Pumping System Assessment

Week 3: MEASUR and Field Measurements

U.S. DEPARTMENT OF ENERGY

Homework 2 review

KEEP
CALM
AND
DO YOUR
HOMEWORK

Homework 2 review

1. Please do an investigation of one or two pump systems in your facility you wish to analyze and obtain the following data for each one of them.

a. Hours/year of operation
b. Cost of electricity, $/kWh
c. Pump type
d. Pump operating speed, RPM
e. Drive type (Direct, Std V-belt, Notched V-belt, Synchronous belt, VFD)
f. Fluid pumped
g. Fluid Temperature, F
h. Fluid specific gravity
i. Fluid kinematic viscosity, cSt
j. Number of pump stages
k. Motor horsepower rating
l. Motor rated RPM
m. Motor efficiency class (Standard, Energy Efficient, Premium Efficiency)
n. Motor rated voltage
o. Motor full load amps
p. Measured flow rate, GPM
q. Measured pump head, Feet
r. Measured motor power (kW with Power Meter or Volts & Current with clamp on meter)

Homework 2 review

2. Why do you think this pumping system has energy reduction potential?

3. List your questions about pumping systems in your facilities.

Homework 2 review

4. A pump operates under the following conditions: flow is 500 gpm; suction pressure is 22.9 psig; discharge pressure is 127.4 psig; suction gauge elevation is 4 feet off the floor; discharge gauge elevation is 8 feet off of the floor; suction piping is 6 inch diameter; discharge piping is 5 inch diameter; the suction side loss coefficients total 1.75; the discharge side loss coefficients total 2.5; the fluid is corn oil with a specific gravity of 0.924. Calculate the pump head with hand calculations and then use MEASUR to determine the pump head.

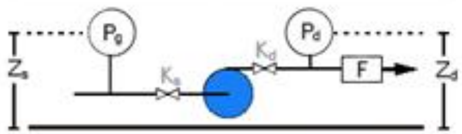
Suction pipe diameter = (Pi x $(6/12)^2$)/4 = 0.19635 ft^2
Discharge pipe diameter = (Pi x $(5/12)^2$/4 = 0.13636 ft^2
Suction flow velocity = (500 gal/min)/(7.4805 gal/ft^3 x 60 s/min x 0.19635 ft^2) = 5.6736 ft/s
Suction pipe velocity head = $(5.6736\ ft/s)^2$/(2 x 32.174 ft/s^2) = 0.50024 ft
Discharge flow velocity = (500 gal/min)/(7.4805 gal/ft^3 x 60 s/min x 0.13635 ft^2) = 8.1700 ft/s
Discharge pipe velocity head = $(8.1700\ ft/s)^2$/(2 x 32.174 ft/s^2) = 1.03731 ft

Pump elevation head = (8 ft – 4 ft) = 4 feet
Pump pressure head = (127.4 – 22.9) x 2.31 / 0.924 = 261.25 feet
Differential velocity head = 1.03731 – 0.50024 = 0.53707 feet
Suction line losses = 1.75 x 0.50024 ft = 0.8754 feet
Discharge line losses = 2.50 x 1.03731 ft = 2.5933 feet
Total Pump Head = 269.26 feet

Homework 2 review

PUMP HEAD TOOL

Suction tank elevation | Suction gauge elevation



K_s represents all suction losses from the tank to the pump

K_d represents all discharge losses from the pump to the gauge P_d

Fluid Specific Gravity	0.924
Flow Rate	500 gpm

Suction		Discharge	
Pipe diameter (ID)	6 in	Pipe diameter (ID)	5 in
Gauge pressure (P_g)	22.9 psi	Gauge pressure (P_d)	127.4 psi
Gauge elevation (Z_s)	4 ft	Gauge elevation (Z_d)	8 ft
Line loss coefficients (K_s)	1.75	Line loss coefficients (K_d)	2.5

RESULTS | HELP

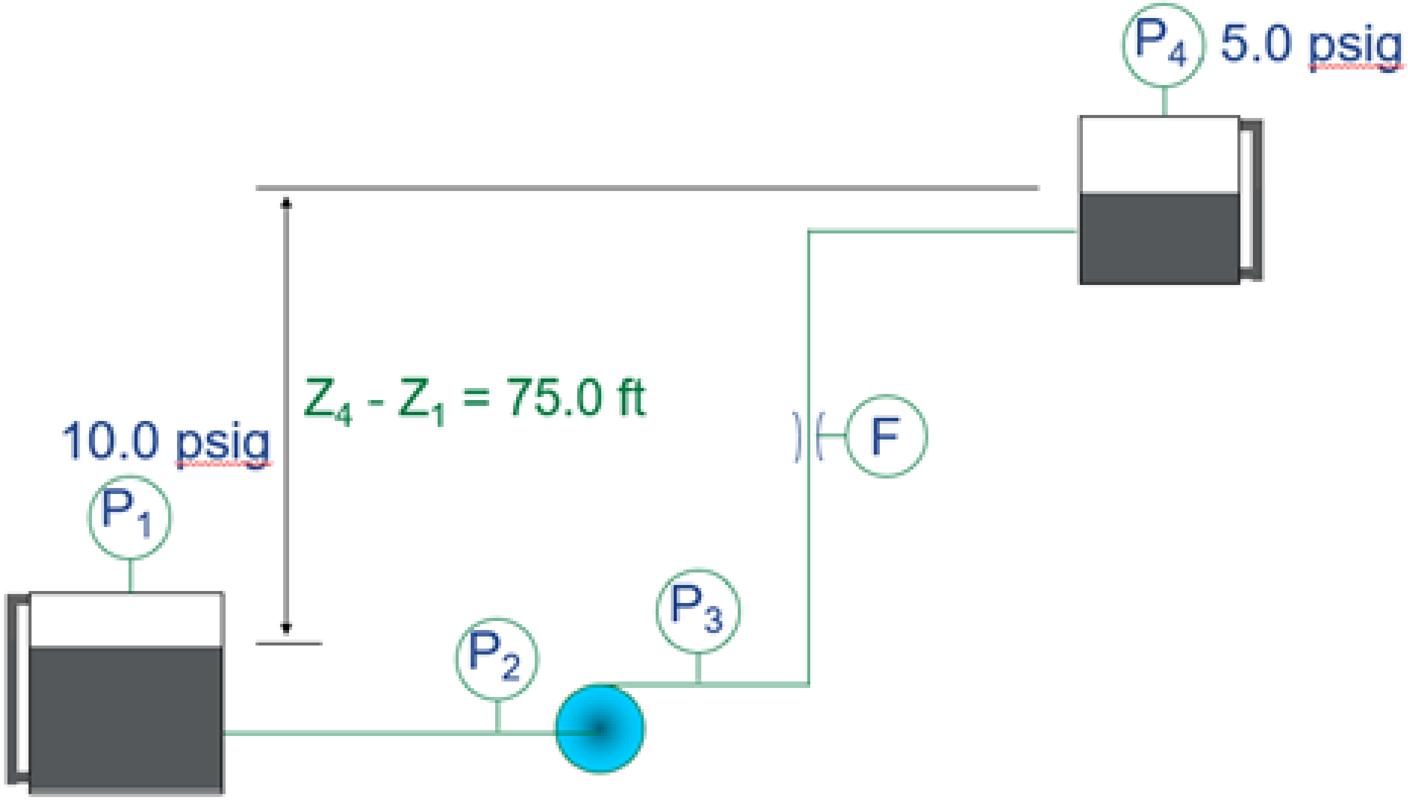
Result Data

Differential Elevation Head	4.0 ft
Differential Pressure Head	261.34 ft
Differential Velocity Head	0.54 ft
Estimated Suction Friction Head	0.88 ft
Discharge Friction Head	2.59 ft
Pump Head	269.35 ft

Copy Table

Homework 2 review

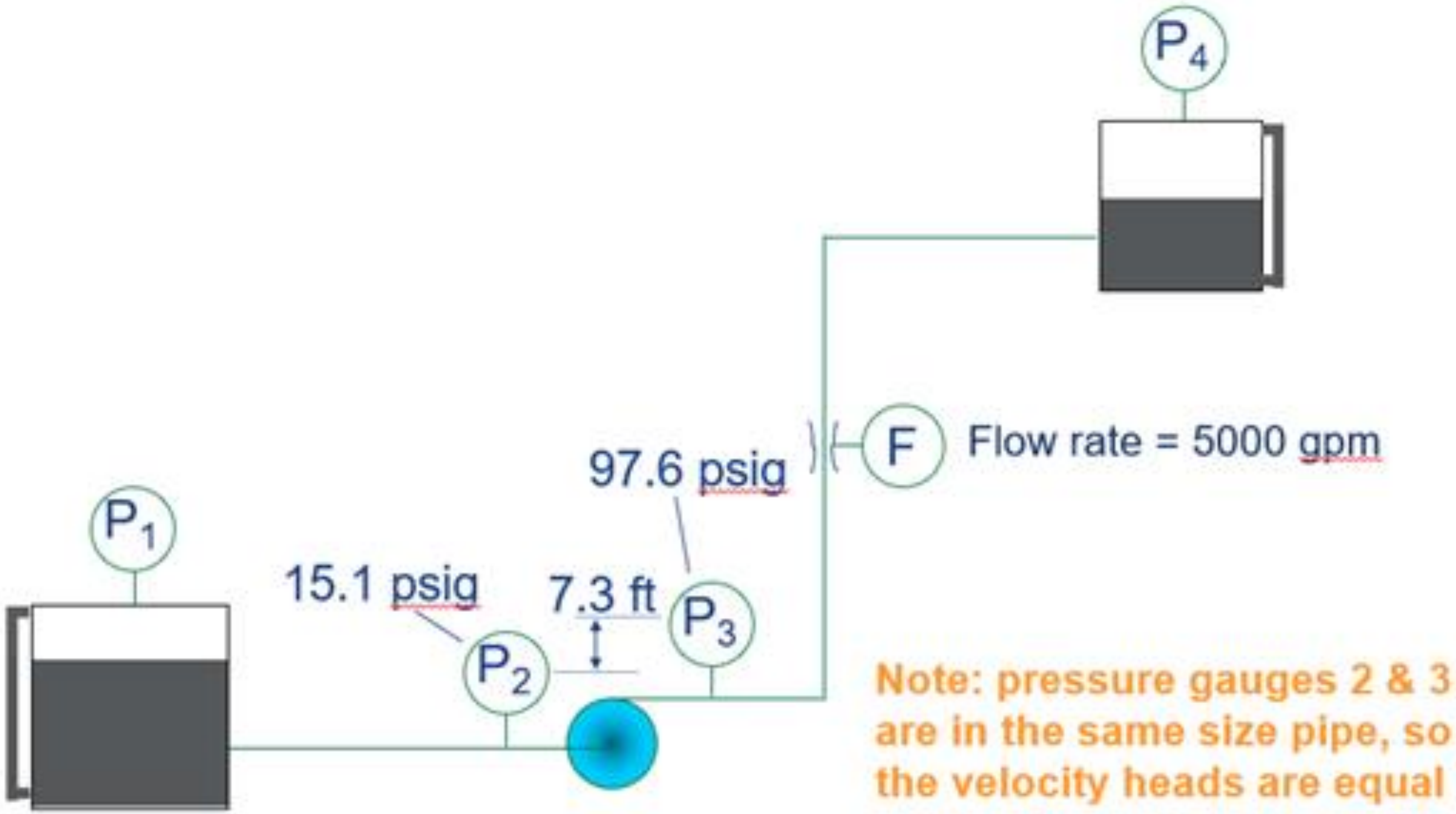
5. Calculate the static head for the system below. Standard water is being pumped.



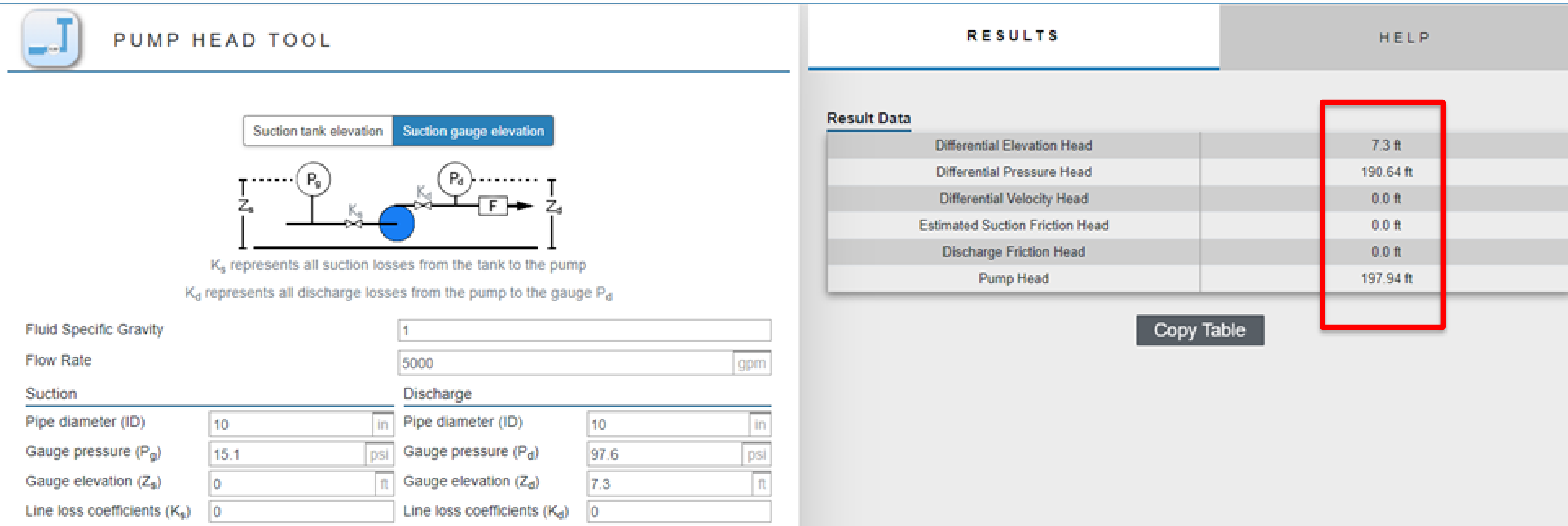
Static Head = 75.0 + 2.31 x (5.0 – 10.0) = 63.45 feet

Homework 2 review

6. Calculate the pump head for the figure below. The flow rate is 5000 gpm of standard water.



Homework 2 review



Pump Head = 197.94 feet

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7. Using the static head from Problem 5 and the pump head and flow from Problem 6, calculate the system curve this piping system by hand and using MEASUR. The equation should be of the form:

$$H_{total} = H_{static} + k'Q^{1.9}$$

Static Head = 63.45; k′ = (197.94 – 63.45)/5000$^{1.9}$ = 0.0000126

System Curve Equation = 63.45 + 0.0000126 x Q$^{1.9}$

System Curve Data

System Curve

Fluid Specific Gravity	1.002
System Loss Exponent, C	1.9

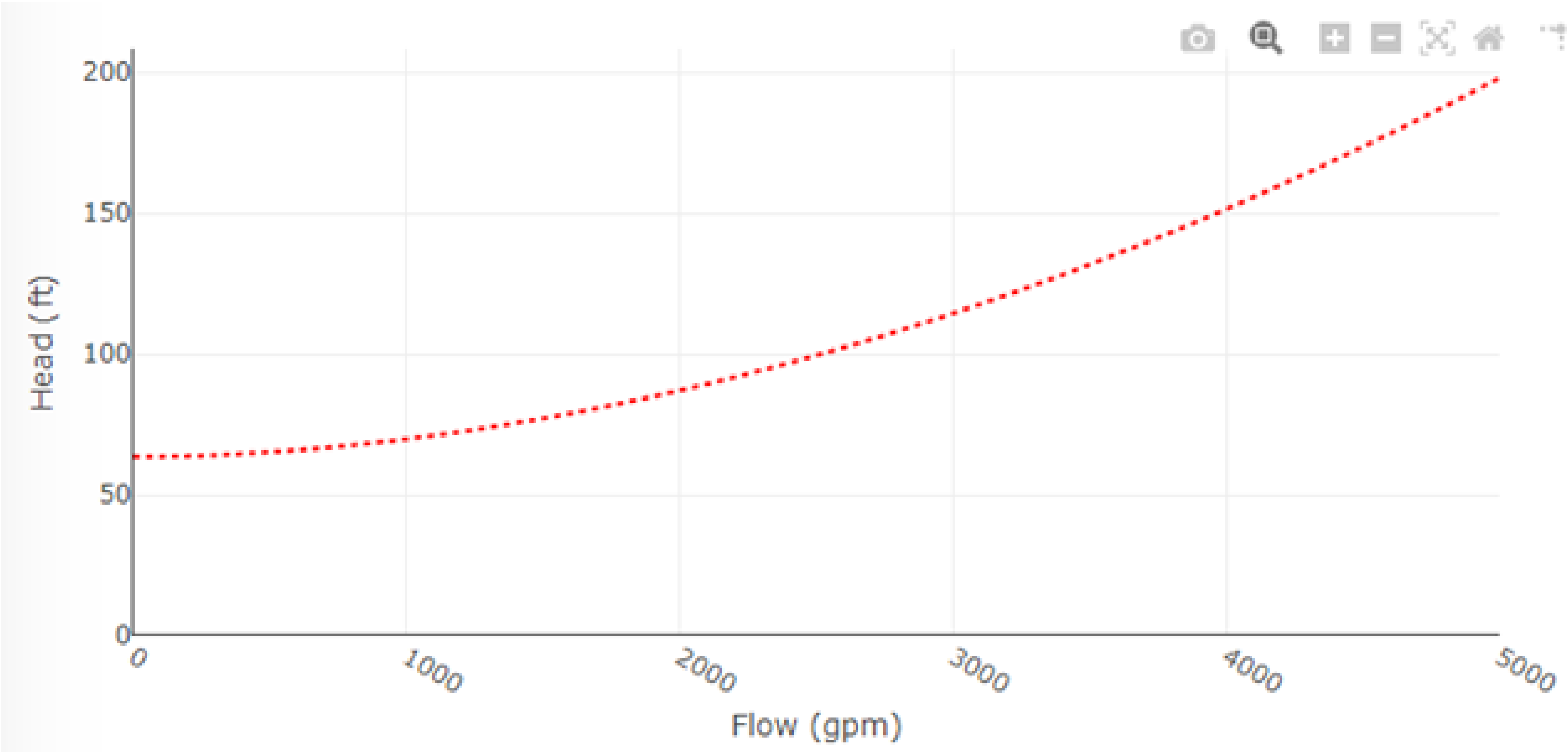
Point 1

Flow Rate	0 gpm
Head	63.45 ft

Point 2

Flow Rate	5000 gpm
Head	197.94 ft

Homework 2 review



System Curve

Head = 63.5 + (0.0000126 × flow$^{1.9}$)

Homework 2 review

8. A plant has a VFD installed on a fully loaded 100 hp pump. The operators continue to run the pump at 60 Hz and the automatic control system is not connected to the VFD. The VFD efficiency is estimated to be 97%. How much has the operating cost for the pump increased per year if the VFD operates at 60 Hz continuously? The average net cost of electricity is $0.08/kWh and the electric motor efficiency is 95%.

Answer:

kW with VFD = (100 hp x 0.746 kW/hp)/(0.95 x 0.97) = 80.95 kW

kW without VFD = (100 hp x 0.746 kW/hp)/0.95 = 78.53 kW

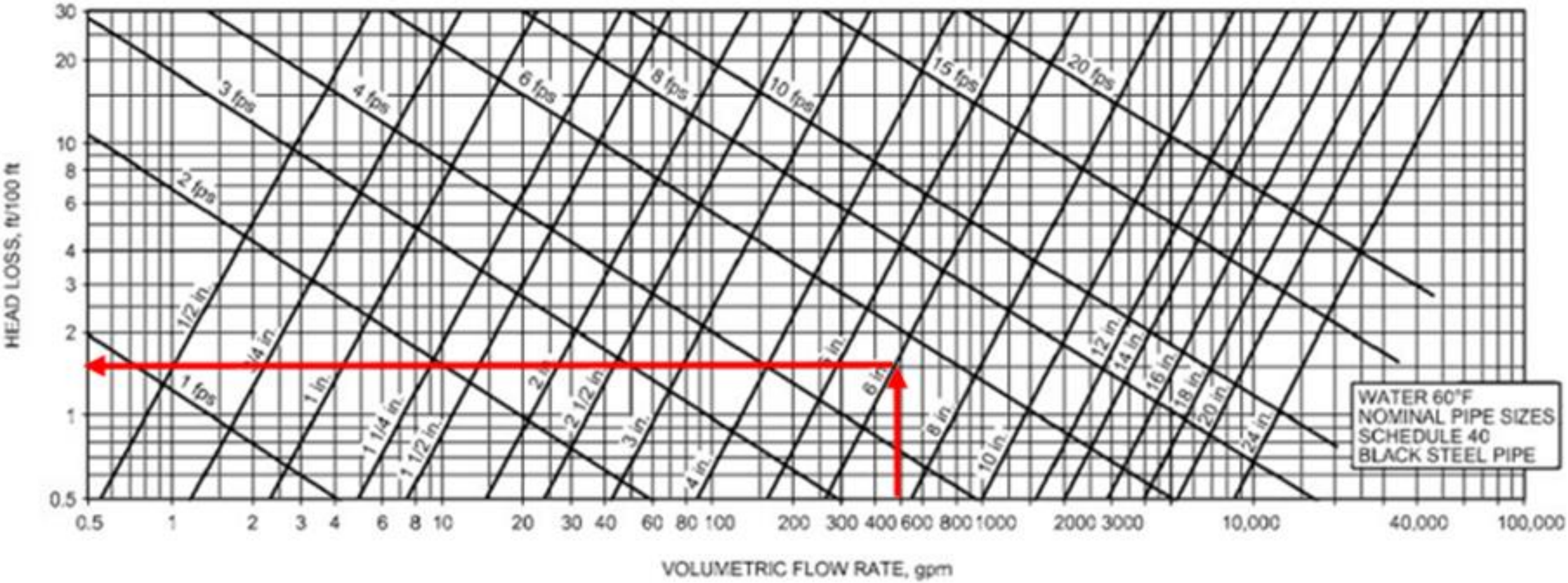
Extra Annual Cost for VFD Losses = (80.95 – 78.53) x 8760 hr/yr x $0.08/kWh = $1,696/yr

Homework 2 review

9. A chilled water closed loop piping system has a 200-ton chiller with the evaporator flow at 480 gpm of water at 42 F. This piping loop has a straight pipe length of 3500 feet, 2-gate valves (wide open), 10-std 90-degree elbows, 1-check valve, and 1-strainer (K = 2.0). The chiller evaporator has a 20-foot head loss and each of the 5 chilled water coils has a 12-foot head loss, all supplied by the chilled water circulating pump. Determine the following:
   a. The size of the pipe is needed for the 480 gpm flow. (See slide 48 first presentation)
   b. The total head loss for the system assuming schedule 40 black steel pipe.
   c. Go to the following link and select a chilled water pump for this system. [ESP Systemwize (esp-systemwize.com)](esp-systemwize.com)

Homework 2 review

a. 6" diameter pipe from slide 48 first presentation



Homework 2 review

b. Pump Head: Straight pipe 1.8 feet loss/100 feet of pipe (from slide) = 1.8 x 35 = 63 feet

Calculate velocity in the 6-inch diameter pipe.

Cross sectional area = (Pi x $(0.5)^2$)/4 = 0.19635 ft^2.

Flow velocity = (480 gal/min)/(7.48 gal/ft^3 x 0.19635 ft^2 x 60 sec/min) = 5.447 ft/s

$V^2/2g$ = $(5.447\ ft/s)^2/(2 \times 32.174\ ft/s^2)$ = 0.461 ft

90-degree elbows = 10 els x 0.3 x 0.461 ft = 1.383 ft

Gate valves = 2 valves x 0.2 x 0.461 ft = 0.184 ft

Check valve = 1 valve x 2.0 x 0.461 ft = 0.922 ft

Strainer = 1 strainer x 2.0 x 0.461 ft = 0.922 ft

Cooling coils = 5 coils x 12 ft/coil = 60 ft

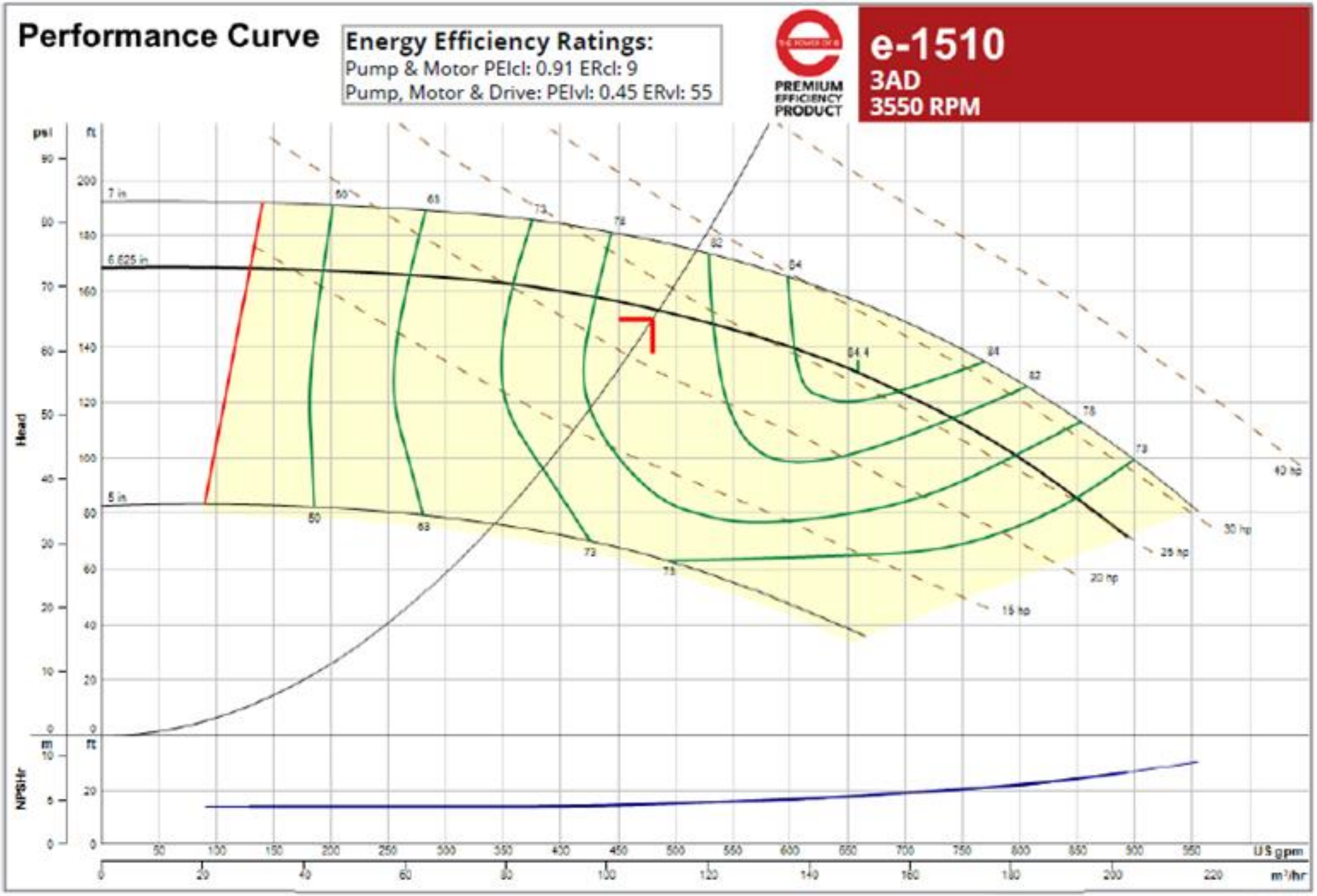
Total head loss = 146.41 feet

Select pump for 480 gpm @ 150 feet of head

Bell & Gossett e1510 3AD 6.625 inch diameter impeller, 23.2 bhp, 30 hp motor, 3550 rpm

Homework 2 review

c.



Homework 2 review

c.

Base Mounted End Suction Pump

Series: e-1510

Model: 3AD

Features & Design

- ANSI/OSHA Coupling Guard
- Center Drop Out Spacer Coupling
- Fabricated Heavy Duty Baseplate
- Internally Self-Flushing Mechanical Seal

*The Bell & Gossett Series e-1510 is available in 26 sizes and a variety of configuration options that enable customization and flexibility to fit a broad range of operating conditions.

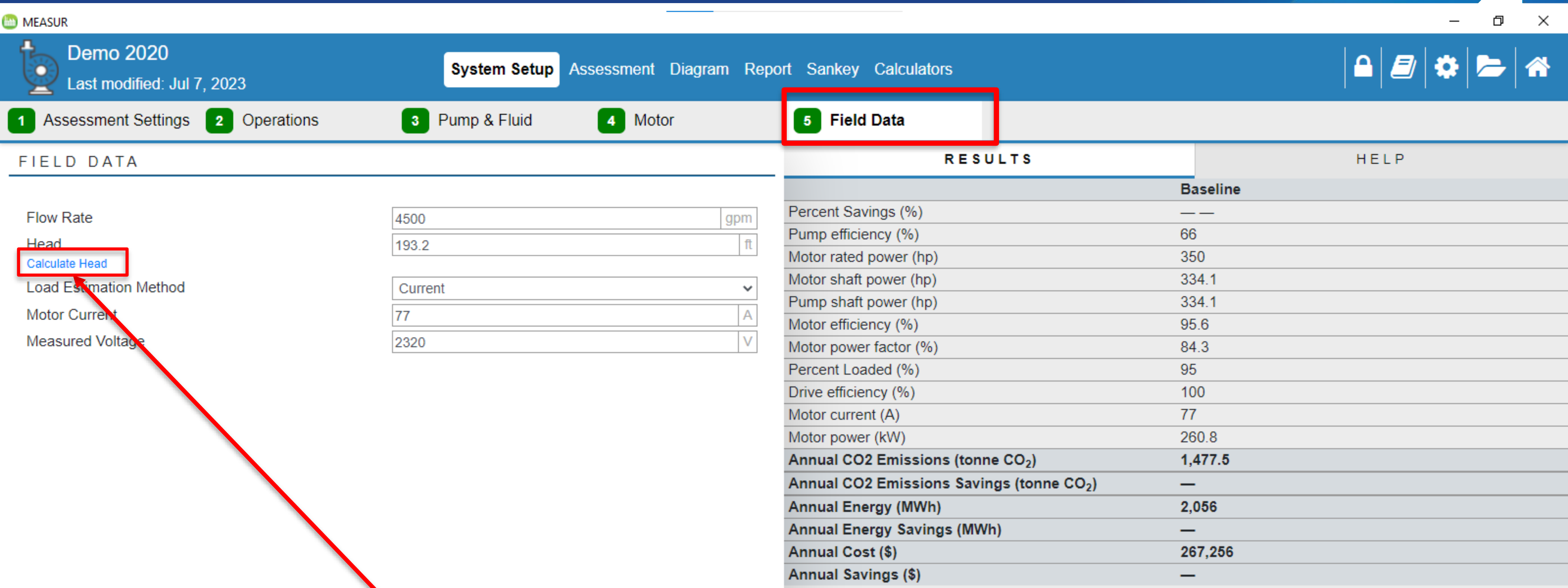
http://bellgossett.com/pumps-circulators/end-suction-pumps/e-1510/

Pump Selection Summary

Duty Point Flow	480 US gpm
Duty Point Head	150 ft
Control Head	0 ft
Duty Point Pump Efficiency	80.1 %
Part Load Efficiency Value (PLEV)	0.0 %
Impeller Diameter	6.625 in
Motor Power	30 hp
Duty Point Power	23.2 bhp
Motor Speed	3600 rpm
RPM @ Duty Point	3550 rpm
NPSHr	15 ft
Minimum Shutoff Head	169 ft
Minimum Flow at RPM	132 US gpm
Flow @ BEP	659 US gpm
Fluid Temperature	68 °F
Fluid Type	Water
Weight *(approx. - consult rep for exact)*	624 lbs
Pump Floor Space Calculation	6.39 ft²

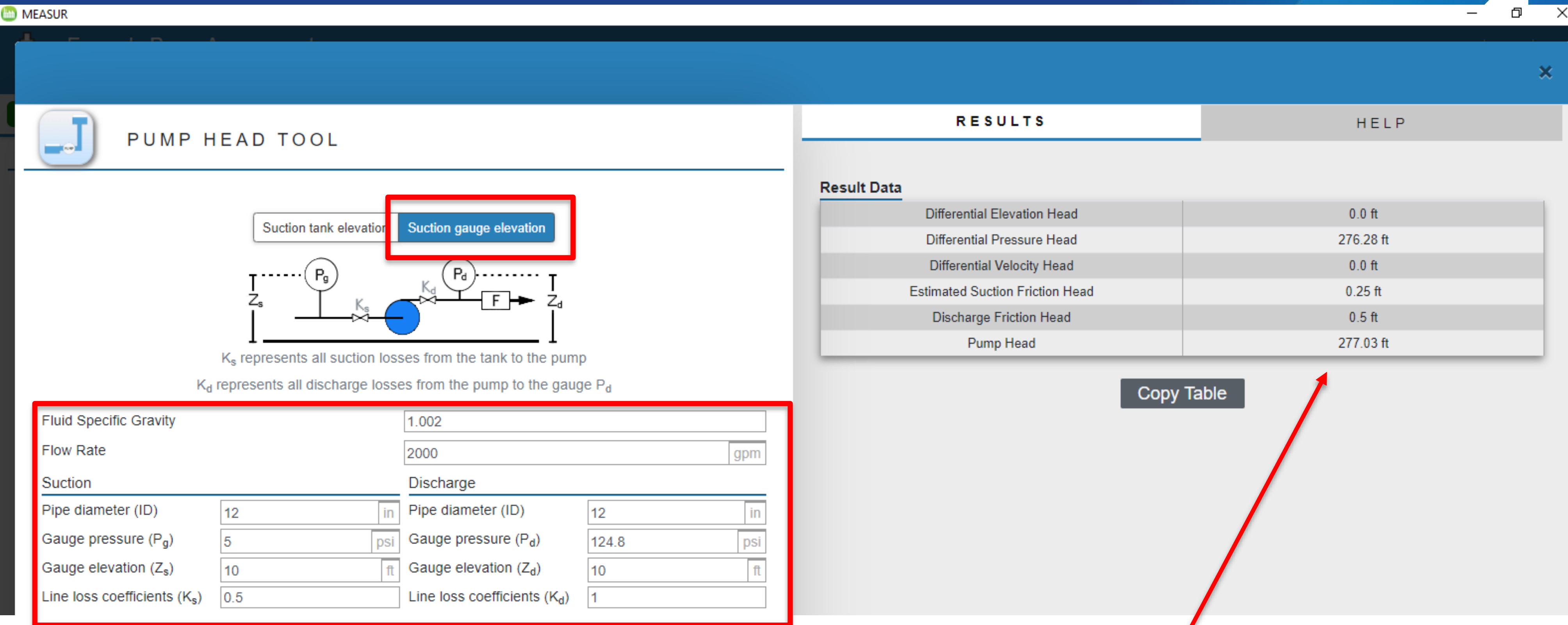
Accessing pump head calculator in MEASUR

System Setup – Calculate Pump Head



Go to the pump head calculator by clicking here

System Setup – Pump Head Calculator

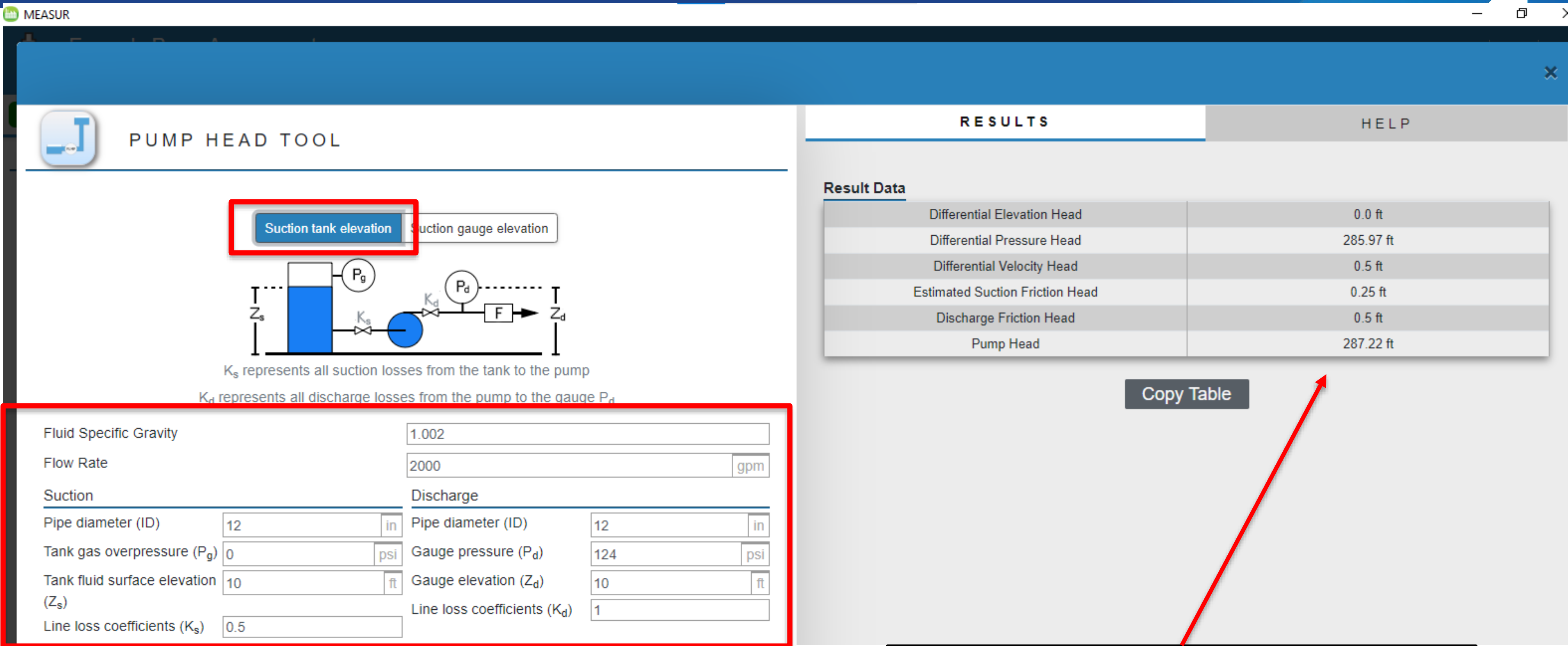


Input Field Data

Pump Head

Two Different Geometries: Suction Gauge

System Setup – Pump Head Calculator



Input Field Data

Pump Head

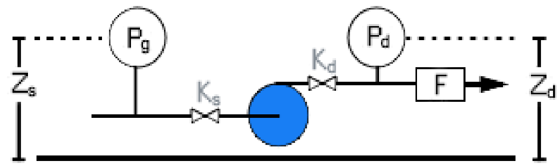
Two Different Geometries: Suction Tank

Loss Coefficients

PUMP HEAD TOOL

An important note on loss coefficients!

Suction tank elevation | Suction gauge elevation



K_s represents all suction losses from the tank to the pump

K_d represents all discharge losses from the pump to the gauge P_d

Fluid Specific Gravity	1
Flow Rate	2000 gpm

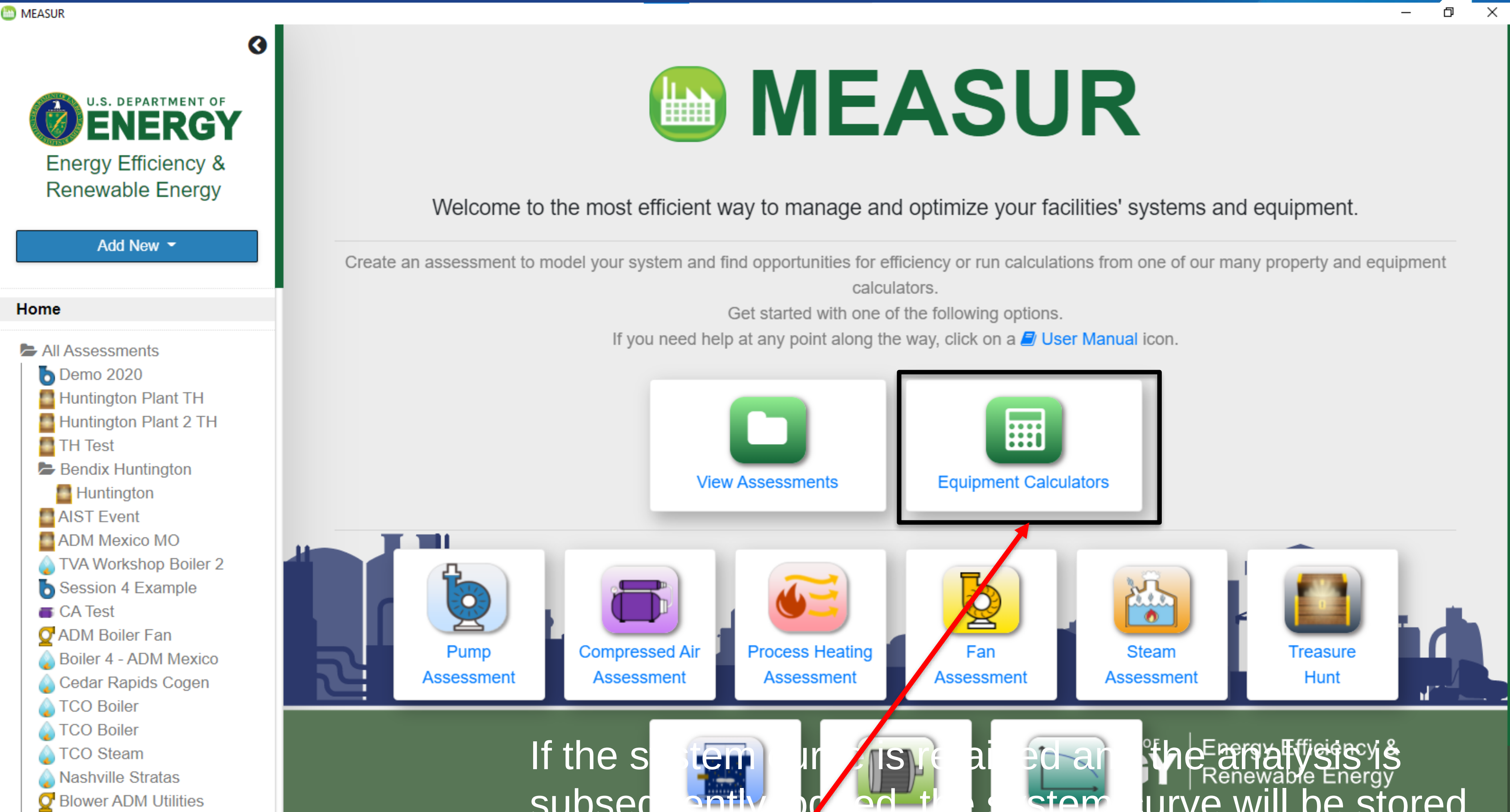
Suction		Discharge	
Pipe diameter (ID)	0 in	Pipe diameter (ID)	0 in
Gauge pressure (P_g)	0 psi	Gauge pressure (P_d)	0 psi
Gauge elevation (Z_s)	0 ft	Gauge elevation (Z_d)	0 ft
Line loss coefficients (K_s)	0	Line loss coefficients (K_d)	0

Important note about loss coefficients

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

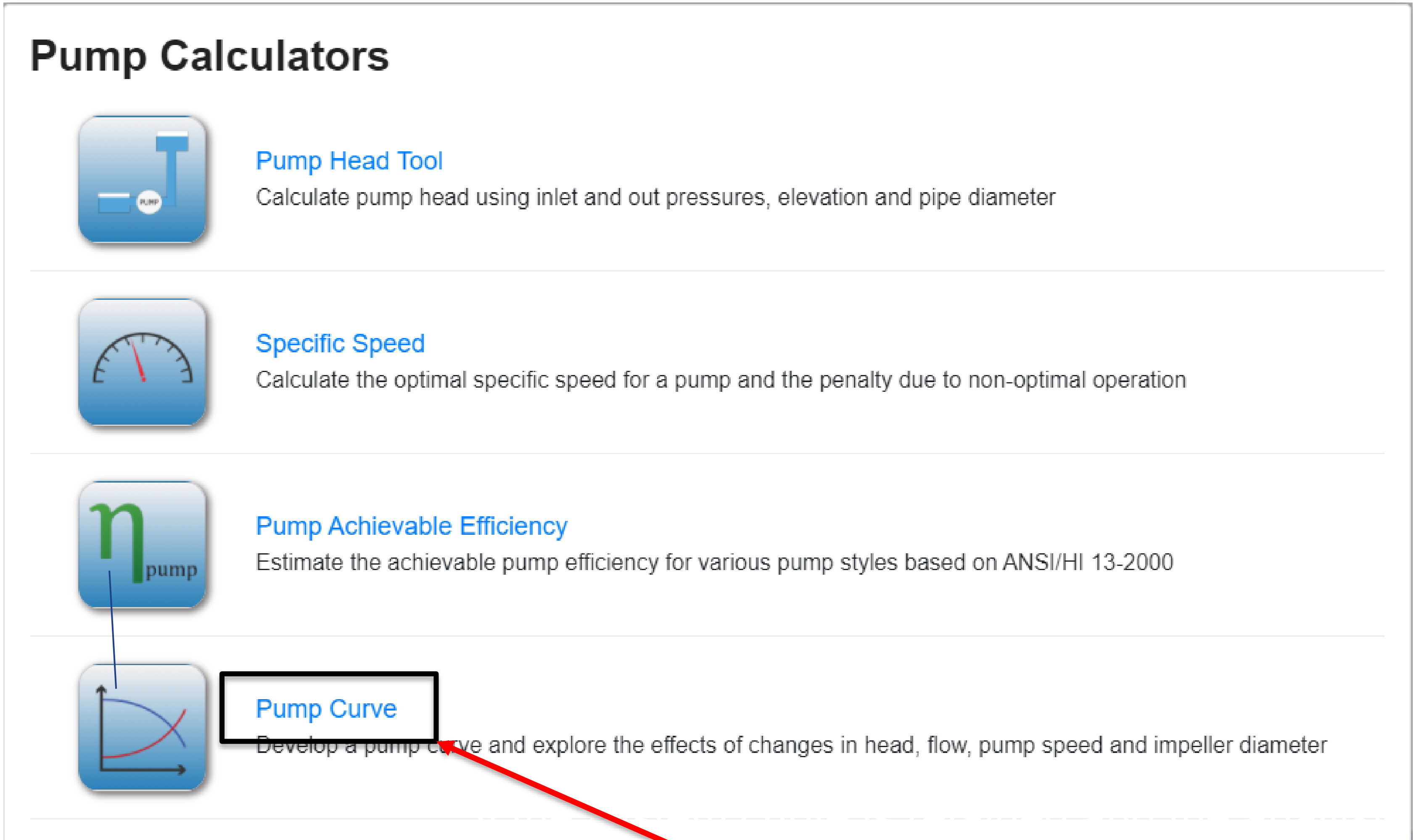
If the loss elements are in different size lines than the points of pressure measurement, they need to be appropriately scaled. It is generally suggested that the losses be scaled in proportion to the 4th power of the diameter ratio. For example, if the discharge pressure is measured in a 12-inch header,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

Accessing system curve calculator



Select the Equipment Calculators

Accessing system curve calculator



Pump Calculators

Pump Head Tool
Calculate pump head using inlet and out pressures, elevation and pipe diameter

Specific Speed
Calculate the optimal specific speed for a pump and the penalty due to non-optimal operation

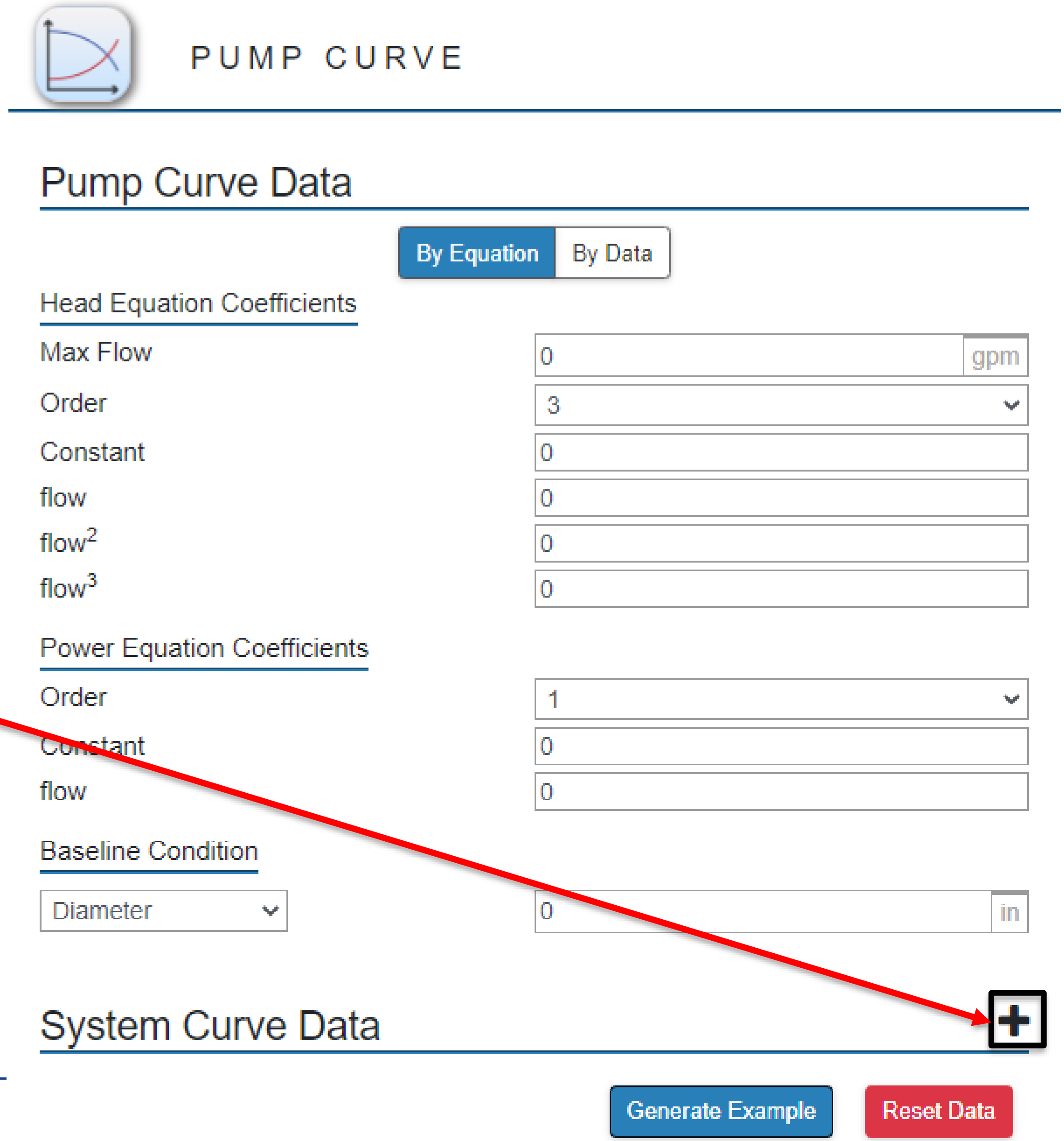
Pump Achievable Efficiency
Estimate the achievable pump efficiency for various pump styles based on ANSI/HI 13-2000

Pump Curve
Develop a pump curve and explore the effects of changes in head, flow, pump speed and impeller diameter

Select the Pump Curve Tool

Accessing system curve calculator

Click the "+" beside the System Curve Data



Accessing system curve calculator

System Curve Data

System Curve

Fluid Specific Gravity	1.0
System Loss Exponent, C	1.9

Point 1

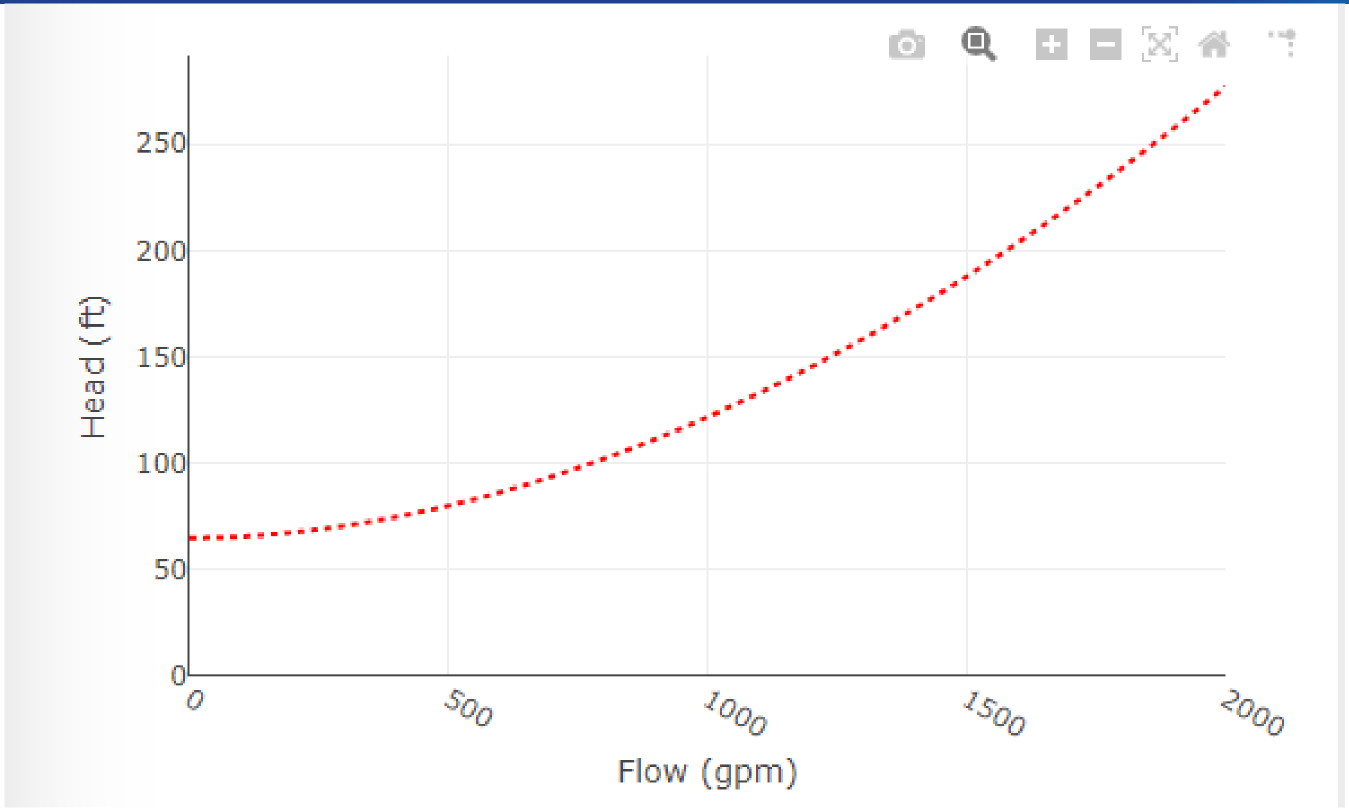
Flow Rate	0	gpm
Head	65	ft

Point 2

Flow Rate	2000	gpm
Head	277	ft

Fill in the required information

Accessing system curve calculator



System Curve

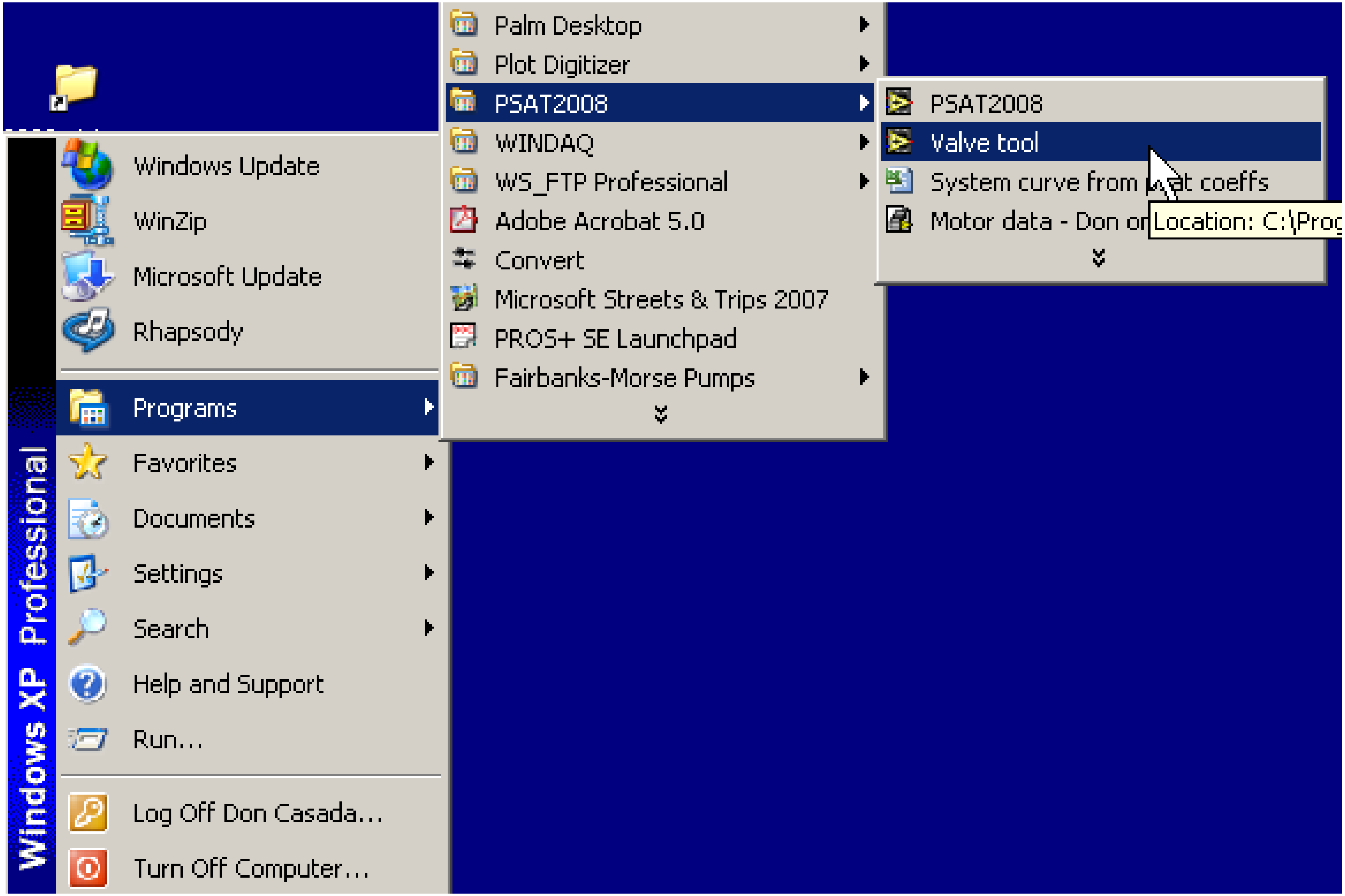
Head = 65.0 + (0.000113 × $flow^{1.9}$)

Get the System Curve Equation & Graph

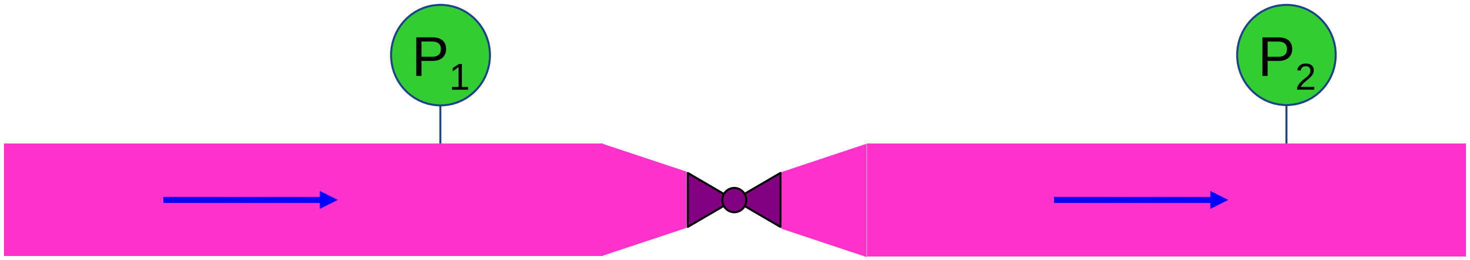
Pumping tool before MEASUR was PSAT (Pumping System Assessment Tool)

- The first Pumping System Analysis Tool developed by US DOE was PSAT
- PSAT download comes with another program, ***Valve Tool***, that is very useful
- Valve Tool has not been added to MEASUR yet
- PSAT and Valve Tool can be downloaded from the following website
- https://www.energy.gov/eere/amo/downloads/pumping-system-assessment-tool-psat

A valve tool is included in the PSAT2008 package



The valve tool works from the fundamental valve relationships



Valve Equation

$$Q = F_p C_v \sqrt{\frac{\Delta P}{s.g.}}$$

In U.S. units:

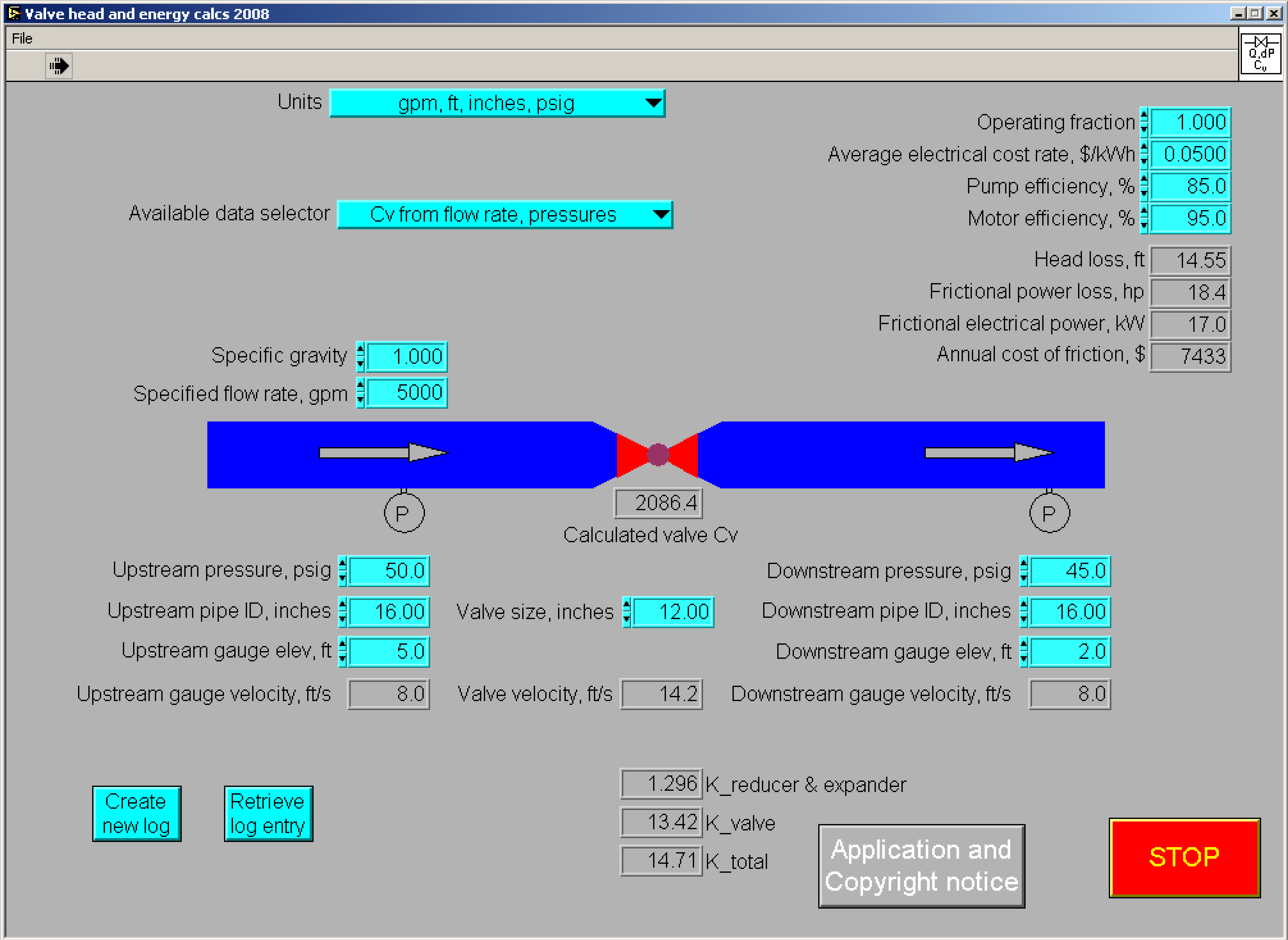
Q = Flow rate (gpm)

F_p = Geometry factor

C_v = Valve flow coefficient

ΔP = pressure drop, psi

s.g. = specific gravity



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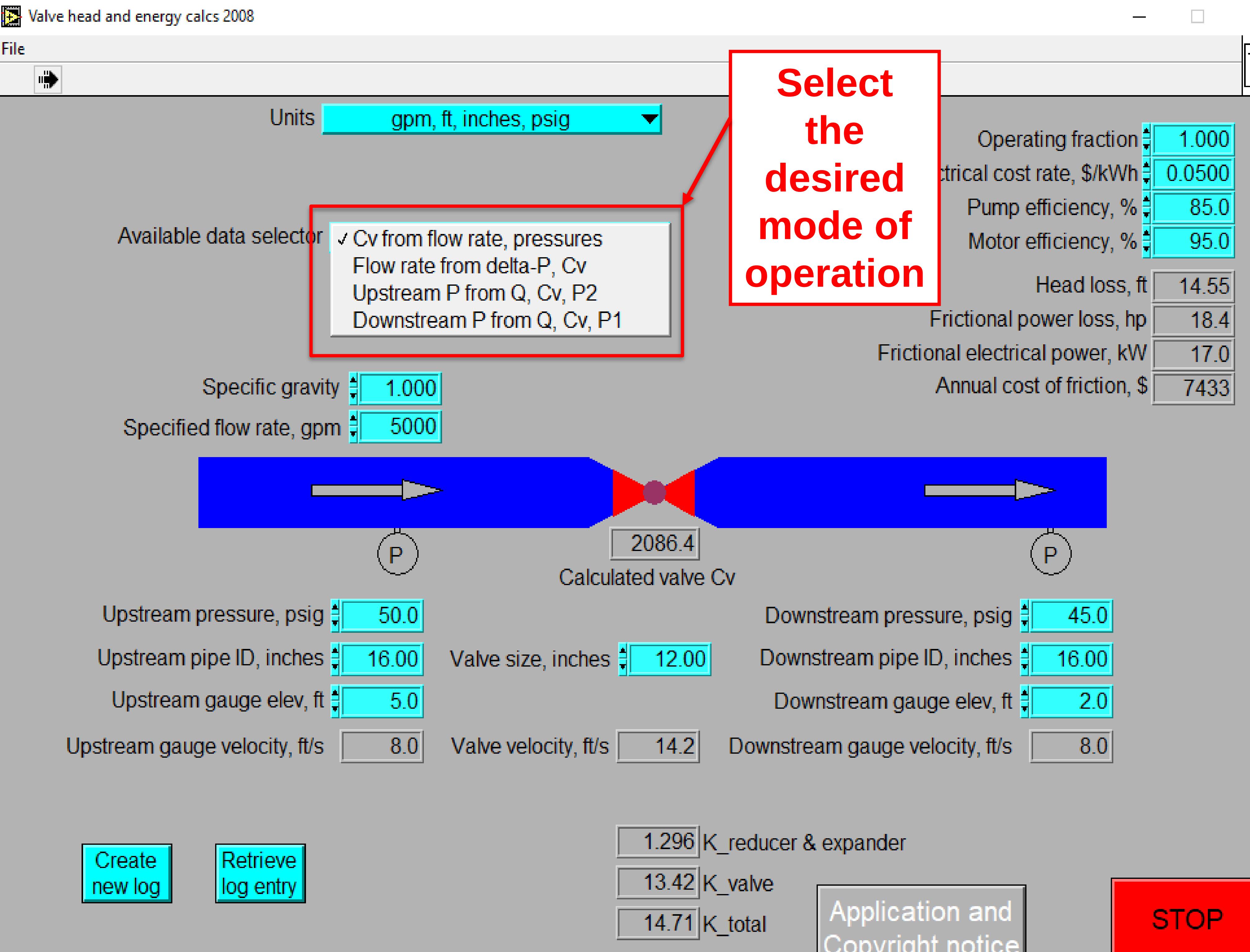
Valve Tool has four possible modes of operation

- There are four parameters that control the analysis
  - Valve upstream pressure, P_{up}
  - Valve downstream pressure, P_{down}
  - Valve C_v
  - Flow rate, Q
- Four modes of operation
  - Know: P_{up} P_{down} and Q. Solve for C_v
  - Know: P_{up} P_{down} and C_v. Solve for Q
  - Know: P_{up} C_v and Q. Solve for P_{down}
  - Know: P_{down} C_v and Q. Solve for P_{up}


Valve head and energy calcs 2008
File
Units
gpm, ft, inches, psig
Select the desired mode of operation
Available data selector
✓ Cv from flow rate, pressures
Flow rate from delta-P, Cv
Upstream P from Q, Cv, P2
Downstream P from Q, Cv, P1
Operating fraction
1.000
ctrical cost rate, $/kWh
0.0500
Pump efficiency, %
85.0
Motor efficiency, %
95.0
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

Example exercises, using Valve Tool and MEASUR's pump head, and system curve tools

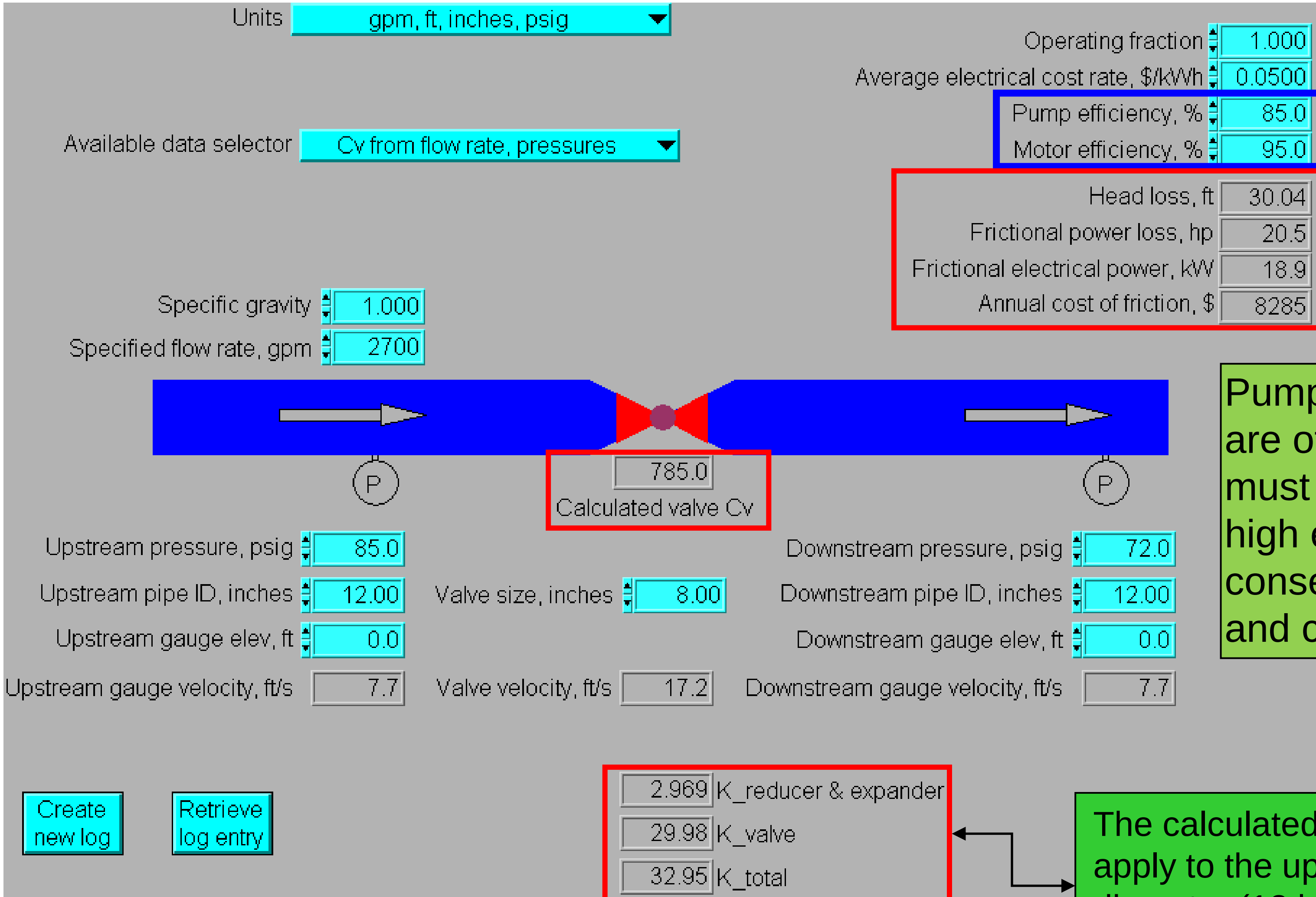
Valve Tool example 1

12" line 8" valve 12" line

Measured flow rate = 2700 gpm
P1 = 85 psig
P2 = 72 psig
Fluid = Water, 70° F
Electricity cost rate = 0.05 $/kWh
System operates continuously

Find: Valve flow coefficient, loss K, power loss, annual energy cost

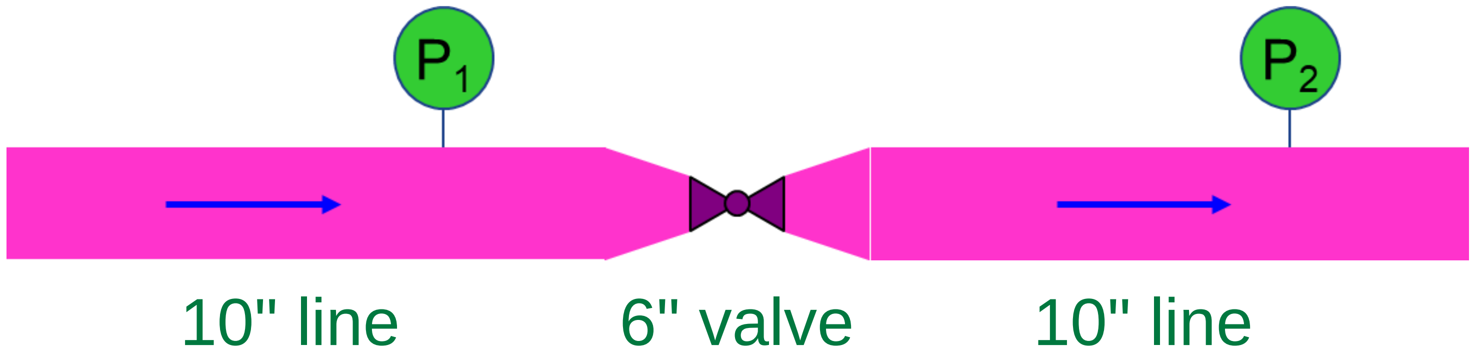
Valve Tool example 1 results



Pump & motor efficiencies are often not known and must be assumed. Using high efficiencies yields conservatively low power and cost estimates.

The calculated loss K values apply to the upstream pipe diameter (12 inches in this case), not the valve size

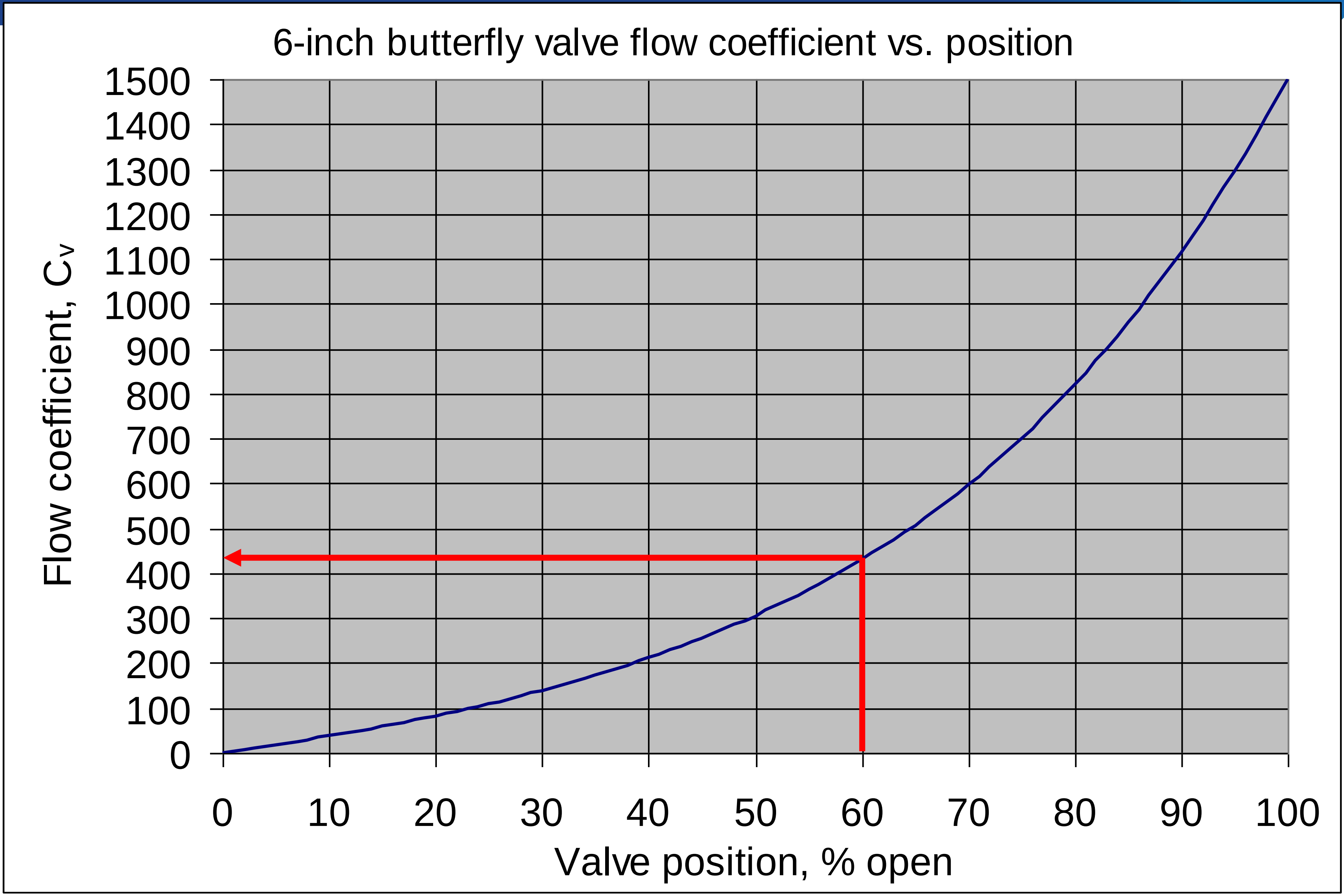
Valve Tool example 2



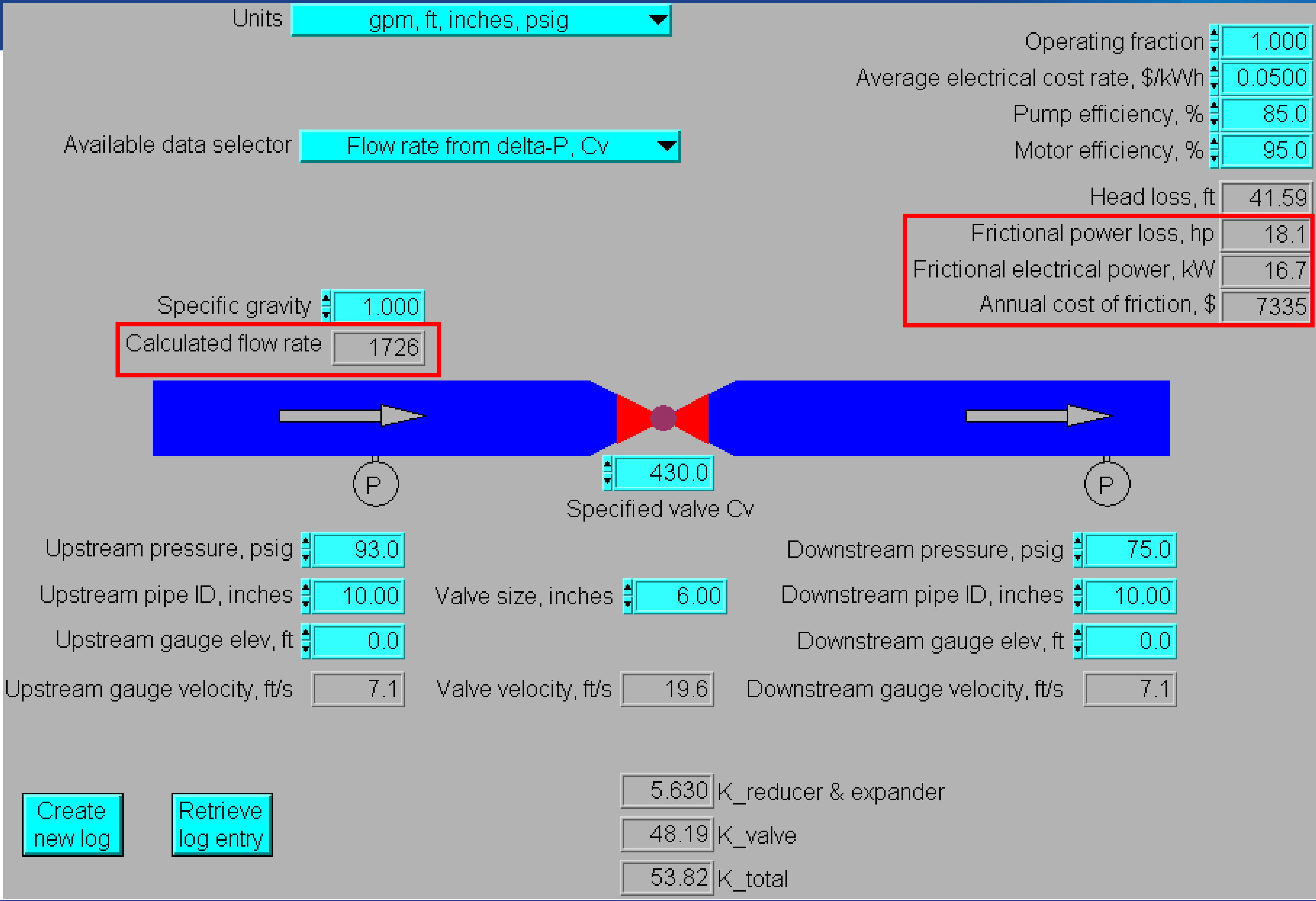
P1 = 93 psig
P2 = 75 psig
Fluid = Water, 70° F
Electricity cost rate = 5 cents/kWh
System operates continuously
Valve position indication = 60% open
Valve generic flow coefficient curve is available

Find: Estimated flow rate, power loss, annual energy cost

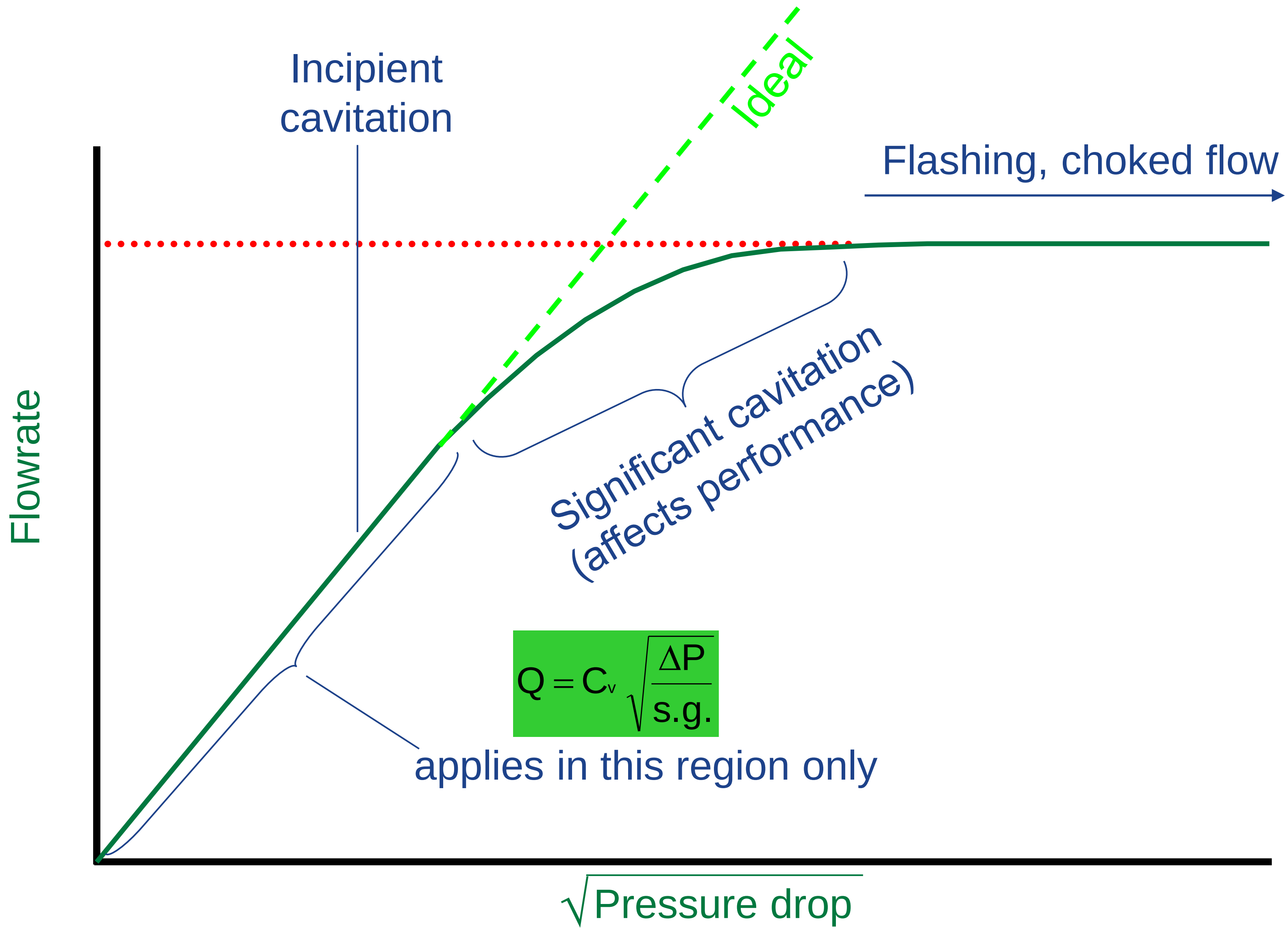
Valve flow coefficient curve



Valve Tool example 2 results



An important applicability caveat



Developing system performance curves from field measurements

But first things first : 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 with you)
- Note 1: one of the reasons for talking with operators and walking the system down is to correct outdated P&ID's
- Note 2: Complex systems with multiple sources and/or delivery points cannot be modeled with a simple system curve (but field data is still invaluable)

Simple type of system curve basics

- Requires a pair of head and flow conditions
- One of the pair can be static head (flow rate = 0)

Point 1

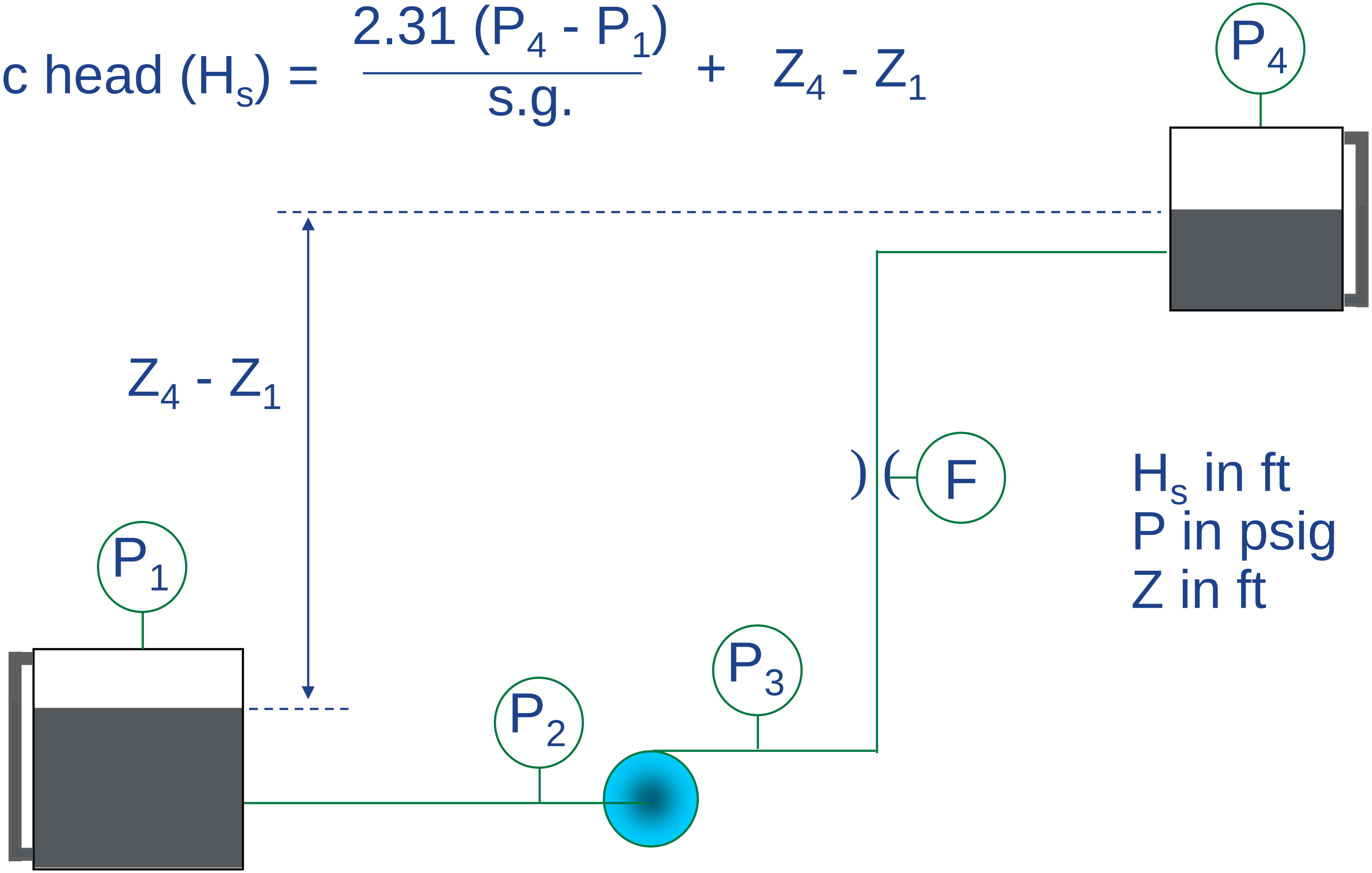
Flow Rate	0	gpm
Head	65	ft

Point 2

Flow Rate	2000	gpm
Head	277	ft

The static head is made up of elevation, and sometimes pressure components

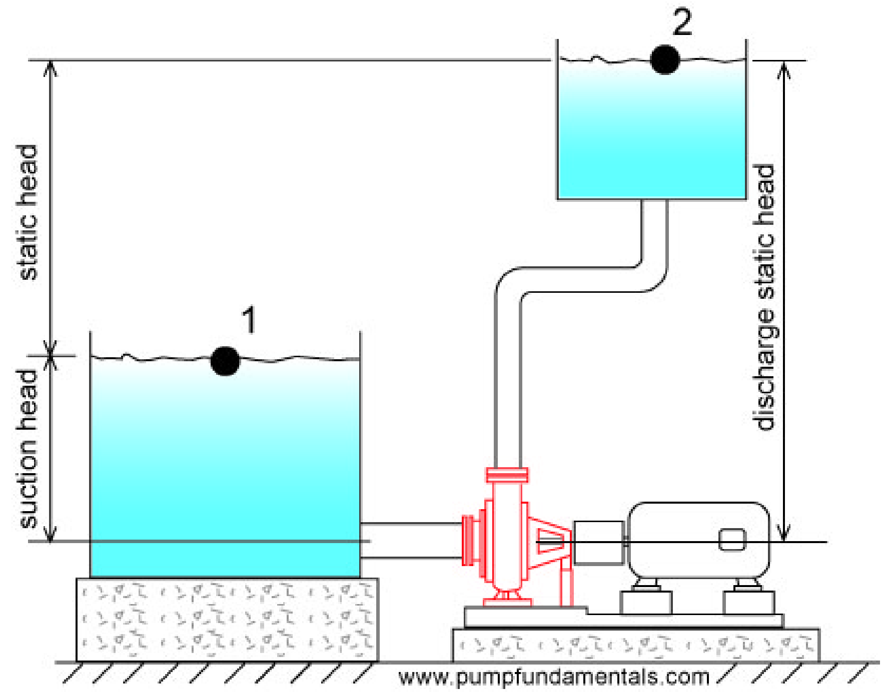
$$\text{Static head } (H_s) = \frac{2.31\,(P_4 - P_1)}{\text{s.g.}} + Z_4 - Z_1$$



H_s in ft
P in psig
Z in ft

Sources of static head data

- Pressure gauges
- Elevation:
  - Level (or pressure) gauges
  - Drawings



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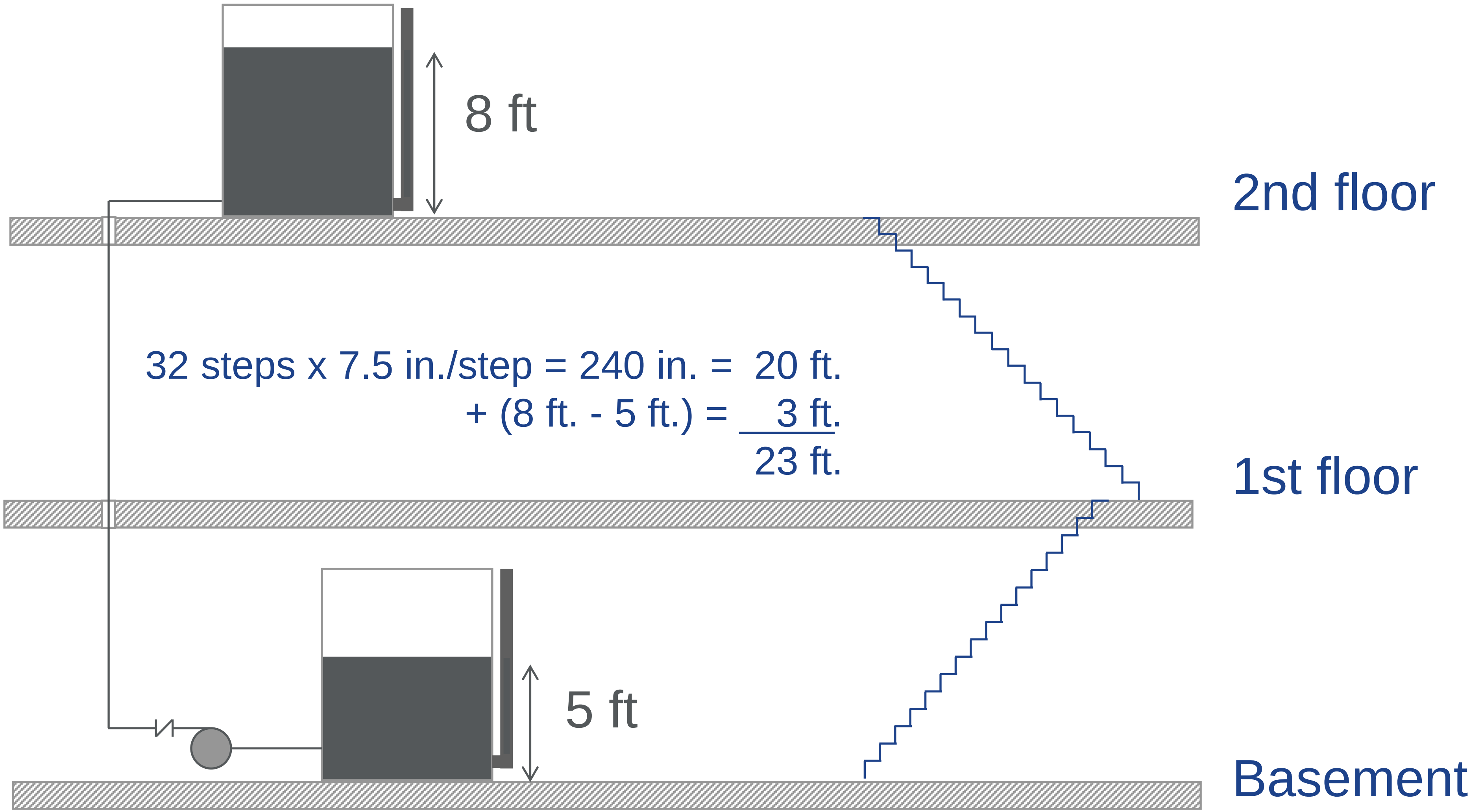
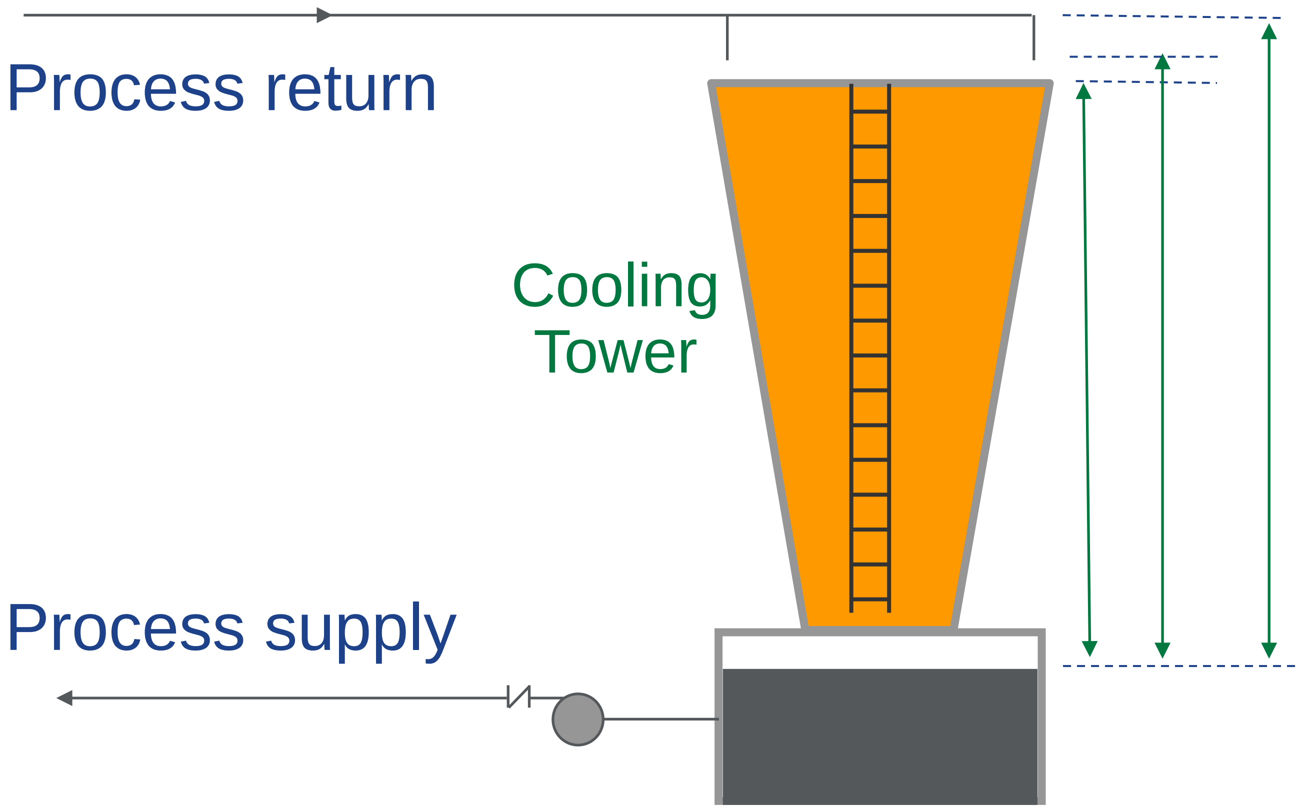
Elevation head estimating example: counting steps



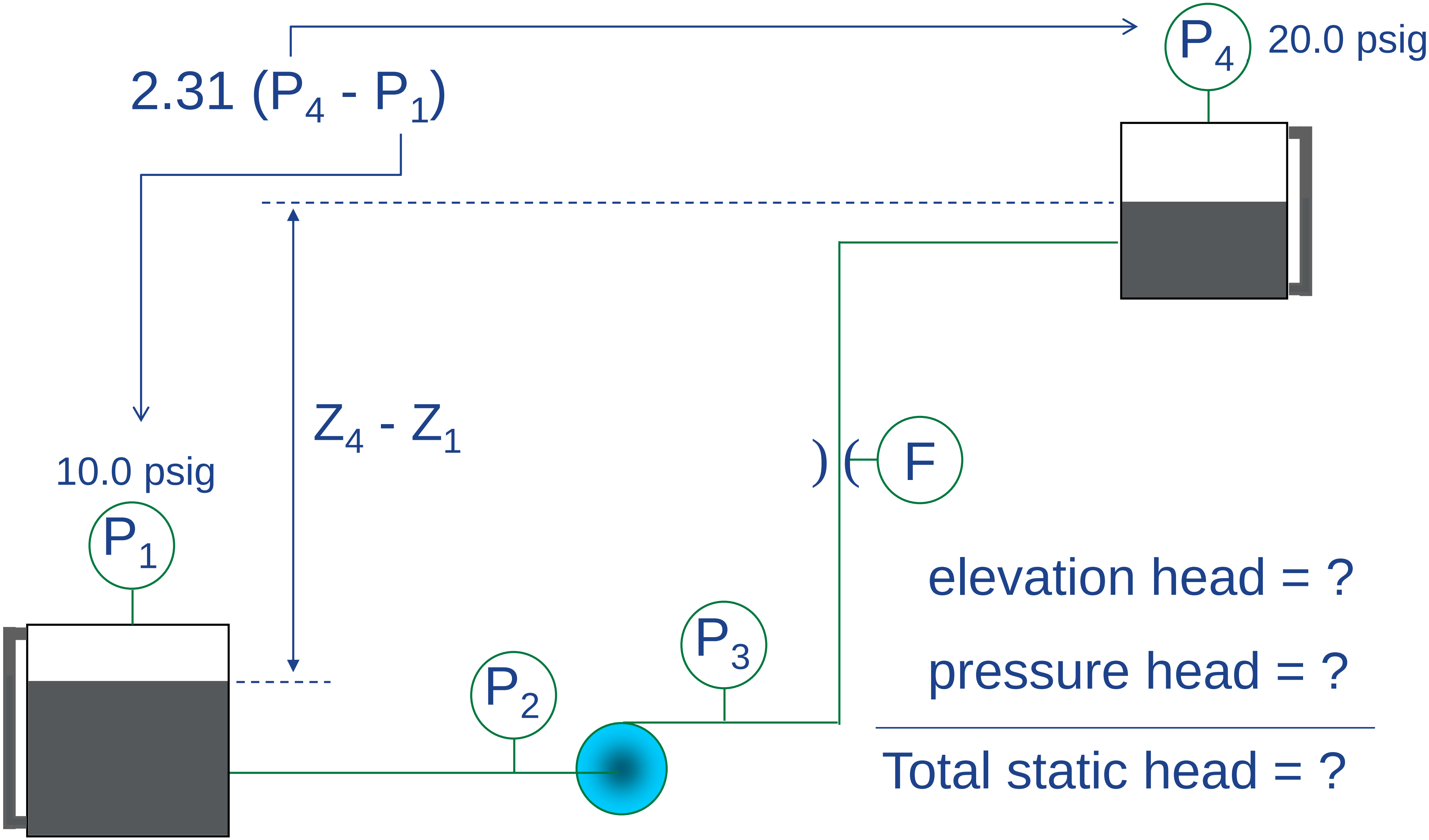
Another quick and simple method: count ladder rungs (standard ladder rung spacing = 1 ft)



Which to use?

Tanks, chests, etc. often use steel sheets or tiles that can be individually measured and counted; marks on concrete from plywood forms may also be useful

Example static head calculation

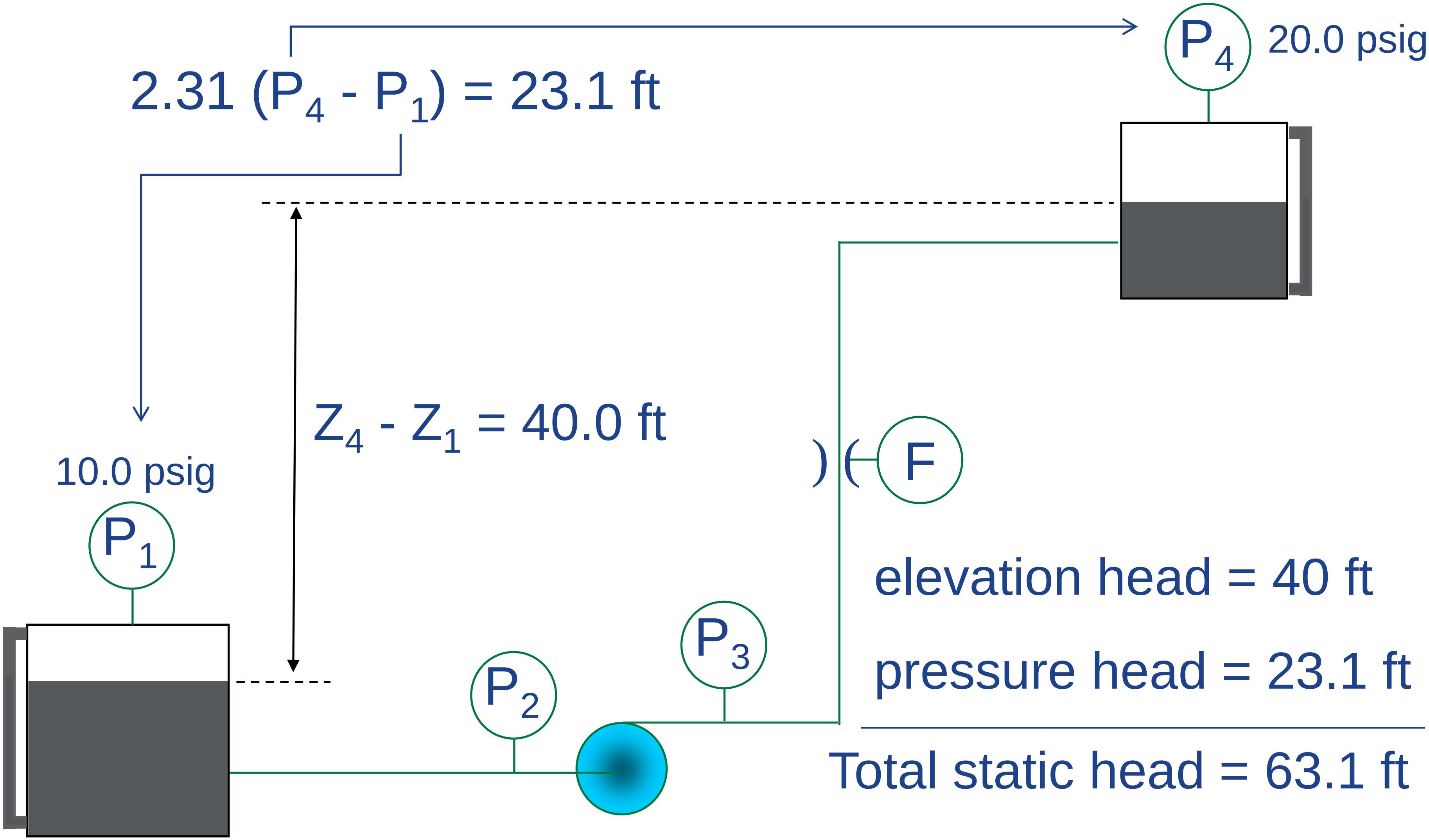


elevation head = ?

pressure head = ?

Total static head = ?

Example static head calculation



elevation head = 40 ft

pressure head = 23.1 ft

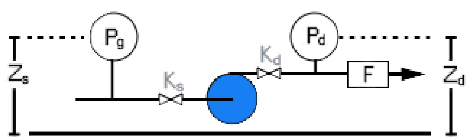
Total static head = 63.1 ft

Or…. use the MEASUR pump head calculator

The head calculator determines the head difference between two points, so it can do a static head calculation for you.

PUMP HEAD TOOL

Suction tank elevation | Suction gauge elevation



K_s represents all suction losses from the tank to the pump

K_d represents all discharge losses from the pump to the gauge P_d

Fluid Specific Gravity: 1

Flow Rate: 0 gpm

Suction		Discharge	
Pipe diameter (ID)	10 in	Pipe diameter (ID)	10 in
Gauge pressure (P_g)	10 psi	Gauge pressure (P_d)	20 psi
Gauge elevation (Z_s)	0 ft	Gauge elevation (Z_d)	40 ft
Line loss coefficients (K_s)	0	Line loss coefficients (K_d)	0

RESULTS | HELP

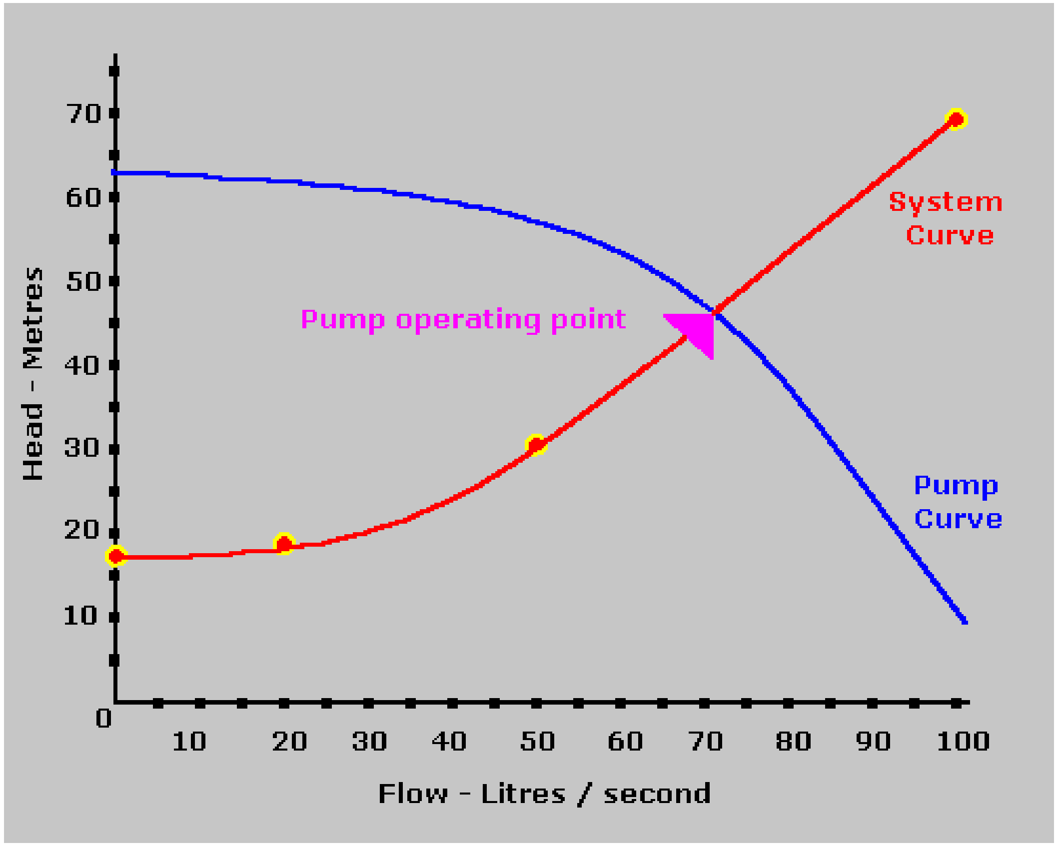
Result Data

Differential Elevation Head	40.0 ft
Differential Pressure Head	23.11 ft
Differential Velocity Head	0.0 ft
Estimated Suction Friction Head	0.0 ft
Discharge Friction Head	0.0 ft
Pump Head	63.11 ft

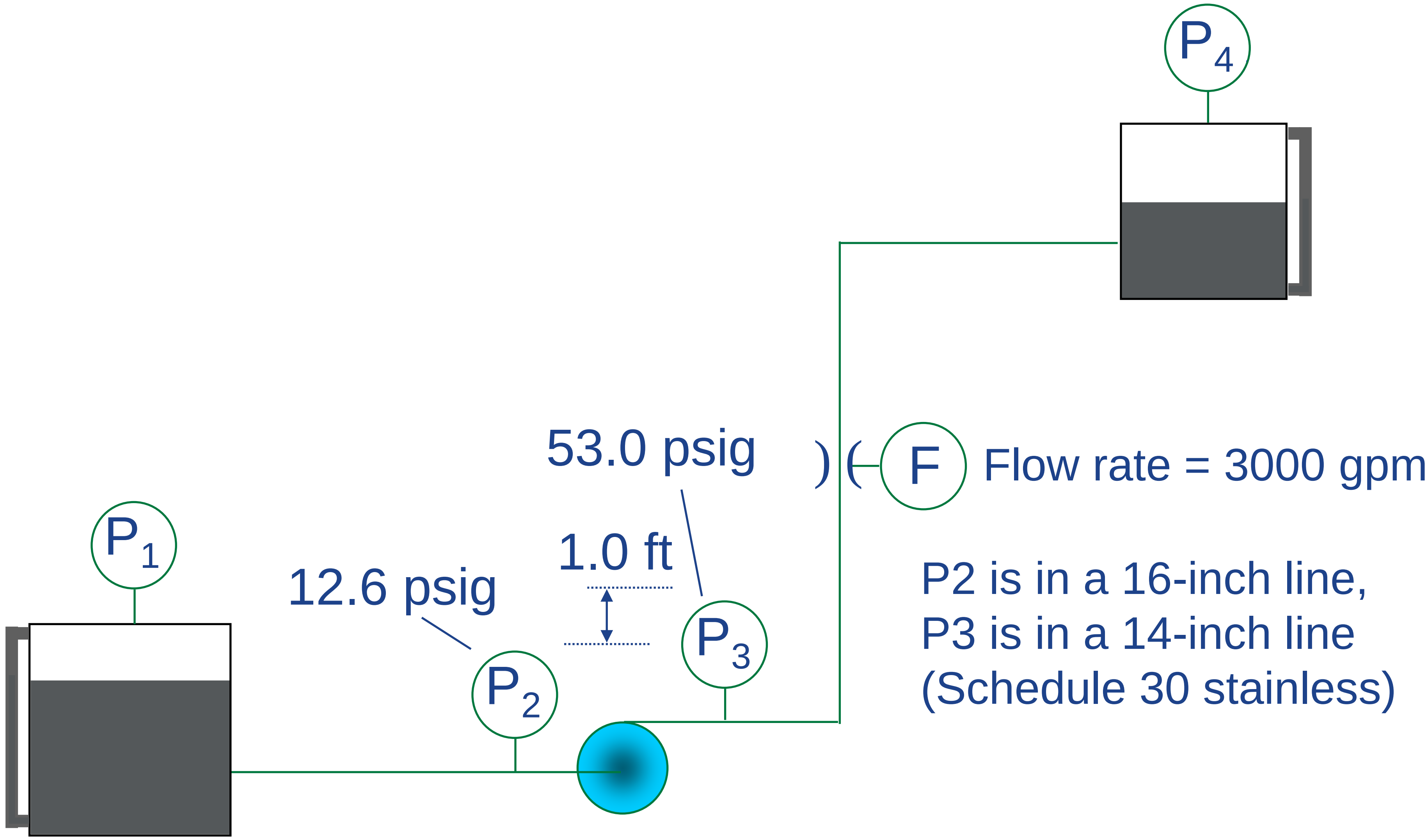
Copy Table

For a second system head/capacity point, we can always use the pump head

- Simplest approach: measure pump head at the operating flow rate and let MEASUR do the rest of the work for you
- Why does this work on a system curve? Because pump head and system head at the operating condition are, by definition, equal



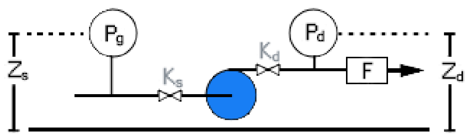
Measured data in the example system



MEASUR-calculated pump head = 94.7 ft

PUMP HEAD TOOL

Suction tank elevation | Suction gauge elevation



K_s represents all suction losses from the tank to the pump

K_d represents all discharge losses from the pump to the gauge P_d

Fluid Specific Gravity	1
Flow Rate	3000 gpm

Suction		Discharge	
Pipe diameter (ID)	15.25 in	Pipe diameter (ID)	13.25 in
Gauge pressure (P_g)	12.6 psi	Gauge pressure (P_d)	53 psi
Gauge elevation (Z_s)	0 ft	Gauge elevation (Z_d)	1 ft
Line loss coefficients (K_s)	0	Line loss coefficients (K_d)	0

RESULTS | HELP

Result Data

Differential Elevation Head	1.0 ft
Differential Pressure Head	93.36 ft
Differential Velocity Head	0.33 ft
Estimated Suction Friction Head	0.0 ft
Discharge Friction Head	0.0 ft
Pump Head	94.68 ft

Copy Table

Final step – plug the two values into the MEASUR system curve calculator

System Curve Data

System Curve

Fluid Specific Gravity	1
System Loss Exponent, C	1.9

Point 1

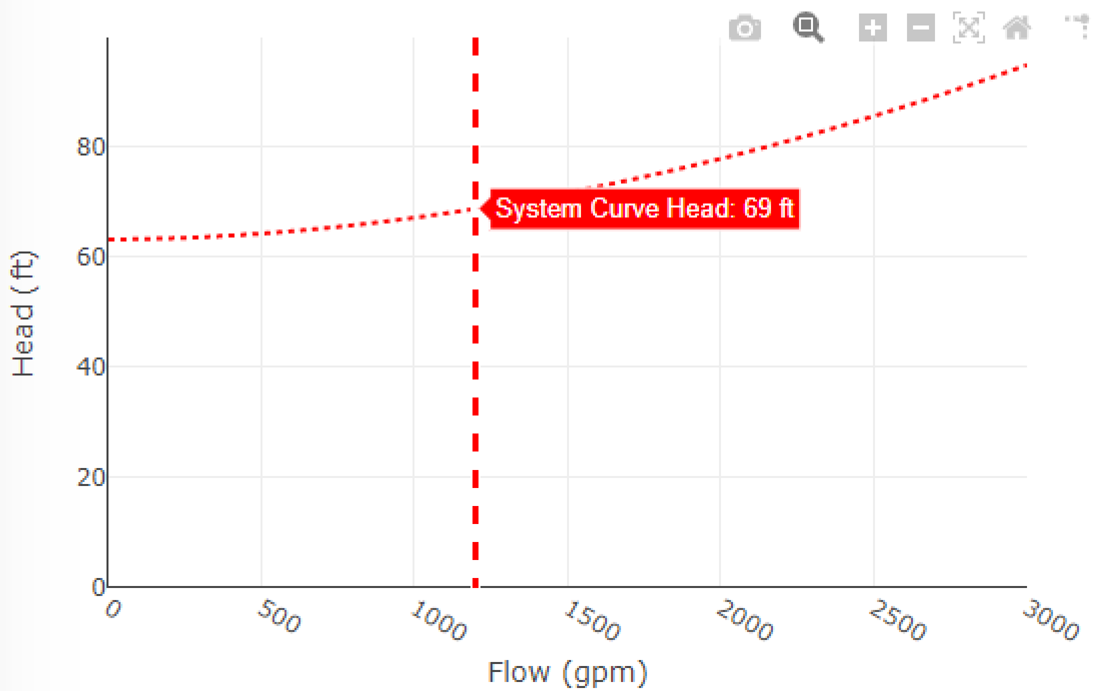
Flow Rate	0 gpm
Head	63.1 ft

Point 2

Flow Rate	3000 gpm
Head	94.7 ft

System Curve

Head = 63.1 + (0.00000782 × flow$^{1.9}$)



Current Point Data	Flow (gpm)	Head (ft)	Fluid Power (hp)
Baseline	— —	— —	20.8
Modification	— —	— —	— —
System Curve	1,200	69	

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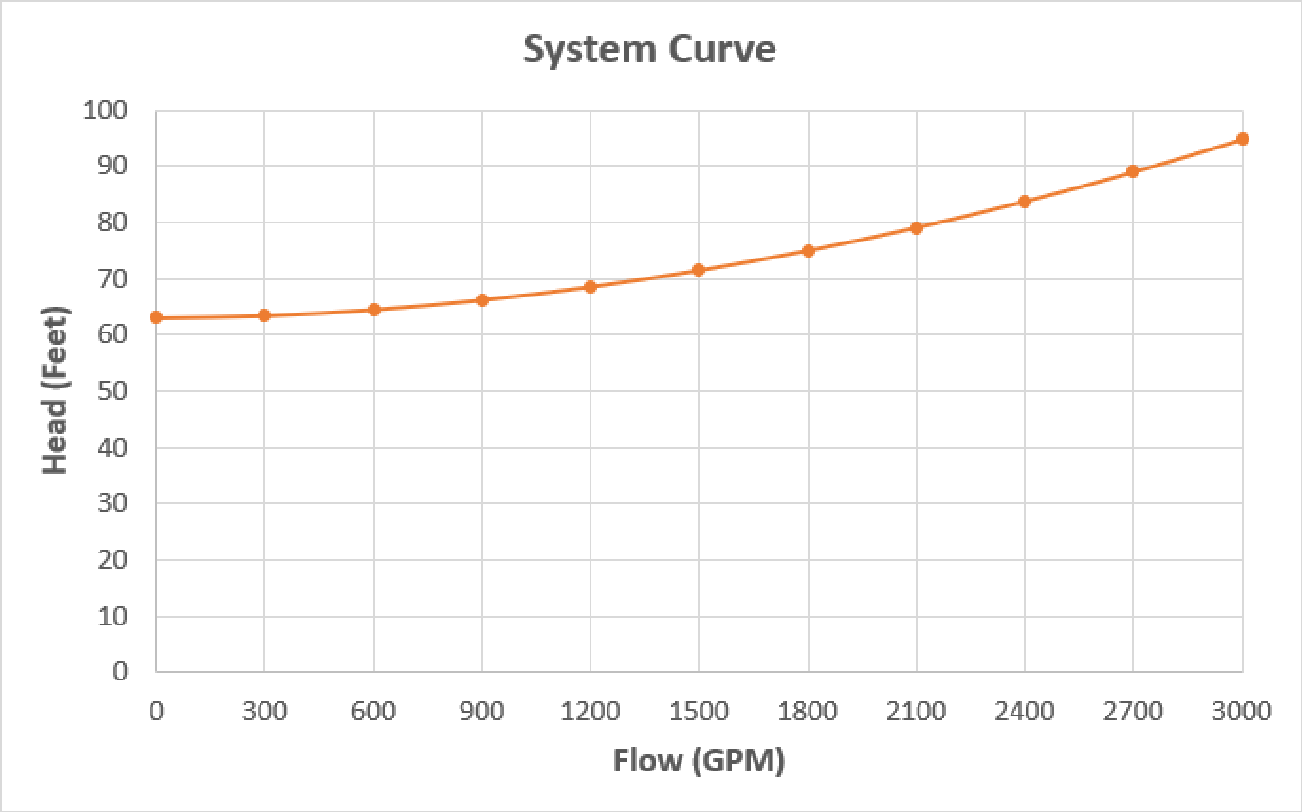
Resulting system curve and table from an Excel spreadsheet

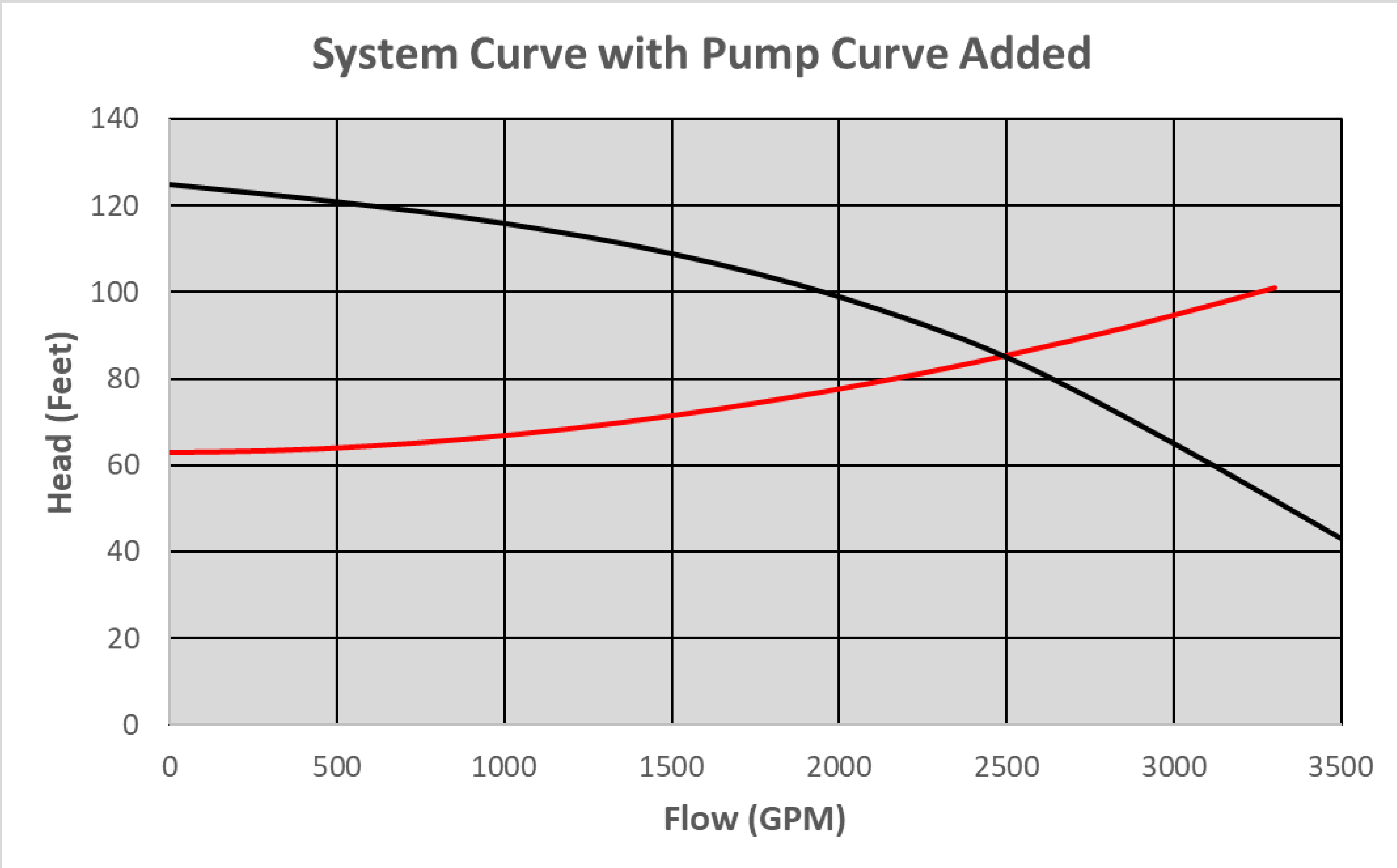
Static Head Feet	Loss Coefficient	Exponent
63.1	0.00000782	1.9

Flow GPM	Head Feet
0	63.100
300	63.498
600	64.585
900	66.308
1200	68.642
1500	71.568
1800	75.074
2100	79.148
2400	83.783
2700	88.970
3000	94.704

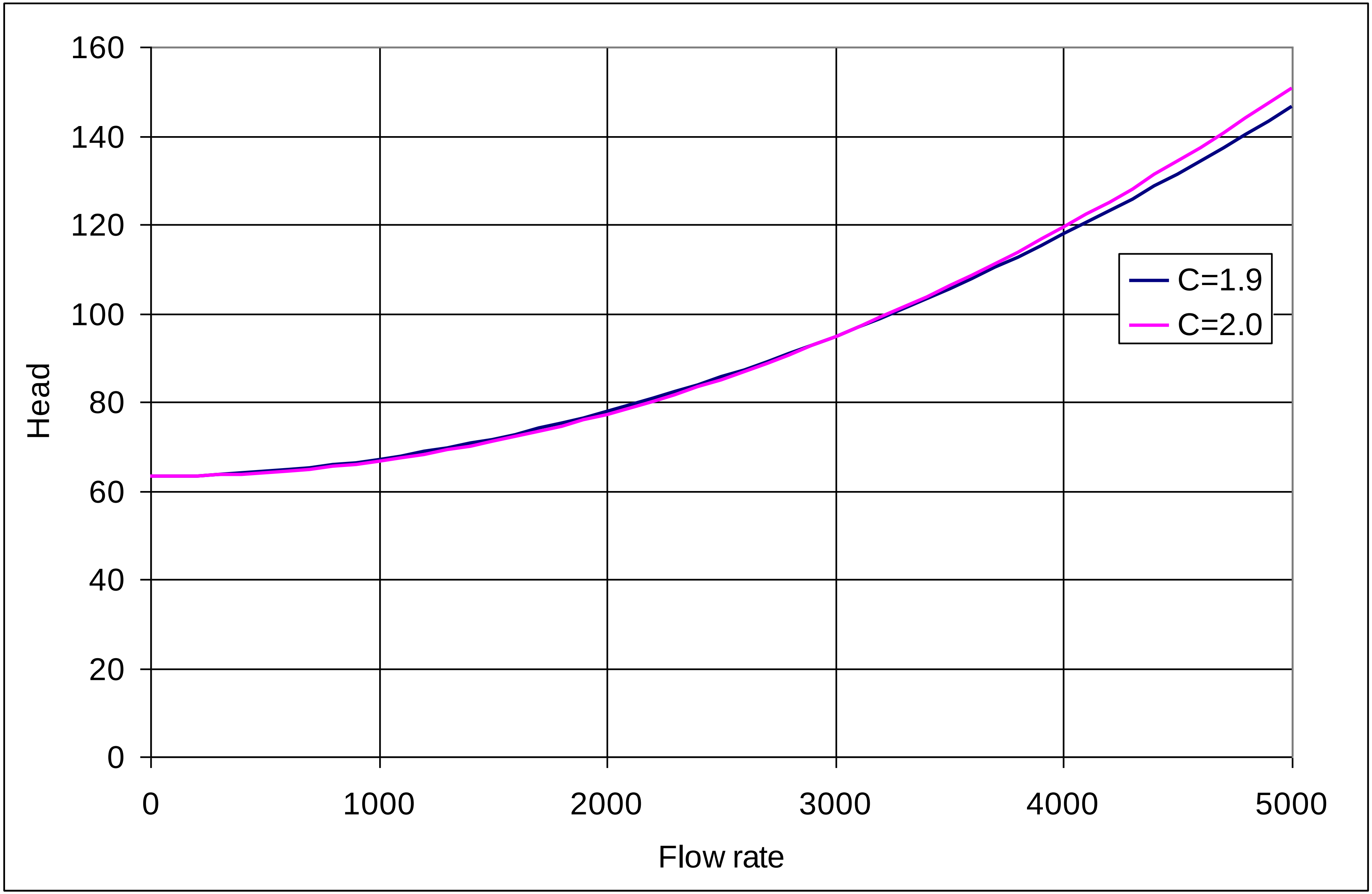


This is very easy to program in Excel!

System curve with pump curve added



The system loss exponent can have a small impact; use care if extrapolating



Remember that there are process factors that can affect the system curve - some examples

- Static head variables
  - Gas overpressure
  - Level
  - Density
- Dynamic loss coefficient variables
  - Valve position
  - Viscosity
  - Age (corrosion, scale)
  - Filter or strainer cleanliness
- The system itself
  - Changes in process flow path(s)

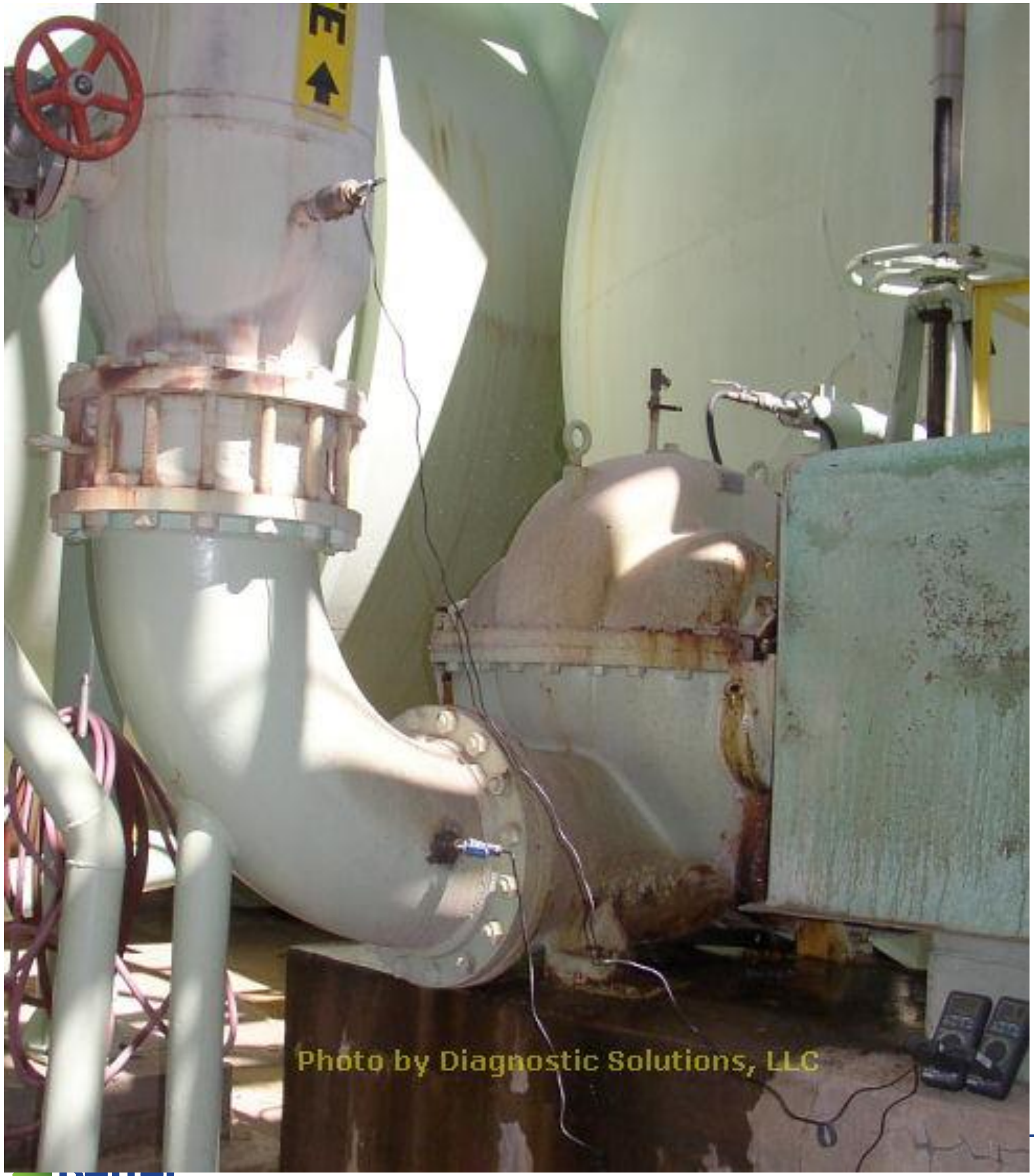
Why is development of a field measurement-based system curve important?

- The system curve is fundamental to everything we do in pumping systems
- The first thing we should do in ANY pumping system optimization is to ask whether we can either change the system curve *or* change where we're operating on it
- The real world is often SIGNIFICANTLY different than the picture painted by designers using generic loss characteristics

An example: comparing design-based head calculations with field data

- **What the designer expected vs.**
- **How the system actually operates!**

Small section of a system - from pump flange through expander



Design organization loss calculation:

Element	Loss K
18" 90 degree elbow:	0.103
18" check valve:	2.000
18-24" expander:	0.400
Knife gate valve:	0.228
????	
Total K:	2.731

Q = 11,400 gpm (15.7 ft/s in 17.25" ID line), for a velocity head of 3.81 ft

$K \times \frac{V^2}{2g}$ = 10.4 ft calculated head loss at 11,400 gpm (design flow rate for the system)

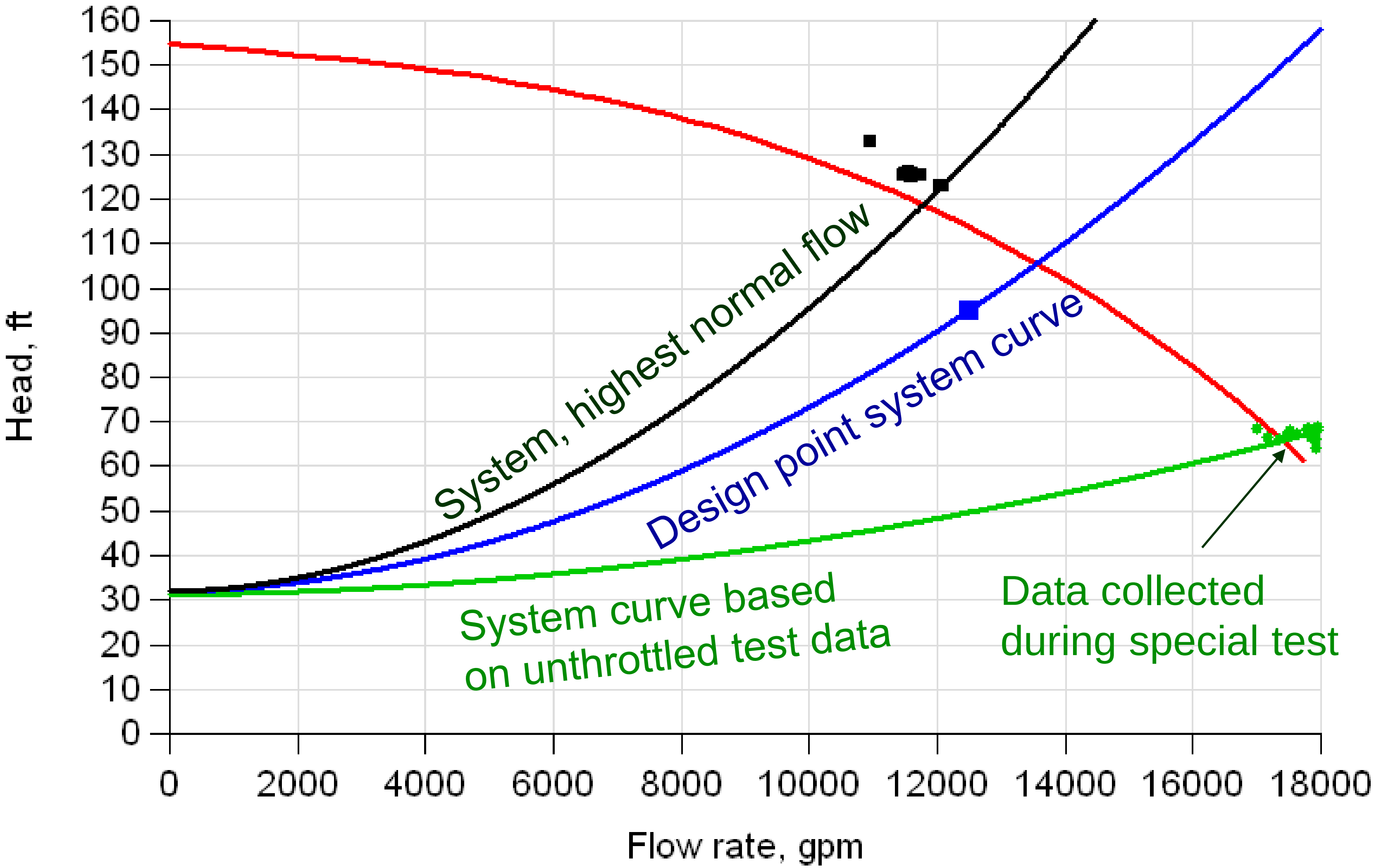
Measured data provide a better perspective (or we would hope it would)

Actual head loss at 12,000 gpm:

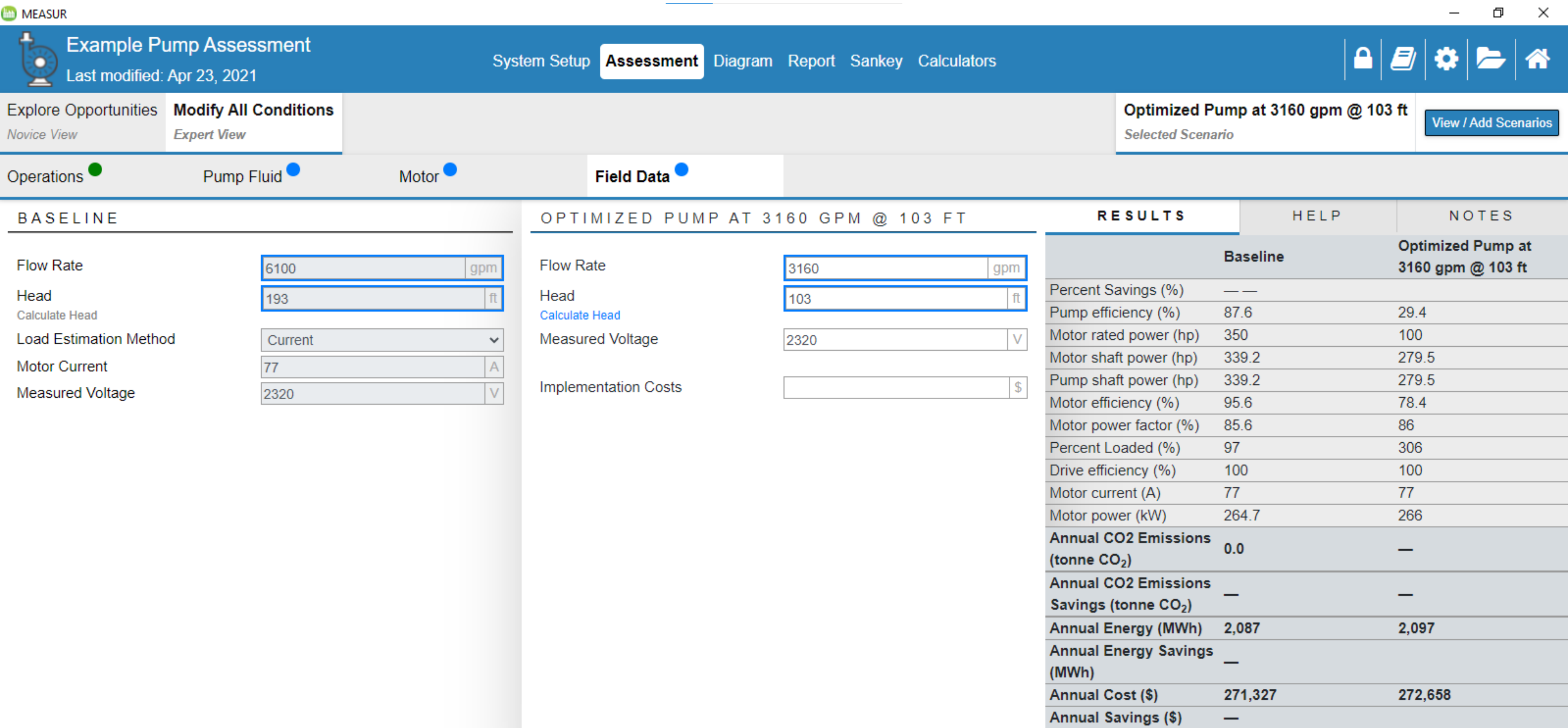
ΔP :	(54.3 - 51.6) x (2.31/0.985)	= 6.3 ft
+ ΔZ :	(4.5 – 8.5)	= -4.0 ft
$+\Delta \frac{V^2}{2g}$:	(4.3 – 1.3)	= 3.0 ft
	Measured head loss	= 5.3 ft

$$\frac{V_1^2}{2g} + \frac{2.31\, P_1}{s.g.} + Z_1 = \frac{V_2^2}{2g} + \frac{2.31\, P_2}{s.g.} + Z_2 + H_{f1-2}$$

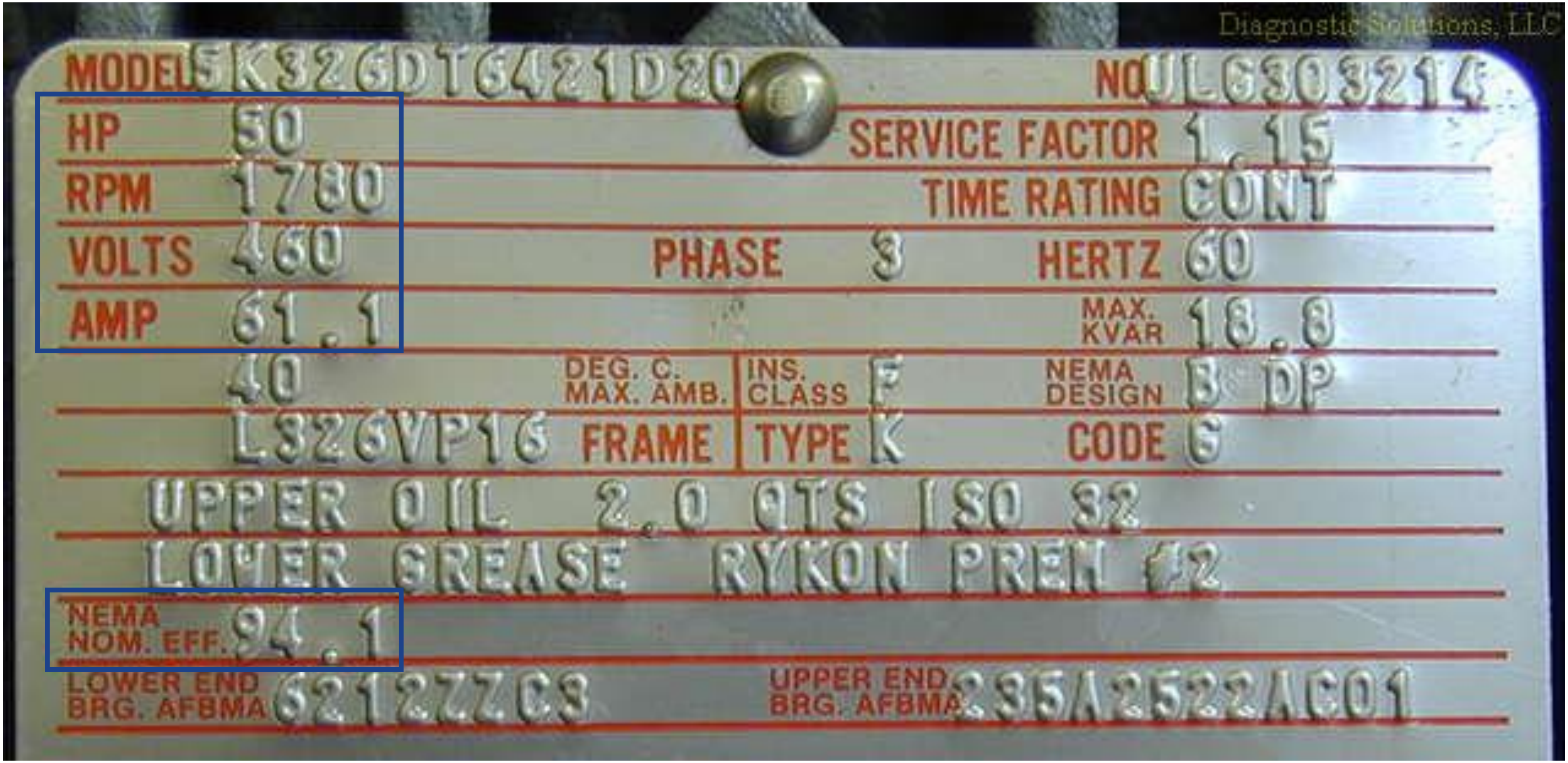
System curves: design-based, normal operating, and unthrottled



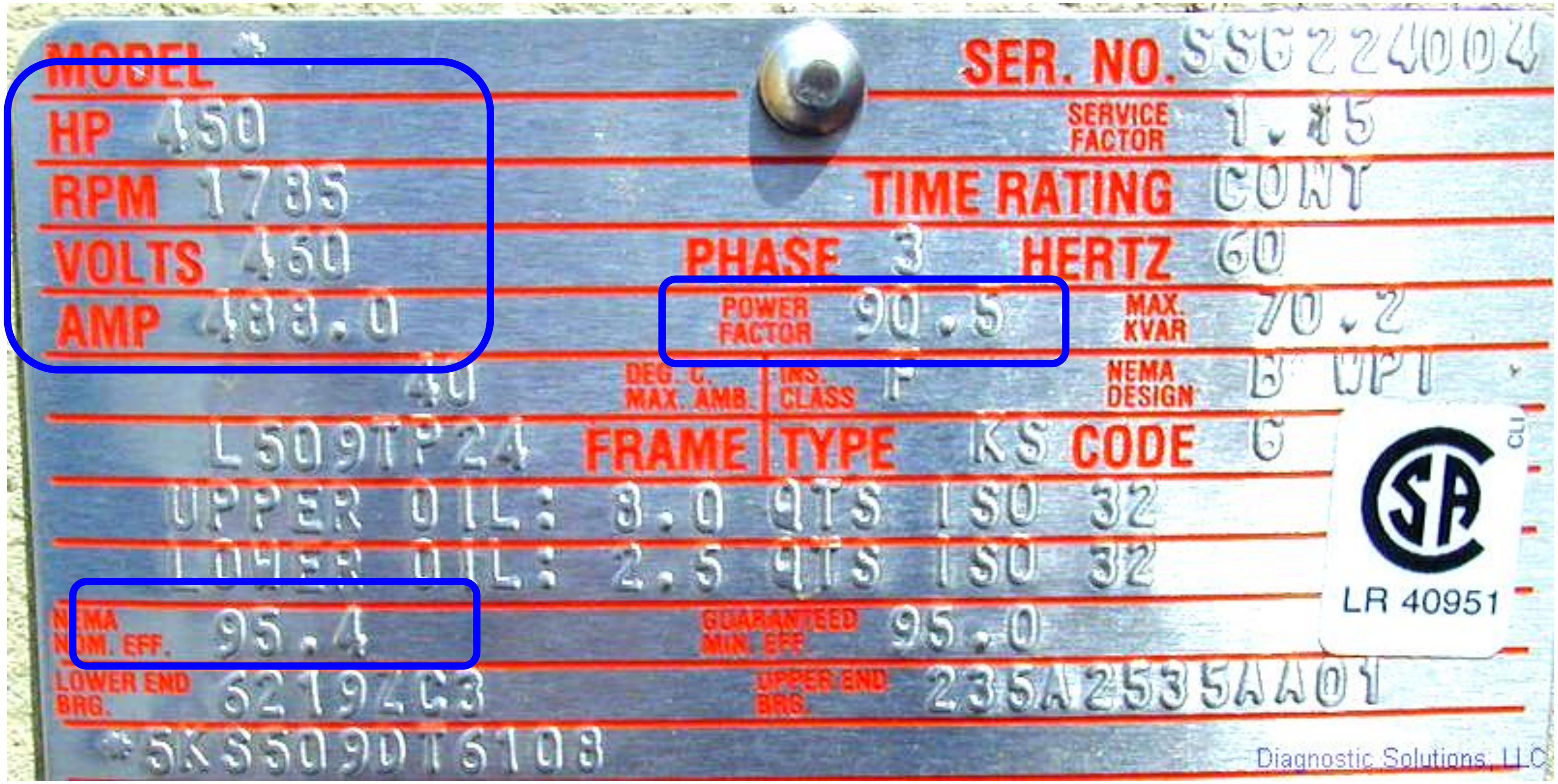
Let's talk about getting the data needed by MEASUR



A motor nameplate



Another motor nameplate



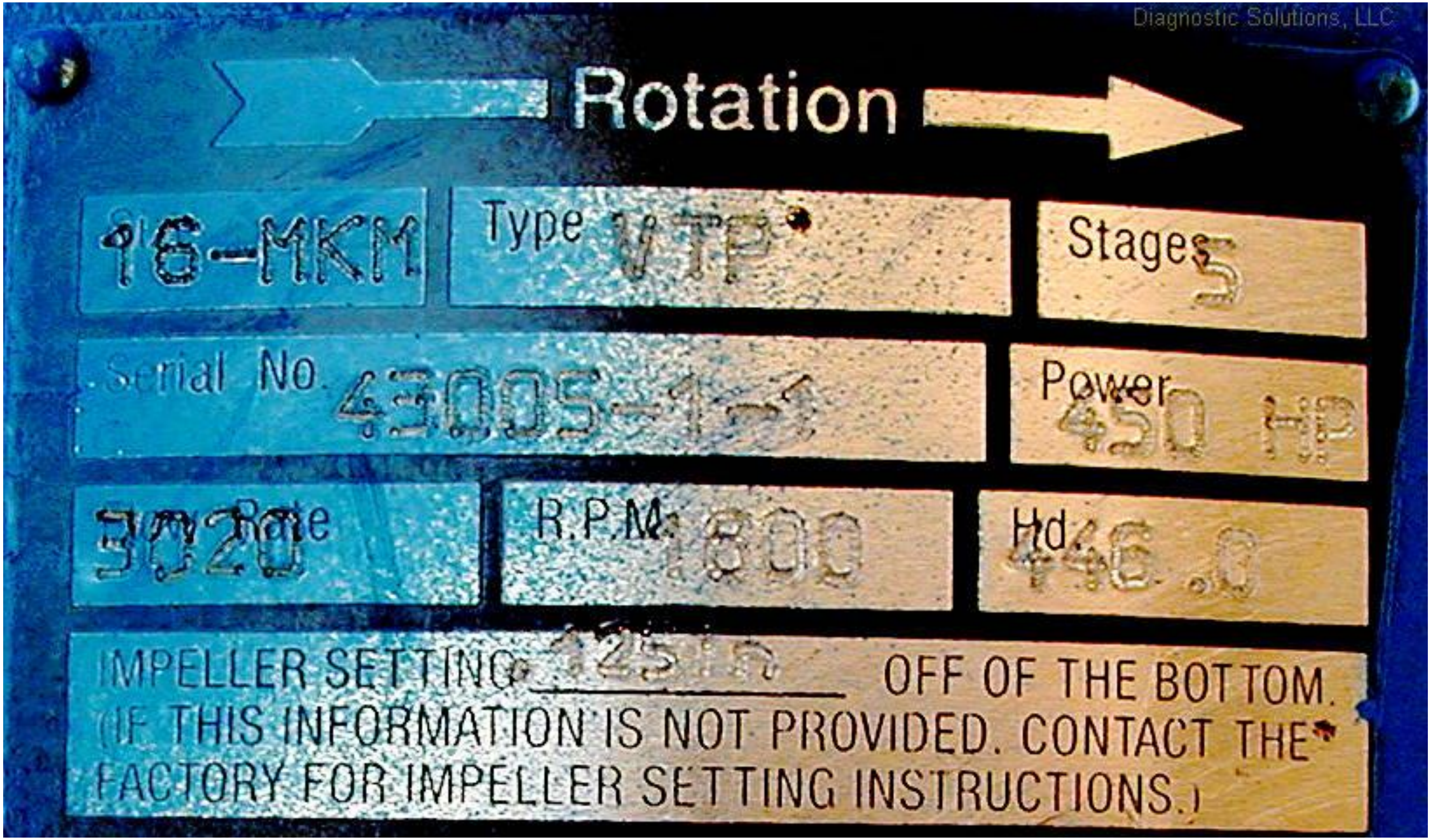
$$\frac{488 \text{ amps} \times 460 \text{ volts} \times \sqrt{3} \times 0.905 \times 0.954}{746 \text{ watts/hp}} = 450 \text{ hp}$$

Note: some published motor data is internally inconsistent

Pump nameplate data (goes with first motor)

Nameplate speed here (1800 rpm) is the *nominal* synchronous speed

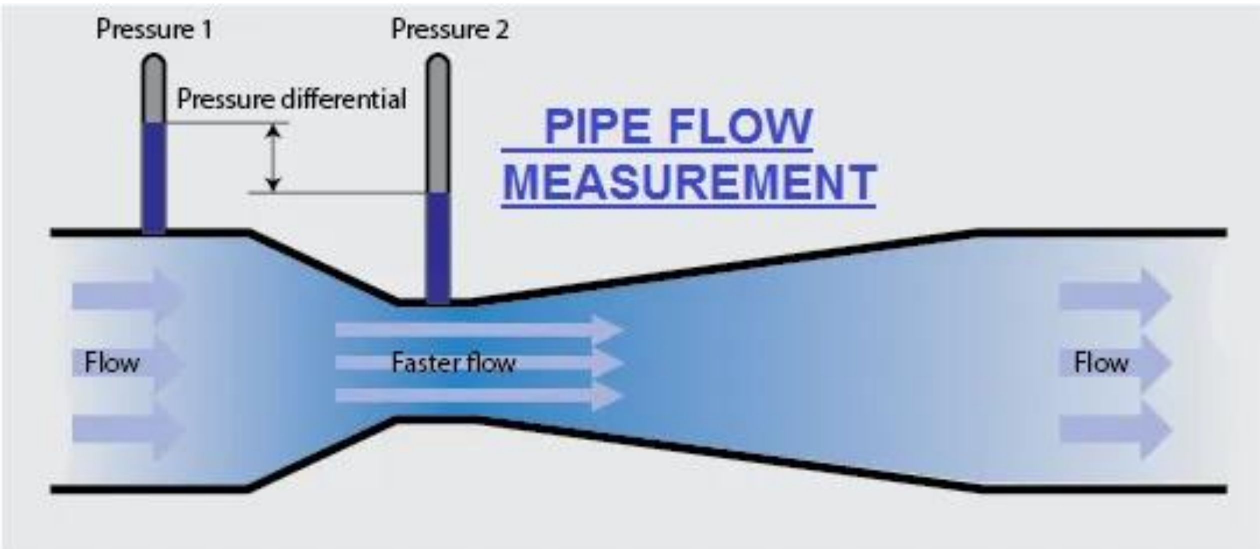
Another pump nameplate (goes with 2nd motor)



Again, the nameplate shows *nominal* synchronous speed

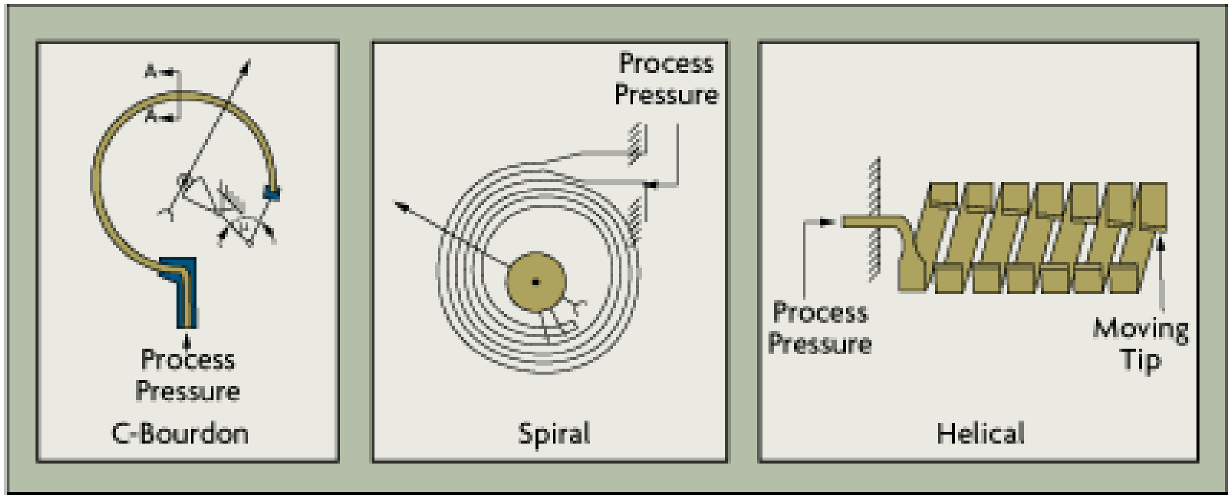
Pressure and flow measurements:

Instruments and miscellaneous considerations

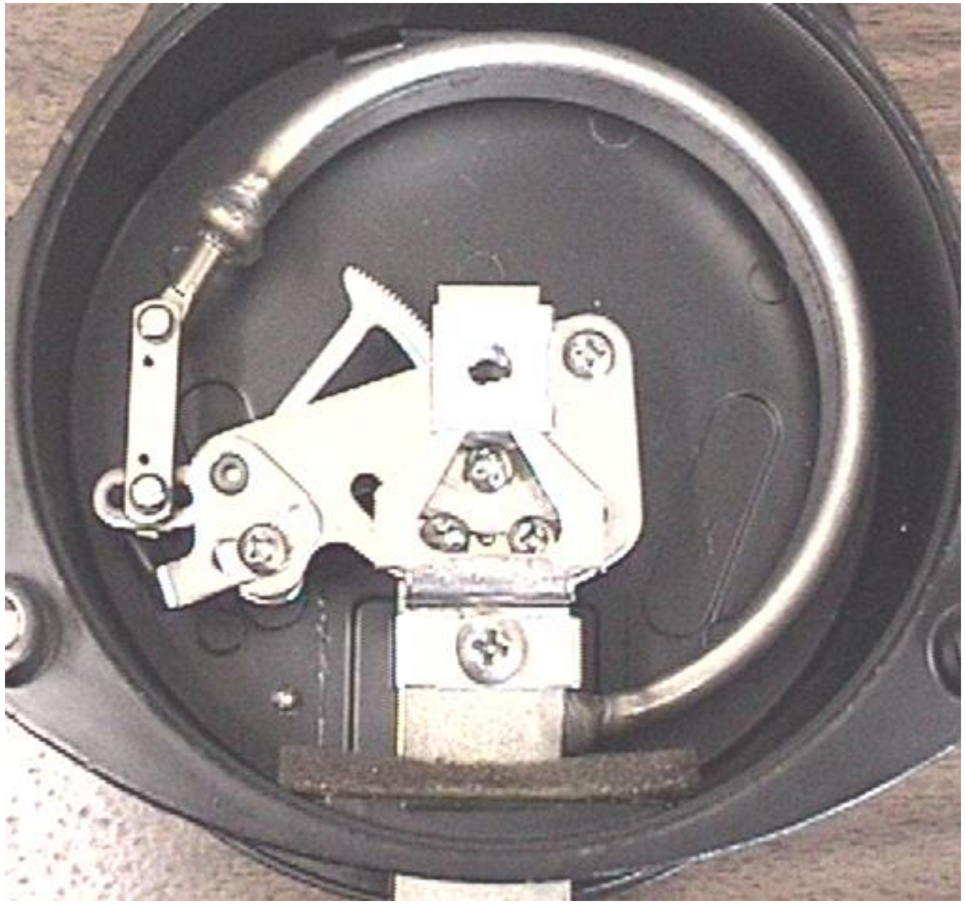


There are several types of pressure transducers

- Bourdon tube (most common for gauges)
- Bellows
- Diaphragm
- Piezoresistive



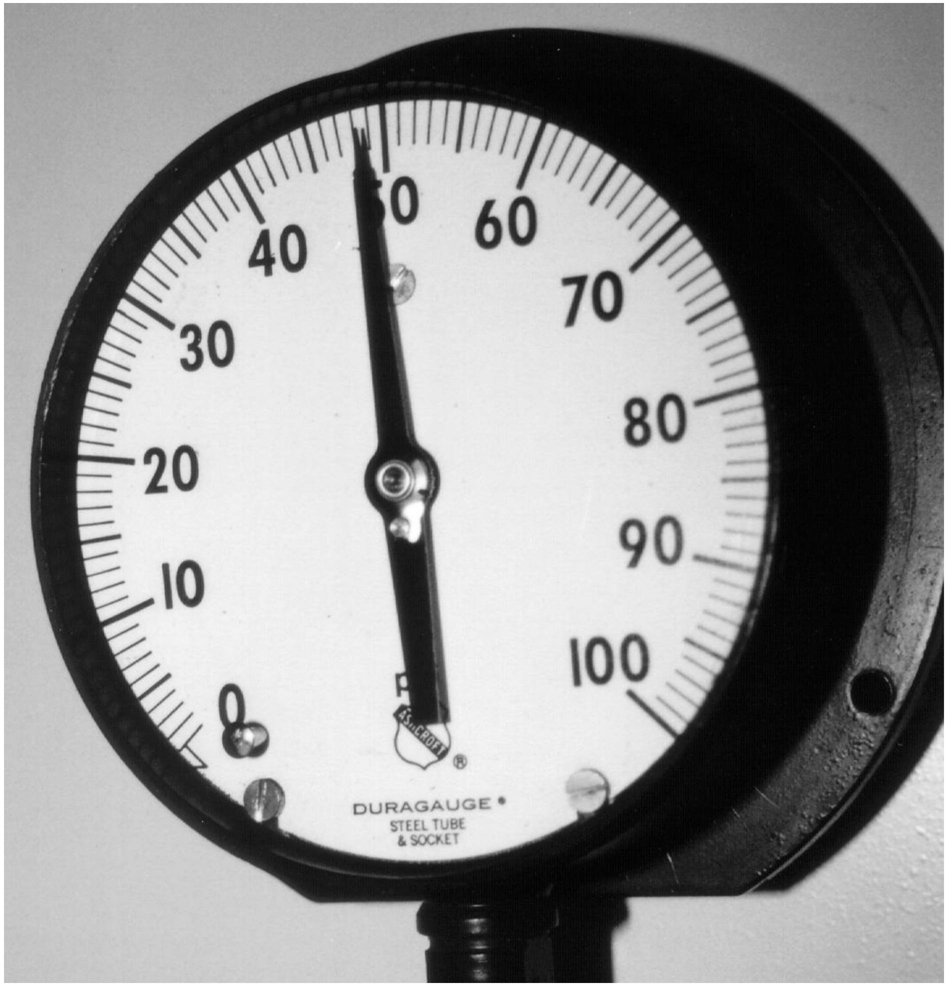
The C-type Bourdon tube is by far the most common industrial pressure gauge



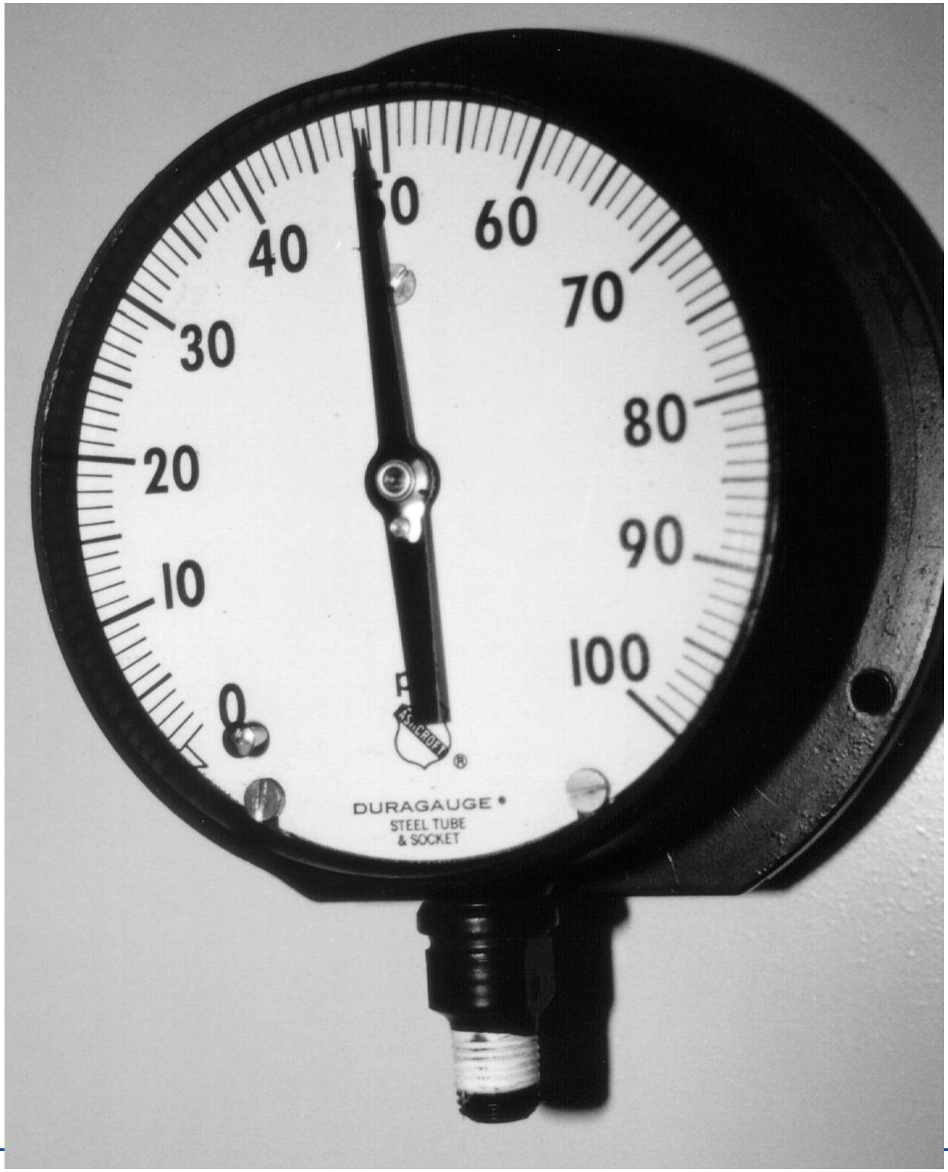
Some practical considerations

- 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

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



Would a little larger picture change your mind?



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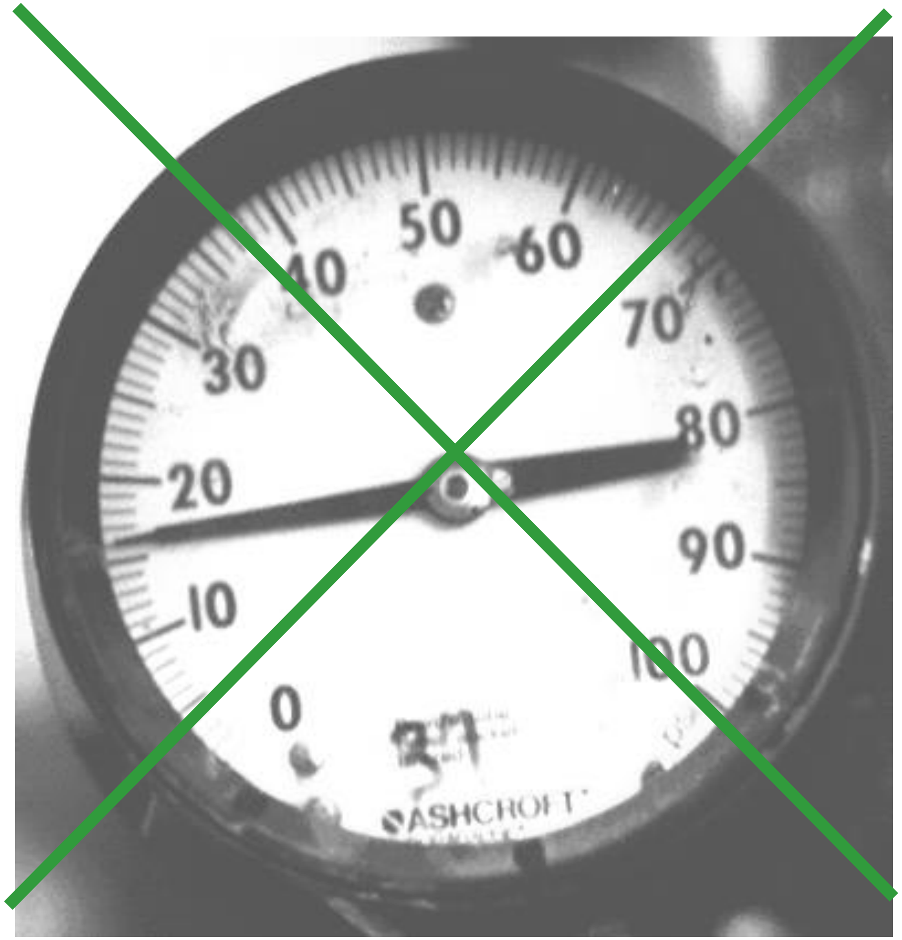
Calibrated, but…maybe not quite accurate

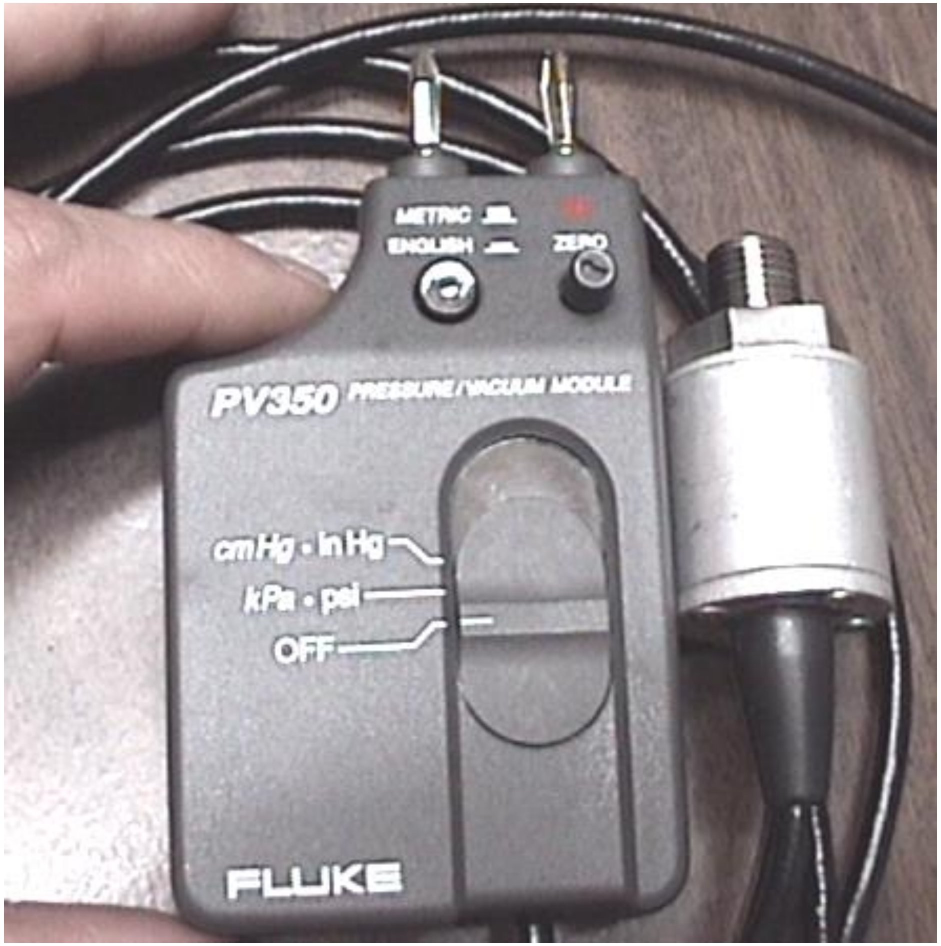
Note: this gauge was removed from system to install a test gauge.

(poor camera work by a yokel from Diagnostic Solutions failed to show the end of the threads)

Picture taken on 10/15/2004; note the calibration sticker was applied only three months before.

The use of portable test instrumentation is advisable when accurate data is needed





Break

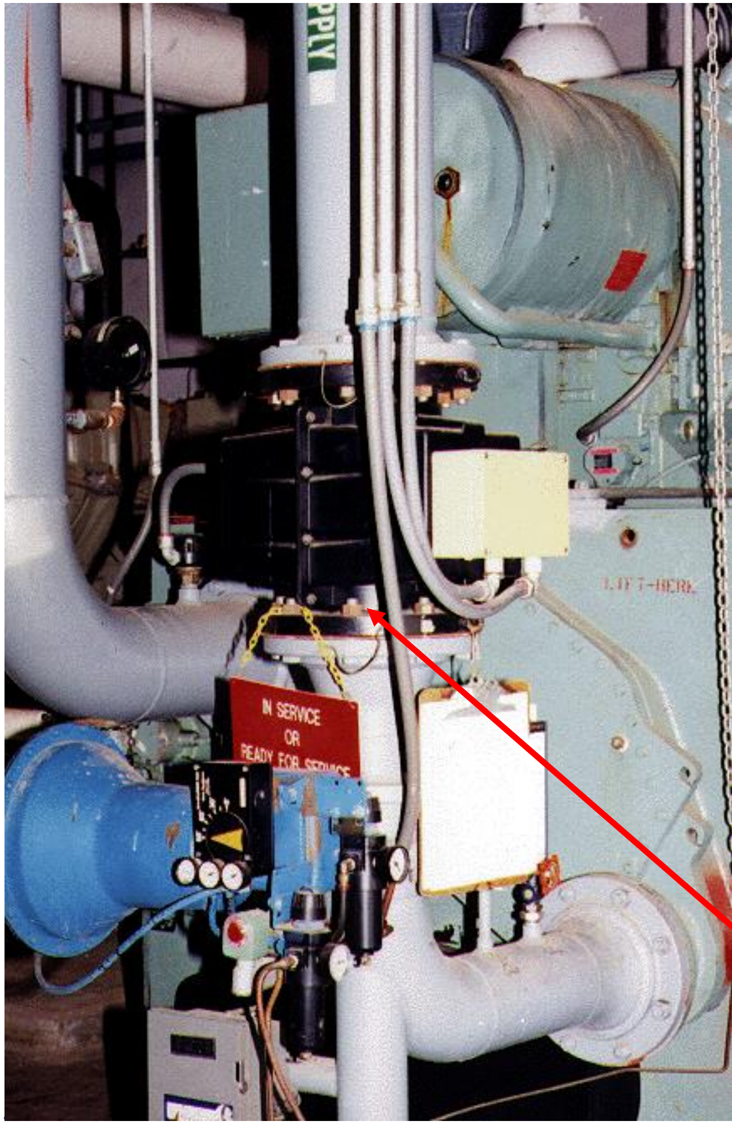
There are a host of flow meter types

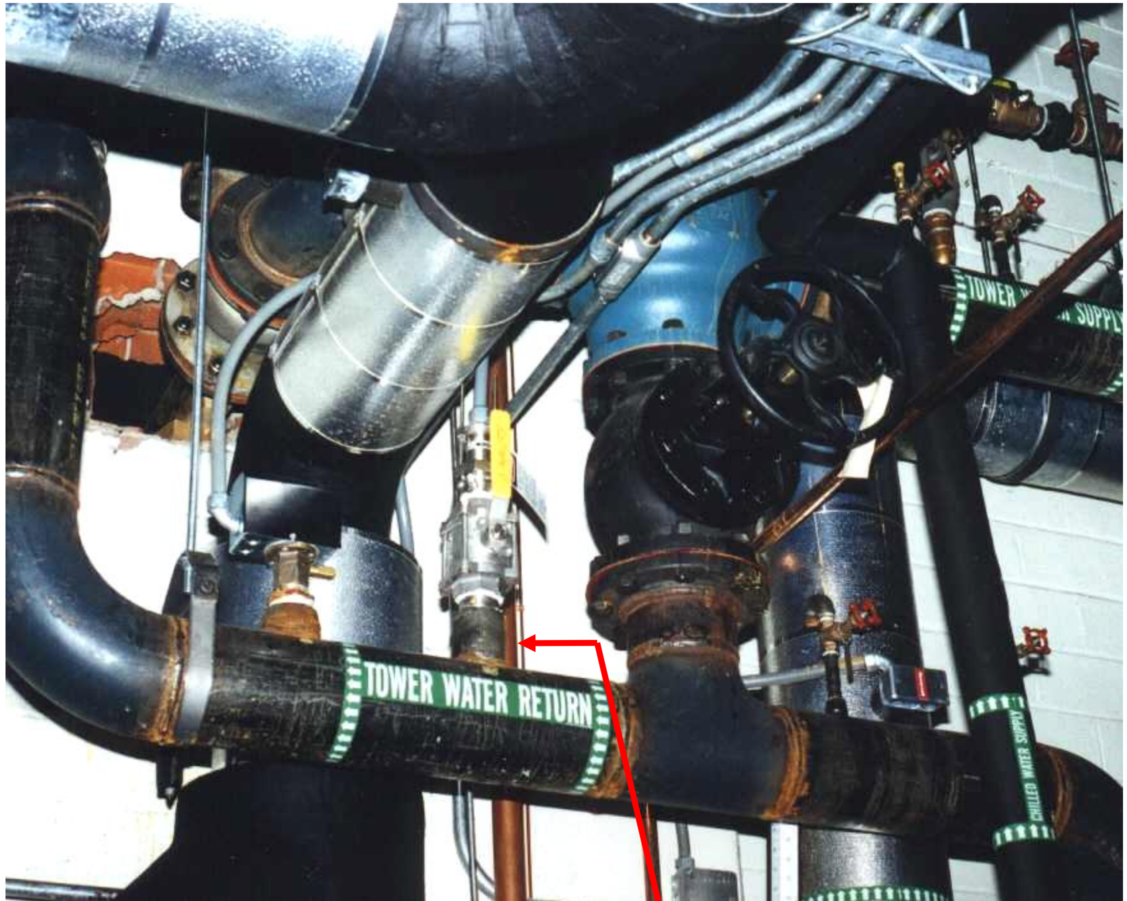
- Differential pressure - orifice, venturi, nozzle, elbow
- Velocity - magnetic, ultrasonic, turbine, vortex shedding, variable area (rotameter), pitot tube
- Open flow - Weir
- Positive displacement - gear, nutating disc
- Mass

Some important flow meter considerations

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

Some all too often found field configurations...





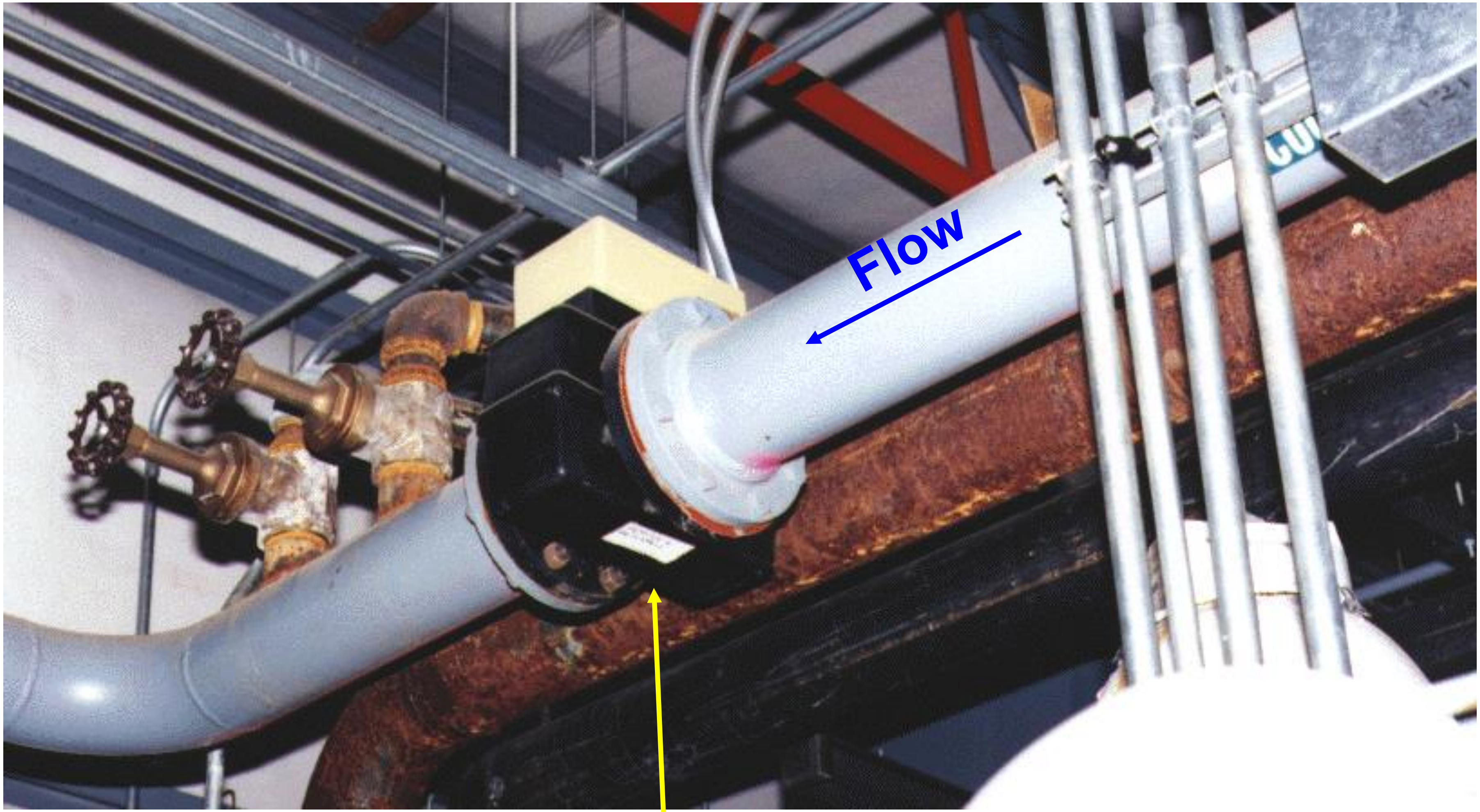
Magnetic flow meter

Insertion-type meter

Another less-than desirable arrangement

venturi flow meter

A good configuration

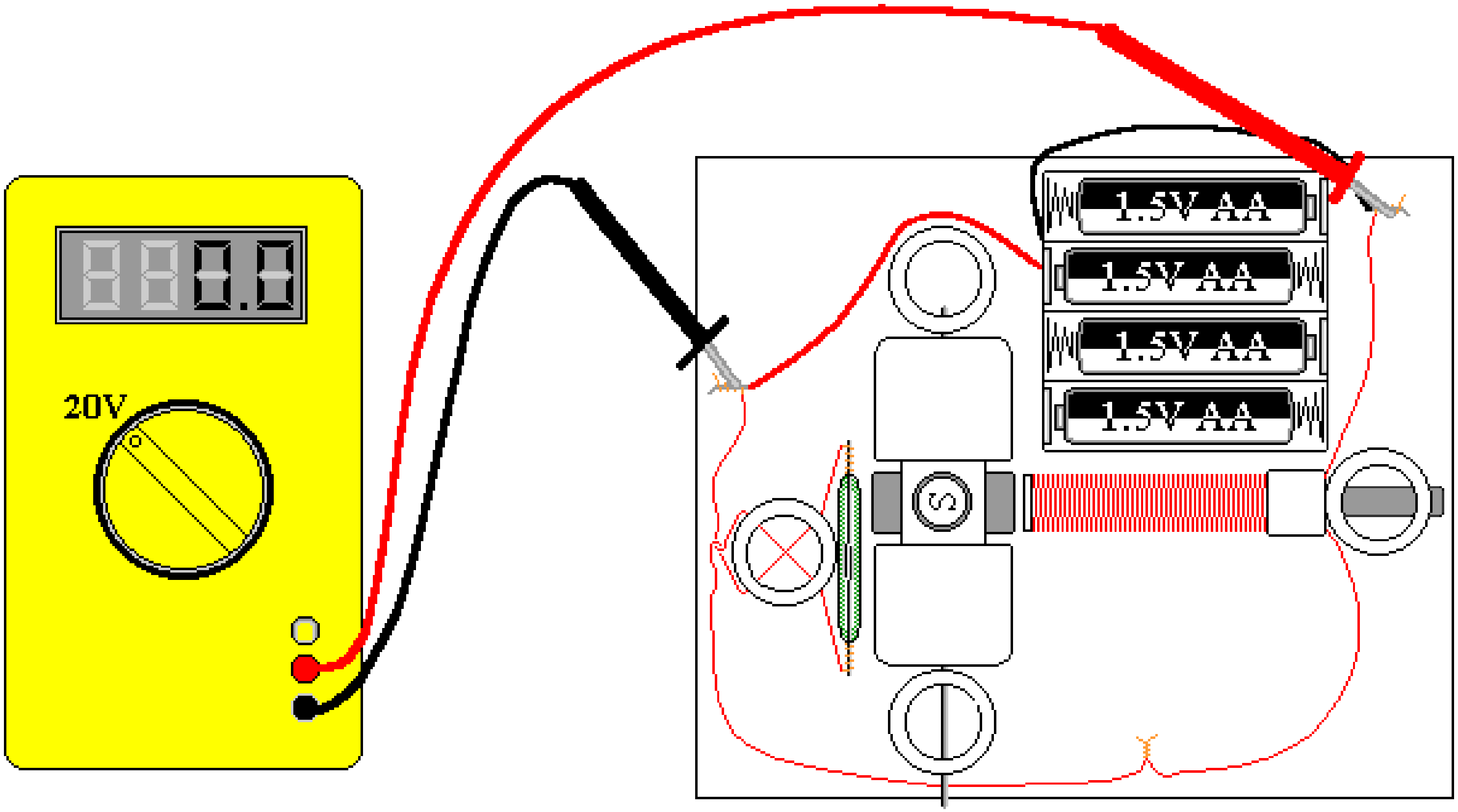


Magnetic flow meter

Another good arrangement

Flow nozzle with upstream flow straightener (compressed air service)

Electrical measurements: Instruments and considerations



The most important consideration in electrical measurements:

- SAFETY

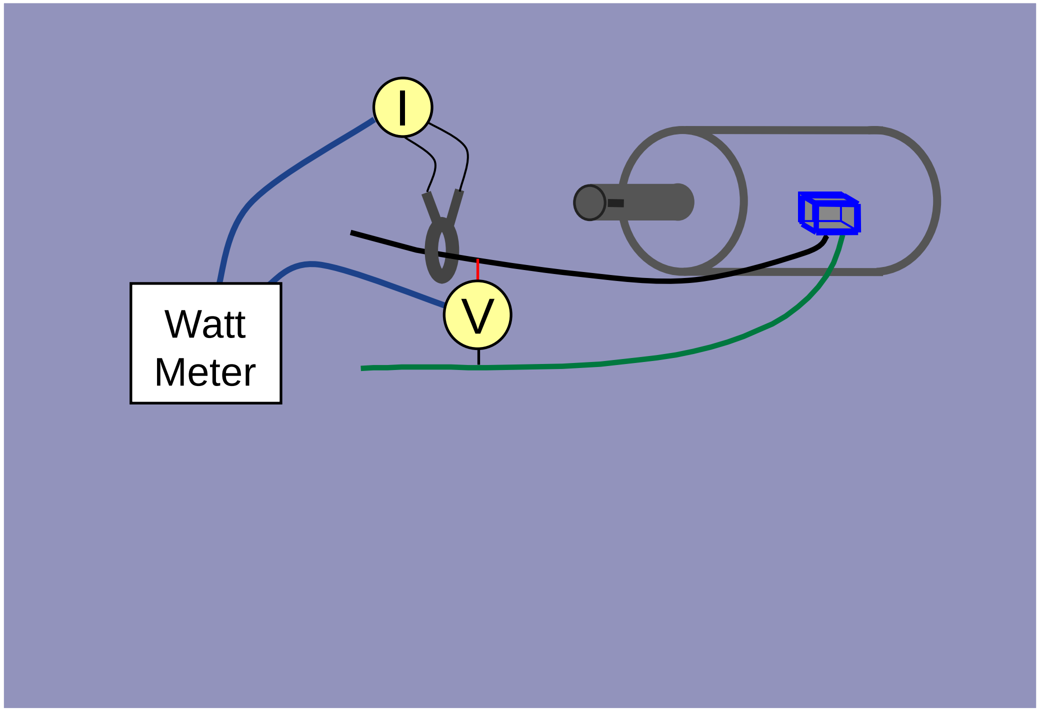
Strongly recommended reading for those planning to make electrical measurements

- NFPA* 70E, Standard for Electrical Safety in the Workplace
- 29CFR 1910.335, Safeguards for personnel protection (OSHA)

* NFPA – National Fire Protection Association, which also publishes the National Electrical Code

Fundamental electrical power relationships: Single phase power

$P_{avg} = I_{rms} \cdot V_{rms} \cdot \text{power factor}$

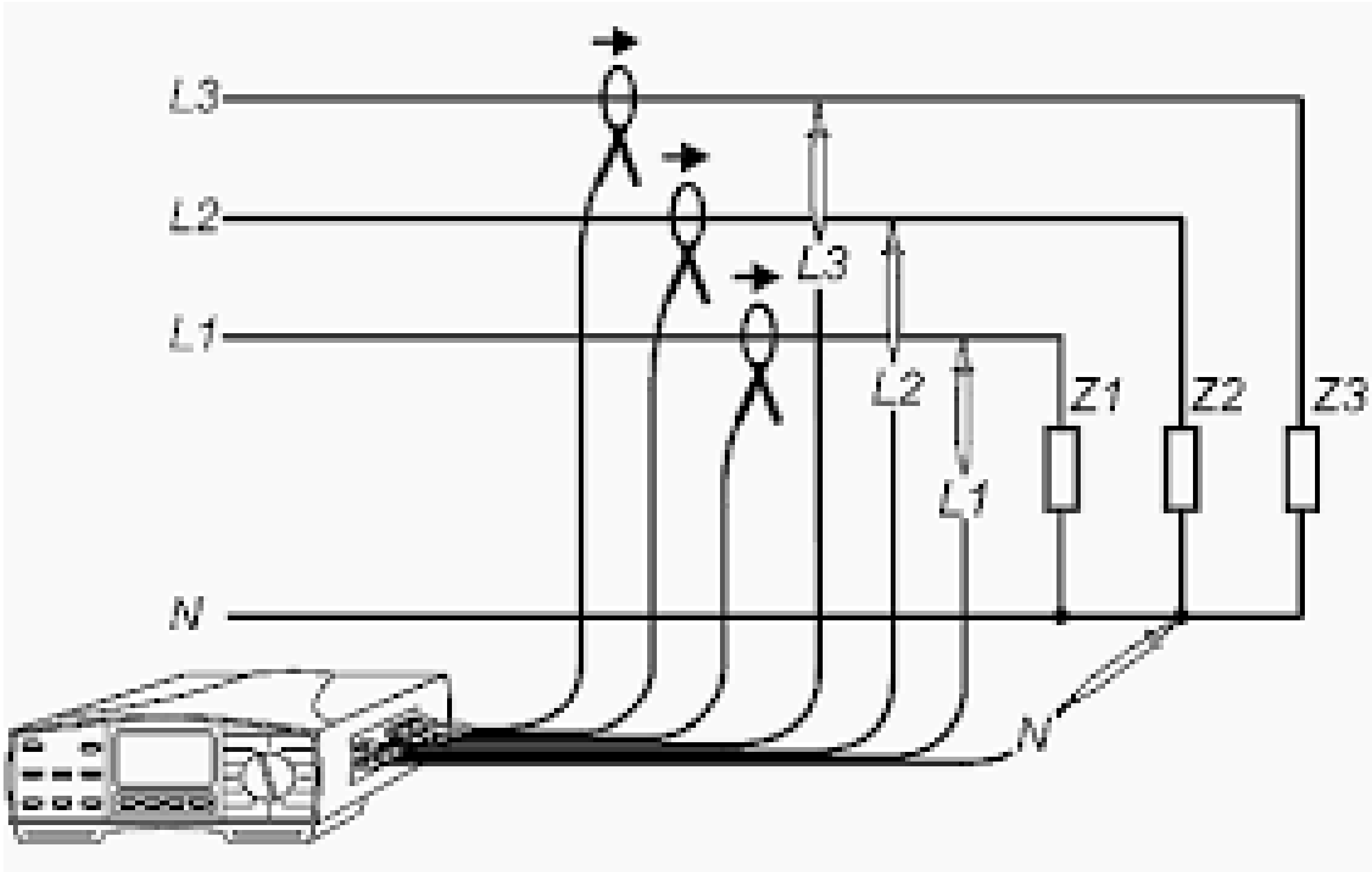


note: the V_{rms} above is line to neutral voltage

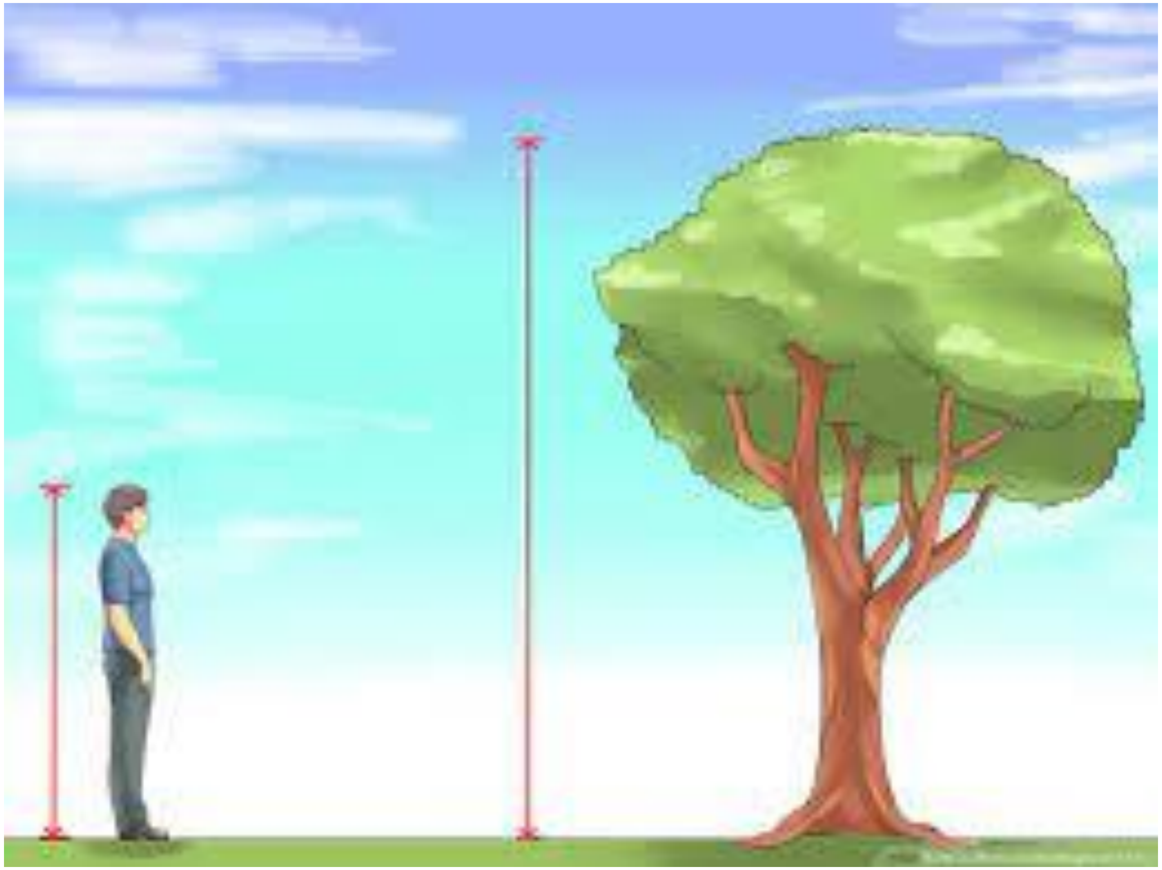
or $P_{avg} = \text{Average}(I_{inst} \cdot V_{inst})$

Three phase portable power meters have become common in recent years

Three phase portable power meter in application



Estimating things you can't measure



Reviewing: Important parameters to be read, measured, or estimated for pumping system analysis

- Flow rate
- Head
- Motor input power
- Rotating speed
- Nameplate information:
  - Motor rated speed, hp, full load amps, nominal efficiency
  - Pump gpm, head, speed

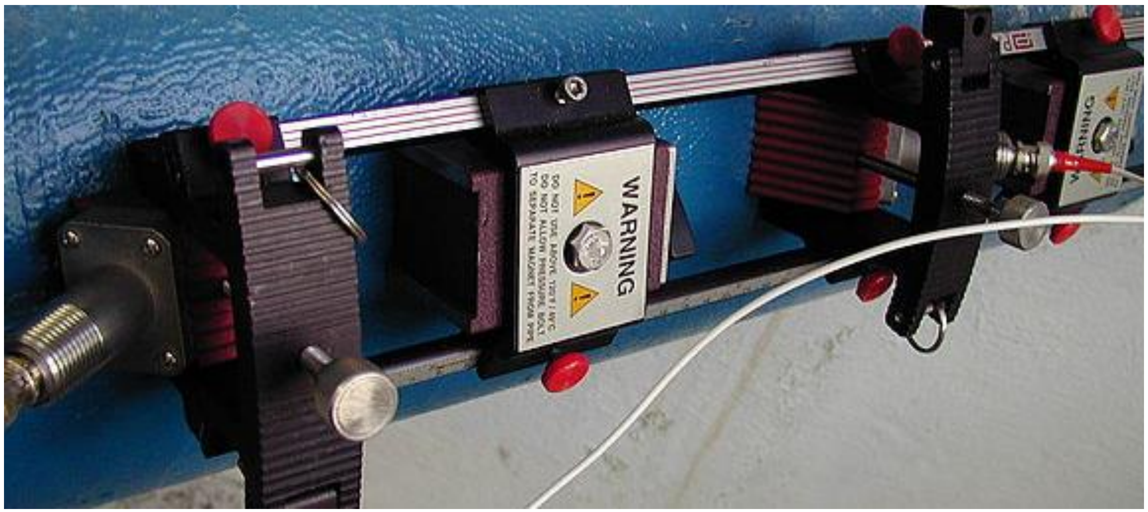
But in many cases, it isn't feasible to measure one or more of these parameters - for example, the flow rate, and for voltages above 600 V, the power.

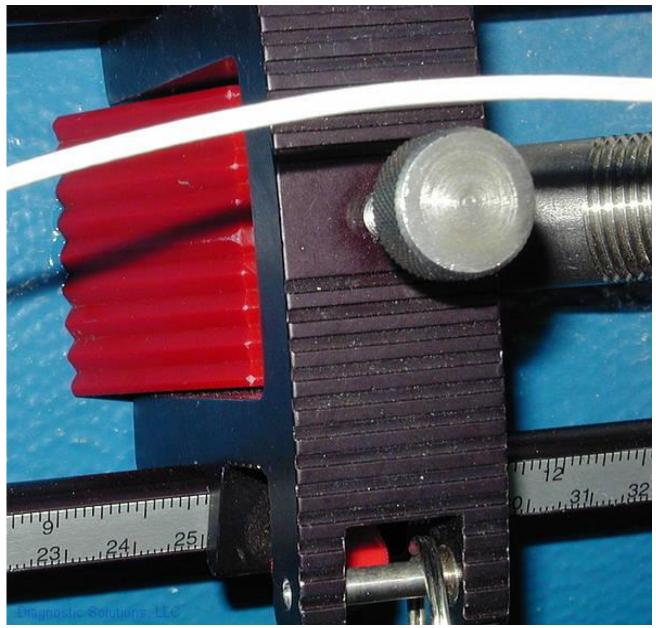
What do we do then?

Estimating flow rate when it isn't permanently metered

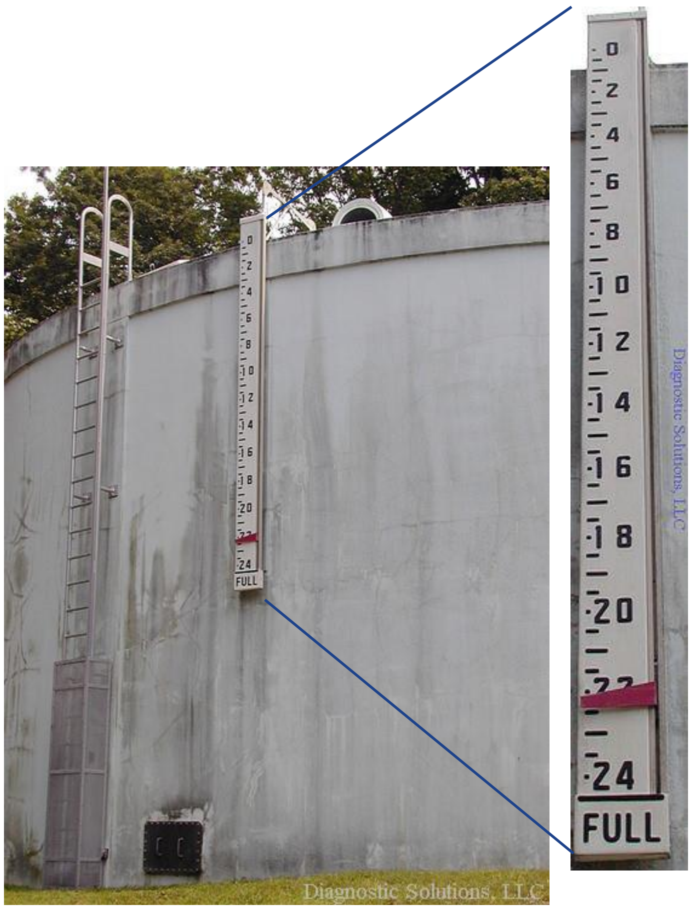
- Portable flow meter
- Special test
- From pump head measurement and pump curve
- From other process parameters (sanity check)
- From component(s) pressure drop

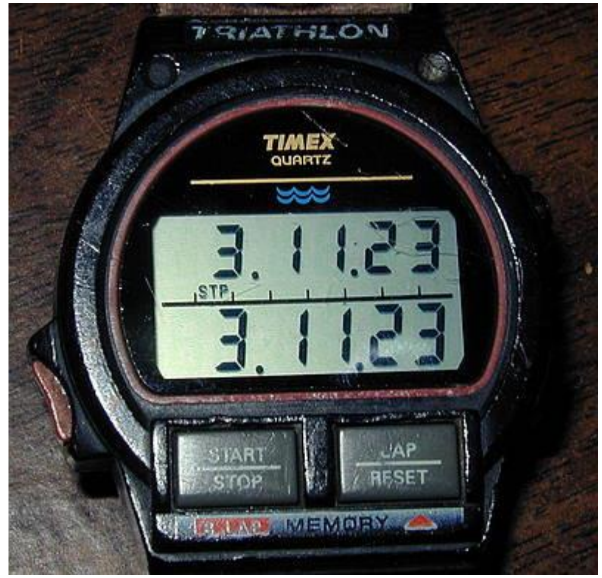
Portable ultrasonic flow meter

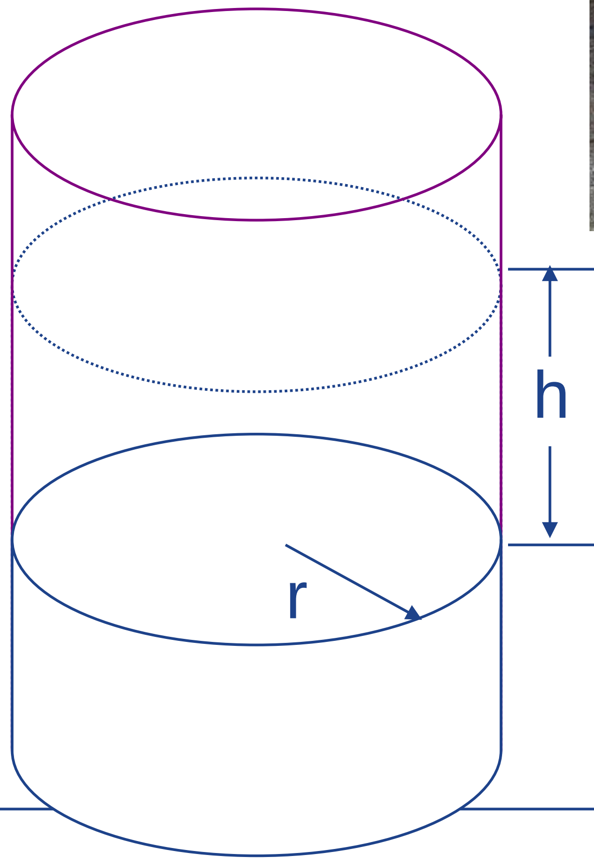




Special test example - tank drain or fill (also a standard way to calibrate flow meters)







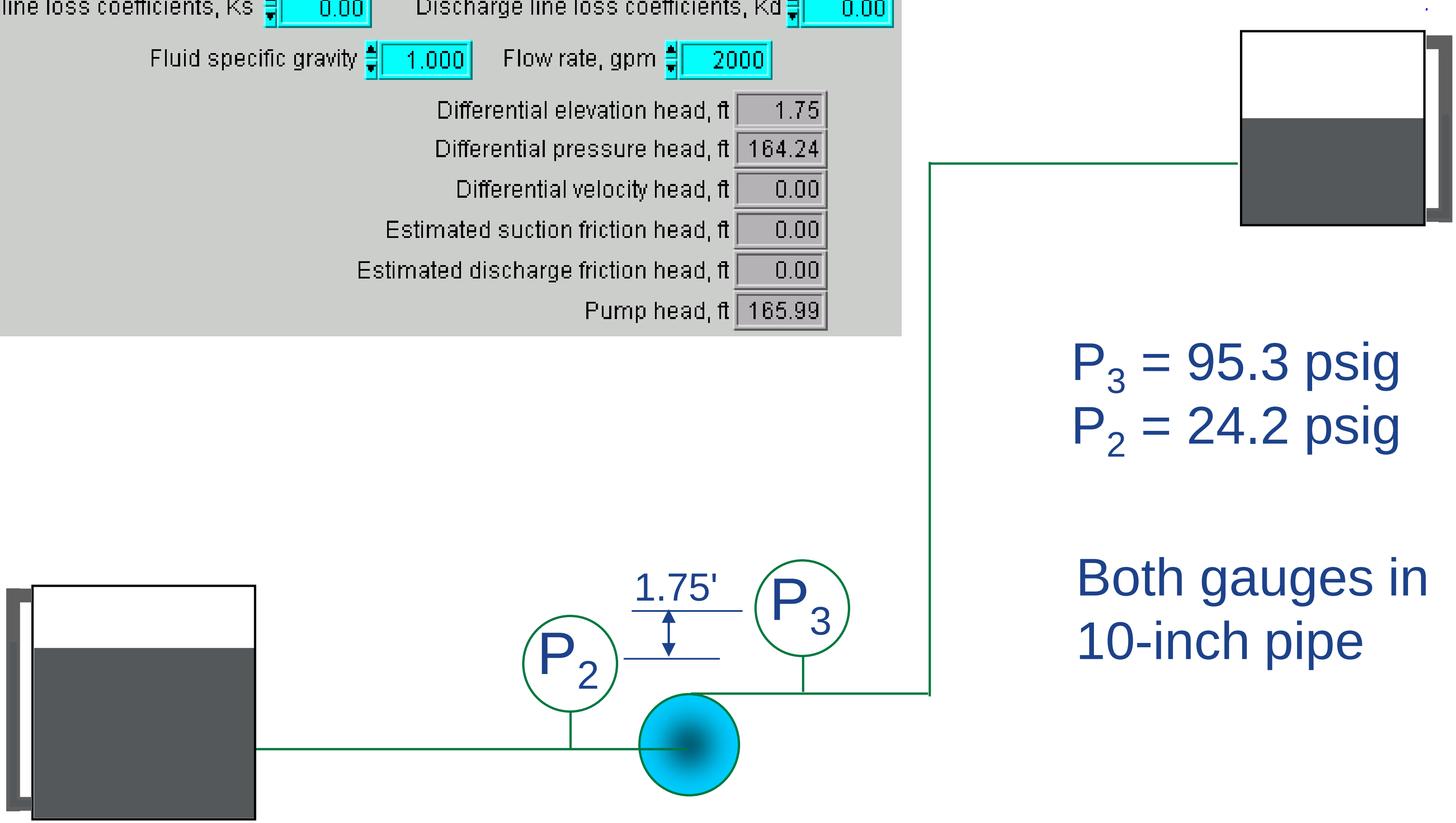
$$Q = \frac{\pi r^2 h}{t}$$

Estimating flow rate from pump head measurements and the pump curve

Step 1: Estimate head from test gauges at the P_2 and P_3 gauge locations

Suction pipe diameter (ID), inches	10.020	Discharge pipe diameter (ID), inches	10.020
Suction gauge pressuge (Ps), psig	24.20	Discharge gauge pressure (Pd), psig	95.30
Suction gauge elevation (Zs), feet	0.00	Discharge gauge elevation (Zd), feet	1.75
Suction line loss coefficients, Ks	0.00	Discharge line loss coefficients, Kd	0.00
Fluid specific gravity	1.000	Flow rate, gpm	2000

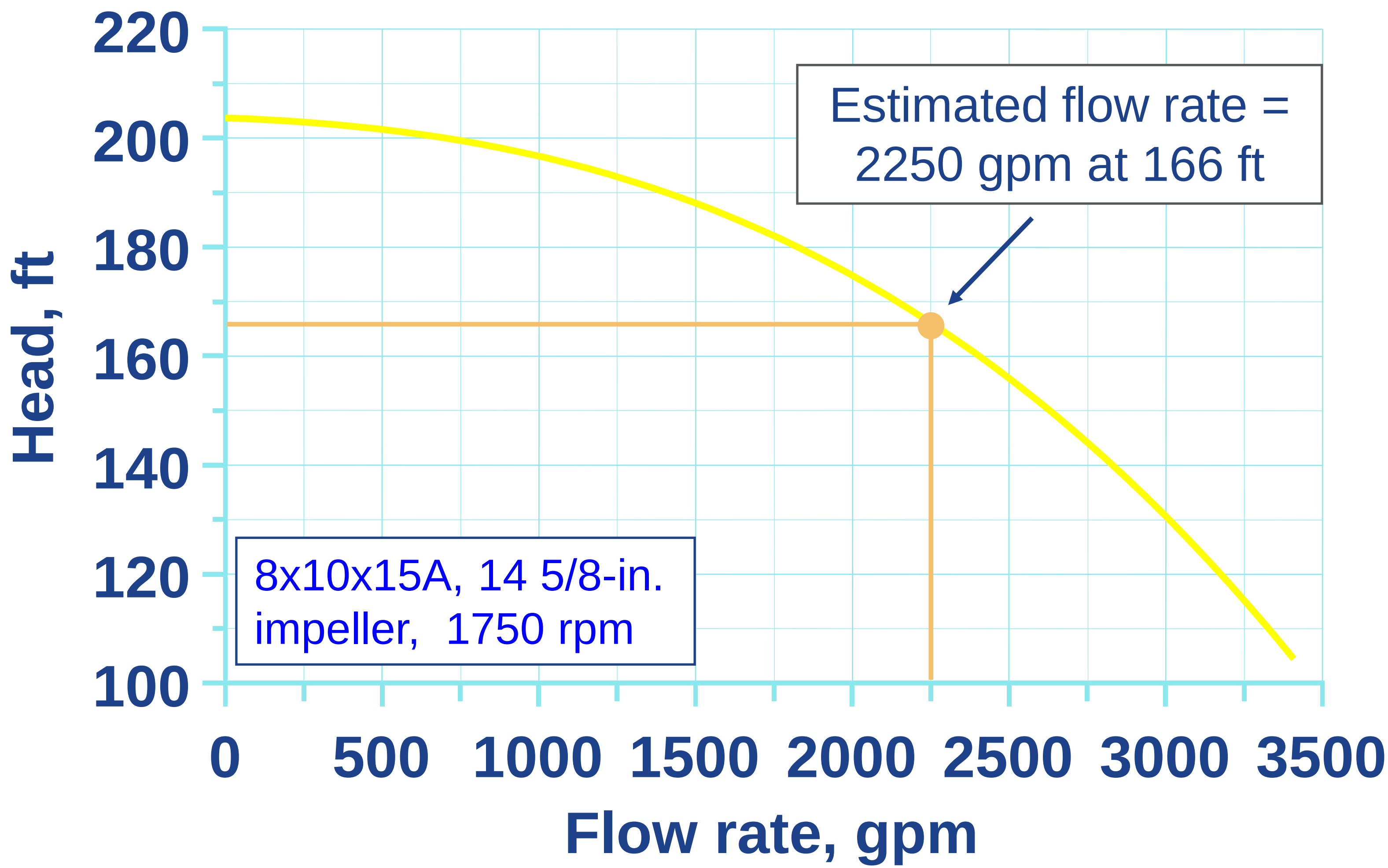
Differential elevation head, ft	1.75
Differential pressure head, ft	164.24
Differential velocity head, ft	0.00
Estimated suction friction head, ft	0.00
Estimated discharge friction head, ft	0.00
Pump head, ft	165.99



P_3 = 95.3 psig
P_2 = 24.2 psig

Both gauges in 10-inch pipe

Step 2: retrieve the manufacturer's generic pump head curve and make initial flow estimate



Calculate pump head and use pump curve to predict flow rate

If suction and discharge line sizes are different or loss elements are present, it is necessary to iterate between the pump head curve and the head calculation, since the pump head is affected by flow rate. Guess a reasonable flow rate and calculate the pump head. Then check the pump curve for agreement.

Result Data

Differential Elevation Head	-4.0 ft
Differential Pressure Head	93.36 ft
Differential Velocity Head	5.21 ft
Estimated Suction Friction Head	0.0 ft
Discharge Friction Head	18.17 ft
Pump Head	112.74 ft

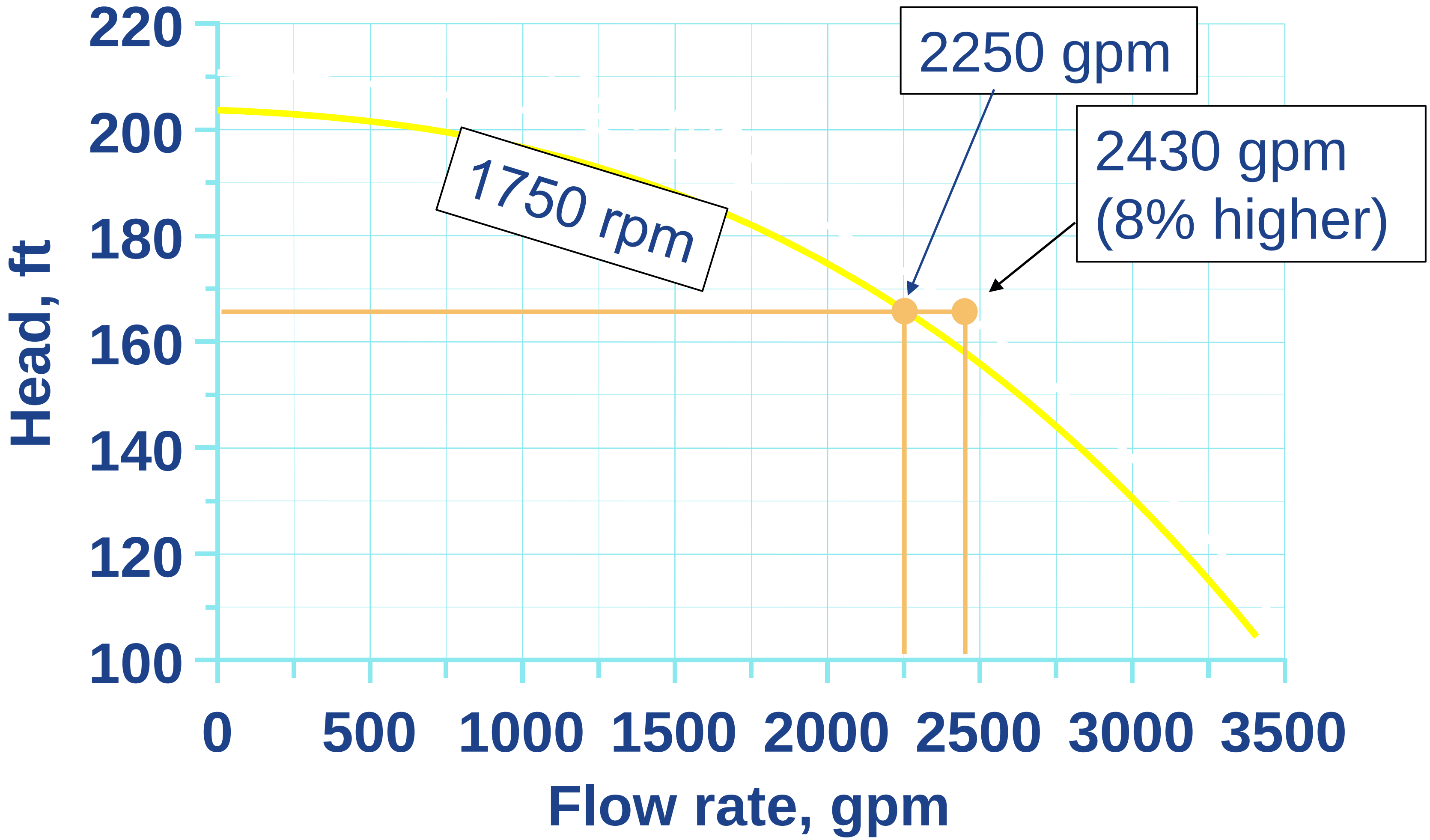
A few possible gotcha's

- Pump head-capacity curve was developed at a different speed
- Pump performs differently in the field than at the test facility
- Inaccurate pressure gauges
- Pump specific curve ≠ pump generic curve
- Impeller, other pump parts have worn
- We don't know the impeller diameter
- The manufacturer exaggerated (nah, couldn't be)

Pump rotational speed can usually be easily and accurately measured with a strobe light

It is *very* common to find pumps operating at greater than the speeds at which they were rated

Accounting for actual vs. rated speed IS important (using the measured head of 166 ft)



Measured speed is 1780 rpm. The difference is 8% in this case

Calculations from previous slide

- To make a one-point estimate of flow rate when the pump is operating at a different speed than that at which the performance curve was developed, it isn't necessary to develop an entirely new curve. Instead, you can simply use the affinity laws for the single measured point.

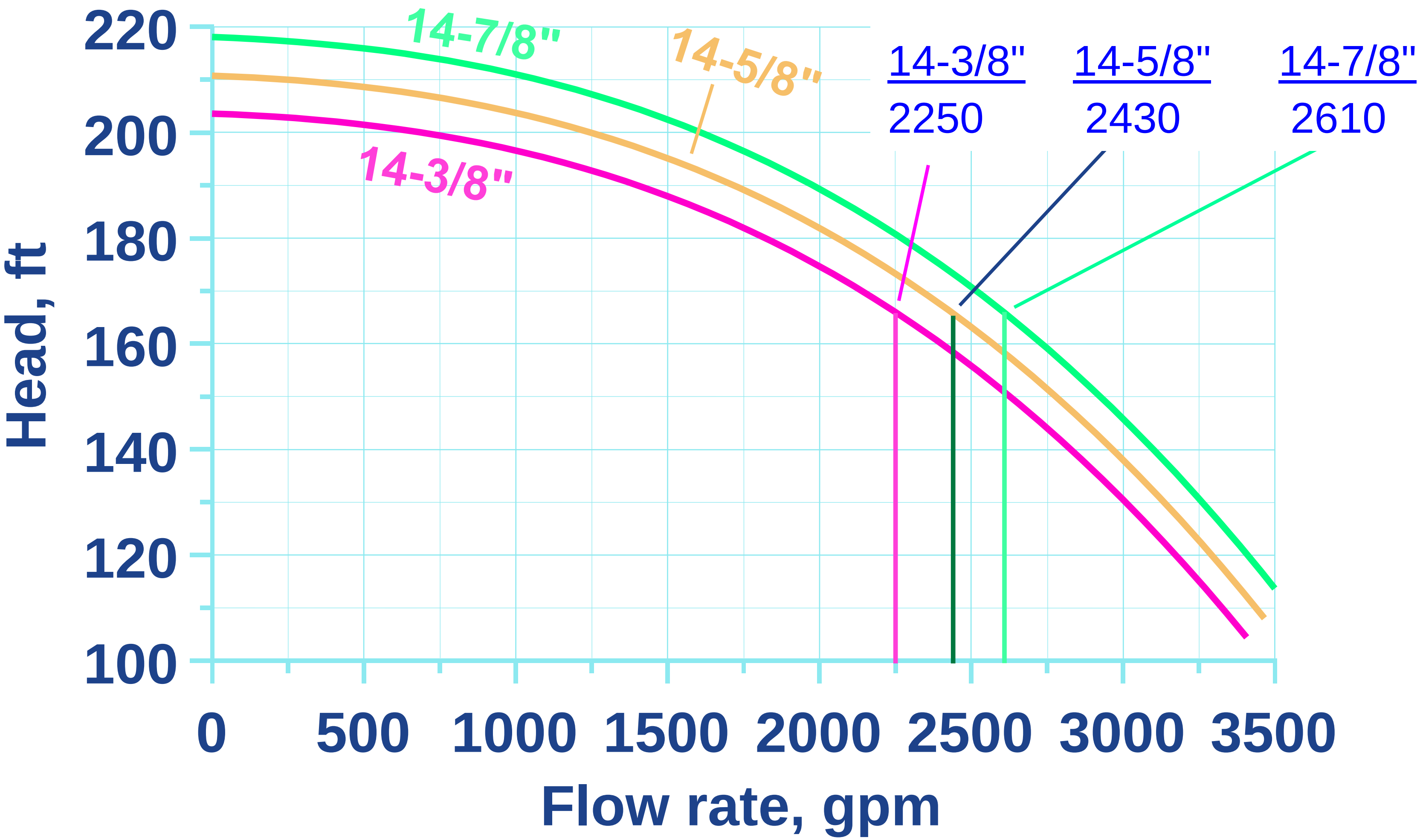
- In this case, the 1750 rpm head corresponding to 166 ft at 1780 rpm, per the affinity laws, is:
  - 166 ft x $(1750 \div 1780)^2$ = 160.5 ft

- Now find the flow rate at 160.5 ft on the 1750 rpm curve - it is about 2390 gpm.

- Finally, the 2390 gpm at 1750 rpm converts to, by the affinity laws is:

- 2390 gpm x (1780 ÷ 1750) = 2430 gpm at 1780 rpm

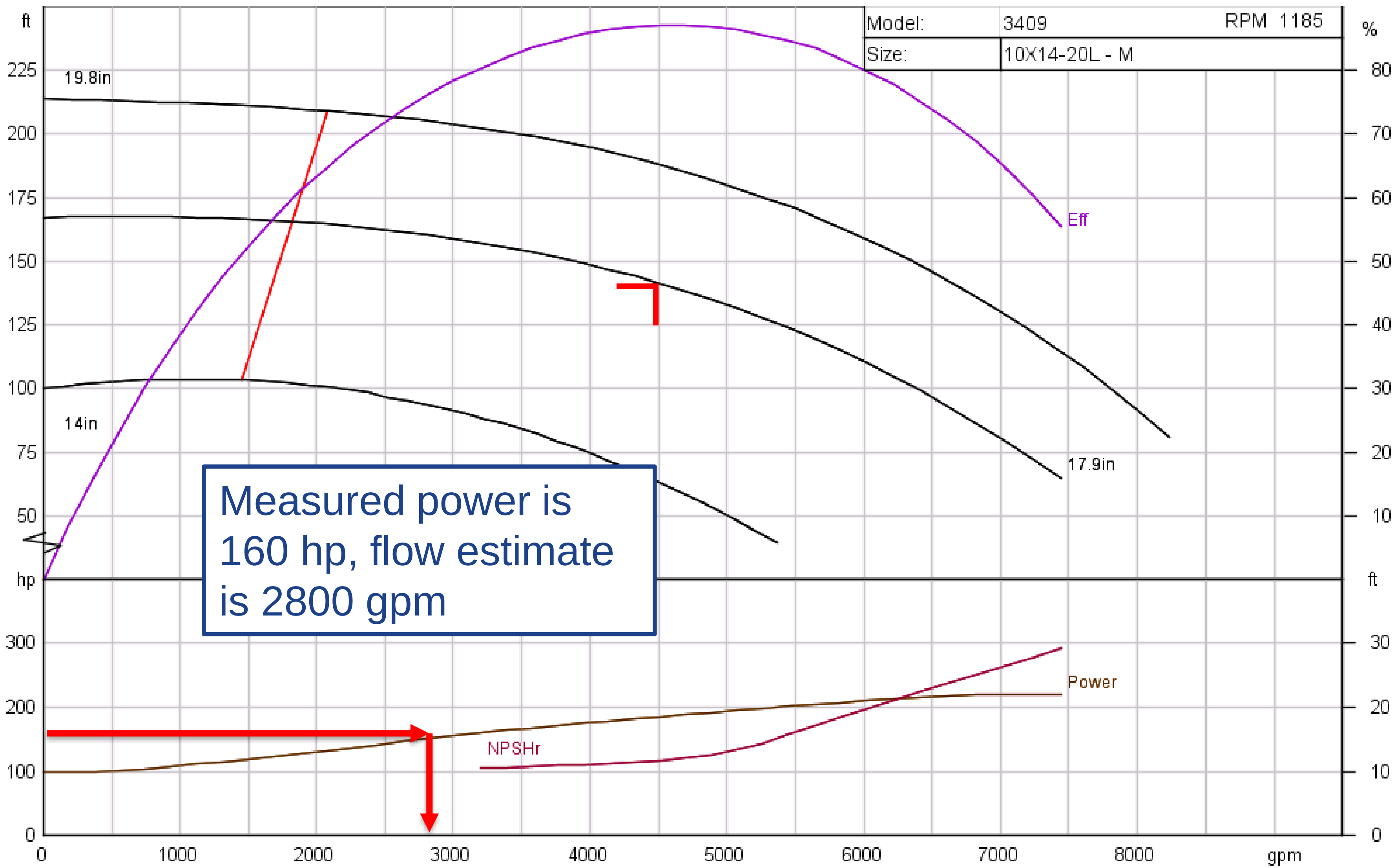
What if you have manufacturer's generic curve set, and aren't sure of the impeller diameter?



A couple of options

- Measure shutoff head (for low energy pumps – and quickly at that)
  - What if wear ring clearance has opened?
  - Does speed change when dead-headed?
- For pumps with rising power curves:
  - Measure electrical power
  - Use MEASUR to estimate shaft power
  - Compare the estimated shaft power with the manufacturer's power curve

Use the measured power to estimate the flow rate

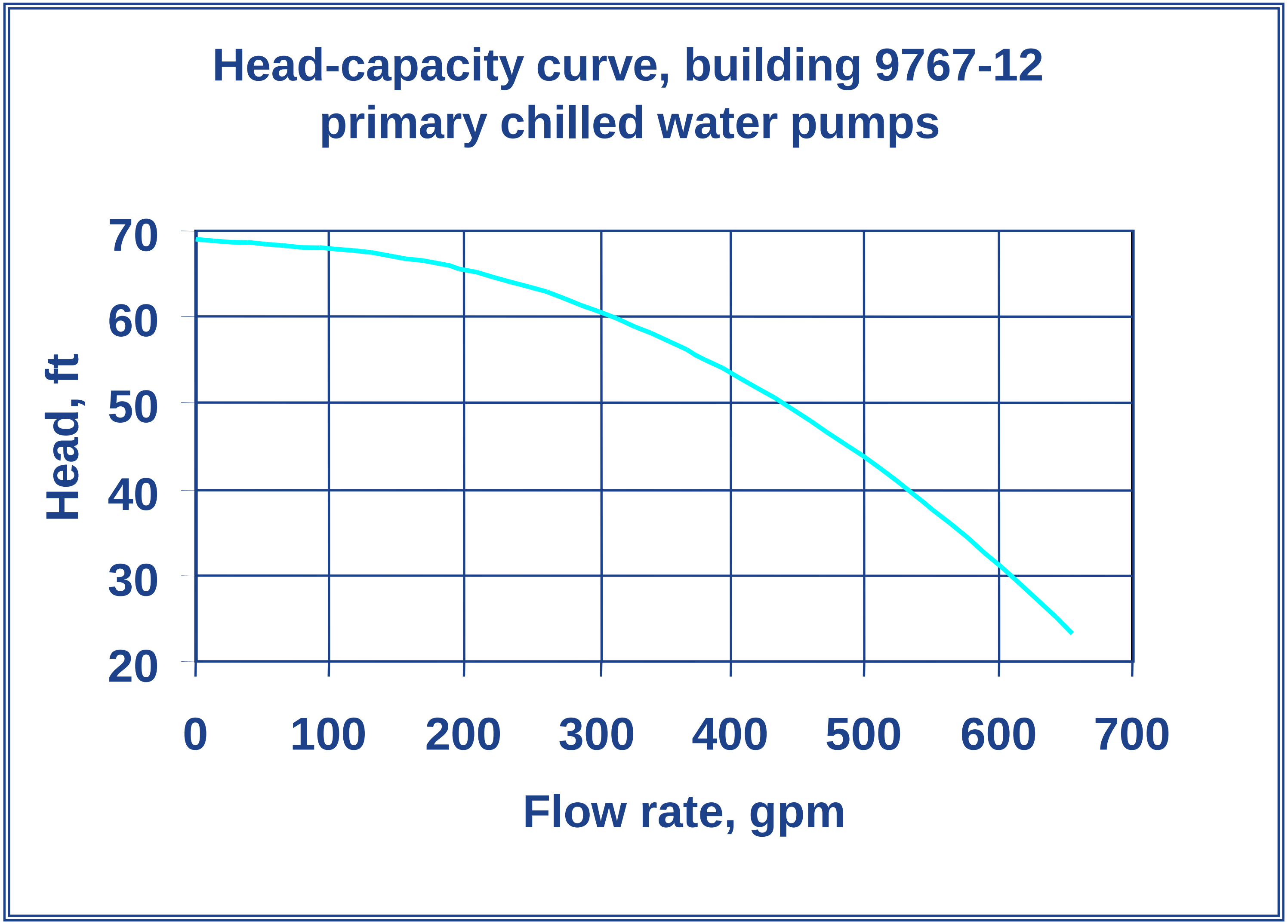


Some related good general practices*

- Request (pay for) a certified test curve for the specific pump
- When possible, have tested with the motor that will be used in actual service
- After installation, benchmark field performance against test facility data
- Do regular hydraulic performance tests

* For pumps that are important energy users; you wouldn't want to do this for 5-hp pumps unless there were other reasons for doing so.

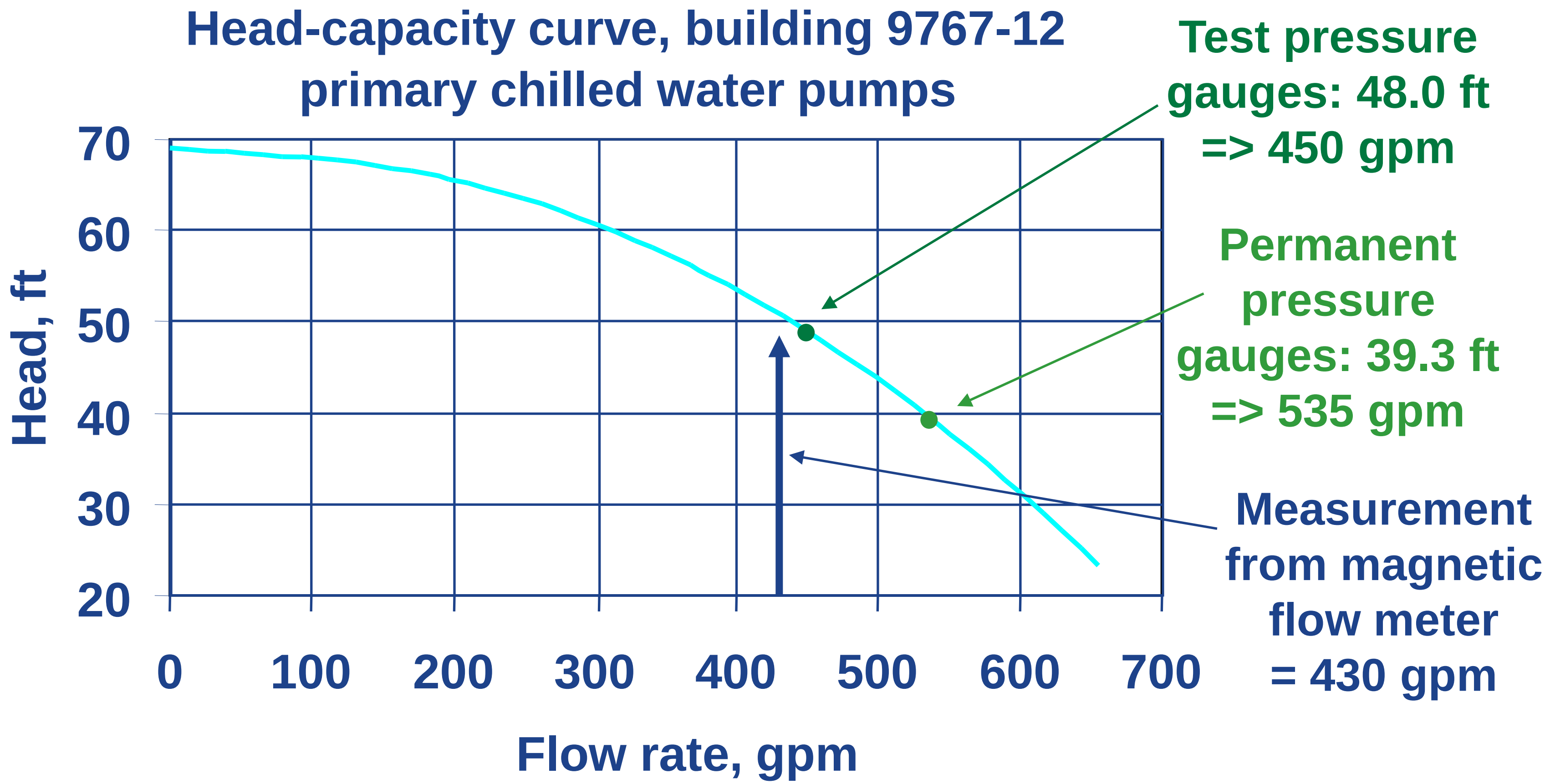
A case study to illustrate flow estimation from pressure measurements



Pump discharge: permanently installed gauge reads 2.5 psig low

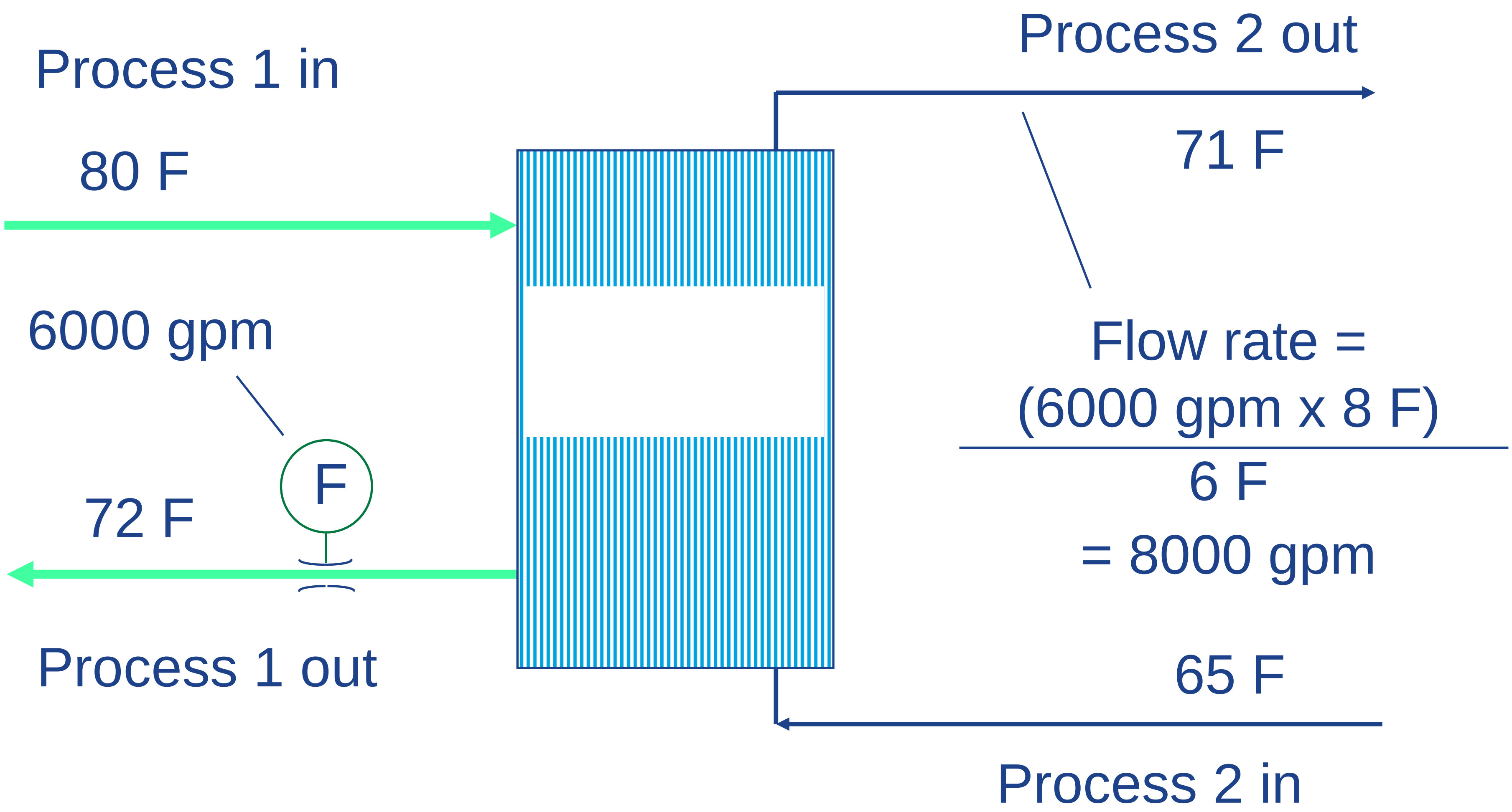
Pump suction: permanently installed gauge reads 1.3 psig high

Comparing permanent and test pressure gauge-indicated flow rates



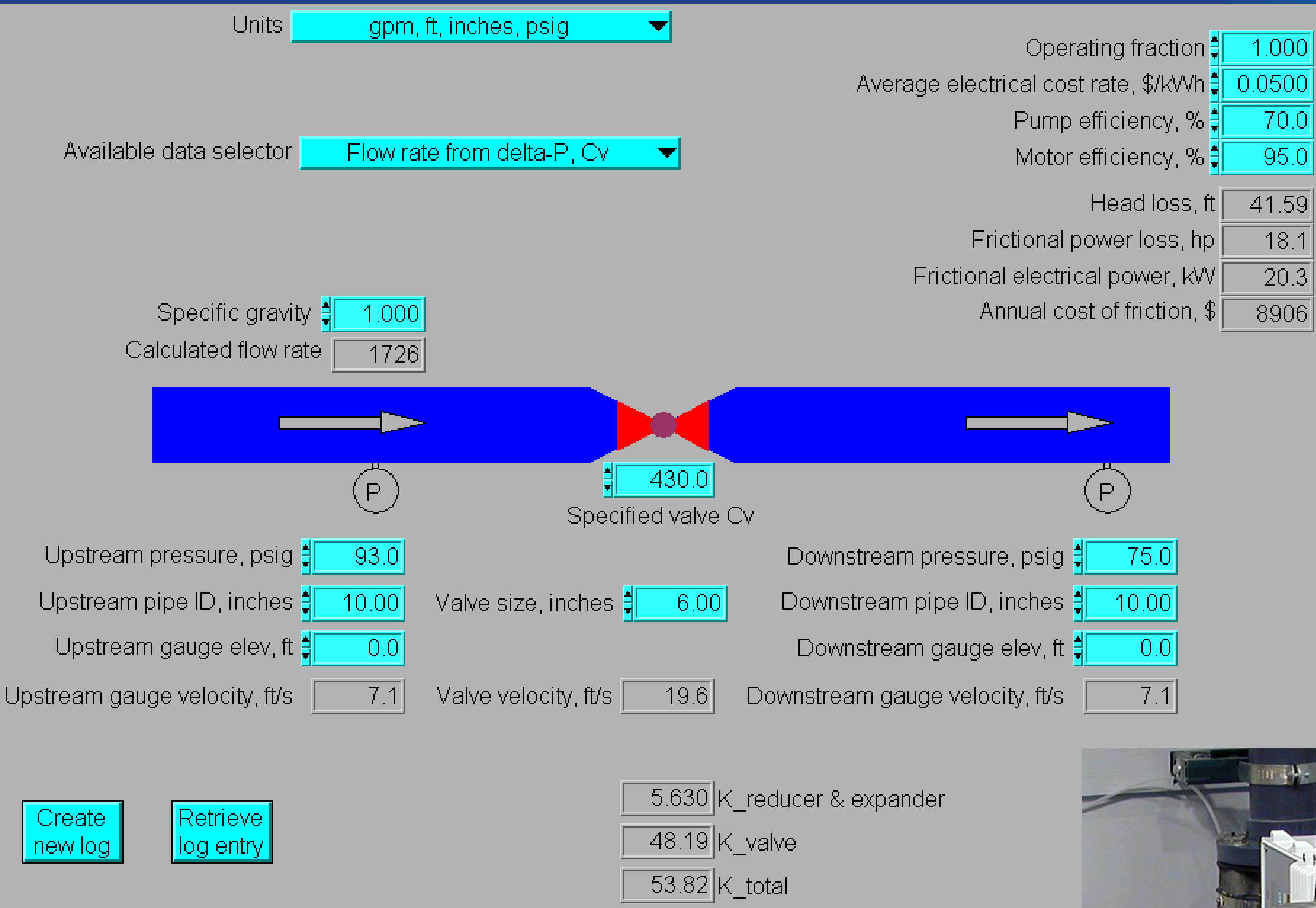
Estimating errors:	Permanent gauges	+ 24%
	Test gauges	+ 5%

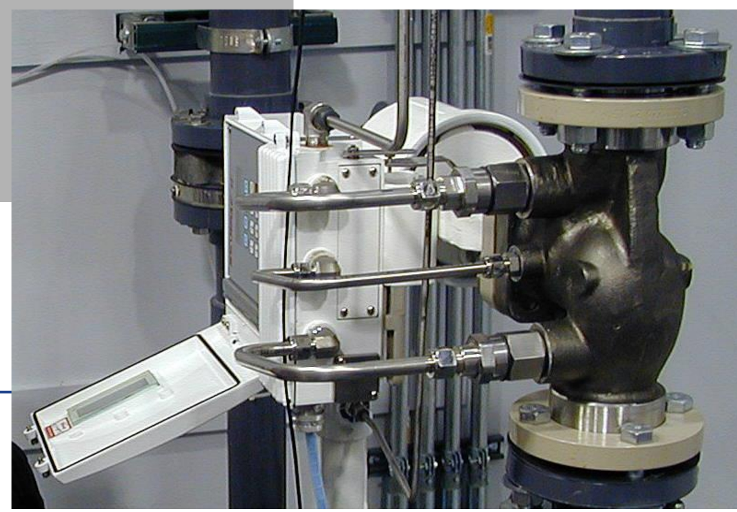
As a sanity check - use other process parameters



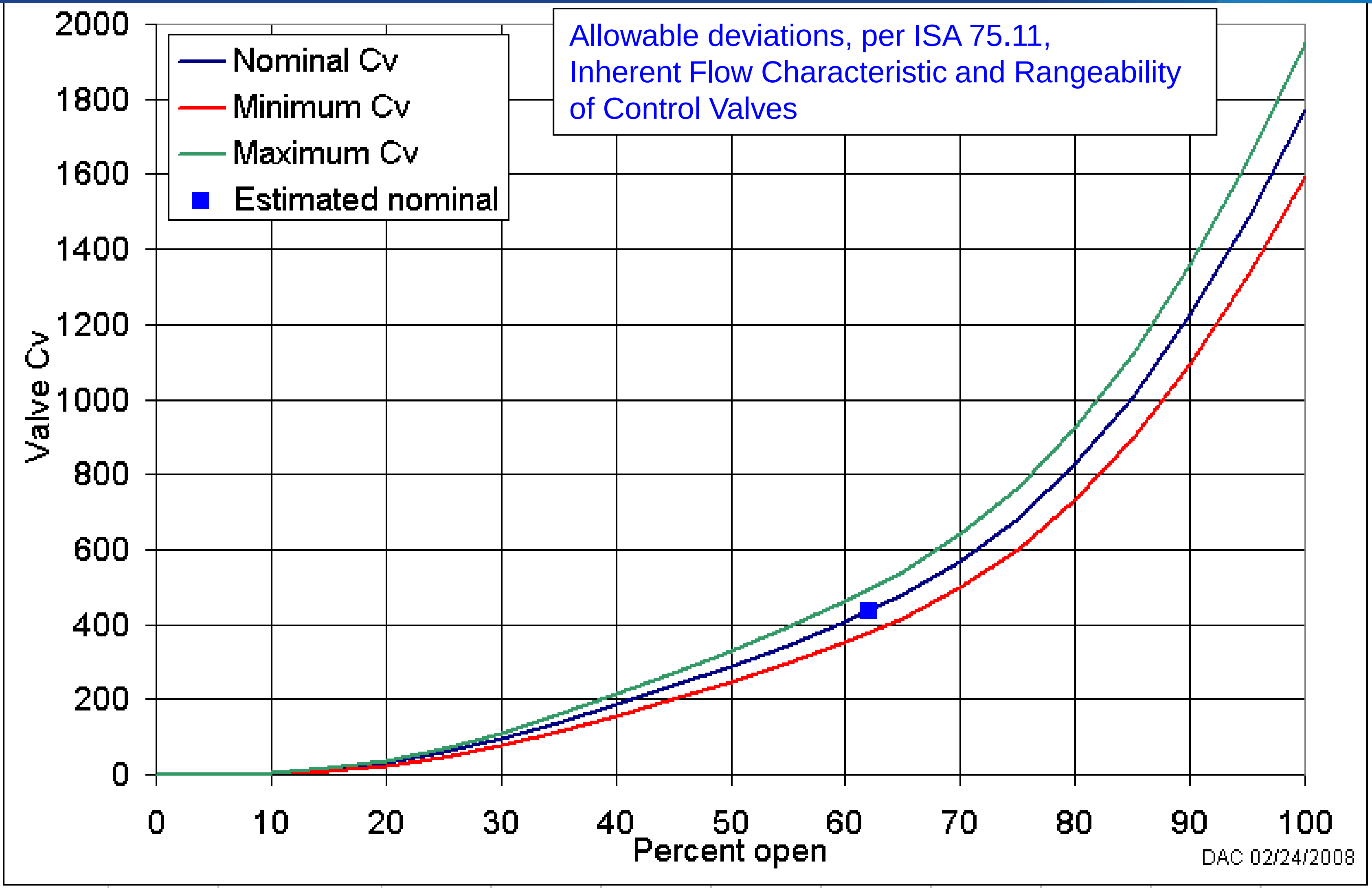
$Q = 500 \times gpm \times \Delta T$ (Std water)

Using valve differential pressure to estimate flow rate



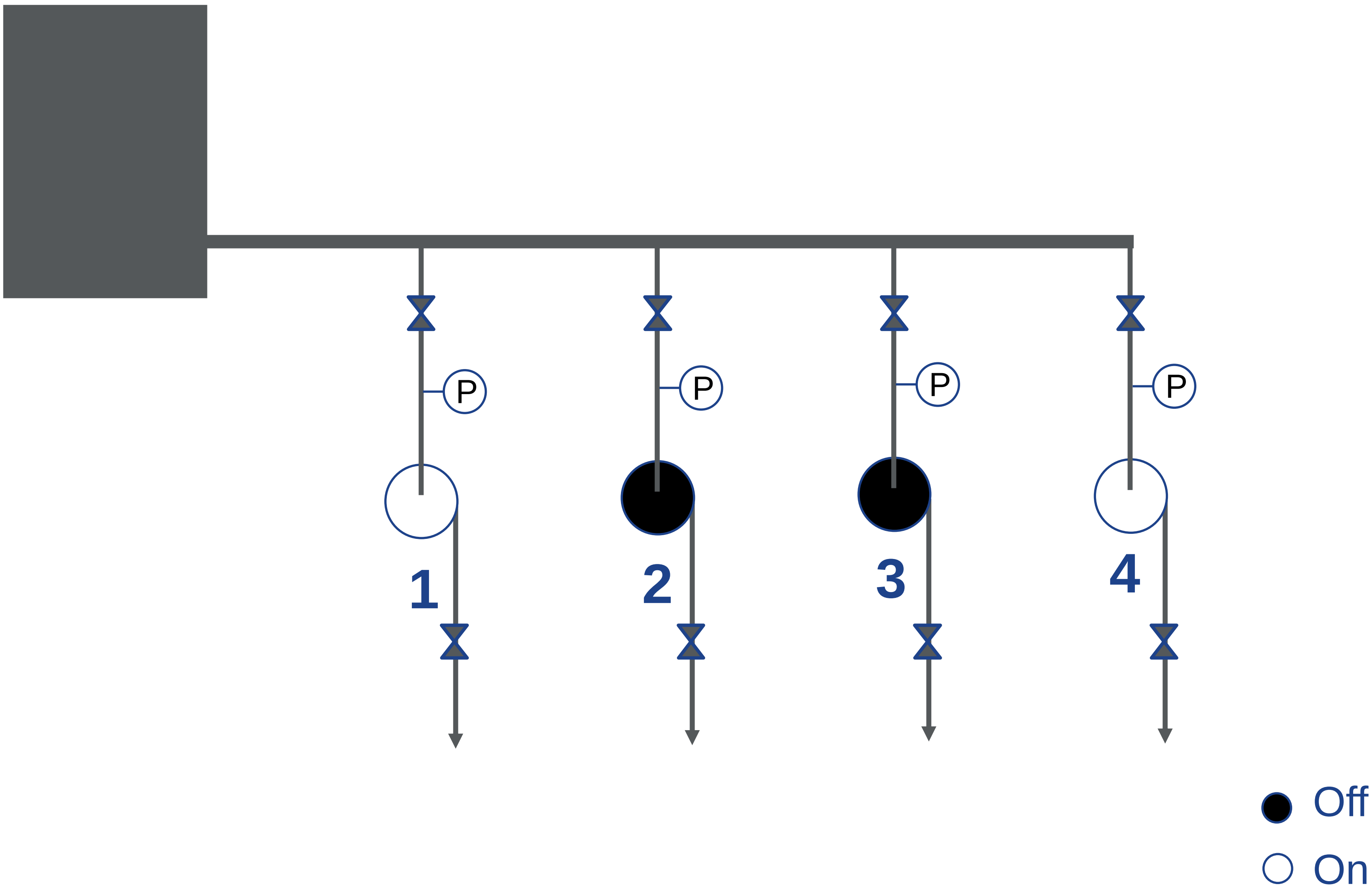


Important: valve characteristic must be known; this is not a precision flow measurement



Maximum	490.4	Allowable, % nominal:	13.3%
Nominal	433.0		
Minimum	375.6		

An effective way to measure flow rate in parallel pumping applications: use Bernoulli



Parallel Pump System – Flow Estimating

- A very common pump configuration is to have several parallel pumps fed from a large common header, tank or reservoir. In most cases, one or more of the parallel pumps is normally idle.

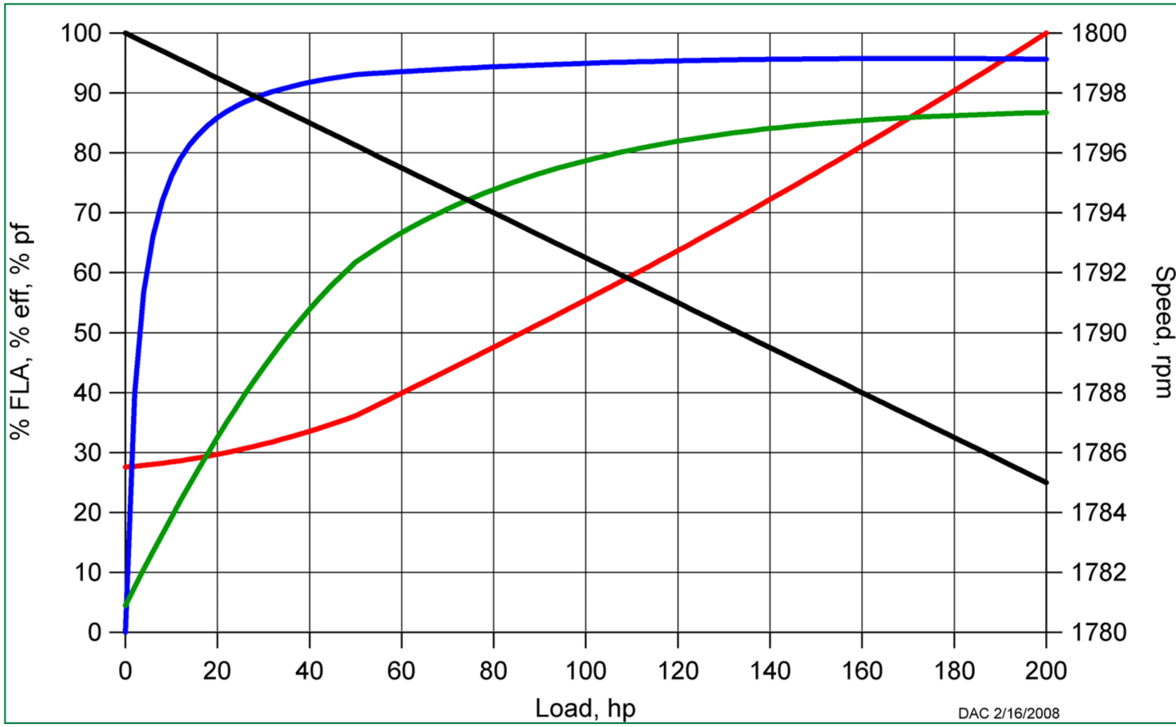
- The total hydraulic head, including pressure, elevation, and velocity should be the same in the suction pipes of running and idle pumps. But since there is no velocity in the idle pumps, the pressure would be higher than in those that are running. By measuring the differences in pressures, the velocity head in the suction of a running pump can be deduced.

Parallel Pump System – Flow Estimating

- Of course, a difficulty with this approach is the fact that there are frictional effects. In the example shown above, there are losses across the suction valves, as well as other pipe fittings (elbows/tees). But using nothing other than typical values for these components, it is often possible to estimate velocity to within an accuracy of a few percent. In some cases, this may be the best estimate that can be made. It also provides an independent means of estimation that can either corroborate or bring into question other flow measurements or estimates.

How about power estimating?

- MEASUR estimates of power from current have proven to be reasonably accurate
- Linear current ratio (measured amps divided by full load amps = fraction of rated load) is a very poor second choice
- MotorMaster algorithms
- Speed - not recommended unless a speed-power calibration curve for the specific motor and for the specific power supply conditions is in hand (i.e., almost never)



MEASUR - example 1

Application: >40 years old, 200-hp, 4-pole motor, unknown repair history

Comparison of electric power estimated from current and voltage and actual electric power

Measure motor current & power & compare

FIELD DATA

Operating Hours	8760	hrs/yr
Electricity Cost	0.08	$/kWh
Flow Rate	2000	gpm
Head Calculate Head	277	ft
Load Estimation Method	Current	
Motor Current	215.5	A
Measured Voltage	472	V

RESULTS

	Baseline
Percent Savings (%)	— —
Pump efficiency (%)	73.1
Motor rated power (hp)	200
Motor shaft power (hp)	191.8
Pump shaft power (hp)	191.8
Motor efficiency (%)	94
Motor power factor (%)	86.4
Percent Loaded (%)	96
Drive efficiency (%)	100
Motor current (amps)	216
Motor power (kW)	152.2
Annual Energy (MWh)	**1,334**
Annual Energy Savings (MWh)	**—**
Annual Cost	**$106,687**
Annual Savings	**—**

Power estimated from motor current, voltage

FIELD DATA

Operating Hours	8760	hrs/yr
Electricity Cost	0.08	$/kWh
Flow Rate	2000	gpm
Head Calculate Head	277	ft
Load Estimation Method	Power	
Motor Power	156.3	kW
Measured Voltage	472	V

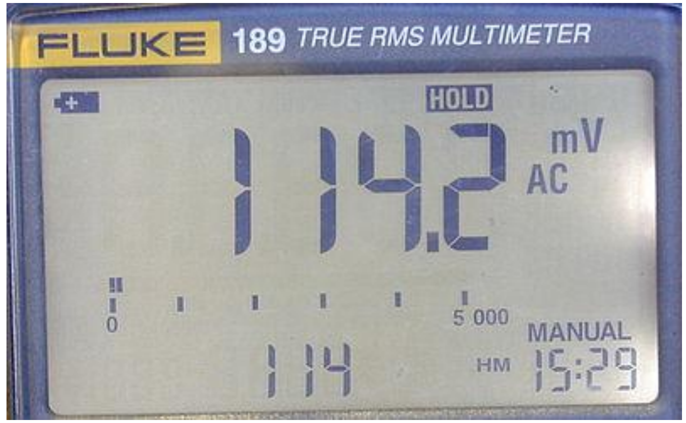
RESULTS

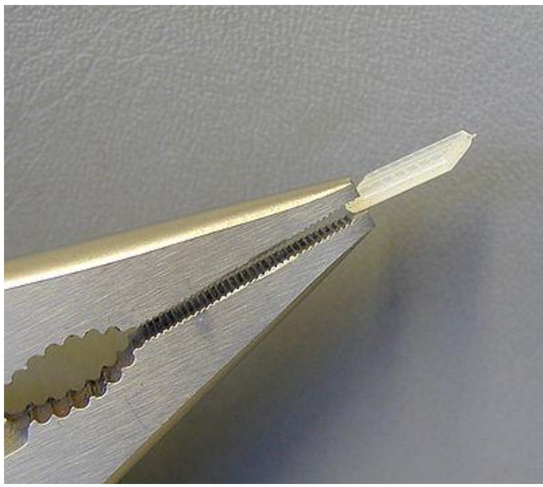
	Baseline
Percent Savings (%)	— —
Pump efficiency (%)	71.2
Motor rated power (hp)	200
Motor shaft power (hp)	196.8
Pump shaft power (hp)	196.8
Motor efficiency (%)	93.9
Motor power factor (%)	86.6
Percent Loaded (%)	98
Drive efficiency (%)	100
Motor current (amps)	221
Motor power (kW)	156.3
Annual Energy (MWh)	**1,369**
Annual Energy Savings (MWh)	**—**
Annual Cost	**$109,535**
Annual Savings	**—**

Power measured

A caution about clamp-on current measurements: CT jaw closure is critical

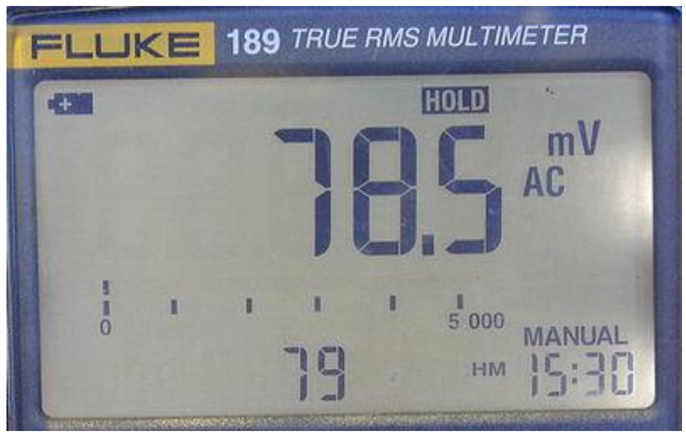
Jaws fully closed - 114.2 amps





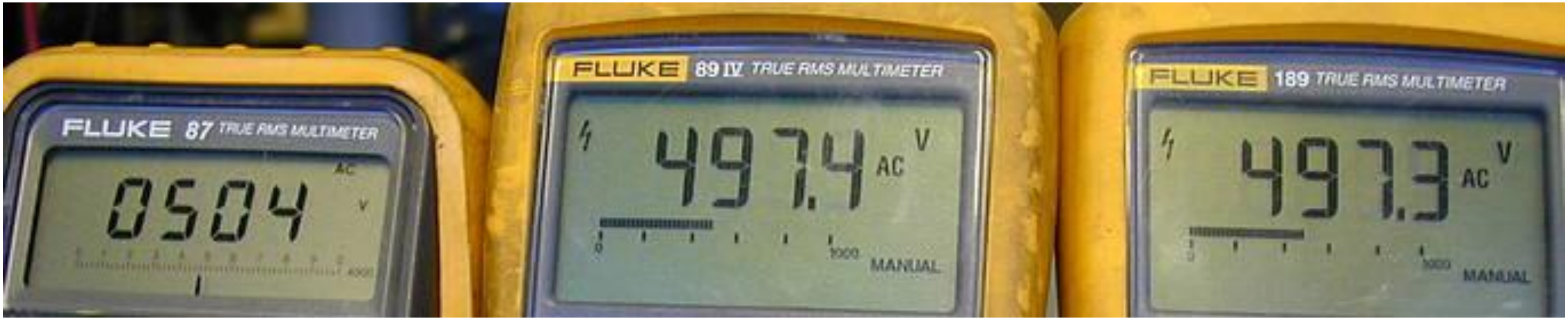
Piece of tie wrap < 0.05 in thick

<0.05 inch gap: 78.5 amps

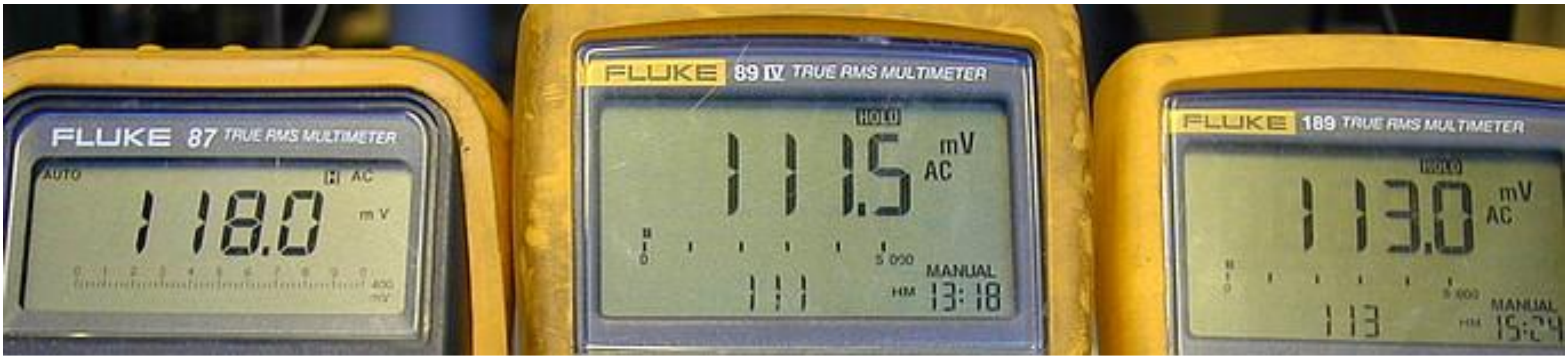


Note: CT scaling is 1 mV/amp

If possible, measure all three phases



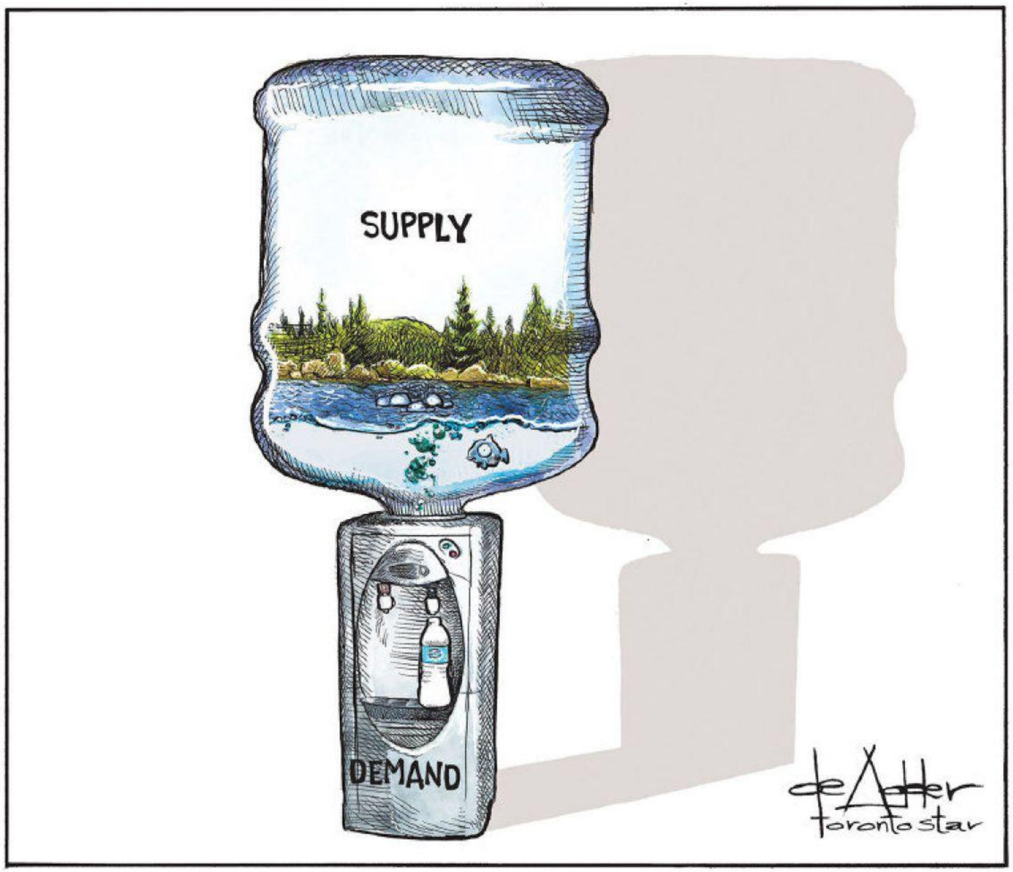
Currents



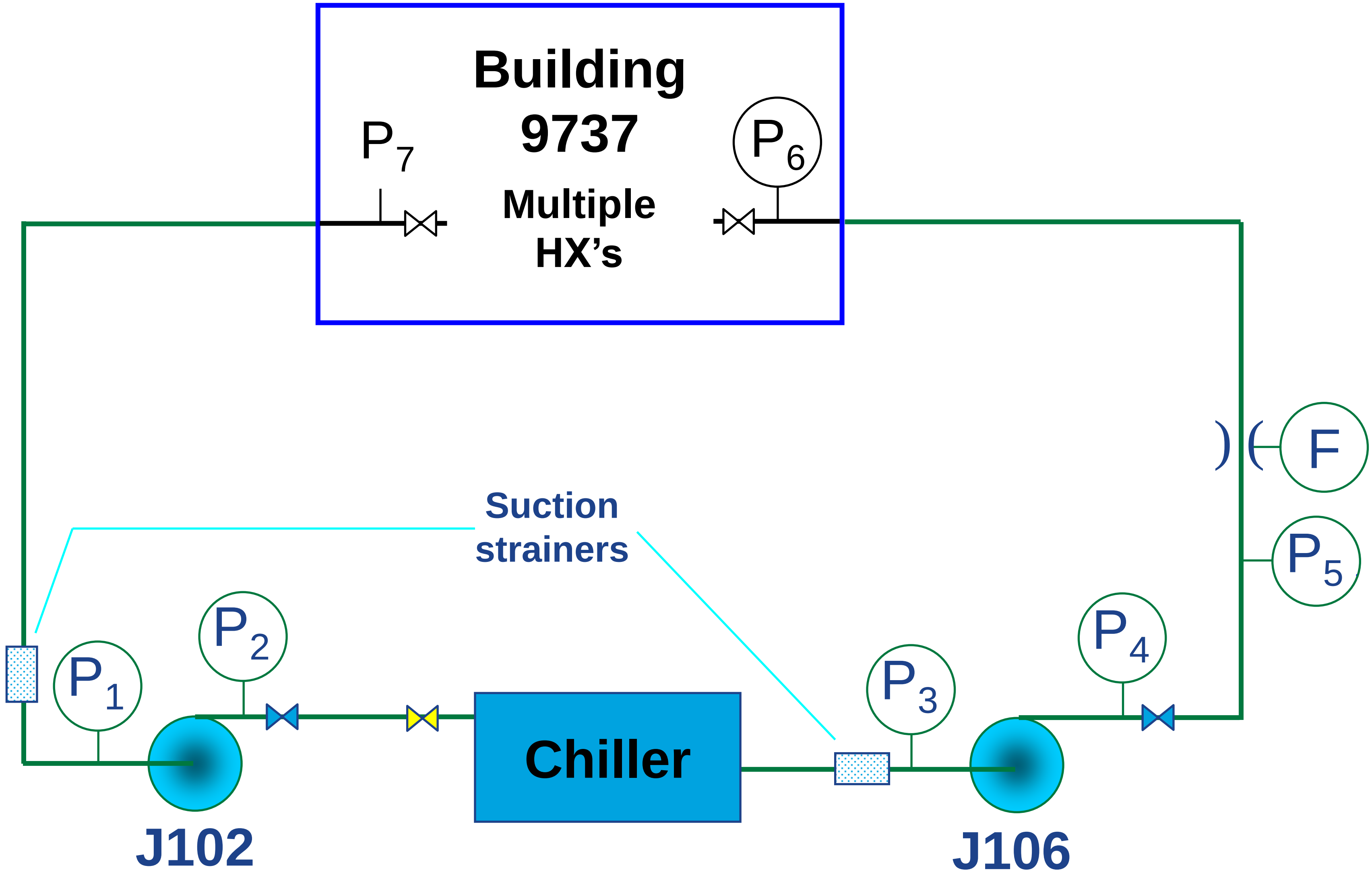
<0.9% voltage unbalance => 3.3% current unbalance

A final, most important consideration:
Demand and Supply - in the engineering domain

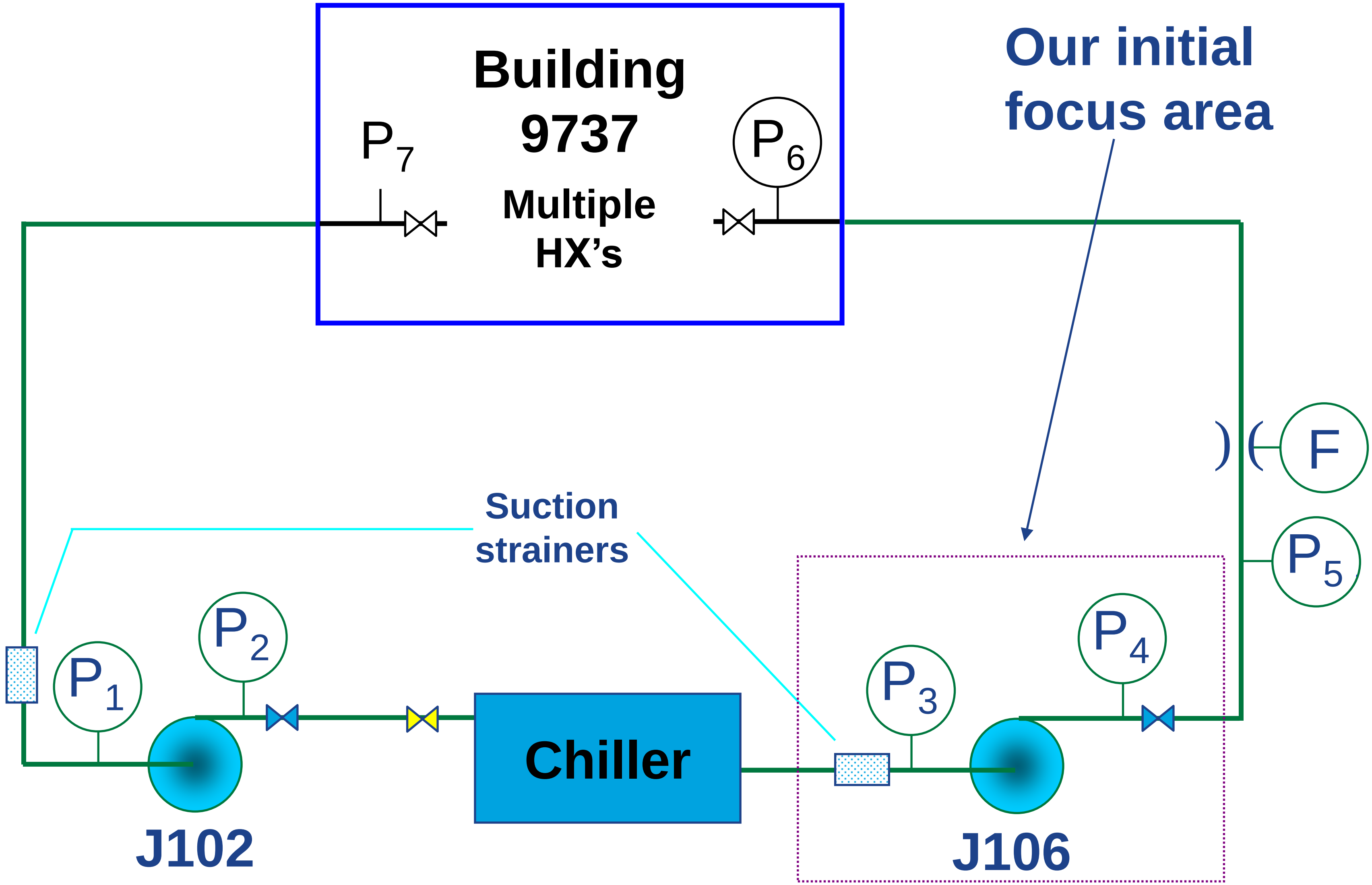
- There is often a difference between what the pump is providing the system and what the system really needs
- Try to think in terms of demand, not supply



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



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



Nameplate data

PUMP & FLUID

Pump Type	End Suction ANSI/API
Pump Speed	1750 rpm
Drive	Direct Drive
Fluid Type	Water
Fluid Temperature	68 °F
Specific Gravity	1
Kinematic Viscosity	1 cSt
Stages	− + 1

MOTOR

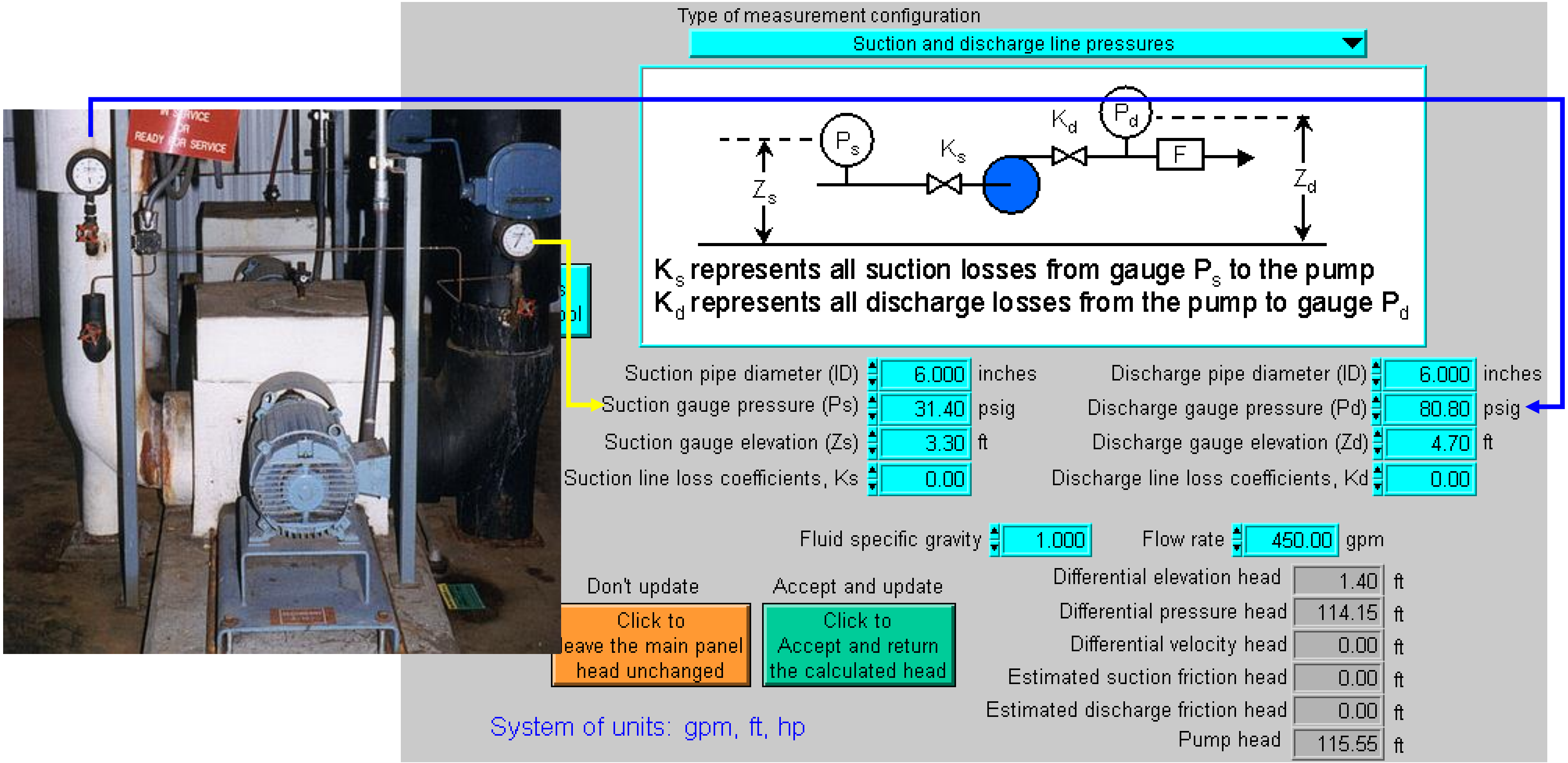
Line Frequency	60 Hz
Rated Motor Power	20 hp

The Field Data Motor he Rated Motor Power, please adjust the input values.

Motor RPM	1760 rpm
Efficiency Class	Standard Efficiency
Rated Voltage	460 V
Full-Load Amps	25.2 A

Estimate Full-Load Amps

Pump data: 115.5 feet head, 450 gpm



The combined pump and motor are good: about 87% of optimal for this size, class of equipment

FIELD DATA

Operating Hours	8760	hrs/yr
Electricity Cost	0.054	$/kWh
Flow Rate	450	gpm
Head Calculate Head	115.55	ft
Load Estimation Method	Current	
Motor Current	23.6	
Measured Voltage	473	

RESULTS

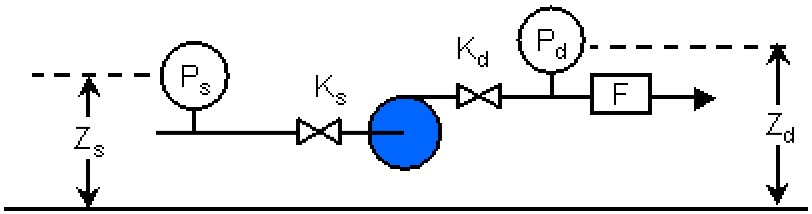
	Baseline
Percent Savings (%)	— —
Pump efficiency (%)	68.4
Motor rated power (hp)	20
Motor shaft power (hp)	19.2
Pump shaft power (hp)	19.2
Motor efficiency (%)	88.9
Motor power factor (%)	83.2
Percent Loaded (%)	96
Drive efficiency (%)	100
Motor current (amps)	24
Motor power (kW)	16.1
Annual Energy (MWh)	**141**
Annual Energy Savings (MWh)	**—**
Annual Cost	**$7,614**

But supply and demand are unbalanced

There is > 23 psig pressure drop across the throttled valve; the downstream pressure was measured to be 55 psig (10 feet above floor)

Type of measurement configuration

Suction and discharge line pressures



K_s represents all suction losses from gauge P_s to the pump
K_d represents all discharge losses from the pump to gauge P_d

Suction pipe diameter (ID)	6.000	inches	Discharge pipe diameter (ID)	6.000	inches
Suction gauge pressure (Ps)	31.40	psig	Discharge gauge pressure (Pd)	55.00	psig
Suction gauge elevation (Zs)	3.30	ft	Discharge gauge elevation (Zd)	10.00	ft
Suction line loss coefficients, Ks	0.00		Discharge line loss coefficients, Kd	0.00	

Fluid specific gravity 1.000 Flow rate 450.00 gpm

Differential elevation head	6.70	ft
Differential pressure head	54.53	ft
Differential velocity head	0.00	ft
Estimated suction friction head	0.00	ft
Estimated discharge friction head	0.00	ft
Pump head	61.23	ft

System of units: gpm, ft, hp

Required pump head

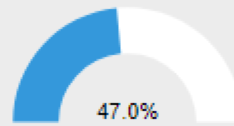
Applying MEASUR to the REQUIREMENTS - the picture of opportunity is quite different

TRIM IMPELLER & OPEN PINCHED VALVE

Operating Hours	8760	hrs/yr
Electricity Cost	0.054	$/kWh
Flow Rate	450	gpm
Head Calculate Head	61.2	ft
Implementation Costs	2000	$

This analysis assumes the pump efficiency stays constant at 68.4%. If this is not true, must estimate the new pump efficiency and rerun.

RESULTS | HELP | NOTES

	Baseline	**Trim Impeller & Open Pinched Valve**
Percent Savings (%)	— —	
Pump efficiency (%)	68.4	68.4
Motor rated power (hp)	20	20
Motor shaft power (hp)	19.2	10.2
Pump shaft power (hp)	19.2	10.2
Motor efficiency (%)	88.9	88.3
Motor power factor (%)	83.2	69.8
Percent Loaded (%)	96	51
Drive efficiency (%)	100	100
Motor current (amps)	24	15
Motor power (kW)	16.1	08.6
Annual Energy (MWh)	**141**	**75**
Annual Energy Savings (MWh)	**—**	**66**
Annual Cost	**$7,614**	**$4,060**
Annual Savings	**—**	**$3,553**

The End for Session 3