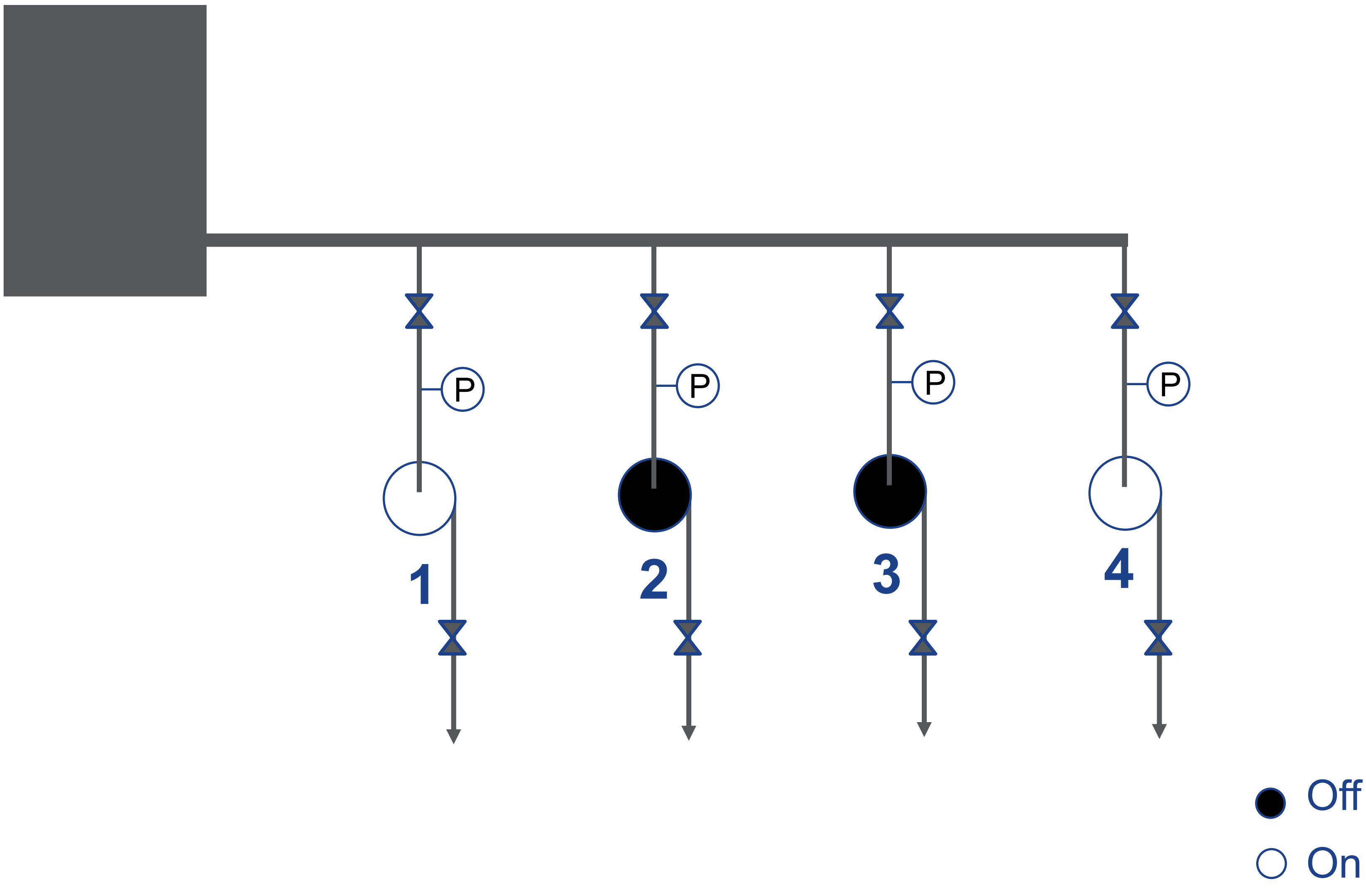
Better Plants®
U.S. DEPARTMENT OF ENERGY

Pumping System Assessment

Week 4: Finding Data and Case Studies

U.S. DEPARTMENT OF ENERGY

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.

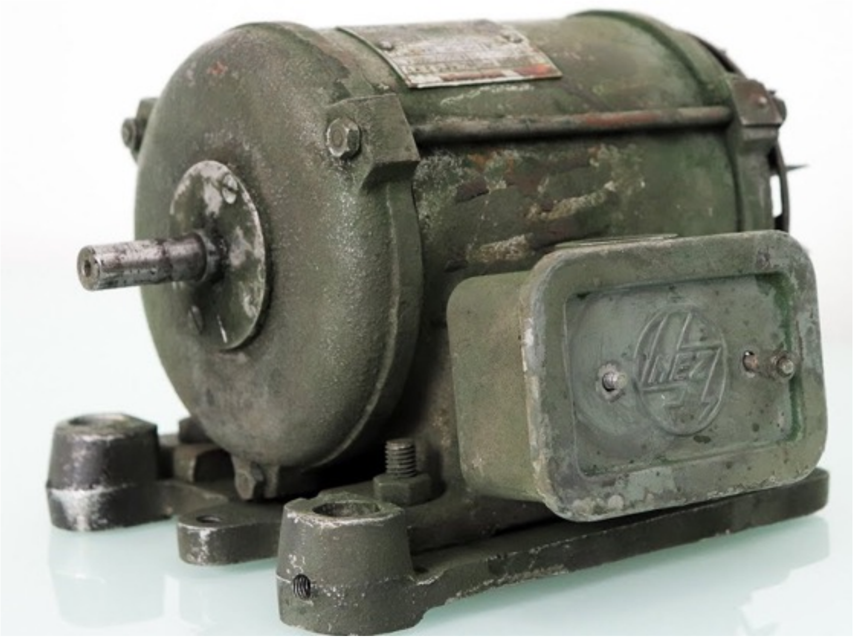
How about power estimating?

- 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

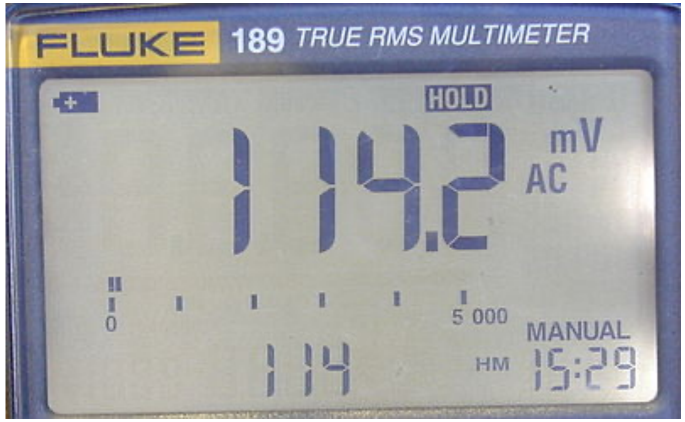
RESULTS

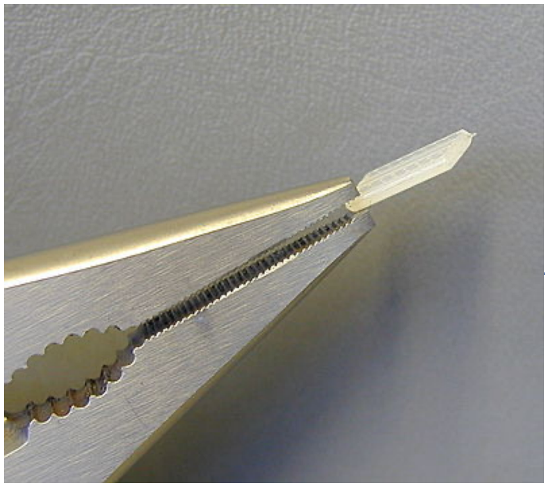
	Baseline
Percent Savings (%)	— —
Pump efficiency (%)	71.2
Motor rated power (hp)	200
Motor shaft power (hp)	196.8
Pump shaft power (hp)	196.8
Motor efficiency (%)	93.9
Motor power factor (%)	86.6
Percent Loaded (%)	98
Drive efficiency (%)	100
Motor current (amps)	221
Motor power (kW)	156.3
Annual Energy (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

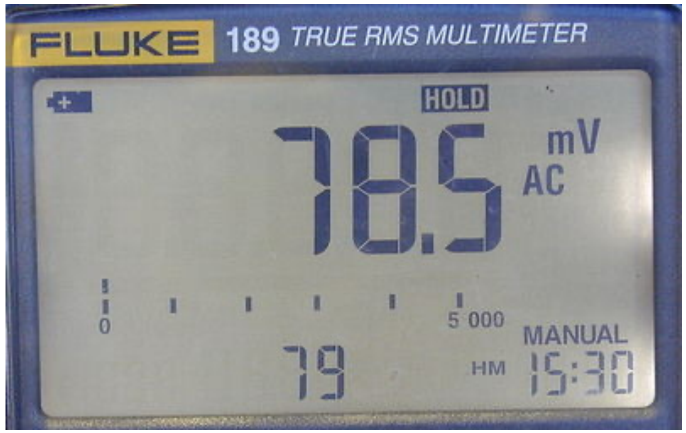
Jaws fully closed - 114.2 amps





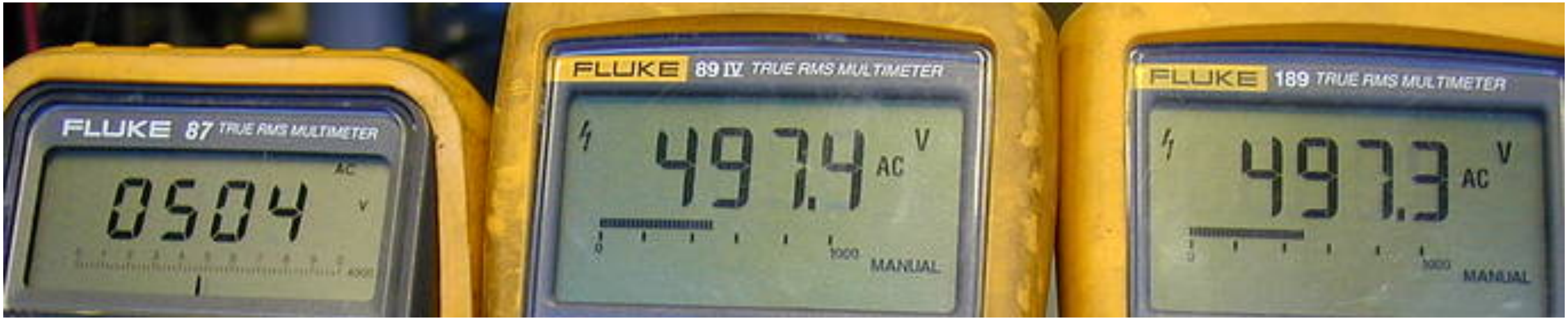
Piece of tie wrap < 0.05 in thick

<0.05 inch gap: 78.5 amps

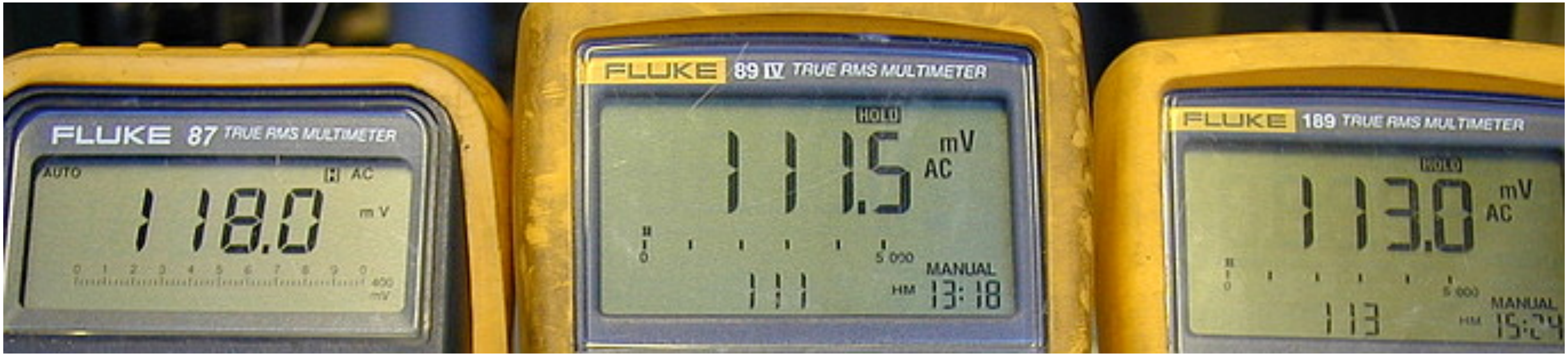


Note: CT scaling is 1 mV/amp

If possible, measure all three phases



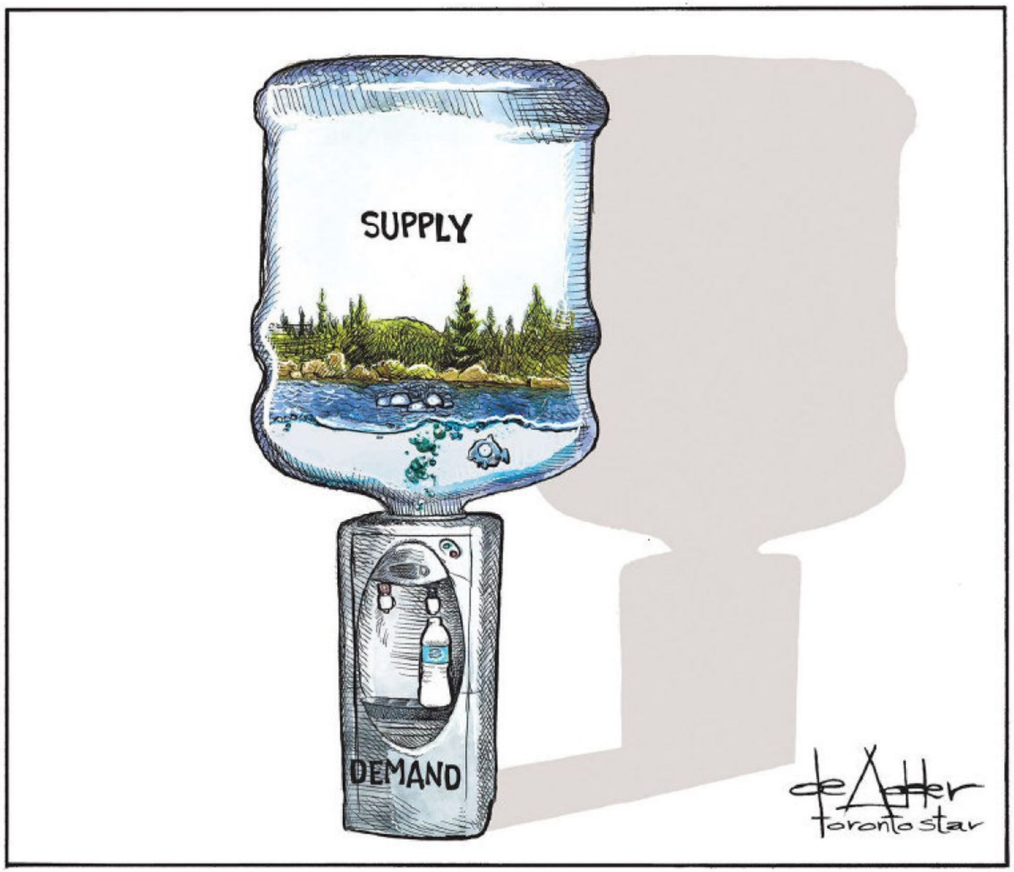
Currents



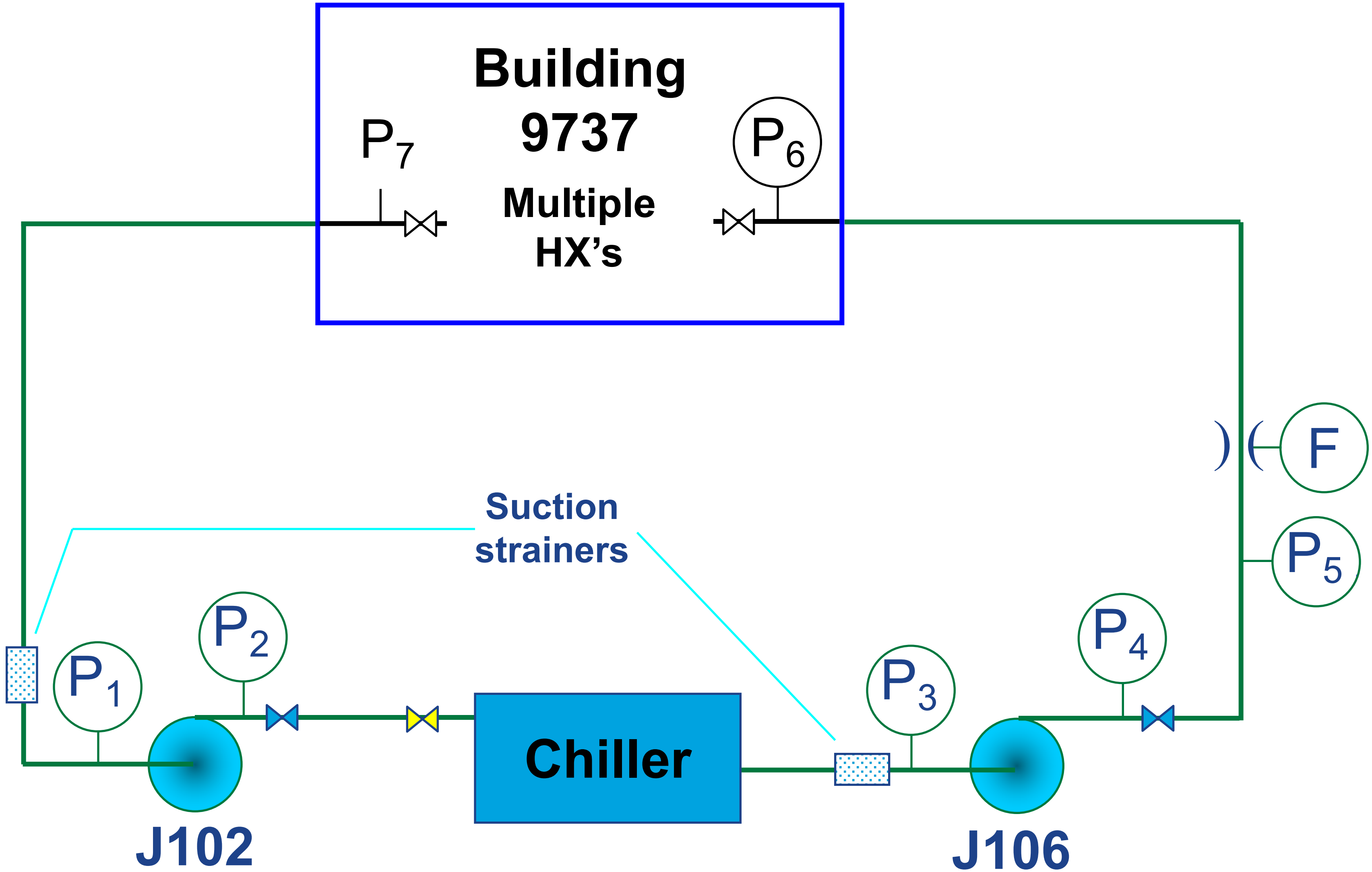
<0.9% voltage unbalance => 3.3% current unbalance

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

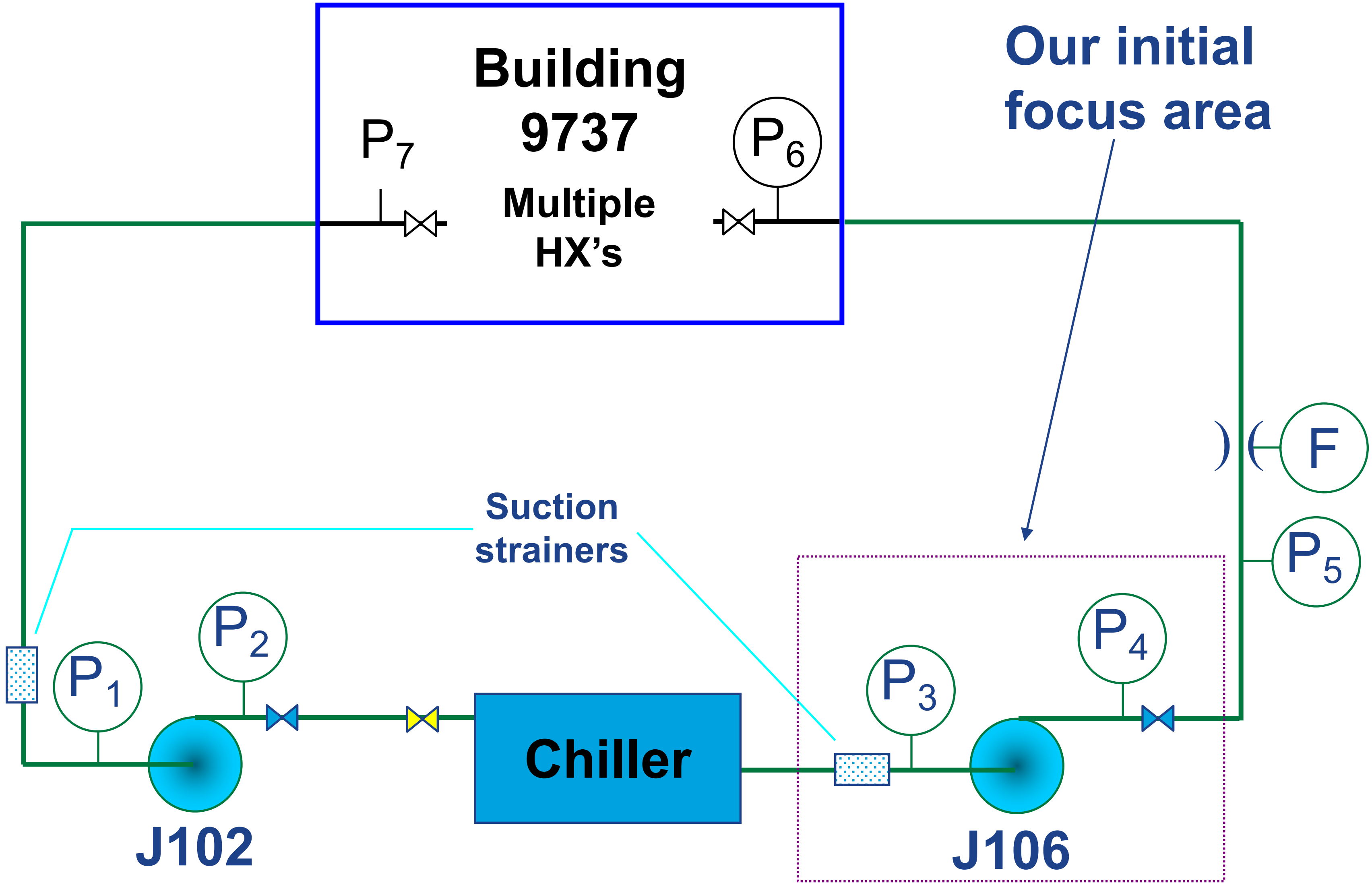
- There is often a difference between what the pump is providing the system and what the system really needs
- Try to think in terms of demand, not supply



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



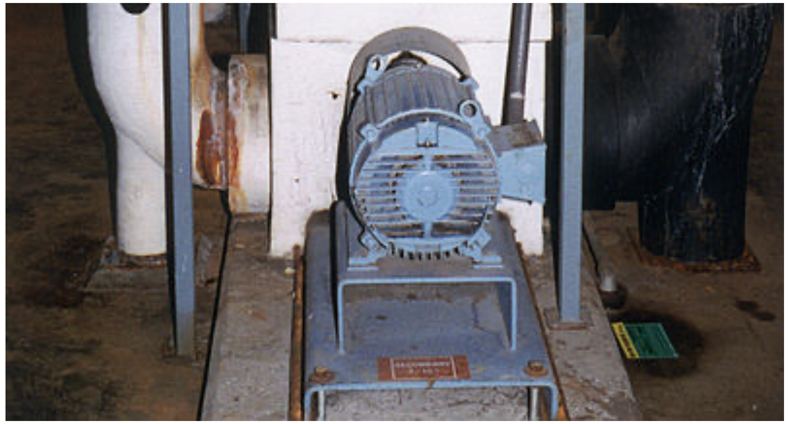
Nameplate data

PUMP & FLUID

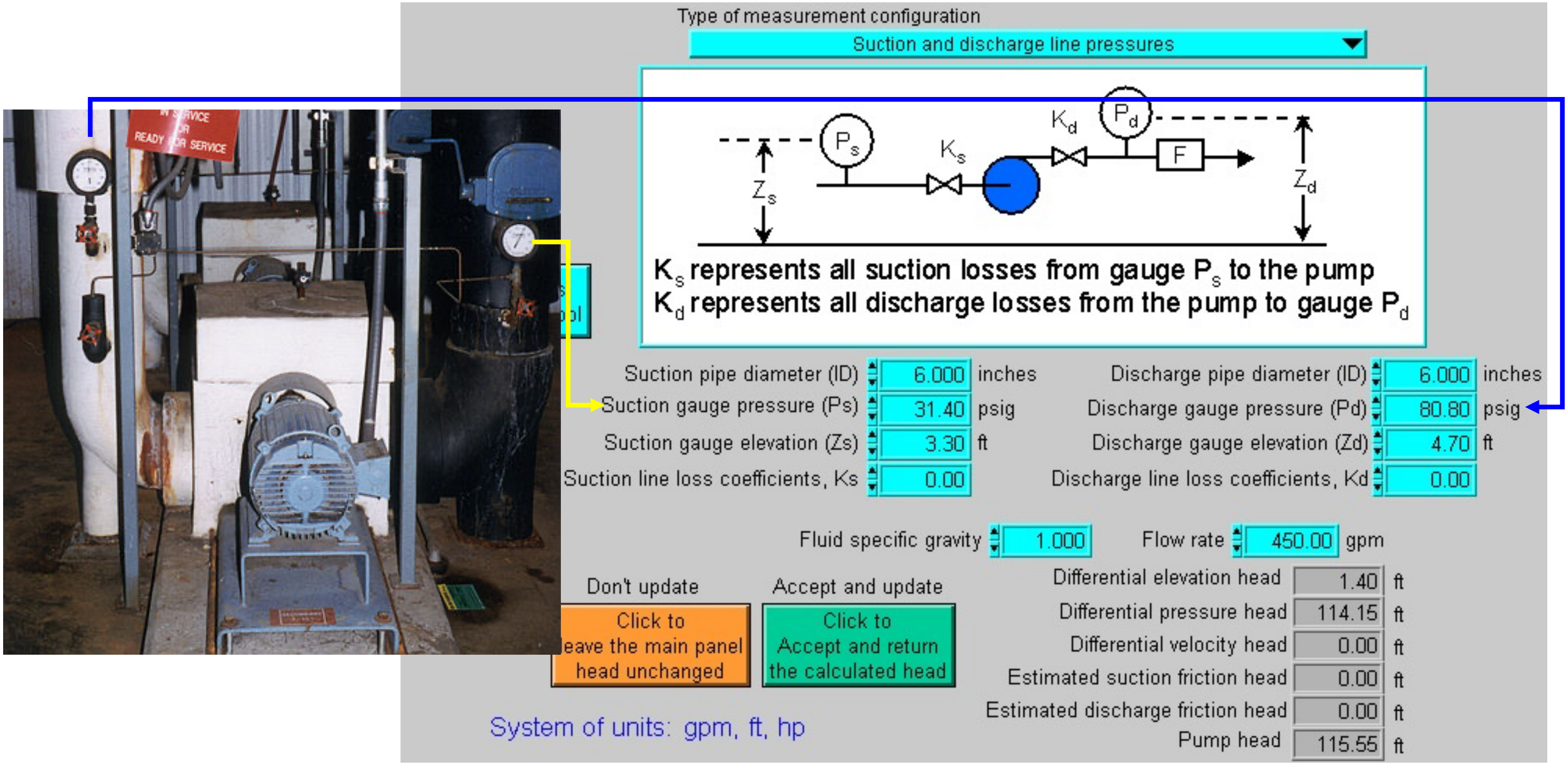
Pump Type	End Suction ANSI/API
Pump Speed	1750 rpm
Drive	Direct Drive
Fluid Type	Water
Fluid Temperature	68 °F
Specific Gravity	1
Kinematic Viscosity	1 cSt
Stages	− + 1

MOTOR

Line Frequency	60 Hz
Rated Motor Power	20 hp
The Field Data Motor	
Motor RPM	1760 rpm
Efficiency Class	Standard Efficiency
Rated Voltage	460 V
Full-Load Amps Estimate Full-Load Amps	25.2 A



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	

Optimum pump efficiency = 78.6%
Ratio = (68.4/78.6)100 = 87%

RESULTS

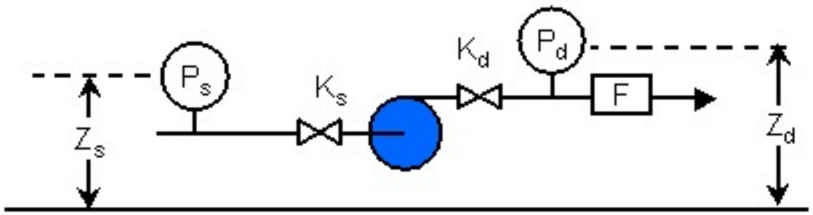
	Baseline
Percent Savings (%)	— —
Pump efficiency (%)	68.4
Motor rated power (hp)	20
Motor shaft power (hp)	19.2
Pump shaft power (hp)	19.2
Motor efficiency (%)	88.9
Motor power factor (%)	83.2
Percent Loaded (%)	96
Drive efficiency (%)	100
Motor current (amps)	24
Motor power (kW)	16.1
Annual Energy (MWh)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

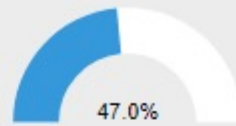
Applying MEASUR to the REQUIREMENTS - the picture of opportunity is quite different

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 run under the Novice View as a VFD retrofit Project.

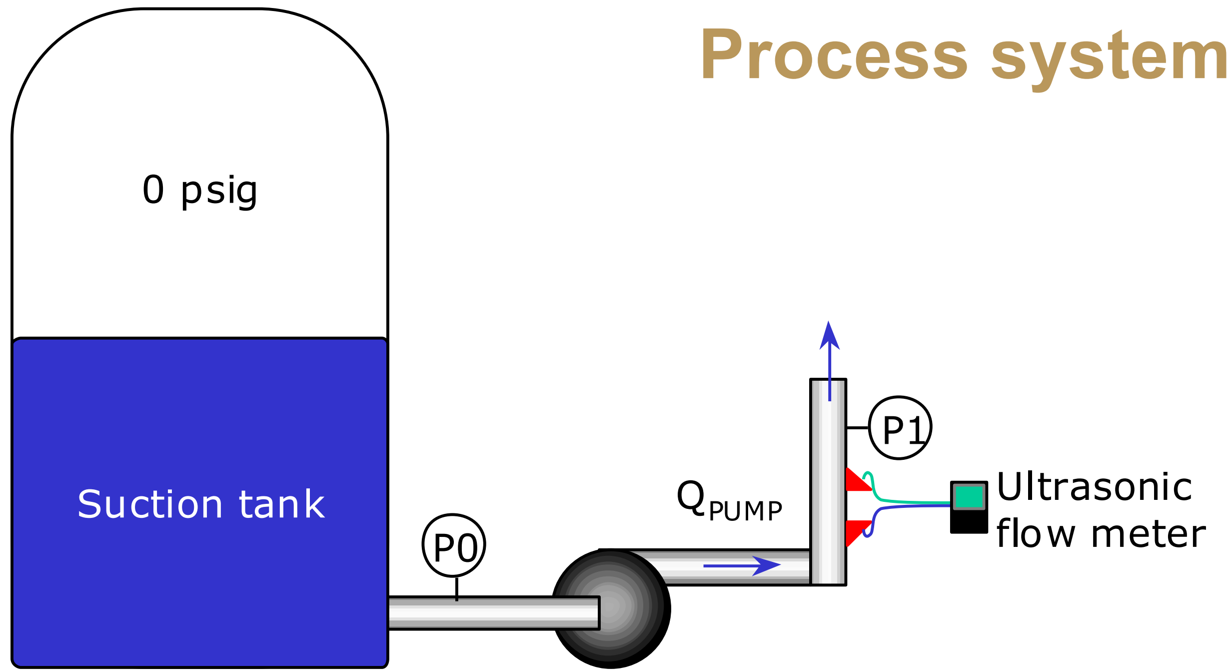
RESULTS | HELP | NOTES

	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**

Example System for Field Investigation and Analysis

A Flow Control System

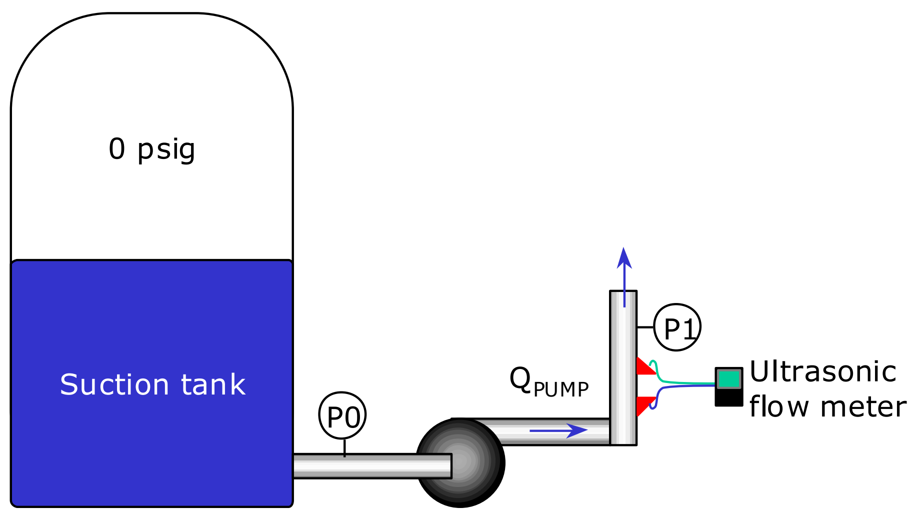
Some systems operate continuously, but need to have their flow regulated. The flow requirements are dictated by the process, and one would not attempt to maximize the pump efficiency by valve operation. However, operating pump efficiency could be deduced using system measurements. An example process pumping system with a flow control valve is shown in below.



Measured data at the pump

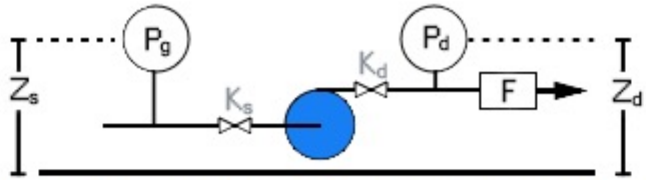
Measured conditions

Water at ambient temperature
P0: 4.3 psig, 7 ft. above floor level; pipe ID = 19.5 inches
P1: 81.2 psig, 12.4 ft above floor level; pipe ID = 12.25 inches
Measured flow rate, using temporary ultrasonic flow meter: 6100 gpm
Motor nameplate data: 2300 volts, 1180 rpm, 80 amps (rated load)
Measured current and voltage: 77 amps, 2320 volts
Pump style: End suction
Observed rotational speed: 1190 rpm
Pump operates about 90% of the time; electricity cost is 13 cents/kWhr



Calculate pump head

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	6100 gpm

Suction		Discharge	
Pipe diameter (ID)	19.5 in	Pipe diameter (ID)	12.25 in
Gauge pressure (P_g)	4.3 psi	Gauge pressure (P_d)	81.2 psi
Gauge elevation (Z_s)	7 ft	Gauge elevation (Z_d)	12.4 ft
Line loss coefficients (K_s)	0.5	Line loss coefficients (K_d)	1.5

Result Data

Differential Elevation Head	5.4 ft
Differential Pressure Head	177.7 ft
Differential Velocity Head	3.62 ft
Estimated Suction Friction Head	0.33 ft
Discharge Friction Head	6.43 ft
Pump Head	193.48 ft

Pump head calculation from MEASUR

Evaluate pump operating efficiency

As a first check of the pump operation, the hydraulic and electrical data were plugged into the MEASUR software. The results, shown below, indicate that the pump is very near the optimum commercially available equipment for the noted conditions. MEASUR estimates the pump efficiency to be 87.8%.

Evaluate pump operating efficiency

BASELINE

Pump Type	API Double Suction
Pump Speed	1190 rpm
Drive	Direct Drive
Fluid Type	Water
Fluid Temperature	68 °F
Specific Gravity	1
Kinematic Viscosity	1 cSt
Stages	− + 1
Line Frequency	60 Hz
Rated Motor Power	350 hp
Motor RPM	1180 rpm
Efficiency Class	Energy Efficient
Rated Voltage	2300 V
Full-Load Amps	80 A

OPTIMAL PUMP

Pump Efficiency: 89.9 %

Optimize Pump

The efficiency of your pump has been calculated based on your system setup. Either directly modify your efficiency or click **"Optimize Pump"** to estimate your pump efficiency based on a different pump type.

Pump Speed	1190 rpm
Drive	Specified Efficiency
Drive Efficiency	100 %
Fluid Type	Water
Fluid Temperature	68 °F
Specific Gravity	1
Kinematic Viscosity	1 cSt
Stages	− + 1
Line Frequency	60 Hz
Rated Motor Power	350 hp
Motor RPM	1180 rpm
Efficiency Class	Energy Efficient
Rated Voltage	2300 V
Full-Load Amps	80 A

Estimate Full-Load Amps

Evaluate pump operating efficiency

BASELINE

Operating Hours	7884	hrs/yr
Electricity Cost	0.13	$/kWh
Flow Rate	6100	gpm
Head Calculate Head	193	ft
Load Estimation Method	Current	
Motor Current	77	A
Measured Voltage	2320	V

OPTIMAL PUMP

Operating Hours	7884	hrs/yr
Electricity Cost	0.13	$/kWh
Flow Rate	6100	gpm
Head Calculate Head	193	ft
Implementation Costs		$

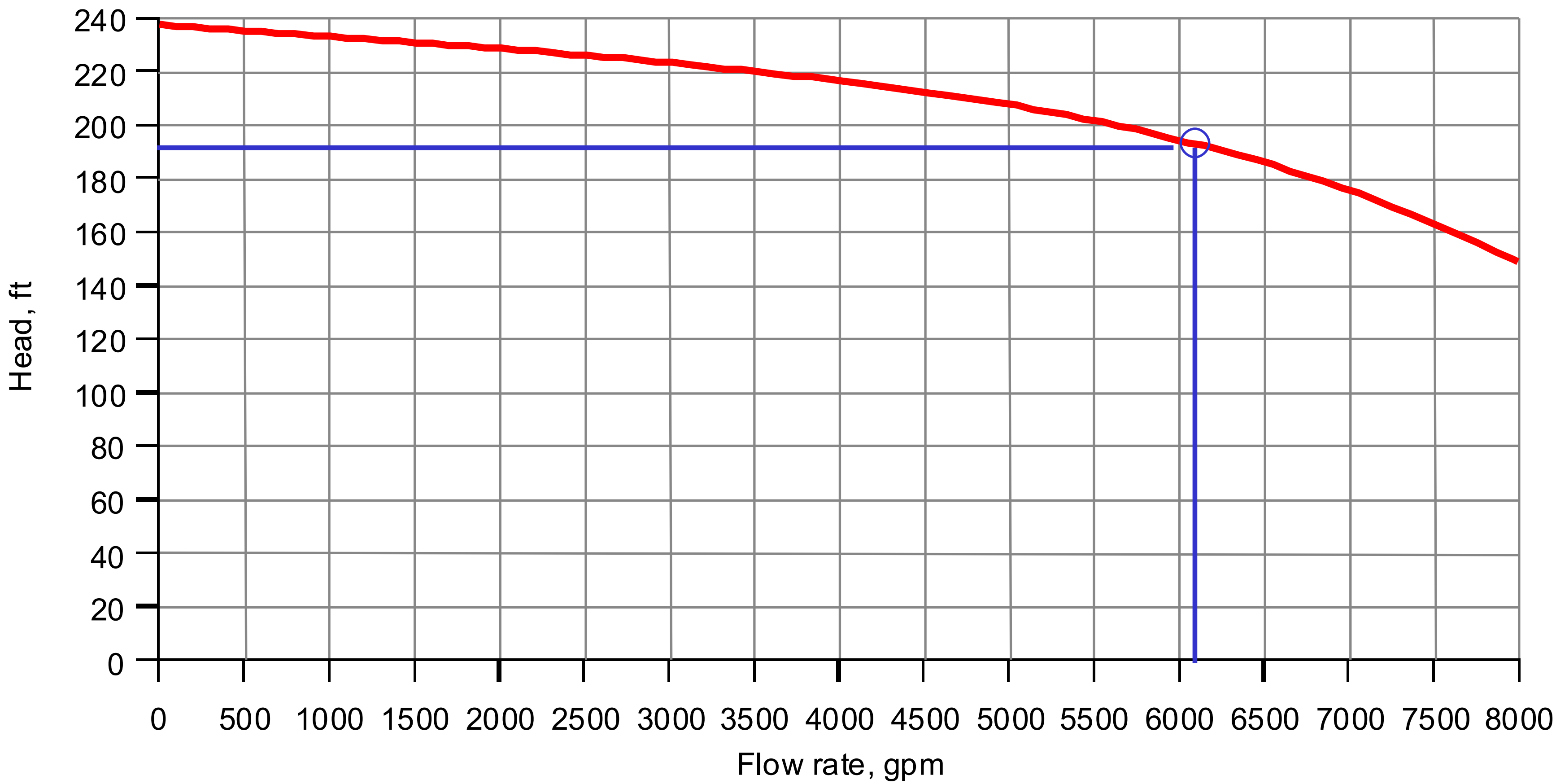
Evaluate pump operating efficiency

RESULTS | SANKEY | HELP

	Baseline	Optimal Pump
Percent Savings (%)	— —	3.0%
Pump efficiency (%)	87.6	89.9
Motor rated power (hp)	350	350
Motor shaft power (hp)	339.2	330.6
Pump shaft power (hp)	339.2	330.6
Motor efficiency (%)	95.6	95.6
Motor power factor (%)	85.6	84.2
Percent Loaded (%)	97	94
Drive efficiency (%)	100	100
Motor current (amps)	77	76
Motor power (kW)	264.7	258
Annual Energy (MWh)	**2,087**	**2,034**
Annual Energy Savings (MWh)	**—**	**53**
Annual Cost	**$271,327**	**$264,429**
Annual Savings	**—**	**$6,899**

Check the manufacturer’s data

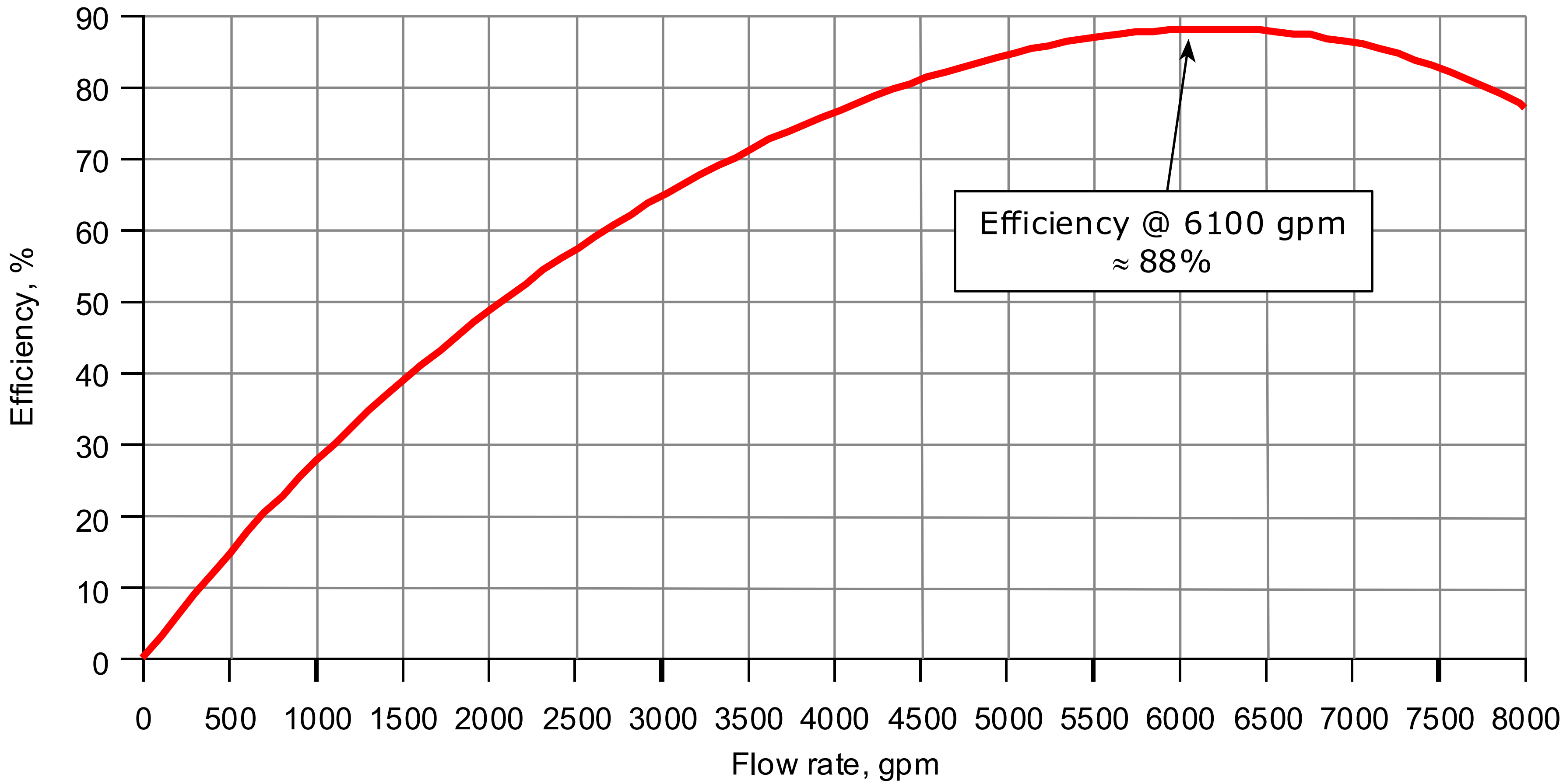
To provide an independent check on the measured data, the manufacturer’s pump performance curves, adjusted for the observed speed (using the pump affinity laws) were consulted. The head-capacity curve is shown below.



Pump head-capacity curve

Check the manufacturer’s data

The efficiency-capacity curve is shown below.



Pump efficiency-capacity curve

A happy pump!

The calculated head and flow rate match the manufacturer's curve; furthermore, the MEASUR-estimated efficiency is consistent with the manufacturer's curve.

In summary, the observed measurements and subsequent analysis suggests that the pump:

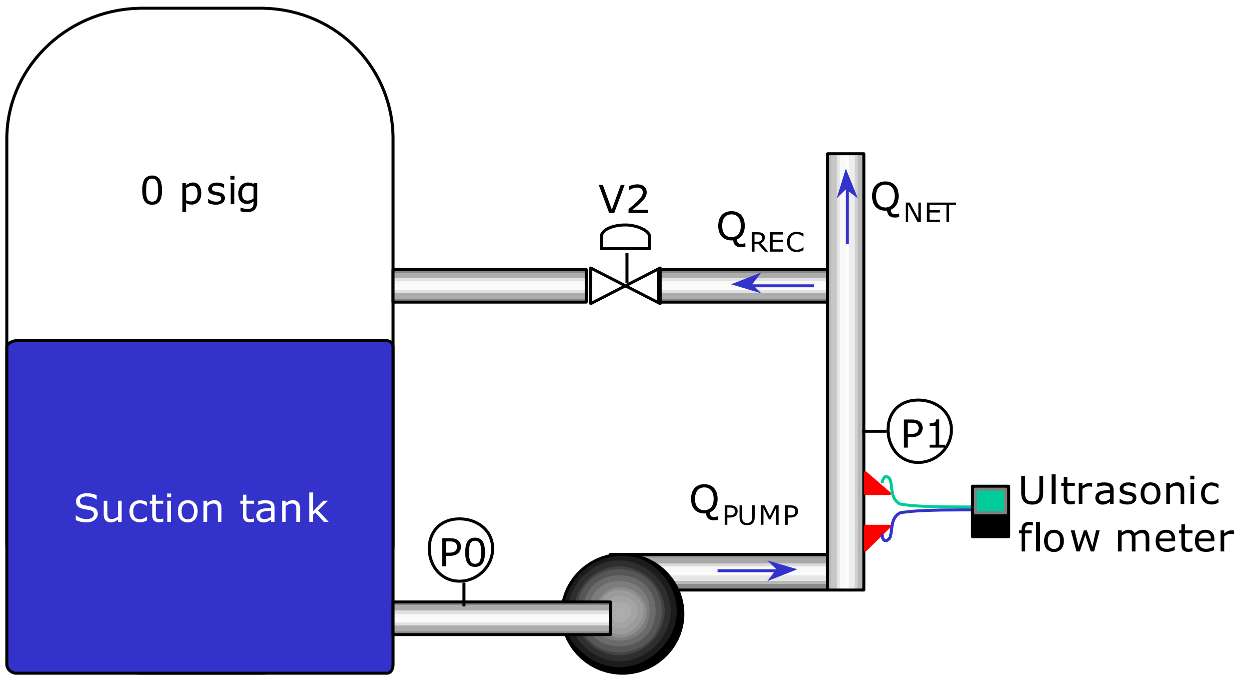
- is operating very near its BEP (best efficiency point)
- is operating consistent with the manufacturer's performance curves, indicating minimal wear along with the motor, is operating near the PSAT-calculated optimal condition (note that the Optimization Rating is 97.6.

The Optimization Rating in MEASUR is a measure of the combined motor and pump performance relative to the optimal commercially available equipment, expressed as a percentage (equivalent to a grade on an exam).

As will be shown, these observations, while true, are very misleading. They apply to the motor and pump *only*.

Moving downstream a little we find…..

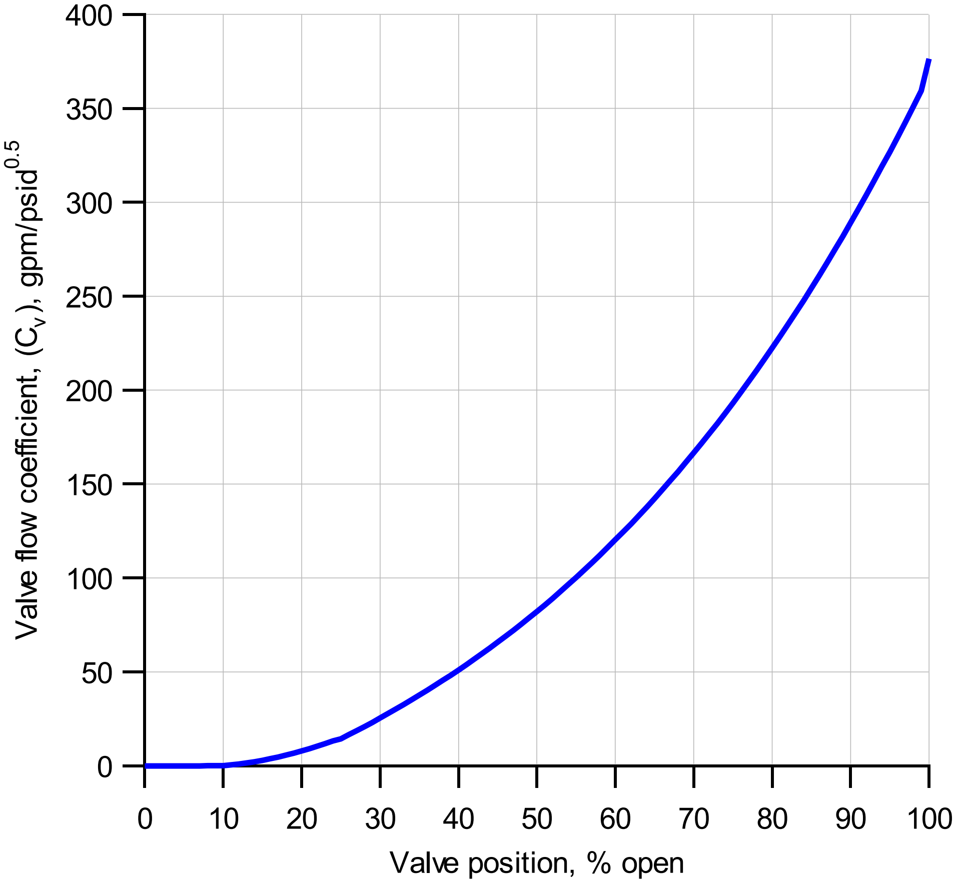
As noted above, the pump and motor are operating very efficiently, as judged by the head and flow rate output compared with the electrical power input. But it should always be the goal to judge how well the system as a whole is functioning, not just the individual components. Below, a slightly broadened view of the system is shown. A portion of the flow handled by the pump is diverted and recirculated back to the suction tank. This recirculated flow represents wasted energy.



Process system, including recirculation line

The recirculation line control valve

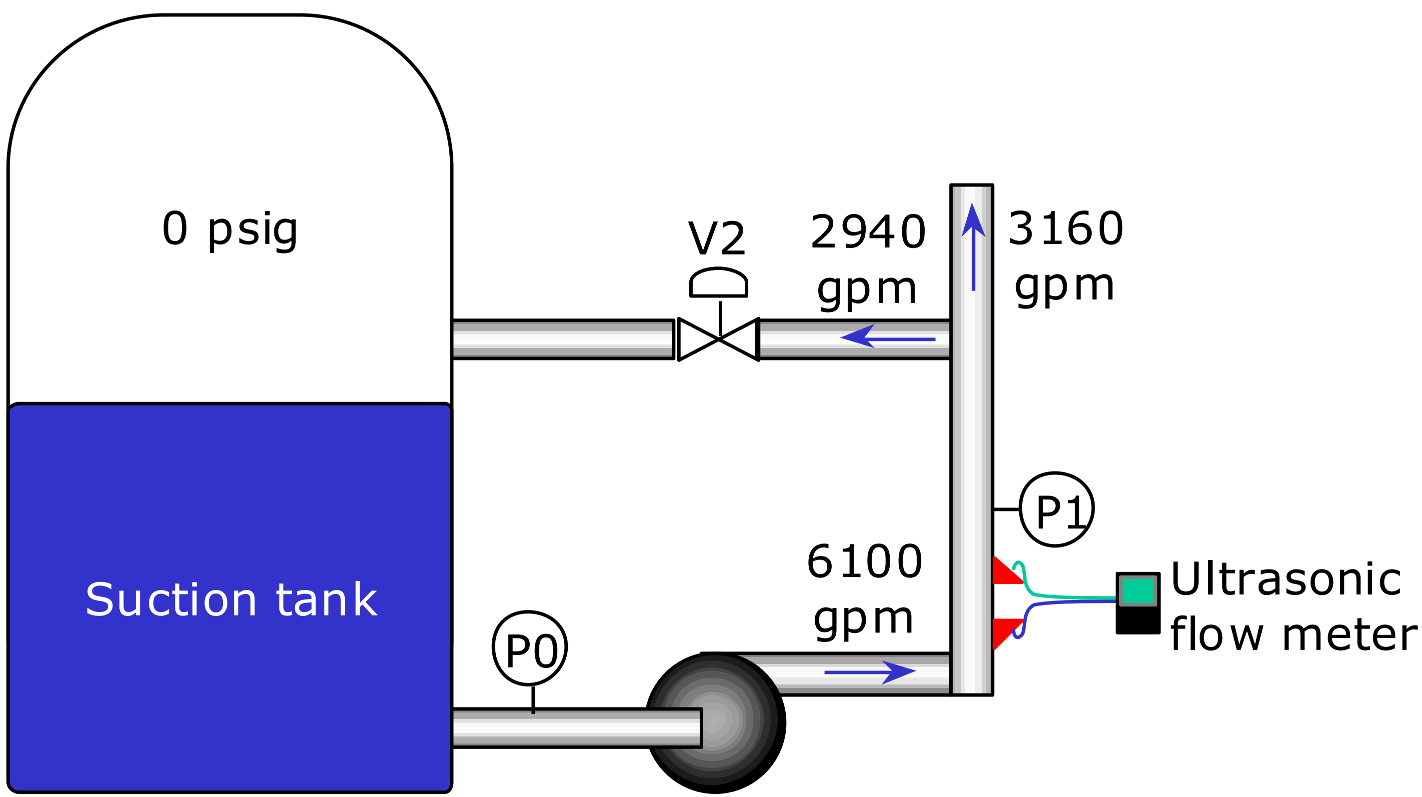
Flow rate was not measured in the recirculation line, but valve V2 position was noted to be full open. A picture of a valve similar to the recirculation valve, and valve flow coefficient vs. position are shown below.



Control valve (similar design to recirculation valve) and flow coefficient vs. position

Pumping 2940 gpm around in a circle!

Using the valve performance data, pipe and component geometric data, and measured pressures, the flow rate through the recirculation line was estimated to be 2940 gpm. Thus, the net flow rate is 3160 gpm. The flow distributions are illustrated below.



Process system flow distribution

Gaining A System Perspective

Recognizing that only a little more than half the pump flow rate (3160 gpm) is going to the intended target, a revised MEASUR analysis can be performed using this net flow value. The result is shown below.

MEASUR analysis

BASELINE

Pump Type	API Double Suction
Pump Speed	1190 rpm
Drive	Direct Drive
Fluid Type	Water
Fluid Temperature	68 °F
Specific Gravity	1
Kinematic Viscosity	1 cSt
Stages	− + 1
Line Frequency	60 Hz
Rated Motor Power	350 hp
Motor RPM	1180 rpm
Efficiency Class	Energy Efficient
Rated Voltage	2300 V
Full-Load Amps	80 A

USEFUL FLOW IS 3160 GPM

Pump Efficiency Optimize Pump	45.3906 %

The efficiency of your pump has been calculated based on your system setup. Either directly modify your efficiency or click **"Optimize Pump"** to estimate your pump efficiency based on a different pump type.

Pump Speed	1190 rpm
Drive	Specified Efficiency
Drive Efficiency	100 %
Fluid Type	Water
Fluid Temperature	68 °F
Specific Gravity	1
Kinematic Viscosity	1 cSt
Stages	− + 1
Line Frequency	60 Hz
Rated Motor Power	350 hp
Motor RPM	1180 rpm
Efficiency Class	Energy Efficient
Rated Voltage	2300 V
Full-Load Amps Estimate Full-Load Amps	80 A

MEASUR analysis continued,

BASELINE	
Operating Hours	7884 hrs/yr
Electricity Cost	0.13 $/kWh
Flow Rate	6100 gpm
Head Calculate Head	193 ft
Load Estimation Method	Current
Motor Current	77 A
Measured Voltage	2320 V

USEFUL FLOW IS 3160 GPM	
Operating Hours	7884 hrs/yr
Electricity Cost	0.13 $/kWh
Flow Rate	3160 gpm
Head Calculate Head	193 ft
Implementation Costs	$

Gaining A System Perspective

RESULTS	SANKEY	HELP

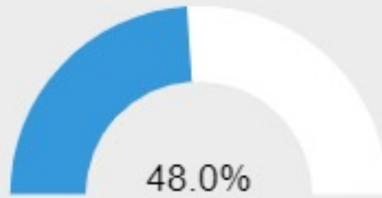
	Baseline	Useful Flow is 3160 gpm
Percent Savings (%)	— —	
Pump efficiency (%)	87.6	45.4
Motor rated power (hp)	350	350
Motor shaft power (hp)	339.2	339.2
Pump shaft power (hp)	339.2	339.2
Motor efficiency (%)	95.6	95.6
Motor power factor (%)	85.6	84.4
Percent Loaded (%)	97	97
Drive efficiency (%)	100	100
Motor current (amps)	77	78
Motor power (kW)	264.7	264.7
Annual Energy (MWh)	**2,087**	**2,087**
Annual Energy Savings (MWh)	**—**	
Annual Cost	**$271,327**	**$271,327**
Annual Savings	**—**	**$00**

Gaining A System Perspective

There is a dramatic effect on the outcome; the Optimization Rating dropped from 97.7 to 51.6. Significantly, the annual cost, estimated to be $271,300, could be reduced by $131,000 with a pump selected to deliver the net flow only (i.e., with the bypass or recirculation valve closed).

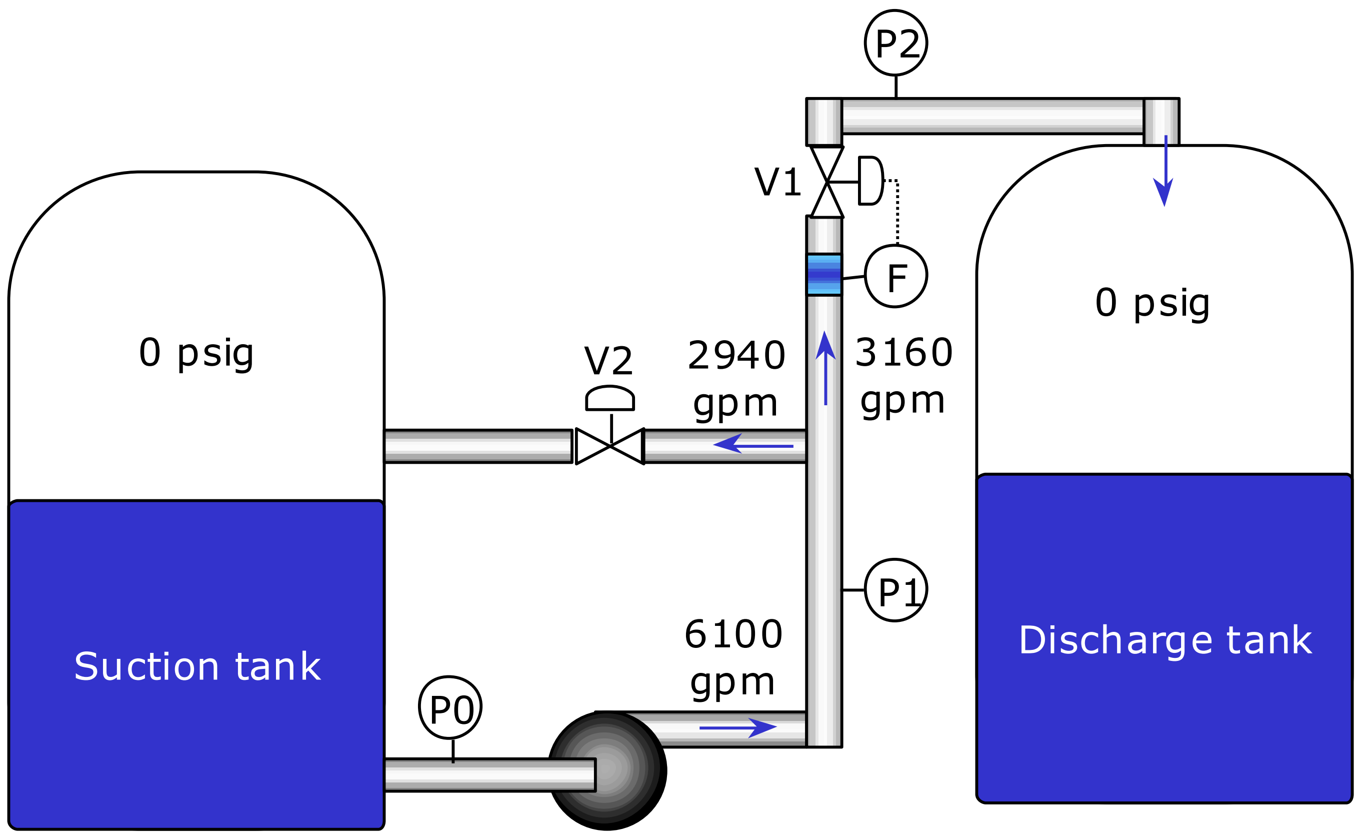
Optimum pump is 88.5% efficient

RESULTS | SANKEY | HELP

	Baseline	Optimized Pump at 3160 gpm
Percent Savings (%)	— —	
Pump efficiency (%)	87.6	88.5
Motor rated power (hp)	350	350
Motor shaft power (hp)	339.2	174
Pump shaft power (hp)	339.2	174
Motor efficiency (%)	95.6	94.7
Motor power factor (%)	85.6	74.9
Percent Loaded (%)	97	50
Drive efficiency (%)	100	100
Motor current (amps)	77	45
Motor power (kW)	264.7	137
Annual Energy (MWh)	**2,087**	**1,080**
Annual Energy Savings (MWh)	**—**	**1,007**
Annual Cost	**$271,327**	**$140,397**
Annual Savings	**—**	**$130,930**

Going further downstream…..

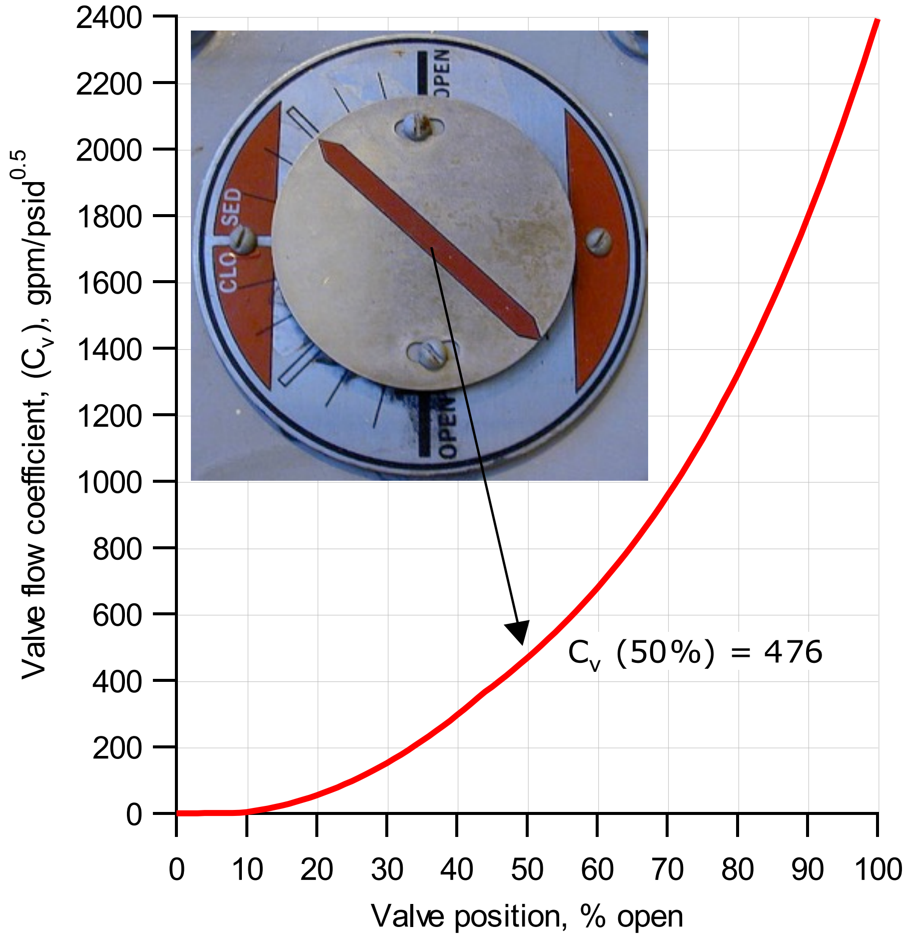
Expanding the view to include the entire system shows that the flow rate to the receiver, or discharge tank, is controlled by another valve, V1, whose position is controlled by a signal from an in-line magnetic flow meter.



Complete process system diagram

There is this pinched flow control valve

A picture of the flow meter and control valve is provided below.



Magnetic flow meter and control valve (valve labeled V1), close-up of valve position, and valve flow coefficient vs. position plot

Using the valve equation

Based on the calculated valve flow coefficient of 476 from the valve indicator and valve flow coefficient plot, the pressure drop across the control valve can be estimated. The fundamental equation relating the valve flow coefficient, flow rate, and pressure drop is:

$$Q = C_v\sqrt{\frac{\Delta P}{s.g.}} \quad \text{or} \quad \Delta P = \frac{s.g. \text{ x } Q^2}{C_v^2} \quad \rightarrow \quad \Delta P = \frac{1.0 \text{ x } 3160^2}{476^2} = 44 \text{ psig}$$

where Q is the flow rate in gpm, Cv is the valve flow coefficient, DP is the pressure drop across the valve in psig, and s.g. is the specific gravity. The pressure drop across the valve was actually measured to be 39 psig.

Gaining A System Perspective

The pressure drop across the valve represents head developed by the pump that exceeds that necessary to deliver the required flow rate to the discharge tank. This pressure drop can be subtracted from the pump head to calculate the head actually required. The PSAT analysis was re-run after subtracting the measured head loss (39 psig * 2.31 ft/psig = 90 ft) from the calculated pump head (193.2 ft) previously used.

Downsize pump and motor

BASELINE

Pump Type	API Double Suction
Pump Speed	1190 rpm
Drive	Direct Drive
Fluid Type	Water
Fluid Temperature	68 ℉
Specific Gravity	1
Kinematic Viscosity	1 cSt
Stages	− + 1
Line Frequency	60 Hz
Rated Motor Power	350 hp
Motor RPM	1180 rpm
Efficiency Class	Energy Efficient
Rated Voltage	2300 V
Full-Load Amps	80 A

OPTIMIZED PUMP AT 3160 GPM @ 103 FT

Pump Efficiency Optimize Pump	88.5 %

The efficiency of your pump has been calculated based on your system setup. Either directly modify your efficiency or click **"Optimize Pump"** to estimate your pump efficiency based on a different pump type.

Pump Speed	1190 rpm
Drive	Specified Efficiency
Drive Efficiency	100 %
Fluid Type	Water
Fluid Temperature	68 ℉
Specific Gravity	1
Kinematic Viscosity	1 cSt
Stages	− + 1
Line Frequency	60 Hz
Rated Motor Power	100 hp
Motor RPM	1180 rpm
Efficiency Class	Energy Efficient
Rated Voltage	2300 V
Full-Load Amps Estimate Full-Load Amps	23.79 A

Downsize pump and motor

BASELINE

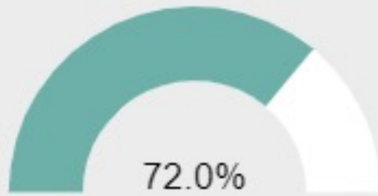
Operating Hours	7884	hrs/yr
Electricity Cost	0.13	$/kWh
Flow Rate	6100	gpm
Head Calculate Head	193	ft
Load Estimation Method	Current	
Motor Current	77	A
Measured Voltage	2320	V

OPTIMIZED PUMP AT 3160 GPM @ 103 FT

Operating Hours	7884	hrs/yr
Electricity Cost	0.13	$/kWh
Flow Rate	3160	gpm
Head Calculate Head	103	ft
Implementation Costs		$

Downsize pump and motor

RESULTS	SANKEY	HELP

	Baseline	Optimized Pump at 3160 gpm @ 103 ft
Percent Savings (%)	— —	
Pump efficiency (%)	87.6	88.5
Motor rated power (hp)	350	100
Motor shaft power (hp)	339.2	92.8
Pump shaft power (hp)	339.2	92.8
Motor efficiency (%)	95.6	94.8
Motor power factor (%)	85.6	82.7
Percent Loaded (%)	97	93
Drive efficiency (%)	100	100
Motor current (amps)	77	22
Motor power (kW)	264.7	73.1
Annual Energy (MWh)	**2,087**	**576**
Annual Energy Savings (MWh)	**—**	**1,511**
Annual Cost	**$271,327**	**$74,888**
Annual Savings	**—**	**$196,439**

Gaining A System Perspective

Thus, when viewed from a component perspective, the pump and motor operate very efficiently; however, when viewed from a system perspective, the pump is significantly oversized for the job at hand. Note that in the MEASUR analysis, the optimal pump could be powered by a 100 hp motor instead of the 350 hp motor required for the existing pump. Also note that the annual energy cost could be reduced by almost $200,000 if the optimal pump and motor were employed.

Concluding Remarks

This article has demonstrated two important perspectives related to valve control of pumping systems:

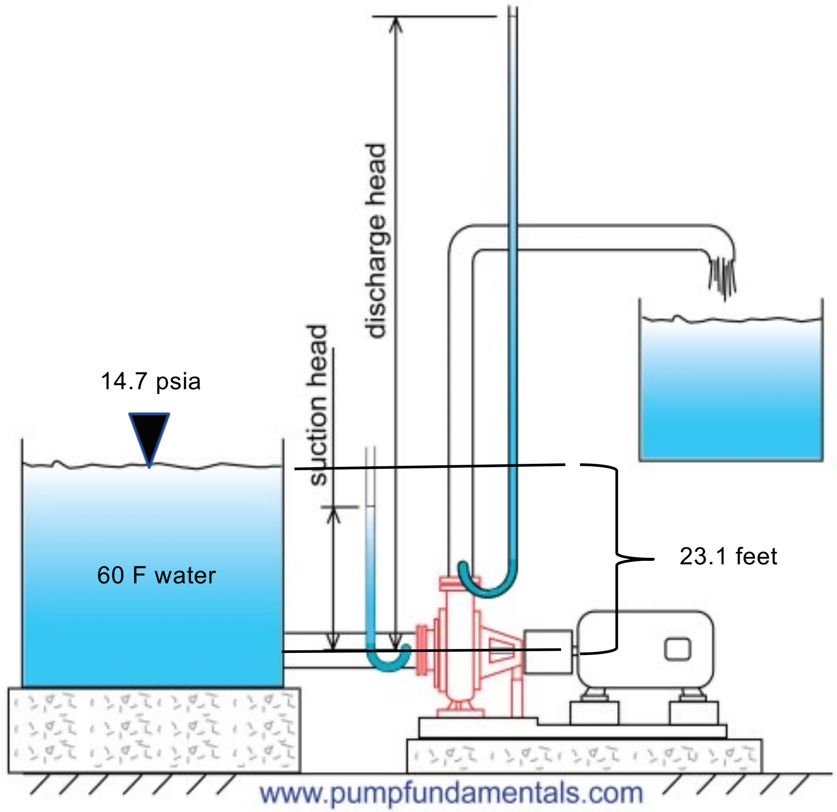
Throttling valves to achieve improved pump efficiency in systems whose function is to deliver a given volume is almost never a good idea,

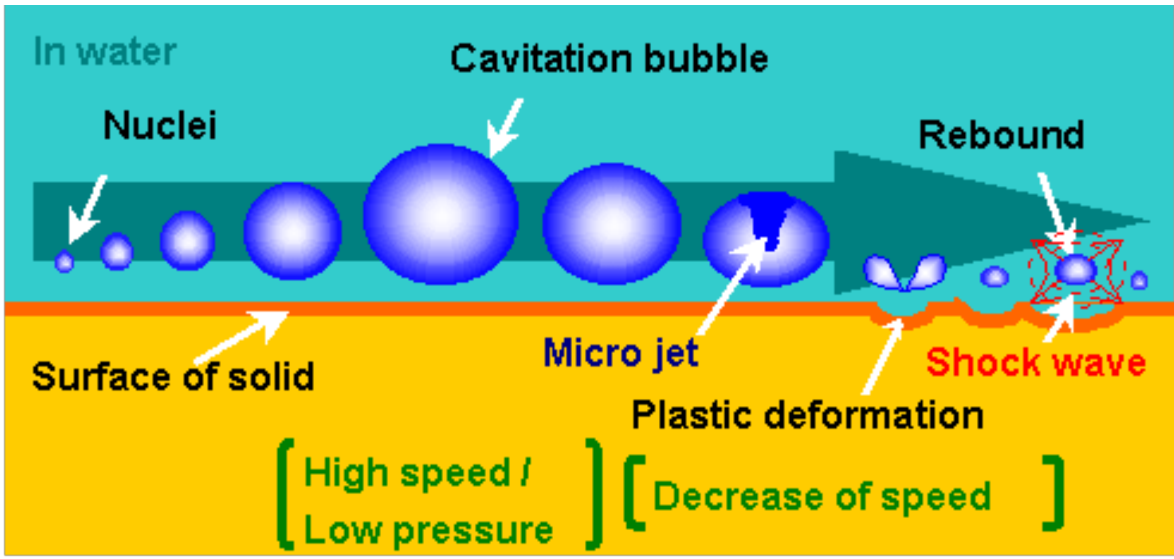
Efficient pump and/or motor operation is decidedly not an indication of effective or efficient system operation.

Cavitation

Water Boils at:

- 212 F when the pressure is 14.70 psia
- 203 F when the pressure is 12.27 psia
- 60 F when the pressure is 0.26 psia
- 250 F when the pressure is 28.84 psia





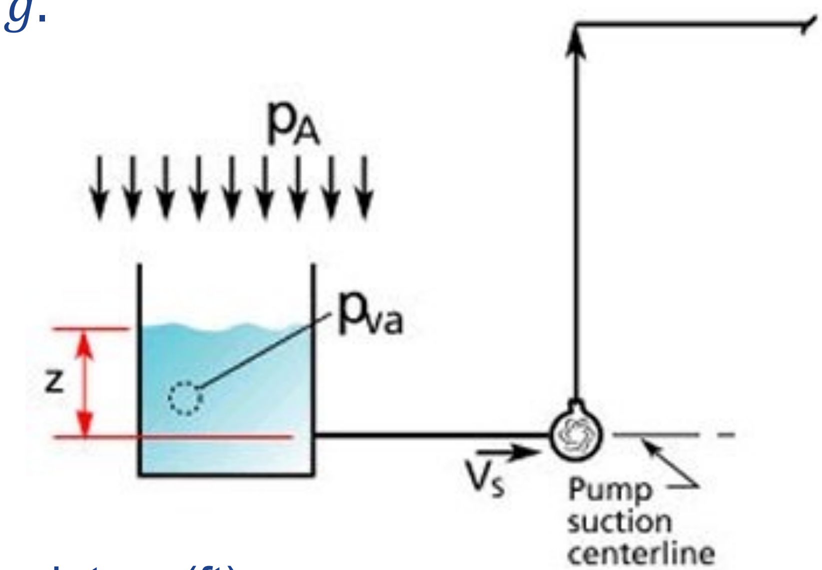
Net Positive Suction Head

Net Positive Suction Head

$$NPSHA = Total\ suction\ head\ (absolute) - fluid\ vapor\ pressure\ (absolute)$$

$$NPSHA = \frac{{V_s}^2}{2g} + \frac{2.31(P_s + P_a)}{s.g.} + Z_s - \frac{2.31P_v}{s.g.}$$

$$NPSHA = \frac{{V_s}^2}{2g} + \frac{2.31(P_s + P_a + P_v)}{s.g.} + Z_s$$

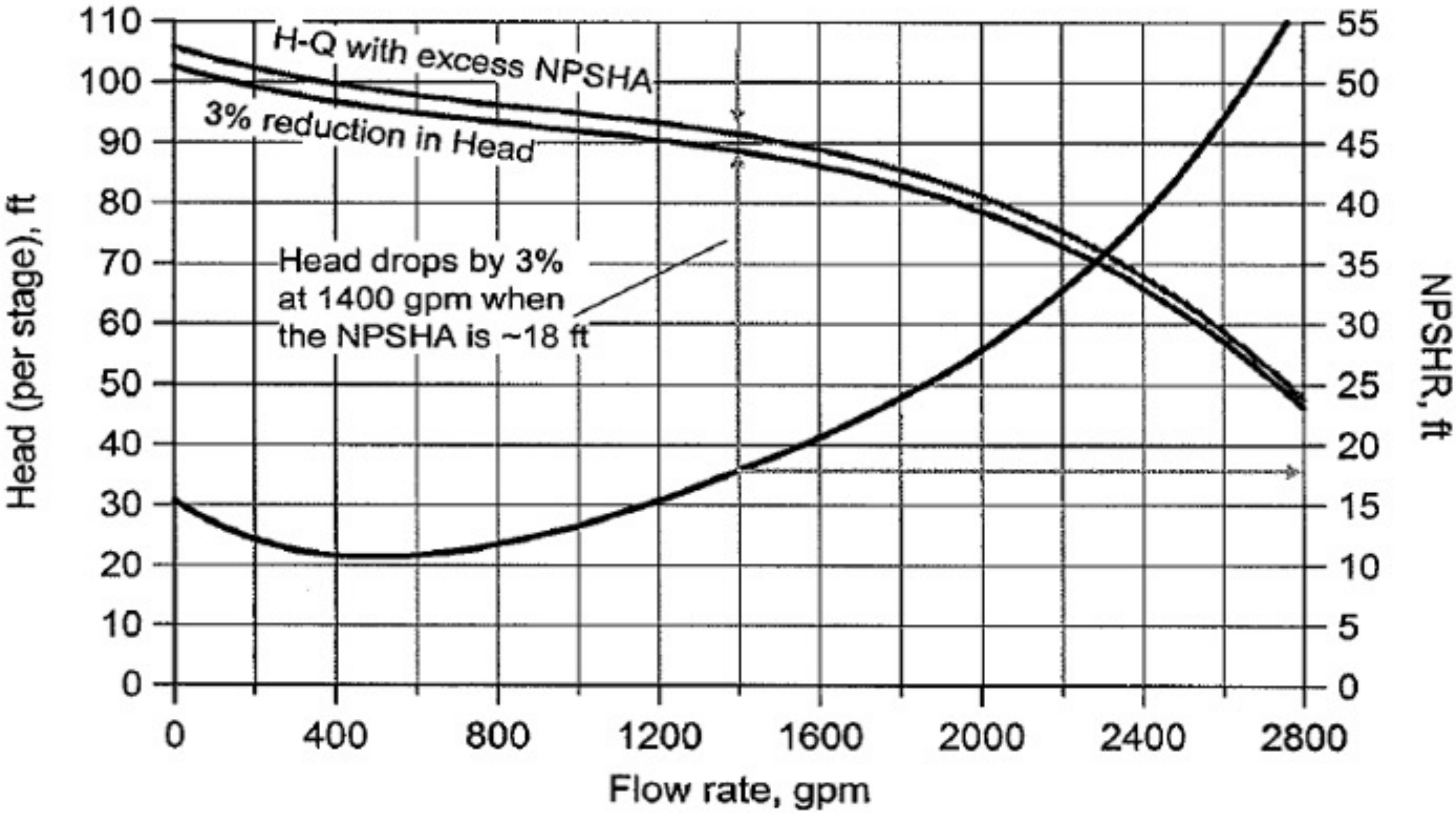


V_s = pump suction velocity (ft/s)
P_s = suction gauge pressure (psig)
P_a = atmospheric pressure (psia)
P_v = fluid vapor pressure (psia)
g = gravitational constant (32.174 ft/s^2)
s.g. = fluid specific gravity (dimensionless)
Z_s = suction gauge elevation above pump suction datum (ft)

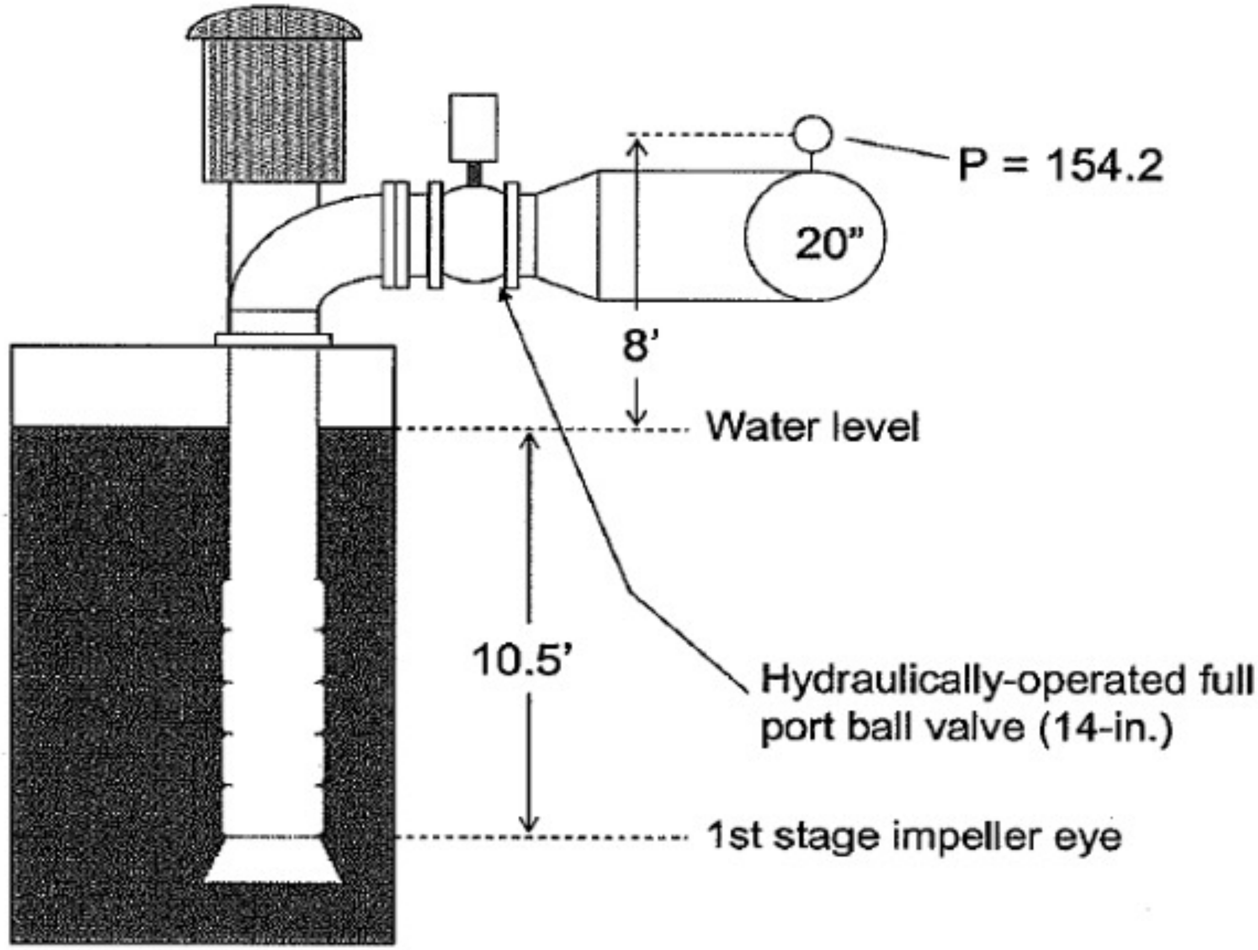
Net Positive Suction Head Required

- NPSHR is, by long-term accepted practice, the available suction head at which the developed pump head has dropped by 3% from the head that it produced with bountiful available suction head
- By definition, then, the pump performance is already degraded due to cavitation-related flow disturbance
- The actual point when cavitation actually begins can be with significantly greater available head than the pump supplier's NPSHR curve
- Two accepted approaches for developing the NPSHR curve:
  - Establish a fixed suction head, then increase flow rate until a 3% reduction in head at a particular flow rate is observed
  - Maintain a constant flow rate and gradually decrease the suction head until the developed head drops by 3%

NPSHR: Available suction head with 3% degradation in developed head



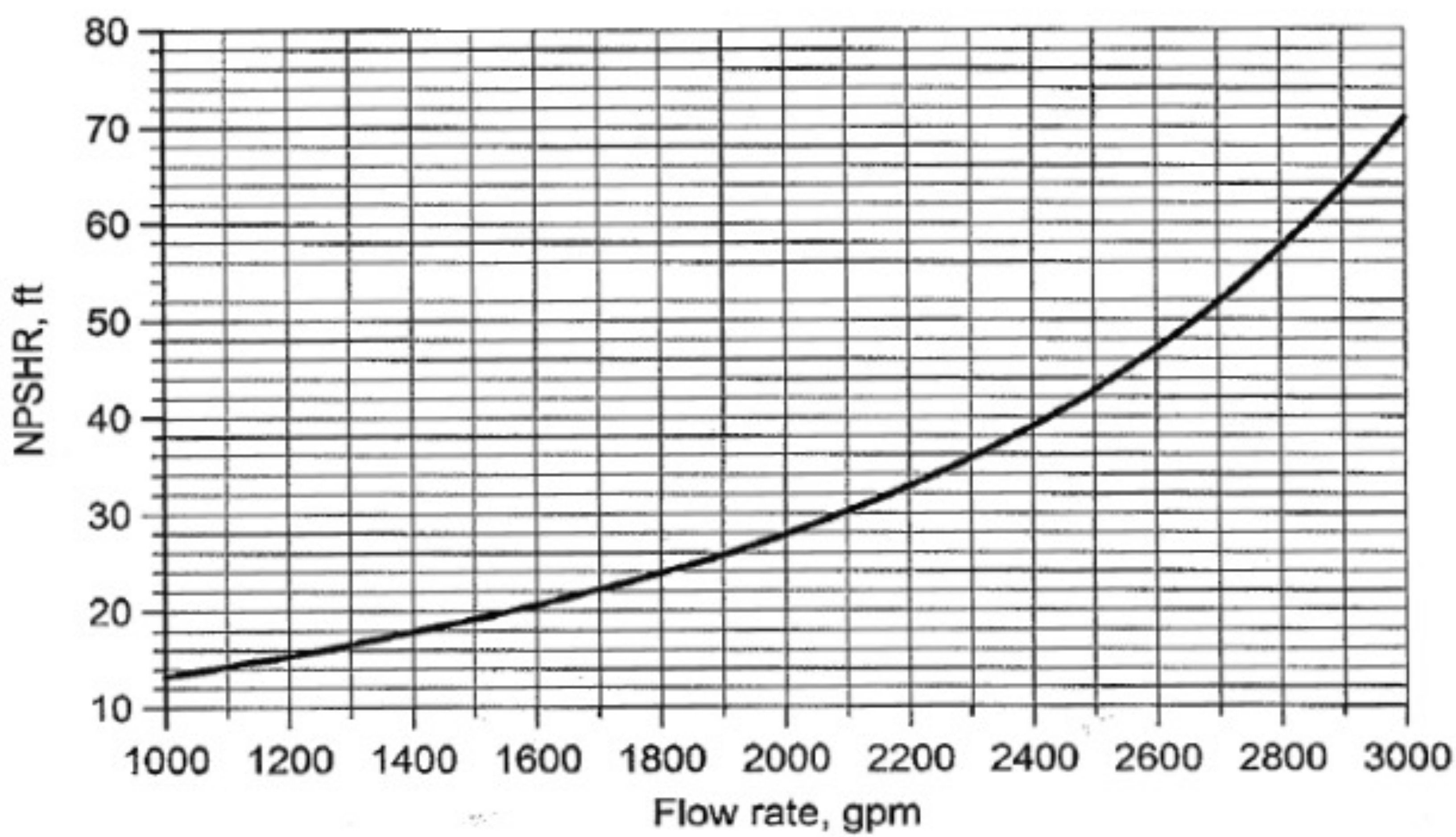
Finish water pump layout



NPSHR Curve for pump on previous slide

At what flow rate would NPSHR exceed NPSHA?

(Assume P_s = 14.7 psia and water temperature = 60 degrees F)



Calculate NPSHA

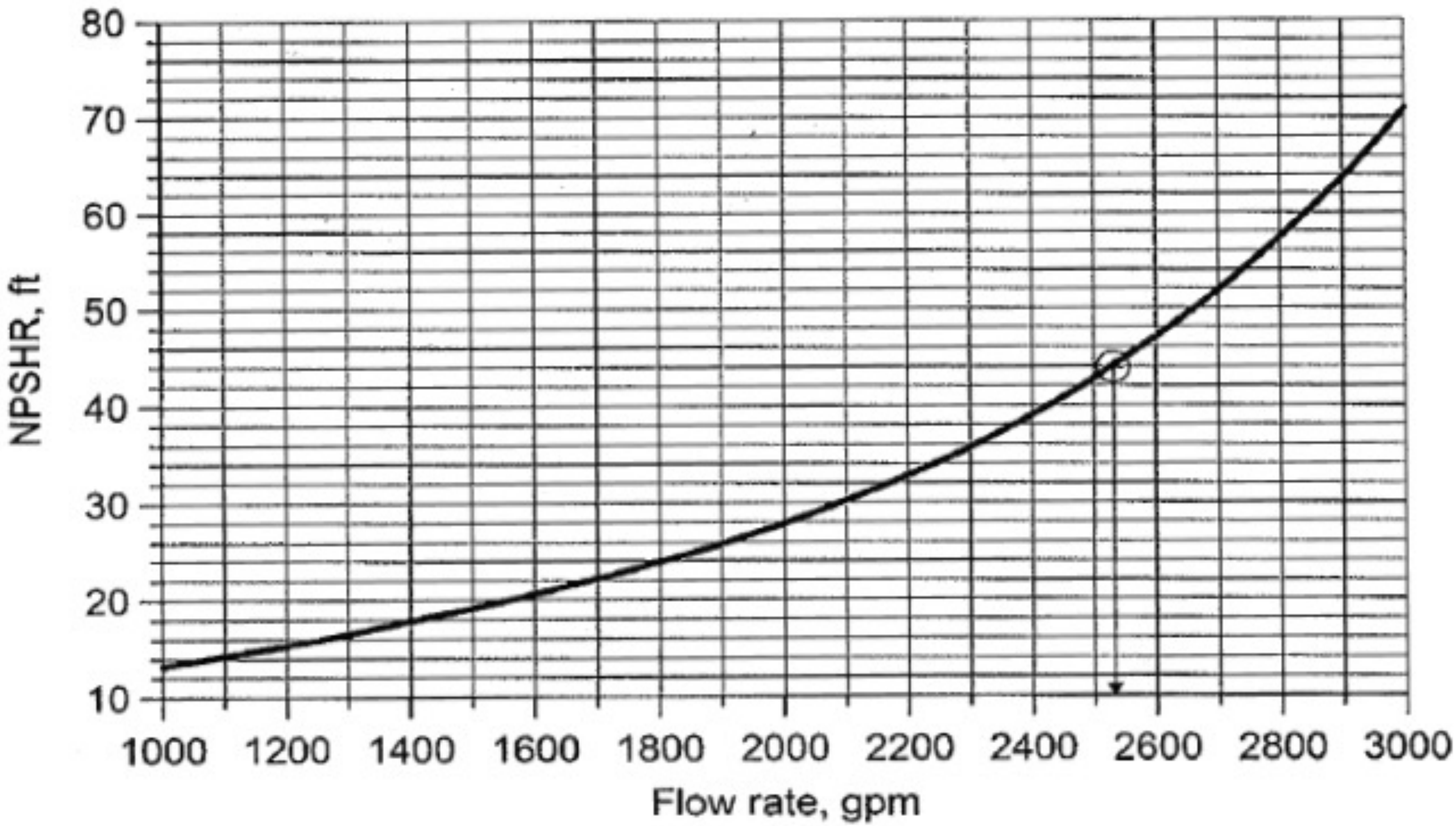
Water saturation vapor pressure at 60 F= 0.26 psia

Reference location for suction head determination is the water surface

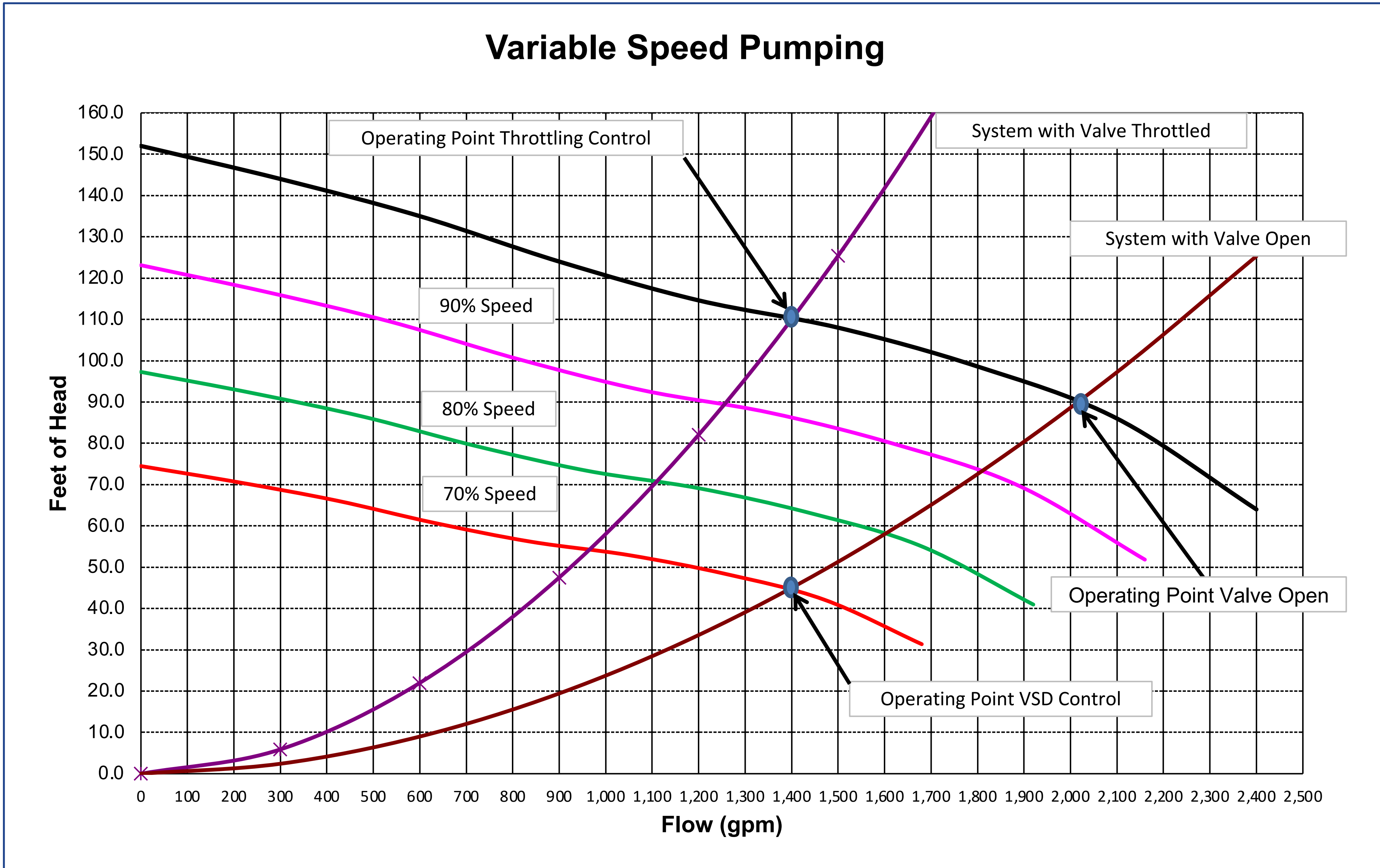
$$NPSHA = \frac{V_s^2}{2g} + \frac{2.31\ (P_s + P_a - P_v)}{s.g.} + Z_s$$

$$NPSHA = \frac{0^2}{64.352} + \frac{2.31\ (0 + 14.7 - 0.26)}{1.00} + 10.5 = \boxed{43.9\ ft}$$

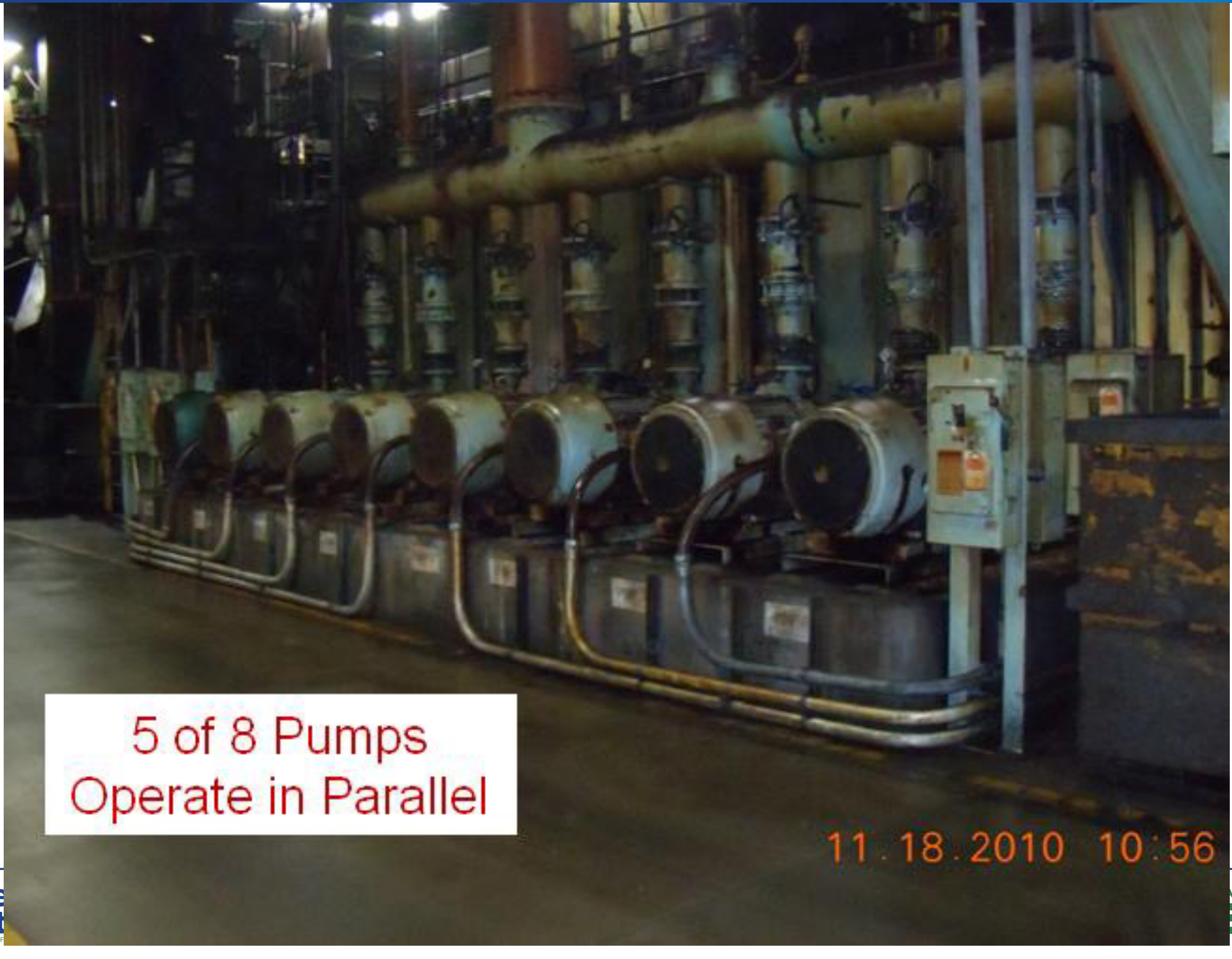
Answer: NPSHR would exceed NPSHA at just over 2500 gpm



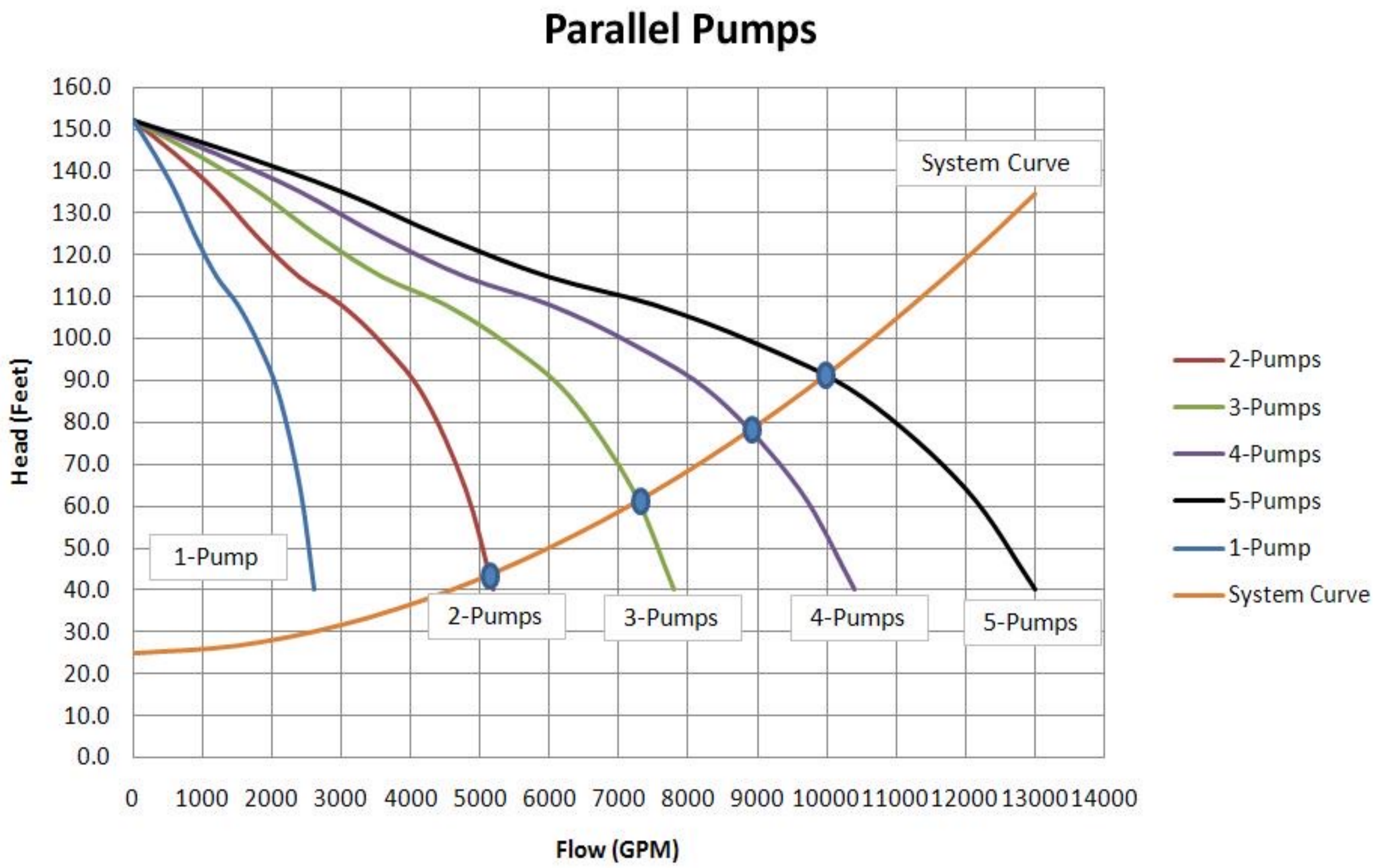
Actual Pump Data for VSD Operation



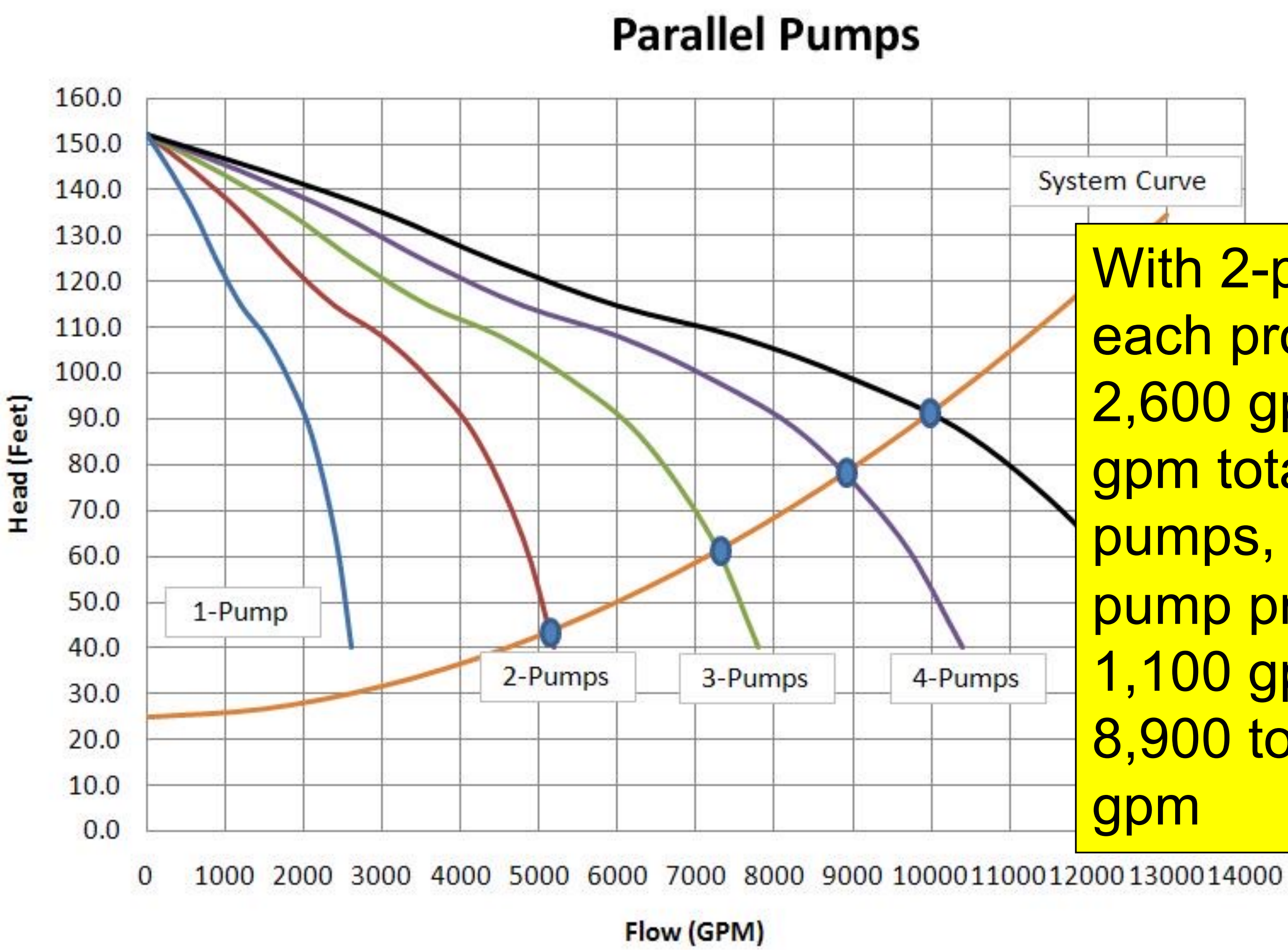
Parallel Pumping Example



Parallel Pumping Example

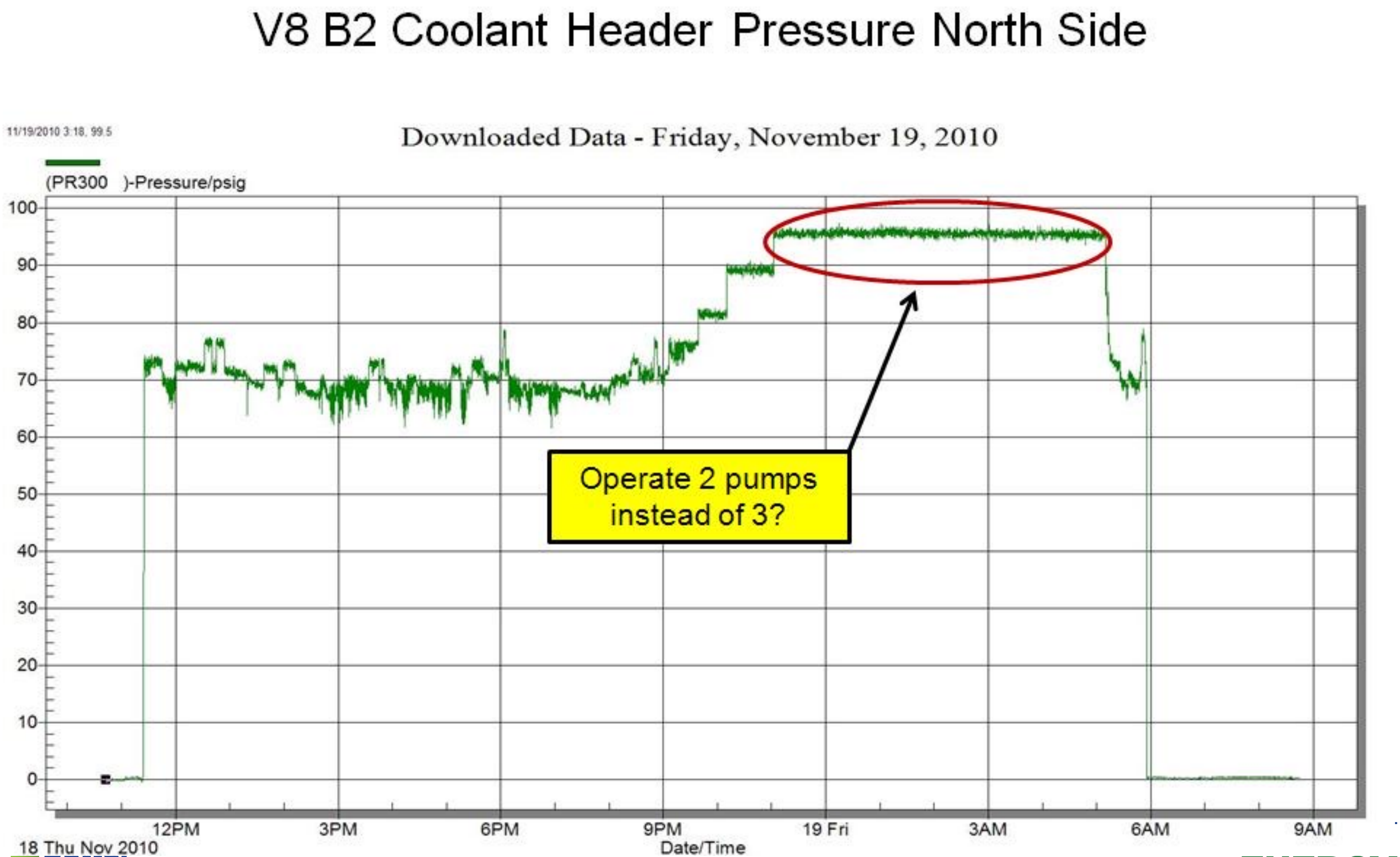


Parallel Pumping Example



With 2-pumps, each produces 2,600 gpm, 5,200 gpm total; With 5-pumps, the last pump produces 1,100 gpm, from 8,900 to 10,000 gpm

Parallel Pumps: Header Pressure



The End for Session 4