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PUMP SYSTEMS MATTER
Energy | Efficiency | Economics

Screening Pumping Systems

Six Step Action Plan

1. **Screen and prioritize your pumping systems to identify good performance improvement candidates**
2. Get management support for improving the highest priority pumping systems
3. Work with appropriate pumping system specialist and/or in-house team to gather and analyze additional data
4. Identify, economically validate, and implement performance improvement opportunities
5. Document actions and report results to management
6. Repeat ***Action Plan*** process for other good candidate systems

Prescreening Form

A = High Priority	Grey fields indicate priority data entries														
B = Med Priority	Equipment Information									Control schemes (check all that apply)					
No Action															
Priority	System name/description	Pump Type [MC, PD, Vacuum, Centrifugal]	Certified Pump Performance Curve	Pump ID/process area	Motor name plate data	Service (e.g. utility, process, etc.)	Time in service (years)	Indicate shared duty pump systems/ in service spares	Voltage	Adjustable speed drive	Throttled (% open if available)	Bypass/Re-circ	On/off	More than one pump/split duty	Not controlled (pumps just run)
A = High Priority															
B = Med Priority															

Operating Parameters (provide if readily available, otherwise indicate with check if it is acquirable)										Other symptoms		Additional Information (is acquirable?)			
Operating hours or % of time equipment operates	Power or Current	Flow requirements have changed or are expected to change	Design flow rate	Operational flow rate	Design head	Operational head	Static head	Upstream pressure	Downstream pressure (after control valve, or bypass line, etc)	Cavitation at pump or in system?	System maintenance level (Hi/Med/Lo)	Typical flow rates and variation thereof	Duration diagrams	Maintenance Costs	PID / DCS screen-shots

Source: Pump System Basic Assessment Guide co-developed with BC Hydro

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Screening–Primary Data3

- Data on all plant systems that are of interest, those that run 24/7)
  - List of pumps
  - Pump description (including: process area, pumped media, pump type, etc.)
  - Installed motor horsepower
  - Motor rewinds
  - Impeller trims
  - Pipe and valve modifications
  - Yearly operational hours (or percent operation)
  - Control method (control valve, variable speed drive (VSD), by-pass)
  - Maintenance records

Screening–Primary Data

- Operating parameters (power/current, flow, pressure)
- Cavitation at pump or in system
- Load over the full range of operation
- Equipment information (service type, time in service, shared duty, voltage)
- Overall installation

Screening–Primary Data

- Typical flow rates and variations
- Duration diagrams
- Maintenance costs
- Process & Instrument Diagrams (P&ID)/Digital Control System (DCS) screen-shots

Data Analysis - Priorities for detailed investigation include:

- Pump systems with high energy use (large motors that run continuously or frequently)
- Systems with higher than average maintenance costs
- Systems with known problems such as cavitation noise or excess vibration
- Systems that have undergone change of duty

Data Analysis - Priorities for Detailed Investigation Include (continued):

- Systems that are controlled by throttling valves
- Systems that use by-pass or recirculation regulation
  Systems where several pumps are normally run in parallel
- Systems which involve a batch type process/one or more pumps operate continuously
- Systems with frequent on/off cycling of a pump in a continuous process
- Systems with no flow, pressure, or power indication

Prioritize Opportunities

- Rank pumps with opportunities for performance improvement

- Focus on energy use, those with maintenance problems, etc.

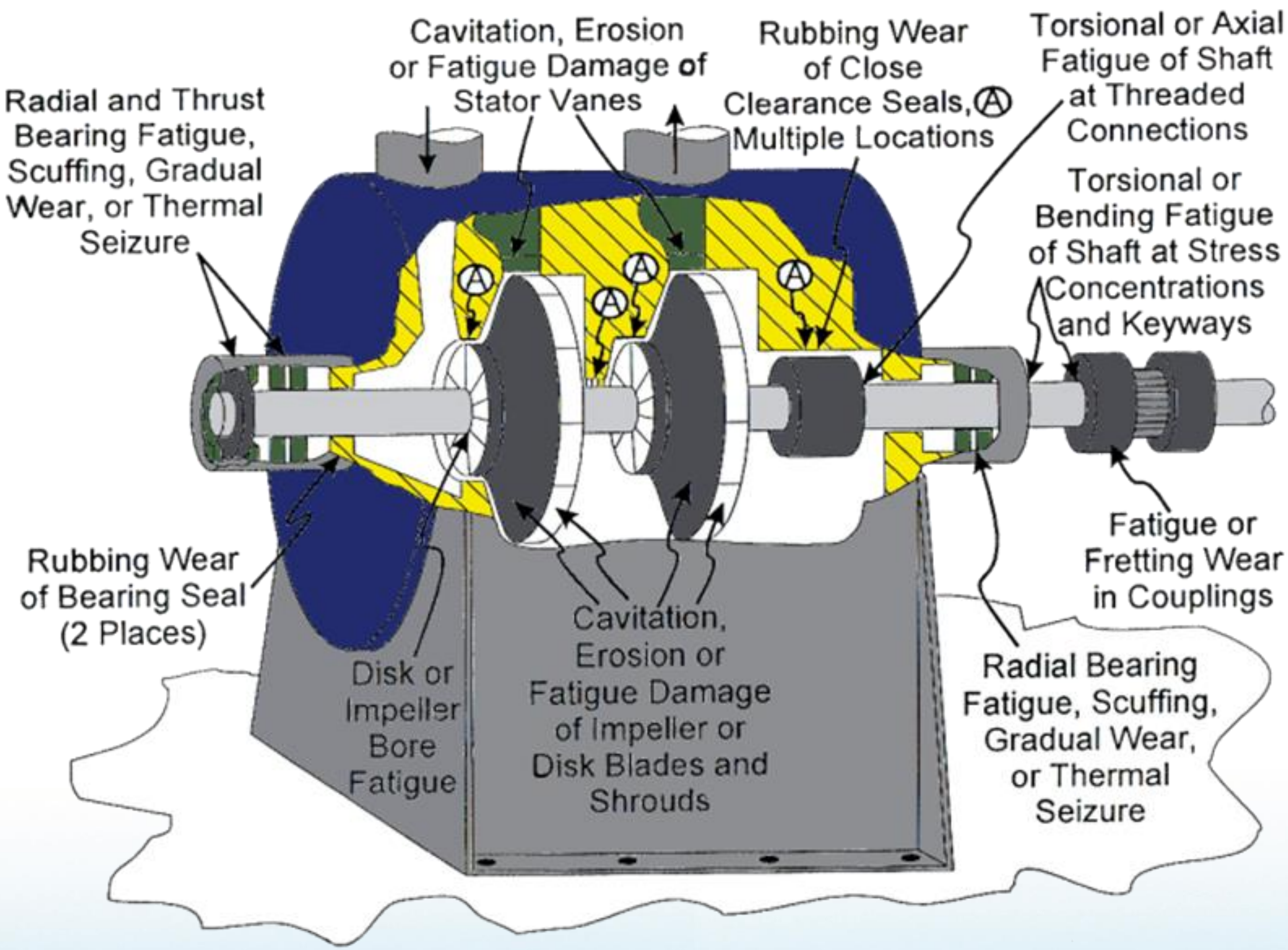
End Result from Screening

- List of pump systems and solutions that can be implemented immediately without further analysis
- List of pump systems that need further analysis
  - System's conditions are steady and a snapshot of performance data is required for the analysis
  - There are changes in system demand over time and the system must be monitored over a longer period of time

Select Pumping Systems for Further Analysis

- Review ability of plant staff to collect additional data and provide solutions
- Consider using an outside pump system specialist
- Contact your electric utility

Typical Failures in Centrifugal Pumps



Source – Mechanical Solutions Inc.

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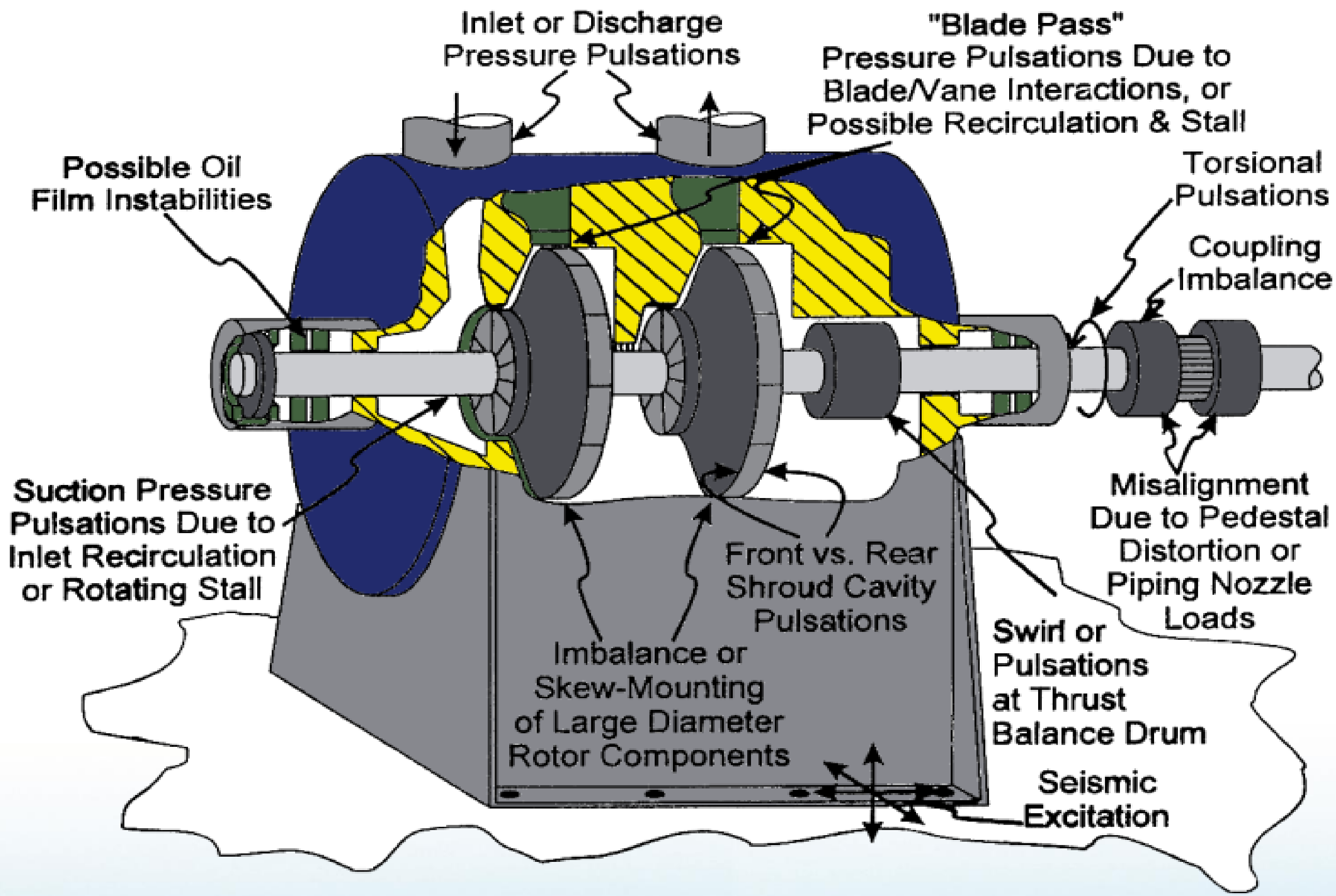
Sources of Damaging Forces in Centrifugal Pumps



Source – Mechanical Solutions Inc.

Common Pump / System Vibrations

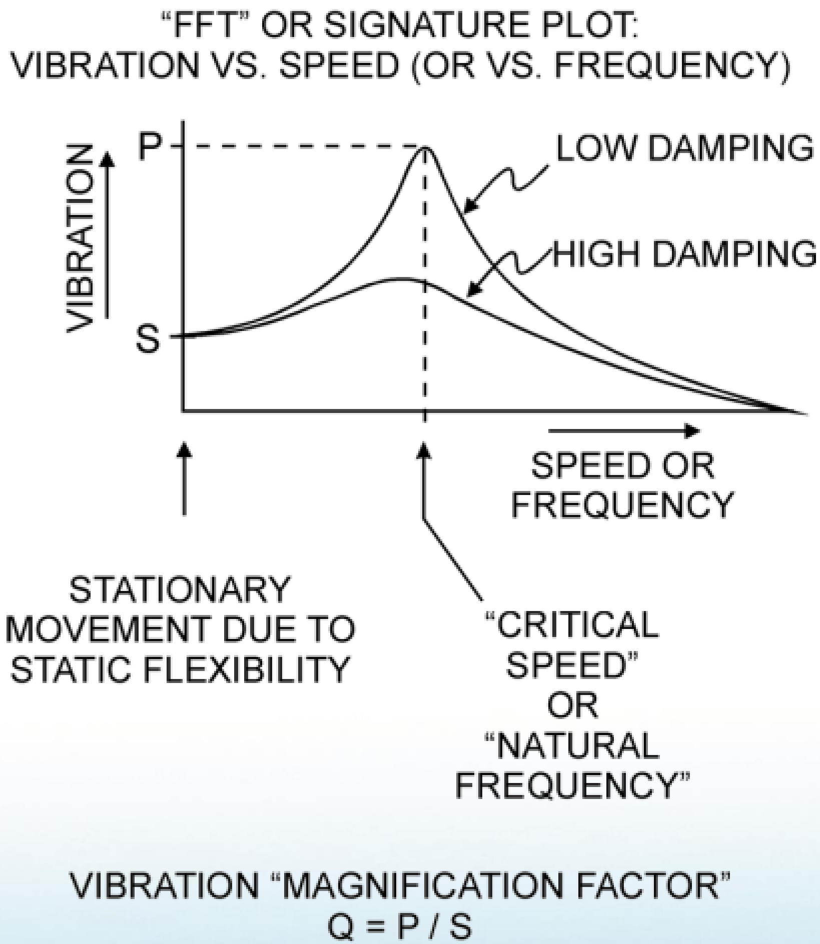
Frequency	Source
0.05 x – 0.35 x	Diffuser Stall
0.43 x – 0.49 x	Instability
0.500 x	Rubbing
0.65 x – 0.95 x	Impeller Stall
1 x	Imbalance
1 x – 2 x	Misalignment
# Vanes x	Vane / Volute Gap
# Blades x	Blade / Diffuser Gap

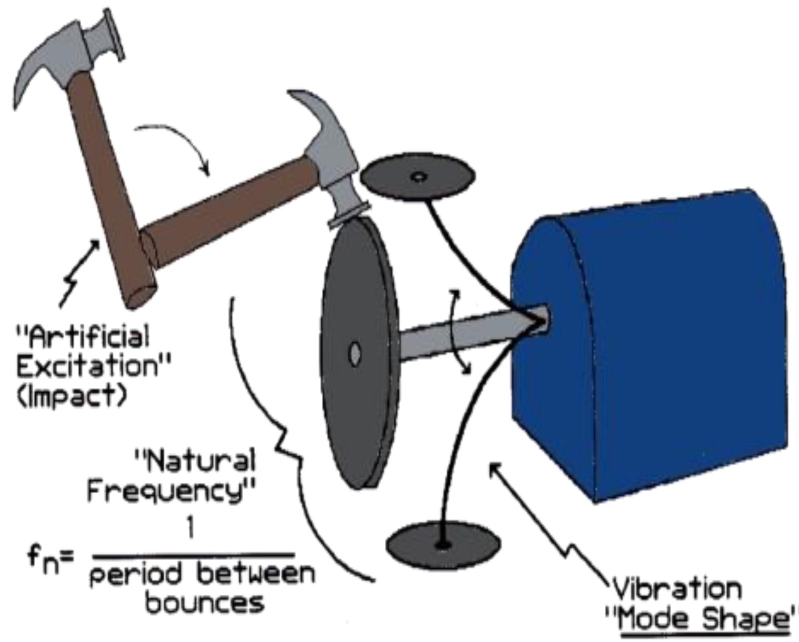
Key Factor in Many Problems
RESONANCE

Source – Mechanical Solutions Inc.

What Is Resonance?

A structural or rotor-dynamic natural frequency being excited.





A vibration and operating life problem when there is not enough damping

Source – Mechanical Solutions Inc.

Six Step Action Plan

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Analysis Tools for Pumping Systems

Tools

- Pump system specialists use a variety of tools to analyze pumping systems
- **Examples:**
  - US DOE's PSAT – Gather field measurements and focus on identifying energy savings opportunities
  - PSmart – Educational tool to model current system and proposed changes to improve performance
  - More tools available in PSM Tool Matrix (both free and commercially available)
  - Many pump system specialists have their own proprietary tool or use excel spreadsheets
  - Most pump system specialists feel that multiple tools are needed during an assessment

Calculating Shutoff Head

How to estimate the shut off head of a pump (inch sizes)

- **At 1750 rpm:**

  Shut off head = Diameter of the impeller squared

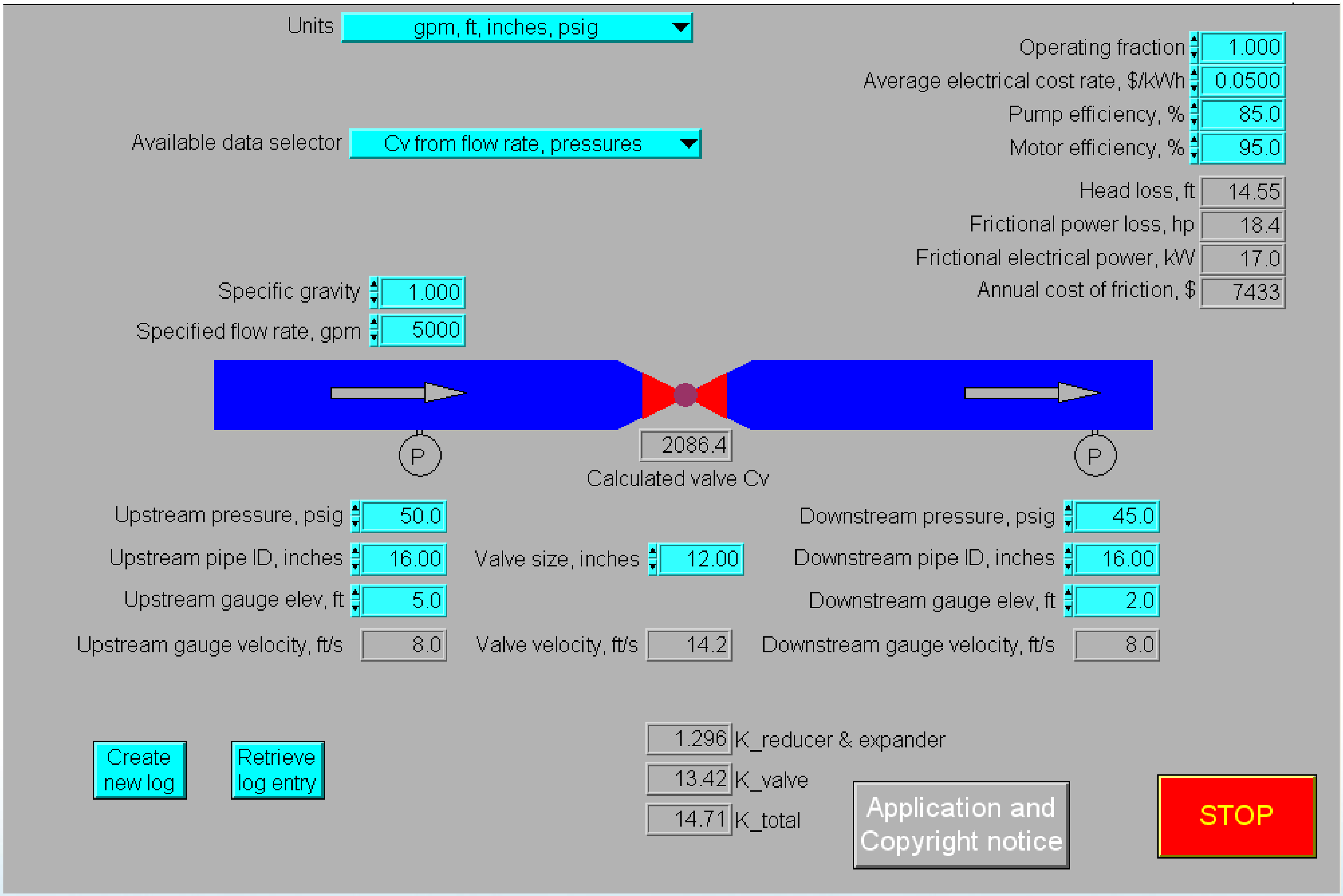
- **At 3500 rpm:**

  Shut off head = Diameter of the impeller squared x 4

- **For other speeds you can use the formula:**

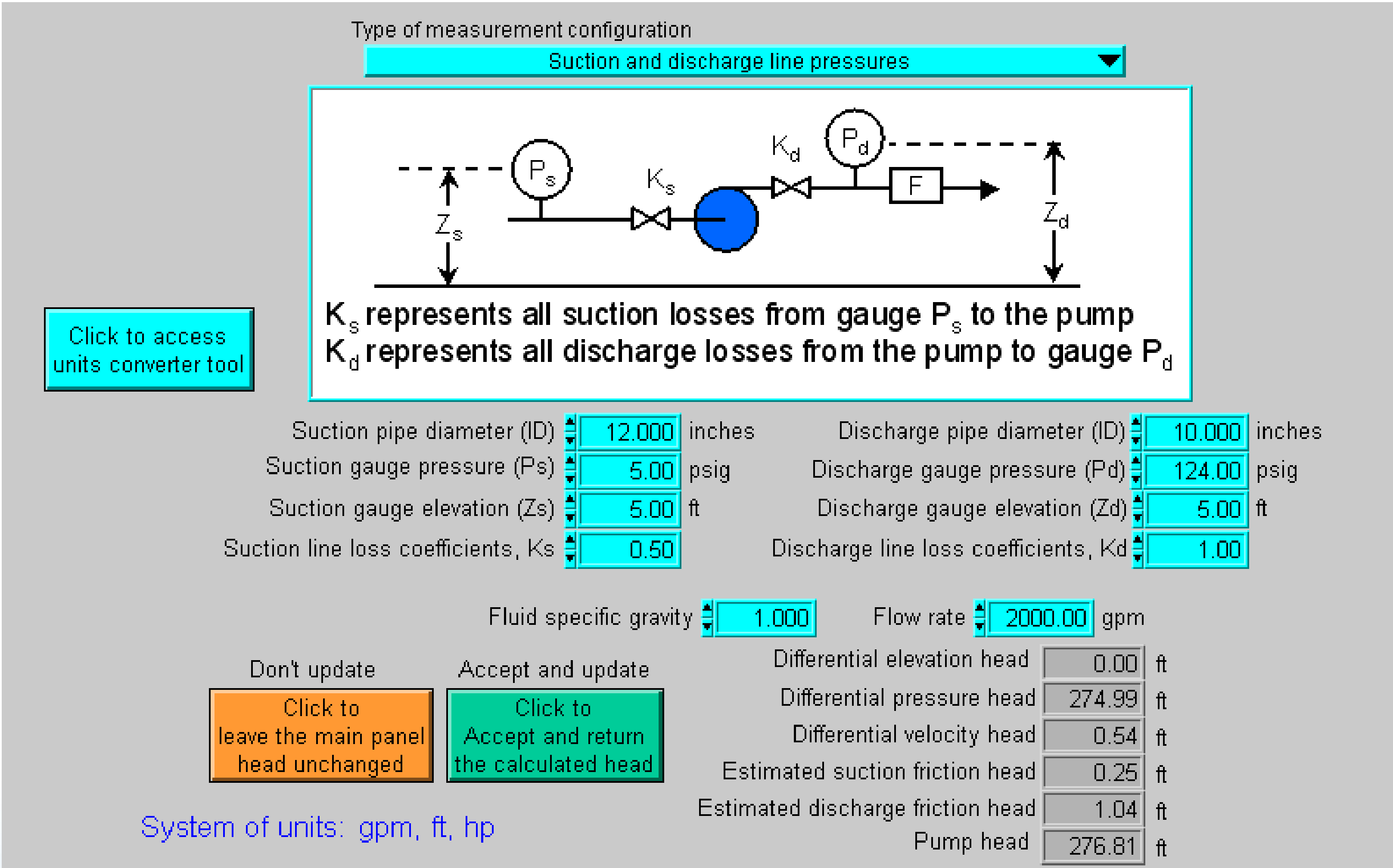
  Shut Off Head = $D2 \times (\text{new rpm} / 1750)^2$

Examples – Valve Equations



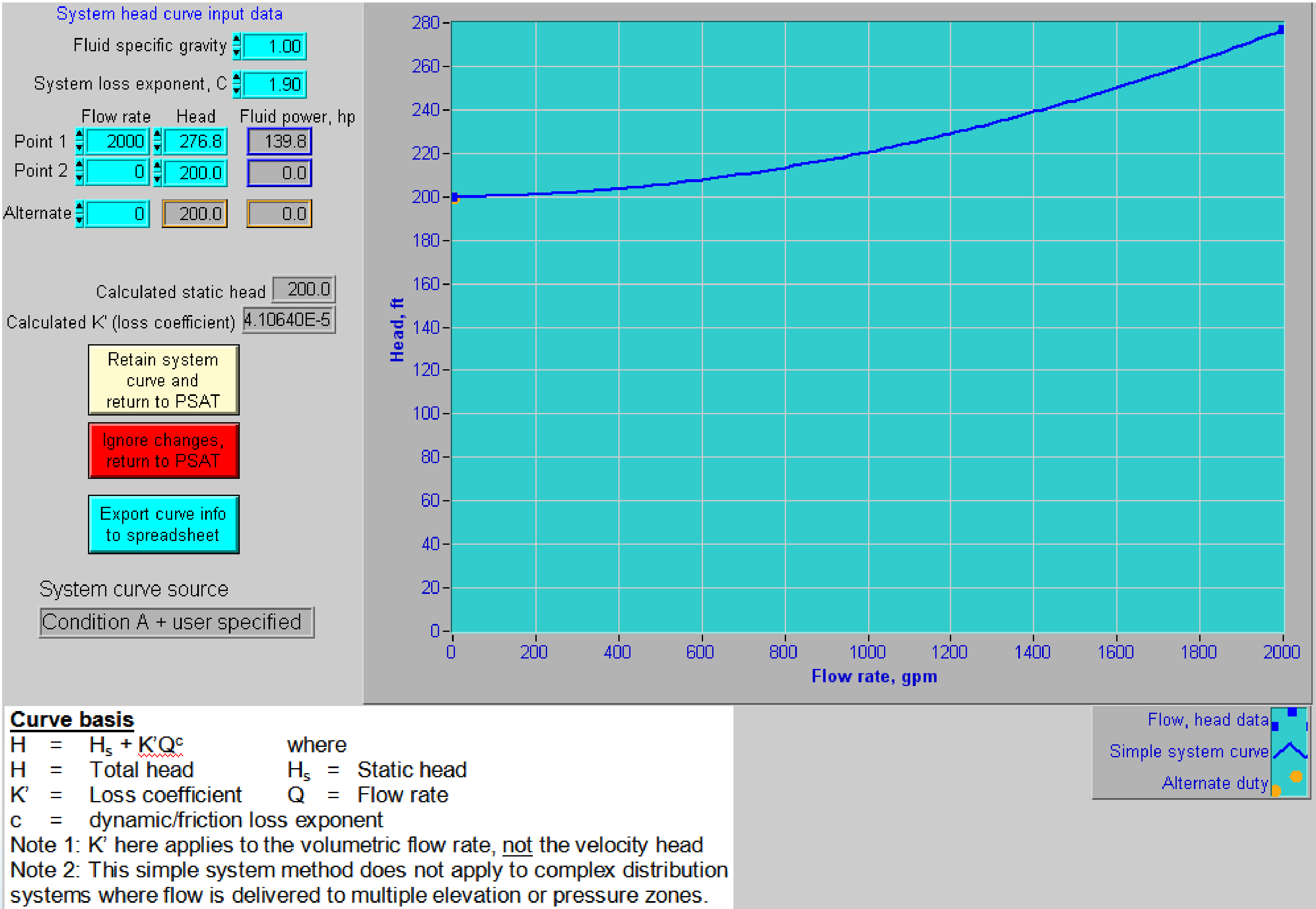
Source: PSAT Software

Pump Head



Source: PSAT Software

System Curve



Source: PSAT Software

Sizing Electric Motors to Pumps

$$BHP = \frac{Q \times H_T \times Sp.Gr.}{3960 \times Eff.}$$

where

- Q = Capacity in gallons per minute (GPM).
- H_T = Total Differential Head ,ft
- $Sp.Gr.$ = Specific Gravity of the liquid
- $Eff.$ = Pump efficiency , %

$$\text{Pump Efficiency } (Eff.) = \frac{WHP}{BHP}$$

$$WHP = \frac{Q \times H_T \times Sp.Gr.}{3960}$$

where

- Q = Capacity in gallons per minute (GPM).
- H_T = Total Differential Head ,ft
- $Sp.Gr.$ = Specific Gravity of the liquid

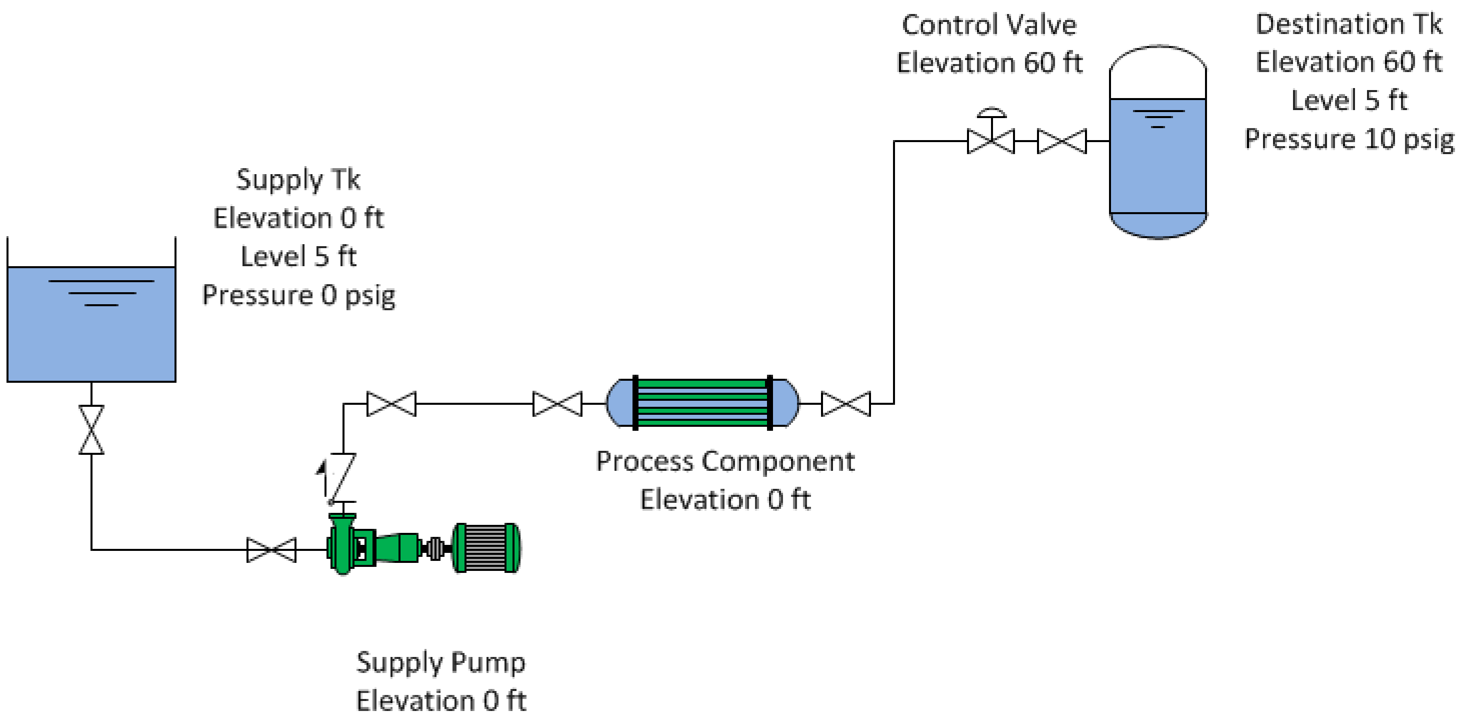
These equations are important as we are going to be calculating bhp in the upcoming exercises.

- Adding a service factor and additional horsepower – it can lead to maintenance problems and higher energy consumption.
- The constant 3960 is obtained by dividing the number or foot-pounds for one horsepower (33,000) by the weight of one gallon of water (8.33 pounds).
- BHP can also be read from the pump curves at any flow rate. Pump curves are based on a specific gravity of 1.0. Other liquids' specific gravity must be considered.
- The brake horsepower or input to a pump is greater than the hydraulic horsepower or output due to the mechanical and hydraulic losses incurred in the pump. Therefore the pump efficiency is the ratio of these two values

PSMART: An Analysis

- A small pumping system exhibits the common problem of a pump oversized.
- Several possible system improvements are hydraulically evaluated, and the energy and economic impact on each improvement is discussed.
- Minimum required flow to the heat exchanger is 200 gpm.
- Assumptions:
  - Pump is currently supplying more flow than the required flow the heat exchanger
  - Cost of energy assumed to be $0.10/kW-hr
  - Pump runs 24/7

Defining All the Elements of a Pumping System

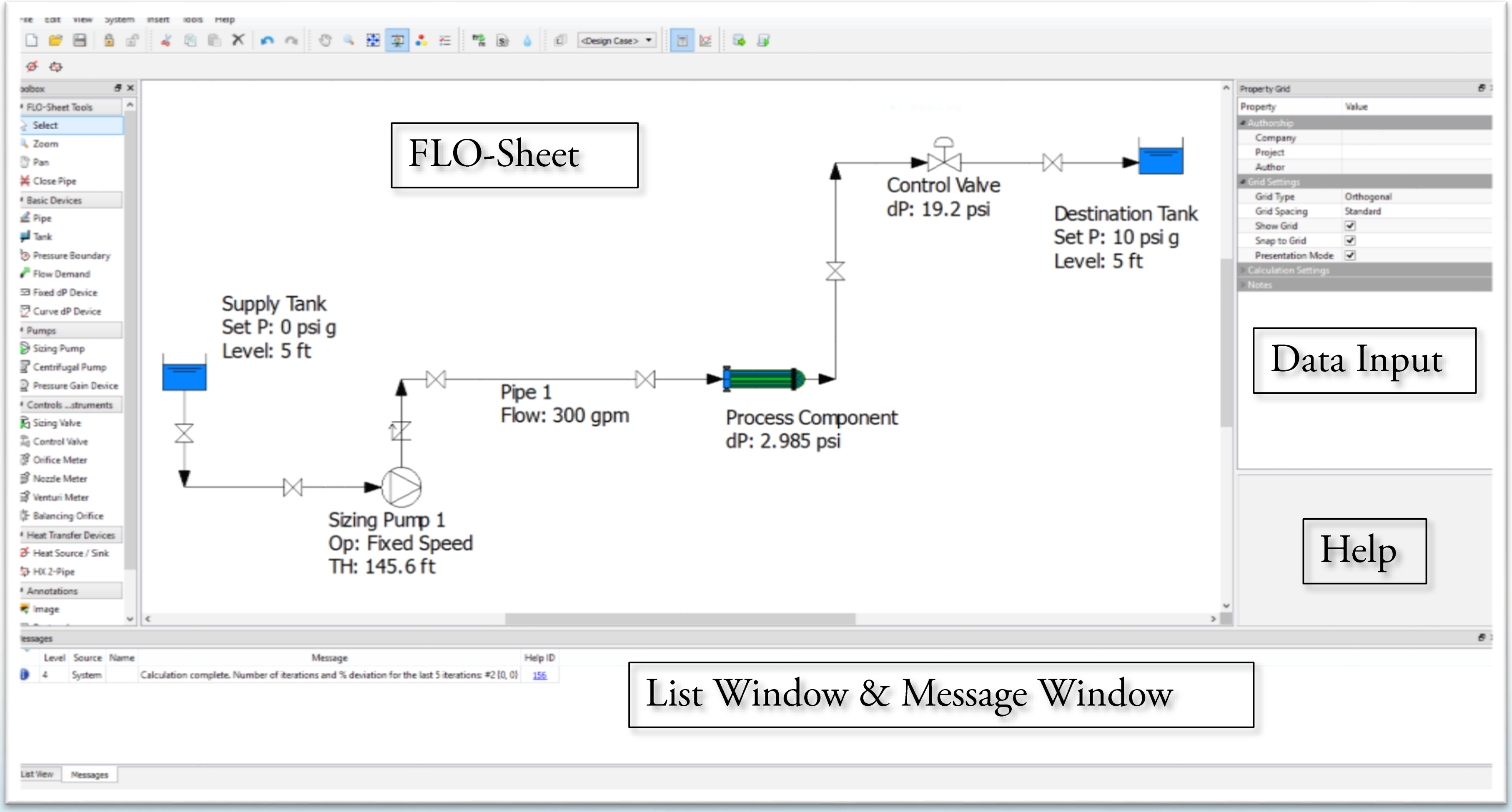


- Pump elements
- Process elements
- Control elements

Steps to Generate a System Model

1. **Draw the system** using drag and drop tools
2. **Enter Design Data**:
   - Pipe sizes, Pump curve, Fluid properties, etc.
3. **Enter Operational Data**:
   - Liquid level, Pump speed, Open or closed pipelines, etc.
4. **Calculate** and Explore your system
   - Calculations, Operational Warnings, List View
   - Gradient colors
5. **Investigate** Improvement Options

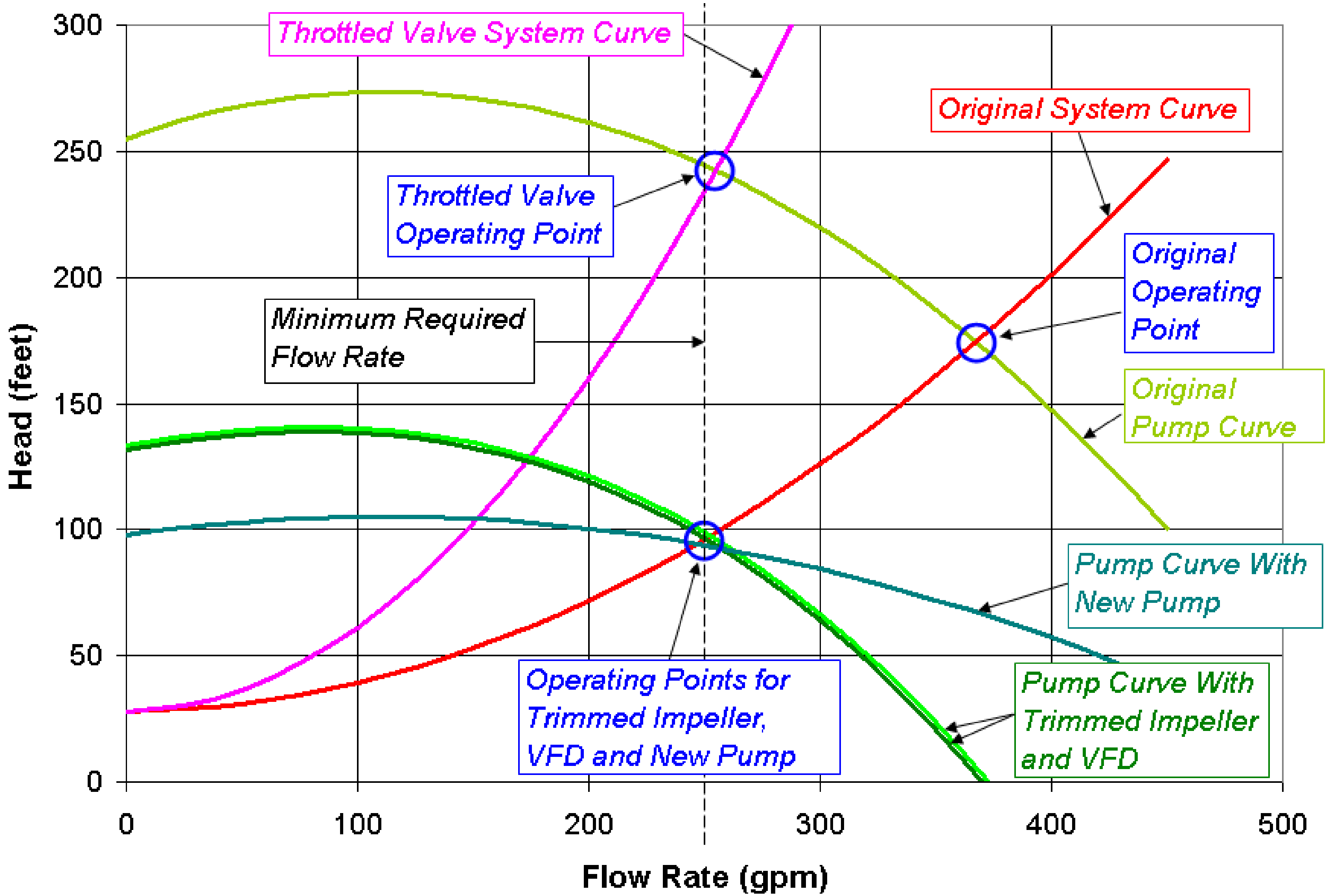
System Model



System Improvement Options

Case	Op Energy Cost (5yr)	Pump Flowrate	Pump Efficiency	Pump Power	Valve dP
Original System	$60,097	300 gpm	72.3%	18.4 hp	19.2 psi
Throttle Valve	$51,605	200 gpm	45.8%	15.8 hp	24 psi
Trim Impeller (9.8”)	$37,398	200 gpm	49.3%	11.45 hp	10 psi
Variable Speed Drive (VSD)	$27,762	200 gpm	52.6%	8.5 hp	0 psi
New Pump	$27,170	200 gpm	69%	7.4 hp	5 psi

System Improvement Options



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System Improvement Options

Case	Energy Cost ($ for 5 yrs)	Pump Flowrate (gpm)	Pump Efficiency (%)	Pump Power (hp)	BEP Proximity (%)	Valve Pressure Drop (psi)
Original System	63,261	367	64	25	151	21
Throttle Valves	45,518	255	85	18.3	105	72
Trim Impeller	22,147	252	70	8.9	144	10
VSD	21,749	250	70	8.7	144	10
New Pump	17,507	250	86	7.0	104	10

Use a Systems Approach to Manage your Pumping Systems

- Focusing on individual components overlooks potential cost-savings
- Component failures are often caused by system problems
- Use a total system approach in designing systems and evaluating repair and maintenance options

System Efficiency

Flow required	2500 gpm	2500 gpm	2500 gpm	2500 gpm
Head required	200 feet	150 feet	200 feet	200 feet
Additional system friction loss	50 ft	0 ft	50 ft	55 ft
Motor eff	94%	94%	94%	96%
VFD efficiency factor	100%	98%	100%	100%
Mechanical drive eff	100%	100%	100%	100%
Pump eff	65%	88%	70%	65%
Energy cost per kWh	$0.07	$0.07	$0.07	$0.07
Operating hours per year	3500	3500	3500	3500
Factor	Base	Reduce friction by 50 feet.	Increase pump efficiency by 5 points.	Increase motor efficiency by 2 points.
System efficiency	49%	81%	53%	49%
System input power required for process	206.6 bhp	116.8 bhp	191.9 bhp	202.3 bhp
Power required for additional friction	51.7 bhp	0.0 bhp	48.0 bhp	55.6 bhp
Total power required	258.3 bhp	116.8 bhp	239.9 bhp	258.0 bhp
Total cost per year	$47,212	$21,350	$43,839	$47,153
Cost Savings		$25,861	$3,372	$59

System Data — **A** — **B** — **C** — **D**

Look Beyond Energy Savings

Energy cost is a top consideration, but there are also values for performing a system assessment:

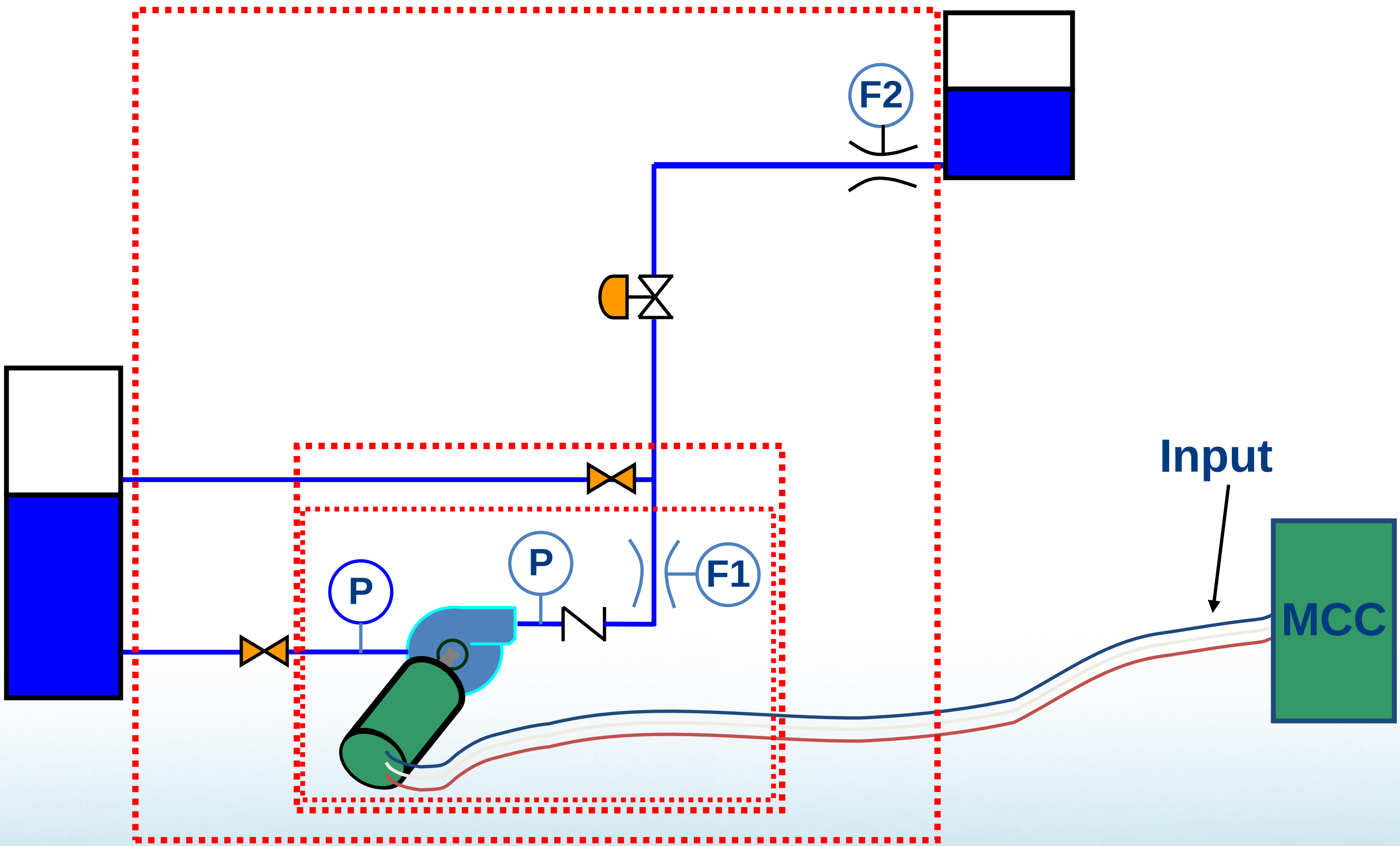
- Higher Reliability
- Increase Productivity
- Less Equipment Wear and Tear
- Reduced Maintenance Cost
- Reduce Production Losses
- Increase Capacity Utilization
- Reduce Environmental Impact

Improving Performance

of

Existing Pumping System

Defining the System



Performance Improvement Opportunities - Solutions

- Eliminate unnecessary uses
- Improve Operations & Maintenance (O & M) practices
- Improve piping configuration
- Consider alternative pump configurations
- Change pump speed

Unnecessary Uses

- Using a pump when the fluid is not needed
- Running two pumps when only one is needed
- Continuing to run pumps in a batch-type process when products are not being produced
- Excessive pump head or flow

System Opportunities

- Systems controlled by throttle valves
- High operating hours per year
- Recirculation or bypass line normally open
- Cavitation noise at valves, pumps, or piping
- Systems with multiple parallel pumps always operating
- Constant pump operation in a batch environment or frequent cycle batch operation in a continuous process

System Opportunities Continued

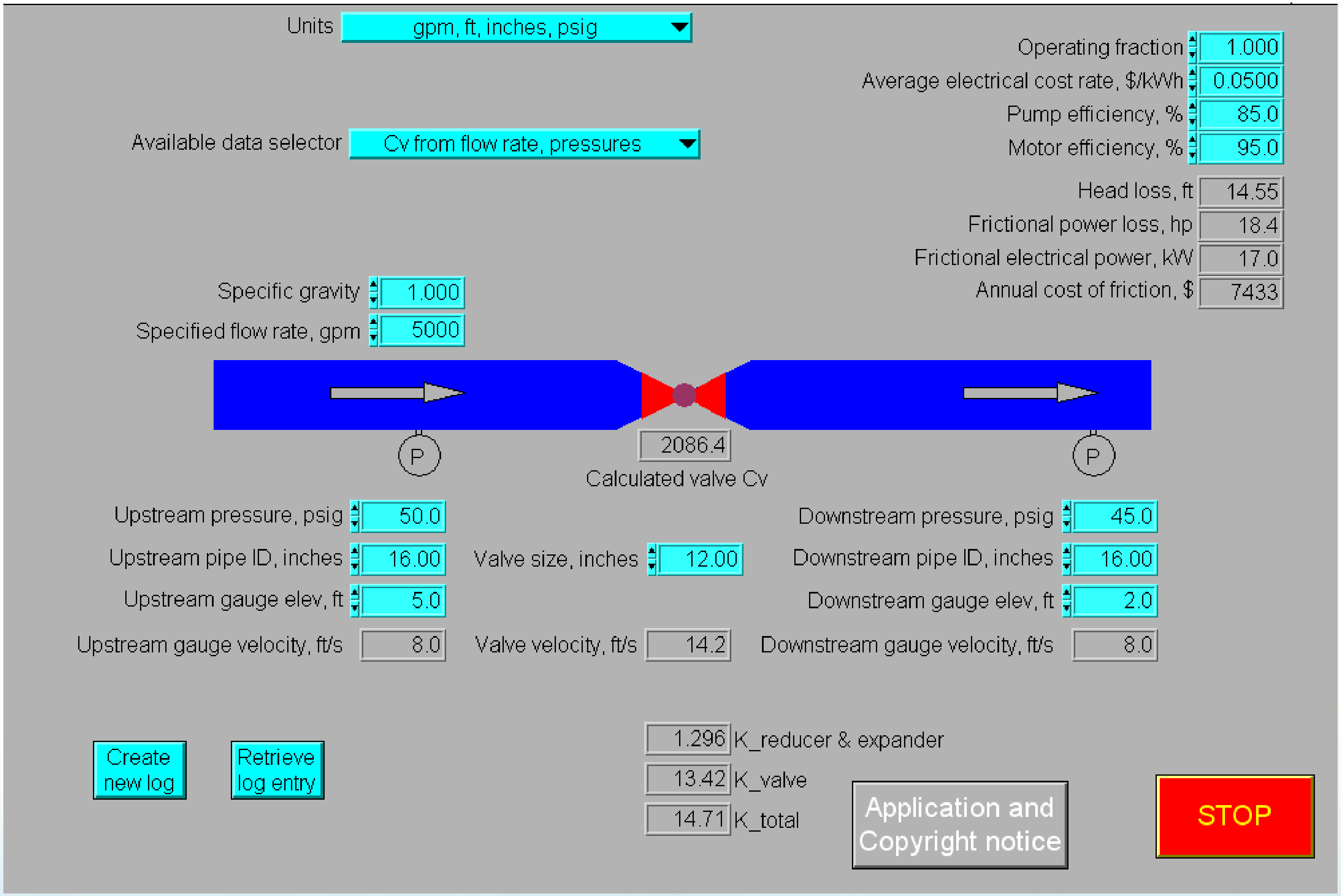
- Systems that have undergone a change
- Variability of operation
- High system maintenance
- Motor tripping out
- Larger pumps
- Excessive seal leakage & packing problems

Excessive Valve Throttling is Expensive

- Lower pump and process reliability
- Higher energy consumption
- Sub-optimal process control
  - increased variability
  - manual operation

Pumps are tightly associated with control loops and should be considered an integral part of the automation architecture

Valve Tool


Units
gpm, ft, inches, psig
Operating fraction
1.000
Average electrical cost rate, $/kWh
0.0500
Pump efficiency, %
85.0
Motor efficiency, %
95.0
Available data selector
Cv from flow rate, pressures
Head loss, ft
14.55
Frictional power loss, hp
18.4
Frictional electrical power, kW
17.0
Annual cost of friction, $
7433
Specific gravity
1.000
Specified flow rate, gpm
5000
P
2086.4
Calculated valve Cv
P
Upstream pressure, psig
50.0
Downstream pressure, psig
45.0
Upstream pipe ID, inches
16.00
Valve size, inches
12.00
Downstream pipe ID, inches
16.00
Upstream gauge elev, ft
5.0
Downstream gauge elev, ft
2.0
Upstream gauge velocity, ft/s
8.0
Valve velocity, ft/s
14.2
Downstream gauge velocity, ft/s
8.0
1.296
K_reducer & expander
13.42
K_valve
14.71
K_total
Create new log
Retrieve log entry
Application and Copyright notice
STOP

Change Pump Speed

- Slower motor
- **Two-speed motor ***
- **Changes to belt drives/gears ***
- Variable Speed Drives
  - Variable Frequency Drive
  - Magnetic Drive
  - Fluid Drive

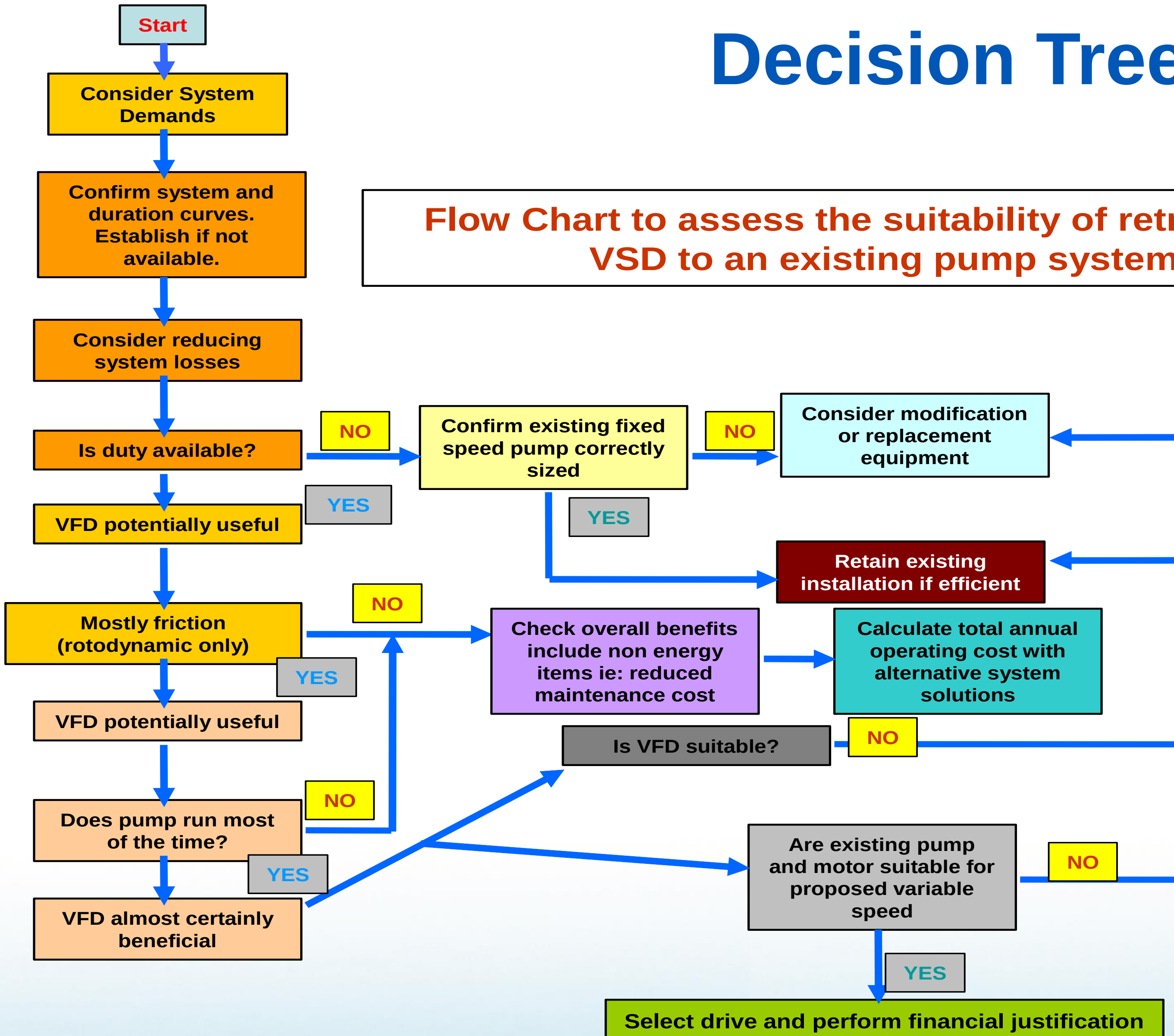
Variable Speed Pumping

- Why use a variable speed pump?
- When to use variable speed?
- When not to use variable speed?

Source: Section supplied by Manitoba Hydro

Decision Tree

Flow Chart to assess the suitability of retrofitting a VSD to an existing pump system



ırce – Hydraulic Institute LCC Guide Book

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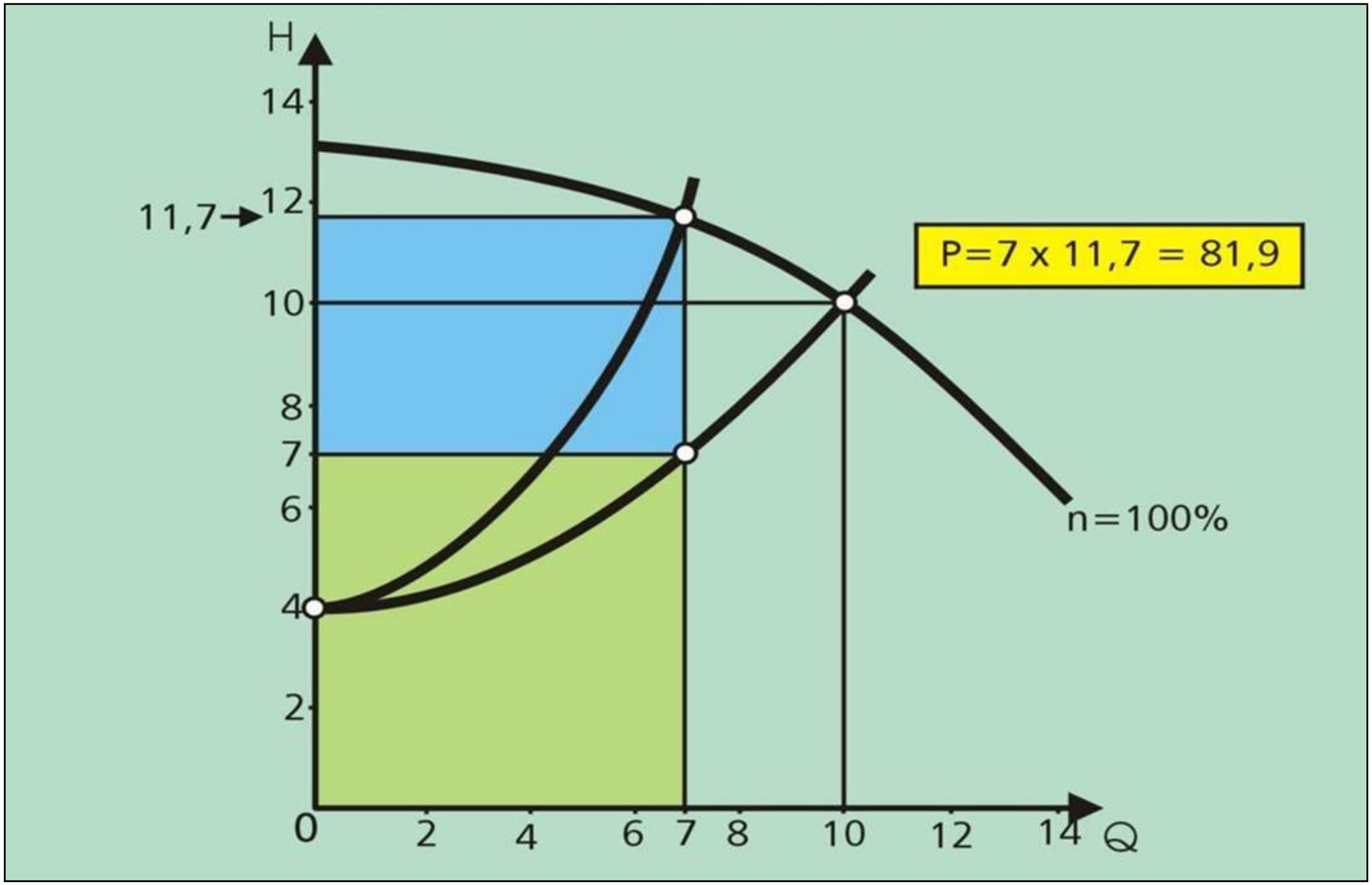
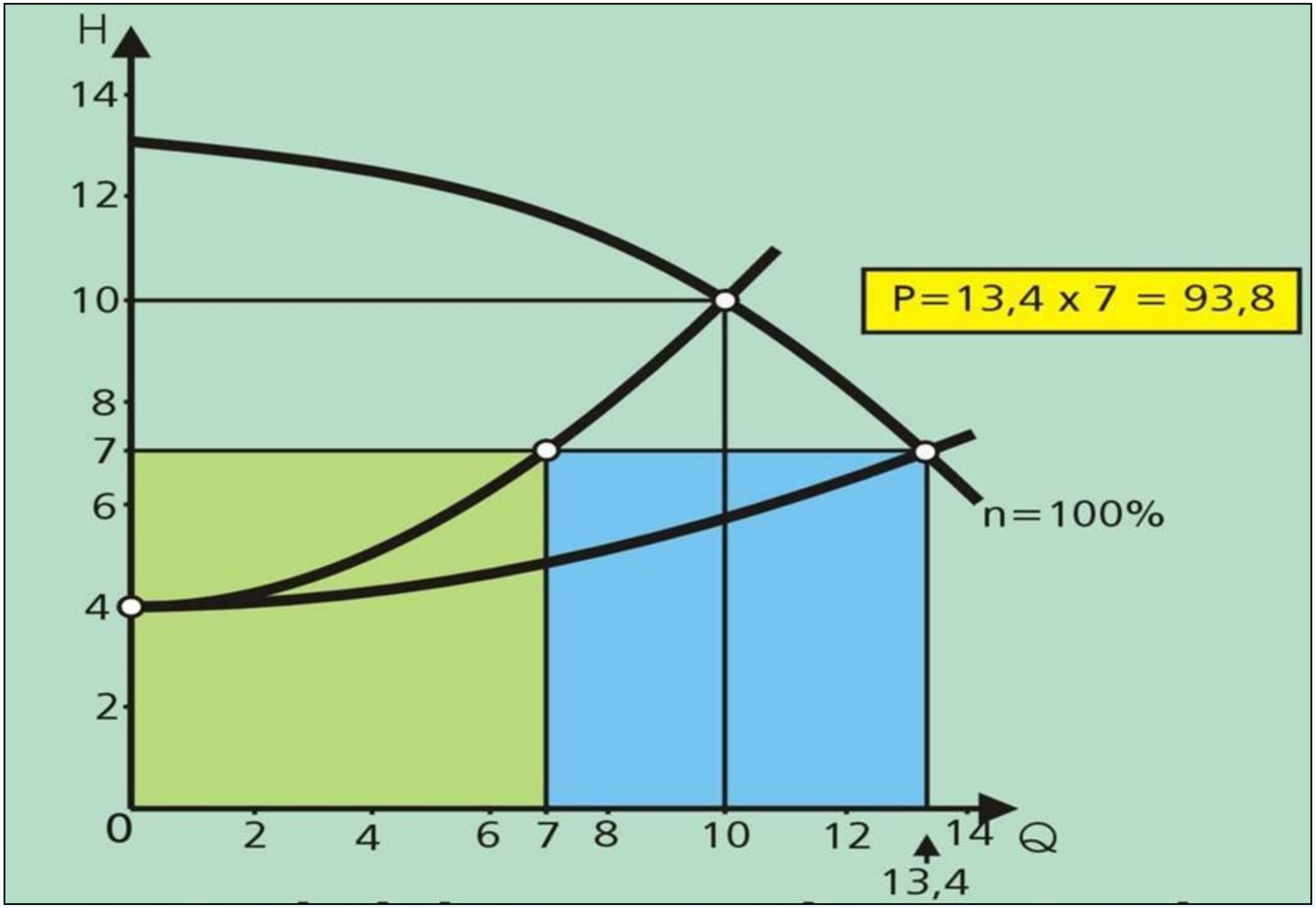
Throttle Control



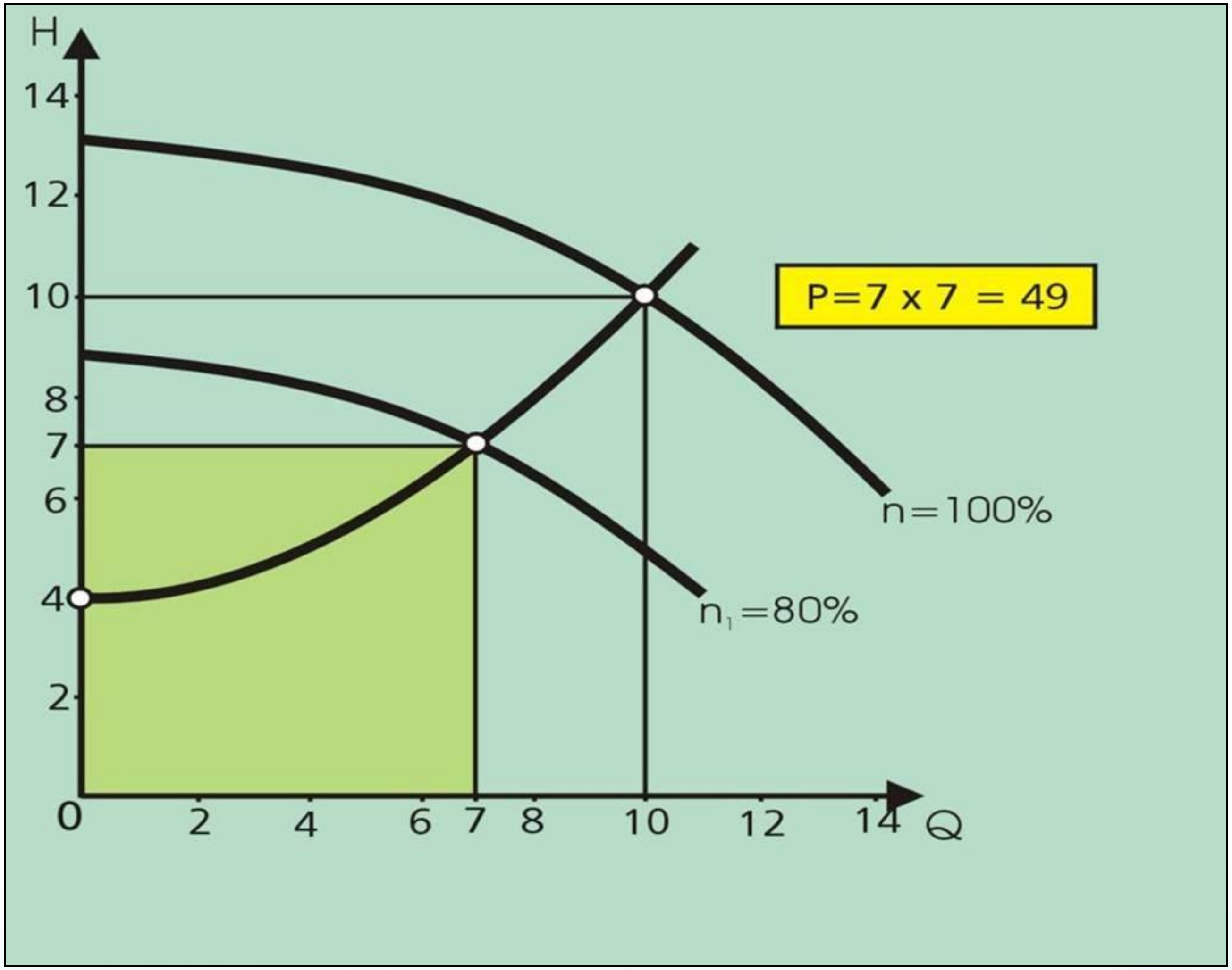
- **Valve throttling increases system head resulting in excess power consumption**
- **Excess energy noted in blue area**
- **Excess energy impacts equipment reliability**

By-Passing



- **Bypass lines require more flow, which results in excess power consumption.**
- **Excess energy impacts equipment reliability**

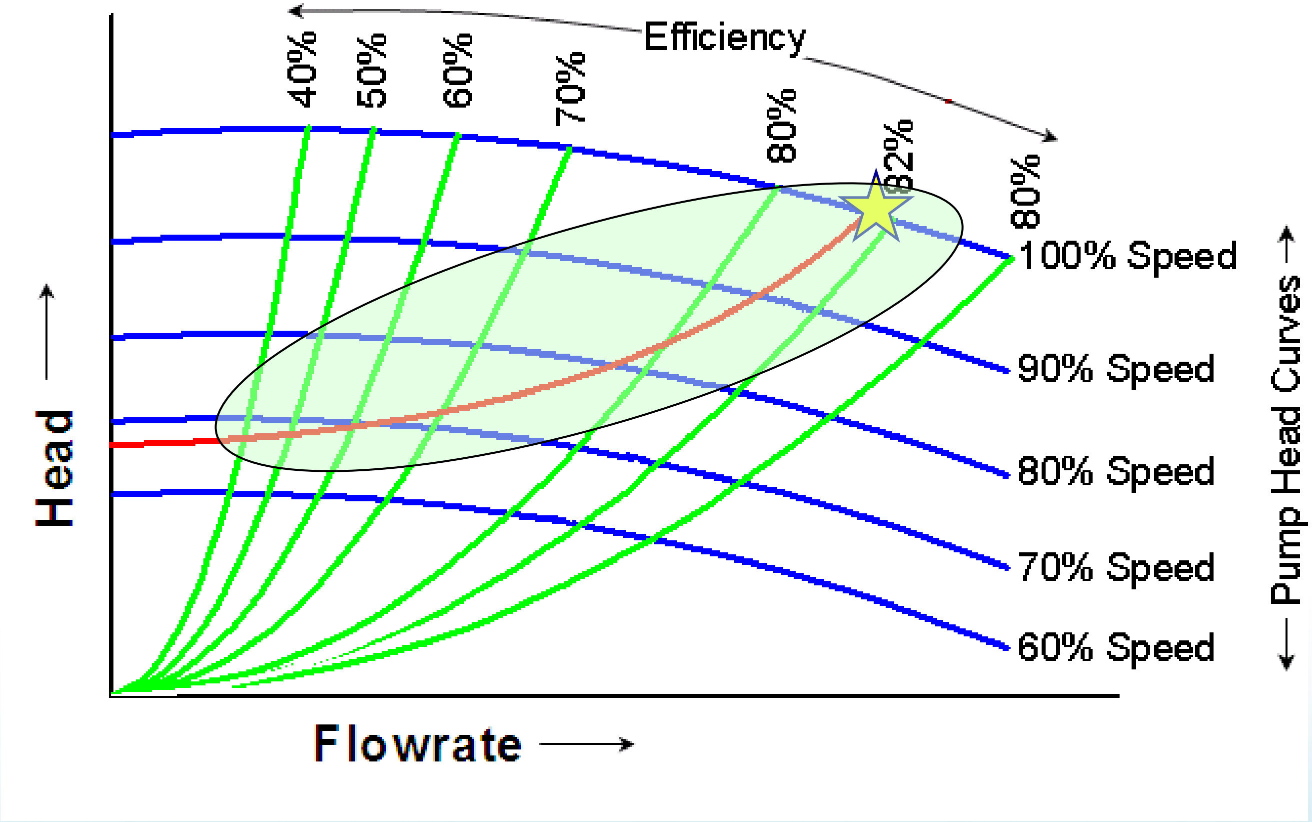
Variable Speed Control



- No excess energy used by the system
- Reliability is maximized

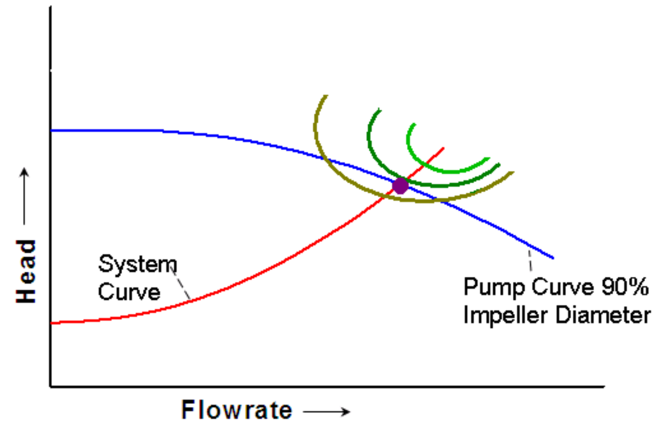
When to use Variable Speed?

Pump and System Curves Perpendicular

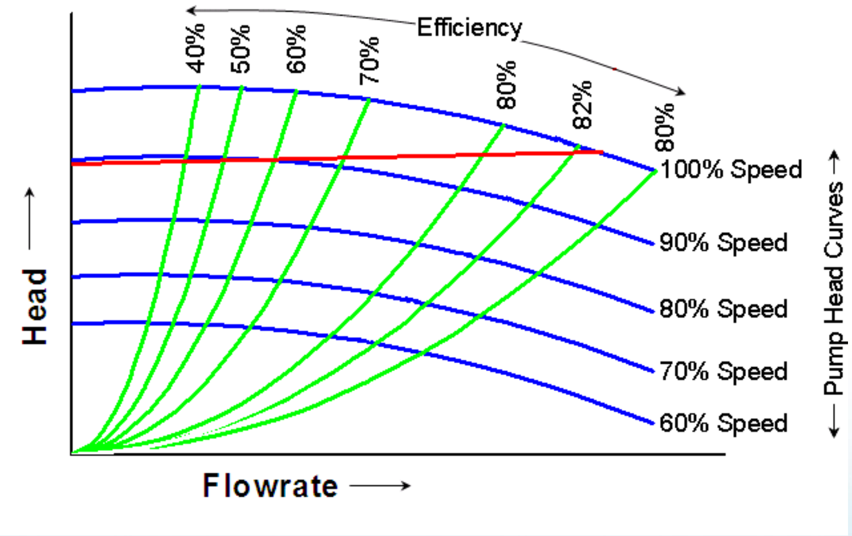


When Not to use Variable Speed Pumps?

No Variability? Use Impeller Trim or Reduced Fixed Speed



Pump and System Curves Parallel



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System Implications to Consider

VFD Pump Systems

- Select pump duty point to the right of BEP
- Consider full speed motor / VFD efficiency?
- Motor heat load due to drive wave form ?
- Check cable lengths (Critical Cable Length Calculation)
- Check if filters are needed (Inlet at drive or termination)
- Design VFD for by-pass operation at 60Hz

Checklist for VFD Pump Operation

- TDH vs. Static head ?
- Length of power cables ?
- Minimum speed
  - Where on pump curve ?
  - Cooling issues ?
- Harmonic filters ?
- Shielded signal cables ?
- How will control be programmed ?

Real World Example

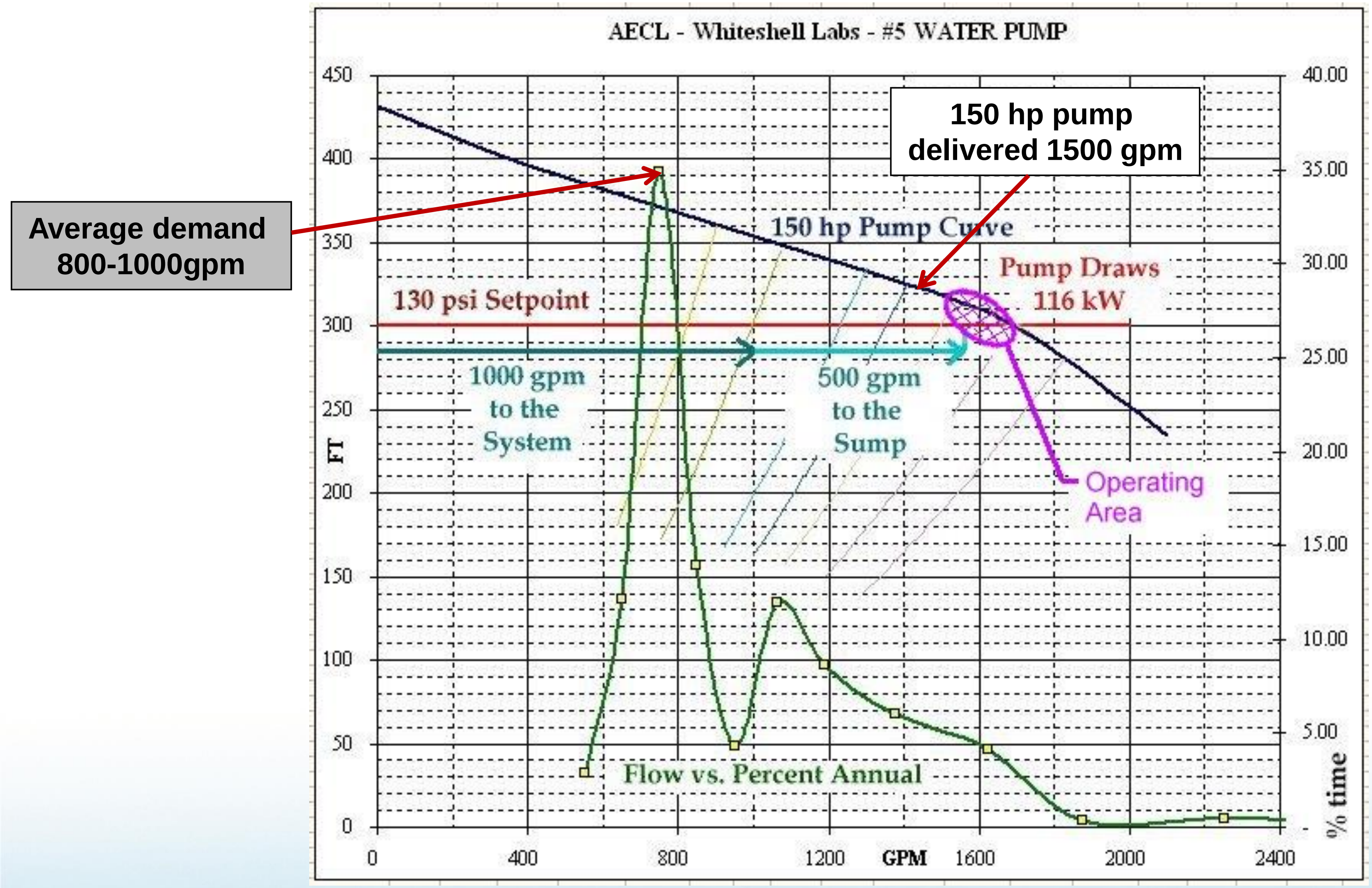
Real World Example

Three Pumps

- 150hp is the main pump.
- With increased demand, the 50hp is started.
- With even more increased demand, 150, 50 shut down, start 250hp.
- Finally, run all three together.
- All adjustments done manually.
- Circulation loop (blue valve) – 6” valve into 2” restriction, back into 6” pipe – controlled with a “dump” valve.

Lots of cavitation

Real World Example



Pumping more water than required

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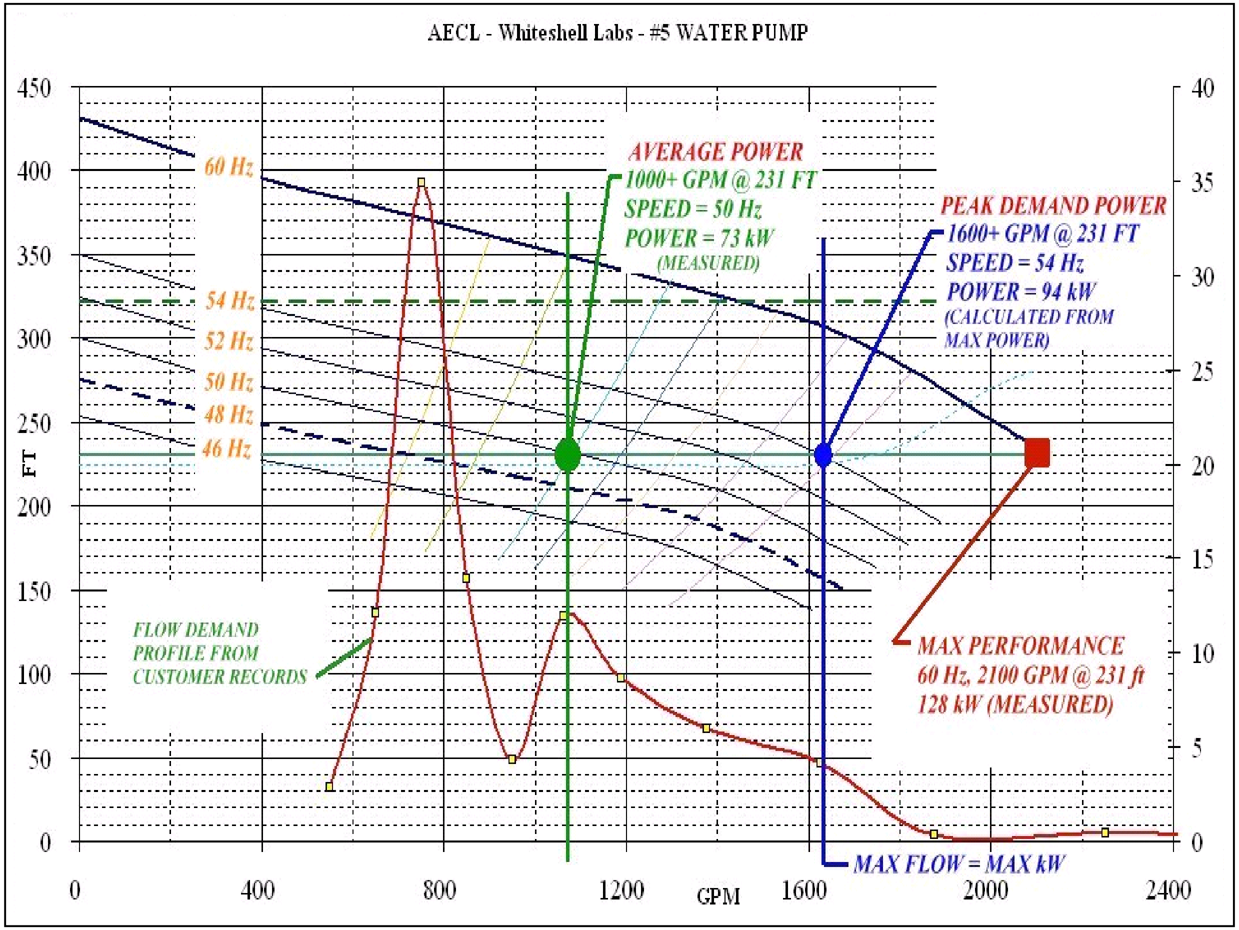
Choose Combinations of Pumps & Controls to Suit the System



- Pressure needed was not 130psi, but 100psi (230 ft. of head).
- Retrofitted to use 150hp pump all the time with a VSD.
- New average power is 73 kW.

Key Points

- Use a system approach to design and manage the pumping system operation
- Understanding the solutions available to improve performance with help you realize that there may be more than one solution to solve the problem!
- Variable Speed Drives are best applied when demand varies over time

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Developing
an
Action Plan

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Conclusion

- If you want to improve your pumping systems, follow the plan:
  - Create a partnership between production, management, purchasing, etc.
  - Find out what they consider important
  - Begin with something small and involve production
  - Always document everything that you do
  - Maintain ongoing communication with production and management
  - Measure and report the impact of system changes in terms that are important to management and production (show them the money)
  - Use life cycle cost analysis

Conclusion

- If you want to improve your pumping systems, follow the plan:
- 1st step is to understand pump system optimization
- 2nd step conduct comprehensive assessment
- 3rd step implement process improvements
- 4th step track results
- 5th present results to management
- 6th continuous improvement

Sustainable Growth

Thank You

Questions / Comments?