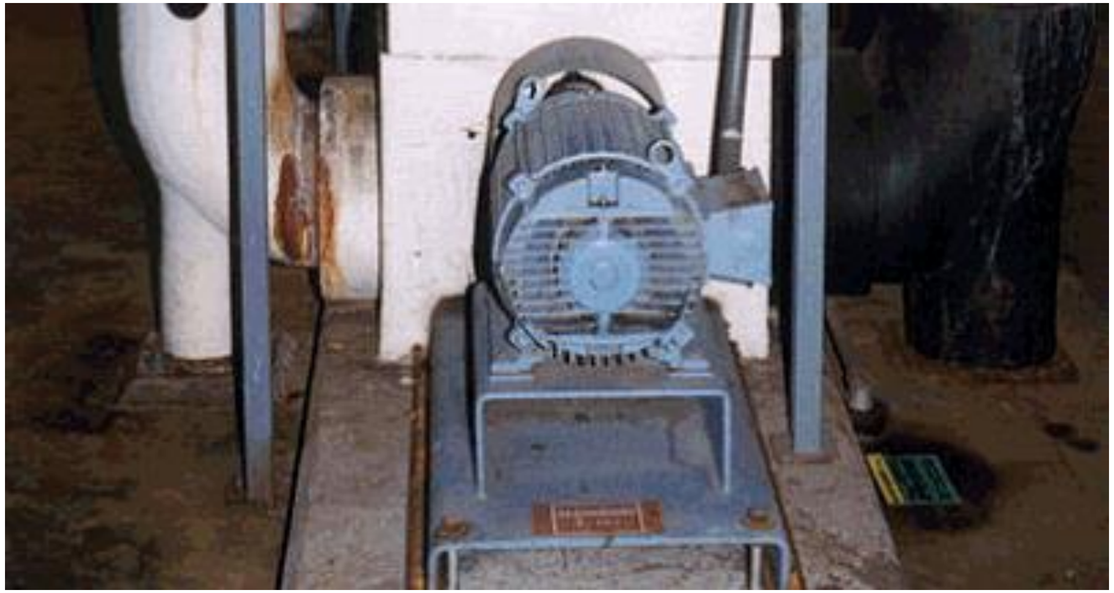
Discharge Data

Total Pump Head

Motor Data (J106)

Nameplate:

- 15 kW
- 1460 rpm @ 50 Hz
- 400 V
- 29.6 A (full load)
- IE0 (standard Eff)



Baseline Results

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RESULTS | HELP

	Baseline
Percent Savings (%)	— —
Pump efficiency (%)	70.9
Motor rated power (kW)	15
Motor shaft power (kW)	13.4
Pump shaft power (kW)	13.4
Motor efficiency (%)	89.1
Motor power factor (%)	81.4
Percent Loaded (%)	89
Drive efficiency (%)	100
Motor current (A)	27
Motor power (kW)	15
Annual Energy (MWh)	**120**
Annual Energy Savings (MWh)	**—**
Annual Cost	**$14,400**
Annual Savings	**—**

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

Slide Courtesy of Oak Ridge National Laboratory

Opportunity: Install VSD instead of Throttle

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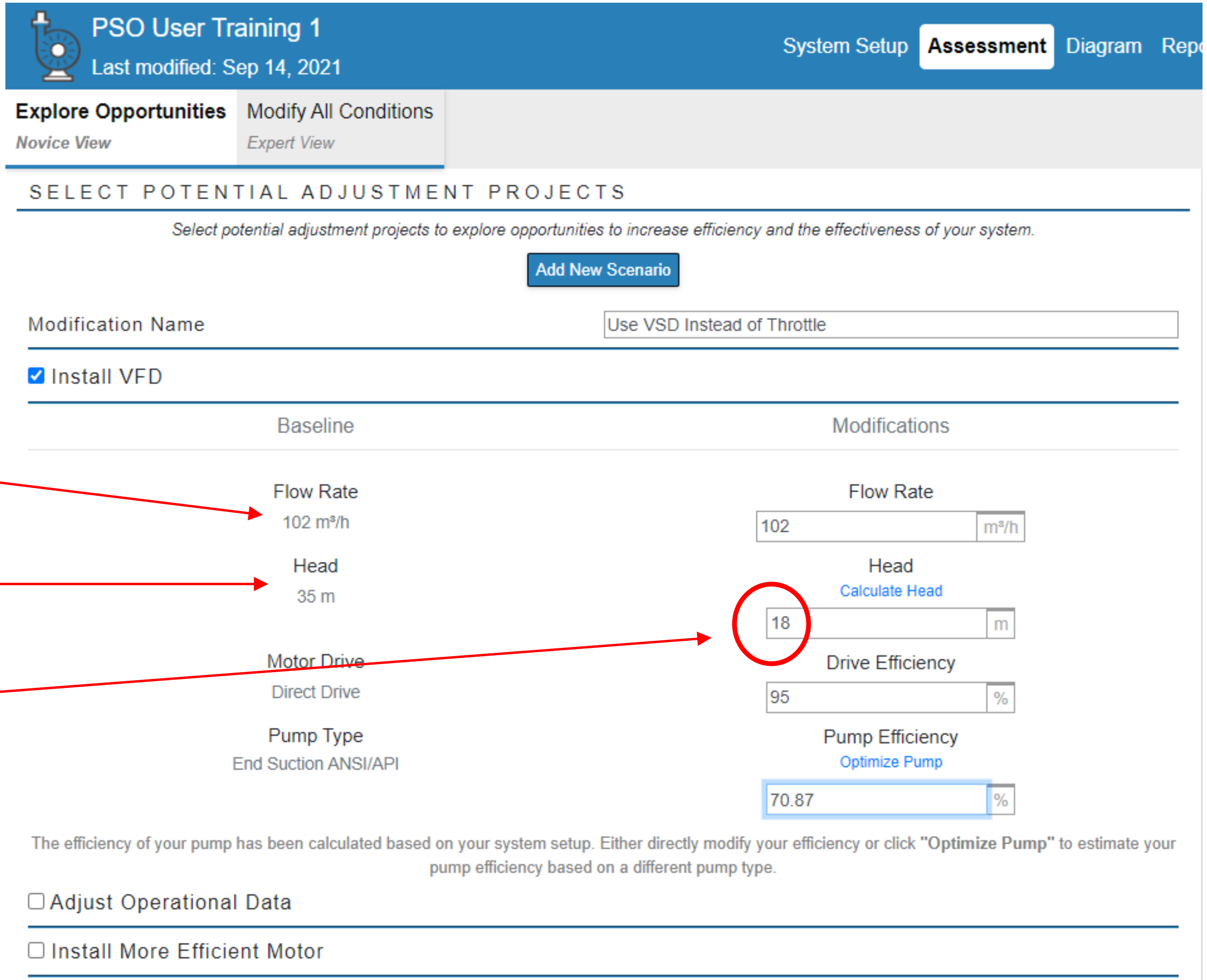
Opportunity:

- Use a VSD instead of a throttle valve for flow control
- Flow is the same
- Head required with throttle is 35.2 m
- Head required with VSD and no throttle is 18 m



Output Results

Savings:

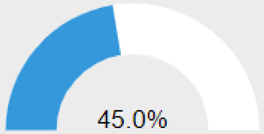
- Original cost $14,400
- New cost $7,882
- Will save 45% of baseline consumption
- Savings of 55 000 kWh

ort Sankey Calculators

Use VSD Instead of Throttle
Selected Scenario

View / Add Scenarios

RESULTS | SANKEY | HELP

	Baseline	Use VSD Instead of Throttle
Percent Savings (%)	— —	 45.0%
Pump efficiency (%)	70.9	70.9
Motor rated power (kW)	15	15
Motor shaft power (kW)	13.4	07.2
Pump shaft power (kW)	13.4	06.8
Motor efficiency (%)	89.1	88
Motor power factor (%)	81.4	60.9
Percent Loaded (%)	89	48
Drive efficiency (%)	100	95
Motor current (A)	27	17
Motor power (kW)	15	08.2
Annual Energy (MWh)	**120**	**65**
Annual Energy Savings (MWh)	**—**	**55**
Annual Cost	**$14,400**	**$7,852**
Annual Savings	**—**	**$6,548**

Pump Demand and Supply

- 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

08. PSAT Case Studies

Pump Systems Software

Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

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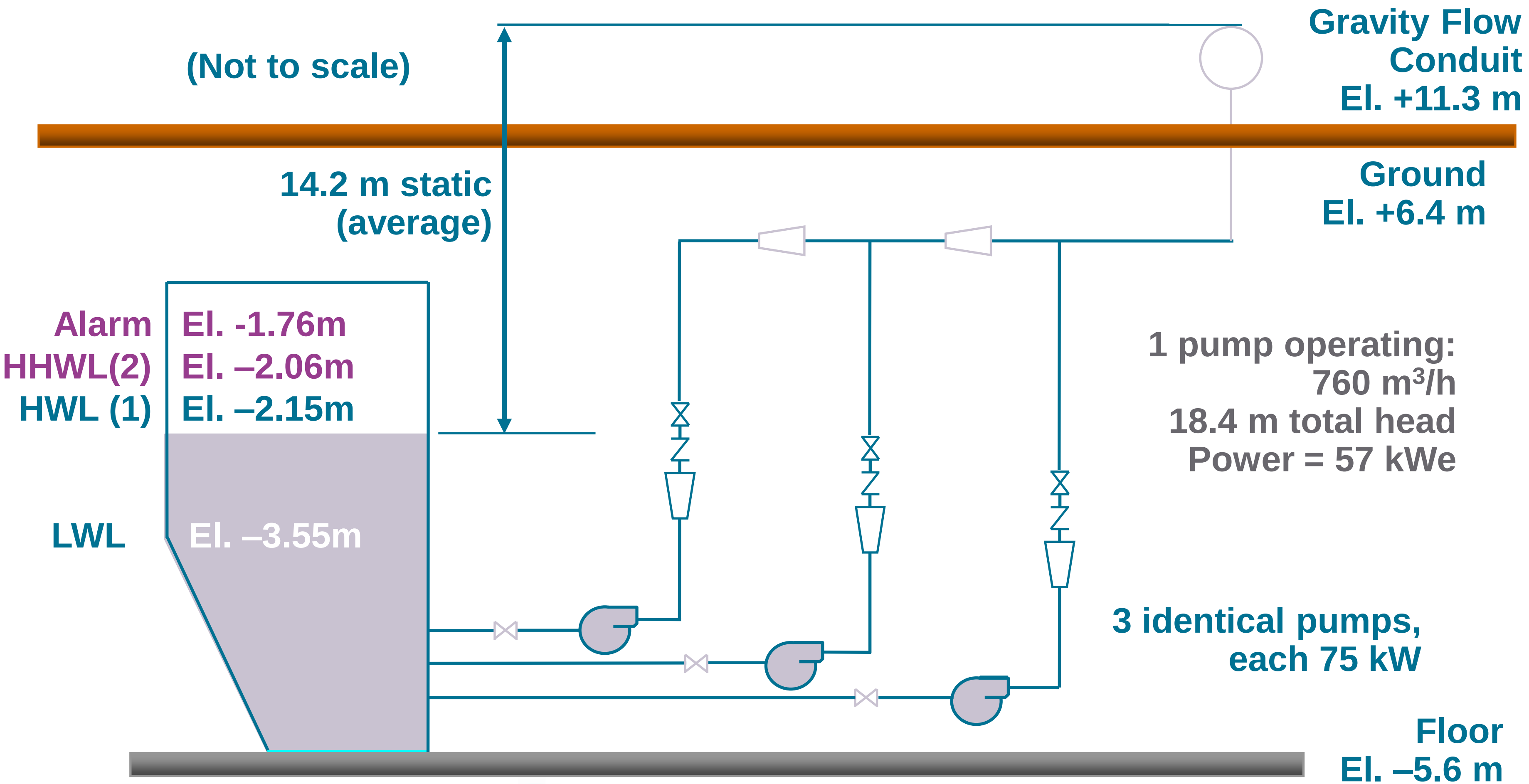
Case Study 1

Welches Point Wastewater Lift Station
(Milford, Connecticut)

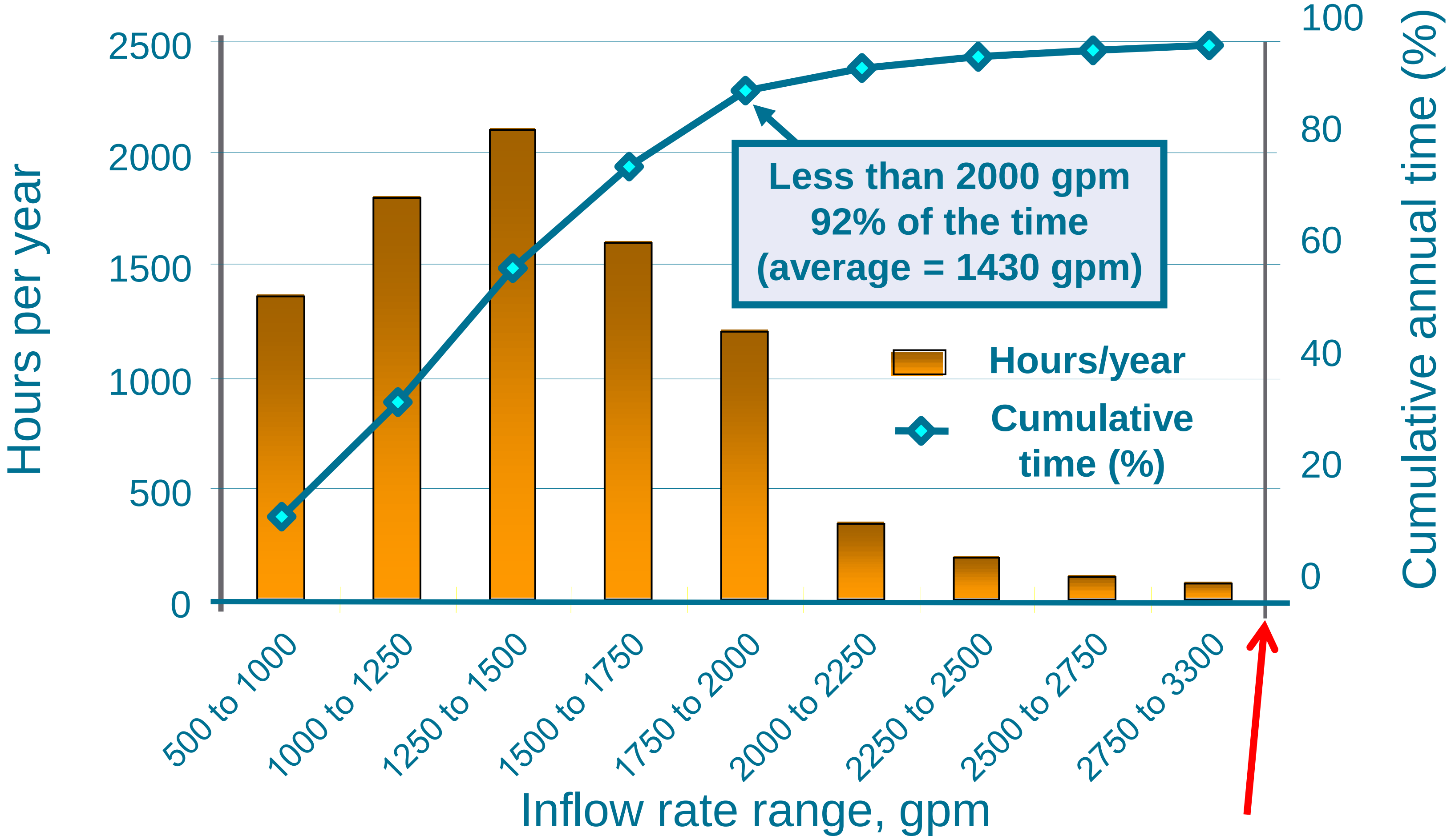
Welches Point Wastewater Lift Station

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



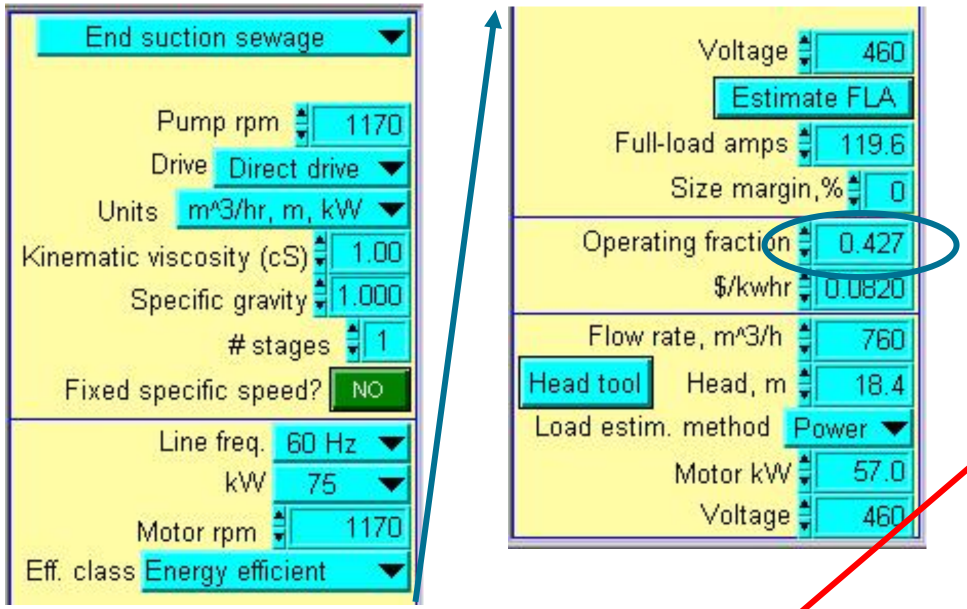
Pump Capacity

The pump design capability greatly exceeds the normal operational requirement



NOTE: Average pump flow rate = 3350 gpm

Efficiency of Original System

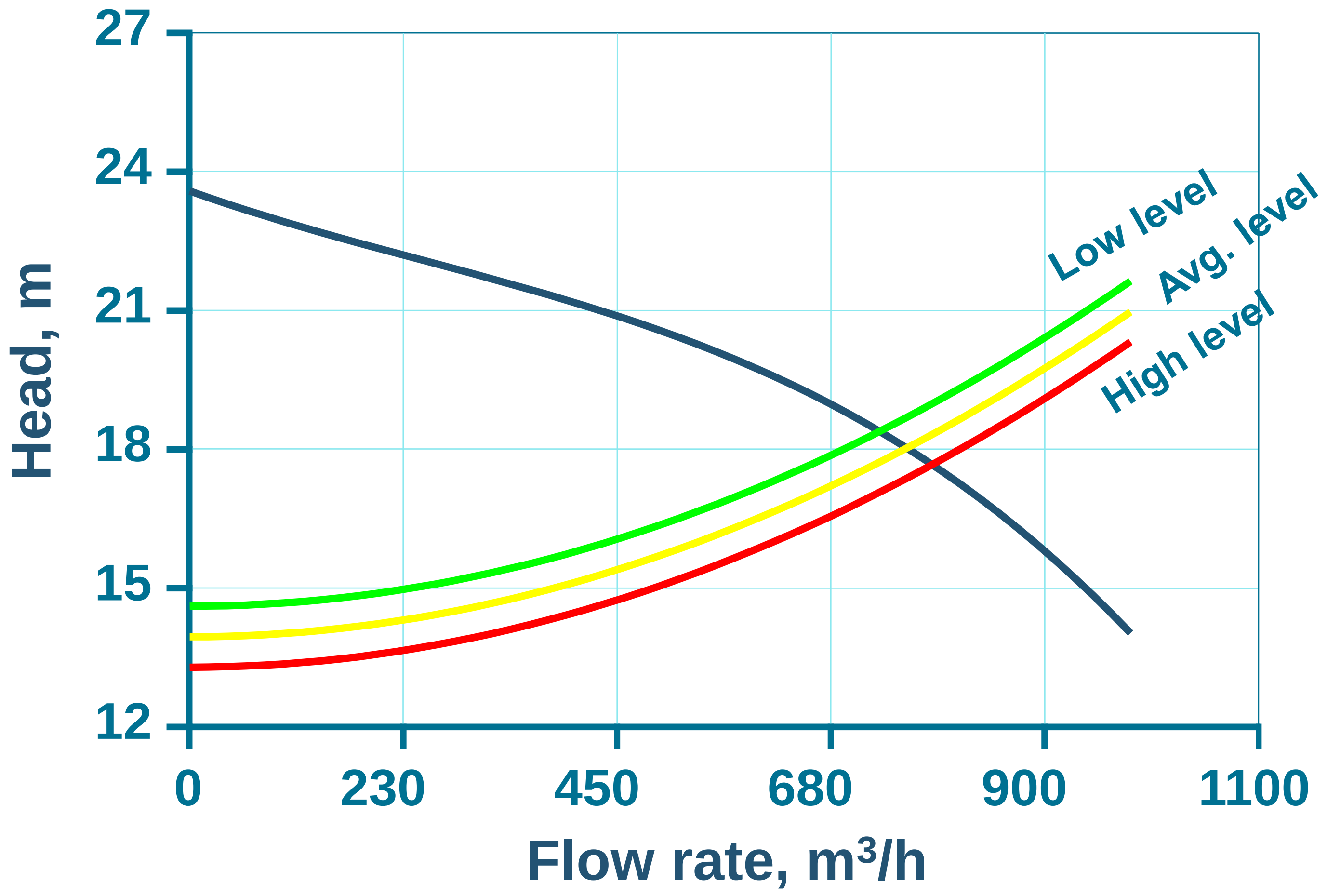


	Existing	Optimal	Units
Pump efficiency	70.4	83.2	%
Motor rated power	75	55	kW
Motor shaft power	54.0	45.7	kW
Pump shaft power	54.0	45.7	kW
Motor efficiency	94.8	94.6	%
Motor power factor	80.3	82.0	%
Motor current	89.1	73.9	amps
Motor power	57.0	48.3	kW
Annual energy	213.2	180.7	MWh
Annual cost	17.5	14.8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



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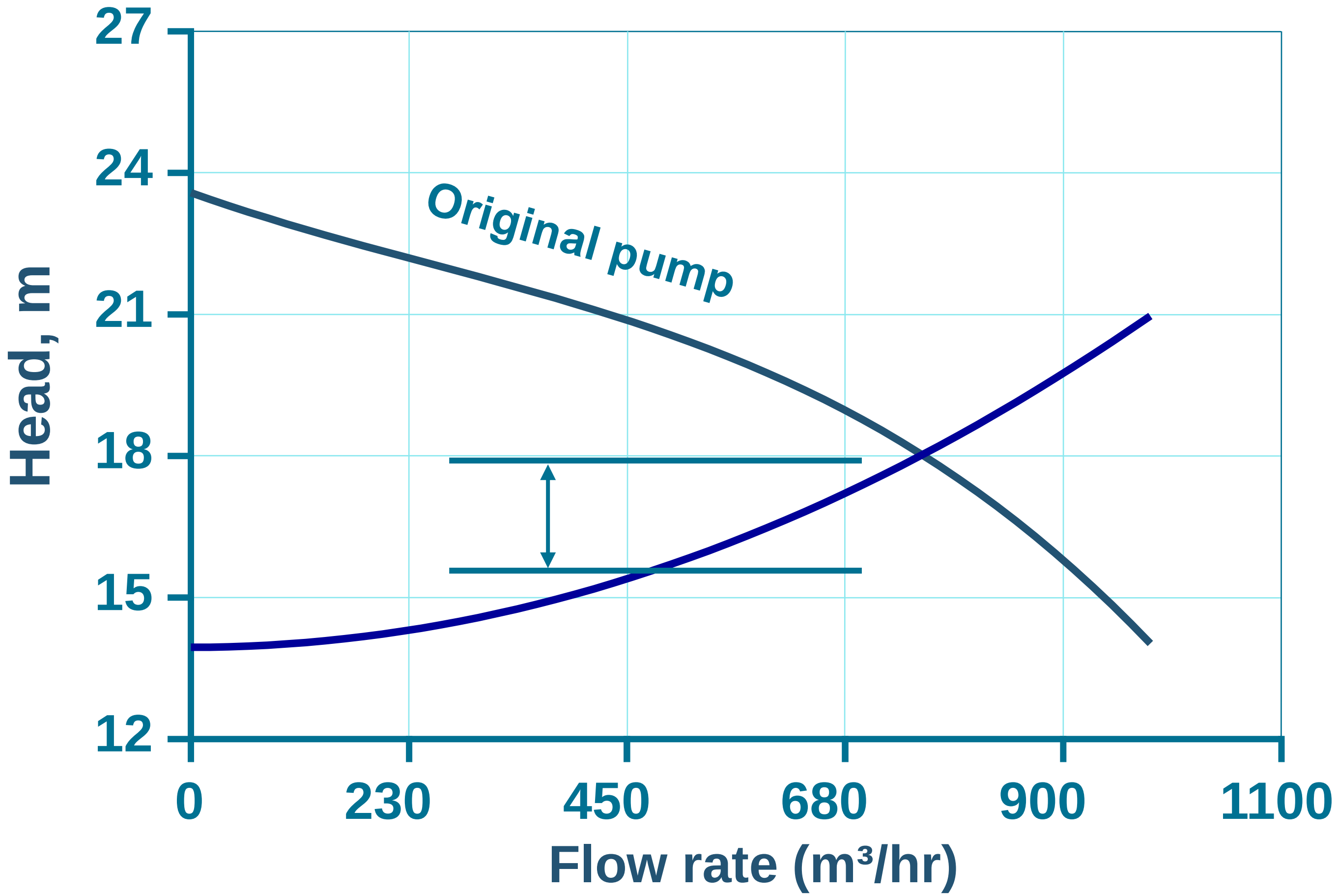
Excessive frictional head losses occur when higher than necessary flow rates occur



Slide Courtesy of Oak Ridge National Laboratory

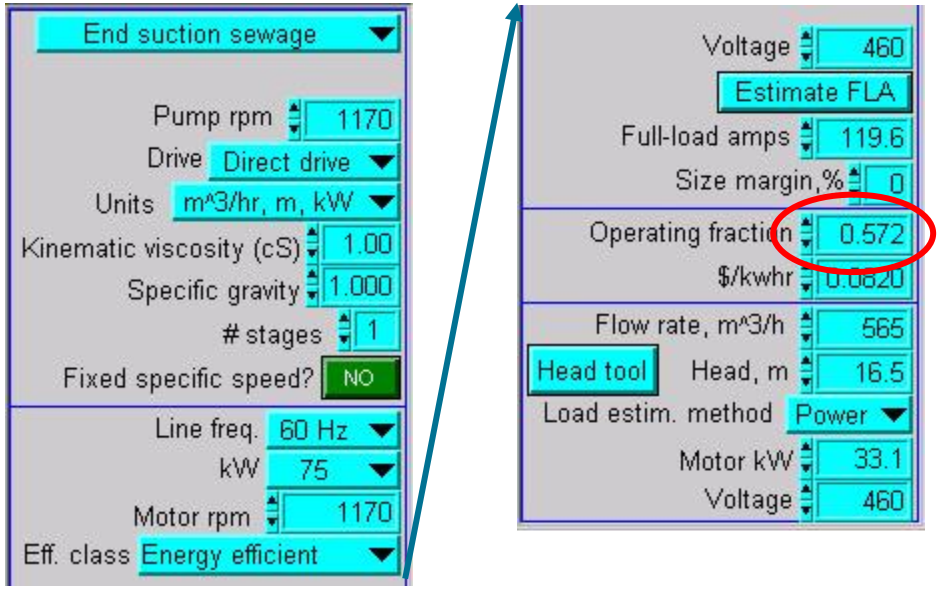
Reducing the Flow Rates…

- The station processes 2.84 million m3 of water/year
- What if we pumped at lower flow rates?

Average operating hours and head at different flow rates:

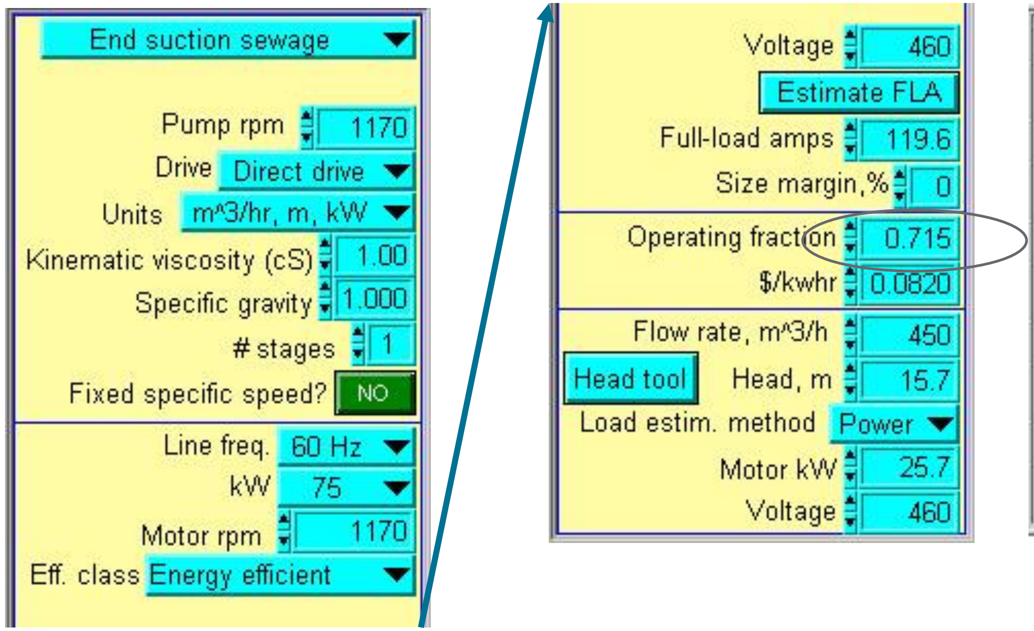
Flow Rate	Hours / Year	% of time on	Head (m)
760 m^3/h	3,741	0.427	18.4m
565 m^3/h	5,013	0.572	16.5m
450 m^3/h	6,267	0.715	15.7m
340 m^3/h	8,356	0.954	15.0m

Optimized Pump at 565 m³/h



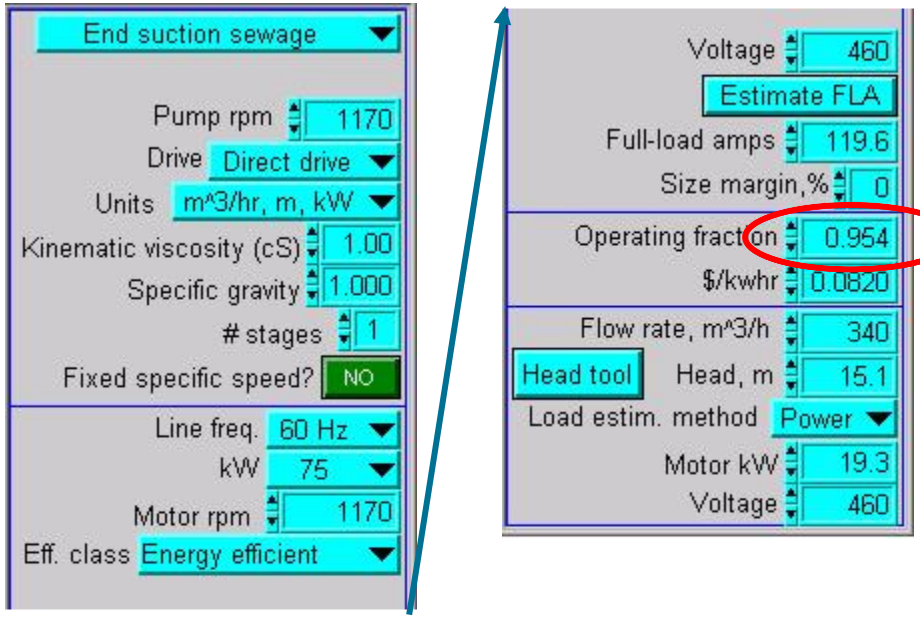
	Existing	Optimal	Units
Pump efficiency	81.7	81.7	%
Motor rated power	75	37	kW
Motor shaft power	31.0	31.0	kW
Pump shaft power	31.0	31.0	kW
Motor efficiency	93.8	94.1	%
Motor power factor	67.1	82.3	%
Motor current	61.9	50.3	amps
Motor power	33.1	33.0	kW
Annual energy	165.9	165.3	MWh
Annual cost	13.6	13.6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

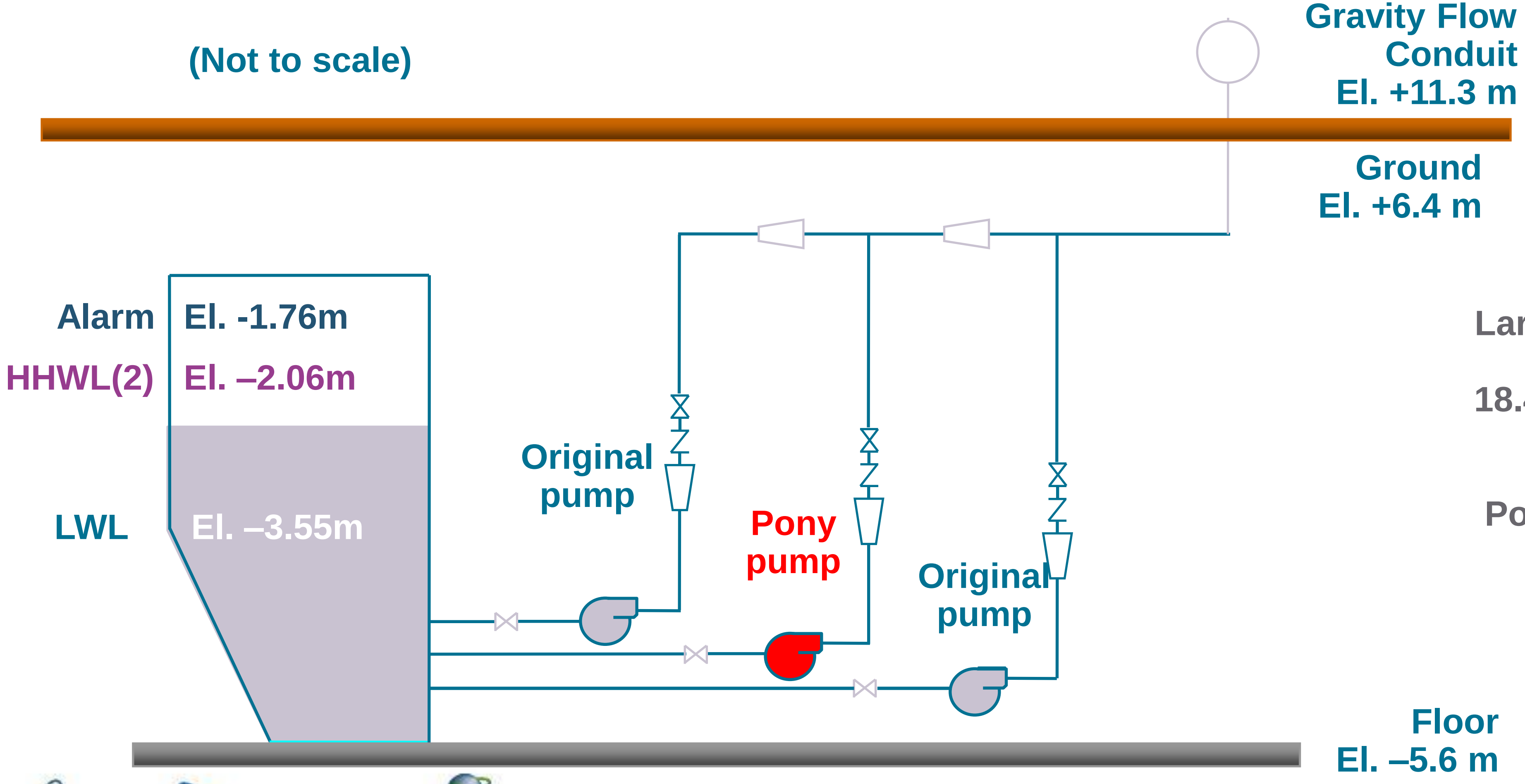
Optimized pump at 340 m^3/h



	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	

After Optimisation

- One lift pump replaced with a smaller pony pump



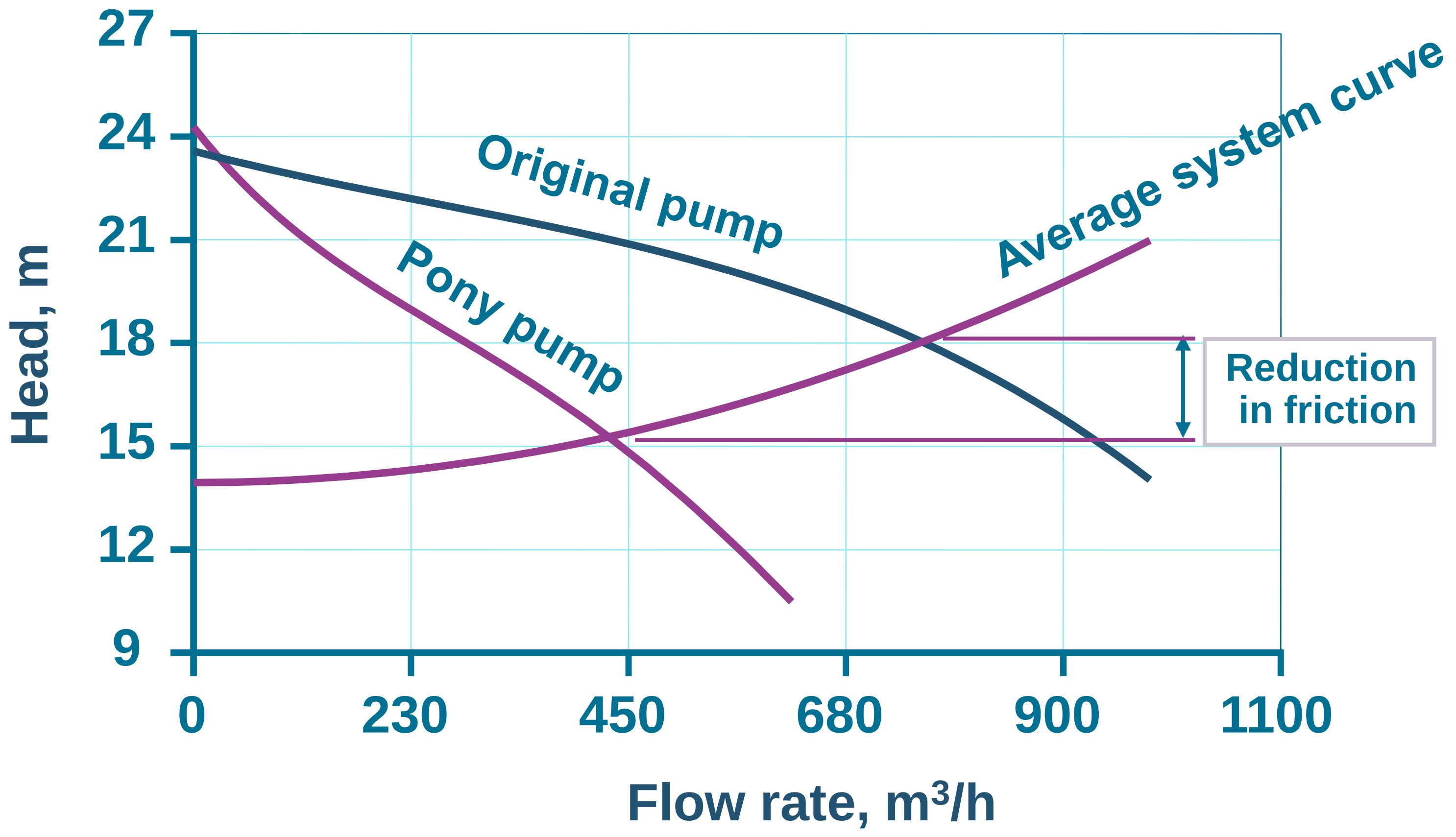
Large pump:
760 m^3/h
18.4 m head)
57 kWe

Pony pump:
438 m^3/h
15.5m
27 kWe

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

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

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



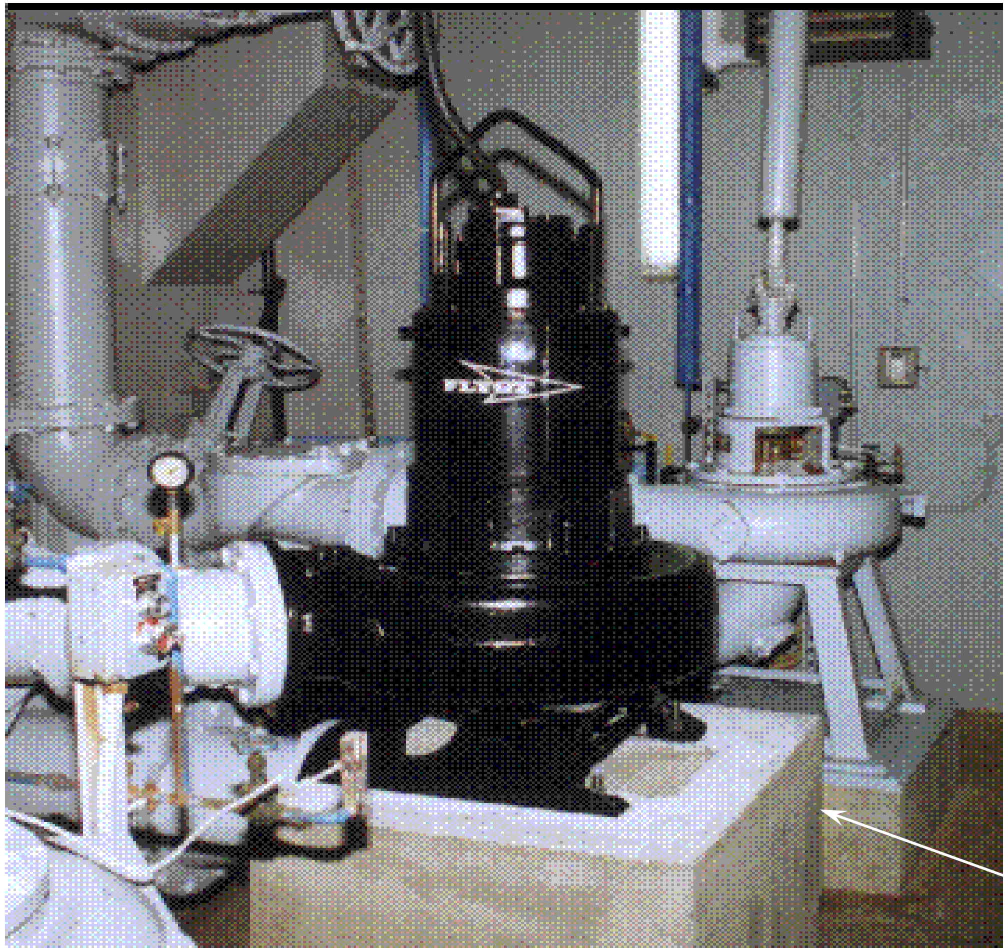
After Optimisation (Smaller Pump Installed)

End suction sewage	
Pump rpm	1170
Drive	Direct drive
Units	m^3/hr, m, kW
Kinematic viscosity (cS)	1.00
Specific gravity	1.000
# stages	1
Fixed specific speed?	NO
Line freq.	60 Hz
kW	75
Motor rpm	1170
Eff. class	Energy efficient

Voltage	460
Estimate FLA	
Full-load amps	119.6
Size margin, %	0
Operating fraction	0.741
$/kwhr	0.0820
Flow rate, m^3/h	438
Head tool / Head, m	15.5
Load estim. method	Power
Motor kW	27.0
Voltage	460

	Existing	Optimal	Units
Pump efficiency	73.5	80.3	%
Motor rated power	75	26	kW
Motor shaft power	25.1	23.0	kW
Pump shaft power	25.1	23.0	kW
Motor efficiency	93.1	93.4	%
Motor power factor	60.6	82.7	%
Motor current	55.9	37.4	amps
Motor power	27.0	24.6	kW
Annual energy	175.3	160.0	MWh
Annual cost	14.4	13.1	$1000
Annual savings potential, $1,000		1.3	
Optimization rating, %		91.3	

Final Outcome: Installed Smaller Pump



Conventional pump in a 3-pump sewage lift station:

New Size:

438 m³/hr (1 928 gpm)

Original Size:

795 m³/hr (3 500 gpm)

Case Study 2

Demineralized Water System
at OAK RIDGE

Demineralised Water System at Oak Ridge

Egyptian program for promoting Industrial Motor Efficiency
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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

335 kW , 2 300 V, 1 785 rpm motor

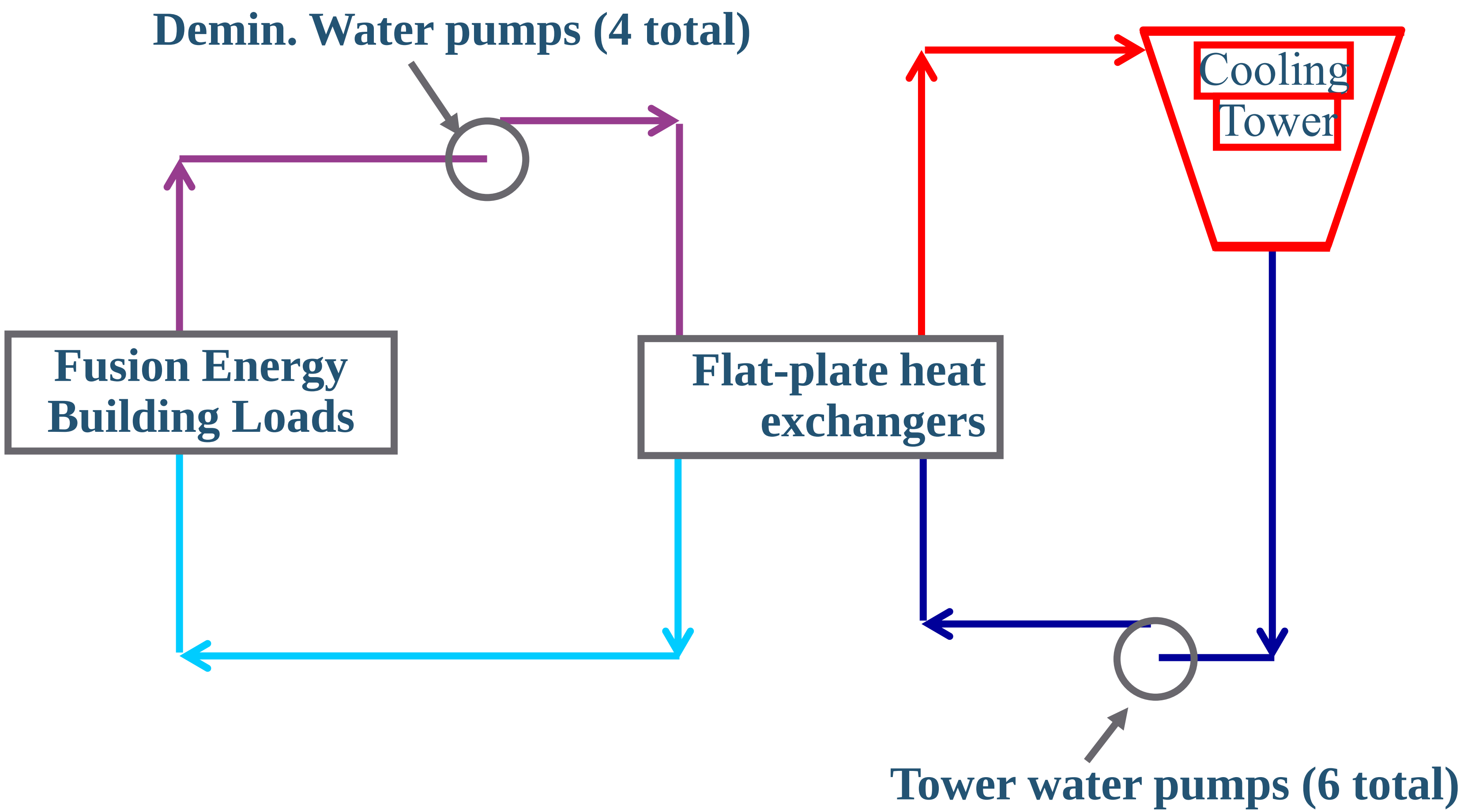
Current system requirements:

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

System Overview

Demineralized and tower water pumping station for the Fusion Energy Complex

Simplified Flow Diagram



Slide Courtesy of Oak Ridge National Laboratory

Pump Operation & System Curve

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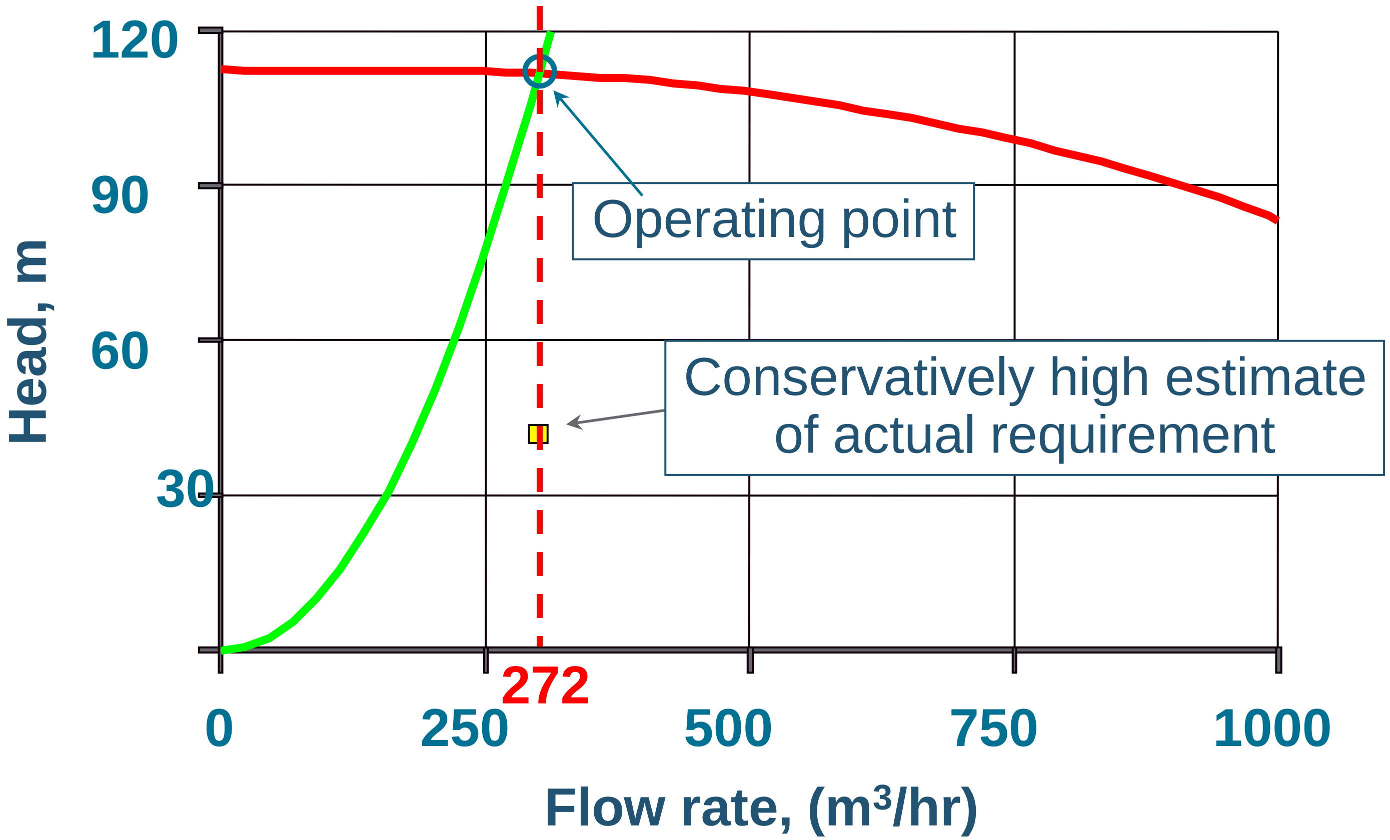
Even a conservative estimate clearly showed the effects of throttling / bypass losses



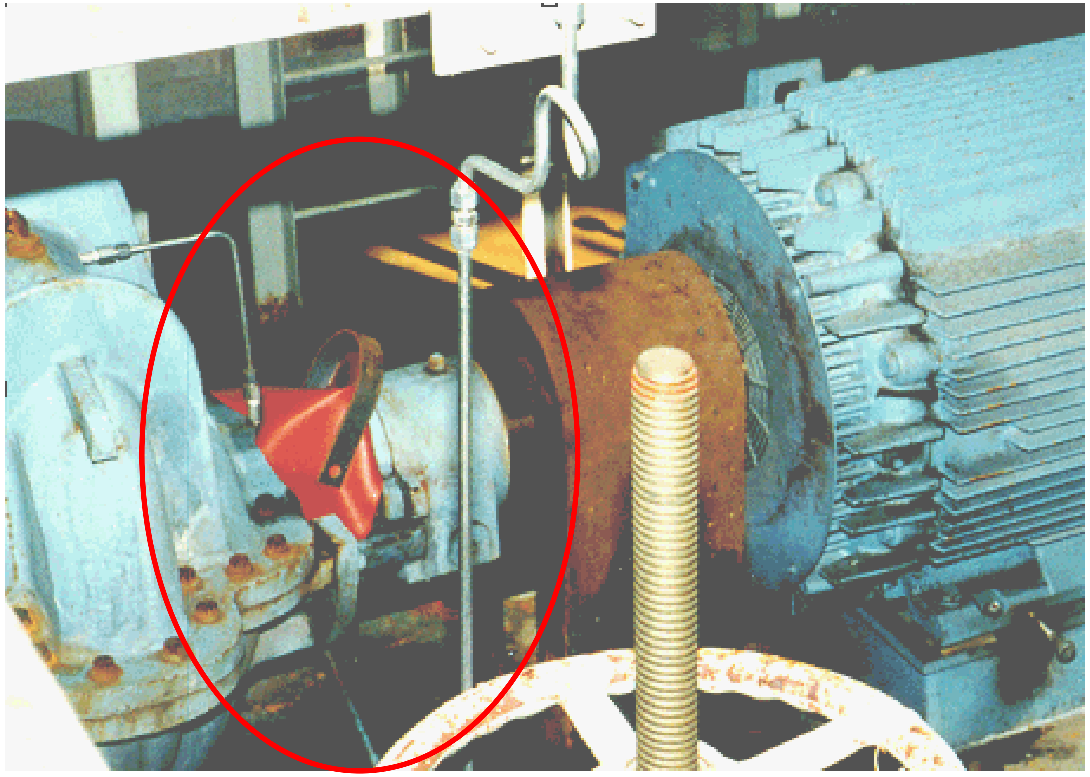
Bottom Line:

System producing significantly more head than necessary

Pump Operating Far from BEP (Off-Design)

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

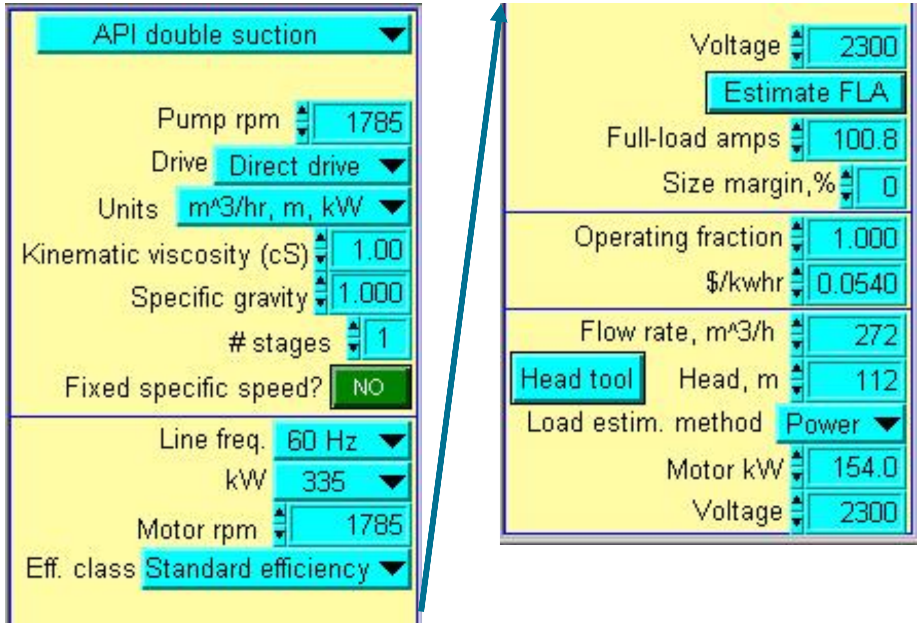
- Premature seal failures are one consequence of off-design operation



Slide Courtesy of Oak Ridge National Laboratory

Potential Savings Estimated Using PSAT

- Applying the PSAT tool to the measured conditions showed significant potential savings
- This savings could be achieved by improving efficiency of motor and pump



	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 approx. $21,600

Potential Savings by Eliminating Throttle Losses

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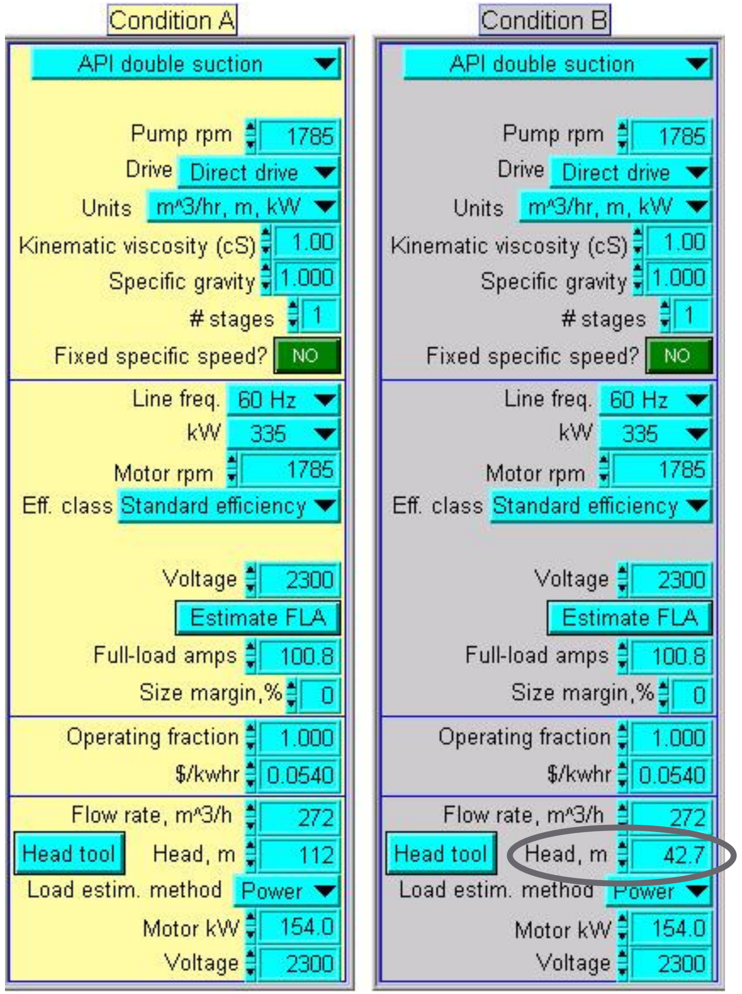
- Using required head estimate instead of the actual operating head could yield much greater savings
- This saving could be achieved by eliminating the throttle losses using a VSD



	Condition A Existing	Condition A Optimal	Units	Condition B Existing	Condition B 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			27.1	

Potential annual savings ~ $53K

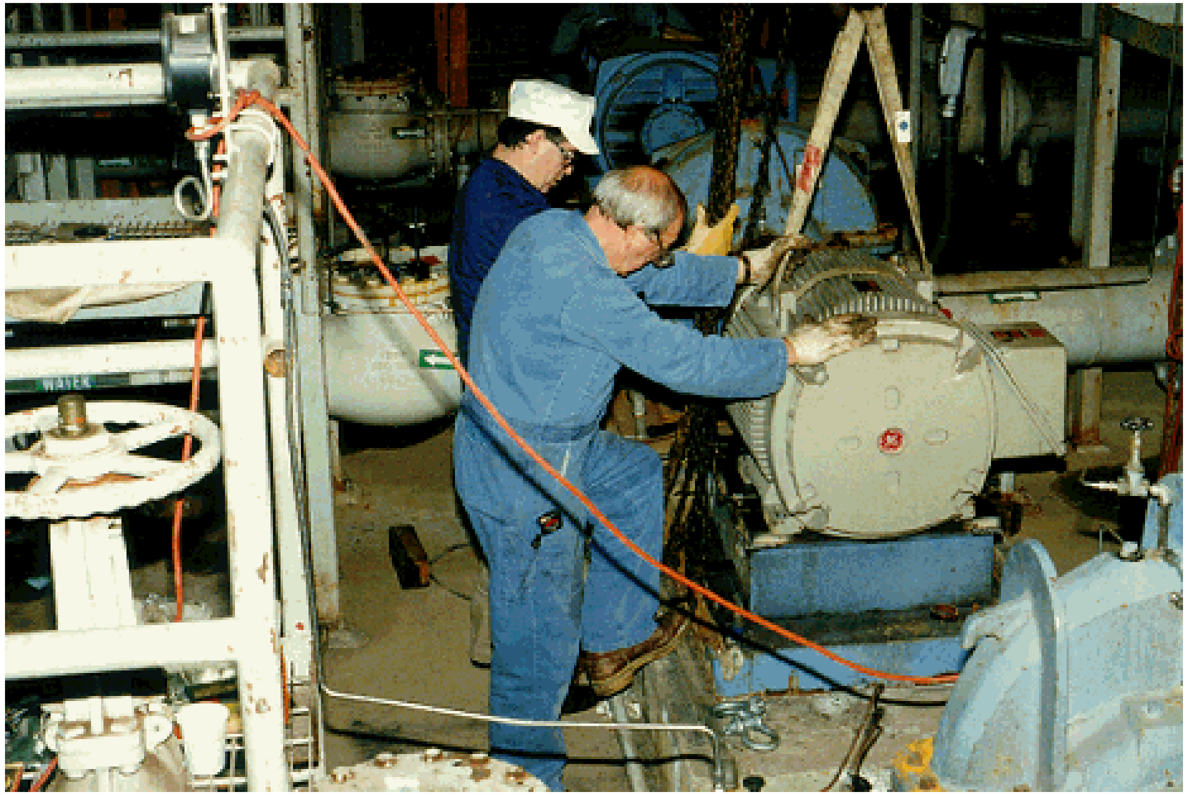
Options Considered

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

But what was finally decided was a little unconventional

A Novel Solution…

- A 93 kW, 6-pole (1 190 rpm) motor was installed on an existing demineralized water pump
- The higher number of poles meant the motor rotated at a lower speed (reduced from 1785 rpm)
- The motor was available as a spare at the plant (no capital cost)



Slide Courtesy of Oak Ridge National Laboratory

Avoided Throttle Losses

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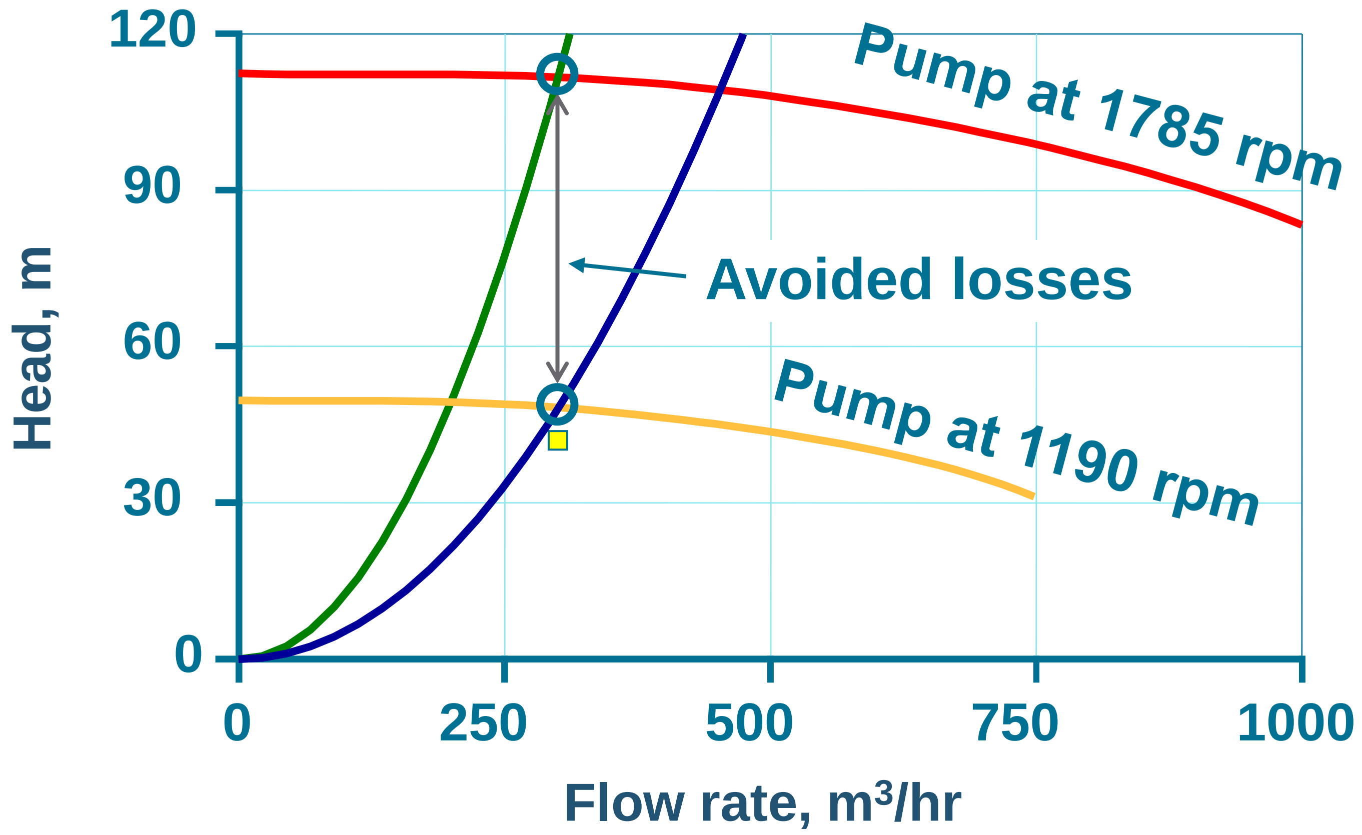
Operation of the pump at reduced speed eliminated much of the throttling losses



Slide Courtesy of Oak Ridge National Laboratory

Evaluation of Lower Speed Motor

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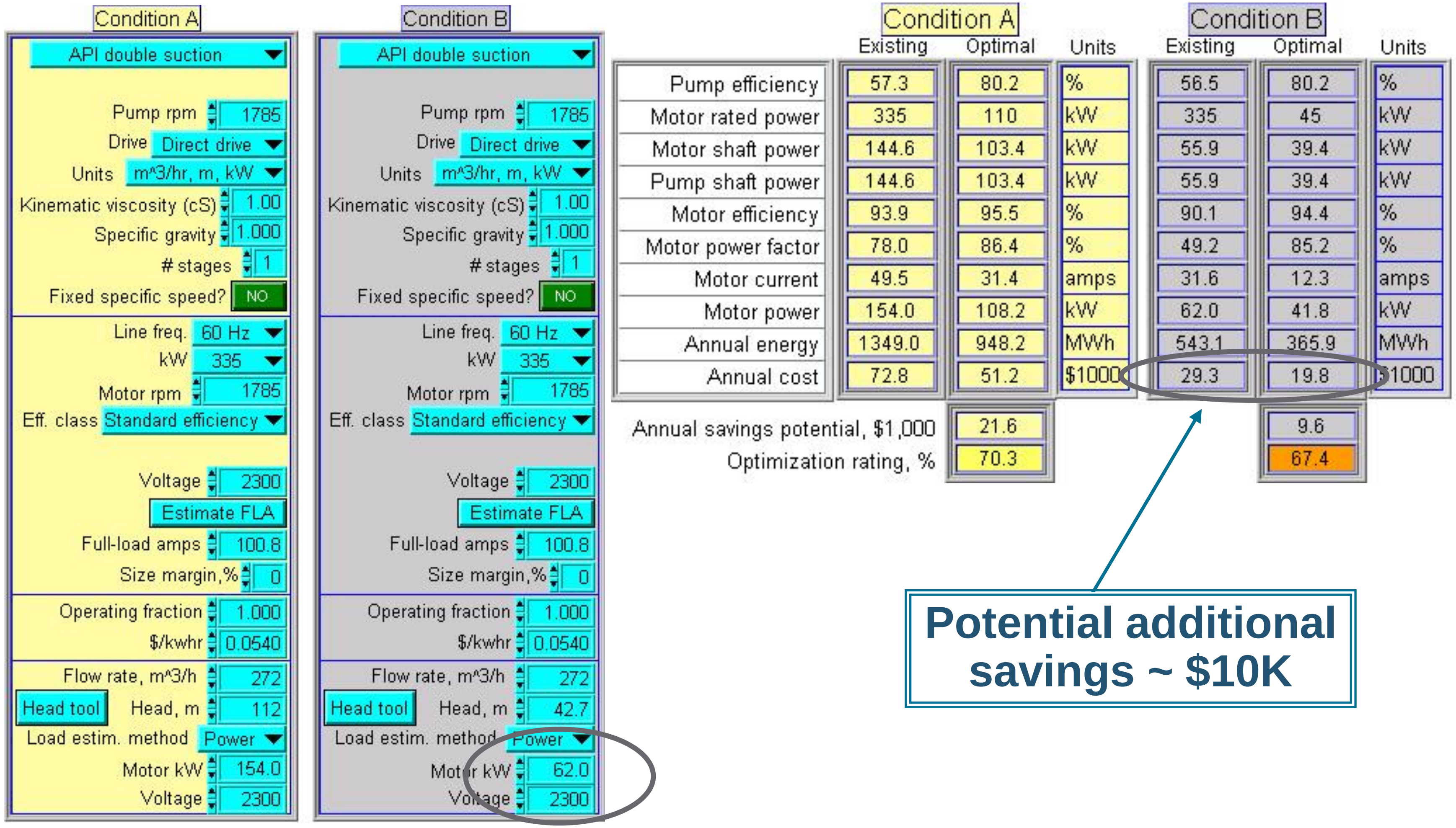
- The new lower speed motor was analysed in PSAT, showing a further reduction in savings was possible.
- This saving could be achieved by replacing the pump and motor with more efficient units.



	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	

Savings Achieved

- Annual electricity cost reduction from this change exceeds $ 50 000 (other changes also made to the system)
- Reduction in annual electrical energy was more than 900 000 kWh
- The motor capital cost was $12 000 (installation and commissioning
- Capital cost repaid in about 3 months

Slide Courtesy of Oak Ridge National Laboratory

Other Non Energy Benefits (NEBs)

- Seal face speed reduced, seal life thereby extended
- Pump more hydraulically stable (because it now operates closer to BEP), 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)

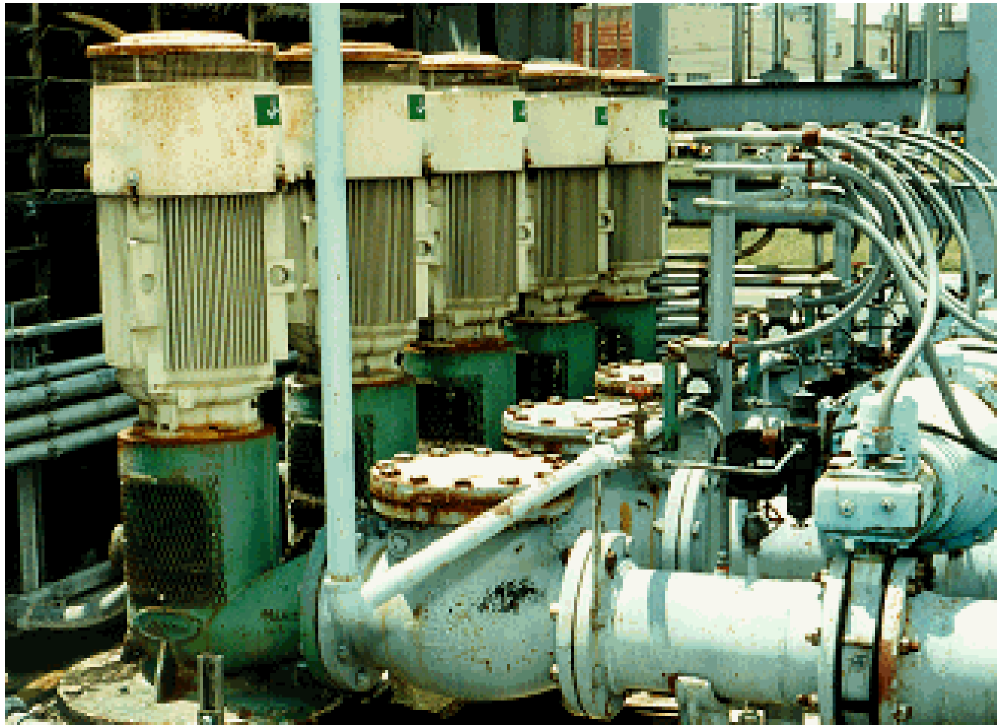
Slide Courtesy of Oak Ridge National Laboratory

Case Study 3

Cooling Tower Water Pump System

Cooling Tower Pump System

- Multiple parallel pumps are an outstanding idea…
- BUT only when used in the correct operational setting
- There is often a temptation to run more pumps than are really needed, defeating the very reason for having multiple pumps



Simplified Flow Diagram

Egyptian program for promoting Industrial Motor Efficiency
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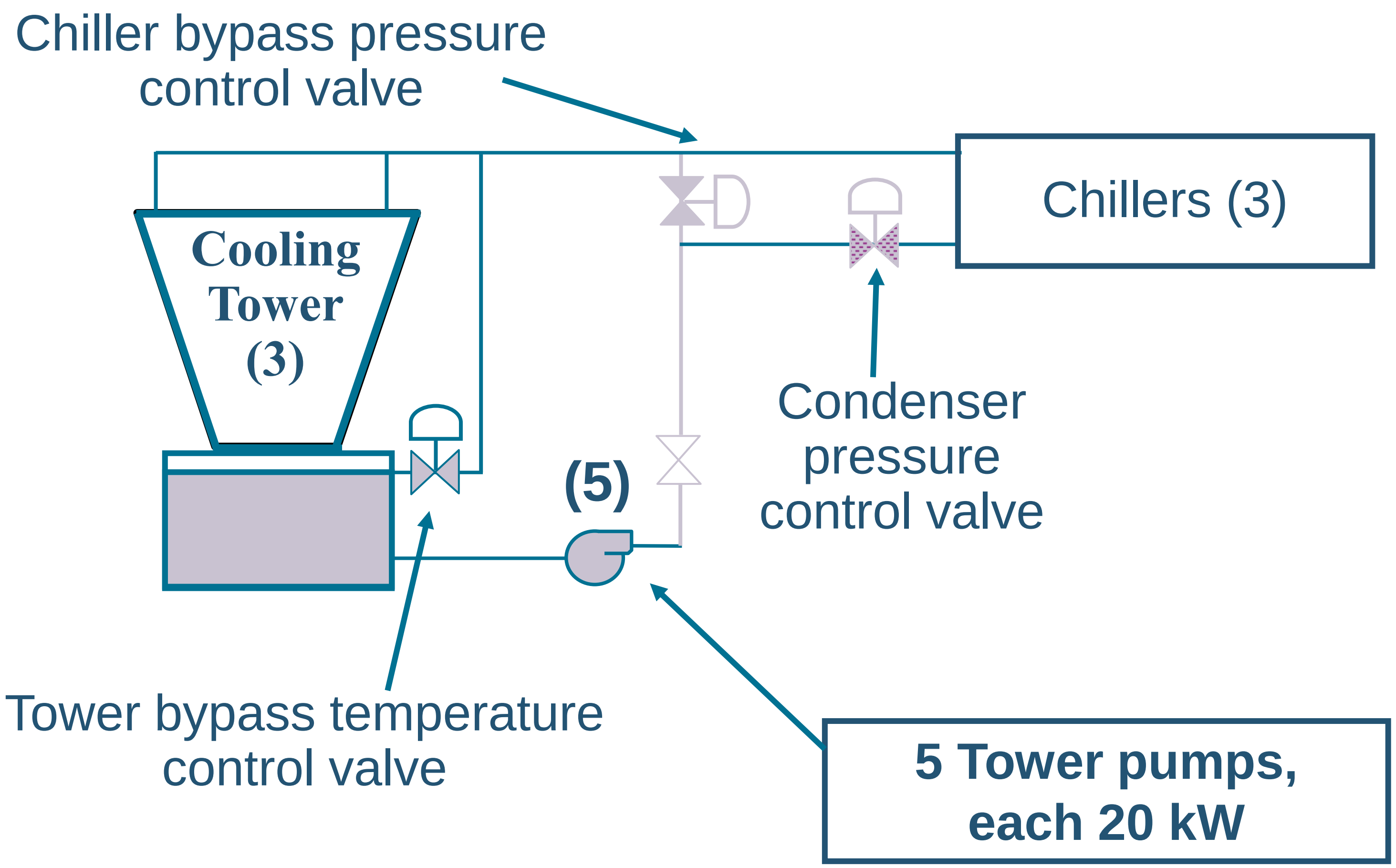
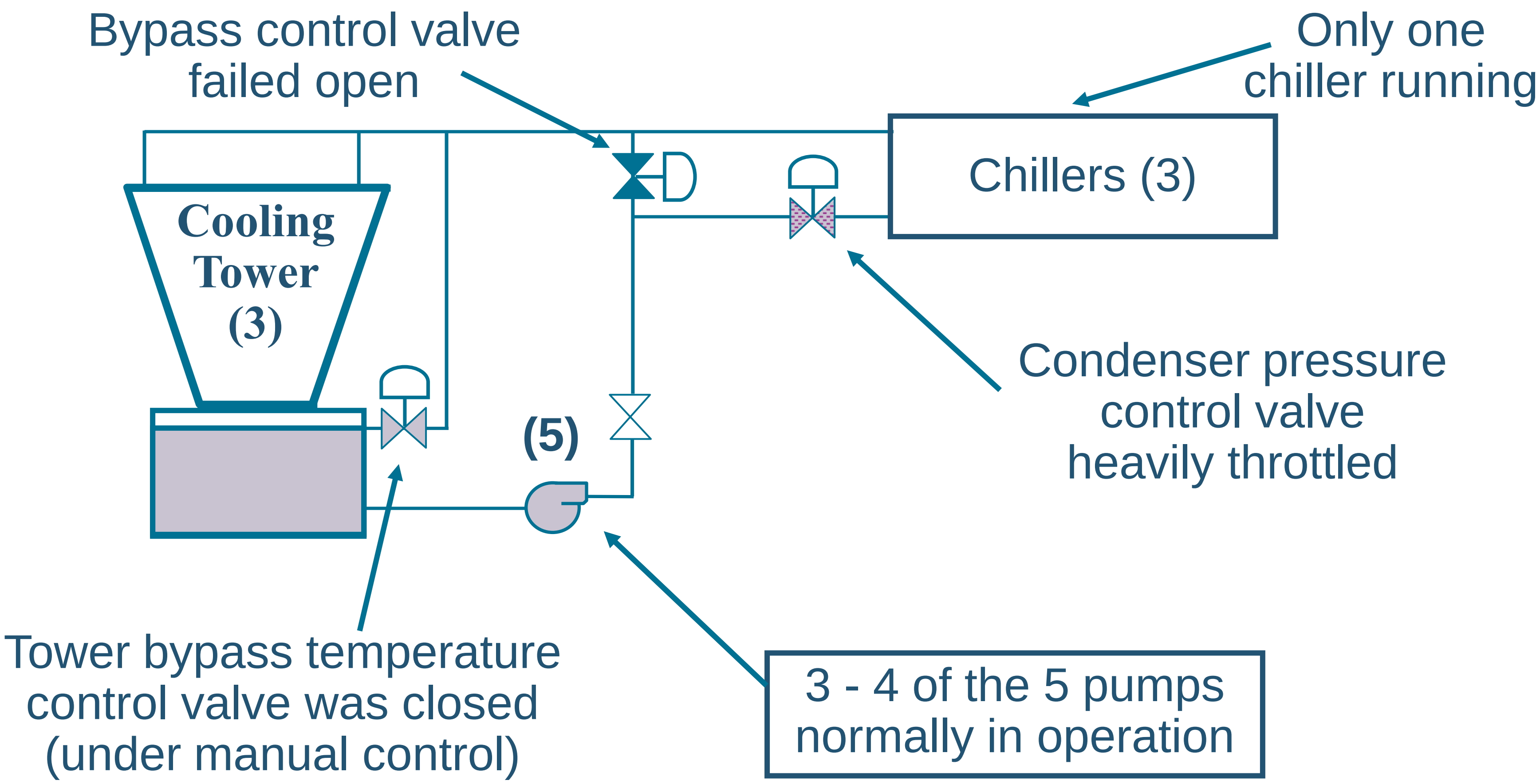


As Found Condition

- One chiller in operation, but 3 or 4 tower pumps running



Slide Courtesy of Oak Ridge National Laboratory

Initial Corrective Action

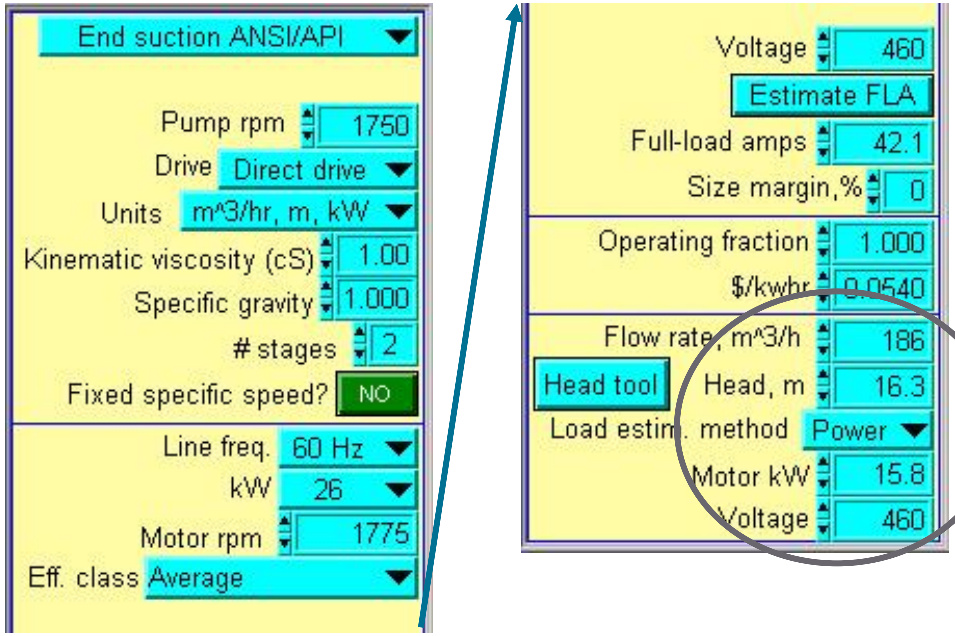
- Repaired diaphragm in failed open bypass valve, eliminating bypass flow

- 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 ~ $2.5K

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Rule of Thumb for Chillers

- Stepping back, consider what is ***actually*** required

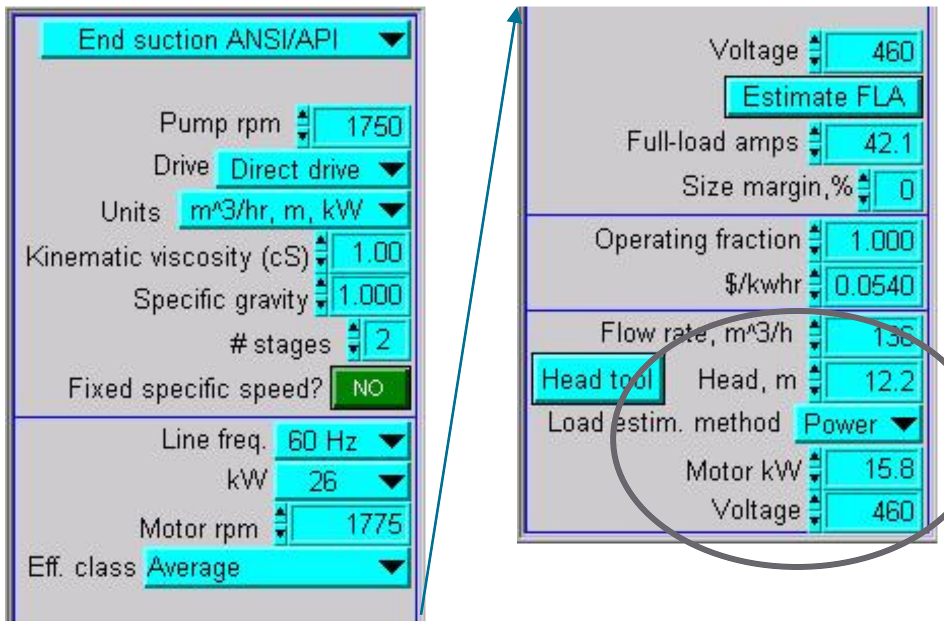
A general rule of thumb for chillers:

3 gpm tower water flow per ton of cooling

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

Load (Flow) Reduction Potential Savings

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	

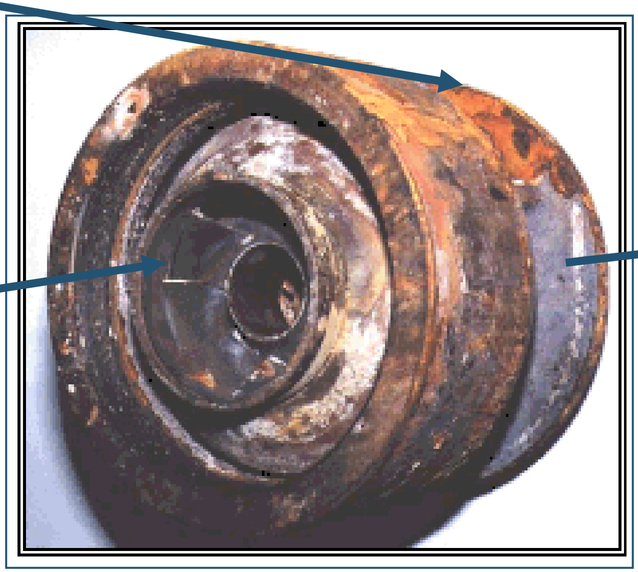
Potential annual savings ~ $4.6K

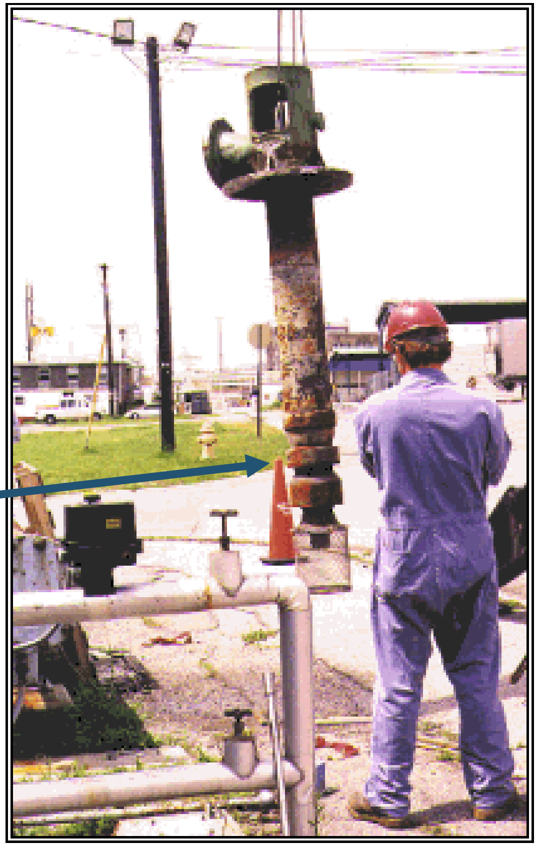
- A great opportunity, but…

NO CAPITAL FUNDS

Alternative solution…

- Removed one stage from the multistage pumps from two of the tower pumps





With One Stage Removed (originally a 3 stage pump)

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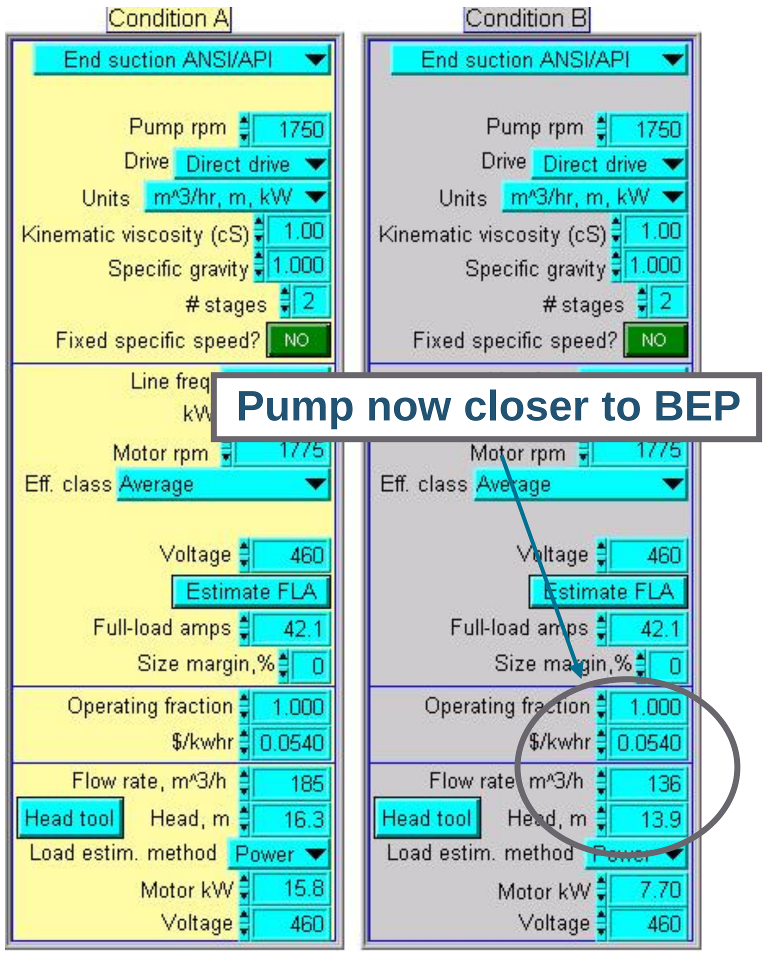


	Condition A Existing	Condition A Optimal	Units	Condition B Existing	Condition B Optimal	Units
Pump efficiency	56.6	83.6	%	76.3	82.0	%
Motor rated power	26	11	kW	26	7.5	kW
Motor shaft power	14.5	9.8	kW	6.7	6.3	kW
Pump shaft power	14.5	9.8	kW	6.7	6.3	kW
Motor efficiency	91.7	92.0	%	87.5	91.1	%
Motor power 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 $4K per pump-year

09. Valve Tool

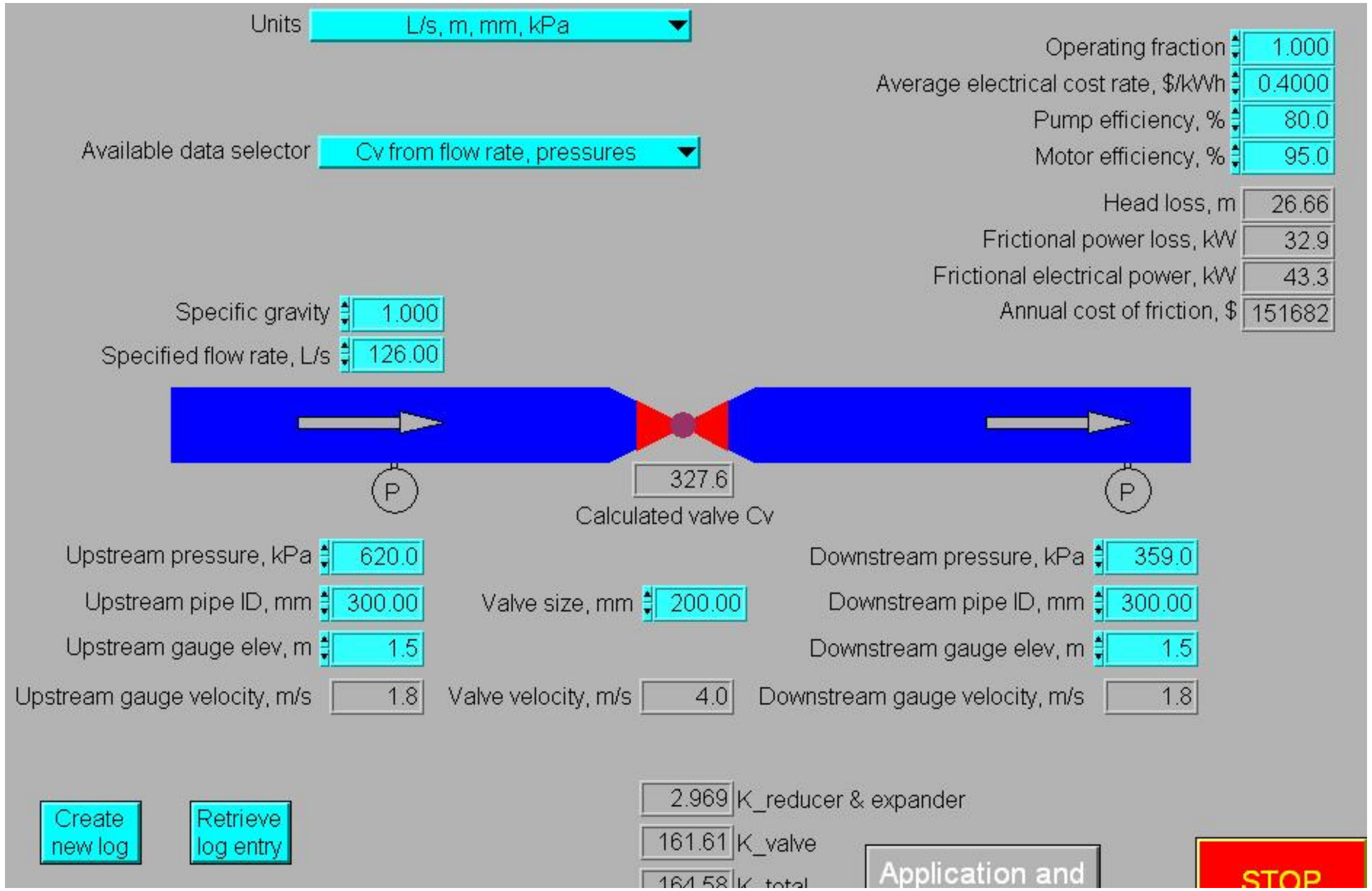
Pump Systems Software

Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

Valve Tool in PSAT Legacy Software

NOTE:
Valve Tool not available in latest edition of MEASUR



Classroom Worked Example

System Configuration and Operating Data

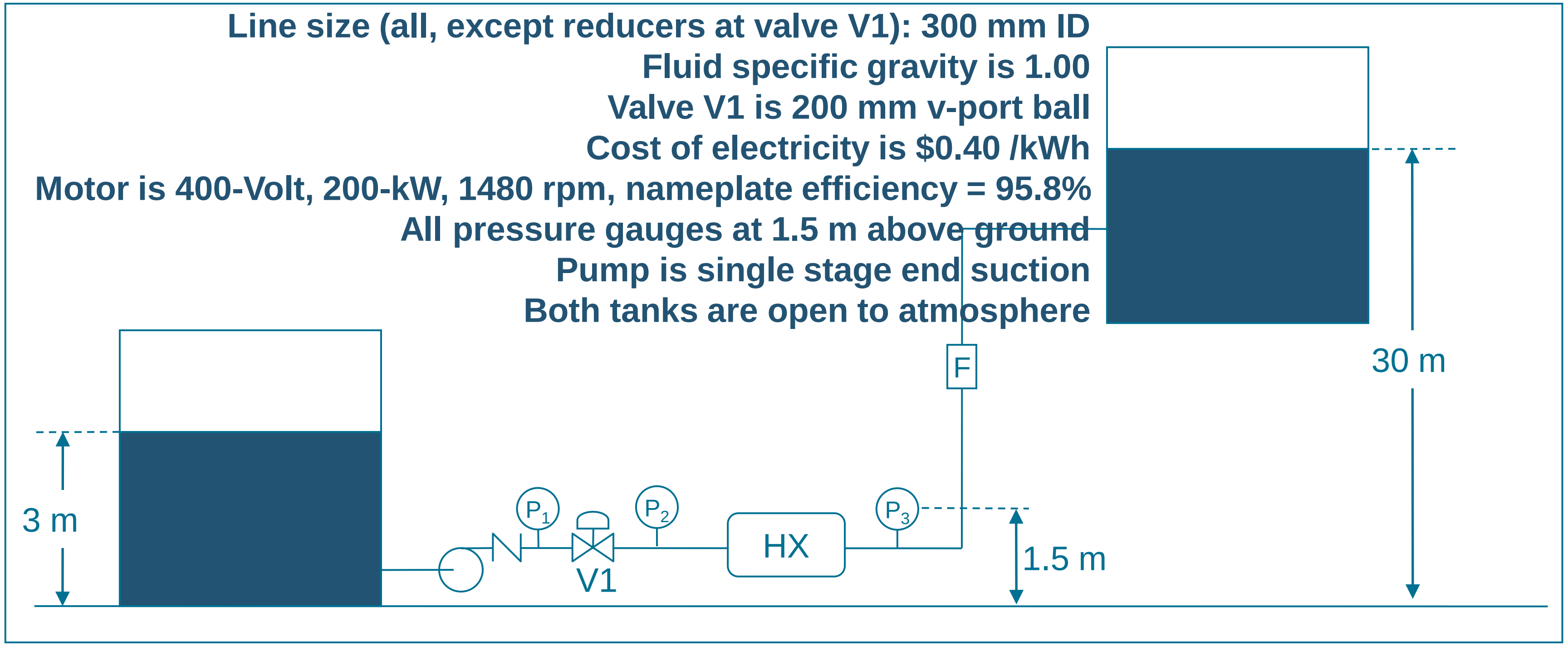
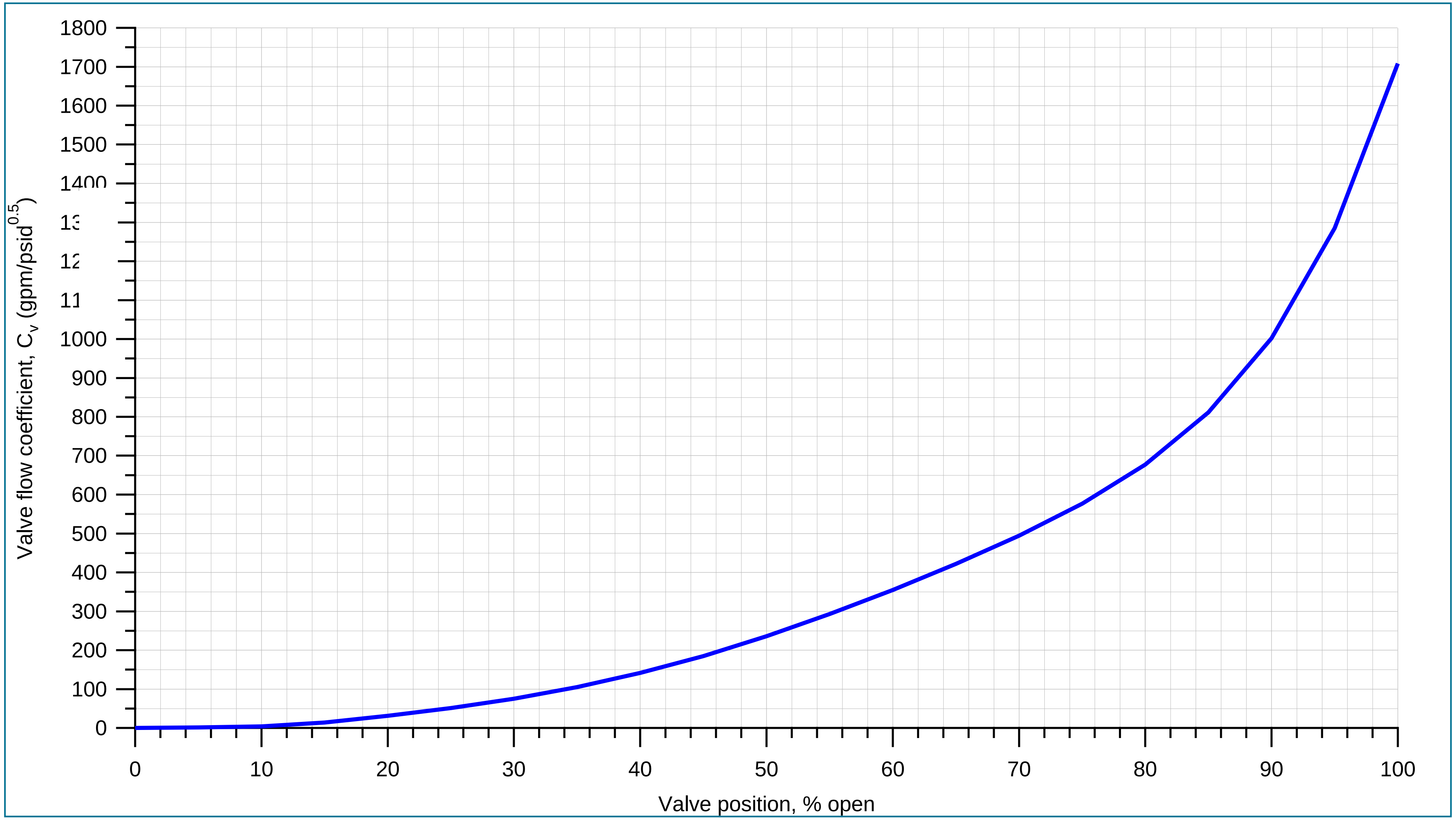


Figure 1. System arrangement, generic information

Table 1. Measured Operating Data

Condition	Q, l/s	P1, kPa	P2, kPa	P3, kPa	Motor kW	% of time at Condition
A	126	620	359	345	135	50%
B	200	517	455	420	150	40%
C	0	???				

Valve F1 Flow Coefficient Curve



Questions

1. For Conditions A and B of Table 1, estimate the actual pump head. You are encouraged to use the PSAT built-in pump head calculator.

Condition A:

Condition B:

(assume Ks = 0.5 loss for suction side and Kd = 1.0 loss for discharge side)

2. Use the PSAT program to calculate Optimization ratings and annual energy costs of operation for the two conditions.

	Optimization rating	Annual energy cost
Condition A:		
Condition B:		

Questions

3. What is the static head for this system?

4. What pressure would you expect at P1 with the pump off (see ??? in Table 1)?

5. Using the system curve calculator built into PSAT2004, develop system curves based on the static head and the Condition A and B flow and head points of Table 1.

NOTE: you will have to develop two different curves, since the control valve V1 position (and associated loss) changes for the two flow conditions.

Questions

6. Valve V1-related calculations:

A. Using the Valve equations tool included with PSAT2004, calculate the valve flow coefficient for Conditions A and B.
Condition A (126 l/s)
Condition B (200 l/s)

B. Assume that the pump efficiency is 80% and the motor efficiency is 95%. What are the estimated power losses (kW) and the annual costs of the friction from valve V1 for the two operating conditions (use the valve equations tool)? (operating fraction = 1.0)

Condition A (126 l/s)

Condition B (200 l/s)

C. Perform a screen capture of the valve equations sheet and paste it into a Word, Powerpoint, or other document to be returned to the instructor.

7. Using the calculated valve flow coefficients from problem 6A above and the valve flow coefficient curve shown in Figure 2, estimate the valve position for the 8-inch V-port ball valve for Conditions A and B.

Condition A (126 l/s)

Condition B (200 l/s)

8. If the artificial head losses across the control valve could be eliminated, what would the PSAT optimization ratings and calculated potential energy savings be?

	Optimization rating	Potential annual savings
Condition A (126 l/s)		
Condition B (200 l/s)		

The required pump head for the two conditions (using the pressure downstream of the control valve) is recalculated. Replacing the original head values with the above required values yields the Optimization ratings and Potential annual savings above.

Questions

9. What would the system curve look like if the control valve were replaced with a full port ball valve or gate valve and an adjustable speed drive was used to regulate flow? Assume that the replacement valve losses are so low that they can be ignored altogether (a valid assumption, by the way).

10. Assuming that you or management conclude that it is worth pursuing, what would be your next step(s), and what options would you consider in your efforts to find ways to reduce the energy cost?

Worked Results

Answers

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1. For Conditions A and B of Table 1, estimate the actual pump head. You are encouraged to use PSAT2004's built-in pump head calculator.

Condition A:	126 l/s	62.2 m
Condition B:	200 l/s	52.3 m

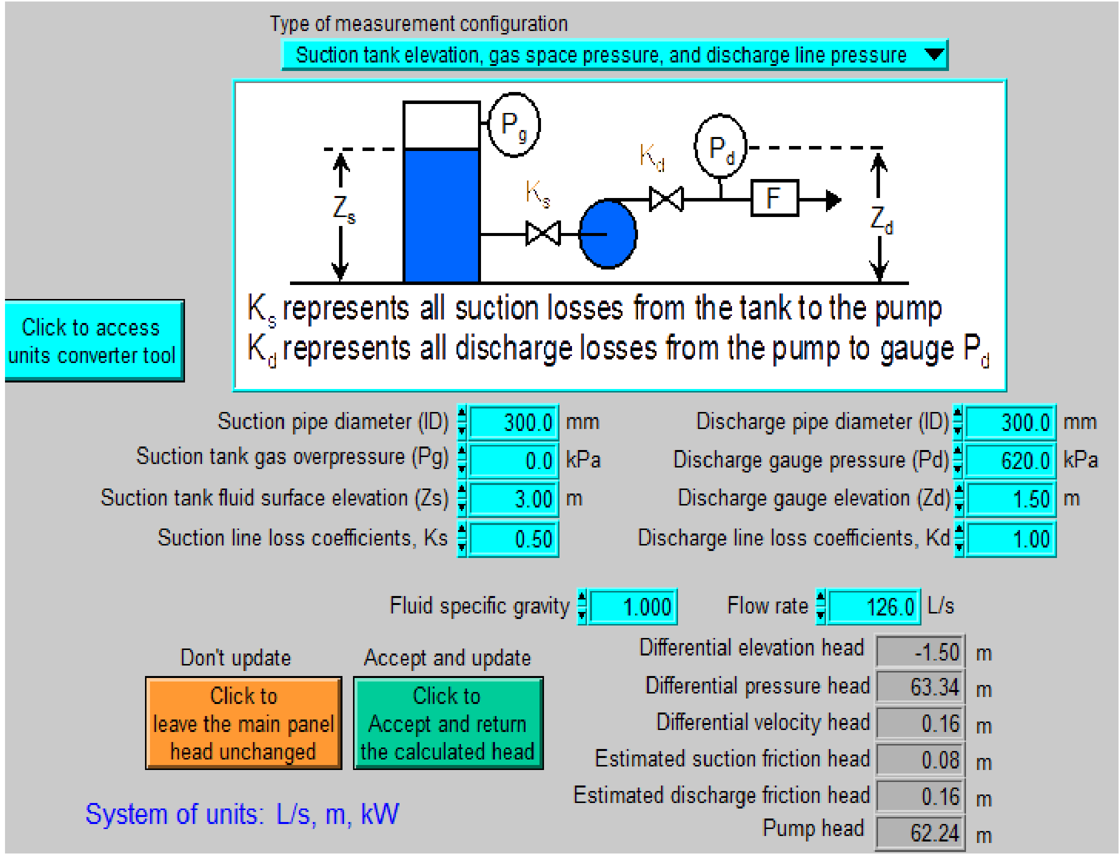
(assumed 0.5 loss K to account for the tank entrance and 1.0 loss K for check valve. See Fig A1)

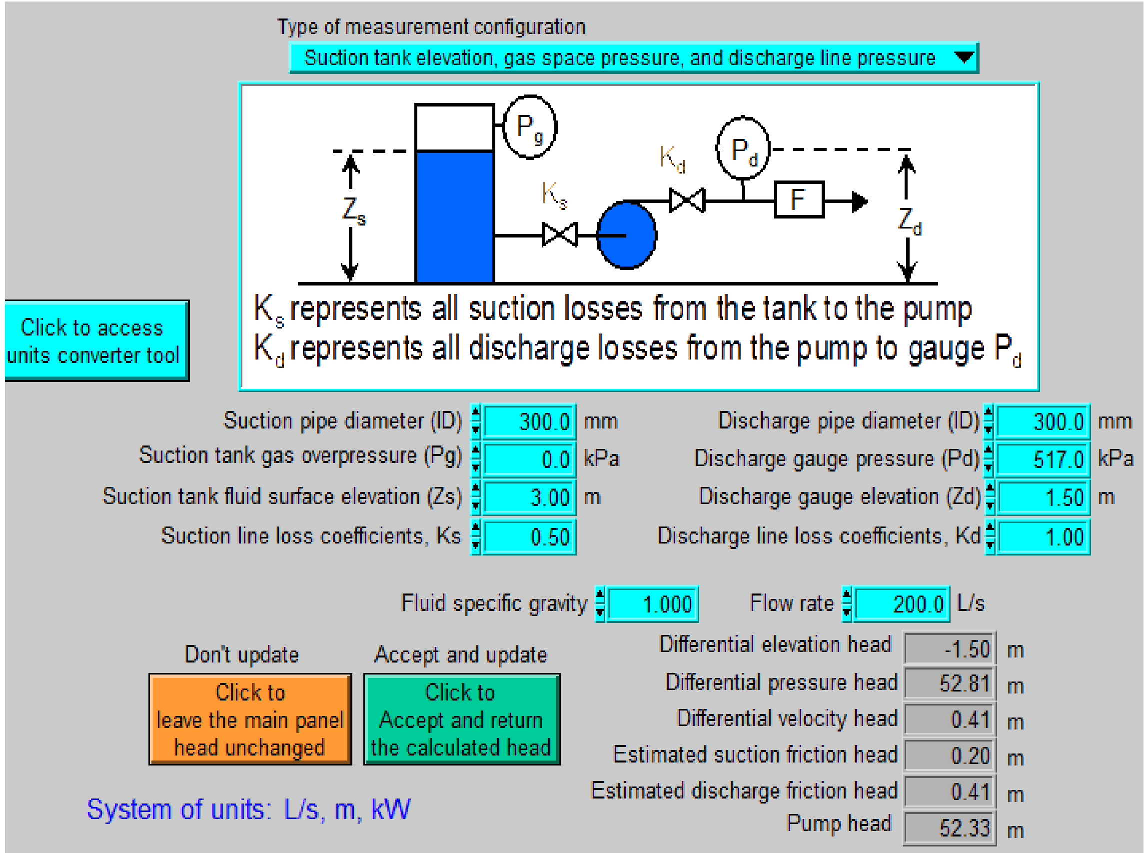
2. Use the PSAT program to calculate Optimization ratings and annual energy costs of operation for the two conditions.

		Optimization rating	Annual energy cost
Condition A:	126 l/s	70.0	$ 71 000
Condition B:	200 l/s	81.1	$ 39 800

(see Fig A2)

Pump Head Calculations





PSAT Analysis for Both Sets

		Condition A	Condition B
Pump, fluid	Pump type	End suction ANSI/API	End suction ANSI/API
	Pump rpm	1480	1480
	Drive	Direct drive	Direct drive
	Units	L/s, m, kW	L/s, m, kW
	Kinematic viscosity (cS)	1.00	1.00
	Specific gravity	1.000	1.000
	# stages	1	1
	Fixed specific speed?	YES	YES
Motor	Line freq.	50 Hz	50 Hz
	kW	200	200
	Motor rpm	1480	1480
	Eff. class	Specified (below)	Specified (below)
	FL efficiency, %	95.8	95.8
	Voltage	400	400
	Estimate FLA		
	Full-load amps	347.1	347.1
	Size margin, %	0	0
Duty, unit cost	Operating fraction	0.500	0.400
	$/kwhr	0.4000	0.4000
Field data	Flow rate, L/s	126	200
	Head tool / Head, m	62.2	52.3
	Load estim. method	Power	Power
	Motor kW	135.0	150.0
	Voltage	400	400

Retrieve defaults | Set defaults | Copy A > to B > | Copy B < to A < | Background information | STOP

System curve tool: select below

	Condition A Existing	Condition A Optimal	Units	Condition B Existing	Condition B Optimal	Units
Pump efficiency	59.5	85.1	%	71.3	88.1	%
Motor rated power	200	110	kW	200	132	kW
Motor shaft power	129.2	90.3	kW	143.7	116.4	kW
Pump shaft power	129.2	90.3	kW	143.7	116.4	kW
Motor efficiency	95.7	95.5	%	95.8	95.7	%
Motor power factor	83.3	85.5	%	84.6	86.1	%
Motor current	234.0	159.5	amps	256.0	204.0	amps
Motor power	135.0	94.5	kW	150.0	121.6	kW
Annual energy	591.3	413.8	MWh	525.6	426.2	MWh
Annual cost	236.5	165.5	$1000	210.2	170.5	$1000
Annual savings potential, $1,000		71.0			39.8	
Optimization rating, %		70.0			81.1	

Log file controls: Create new log | Add to existing log | Retrieve log entry | Delete log entry

Summary file controls: Create new summary file

Existing summary files: CREATE NEW

Condition A Notes — Documentation section

Facility | System | Date
Application | Evaluator
General comments

Condition B Notes

Facility | System | Date
Application | Evaluator
General comments

Answers

3. What is the static head for this system?

30 m – 3 m = 27 m

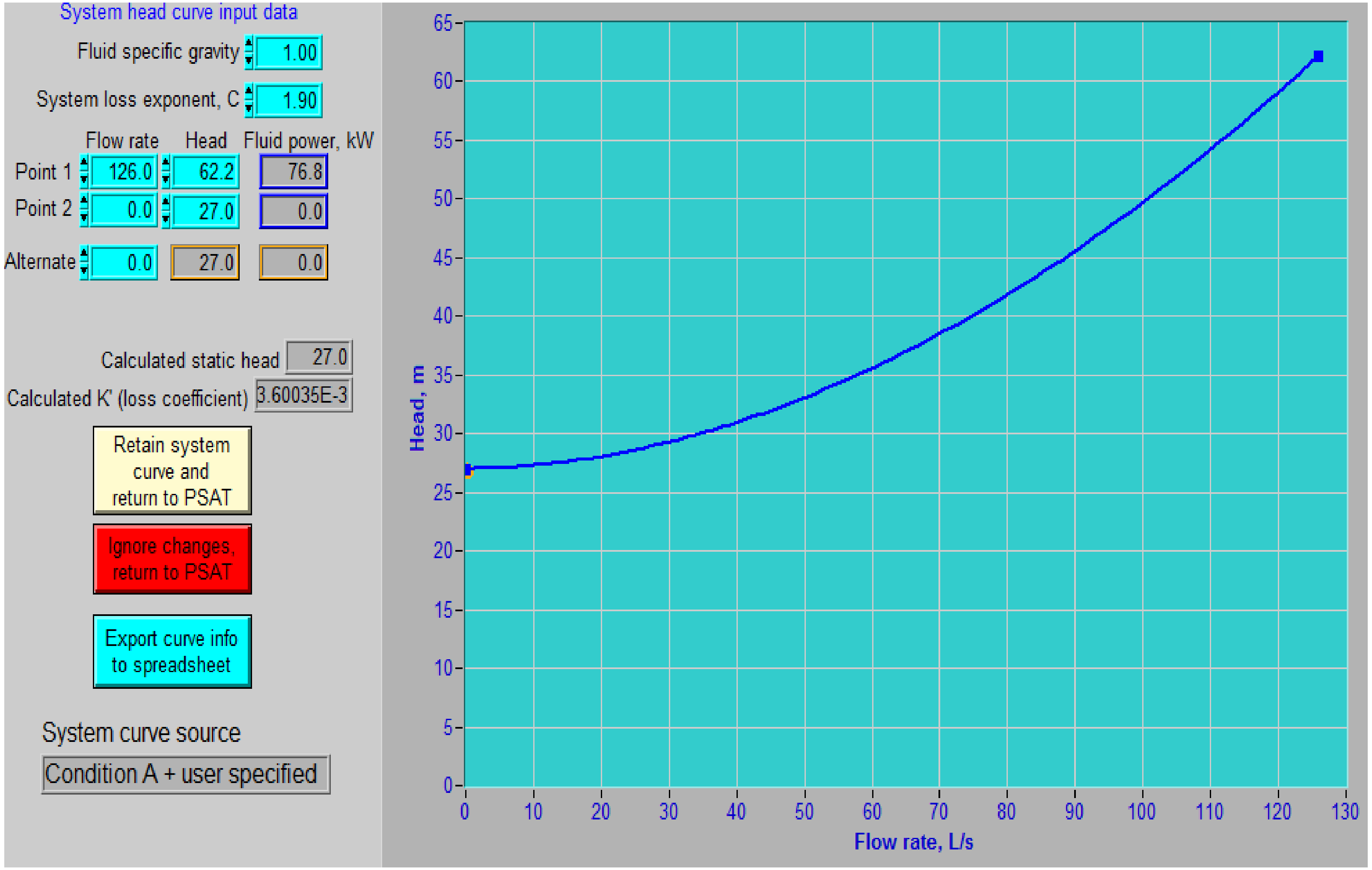
4. What pressure would you expect at P1 with the pump off (see in Table 1)?

28.5 m x (9.8/s.g.) kPa/m = 279 kPa

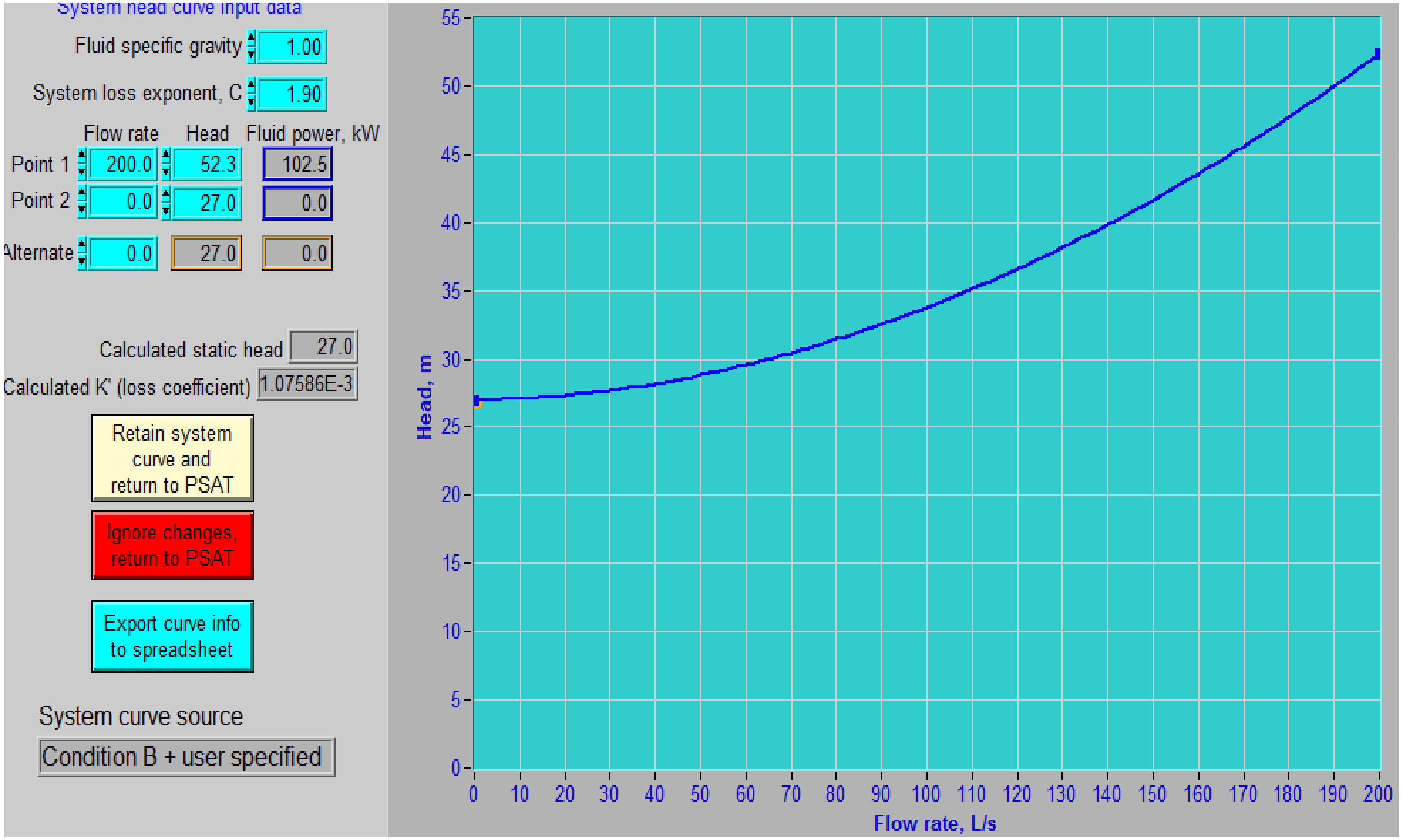
5. Using the system curve calculator built into PSAT2004, develop system curves based on the static head and the Condition A and B flow and head points of Table 1.

NOTE: You will have to develop two different curves, since the control valve V1 position (and associated loss) changes for the two flow conditions.

System Curves: Condition A



System Curves: Condition B



Answers

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6. Valve V1-related calculations:

A. Using the Valve Tool included with PSAT2004, calculate the valve flow coefficient for Conditions A and B.

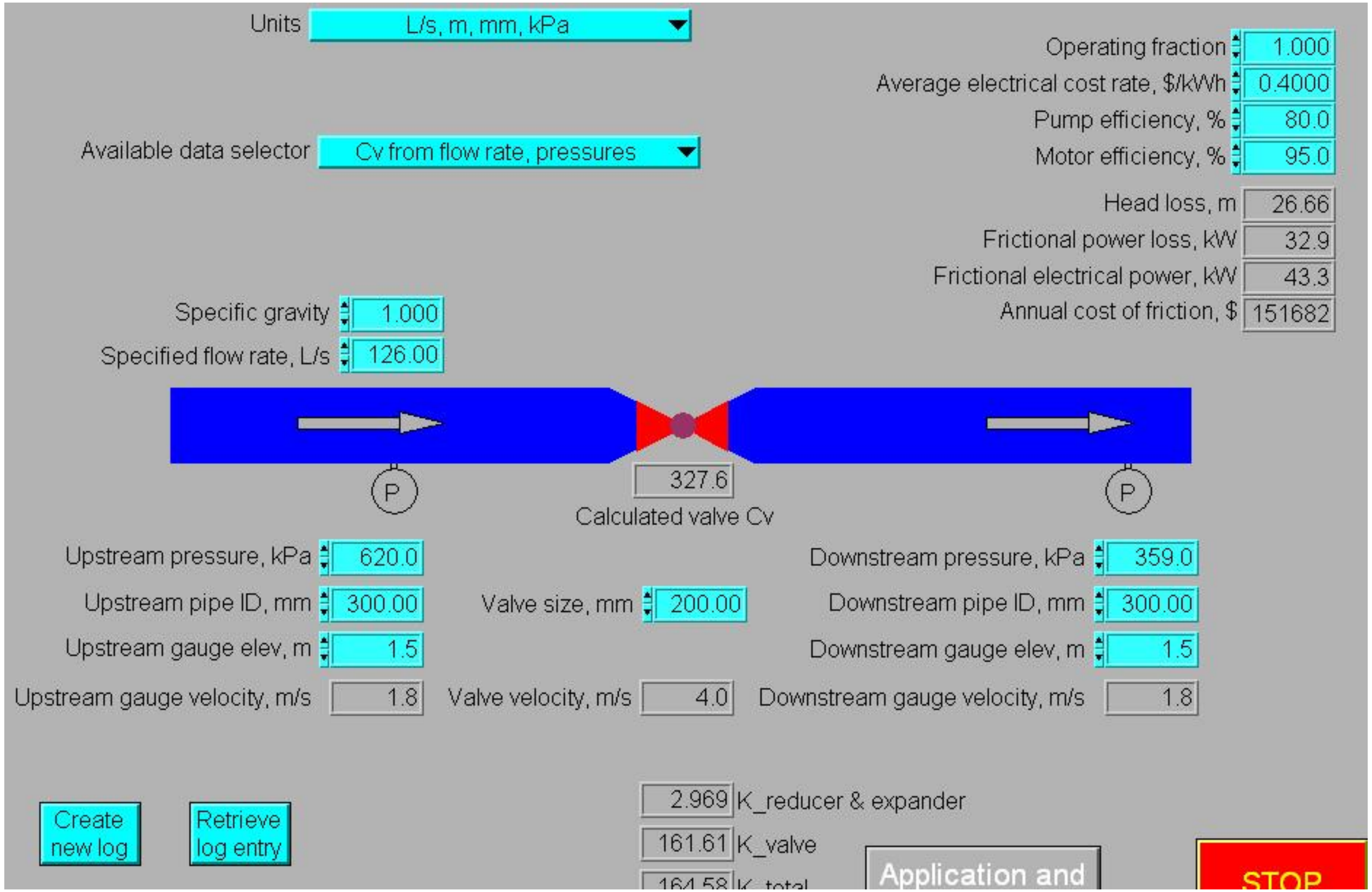
Condition A (126 l/s)	327
Condition B (200 l/s)	1176

B. Assume that the pump efficiency is 80% and the motor efficiency is 95%. What are the estimated power losses (kW) and the annual costs of the friction from valve V1 for the two operating conditions (use the valve equations tool)? (operating fraction = 1.0)

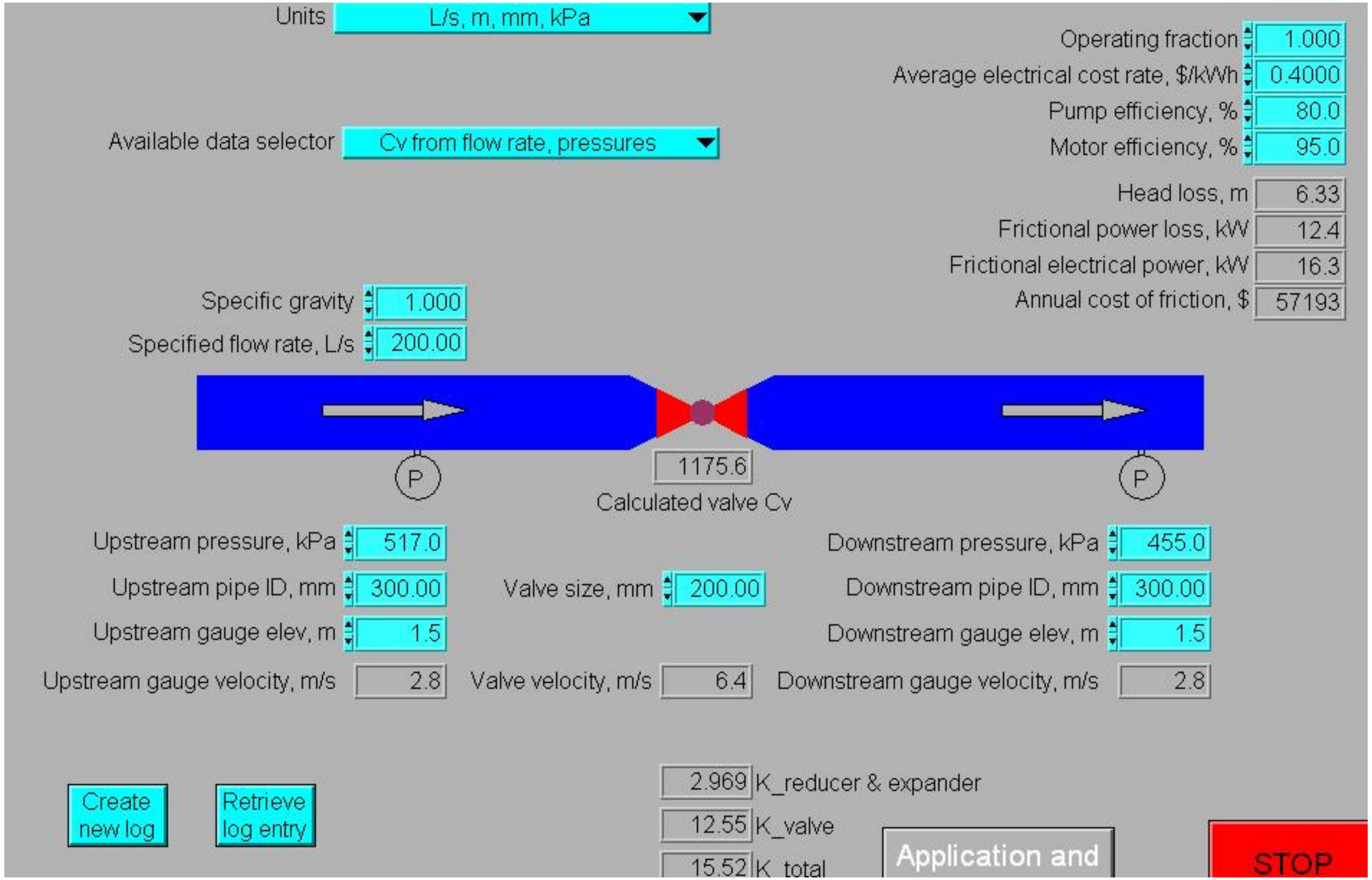
Condition A (126 l/s)	$ 151,682 /yr	32.9 fluid kW
Condition B (200 l/s)	$ 57,193 /yr	12.4 fluid kW

C. Perform a screen capture of the valve equations sheet and paste it into a Word, Powerpoint, or other document to be returned to the instructor

Valve Tool: Low Flow Condition



Valve Tool: High Flow Condition



7. Using the calculated valve flow coefficients from problem 6A above and the valve flow coefficient curve shown in Figure 2, estimate the valve position for the 8-inch V-port ball valve for Conditions A and B.

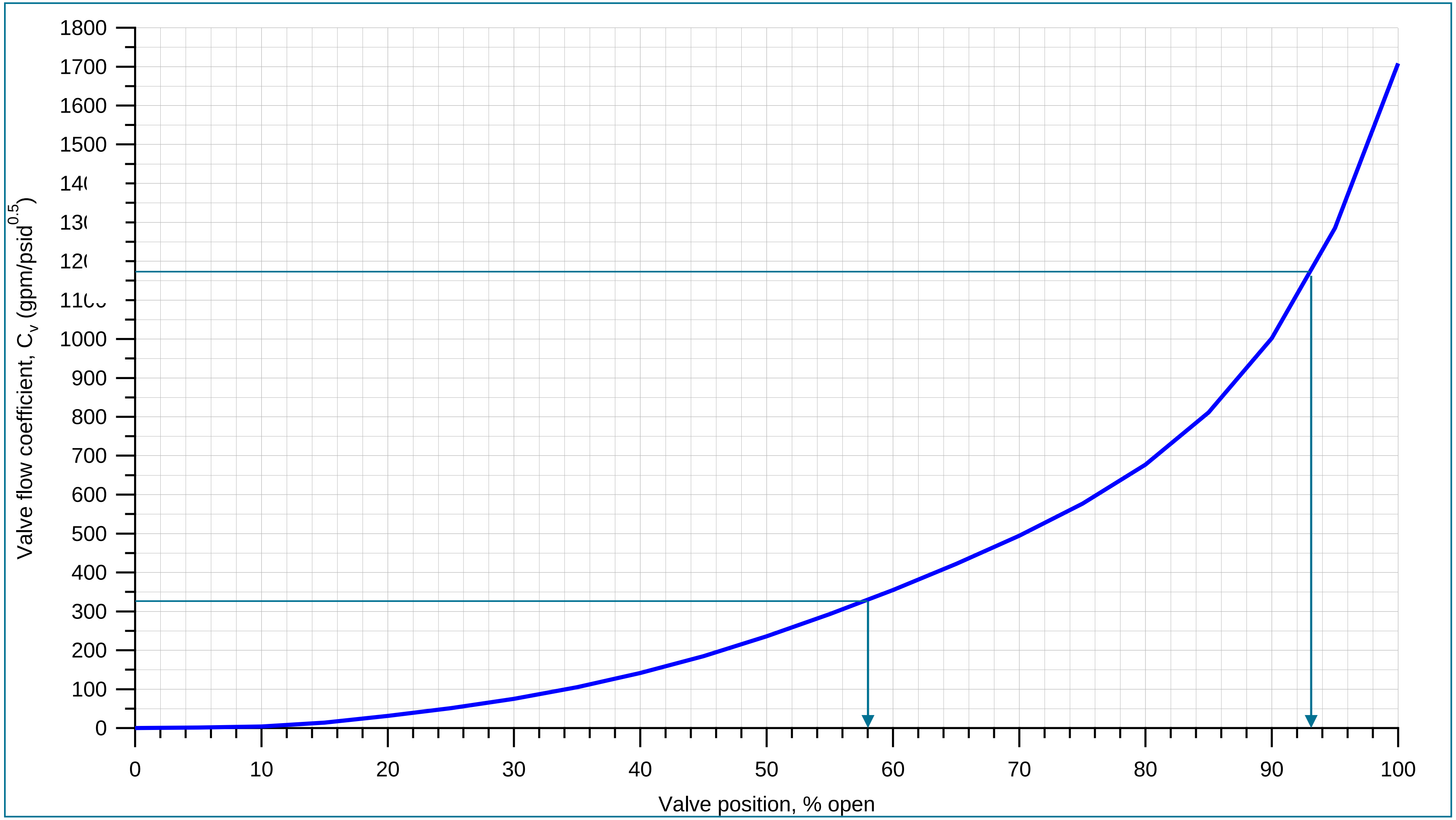
Condition A (126 l/s)	58 % open
Condition B (200 l/s)	93 % open

8. If the artificial head losses across the control valve could be eliminated, what would the PSAT optimization ratings and calculated potential energy savings be?

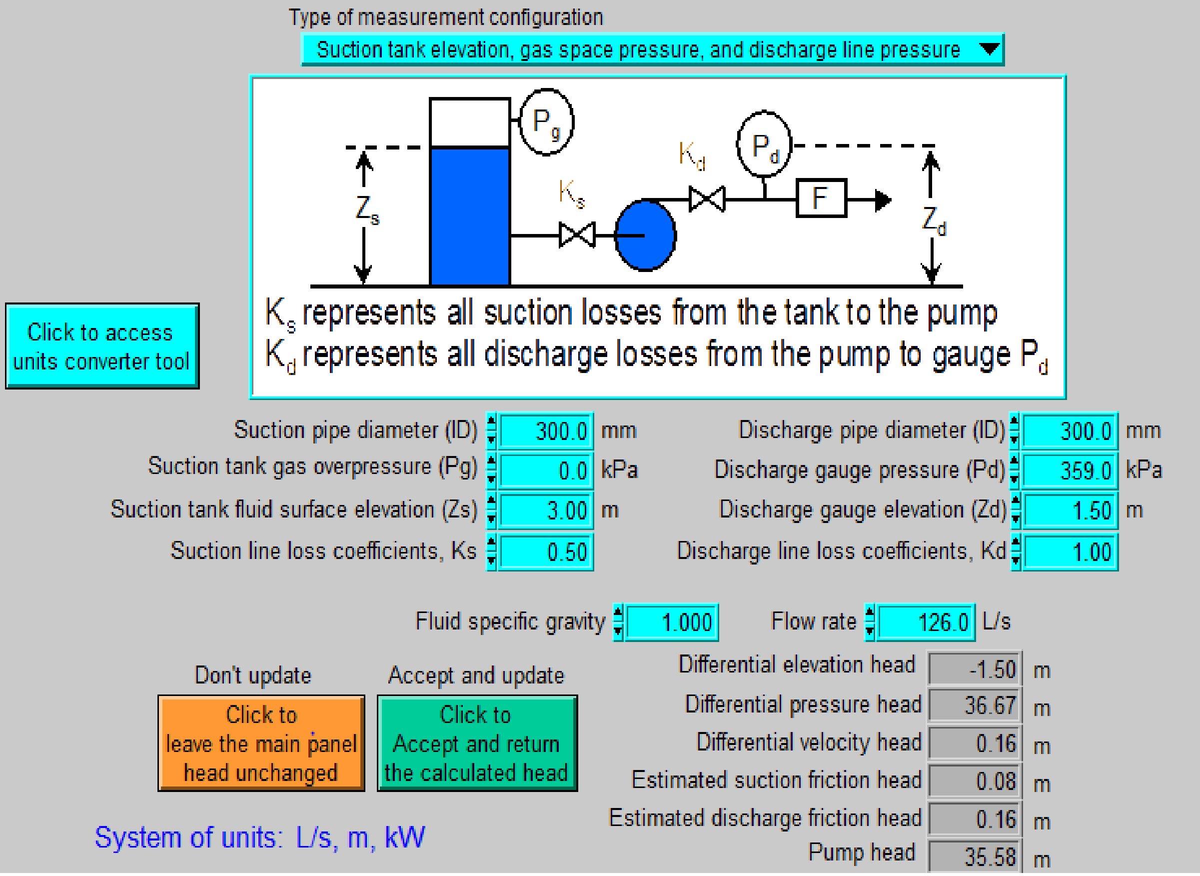
	Optimization rating	Potential annual savings
Condition A (126 l/s)	39.6	$ 142,900
Condition B (200 l/s)	71.3	$ 60,400

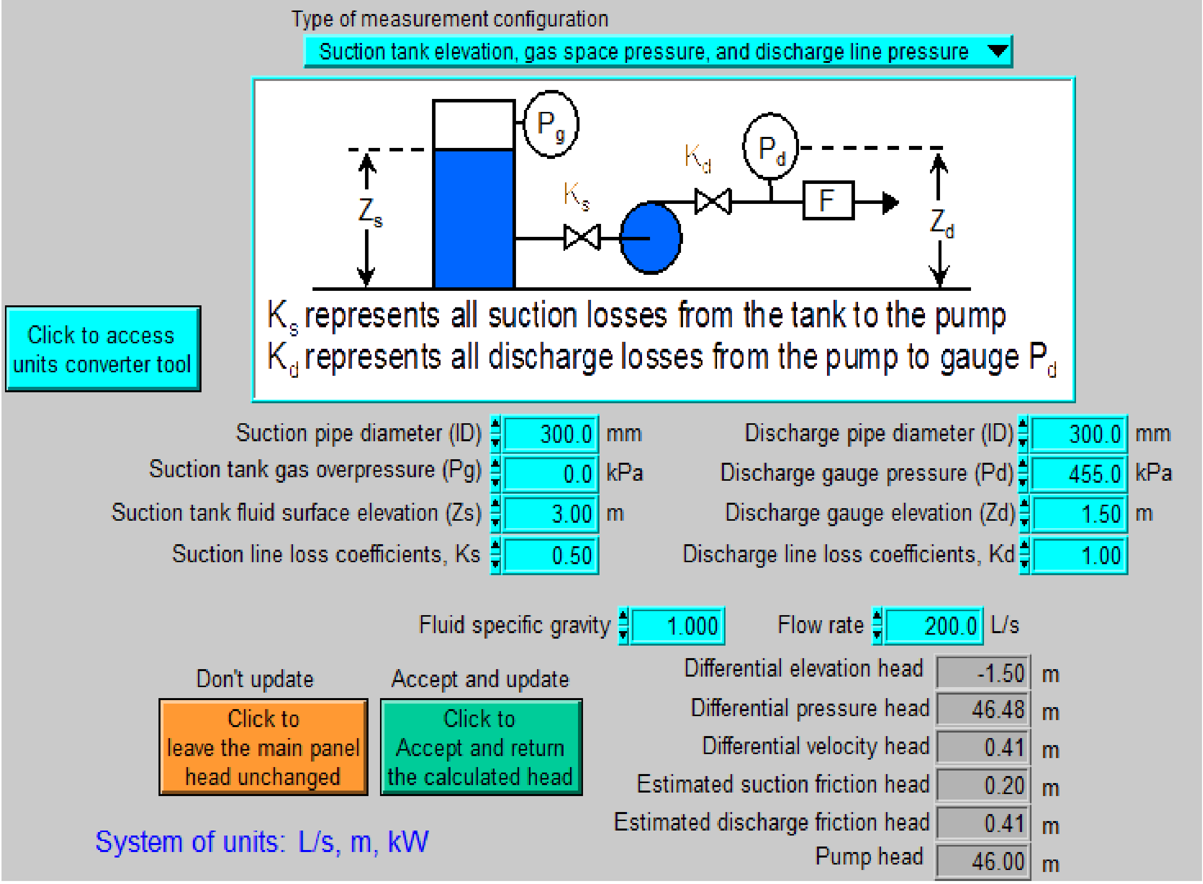
The required pump head for the two conditions (using the pressure downstream of the control valve) is recalculated. Replacing the original head values with the above required values yields the Optimization ratings and Potential annual savings above.

Valve Position Estimation



Calculations for Required Pump Head





PSAT for Required Head Conditions

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	Condition A	Condition B
Pump type	End suction ANSI/API	End suction ANSI/API
Pump rpm	1480	1480
Drive	Direct drive	Direct drive
Units	L/s, m, kW	L/s, m, kW
Kinematic viscosity (cS)	1.00	1.00
Specific gravity	1.000	1.000
# stages	1	1
Fixed specific speed?	YES	YES
Line freq.	50 Hz	50 Hz
kW	200	200
Motor rpm	1480	1480
Eff. class	Specified (below)	Specified (below)
FL efficiency, %	95.8	95.8
Voltage	400	400
	Estimate FLA	Estimate FLA
Full-load amps	346.9	346.9
Size margin,%	0	0
Operating fraction	0.500	0.400
$/kwhr	0.4000	0.4000
Flow rate, L/s	126	200
Head, m (Head tool)	35.6	46.0
Load estim. method	Power	Power
Motor kW	135.0	150.0
Voltage	400	400

Retrieve defaults | Set defaults | Copy A > to B > | Copy B < to A < | Background information | STOP

System curve tool: select below

	Condition A Existing	Condition A Optimal	Units	Condition B Existing	Condition B Optimal	Units
Pump efficiency	34.0	86.9	%	62.7	88.3	%
Motor rated power	200	55	kW	200	110	kW
Motor shaft power	129.2	50.5	kW	143.7	102.1	kW
Pump shaft power	129.2	50.5	kW	143.7	102.1	kW
Motor efficiency	95.7	94.6	%	95.8	95.5	%
Motor power factor	83.3	85.9	%	84.6	86.3	%
Motor current	233.8	89.7	amps	255.9	178.7	amps
Motor power	135.0	53.4	kW	150.0	106.9	kW
Annual energy	591.3	233.9	MWh	525.6	374.5	MWh
Annual cost	236.5	93.6	$1000	210.2	149.8	$1000
Annual savings potential, $1,000		142.9			60.4	
Optimization rating, %		39.6			71.3	

Log file controls: Create new log | Add to existing log | Retrieve log entry | Delete log entry

Summary file controls: Create new summary file

Existing summary files: CREATE NEW

Documentation section

Condition A Notes

Facility | System | Date

Application | Evaluator

General comments

Condition B Notes

Facility | System | Date

Application | Evaluator

General comments

UNIDO | INDUSTRIAL MODERNISATION CENTRE | gef www.theGEF.org

Answers

9. What would the system curve look like if the control valve were replaced with a full port ball valve or gate valve and an adjustable speed drive was used to regulate flow? Assume that the replacement valve losses are so low that they can be ignored altogether (a valid assumption, by the way).

   The system curve is shown in the following diagram, based on the static head and the required head at 200 l/s. Note that the estimated head at 126 l/s varies a bit with the friction exponent used.

10. Assuming that you or management conclude that it is worth pursuing, what would be your next step(s), and what options would you consider in your efforts to find ways to reduce the energy cost?

    Verify measured = required (heat load consideration); get pump curves and compare measured data with curves; check physical layout for possible addition of a second pump and/or VFD. Evaluate potential for a slight trim on the existing impeller.

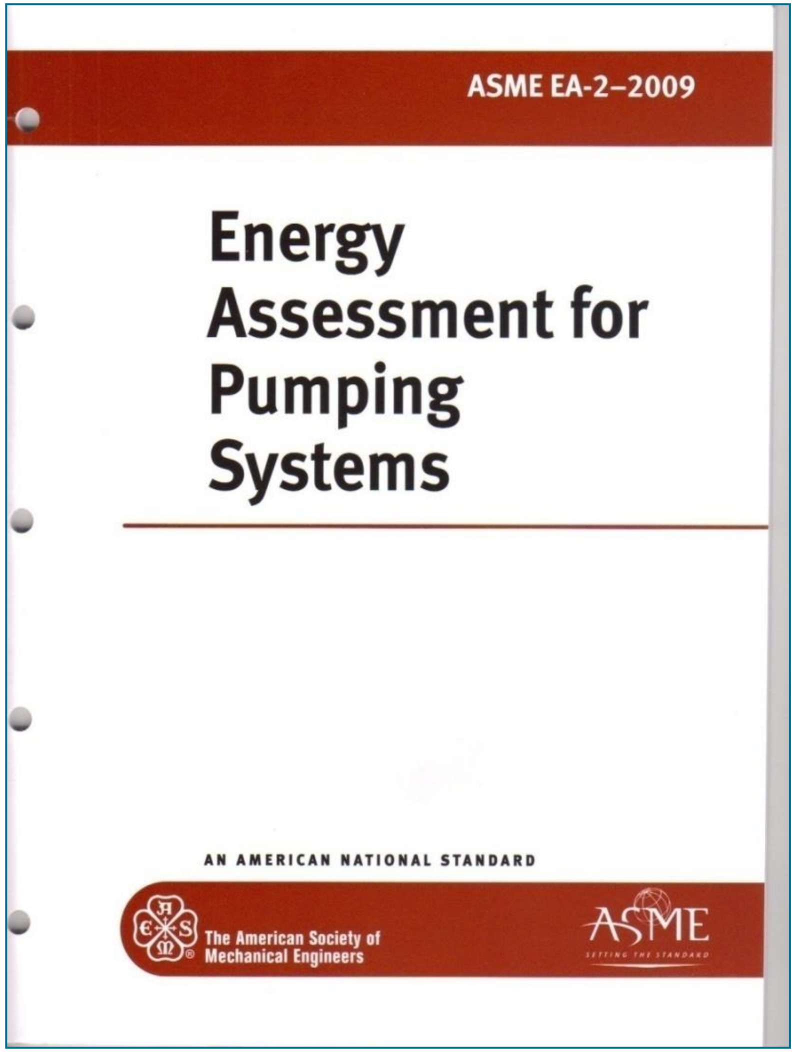
10. ASME Standards & Guides

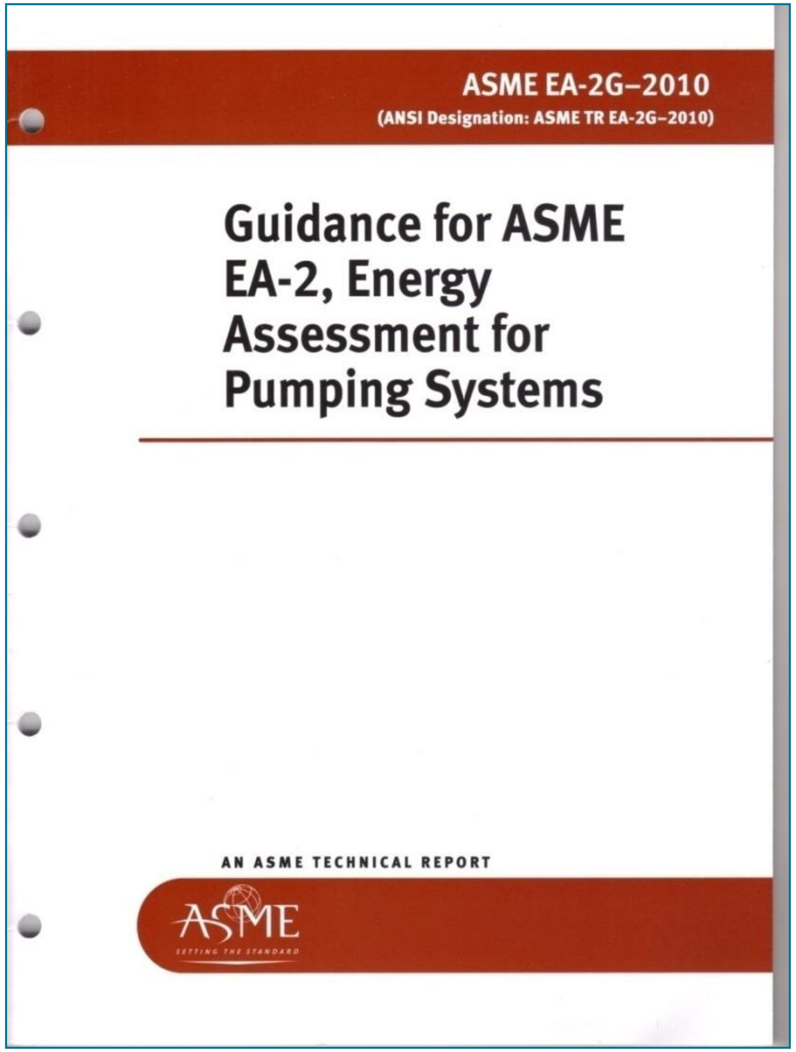
Pump System Assessment

Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

ASME Standards & Guides





Standard vs Guide

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 Documents

- 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

Organising the Assessment

ASME EA 2 2009 – Chapter 4

Organising 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.*

Organising the Assessment

BEFORE ARRIVING ON SITE & 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)

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

4.6 Initial Data Collection and Evaluation

Before Arriving on Site

Obtain energy ***use and cost data*** to determine unit costs

Save ENERGY Now — *SAVE ENERGY NOW* PRE-ASSESSMENT SURVEY FORM — U.S. DEPARTMENT OF ENERGY

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

Organising the Assessment

AS PART ON INITIAL PLANT TOUR

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

Organising 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.

INITIAL DATA COLLECTION & EVALUATION

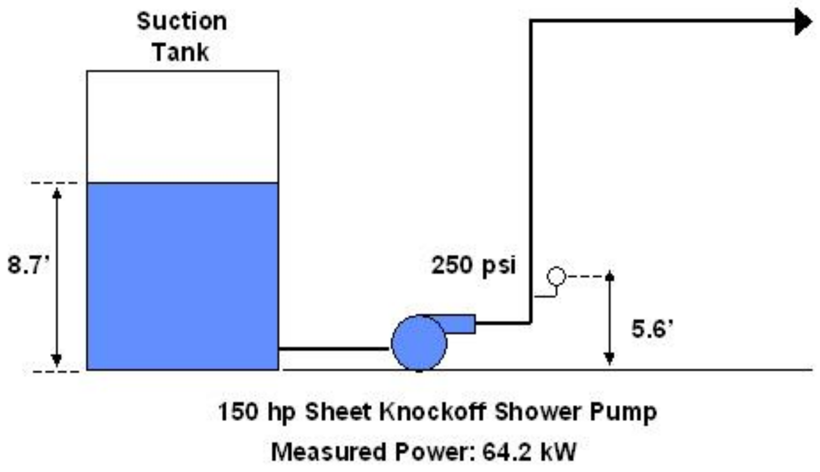
Paper Mill Spray Pump Example:

- 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.

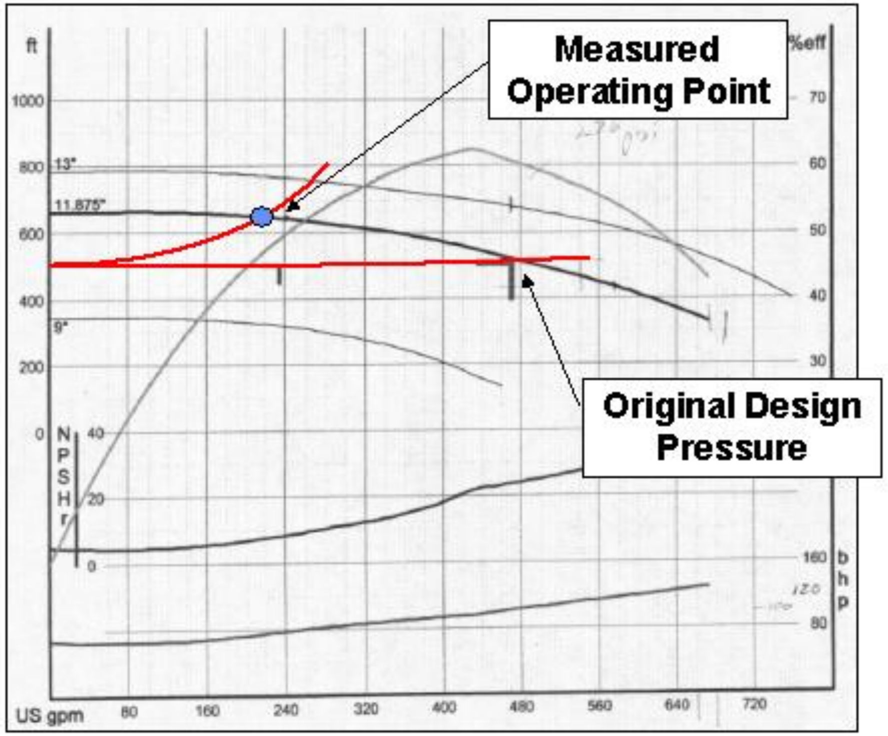
***Normally we would move on to the next pump, but there was an existing pressure tap (reading 250 psi) and straight pipe for a flow measurement*.**

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



DEVELOP AN ACTION PLAN

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

Conducting the Assessment

ASME EA 2 2009 – Chapter 5

Conducting the Assessment (Ch 5)

Egyptian program for promoting Industrial Motor Efficiency
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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

- ***Level #1***

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

- ***Level #2***

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

- ***Level #3***

  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

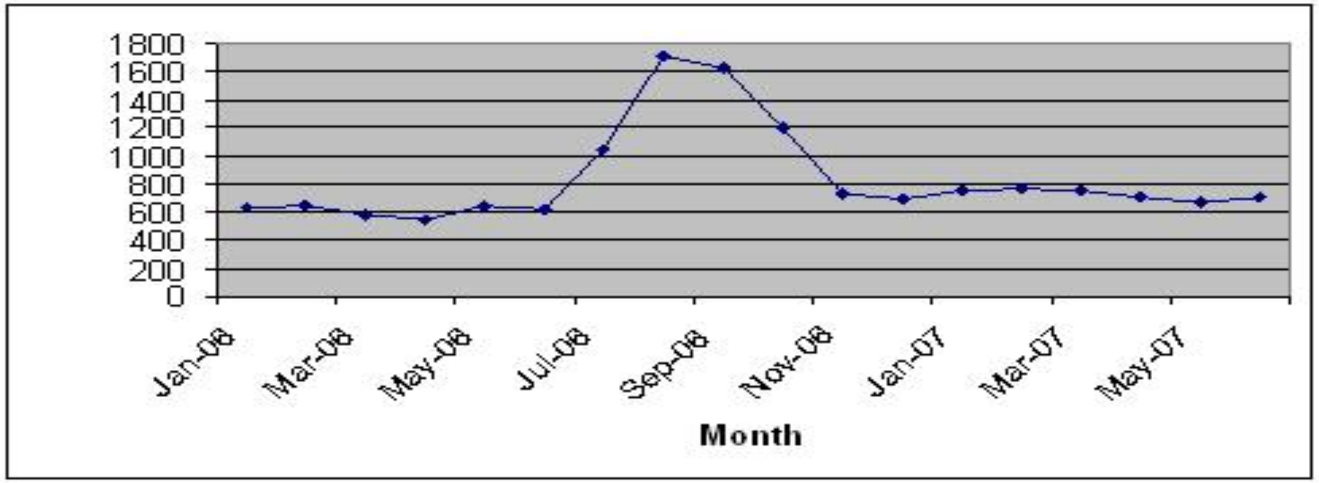
- Determine if changes will affect other systems and constrain optimization options.
- Collect Level 1 required data.

Level 2 Assessments

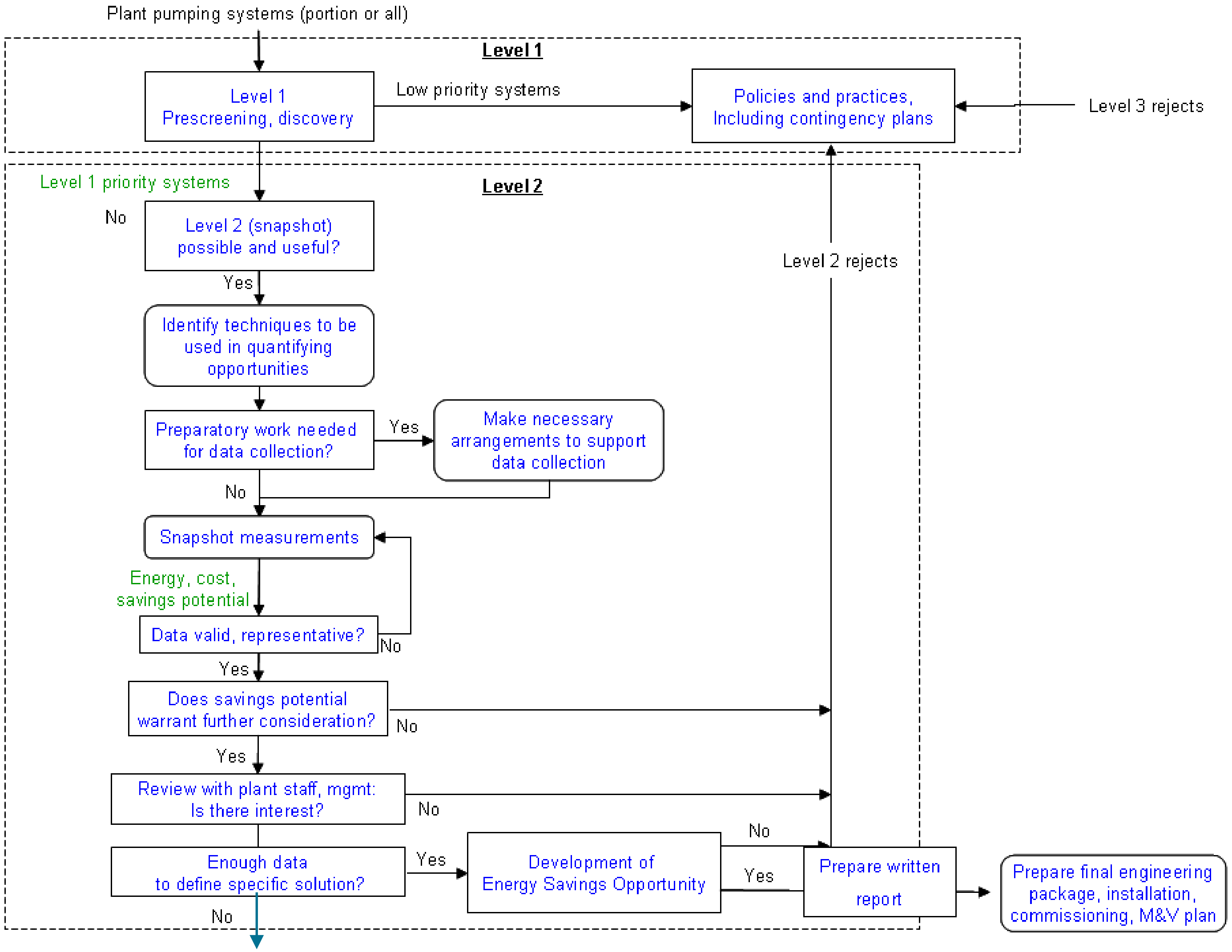
- Level 2 assessment performed using measurements of system variables from digital or paper records (operating logs, trend charts, DCS screens, etc.) or portable measuring instruments.
- Measurements taken over a limited time frame and provide a snapshot of the operating conditions.
- Observed data is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

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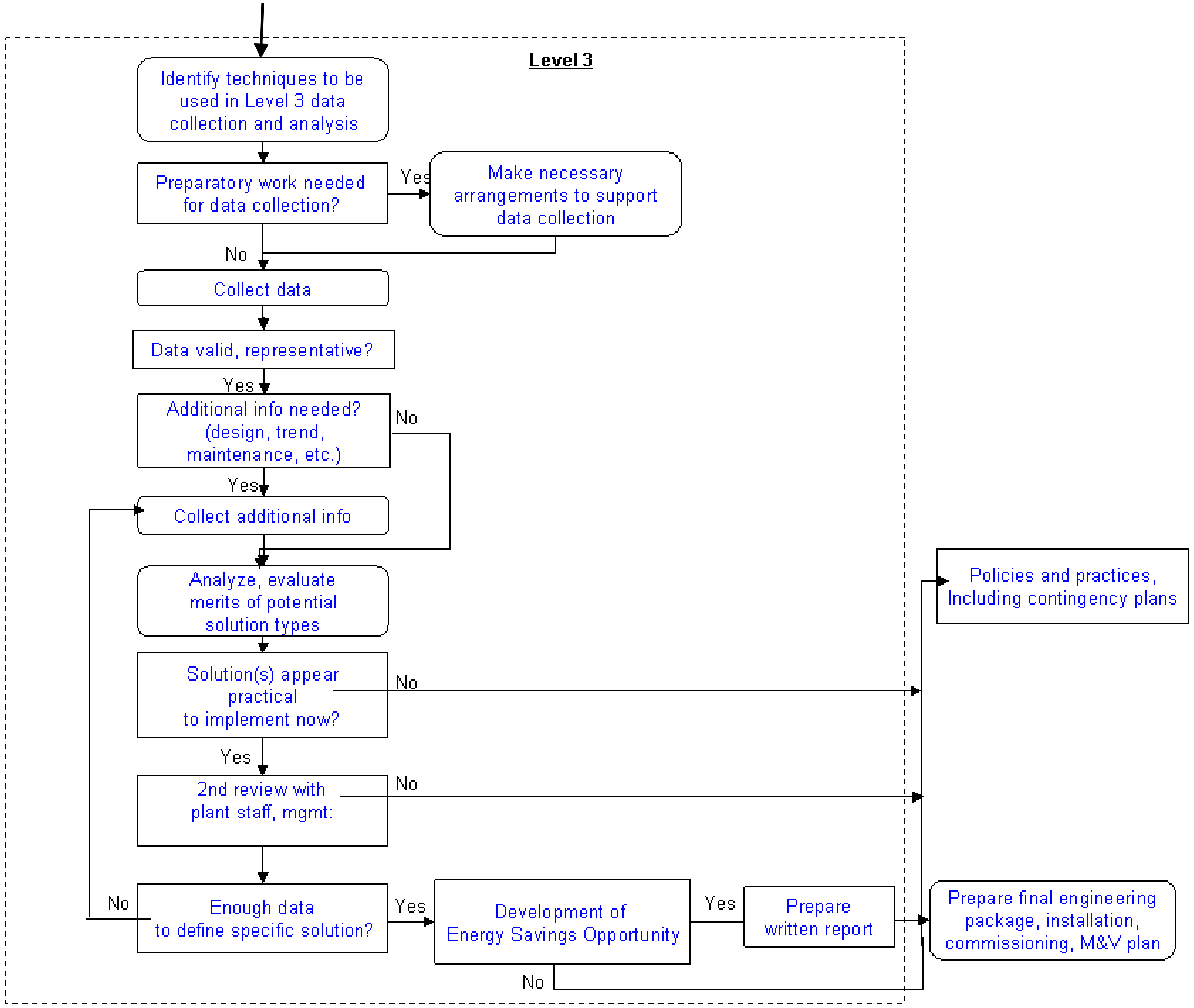
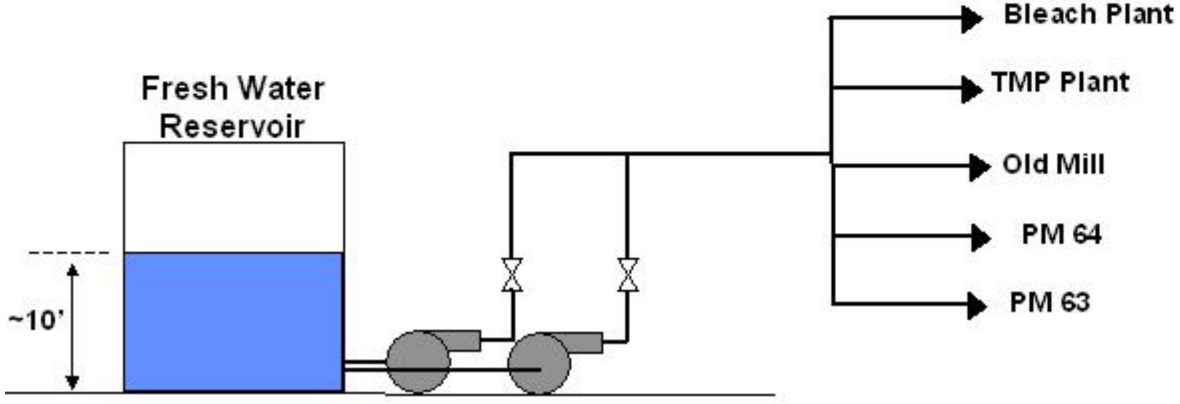


System Walk Through

- 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

Example #1: What assessment level is applicable here?

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?

Example #1

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

Example #2:

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?

Measurement Plan Questions

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Example #2 Sample Questions

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.

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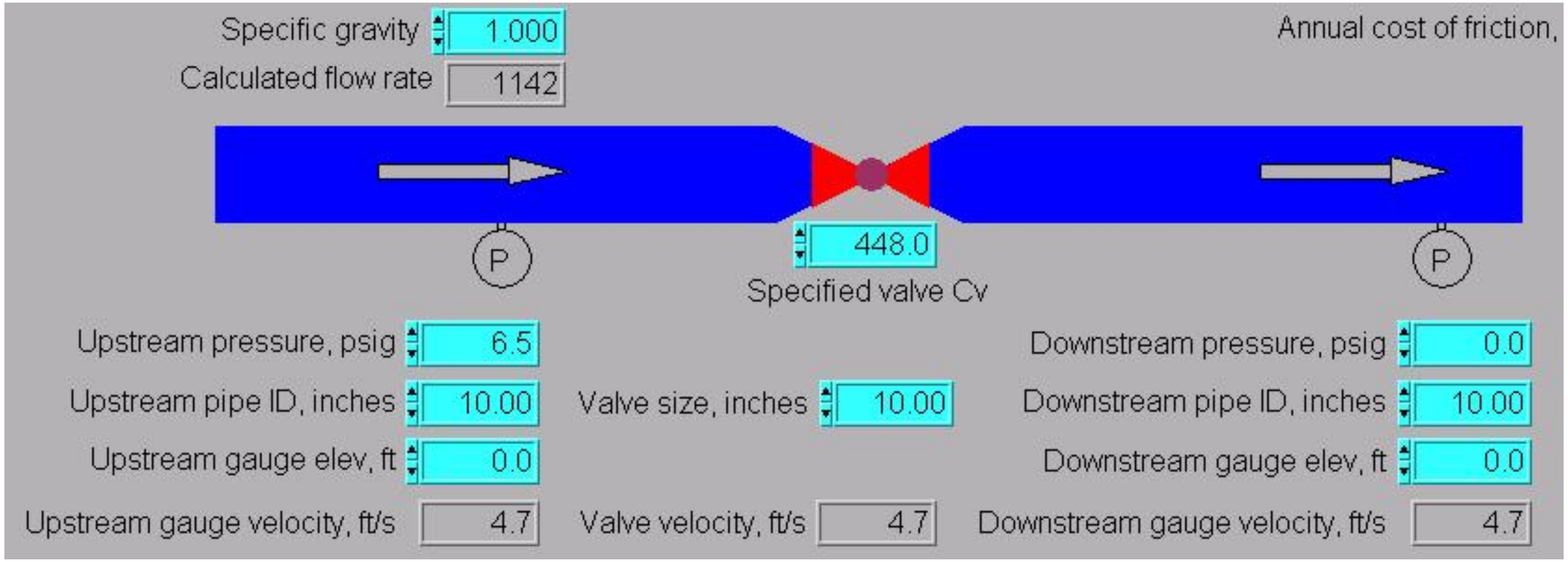
Example #2 Questions

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.



From Valve Tool

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.

11. Data Collection & Analysis

Pump System Assessment

Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

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

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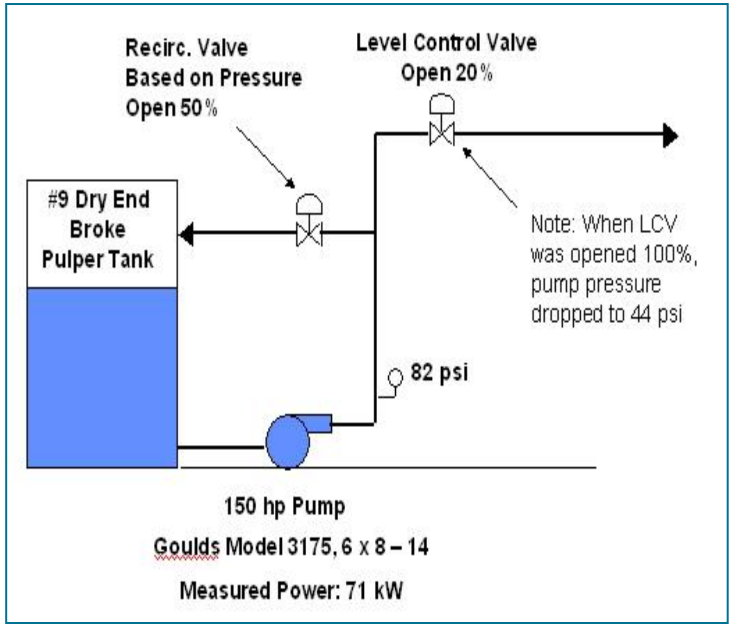
Tester		Date		Time	
Facility		System		Parallel Pumps Running:	

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)

Obtain the Pump Curve

- 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

NOTE: 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 installation in the field.

Pump Curve with Impeller Trims

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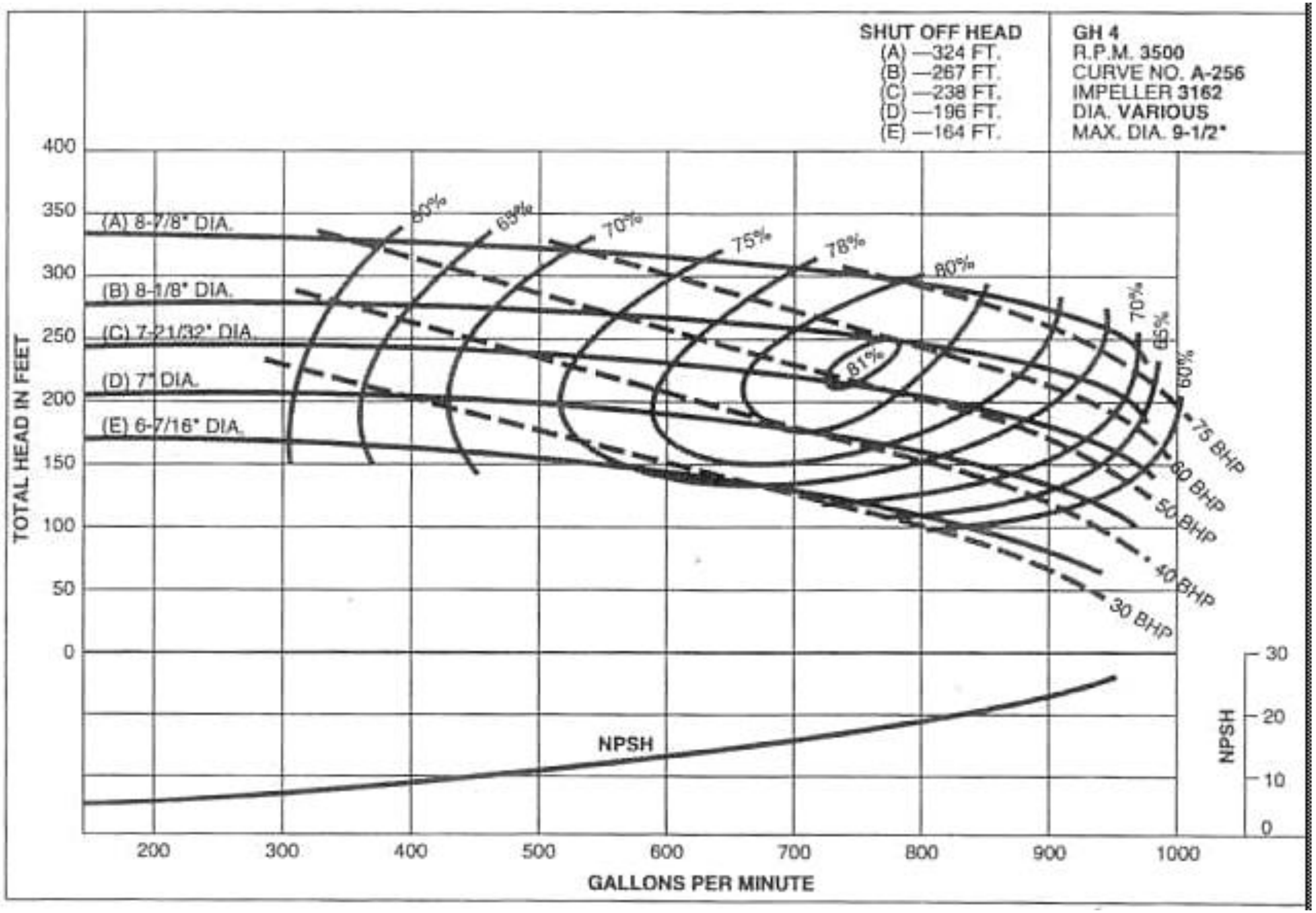
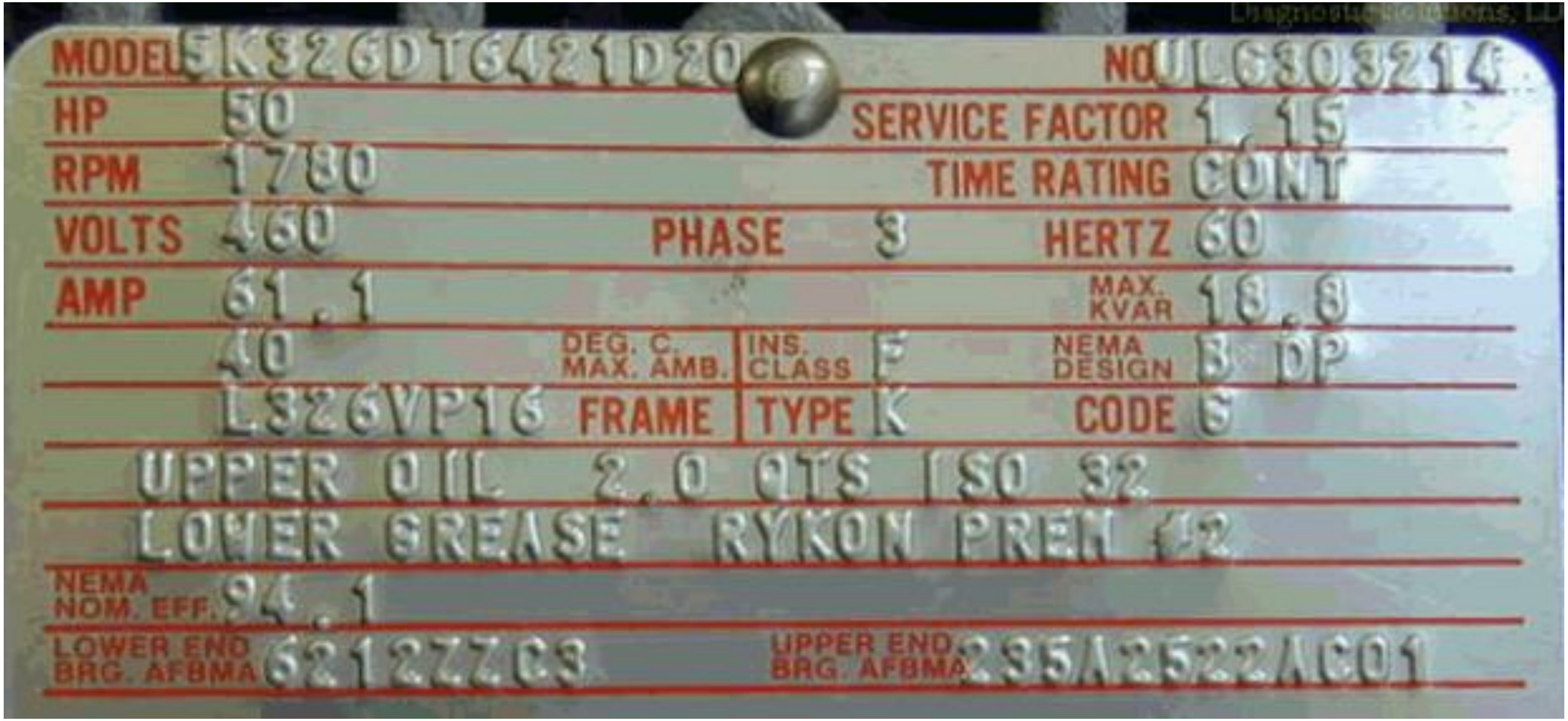


Figure Courtesy of ACR Publications

Motor Nameplate



Pump Nameplate

Nameplate speed here (1 800 rpm) is **NOT** consistent with flow rate and head, it is the ***nominal*** synchronous speed

12. Measuring Flow, Pressure and Head

Pump Assessments

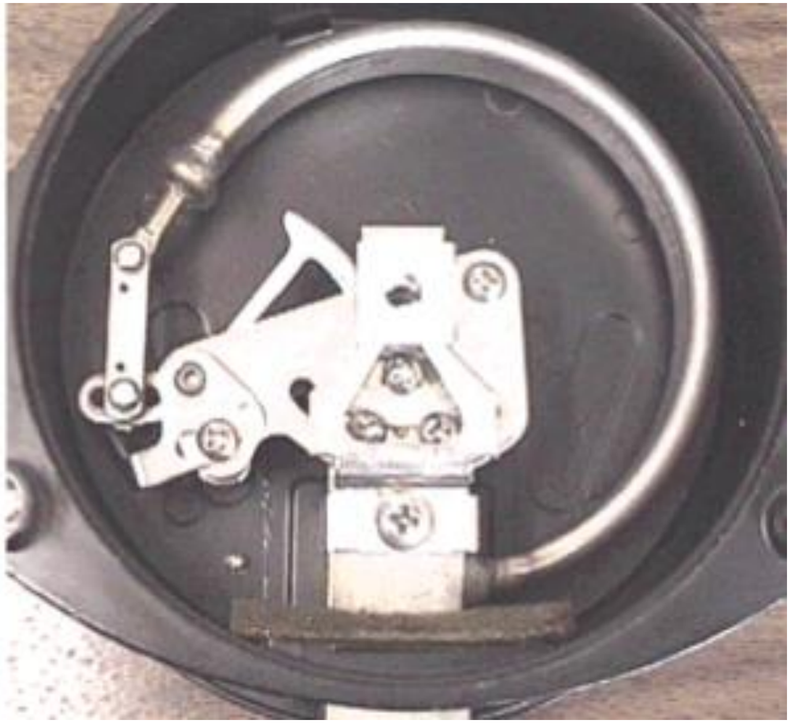
Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

Measuring
Flow, Pressure and Head

Pressure Indicators

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



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

Errors in Reading

What do you think the system pressure is?

(note the angle from which the picture is taken)

What accuracy is required?

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

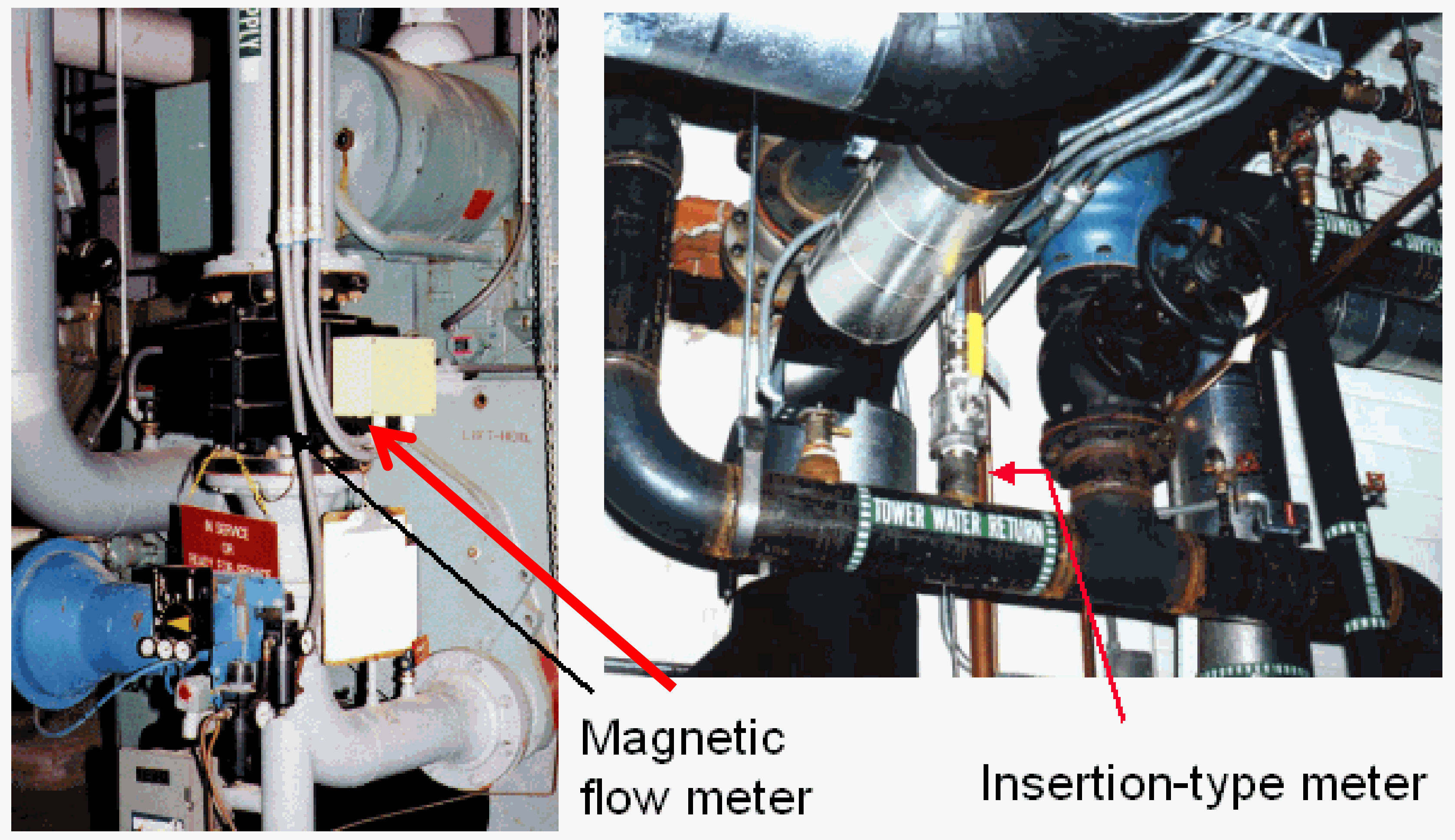
Types of Flow Meters

- 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

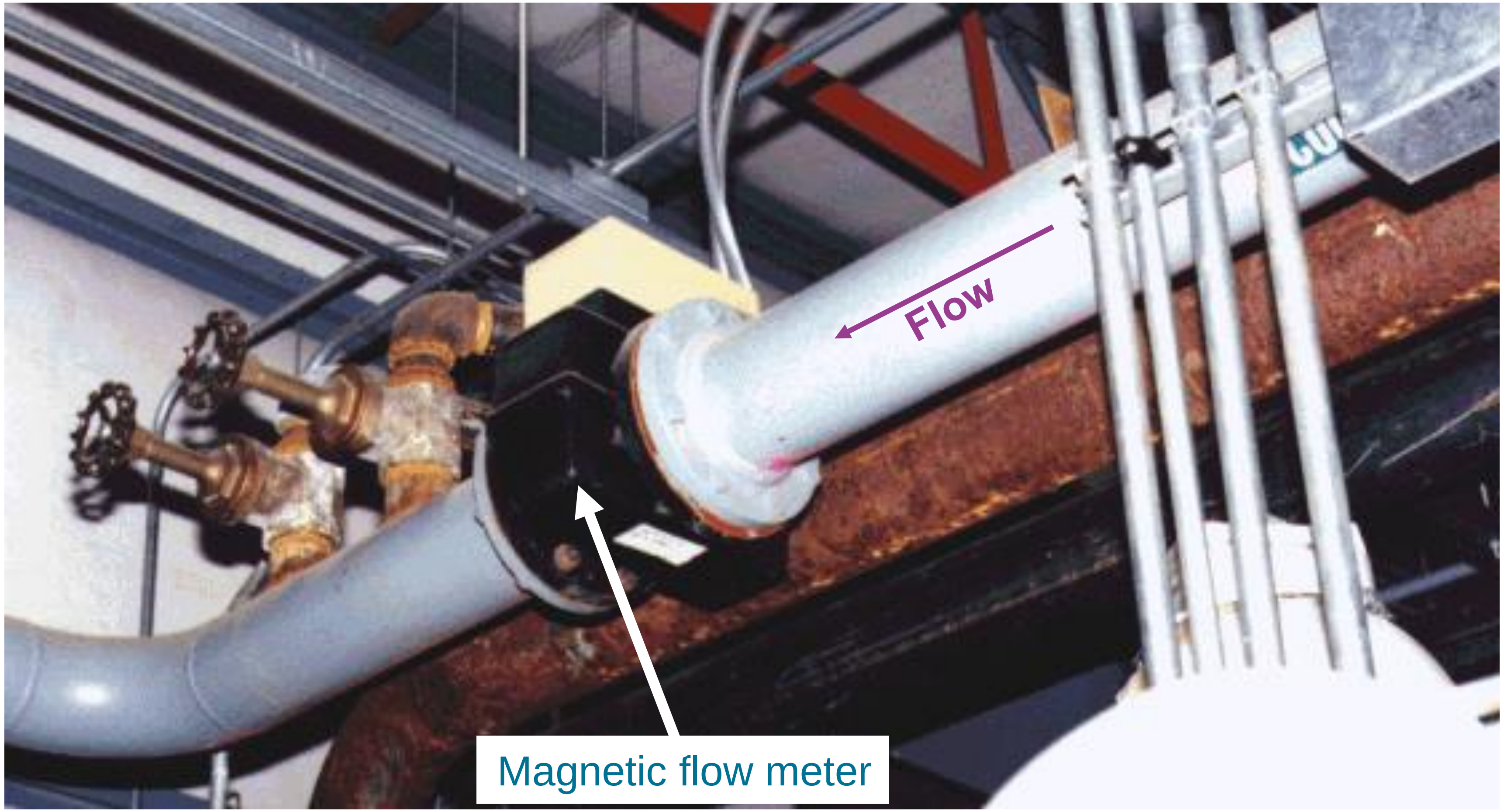
Important Flow Meter Considerations

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

Typical meter installation configurations...



A Better Configuration



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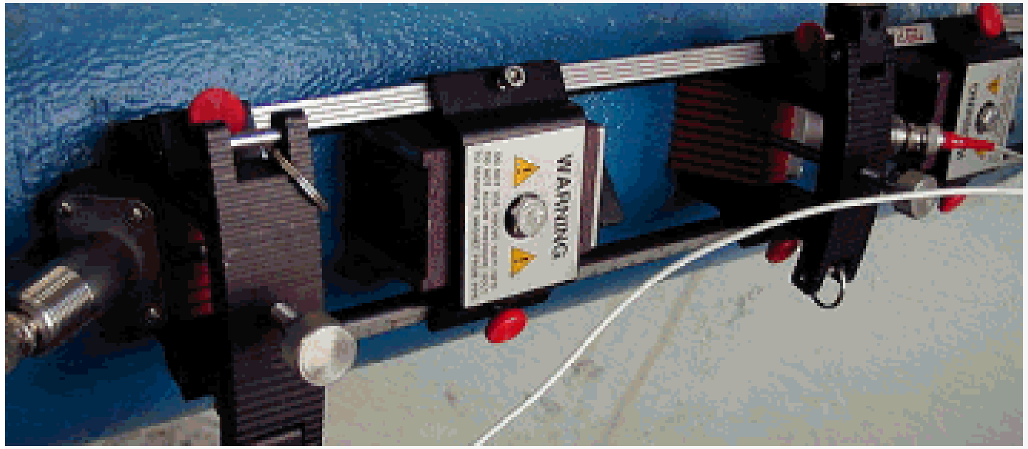
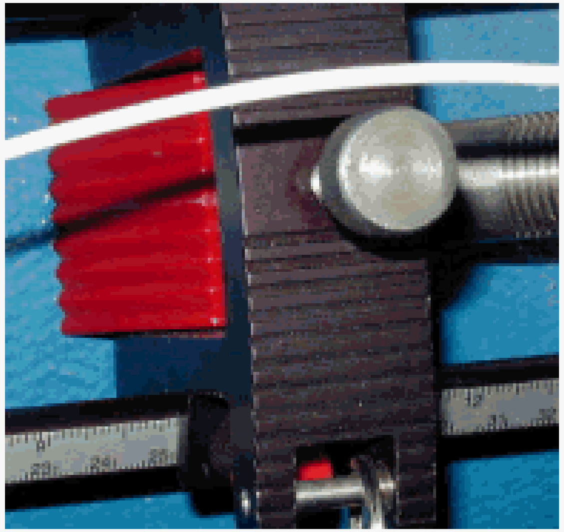
Portable Ultrasonic Flow Meter





Calibrating a flow meter…

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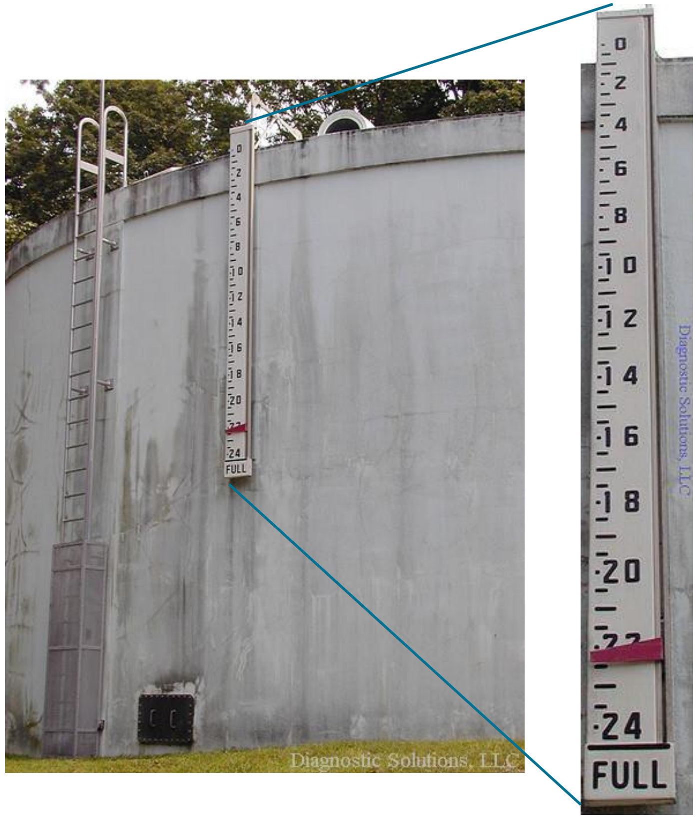
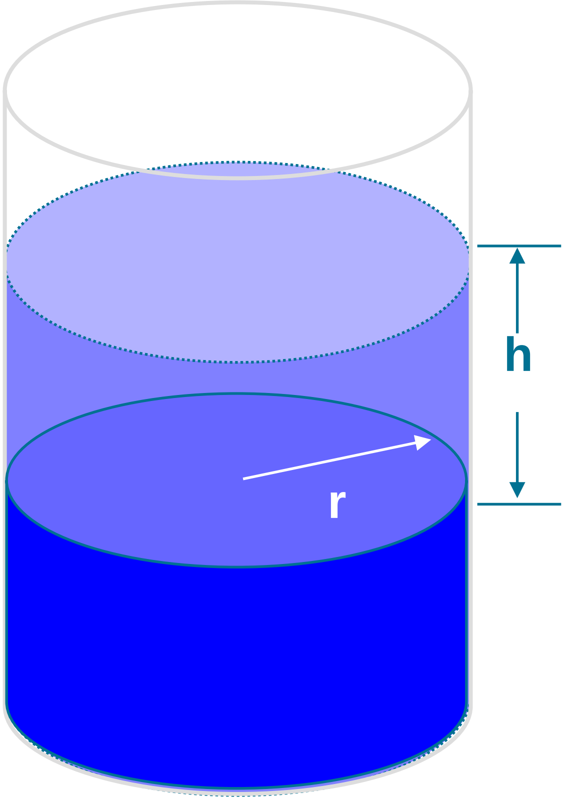
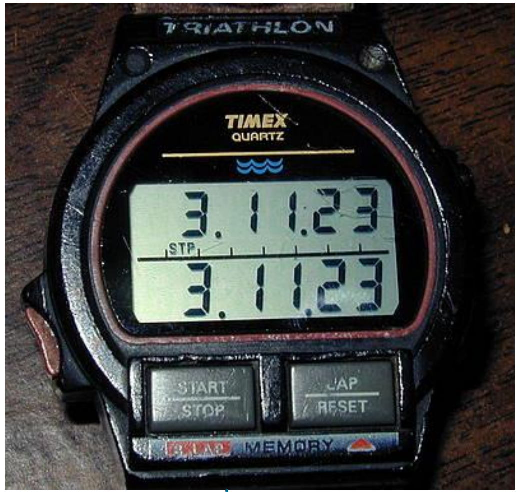
Tank drain or fill

Also a standard way to calibrate flow meters







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

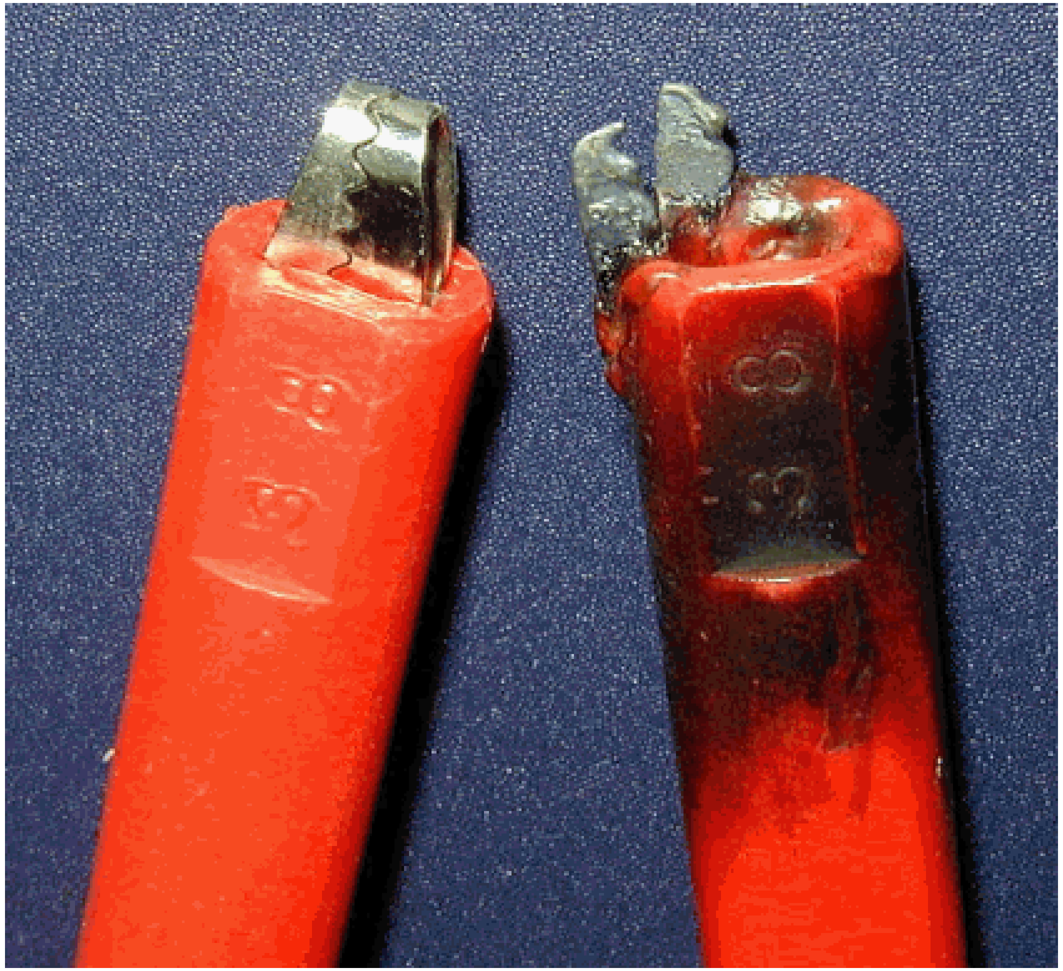
Electrical Measurements

Instruments and considerations

The most important consideration in electrical measurements:

SAFETY

These two alligator clips used to look alike...



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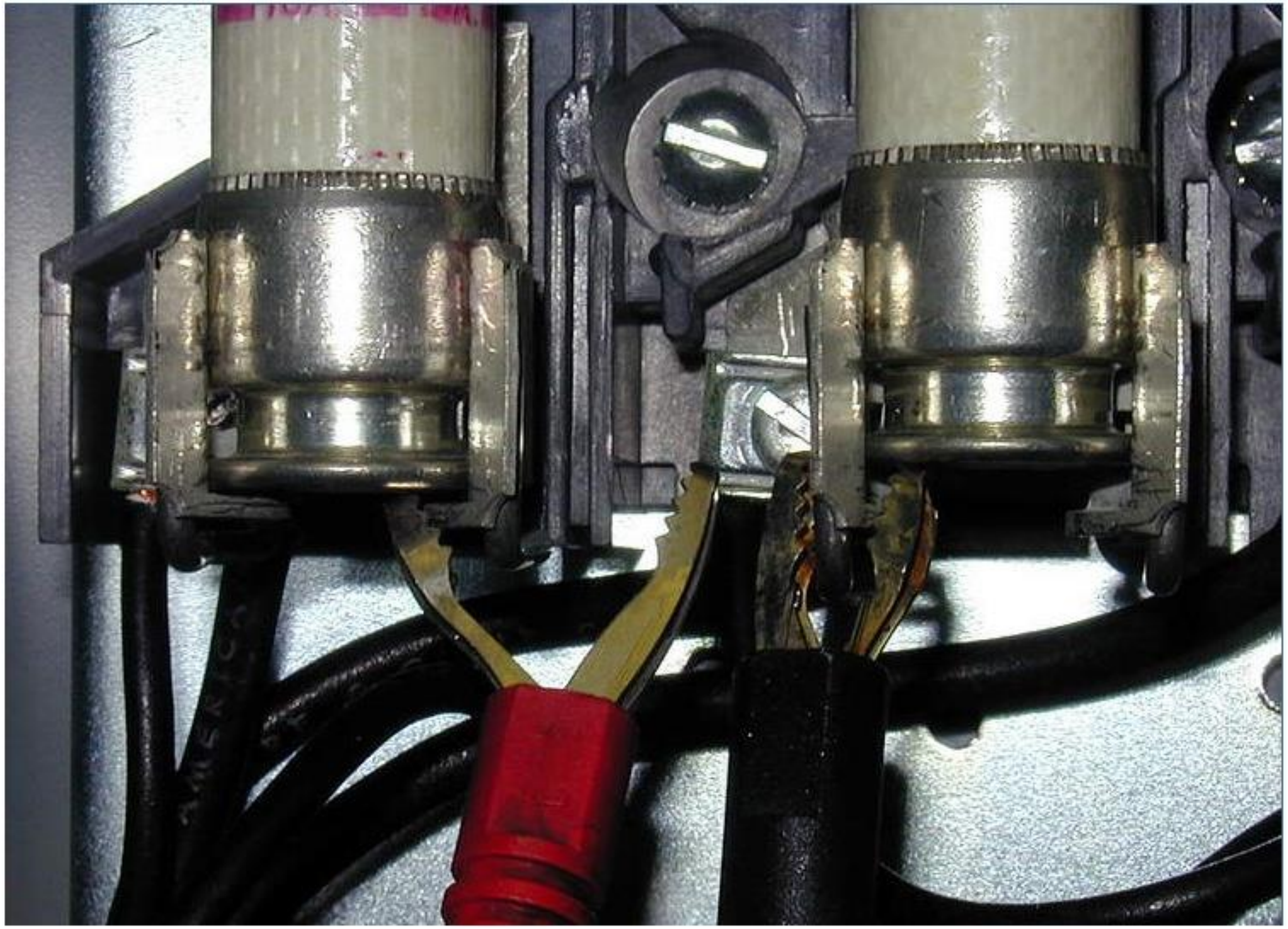
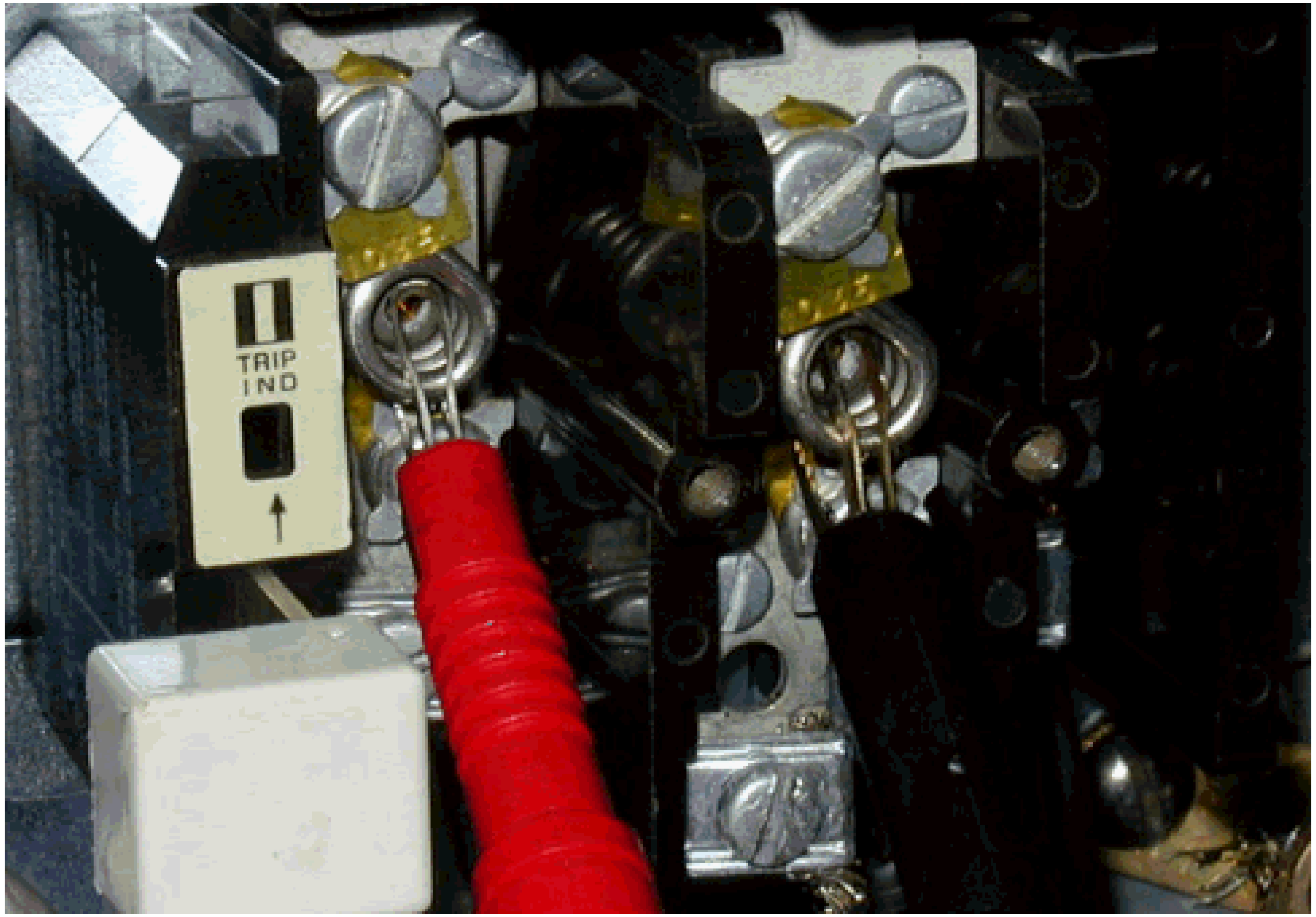
What happened?



A Better Alternative – Shrouded Probes



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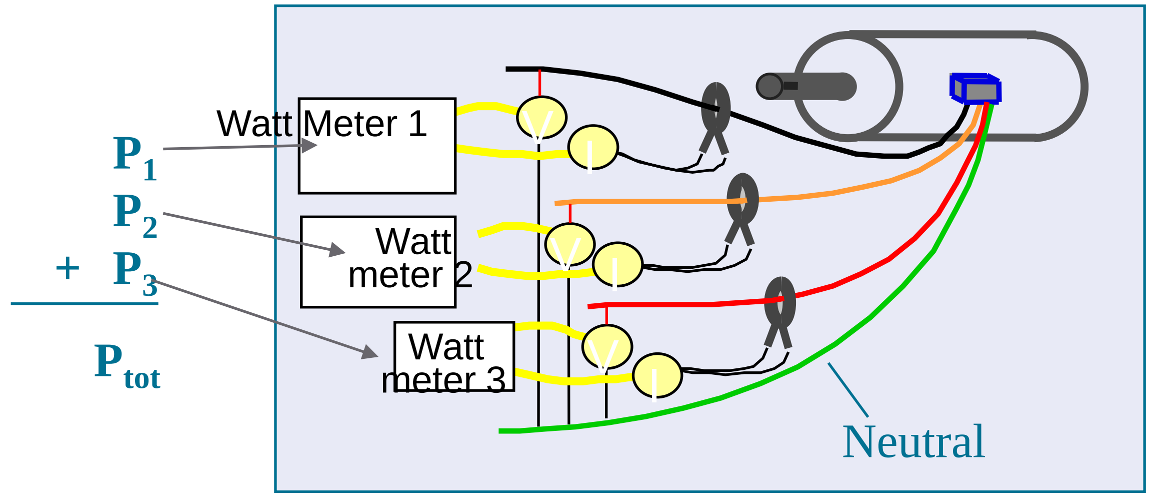
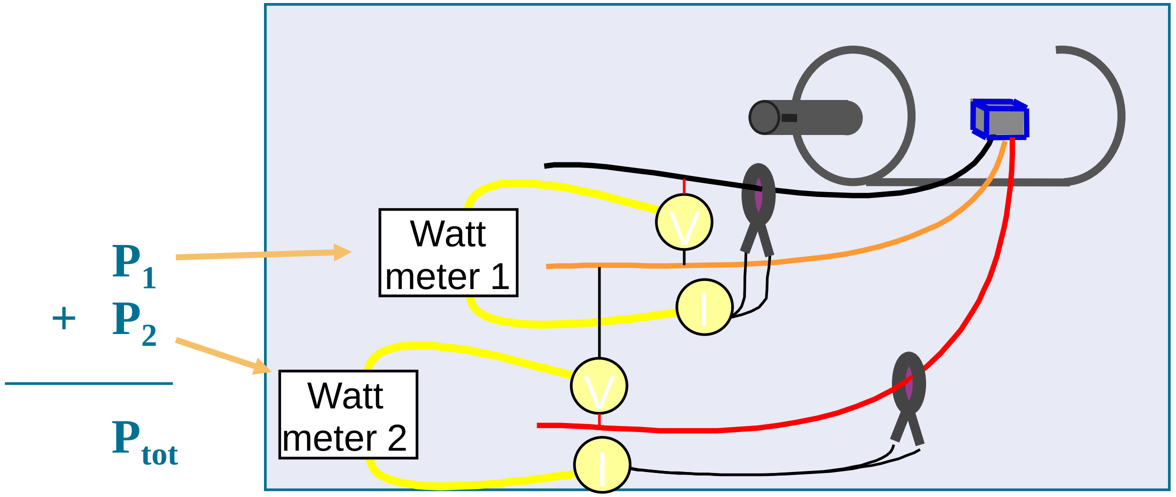
Three Phase Power

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

Unbalanced 3-phase power: Measure each phase individually (3 Watt meter) or use the 2 Watt meter method

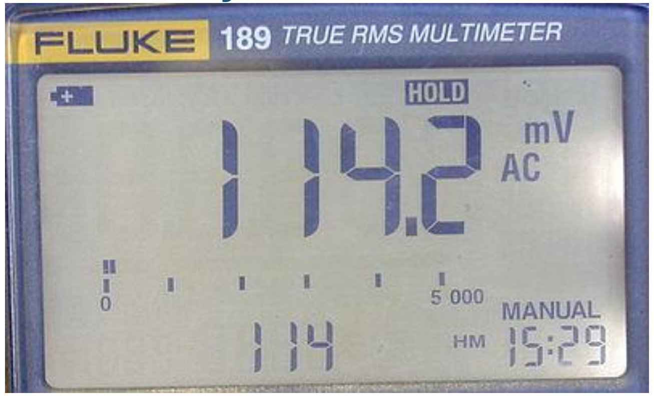




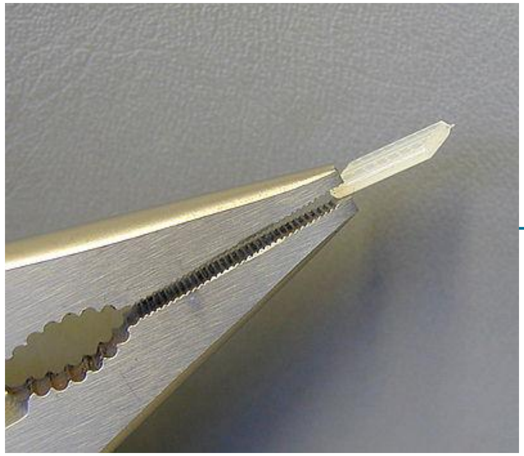
Note: the V_{rms} above is line to line voltage

Ensure CT clamp jaw is closed…

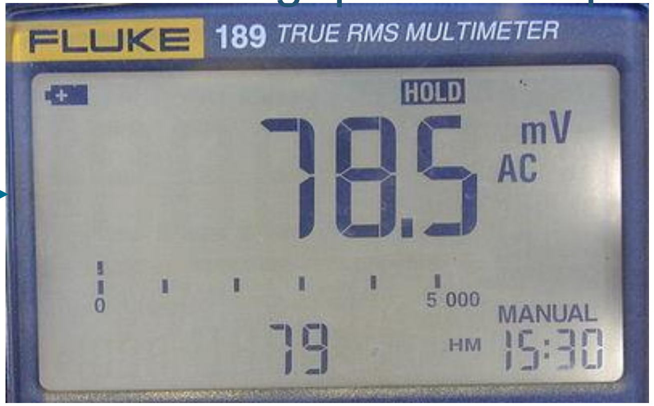
Jaws fully closed - 114.2 amps



Piece of tie wrap
< 1.5mm thick



<0.05 inch gap: 78.5 amps



Note: CT scaling is 1 mV/amp

If possible, measure all three phases

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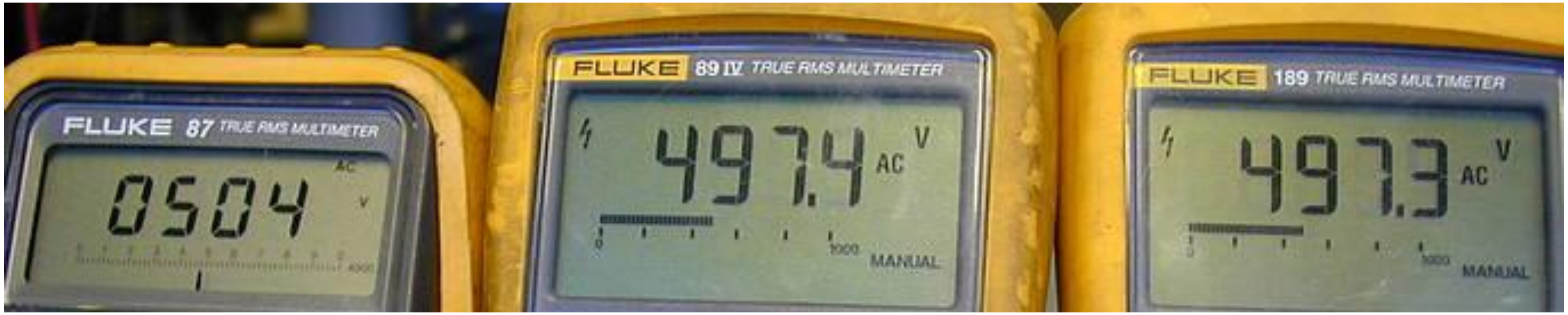
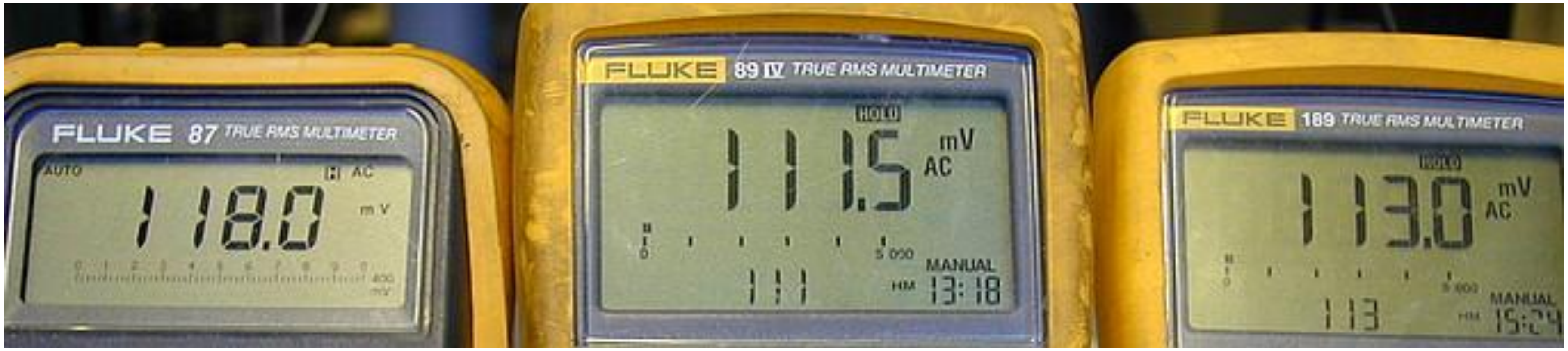
Line to Line Voltages



Currents



<0.9% voltage unbalance => 3.3% current unbalance

Slide Courtesy of Oak Ridge National Laboratory

Data Logging

Data Loggers

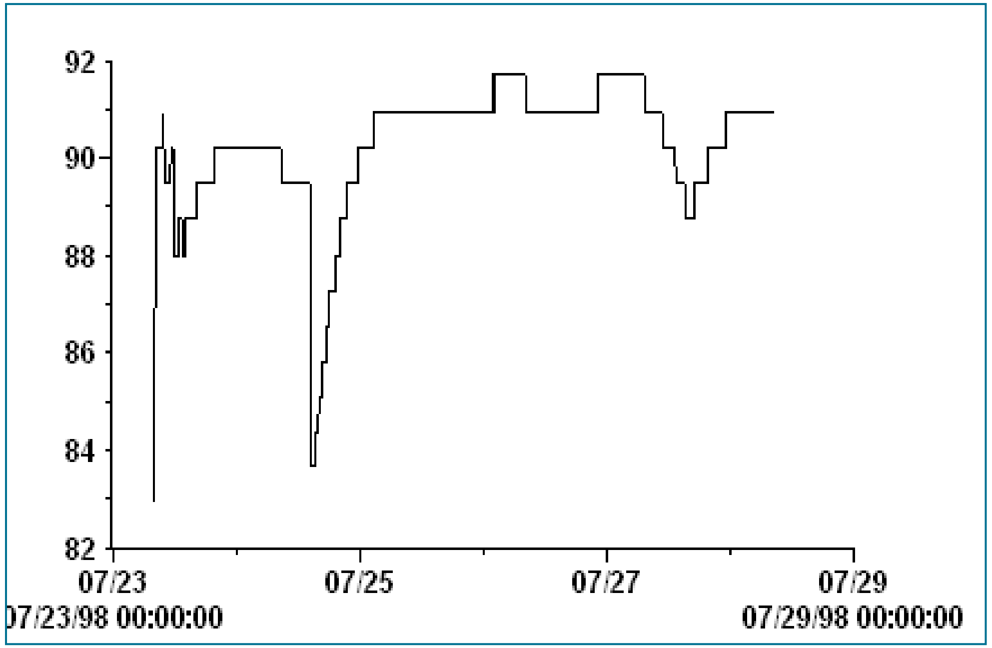
- Data loggers can provide more insight on how a pump system operates over an hour, a day or several weeks

- 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)

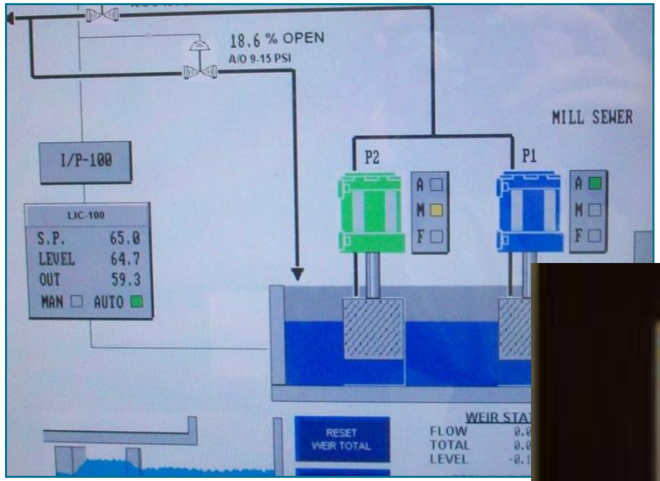
- Many flow and power meters also have data logging features that can be used

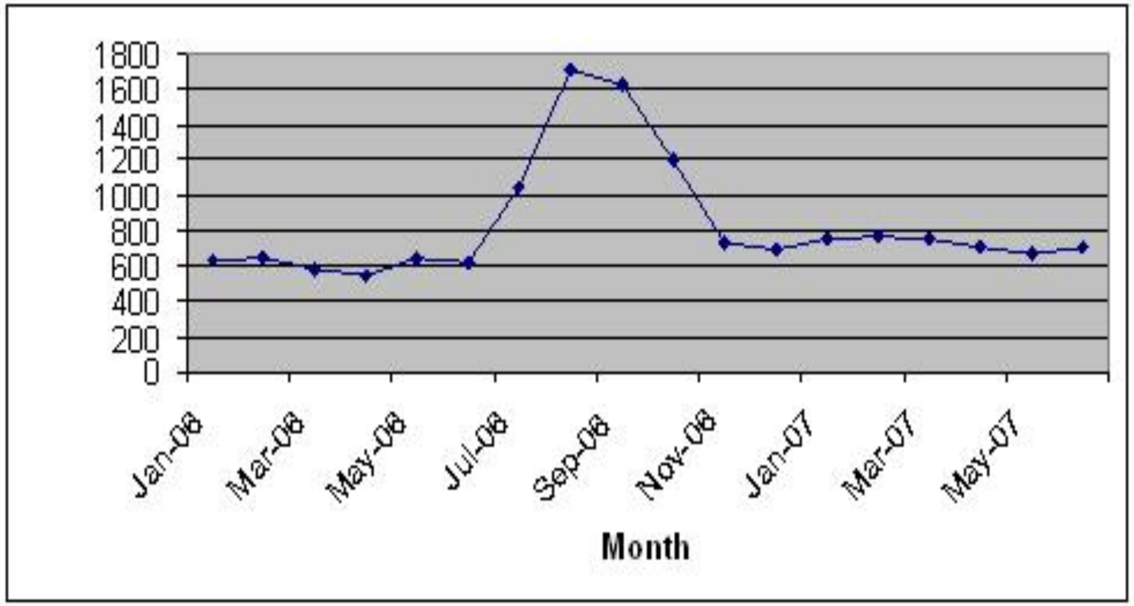
Multi-Channel Data Loggers

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





12. Example: System Analysis

Pump System Assessment

Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

Example: Problem Statement

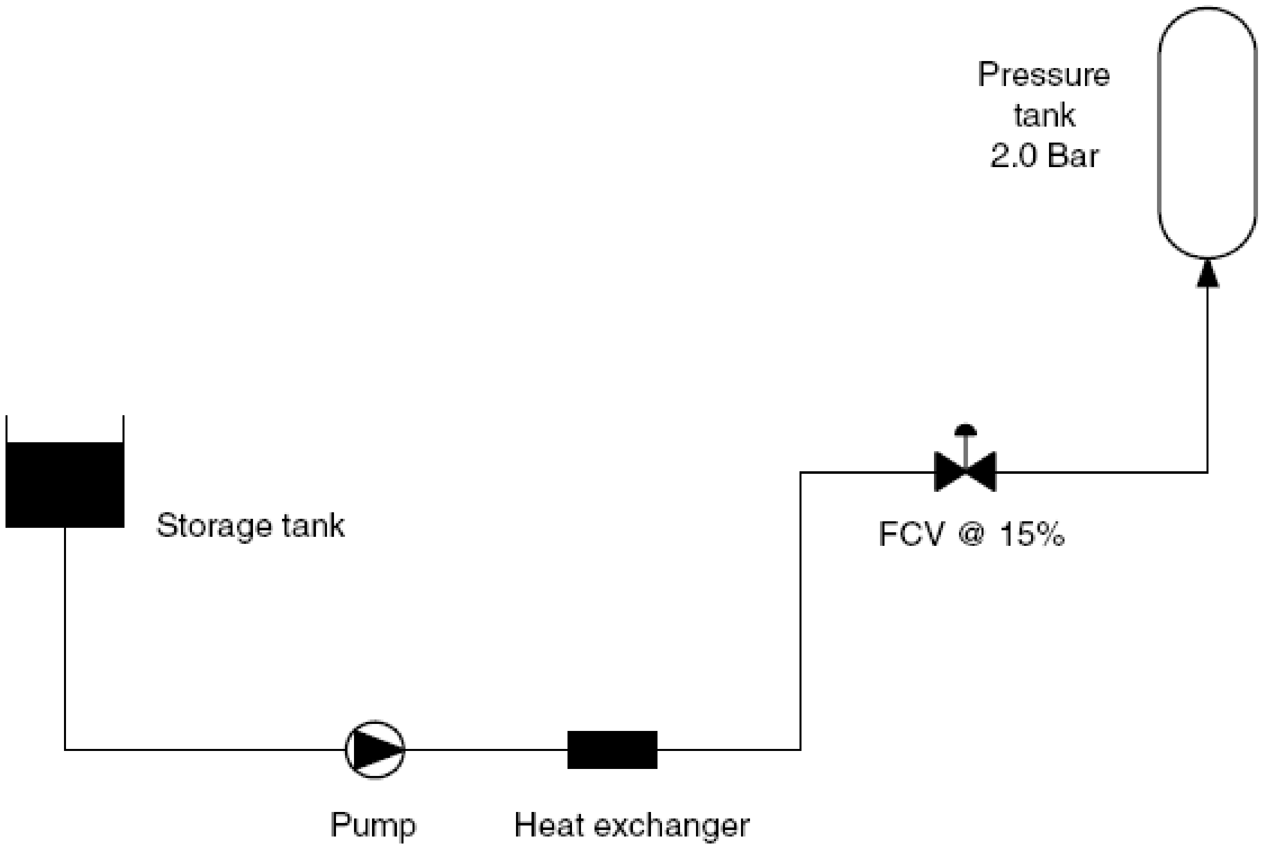
System with a Problem Control Valve

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 m3/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.

Example: System Overview



Sketch of pumping system in which the control valve fails

- Storage tank
- Pump
- Heat exchanger
- FCV @ 15%
- Pressure tank 2.0 Bar

Example: System Operation Description

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 % 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 m^3/h instead of 80 m^3/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.

Example: Potential Solutions

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 frequency drive [VFD]) can be installed, and the flow control valve removed. The VFD can vary the pump speed and thus achieve the desired process flow.

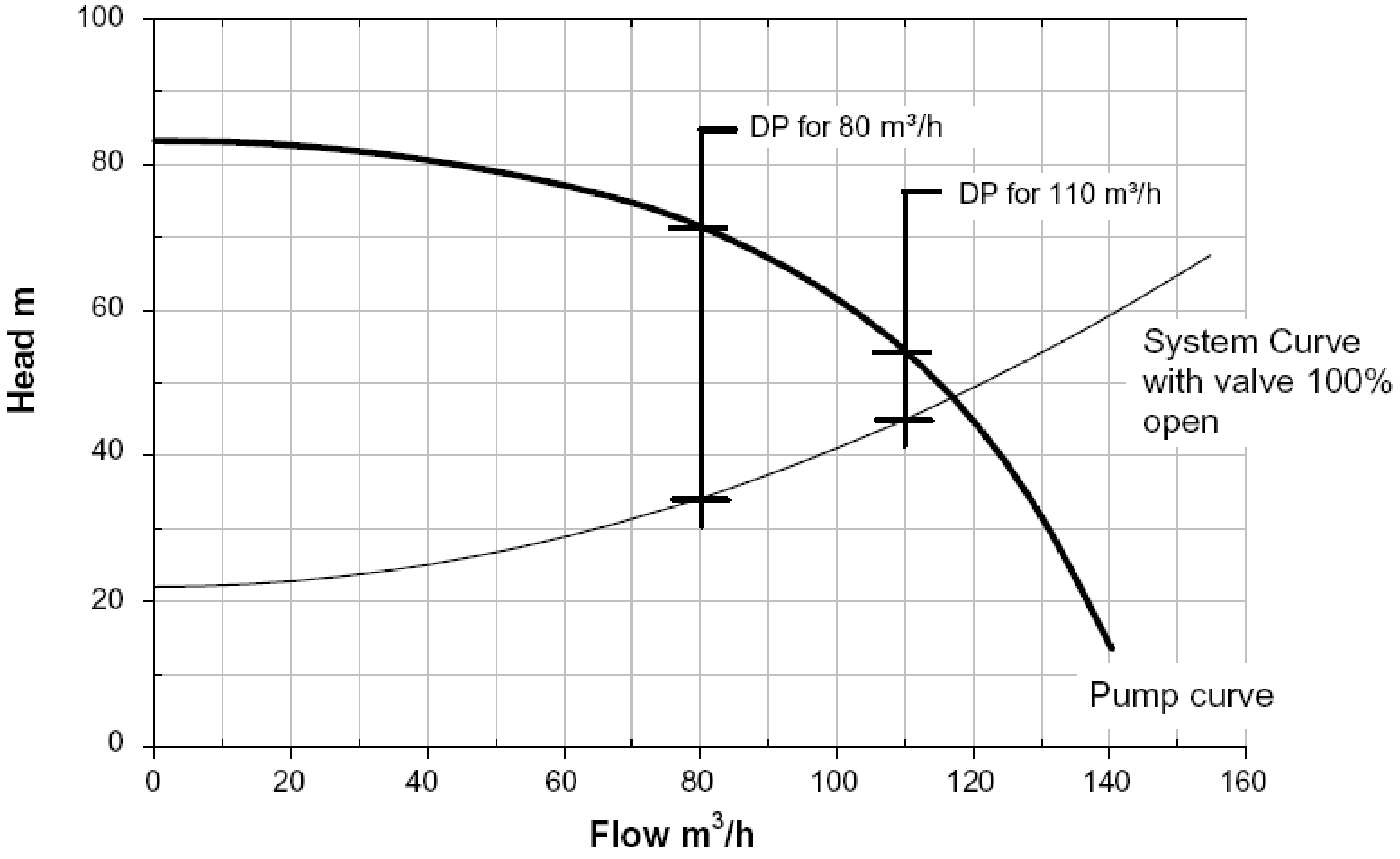
D. The system can be left as it is, with a yearly repair of the flow control valve to be expected.

Example: Evaluation of Potential Solutions

The following key factors were considered during the evaluation

- 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 VFD costs $ 20 000, and an additional $ 1 500 to install. The VFD 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 m3/h for 6 000 h/year. The energy cost is $ 0.08 per kWh and the motor efficiency is 90 percent.

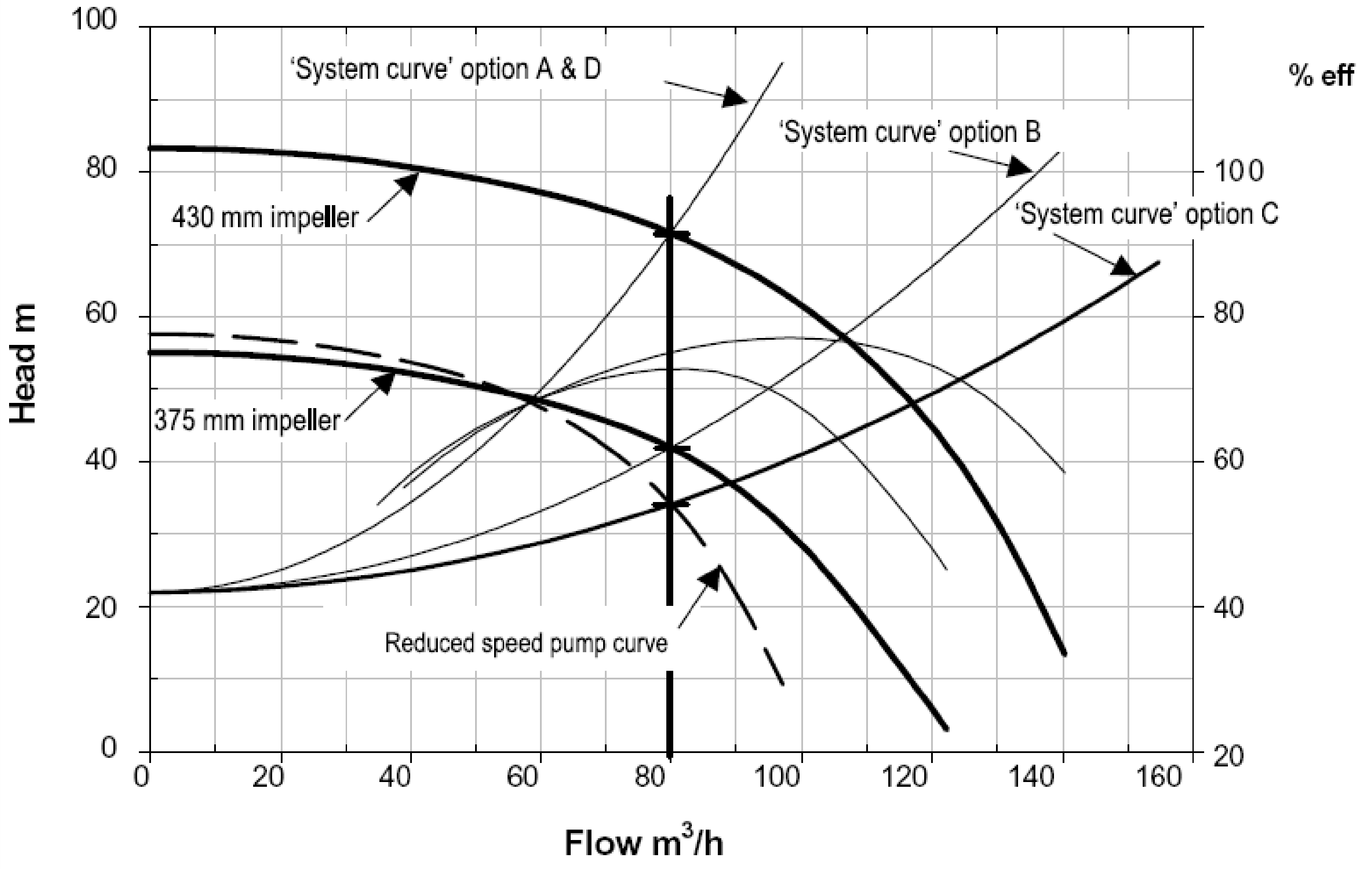
Example: Pump & System Curves



Example: Impeller Trimming or VSD

Pump and system curves for:

- impeller trimming
- variable speed operation
- different system curves



Example: Results

- When operating at 71.1m head, the total annual energy cost is $ 1 108.

- By trimming the impeller to 375 mm, the pump's total head is reduced to 42 m at 80 m^3/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 m^3/h. The resulting annual energy cost with the reduced speed is $ 5 568.

Example: Summary of 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)	VFD (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
VFD	0	0	$ 20 000	0
Installation of VFD	0	0	$1 500	0
Valve repair/year	0	0	$ 500	$ 4 000

Example: Last thoughts…

- **What benefits do you see in the different solutions?**

- **Which would you recommend and why?**

Any Questions?

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13. Class Test

Pump Systems Optimisation (PSO) User Training
(Egypt Edition – Sep 2021)

Albert Williams
Siraj Williams

Class Test Rules

- Those wanting to participate in the PSO Expert Training program and those requiring a certificate of competence must achieve 70% or more
- Duration: 1 hour
- Multiple Choice – 25 Questions
- Open book, calculators
- No internet permitted
- No use of mobile phones

End of Course

Thank you for your participation

Please complete the course evaluation

Contact Details

Egyptian program for promoting Industrial Motor Efficiency
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