HYDRAULIC INSTITUTE™

PUMP TRAINING RESOURCES

BROUGHT TO YOU BY **PUMP SYSTEMS MATTER®**

Pump System Assessment Course

Pumping System Assessment

FloFab

Instructor: Alex Kramer

Date: September 2018

Course Overview

1. Pump World – 1-1/2hrs
   - Hydraulic Institute
   - Introduction to Pumping Systems
2. Water World – 1-1/2hrs
   - Pump System Types in Commercial Buildings
   - Examples
3. Flow Control & DHW – 1-1/2hrs
   - Methods of Controlling Pumps
   - Variable Frequency Drives
   - Conclusions

Hydraulic Institute and Pump Systems Matter

Introduction

- **About the Hydraulic Institute:** The mission of the Hydraulic Institute is to be a value-adding resource to member companies, engineering consulting firms, and pump users worldwide by developing and delivering comprehensive industry standards, expanding knowledge by providing education and tools for the effective application, testing, installation, operation, maintenance, and performance optimization of pumps and pumping systems, and by serving as a forum for the exchange of industry information. For more information on the Hydraulic Institute, its member companies and its partners, visit www.Pumps.org
- **Pump Systems Matter:** Established by the Hydraulic Institute, and leading utilities and energy efficiency organizations, PSM provides educational resources on the benefits to pump systems optimization and energy efficiency to improve bottom-line savings of end-user companies. PSM offers a robust schedule of webinars on pumps and pumping systems, based on HI standards and industry guidelines, and offers Pump Optimization course hosting opportunities to pump and supplier OEMs, pump distributors, energy efficiency organizations, water/wastewater utilities, electric power utilities and associations.

HI Activities are Organized Around the Principle that Sound Technical Expertise will Educate and Inform…

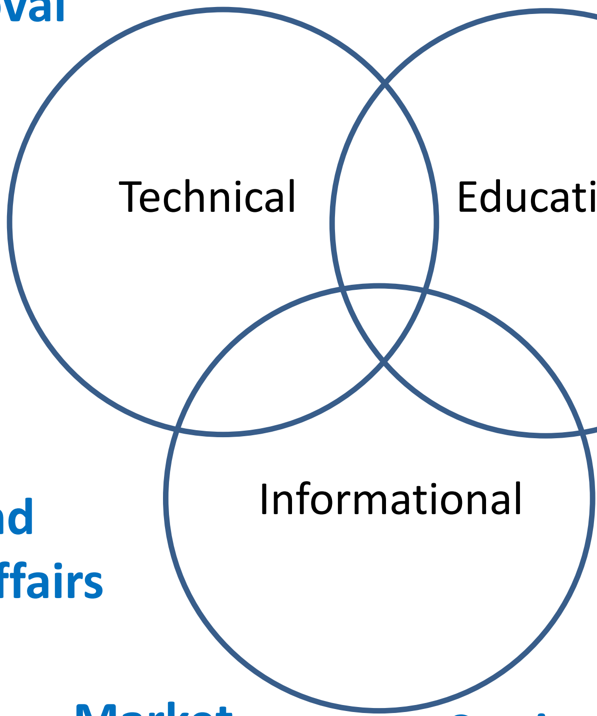
HI Standards

HI Guidebooks

Laboratory Approval

Tools, Templates & FAQs

Product Labeling



HI Certification

HI Regulatory Activities

HI Training

HI Advocacy and Government Affairs

Intl. Trade Task Force

Market Intelligence

Statics and Surveys

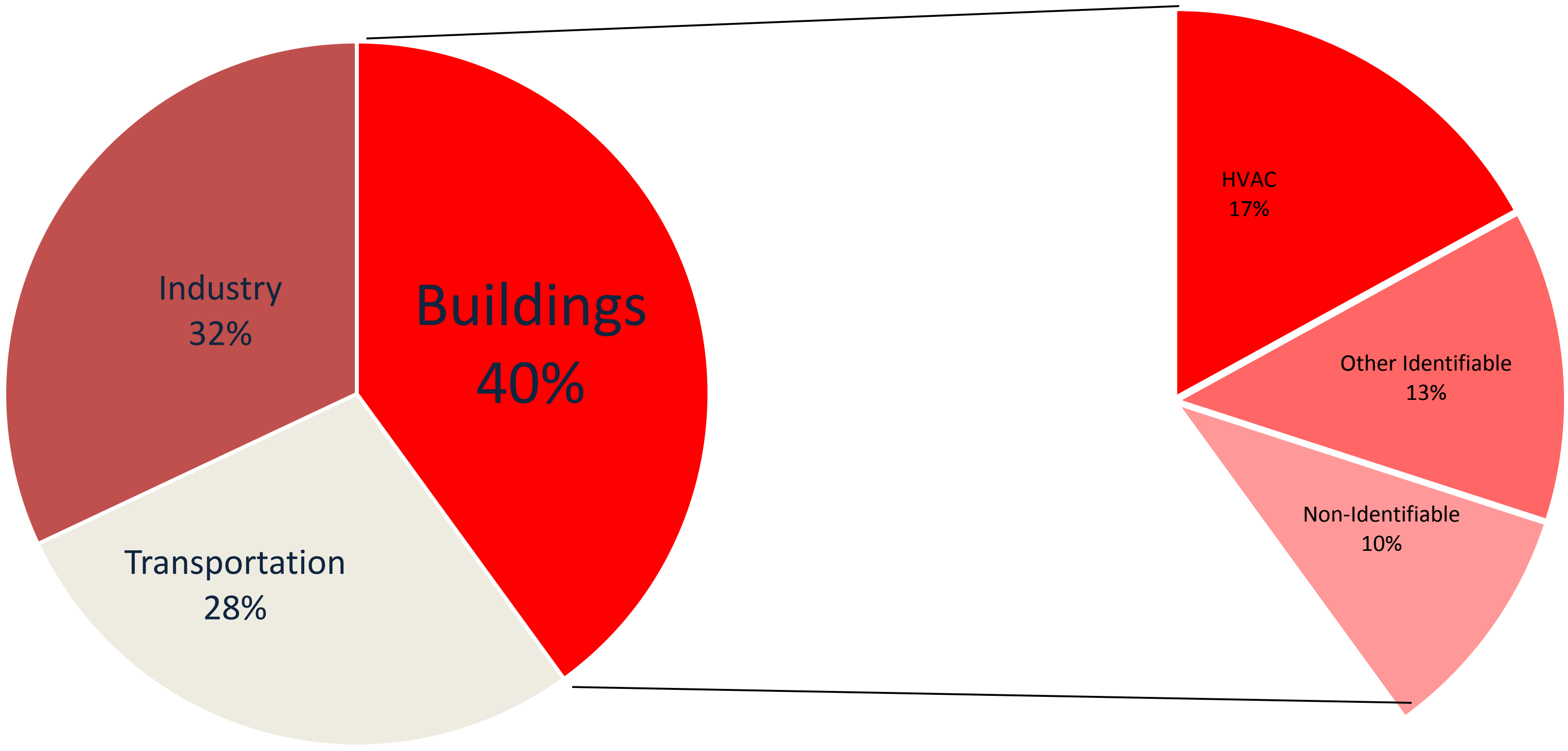
Educational Case Studies Working with Other Institutions: "Pump System Optimization" Case Studies

Pump World

Use Energy Consumption

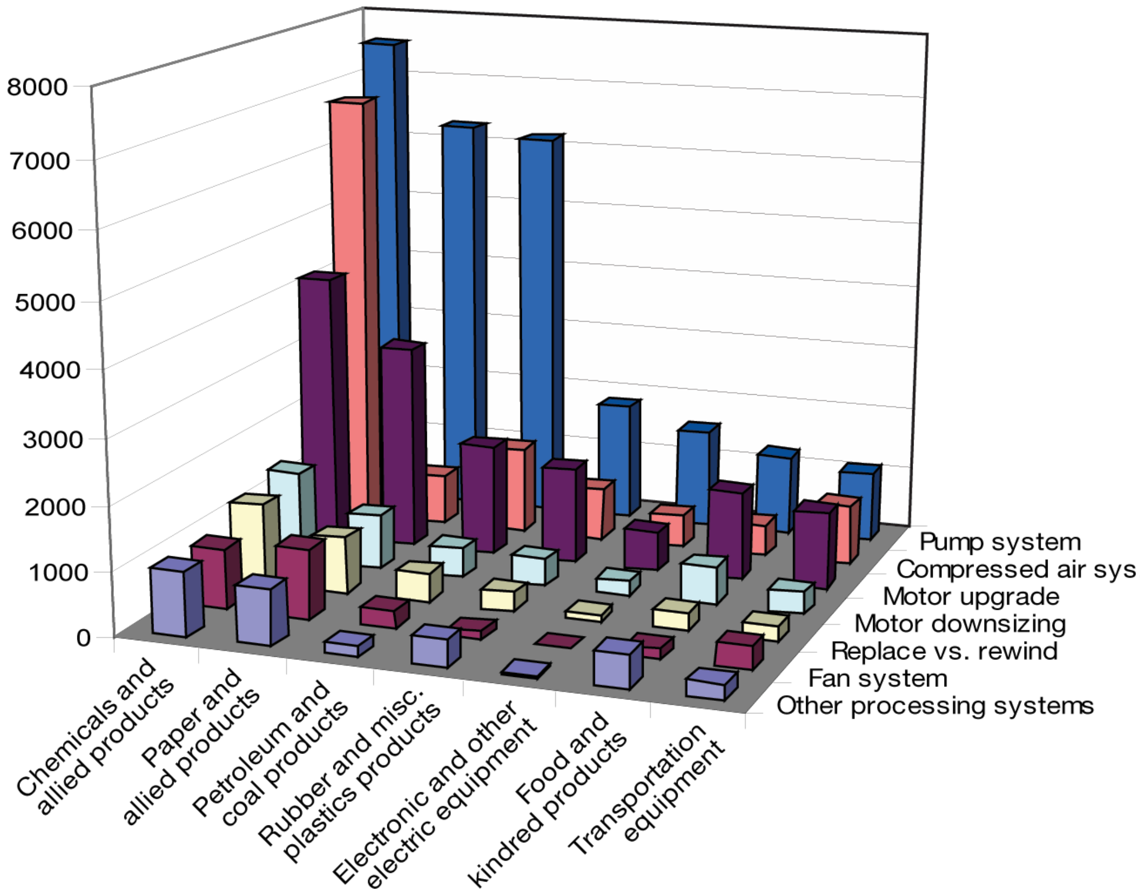
Total US Energy Consumption

US Building Energy Consumption

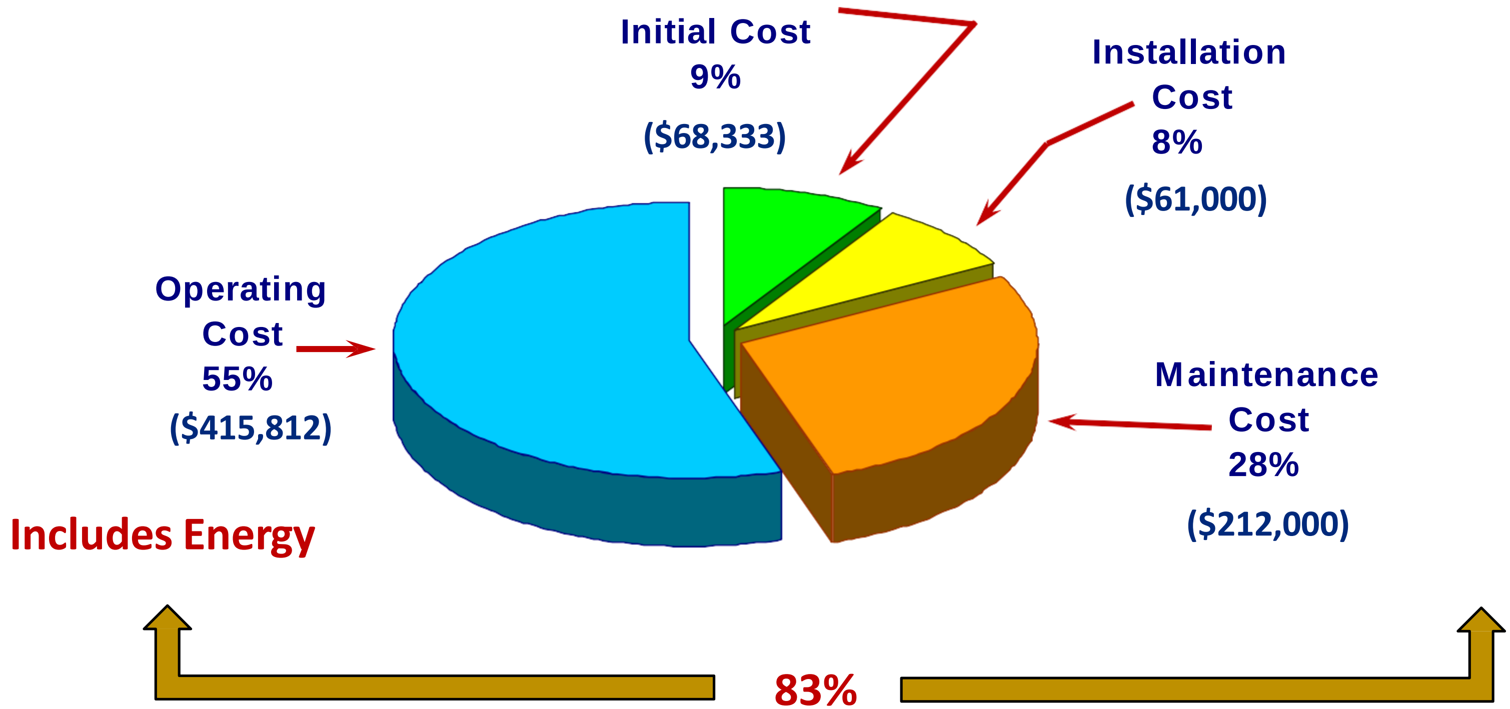


Source: US Department of Energy – Buildings Energy Data Book (2010)

Pump Systems Have Greatest Energy-Saving Potential Across All Industries



20 Year Life Cycle Cost of Conventional 75HP Pumping System



Total 20 year life cycle cost = $757,145

Initial Costs are the Wrong Focus

Example: Lifetime Energy Costs of a Motor

Purchase Price

$5,000

Installed

$20,000

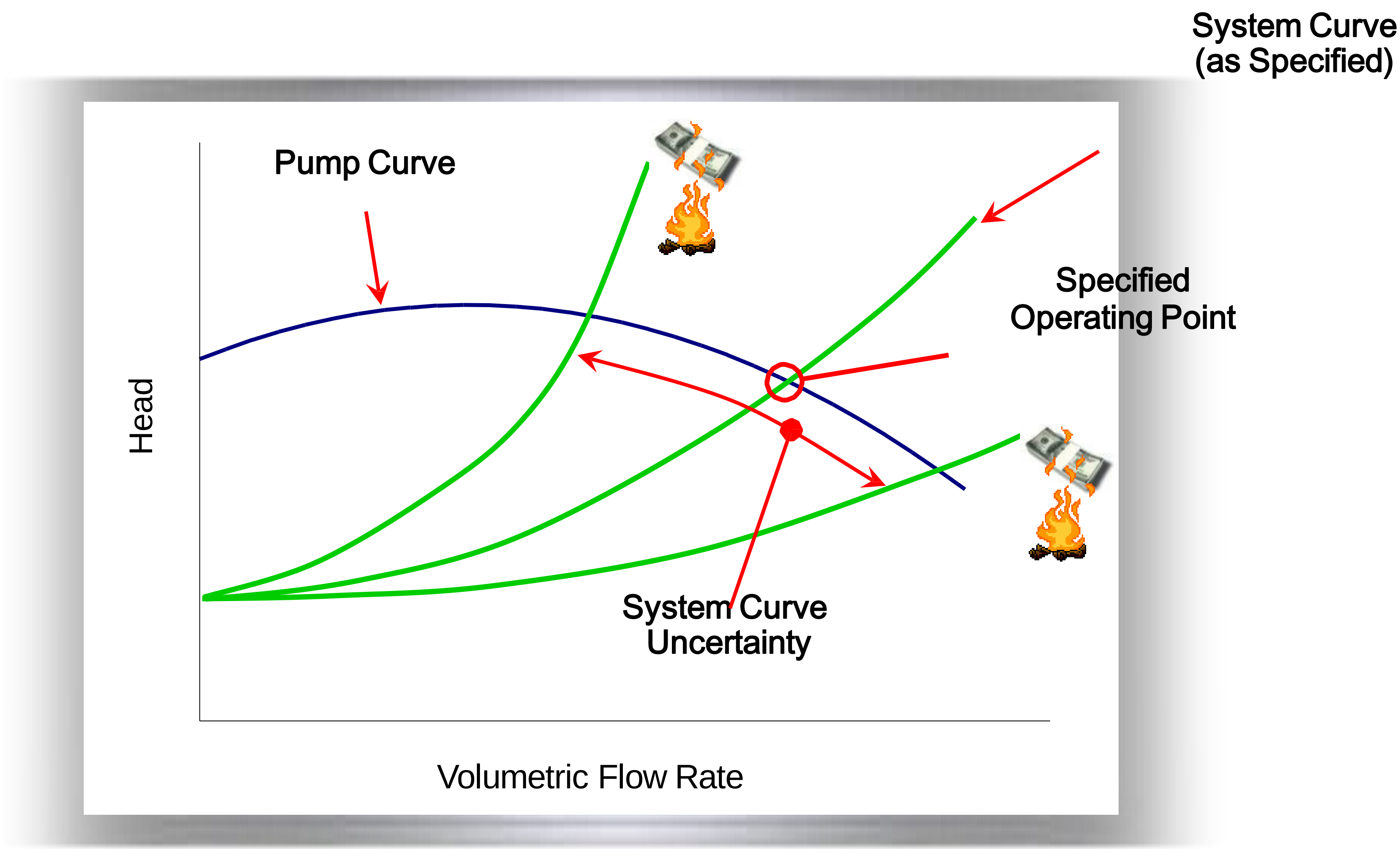
Energy Cost

$810,000

(162 X Purchase)
(40 x Installed)

Example: 100 HP motor @ $0.08/kWh electricity ($54K/yr) 24/7 for 15-yr life

Key Concept


System Curve
(as Specified)
Pump Curve
Specified
Operating Point
Head
System Curve
Uncertainty
Volumetric Flow Rate

Key Points

- Most pump systems are oversized
- Look beyond energy savings,
- Evaluate the entire system,
- Life time energy cost is a major cost compared to first cost

Think System


Electric Utility


Transformer


Switchgear

Component Optimization involves segregating components and analyzing in isolation.

System Optimization involves looking at how the whole group functions together and how changing one can help improve the value of the entire application solution.

At each interface, there are inefficiencies. The primary objective should be to maximize the overall cost effectiveness of the entire system, or simply stated…"how much output energy is delivered per unit of input energy."

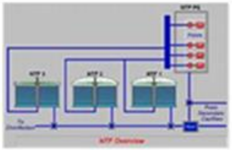

Variable Frequency Drive


Motor


Gearbox


Coupling


Pump

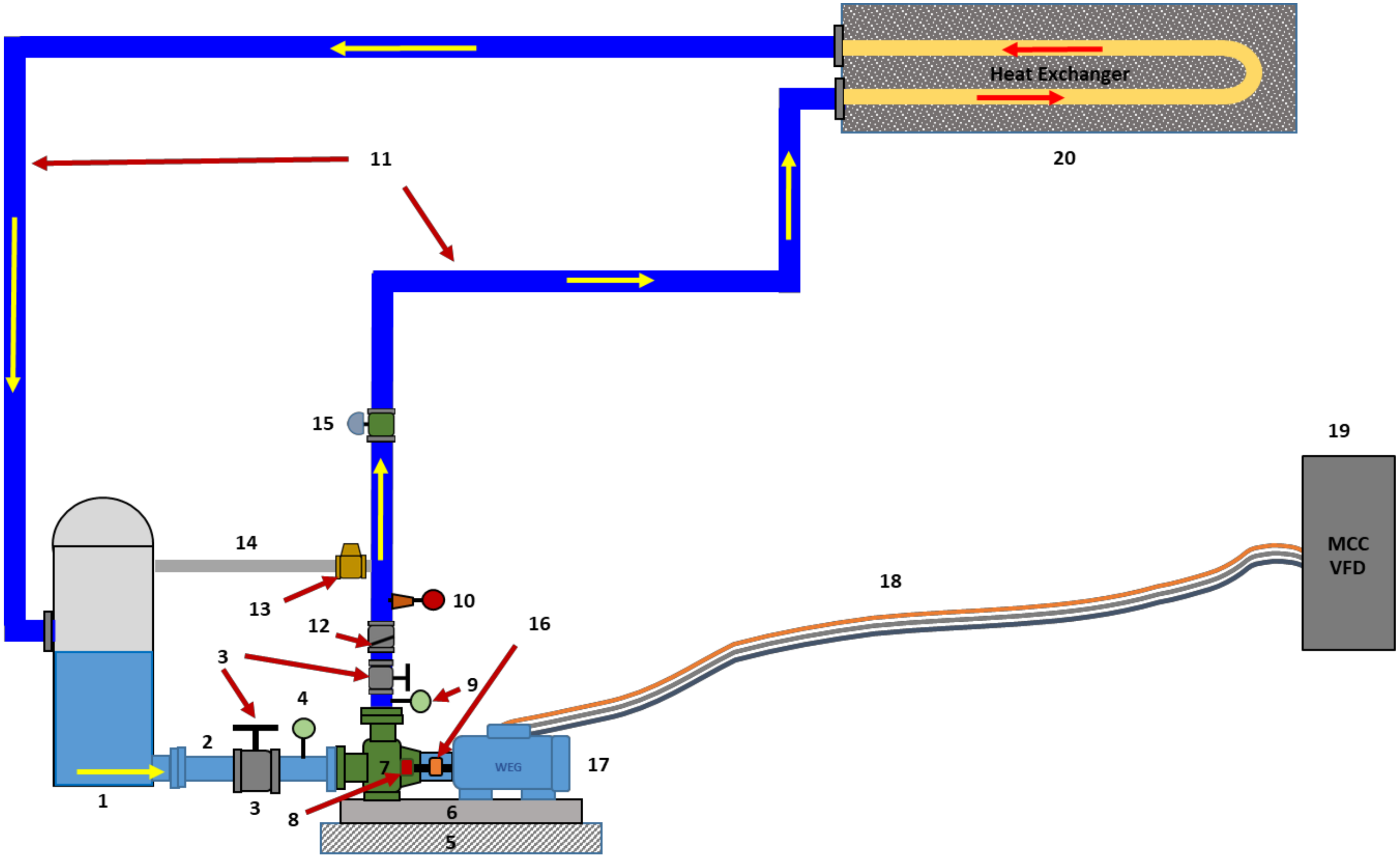

System

Energy Efficiency Improvements

Look at Entire System to Save Energy

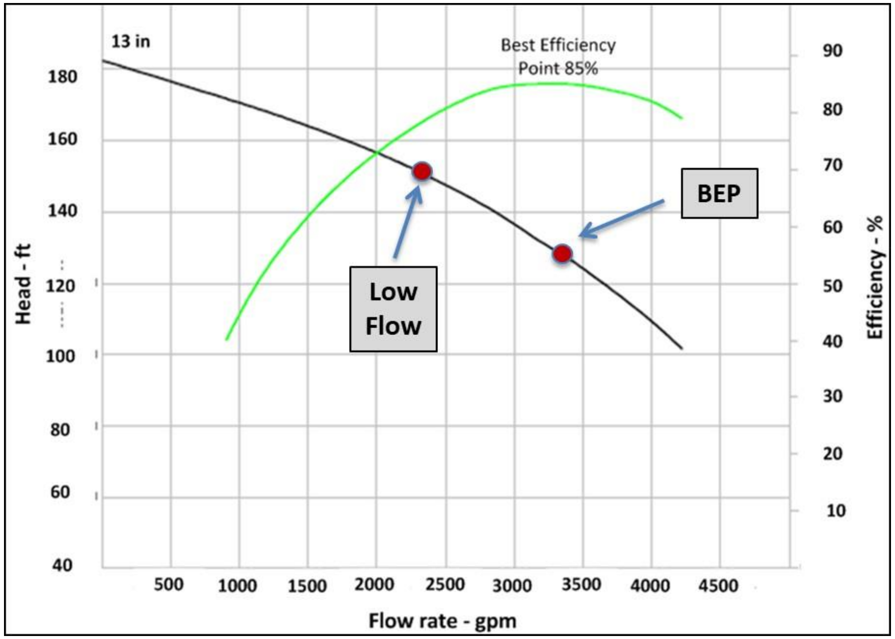
Process Requirements	Flow required Head required	17200 gpm 200 feet	17200 gpm 150 feet	17200 gpm 200 feet	17200 gpm 200 feet
Piping elements	Additional system friction loss	50 ft	0 ft	50 ft	55 ft
Component Efficiencies	Motor eff VFD efficiency factor Mechanical drive eff Pump eff	94% 100% 100% 65%	94% 98% 100% 88%	94% 100% 100% 70%	96% 100% 100% 65%
Electrical	Energy cost per kWh Operating hours per year	$0.05 6250	$0.05 6250	$0.05 6250	$0.05 6250
	Factor	Base	Reduce friction by 50 feet.	Increase pump efficiency by 5 points.	Increase motor efficiency by 2 points.
Output	System efficiency System input power required for process Power required for additional friction Total power required Total cost per year	49% 1421.7 bhp 355.4 bhp 1777.2 bhp $414,306	81% 803.7 bhp 0.0 bhp 803.7 bhp $187,360	53% 1320.2 bhp 330.0 bhp 1650.2 bhp $384,712	49% 1392.1 bhp 382.8 bhp 1775.0 bhp $413,788
	Cost Savings		$226,946	$29,593	$518
1	2	A	B	C	D

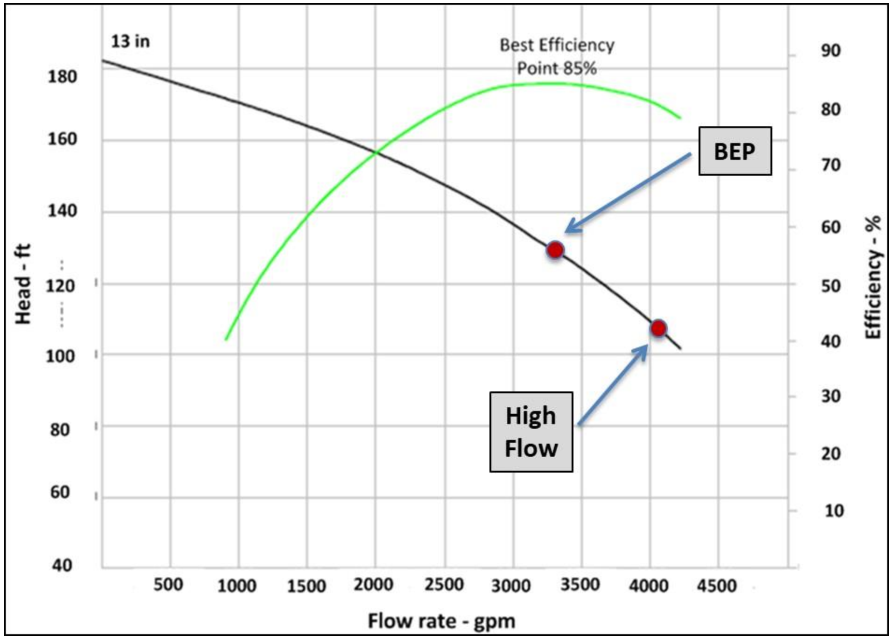
Typical Pump System Components



Centrifugal Pump Facts

Centrifugal pumps should be selected and normally operated at or near the manufacturer's design rated conditions of head and flow.



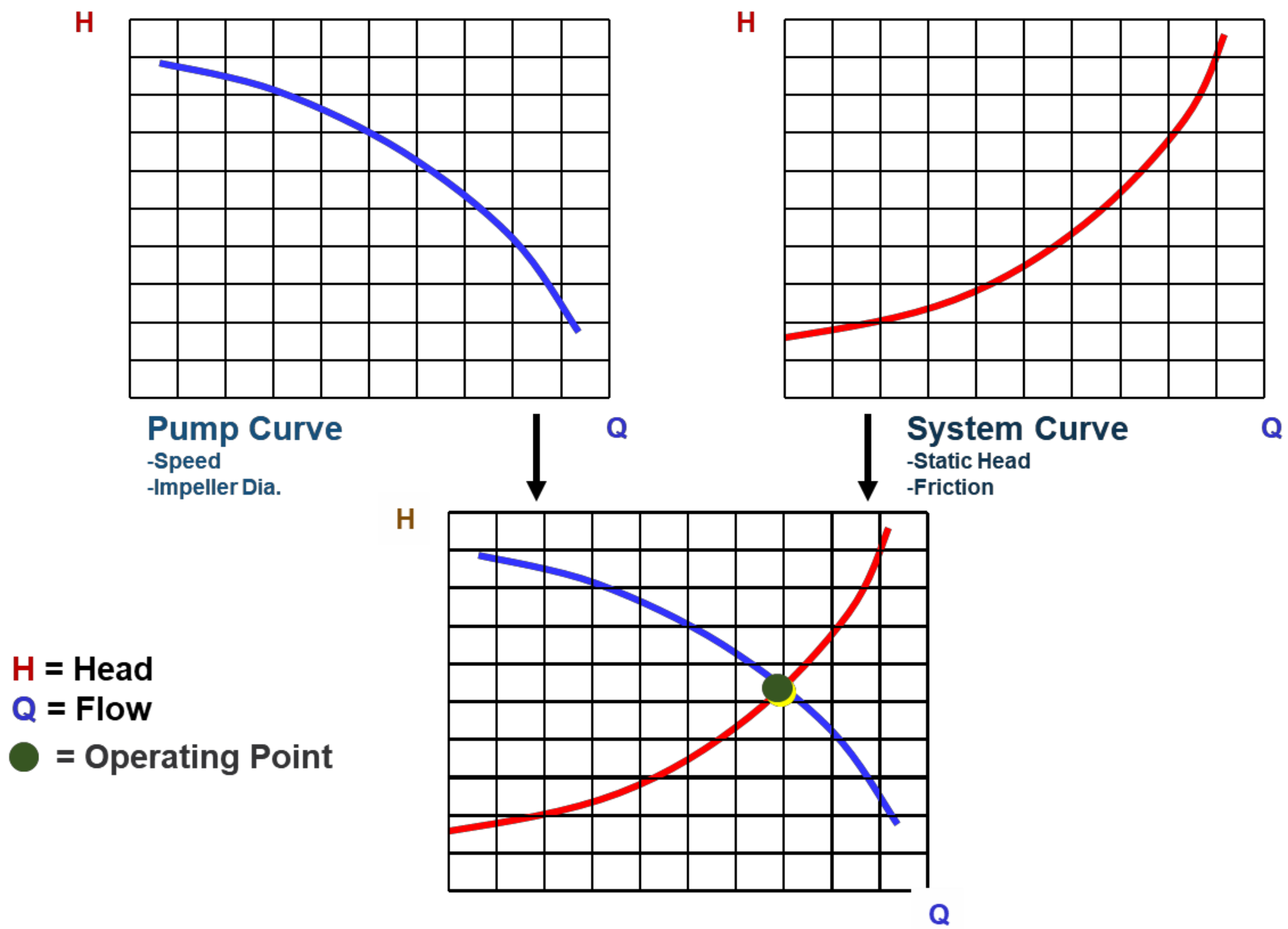


The System: What is a System Curve?

A system curve represents the sum of the static head and the friction loss due to flow of fluid through a system.
The pumping system will operate where the pump and system curves intersect
System curves help demonstrate pumping system behavior in a graphical manner

If a system curve can be determined, it can help identify the effects of pump and/or system modifications

System Curve



System Optimization and Improvement Opportunities

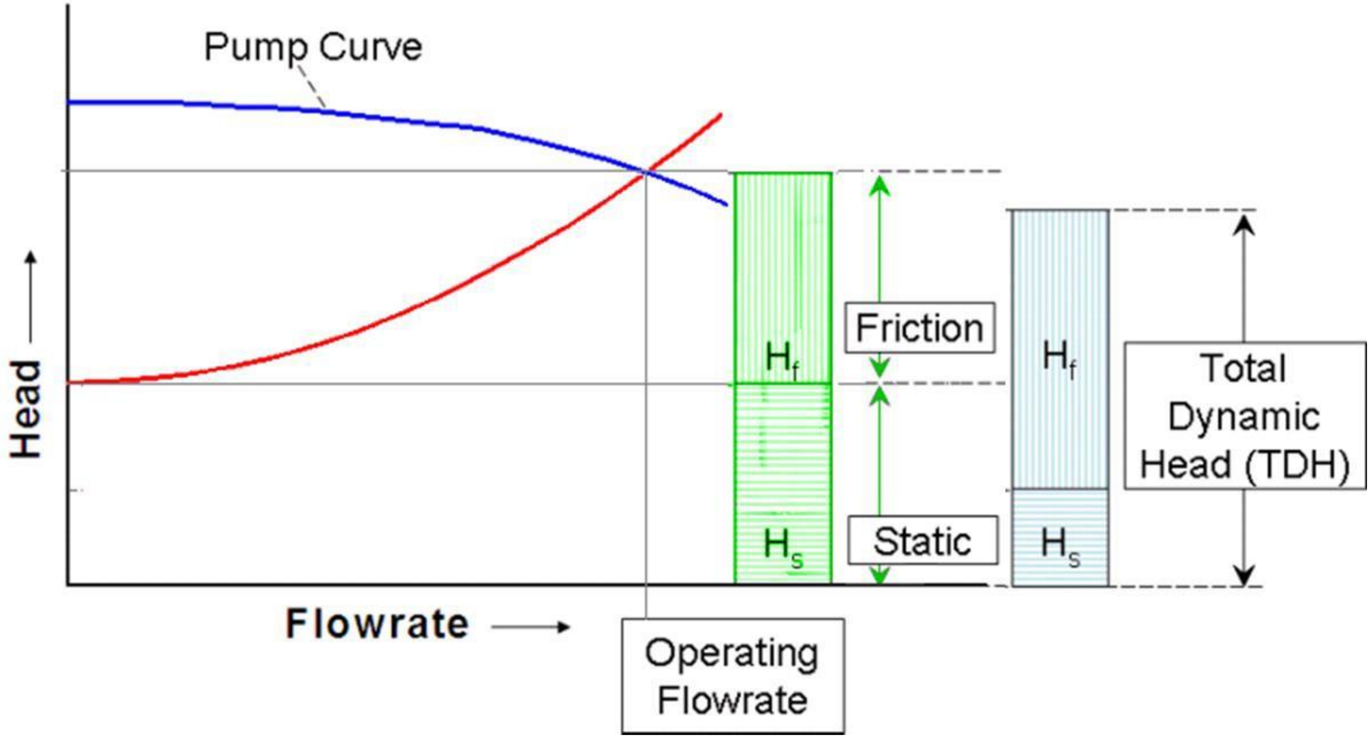
- Eliminate unnecessary uses
- Improve Operations & Maintenance (O&M) practices
- Improve piping configuration
- Consider alternative pump configurations
- Change pump speed

More System Optimization Opportunities

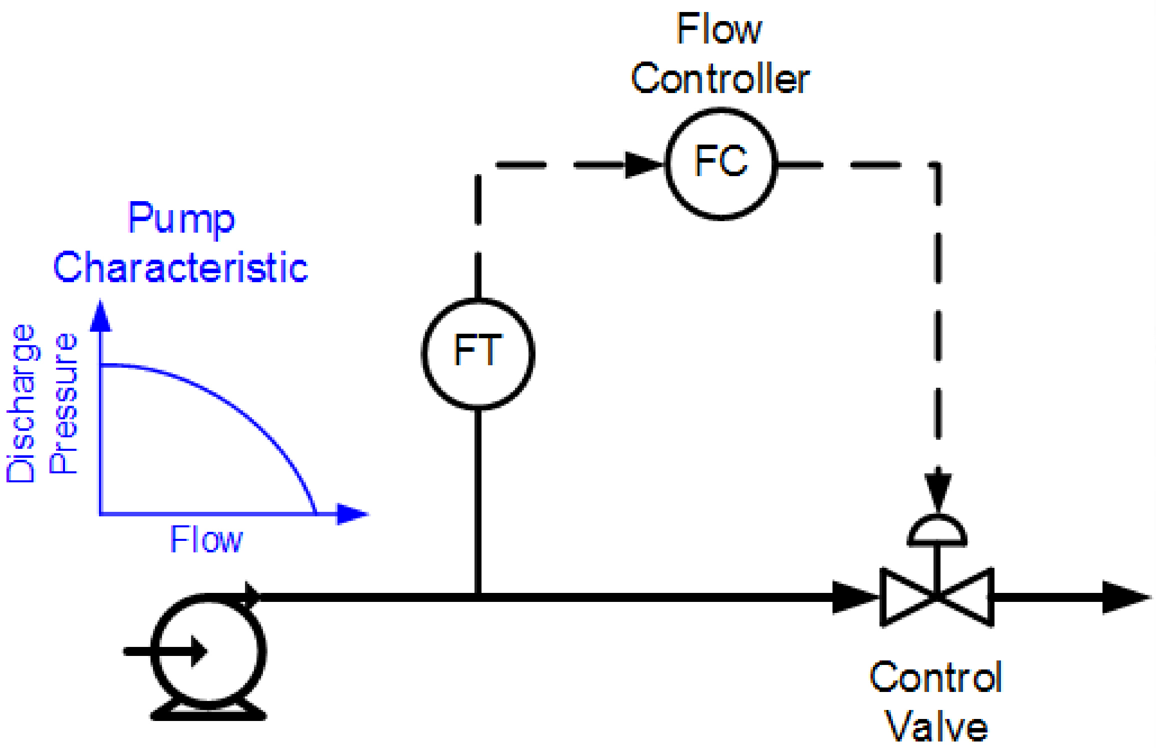
- Using a pump when the fluid is not needed
- Running two pumps when only one is needed
- Continuing to run pumps in a batch-type process when products are not being produced
- Excessive pump head or flow

Friction in Pump Systems

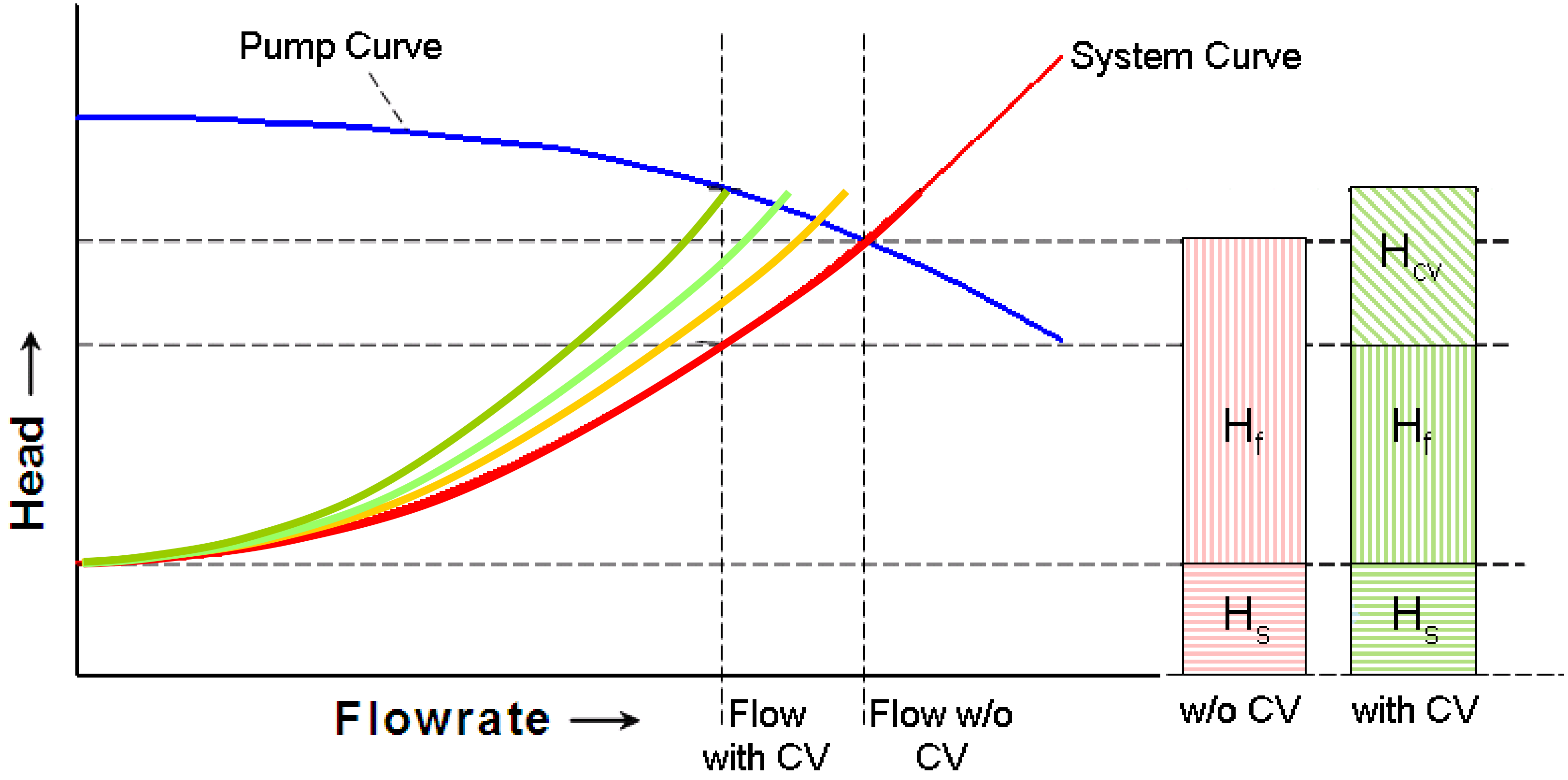
- Friction occurs in pump systems due to **irrecoverable** hydraulic losses
- Friction is also used to control flow or pressure, **recoverable hydraulic losses**



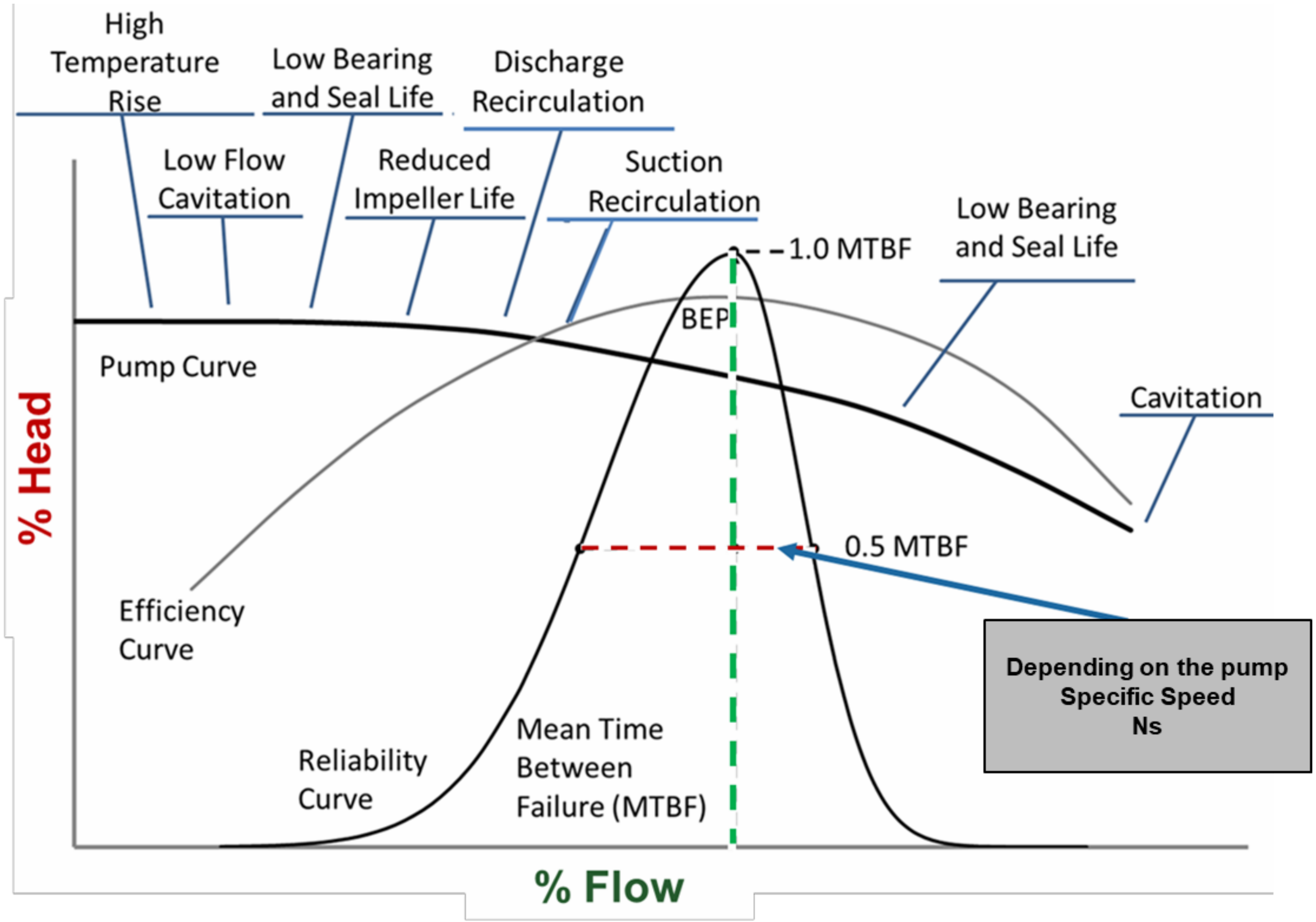
Throttling Valves and Friction



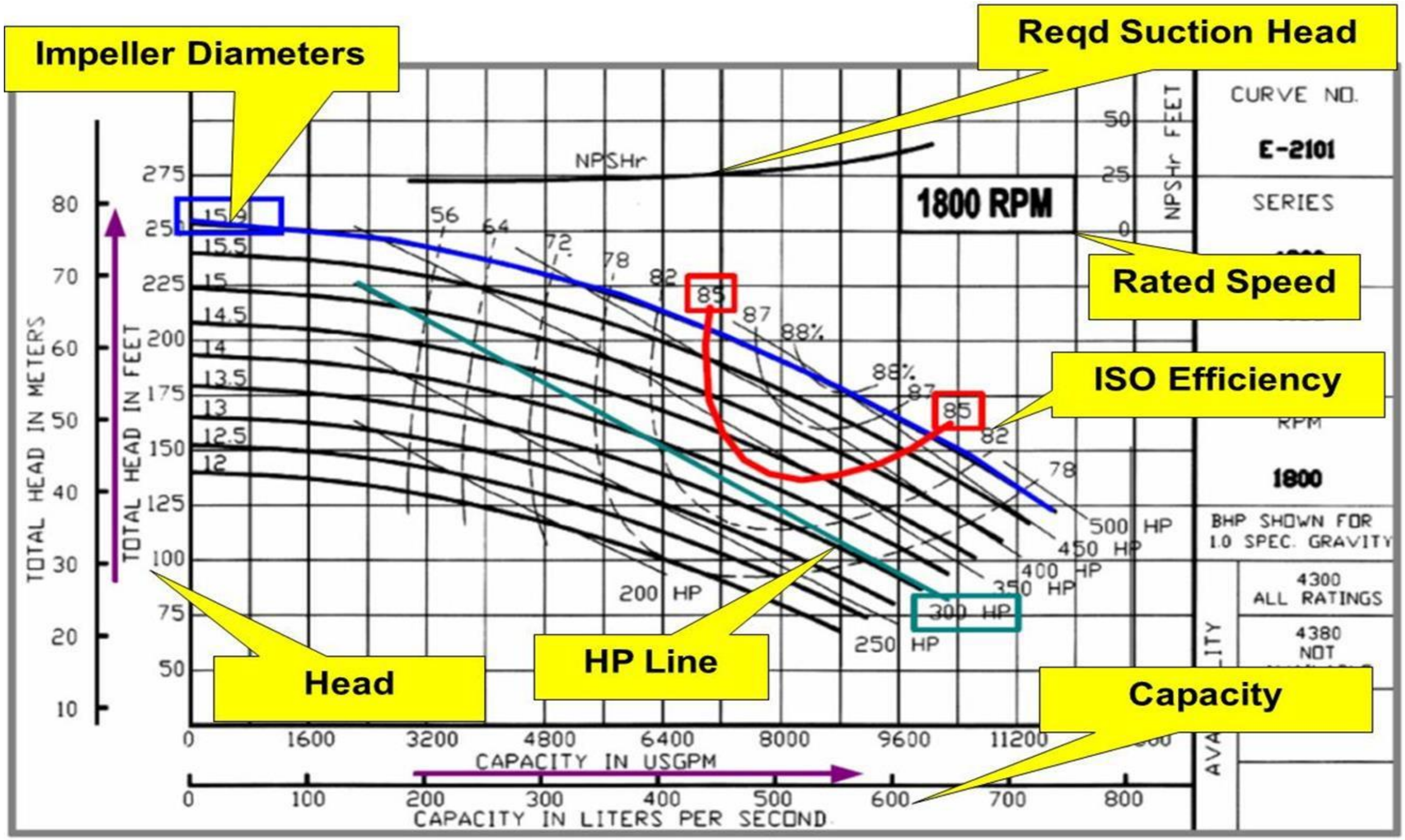
Effects of a Control/Throttling Valve



Pump Reliability and BEP



Data for Specific Area of Pump Curve



Pump Affinity Rules

Speed

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

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

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

Diameter

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

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

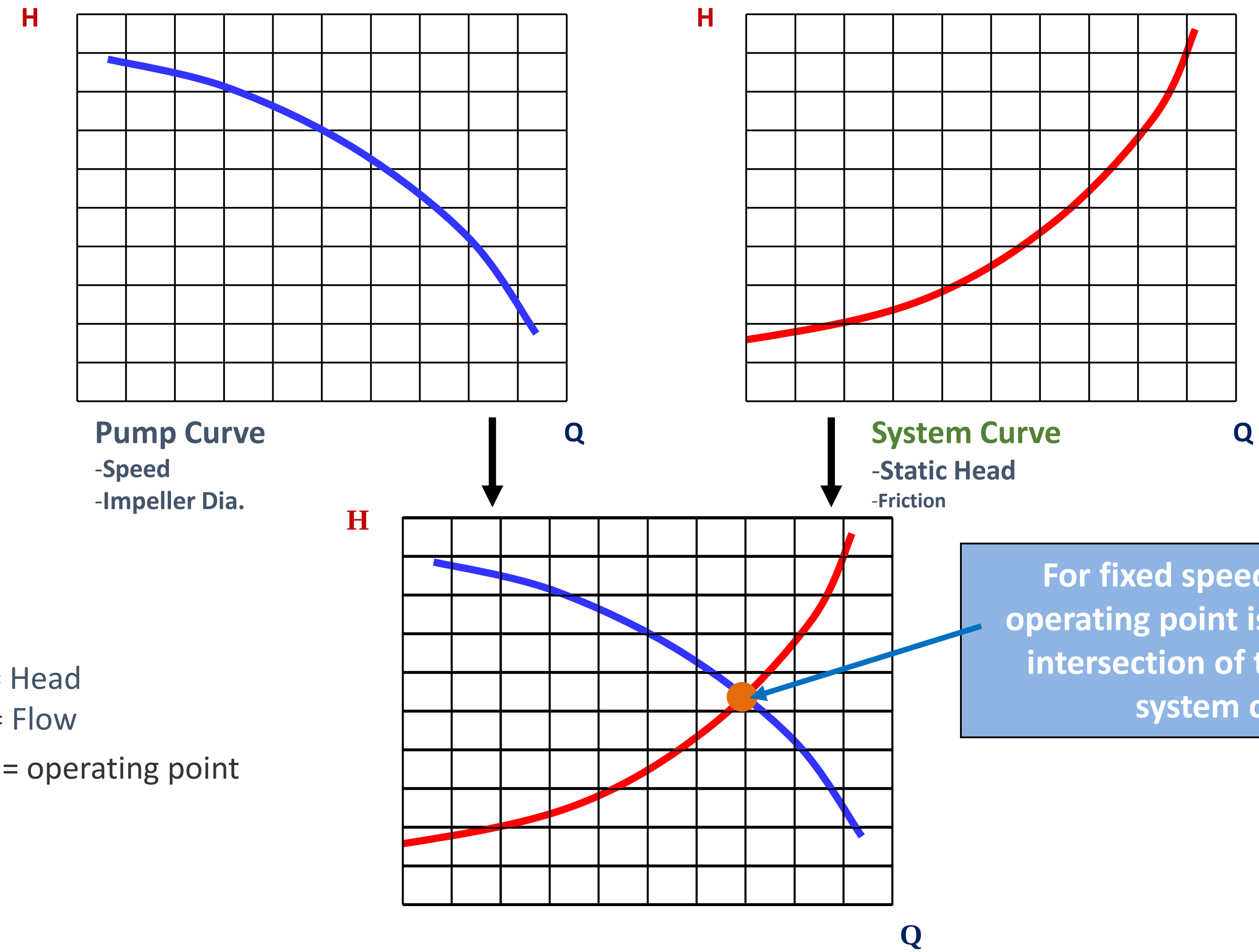
$$\left(\frac{P_1}{P_2}\right) = \left(\frac{D_1}{D_2}\right)^3$$

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

Pump Affinity Rules

Speed	Volume	Pressure/ Head	Horsepower Required
100%	100%	100%	100%
90%	90%	81%	73%
80%	80%	64%	51%
70%	70%	49%	34%
60%	60%	36%	22%
50%	50%	25%	13%
40%	40%	16%	6%
30%	30%	9%	3%

Pump and System Curves



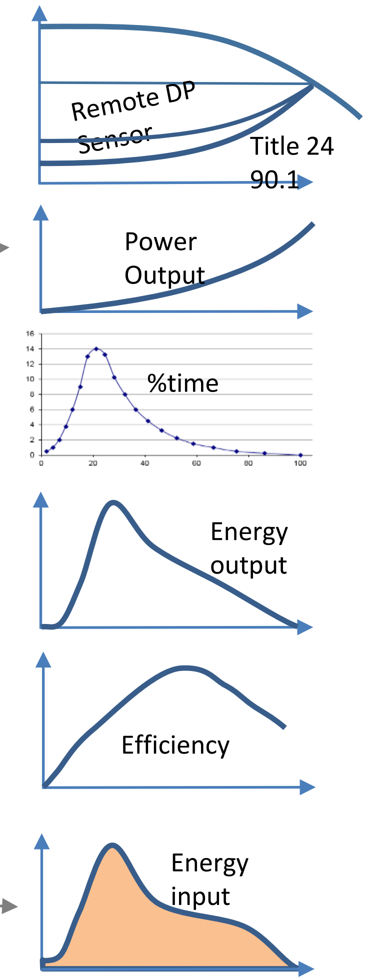
H = Head
Q = Flow
● = operating point

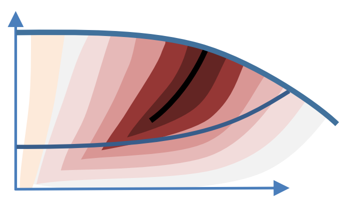
For fixed speed pumps, the operating point is located at the intersection of the pump and system curves.

Pump Selection Process

Annual Energy Use Estimation

- Step 1 – Determine the Control Method
- Step 2 – Calculate the Power Delivered at each flow: Flow x Diff Press
- Step 3 – Use the flow profile to determine the pump Energy Output profile:
  Pwr x hrs
- Step 4 – Determine the pump/fan Efficiency at each flow for the control method
- Step 5 – Calculate the Energy Input profile (Energy output / Eff) and integrate



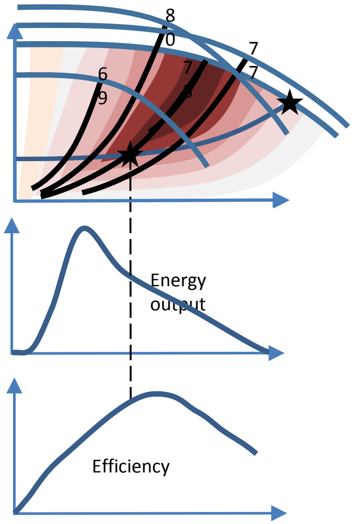


Combined drive, motor & pump efficiency

Best Energy Efficiency Estimation

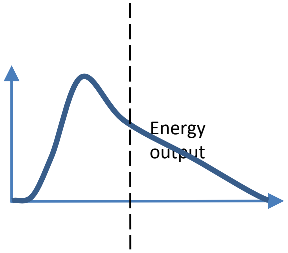
- If we have to select a pump in a group, the one which will use minimum energy input, maximizes the correlation between Efficiency and Energy output
- This happens for the pump which has its best efficiency curve closest to the Energy output "center of mass"
- The information usually available is the efficiency curves and values
- The pump has to be able to provide the design day flow and diff pressure

Smart selection of the right equipment for the application

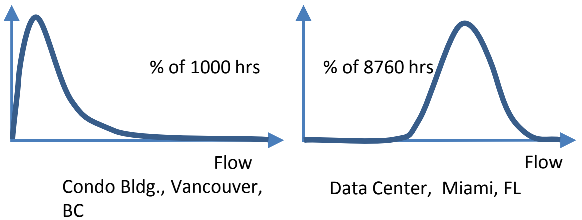


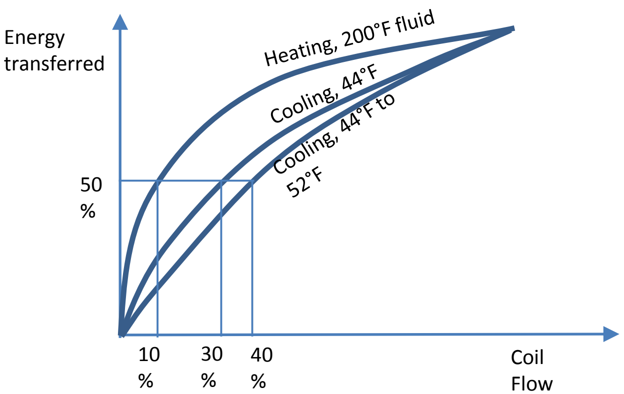
Best Energy Efficiency Selection

- The determination of the output energy "center of mass" depends heavily on the flow profile
- The flow profile depends on:



1. The type of building (school, residential, hospital, data center, mixed…), which determine the occupancy patterns and use. I.e. internal loads profile
2. The location (weather) and building insulation. I.e. external load profile
3. The presence of heat recovery and free air cooling
4. The pump application (primary, secondary, condenser)
5. The fluid type and temperature control method

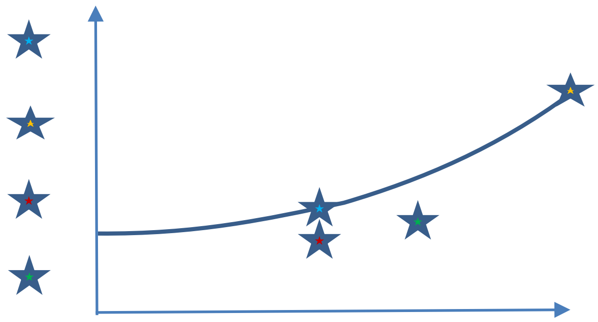




Best Energy Efficiency Selection – Rules of Thumb

If all that info is not available, then use the following "center of mass", relative to the design day flow and head:

		Flow	Head
• Secondary pumps	0.5	0.65	
• Primary pumps in VP/VS	1	1	
• Distribution primary pumps	0.5	0.4	
• VS condenser pumps	0.7	0.5	



- CS condenser pumps should be designed for 12 to 14°F design day ΔT
  (see "Optimizing Design &Control of Chilled Water Plants Part 4 Chiller & Cooling Tower Selection", ASHRAE Journal, Mar 2012)

Life Cycle Costs: Energy Is Only Part Of The Story

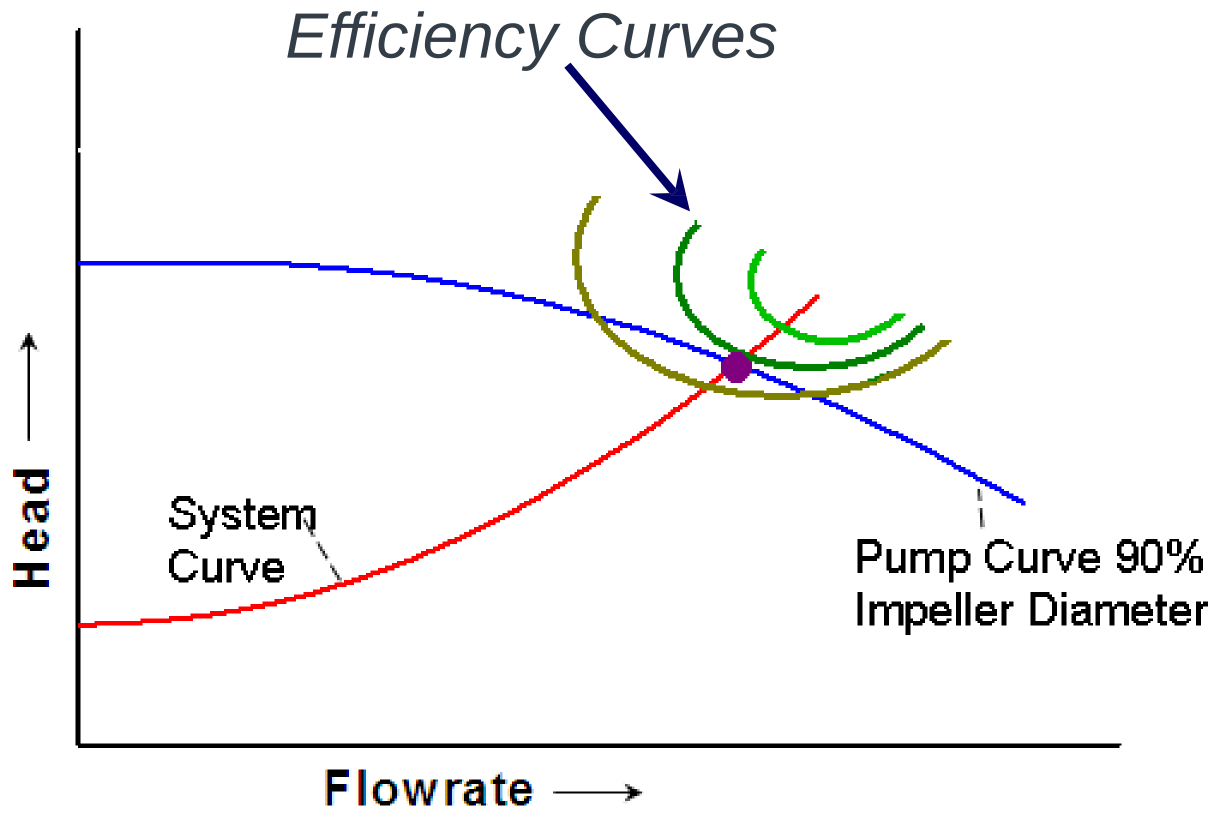
	Constant Speed Pump	Variable Speed Pump	Smart Pump
Initial Cost	$150,000	$200,000	$215,000
Installation Cost	$34,500	$47,000	$37,000
Annual KwhR (Reactive)	140,515	58,789	58,789
Total Energy Cost (P.V.)	$174,961	$73,200	$53,200
Operating Cost (P.V.)	$451,300	$338,475	$305,116
Repair/Maint. Cost (P.V.)	$56,412	$66,715	$45,652
Downtime Cost (P.V.)	$112,825	$98,615	$56,000
Environmental Cost (P.V.)	$5,614	$5,614	$5,614
Disposal Cost (P.V.)	$232	$232	$232
Scrap Value (P.V.)	($673)	($673)	($673)
Depreciation (P.V.)	($45,168)	($52,251)	($52,251)
Present Value of Cost	**$940,003**	**$776,927**	**$664,890**

- 20 year life cycle
- Annual Discount Rate 6%
- Customer Tax Rate 31%
- Straight Line Depreciation Over 7 Years

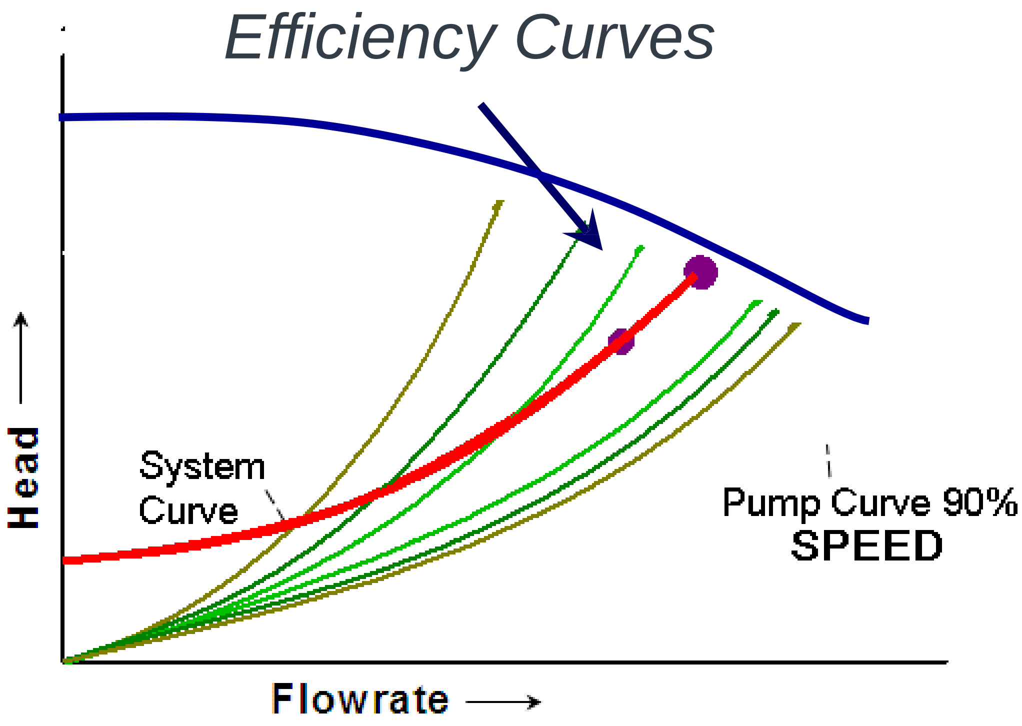
- $0.1 per kWh
- Energy cost increases 5%/year
- Non-energy inflation 4%

The above is an example to give relative cost information

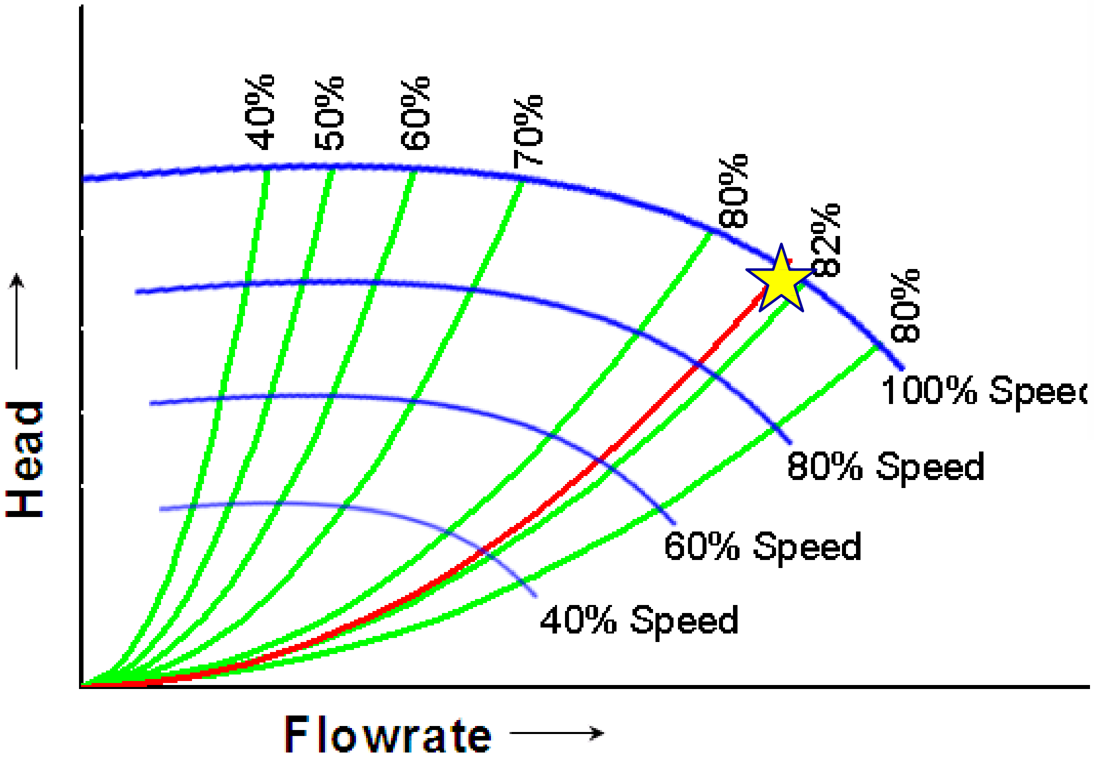
Adjusting for Impeller Diameter

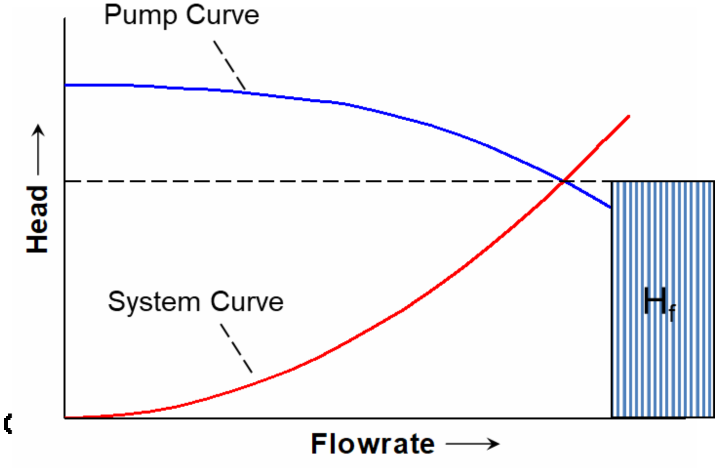


Adjusting Pump Head Curve for Different Speeds

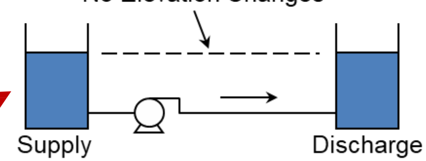


Friction-Dominated System



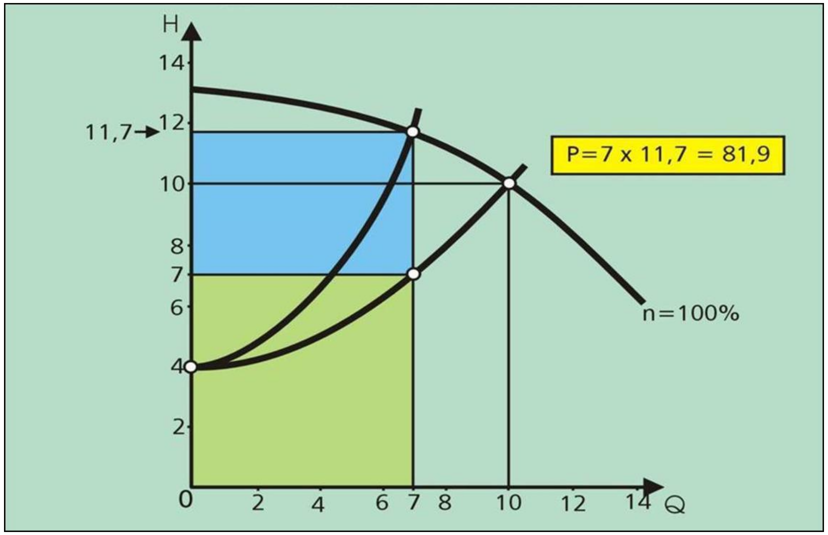


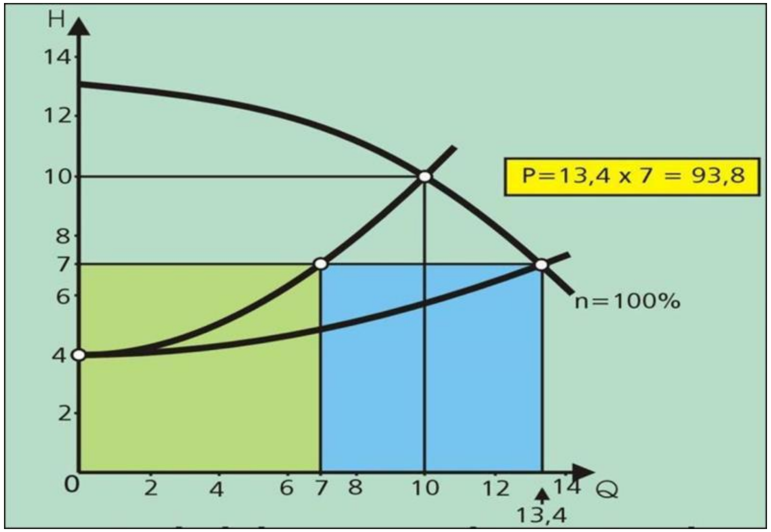
Example:



Any pump can produce flow (no elevation to overcome)

Indicators of Poor System Energy Optimization





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

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

Pump System Prescreening Spreadsheet

A = High Priority	Grey fields indicate priority data entries																														
B = Med Priority No Action	Equipment Information									Control schemes (check all that apply)						Operating Parameters (provide if readily available, otherwise indicate with check if it is acquirable)										Other symptoms		Additional Information (is acquirable?)			
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)	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
A = High Priority																															
B = Med Priority																															

Suction Specific Speed NSS Calculator

Suction Specific Speed (NSS) Calculator		
N =	3560	Pump Shaft Rotation Speed (rpm)
Q =	800	Flow Rate Capacity (m3/h, m3/min, US gpm, British gpm) at Best Efficiency Point (BEP)
NPSHr =	18	Required Net Positive Suction Head for the pump at the BEP (m, ft)
NSS =	8147.5	Suction Specific Speed

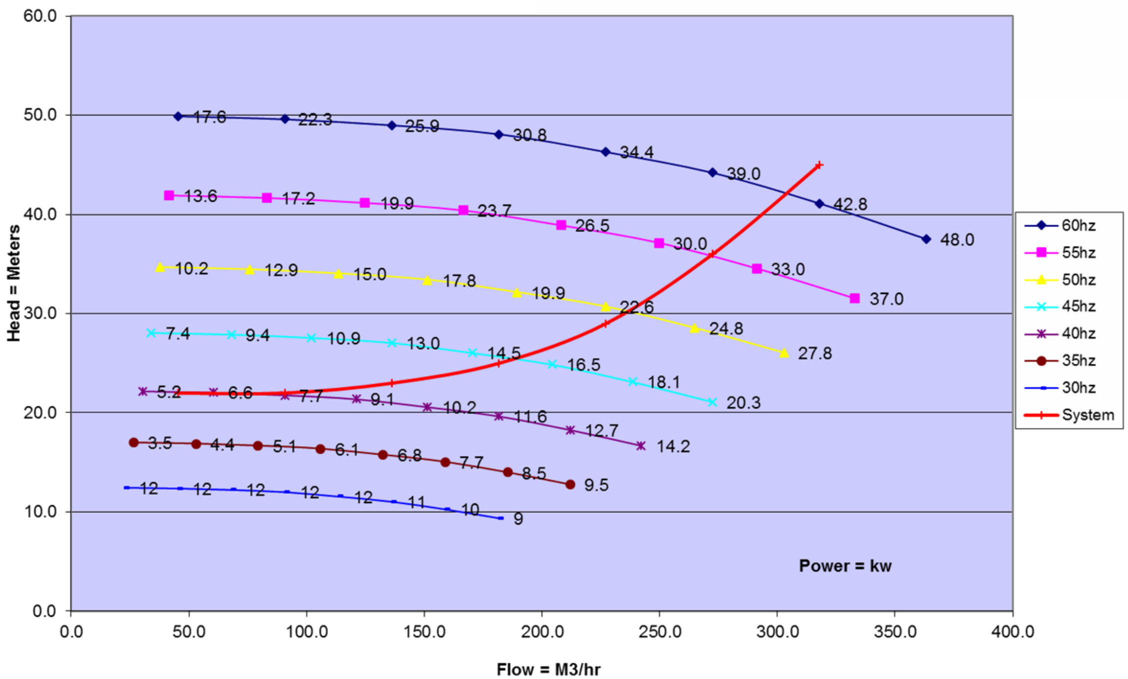
Rule of Thumb:

Nss Should be Below 8500 with US GPM, to Avoid Cavitation

Variable Speed Pumping Analyzer

1	Aurora 5X6X12 12" Trim 1750RPM
2	Flow = M3/hr
3	Head = Meters
4	Power = kw

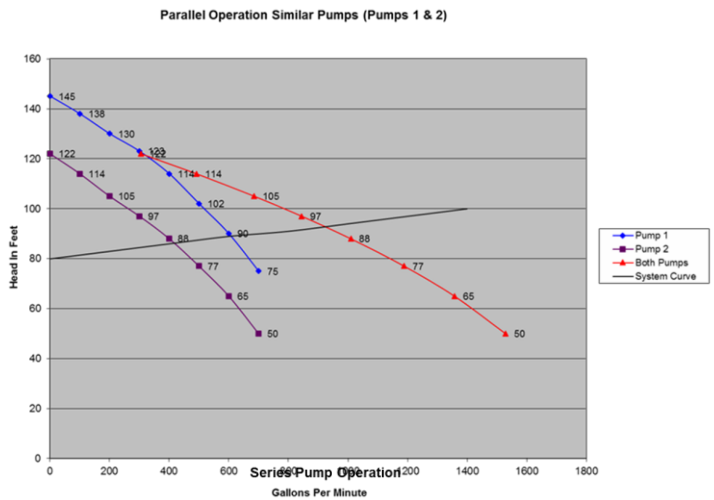
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	H1	H2	H3	H4	H5	H6	H7	H8
45.4	90.8	136.2	181.7	227.1	272.5	317.9	363.3	49.9	49.6	49.0	48.1	46.3	44.2	41.1	37.5



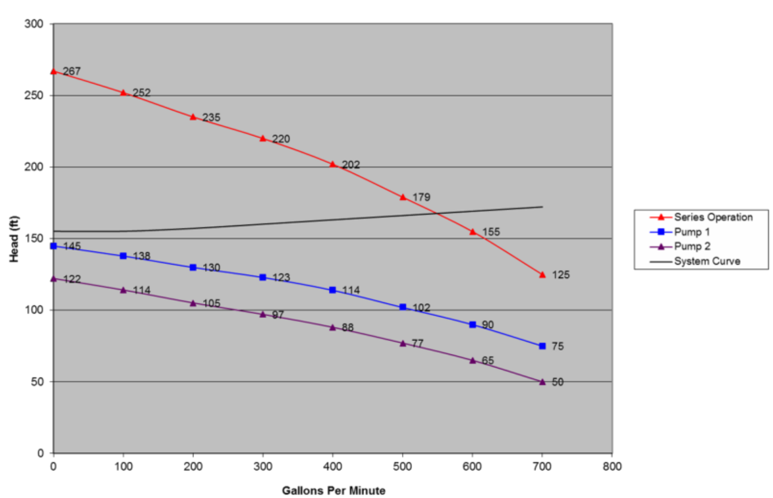
SH1	SH2	SH3	SH4	SH5	SH6	SH7	SH8
22.0	22.0	23.0	25.0	29.0	36.0	45.0	

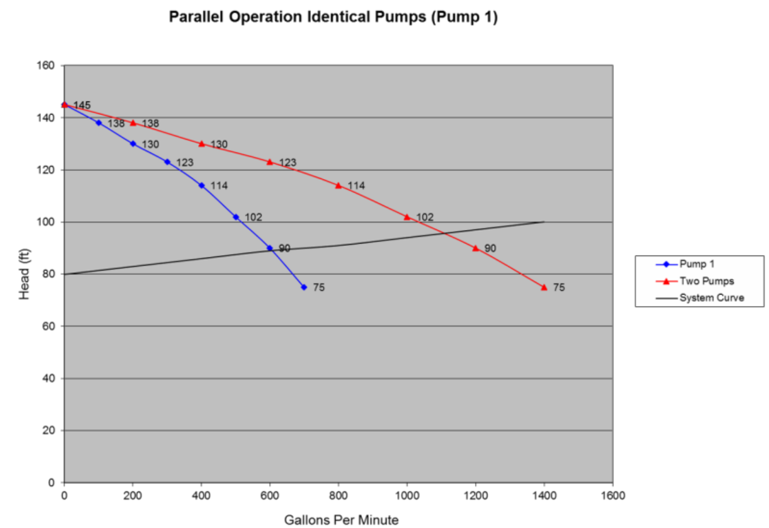
P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8
17.6	22.3	25.9	30.8	34.4	39.0	42.8	48.0

Series/Parallel Calculator



FLOW / HEAD	Q1 / H1	Q2 / H2	Q3 / H3	Q4 / H4	Q5 / H5	Q6 / H6	Q7 / H7	Q8 / H8
FLOW	0	100	200	300	400	500	600	700
HEAD PUMP 1	145	138	130	123	114	102	90	75
HEAD PUMP 2	122	114	105	97	88	77	65	50
SYS CURVE (SER)	155	155	157	160	163	166	169	172
SYS CURVE (PAR)	80	83	86	89	91	94	97	100





Darcy Friction Loss Calculator

Given Data

Flow Rate (Q)	m3/hr	8	0.00222	m3/s	
Pipe Inside Diameter (D)	mm	53.7	0.0537	m	
Kinematic Viscosity (ν)	cSt	1	1.000E-06	m2/s	
Specific Roughness (€)	m	1.50E-06			
Pipe Length (L)	m	230			

INPUTS

CALCULATED VALUES

Calculated Data

Average Velocity - V (m/s)	0.98
Reynolds Number	52689
Darcy Friction Factor	0.021
Head Loss - Pipe (m)	**4.34**

TOTAL HEAD LOSS, h_f (m) **5.06**

Calculated Head Loss in Fittings, Valves, Entrances & Exits

	K	**Qty**	**Sub Total K**
Angle Valve	5	0	0
Ball Valve, Full Port	0.05	2	0.1
Butterfly Valve	0.6	0	0
Check Valve, Swing Type	2.3	1	2.3
Elbow 45 Degrees	0.4	0	0
Elbow 90 Degrees, Long Radius	0.6	0	0
Elbow 90 Degrees, Standard	0.9	12	10.8
Flow Meter, Turbine Type	7	0	0
Foot Valve	0.9	0	0
Gate Valve	0.2	0	0
Globe Valve	10	0	0
Pipe Entrance, Inward Projected Pipe	1	0	0
Pipe Entrance, Sharp Edge	0.5	1	0.5
Pipe Exit	1	1	1
Tee, Standard, Flow Through Branch	1.8	0	0
Tee, Standard, Flow Through Run	0.6	0	0
			14.7

Head Loss - Valves & Fittings (m) **0.72**

System Energy Calculator

Required Data	Option 1	Option 2
System Condition:	Steel Pipe	Steel Pipe
	8" 600'	6" 600'
Pump Operation - Hours / Day	8	8
Pump Operation - Days / Year	365	365
Pump Flow - GPM	600	600
Pump Head - Feet	50	65
Pump Efficiency - %	71%	71%
Motor Efficiency - %	82.0%	82.0%
Energy Cost in $/KWH	$0.11	$0.11
Results		
BHP At Design Point	10.7	13.9
Wire to Water Efficiency - %	58%	58%
Annual Energy Cost	$3,117.94	$4,053.33
KW Per 1000 Gallons Pumped	0.270	0.351
Cost Per 1000 Gallons Pumped	$0.030	$0.039

PAYBACK	
Annual Savings - $$	$935.38
Annual Savings - %	23.08%
Cost of Option 1	$12,000.00
Cost of Option 2	$9,000.00
Payback - Years	3.2

Motor Yearly Energy Cost Calculator

Site Energy Cost (KW/Hour)	Site Demand Charge (KVA/Year)	Estimated Motor Usage (Hrs/Year)
$0.060	$75.00	8760

Synchronous Motor Characteristics		Induction Motor Characteristics	
Horsepower		Horsepower	
Power Factor		Power Factor	
Efficiency		Efficiency	
Kilowatts		Kilowatts	
Total KVA		Total KVA	
Yearly Energy Cost		Yearly Energy Cost	
Yearly Demand Cost		Yearly Demand Cost	

Synchronous Yearly Energy Savings Due to Efficiency	
Synchronous Yearly Energy Savings Due to Demand	

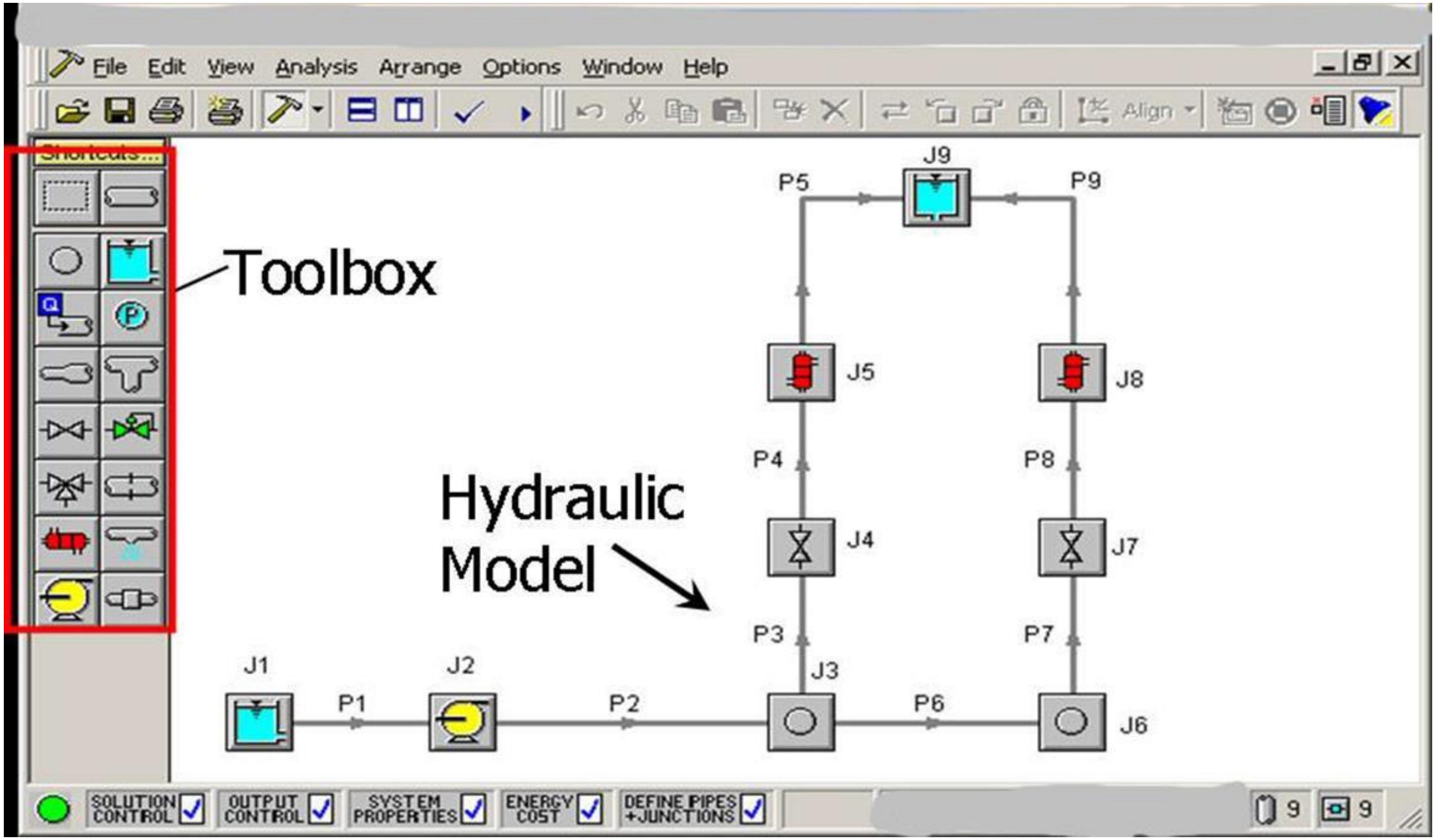
Total Yearly Energy Savings Using Synchronous Motor Technology

Total Life Cycle Energy Savings Using Synchronous Motor Technology (per motor)

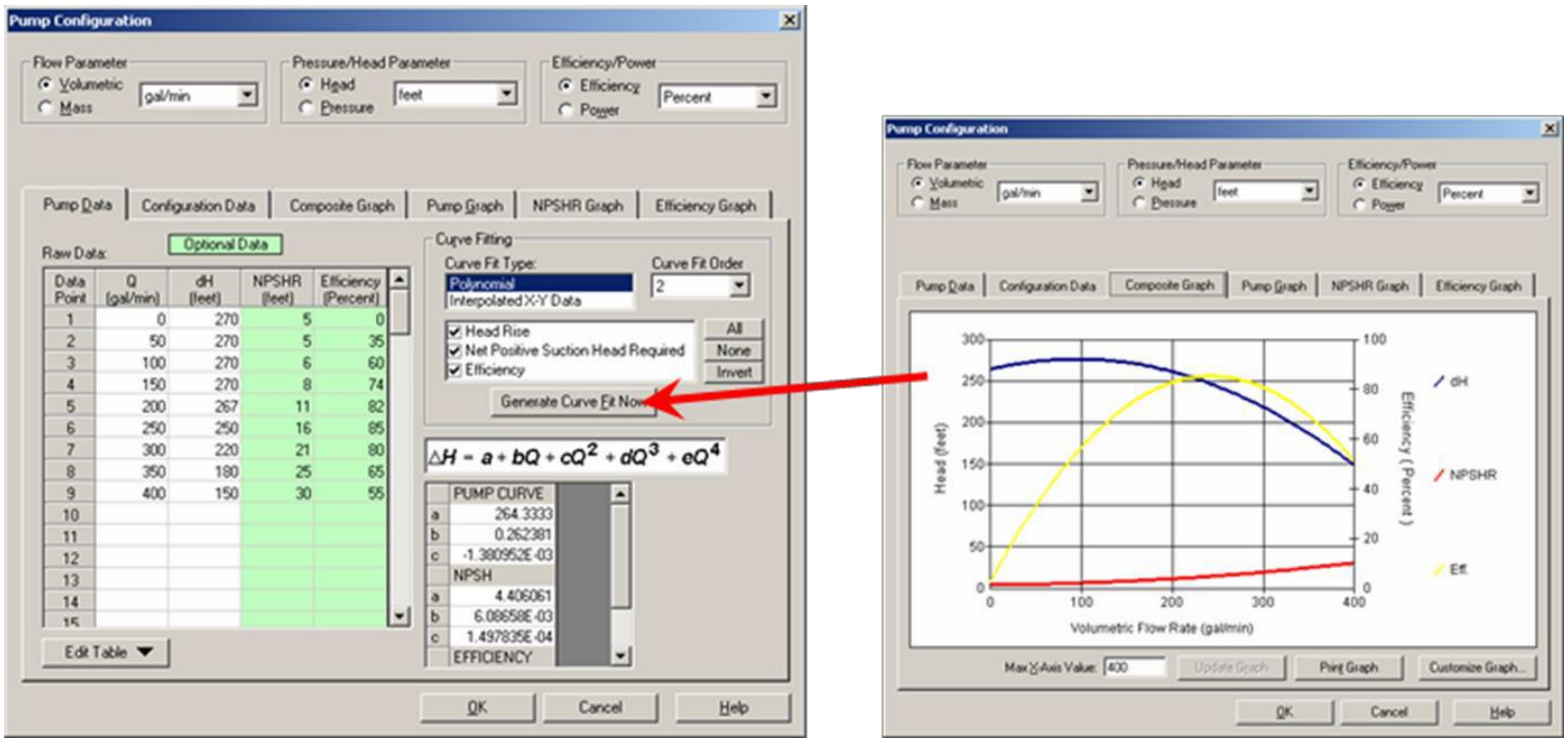
PSIM Tool

PUMP
SYSTEM
IMPROVEMENT
MODELING TOOL

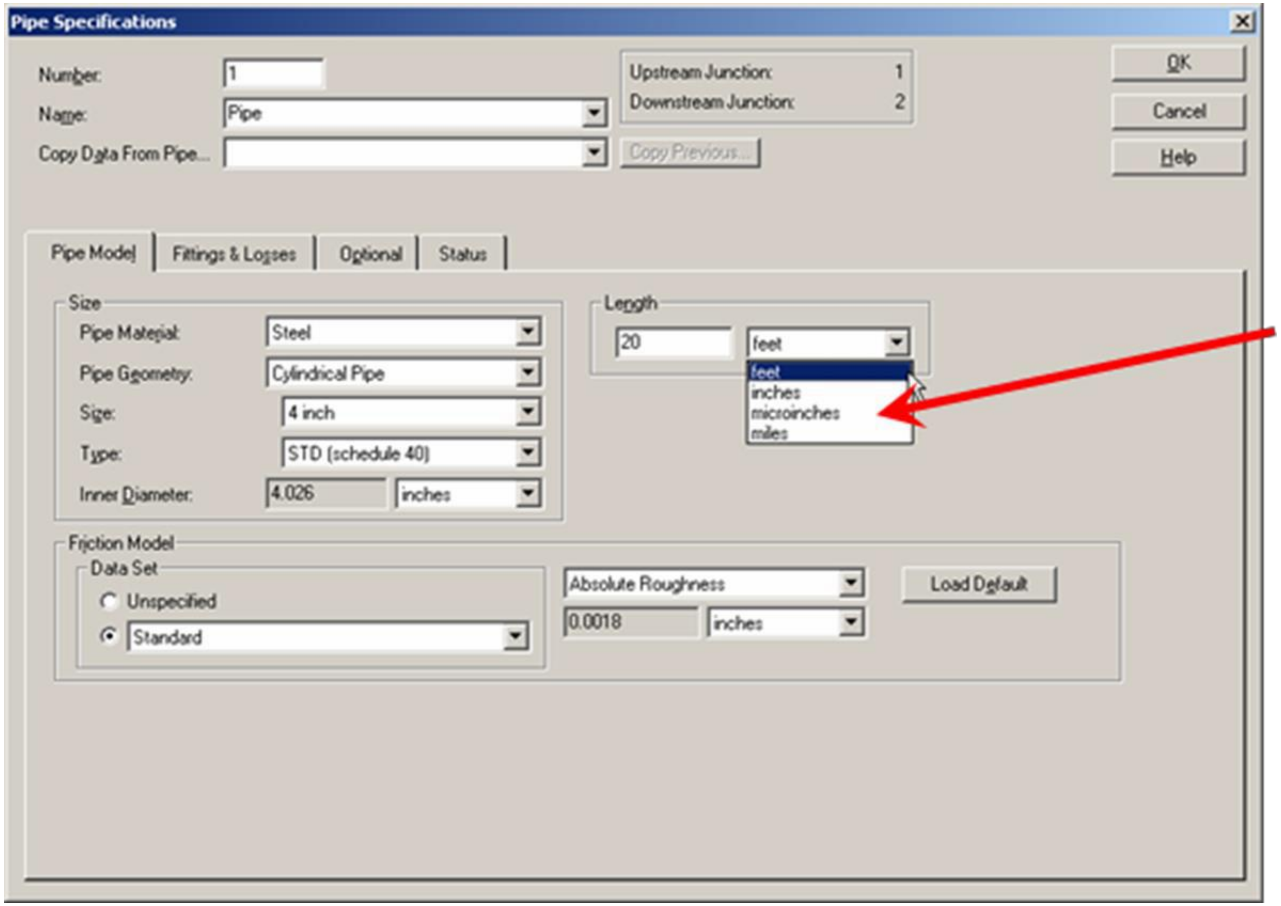
Case Study Using PSIM



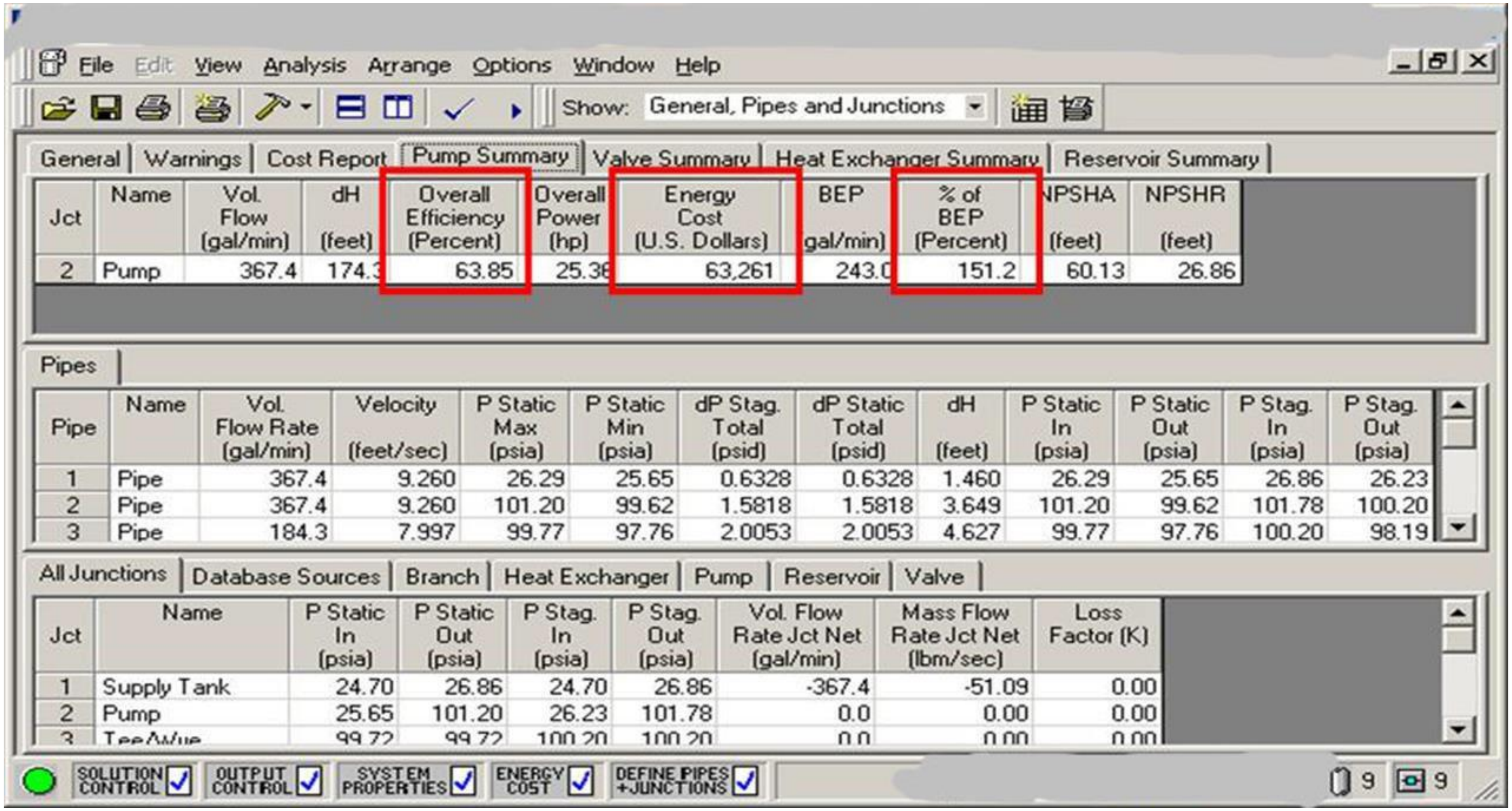
Building the Model Using PSIM



Entering the Pipe Data



System Predictions Based on Model



File Edit View Analysis Arrange Options Window Help

Show: General, Pipes and Junctions

General | Warnings | Cost Report | Pump Summary | Valve Summary | Heat Exchanger Summary | Reservoir Summary

Jct	Name	Vol. Flow (gal/min)	dH (feet)	Overall Efficiency (Percent)	Overall Power (hp)	Energy Cost (U.S. Dollars)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)	NPSHR (feet)
2	Pump	367.4	174.3	63.85	25.3	63,261	243.0	151.2	60.13	26.86

Pipes

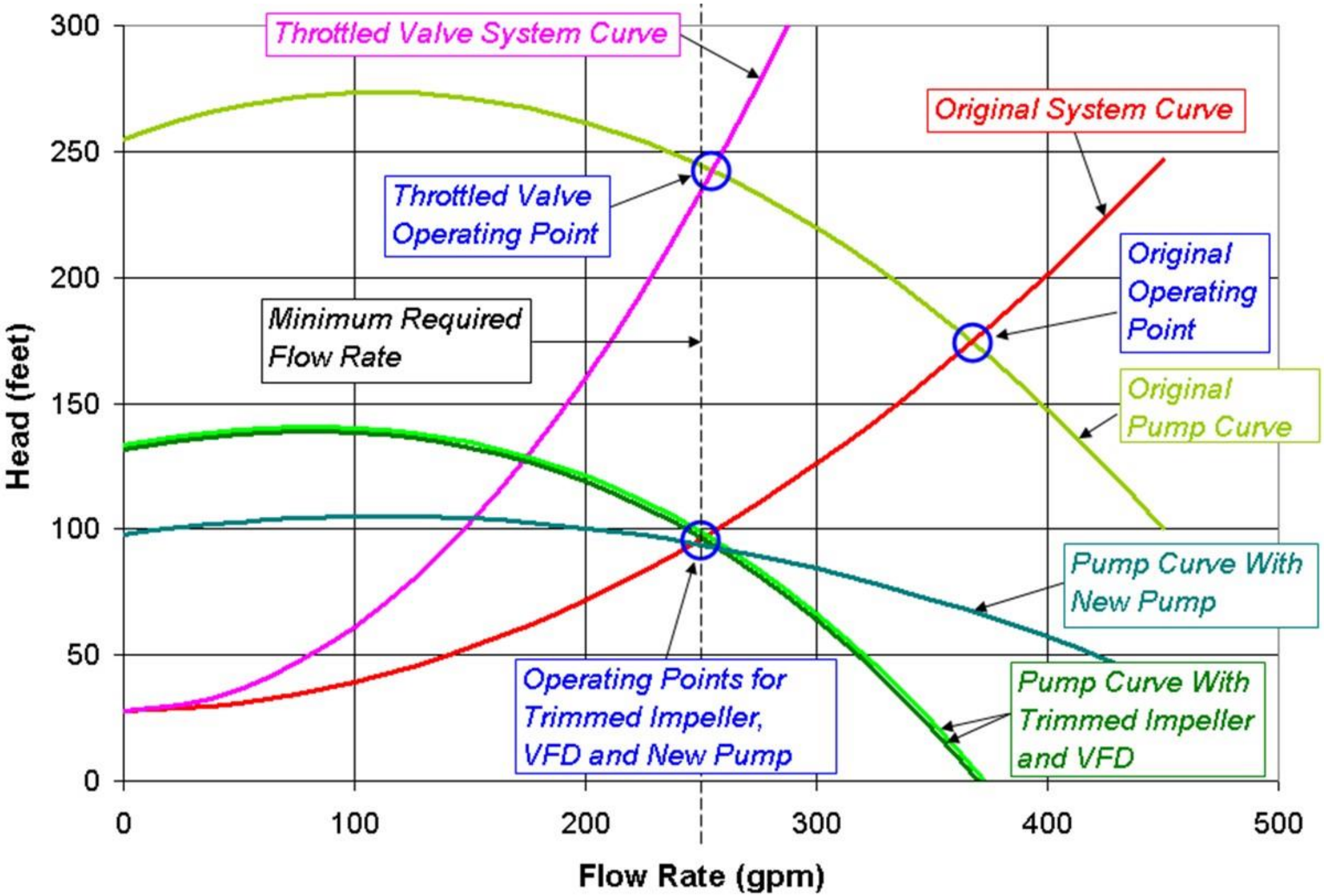
Pipe	Name	Vol. Flow Rate (gal/min)	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	dP Stag. Total (psid)	dP Static Total (psid)	dH (feet)	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)
1	Pipe	367.4	9.260	26.29	25.65	0.6328	0.6328	1.460	26.29	25.65	26.86	26.23
2	Pipe	367.4	9.260	101.20	99.62	1.5818	1.5818	3.649	101.20	99.62	101.78	100.20
3	Pipe	184.3	7.997	99.77	97.76	2.0053	2.0053	4.627	99.77	97.76	100.20	98.19

All Junctions | Database Sources | Branch | Heat Exchanger | Pump | Reservoir | Valve

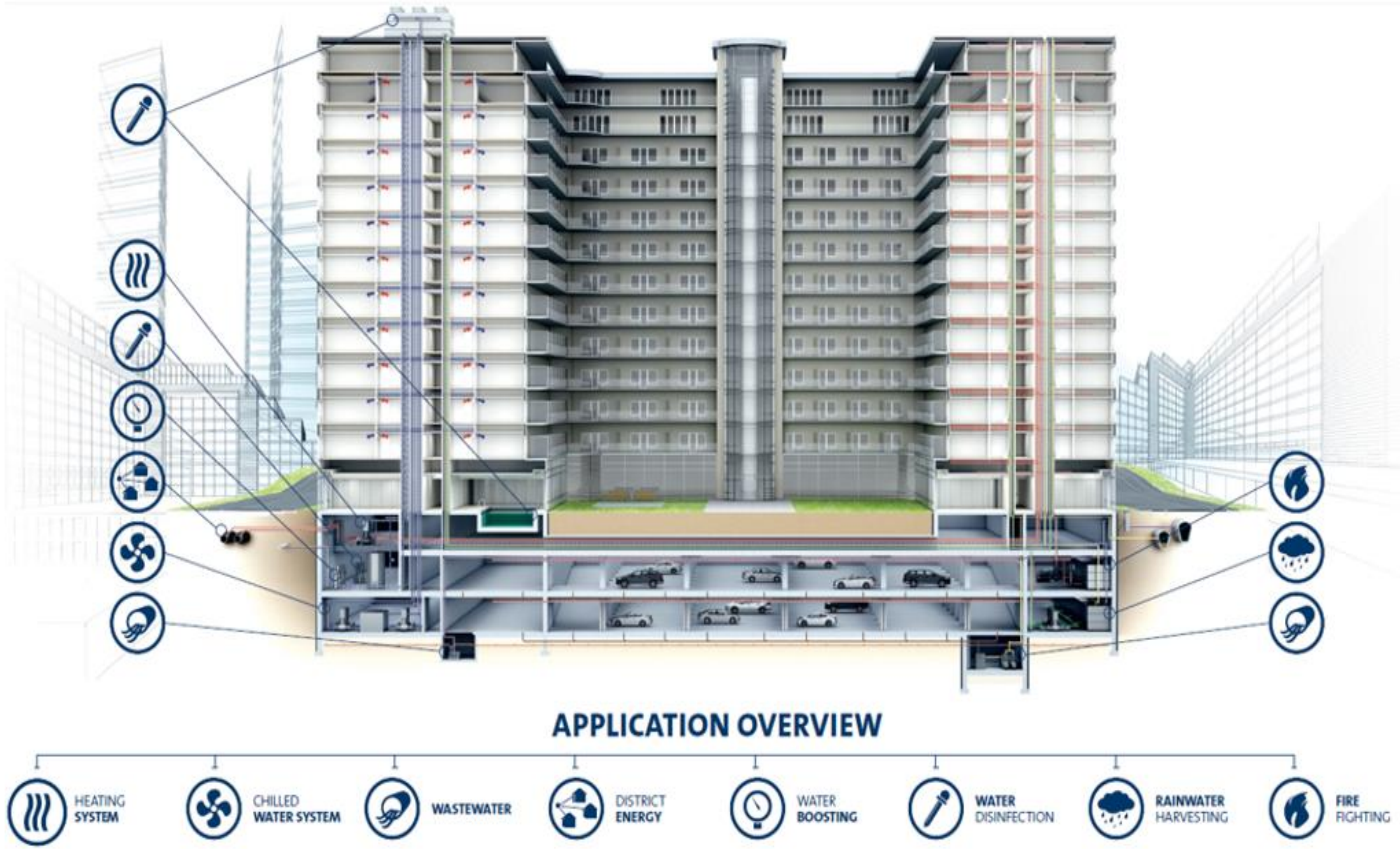
Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Jct Net (gal/min)	Mass Flow Rate Jct Net (lbm/sec)	Loss Factor (K)
1	Supply Tank	24.70	26.86	24.70	26.86	-367.4	-51.09	0.00
2	Pump	25.65	101.20	26.23	101.78	0.0	0.00	0.00
3	Tee/Wye	99.72	99.72	100.20	100.20	0.0	0.00	0.00

SOLUTION CONTROL | OUTPUT CONTROL | SYSTEM PROPERTIES | ENERGY COST | DEFINE PIPES +JUNCTIONS

Graphically-Illustrated Options



Hot Water World



RESOURCE: http://www.grundfos.com/content/dam/Global%20Site/campaigns/Grundfos-isolutions/5/download-pdfs/1013669_GFS_CBS_Poster_A0_841x1189_ART10_CM.pdf

Piping and Pumping Systems Can Be Very Complex

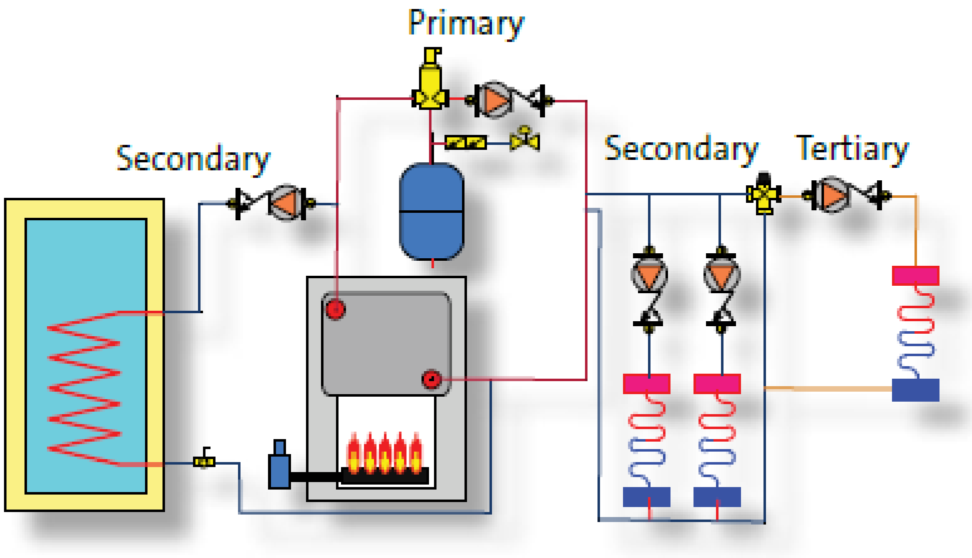
Pump System Types in Commercial Buildings

1. Temperature Control
   a) Heating system applications
   b) Cooling system applications

2. Plumbing systems
   a) Domestic water applications
   b) Drainage applications

Heating Applications

- Primary, secondary and tertiary loops
- Mixing loops
- Steam
  - Boiler feed
  - Condensate return
  - Etc.
- Geothermal
- Solar
- District heating

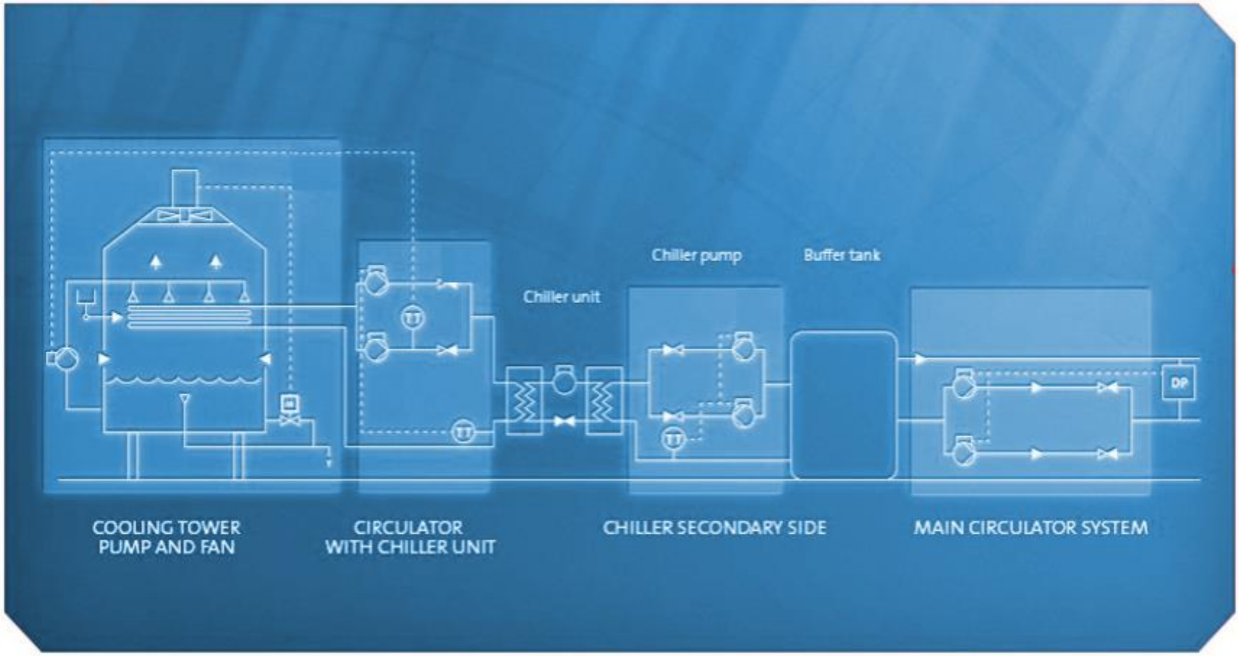


Heating Optimization Targets

Primary, Secondary, and Tertiary loops	X
Mixing loops	
Steam:	
Boiler Feed	X
Condensate return	
Collection tank pumps	
Water treatment pumps	
Deaerator tank recycle pumps	
Economizer pumps	X
Deaerator vacuum pumps (vacuum deaerator tanks only)	
Geothermal	
Solar	
District heating	X

Cooling Applications

- Primary, Secondary, and Tertiary loops
- Condenser water
- Thermal energy storage
- Cooler tower
- Geothermal
- District cooling



Cooling Optimization Targets

Primary, Secondary, and Tertiary loops	X
Condenser water	X
Cooling tower	X
Thermal energy storage	
Geothermal	
District cooling	X

Domestic Water Applications

- Booster system
  - With break tank
  - With connection to water main
  - With roof tank
- Water transfer to roof tank
- Hot water recirculation
- Landscaping
- Swimming pool

Domestic Water Optimization Targets

Booster system:	
With Hydro-pneumatic tank	X
With connection to water main	X
With roof tank	
Water transfer to roof tank	
Hot water recirculation	X
Landscaping	X
Swimming pool	

Drainage Applications

- Storm drainage
- Drainage from facility rooms
- Emptying of pools and tanks
- Laundry
- Effluent/sewage
- Elevator sump
- Parking garages

Drainage Optimization Targets

Storm drainage	X
Parking garages	X
Drainage from facility rooms	
Laundry	
Emptying of pools and tanks	
Effluent/sewage	X
Elevator sump	

Example: Domestic Water Pressure Booster Optimization

Domestic Pressure Boosting Example – Specification (Open System)

Constant pressure system – 50 psi

Multi-story building

Duty point – 400 gpm at 300 feet

Second flow point – 300 gpm

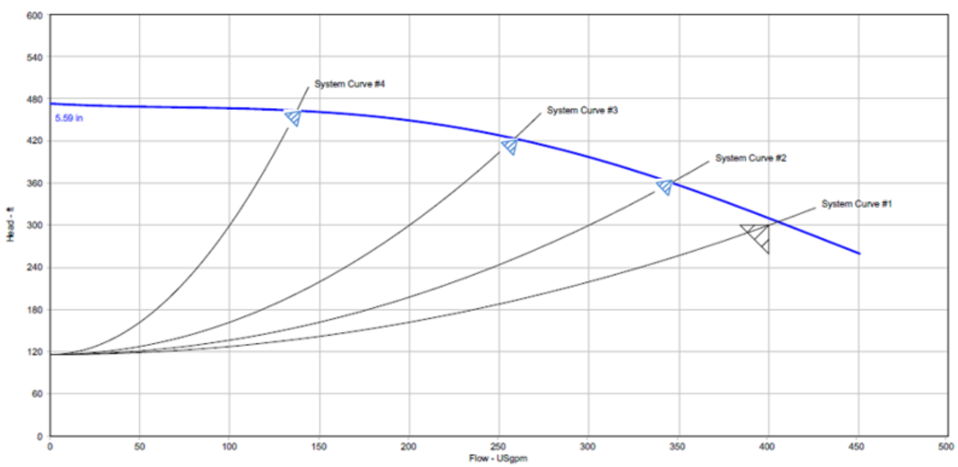
Third flow point – 200 gpm

Fourth flow point – 100 gpm

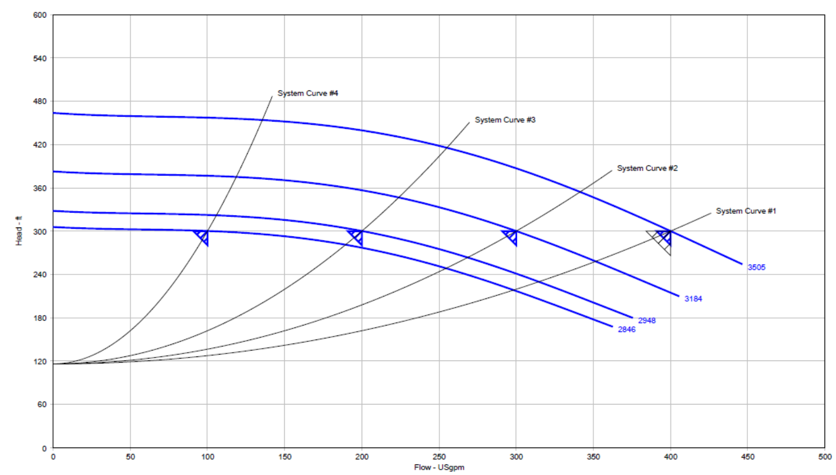
Load profile – next slides

50 psi municipal water supply

Curve Comparison



Fixed Speed Pump



Variable Speed Pump

Annual Power Consumption

Fixed Speed Pump

Expected pump life: 1 years	Load Profile #1	Load Profile #2	Load Profile #3	Load Profile #4	Load Profile #5	Total
Flow: (USgpm)	400.0	300.0	200.0	100.0	-	-
Operation: (hours per year)	250	500	1,000	2,000	-	3,750
Energy cost, present value (per kWh)	0.1000	0.1000	0.1000	0.1000	-	-
Speed, rated (rpm)	3540	3540	3540	3540	-	-
Head (ft)	310.0	396.9	449.1	466.4	-	-
Efficiency (%)	75.03	77.97	68.33	43.97	-	-
Rated power (based on duty point) (hp)	41.73	38.56	33.18	26.78	-	-
Motor efficiency (%)	93.00	94.00	93.00	92.00		-
Drive/gear efficiency (%)	100.00	100.00	100.00	100.00		-
System curve	System Curve #1	System Curve #2	System Curve #3	System Curve #4	-	-
Energy, total (kWh)	8,364.2	15,292.9	26,607.6	43,410.6	-	93,675.5
Energy cost, per year	836.42	1,529.29	2,660.76	4,341.06	-	9,367.55
Energy cost, total present value	812.75	1,486.01	2,585.46	4,218.20	-	9,102.43

Variable Speed Pump

Expected pump life: 1 years	Load Profile #1	Load Profile #2	Load Profile #3	Load Profile #4	Load Profile #5	Total
Flow: (USgpm)	400.0	300.0	200.0	100.0	-	-
Operation: (hours per year)	250	500	1,000	2,000	-	3,750
Energy cost, present value (per kWh)	0.1000	0.1000	0.1000	0.1000	-	-
Speed, rated (rpm)	3505	3184	2948	2846	-	-
Head (ft)	300.0	300.0	300.0	300.0	-	-
Efficiency (%)	74.65	78.36	73.79	51.48	-	-
Rated power (based on duty point) (hp)	40.59	29.00	20.54	14.72	-	-
Motor efficiency (%)	93.00	92.00	83.00	70.00		-
Drive/gear efficiency (%)	97.00	96.00	95.00	91.00		-
System curve	System Curve #1	System Curve #2	System Curve #3	System Curve #4	-	-
Energy, total (kWh)	8,388.3	12,244.3	19,425.8	34,466.7	-	74,525.1
Energy cost, per year	838.83	1,224.43	1,942.58	3,446.67	-	7,452.51
Energy cost, total present value	815.09	1,189.77	1,887.60	3,349.13	-	7,241.59

Annual power consumption

Fixed Speed Pump

Expected pump life: 1 years	Load Profile #1	Load Profile #2	Load Profile #3	Load Profile #4	Load Profile #5	Total
Flow: (USgpm)	400.0	300.0	200.0	100.0	-	-
Operation: (hours per year)	250	500	1,000	2,000	-	3,750
Energy cost, present value (per kWh)	0.1000	0.1000	0.1000	0.1000	-	-
Speed, rated (rpm)	3540	3540	3540	[illegible]	-	-
Head (ft)	310.0	[illegible]	449.1	466.4	-	-
Efficiency (%)	[illegible]	[illegible]	[illegible]	[illegible]	-	-
Rated power (based on duty point) (hp)	[illegible]	[illegible]	33.18	26.78	-	-
Motor efficiency (%)	93.00	94.00	93.00	92.00	-	-
Drive/gear efficiency (%)	100.00	100.00	100.00	100.00	-	-
System curve	System Curve #1	System Curve #2	System Curve #3	System Curve #4	-	-
Energy, total (kWh)	8,364.2	15,292.9	26,607.6	43,410.6	-	[illegible]
Energy cost, per year	836.42	1,529.29	2,660.76	4,341.06	-	9,367.55
Energy cost, total present value	812.75	1,486.01	2,585.46	4,218.20	-	9,102.43

Variable Speed Pump

Expected pump life: 1 years	Load Profile #1	Load Profile #2	Load Profile #3	Load Profile #4	Load Profile #5	Total
Flow: (USgpm)	400.0	300.0	200.0	100.0	-	-
Operation: (hours per year)	250	500	1,000	2,000	-	3,750
Energy cost, present value (per kWh)	0.1000	0.1000	0.1000	0.1000	-	-
Speed, rated (rpm)	3505	[illegible]	2948	2846	-	-
Head (ft)	300.0	300.0	300.0	300.0	-	-
Efficiency (%)	[illegible]	[illegible]	[illegible]	[illegible]	-	-
Rated power (based on duty point) (hp)	[illegible]	29.00	20.54	14.72	-	-
Motor efficiency (%)	93.00	92.00	83.00	70.00	-	-
Drive/gear efficiency (%)	97.00	96.00	95.00	91.00	-	-
System curve	System Curve #1	System Curve #2	System Curve #3	System Curve #4	-	-
Energy, total (kWh)	8,388.3	12,244.3	19,425.8	34,466.7	-	[illegible]
Energy cost, per year	838.83	1,224.43	1,942.58	3,446.67	-	7,452.51
Energy cost, total present value	815.09	1,189.77	1,887.60	3,349.13	-	7,241.59

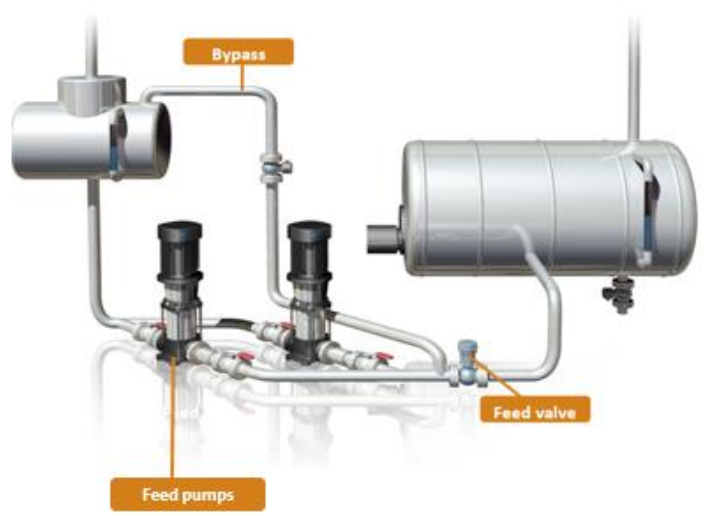
Advantages of Variable Speed Pumps in Pressure Booster Applications

- **Saves at least 30% energy usage**
- Eliminates need for throttling Valves & their energy Loss
- Reduces size of Hydro-pneumatic tank
- Steadier pressures as usage varies – Improved control
- Matches actual flow rate to system requirements
- Reduced wear on pumps/motors- No across line start
- Elimination of water hammer

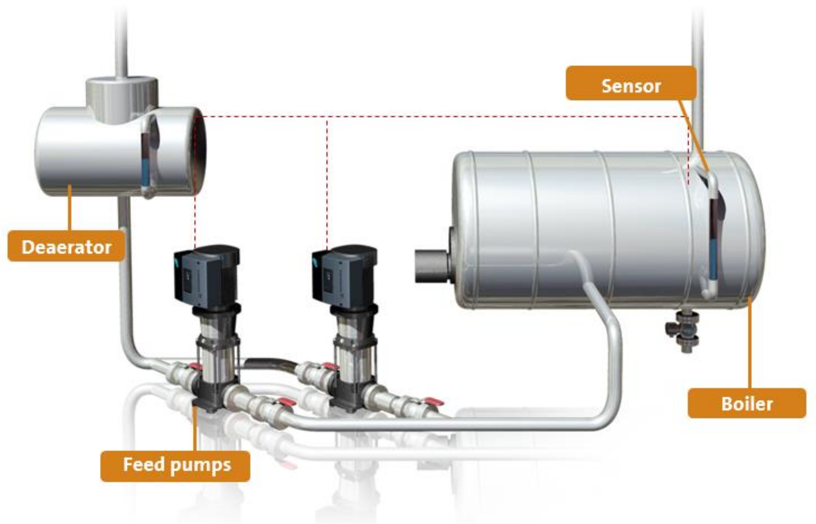
Example: Boiler Feed Pump Optimization

http://www.bls.gov/ooh/production/stationary-engineers-and-boiler-operators.htm#tab-4

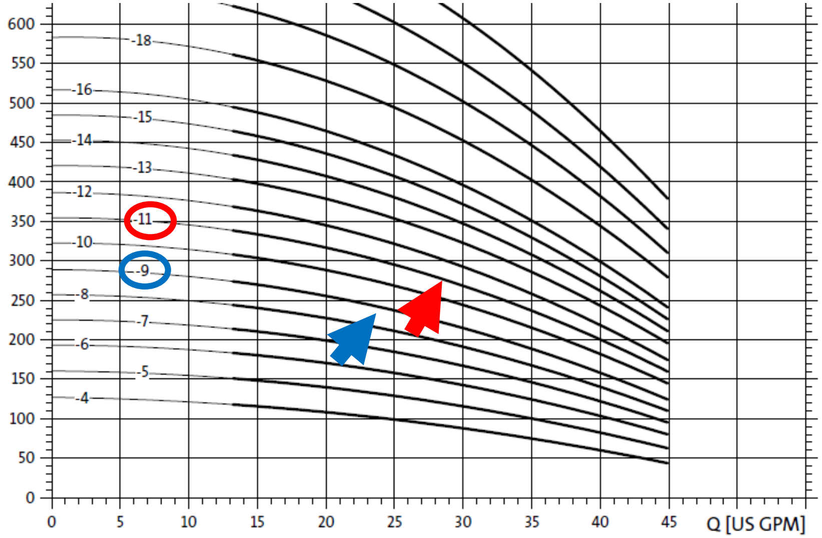
Fixed speed pump with feed valve and with bypass line



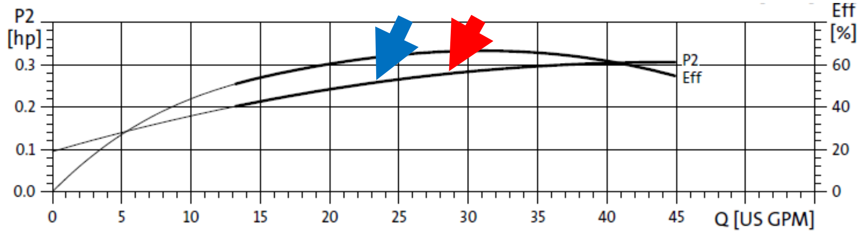
Variable speed pumps less feed valve and less bypass line



Fixed Speed Pump vs Variable Speed Pump



Performance Curve



Power

Summary of Duty Point Performance Characteristics

Pump #	Speed Type	Boiler Maximum Horsepower	Use Feed Valve?	Use Bypass Line?	Flow in gpm	Head in feet	Pump Size Inches	Number of Stages	BHP at Duty Point
1	Fixed	250	Yes	Yes	28	272	**1.25 x1.25**	11	3.0
2	Variable	250	No	No	23	237	**1.25 x1.25**	9	2.3

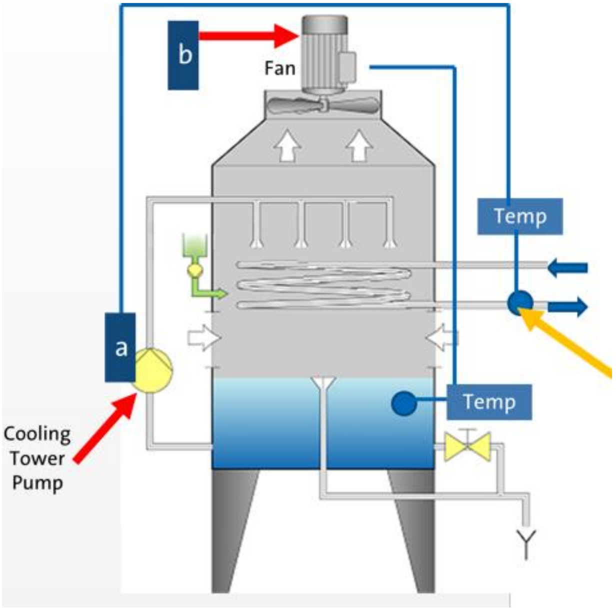
This data shows the potential for power savings at one duty point. But what about at reduced rates of steam production and reduced flow rates? The percentage of savings can be even greater than shown here. And the savings demonstrated in this example can be extended to larger boiler feed systems.

Advantages of Variable Speed Pumps in Boiler Feed Applications

- Even steam production
- Faster reaction with changed speed
- Smaller loss of water
- Fewer stages – lower initial cost
- Eliminate feed valve expense, maintenance, and head loss
- Eliminate bypass line expense and wasted flow recirculation
- Smaller HP motor
- Reduced water treatment costs
- ***Reduced energy consumption and costs***

- The downside to this variable speed system is that it requires precise commissioning and start-up, and requires highly qualified technicians.

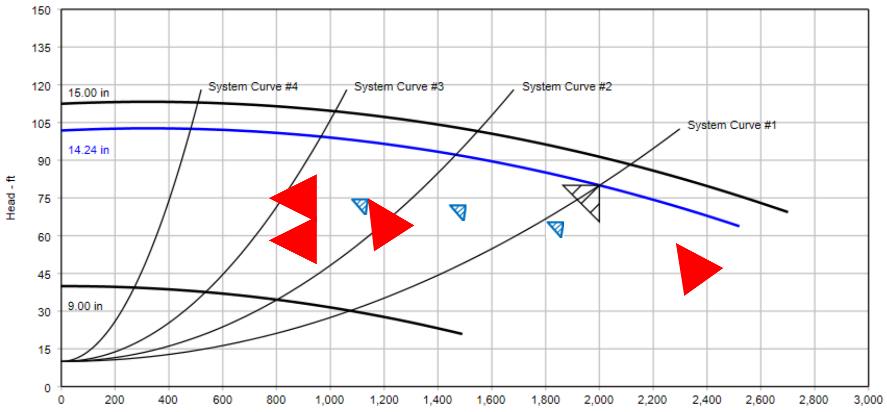
Example: Cooling Tower Pump Optimization



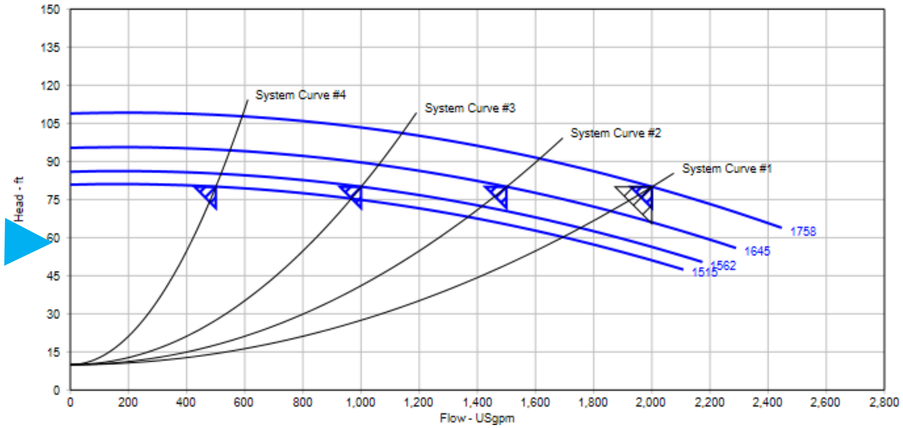
Cooling Tower Example - Specification

- Duty point = 2000 gpm at 80 feet of head
- Second flow rate point = 1500 gpm
- Third flow rate point = 1000 gpm
- Fourth flow rate point = 500 gpm
- Pump type – Horizontal split case

Curve Comparison



Fixed Speed Pump



Variable Speed Pump

(gpm X Feet of Head) ÷ Pump Efficiency X 3960)

Fixed = (500 X 103) ÷ (.86 X 3960) = 15.1 BHP

Variable = (500 X 103) ÷ (.85 X 3960) = 11.9 BHP

Building Loads

Commercial buildings use chilled water systems for cooling, and hot water systems for heating and domestic water for consumption

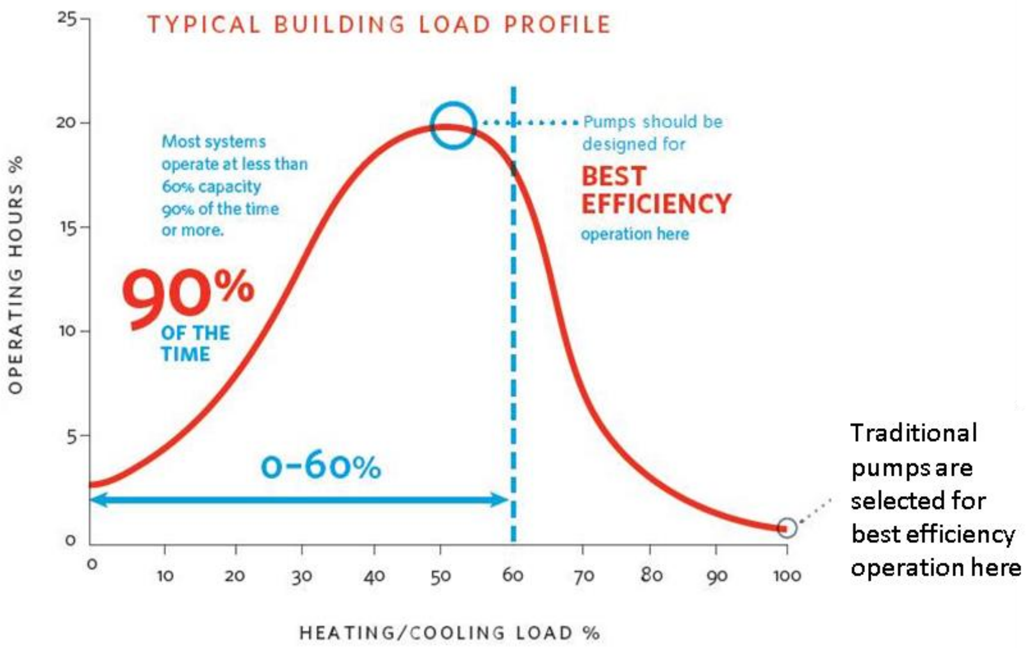
These systems operate at less than full load or part-load the vast majority of the time.

The emphasis on meeting design day heating and cooling loads results in oversized pumps.

A systems approach will typically yield a more efficient, more reliable and quiteter hydronic system.

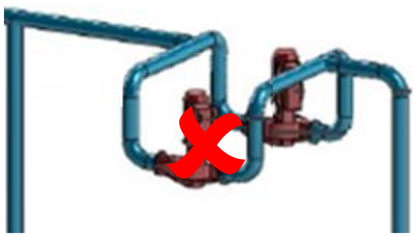
Building Load Profile

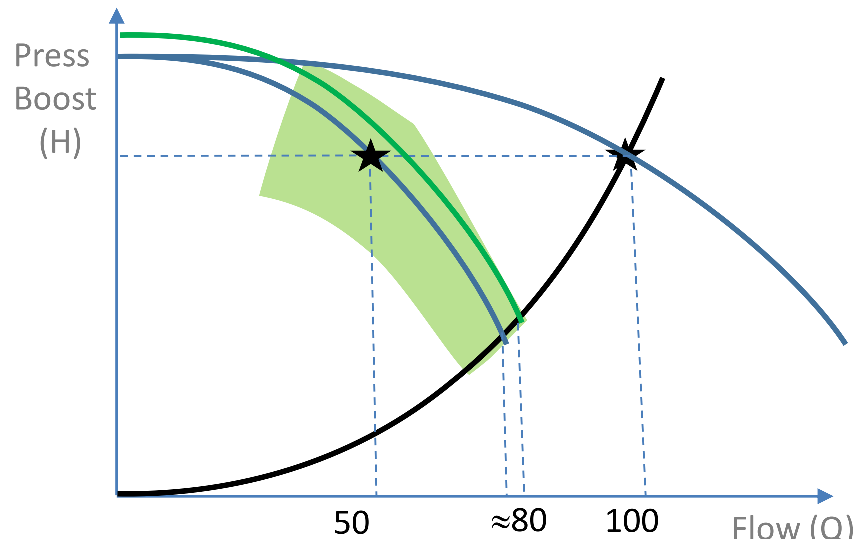
Most systems operate at less than 60% capacity, 90% of the time or more.



Standby versus Redundancy

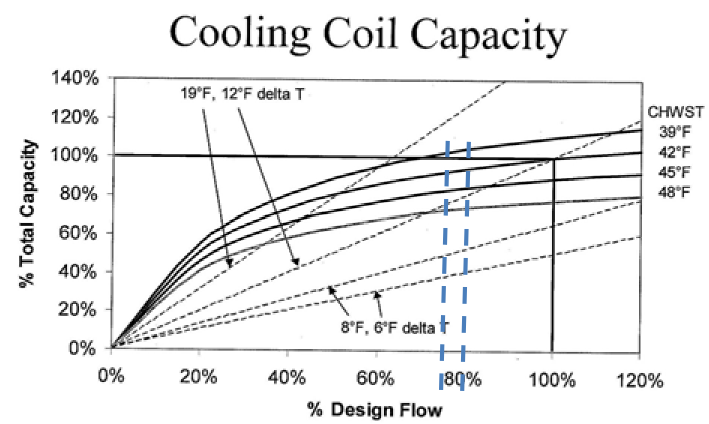
Redundancy





Percent of Design Point heat

	80% Flow	85% Flow
45°F	85	87
42°F	95	97
41°F	98	100
40°F	101	103
39°F	104	107



Not All Projects Require Complete Pump Replacement

Constant Speed Pumps Retrofit
What is Involved?

- Retain casing
- Install a variable speed rotating assembly (new motor/drive/impeller, adapter, flush line and seal)
- No piping changes, no new insulation and no pressure testing required!
- Has to be done by a professional

Equipment to be Covered

- Source Equipment
  - Boilers
  - Chillers
- Cooling Towers/Economizer
- Expansion Tanks
- Air Separators
- Heat Emitters (Fan coils, AHU)
- Control Valves
- Balance Valves & Automatic Flow Limiters

Types of Boilers

Gas or oil fired hydronic boilers

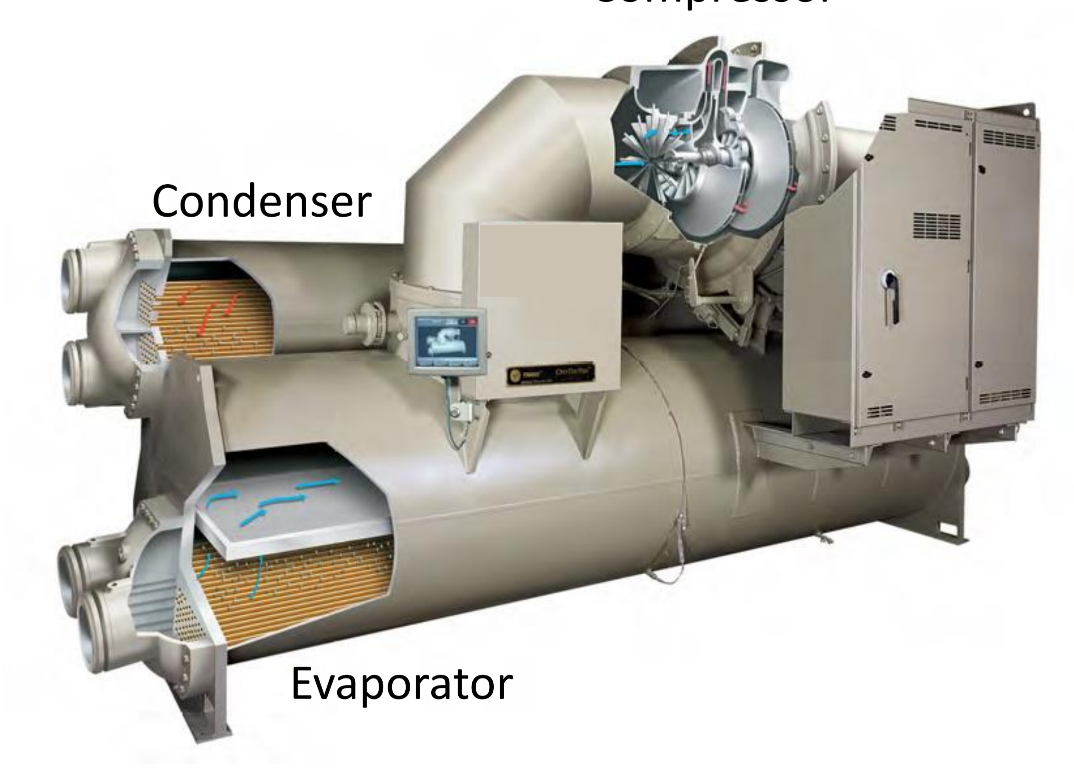
- Non-condensing: Minimum 130°F return temp
  - Cast iron
  - Copper tube
- Condensing: Low temp high efficiency boilers
  - Stainless Steel
  - Aluminum

Other Sources of Heat

- Electric boilers
- Hydronic heat pumps

Types of Chillers

- Reciprocating
- Rotary screw
- Centrifugal (shown)
- Absorption



Where is What Used?

Most common

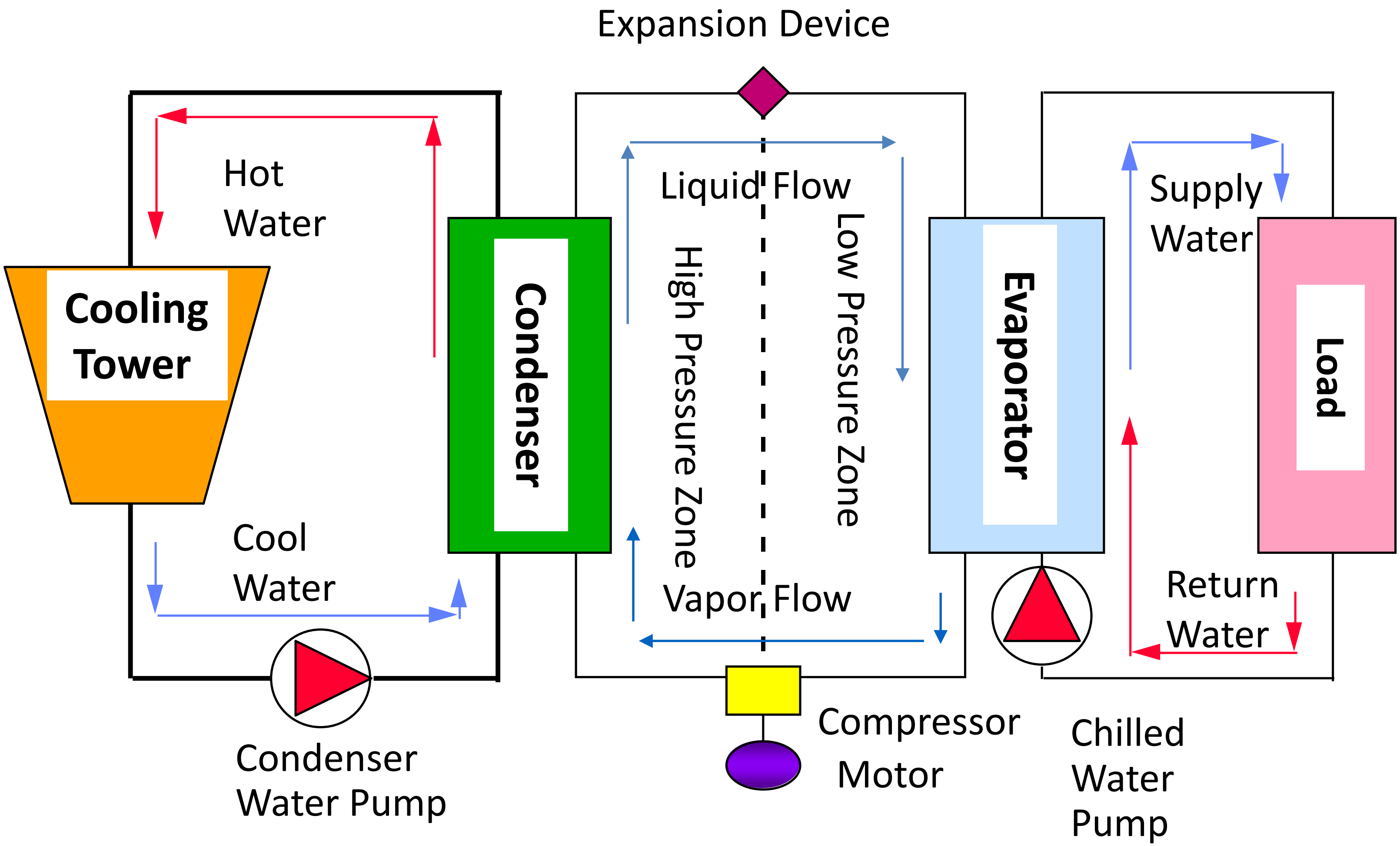
- Large chilled water plants - Centrifugal
- Mid-range size application - Rotary Screw

Less common

- Smaller size application - Reciprocating
- Inexpensive source of steam or heat - Absorption

Combinations of the above

Refrigeration Cycle



Condenser Head Pressure Control

With centrifugal chillers a minimum supply water temperature is needed to:

- Maintain optimum efficiency
- Maintain a minimum pressure differential between condenser and evaporator
- Prevent pressure imbalance

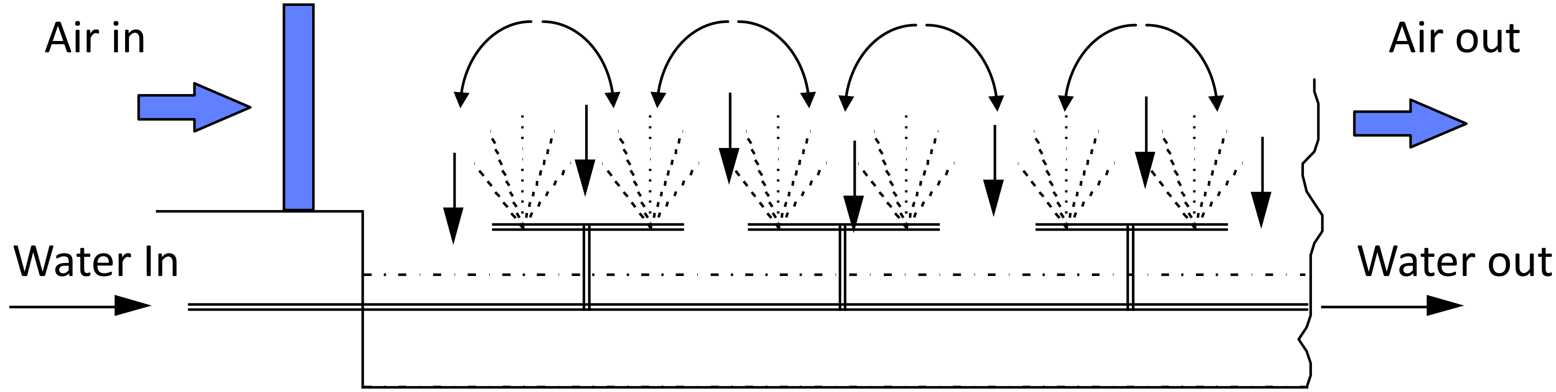
Hermetic Compressor Guidelines

- Condenser water temperature > 75 °F.
- Establish 75 °F within 15 minutes.
- N/O condenser water throttling valve.
- Constant condenser water flow.
- Water temperature control through fan modulation, or other methods

Open Compressor Guidelines

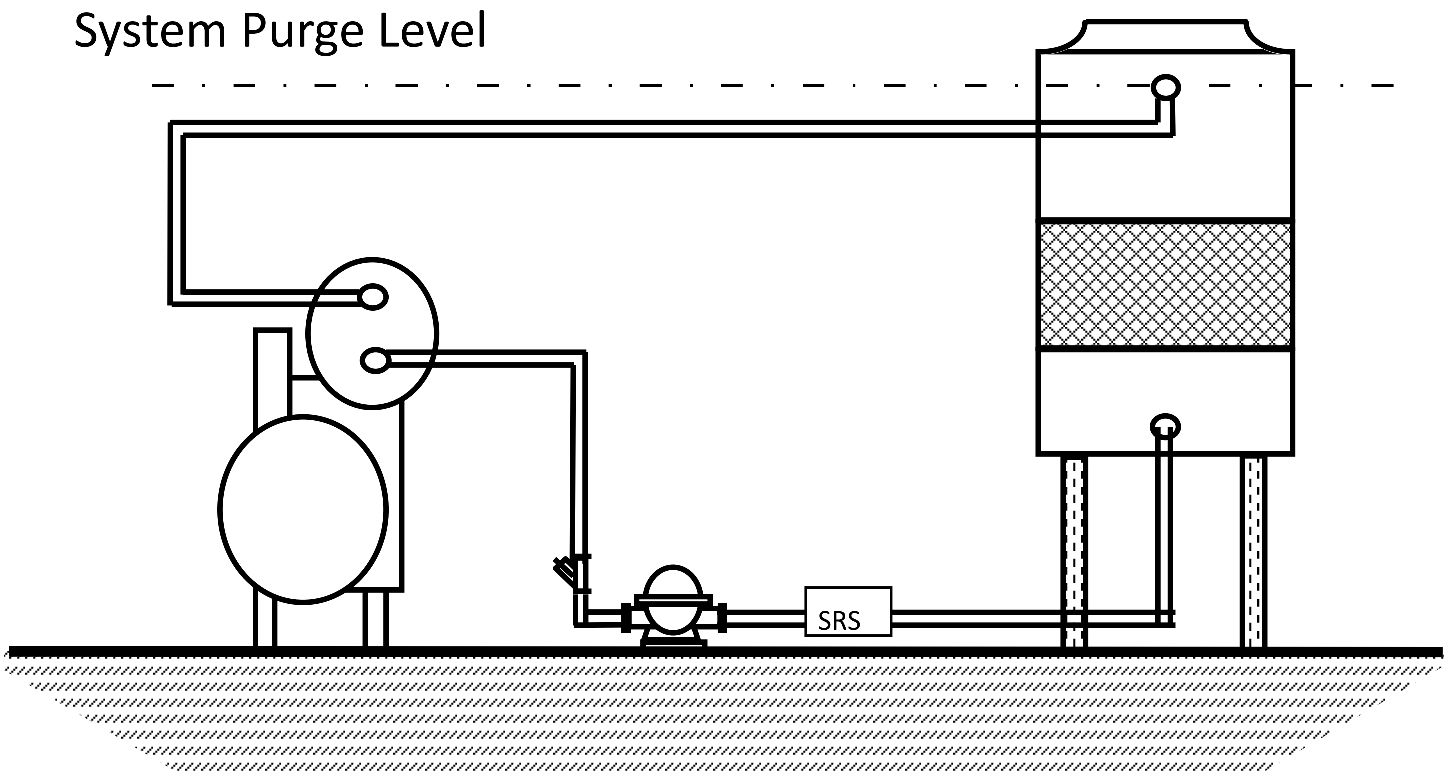
- Condenser water temperature > 55 °F.
- N/O condenser water throttling valve.
- Constant condenser water flow.
- Water temperature control through fan modulation, or other methods

Cooling Towers – Evaporative Cooler

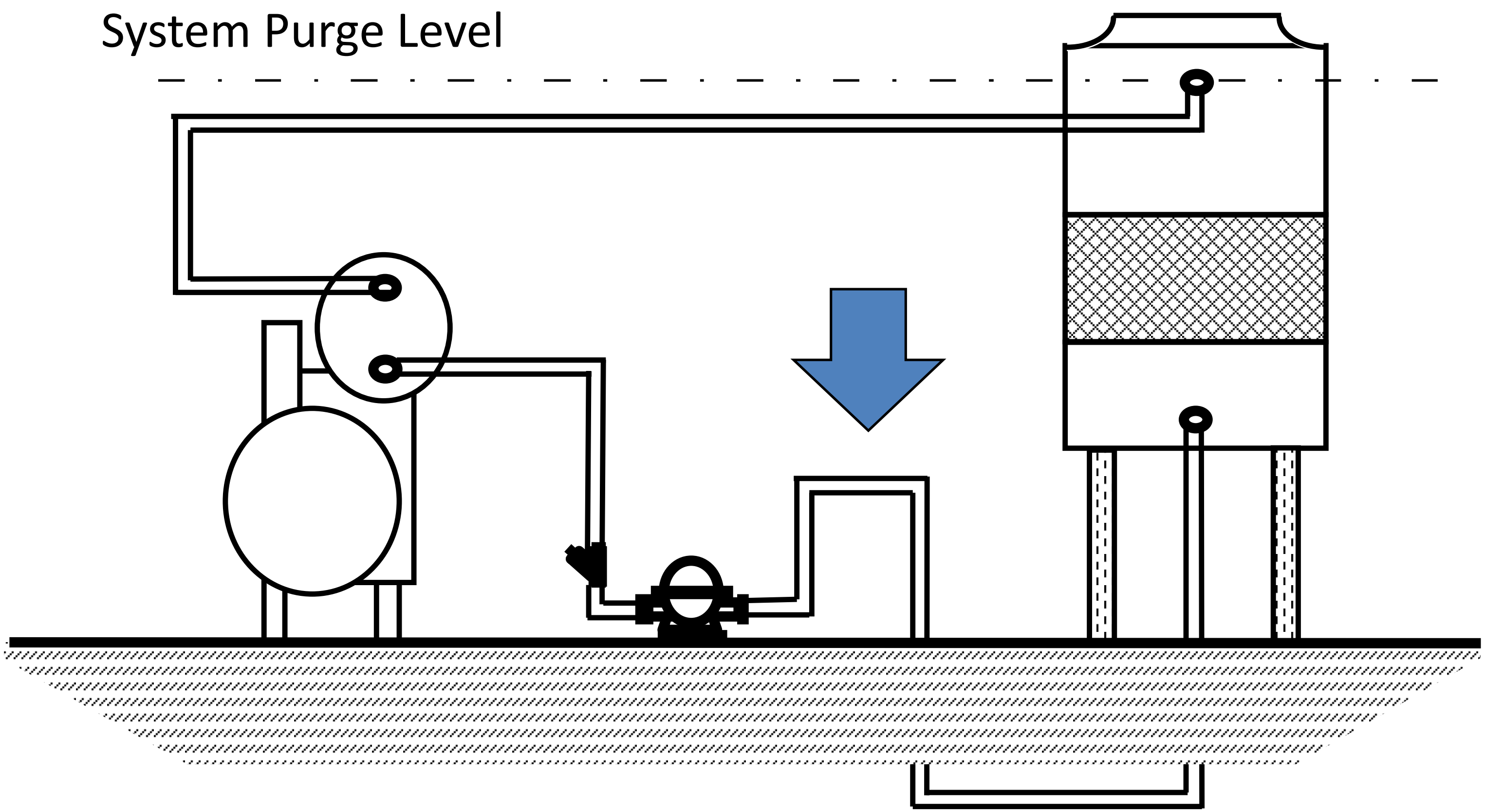


Induced Draft, Counter-flow Tower
Forced Draft, Cross-flow Tower

Condenser Water Piping Above Grade



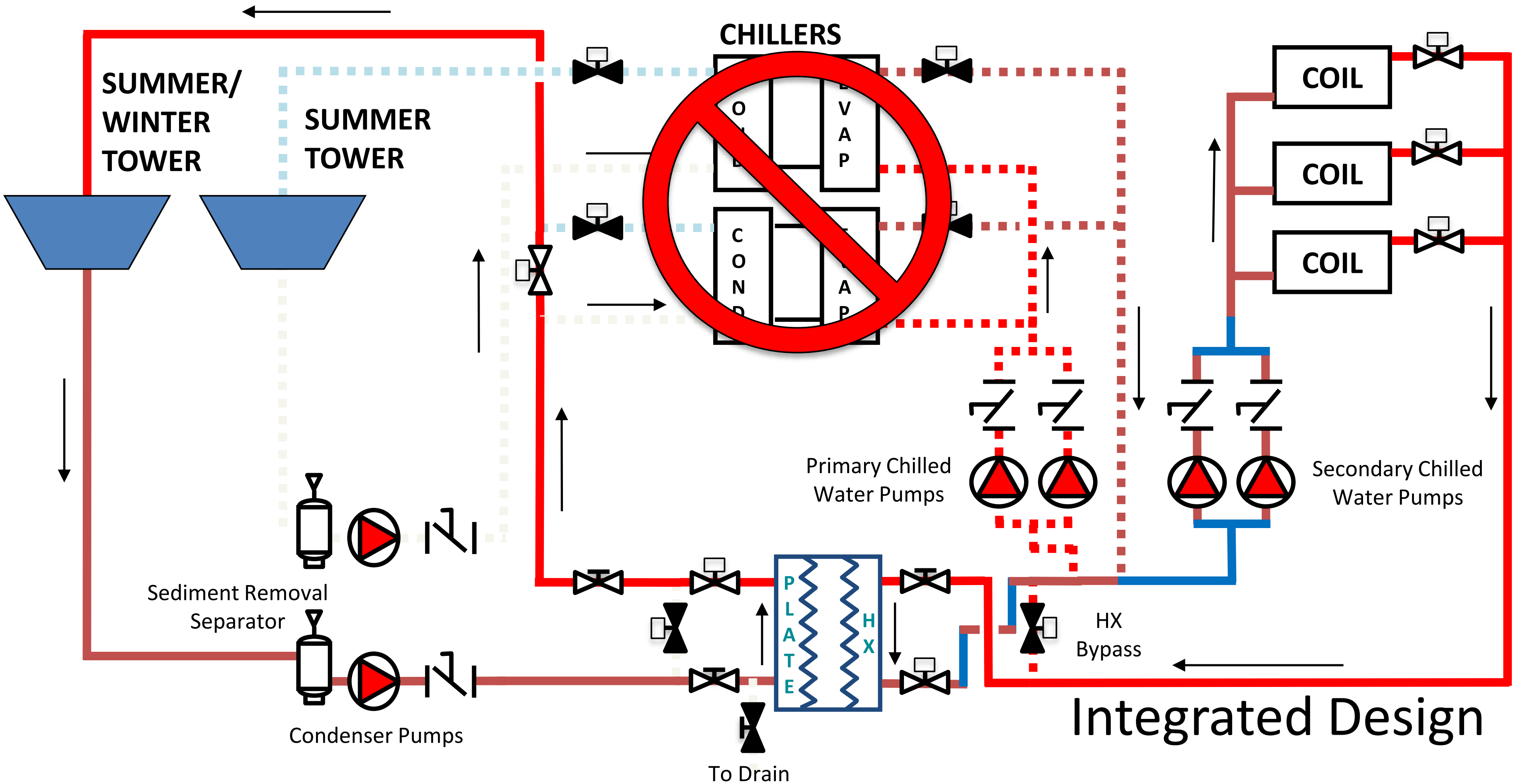
Improper High Suction Piping



Economizers – Goal/Definitions

- Mechanical devices intended to reduce energy consumption or to perform another useful function such as precooling a fluid.
- Airside economizers – use cool outside air directly as a means of cooling the indoor space.
- Waterside economizers – use cooled water indirectly as a means of cooling the indoor space.
- Numerous design variations of waterside economizers – typically they utilize a cooling tower and heat exchanger to indirectly cool the chilled water loop, which is used to reject heat from the building via the hydronic coils.

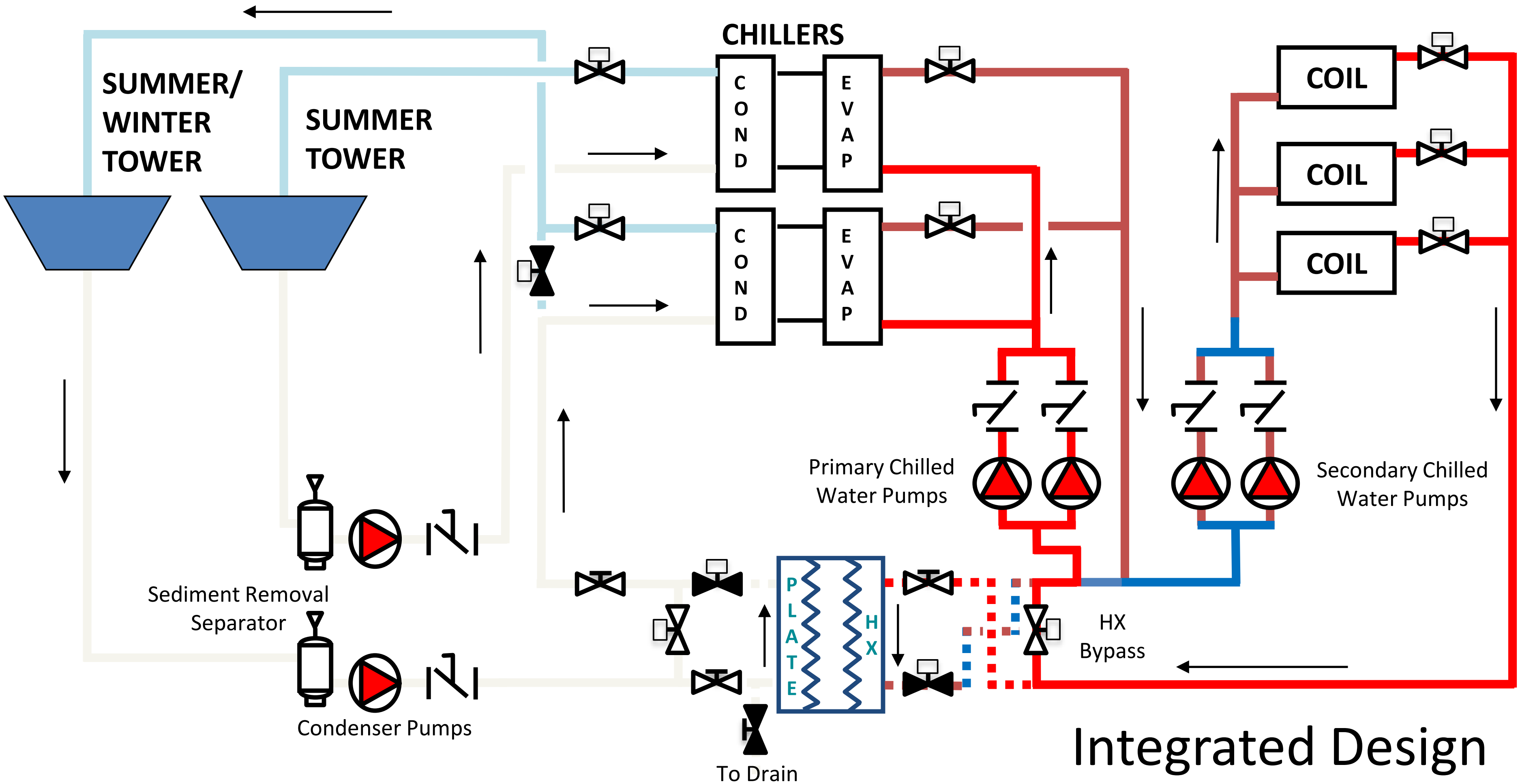
2 Identical Cooling Towers & Plate & Frame HX
Winter Cycle – Chillers Off – Economizer



Economizer System Design Alternative

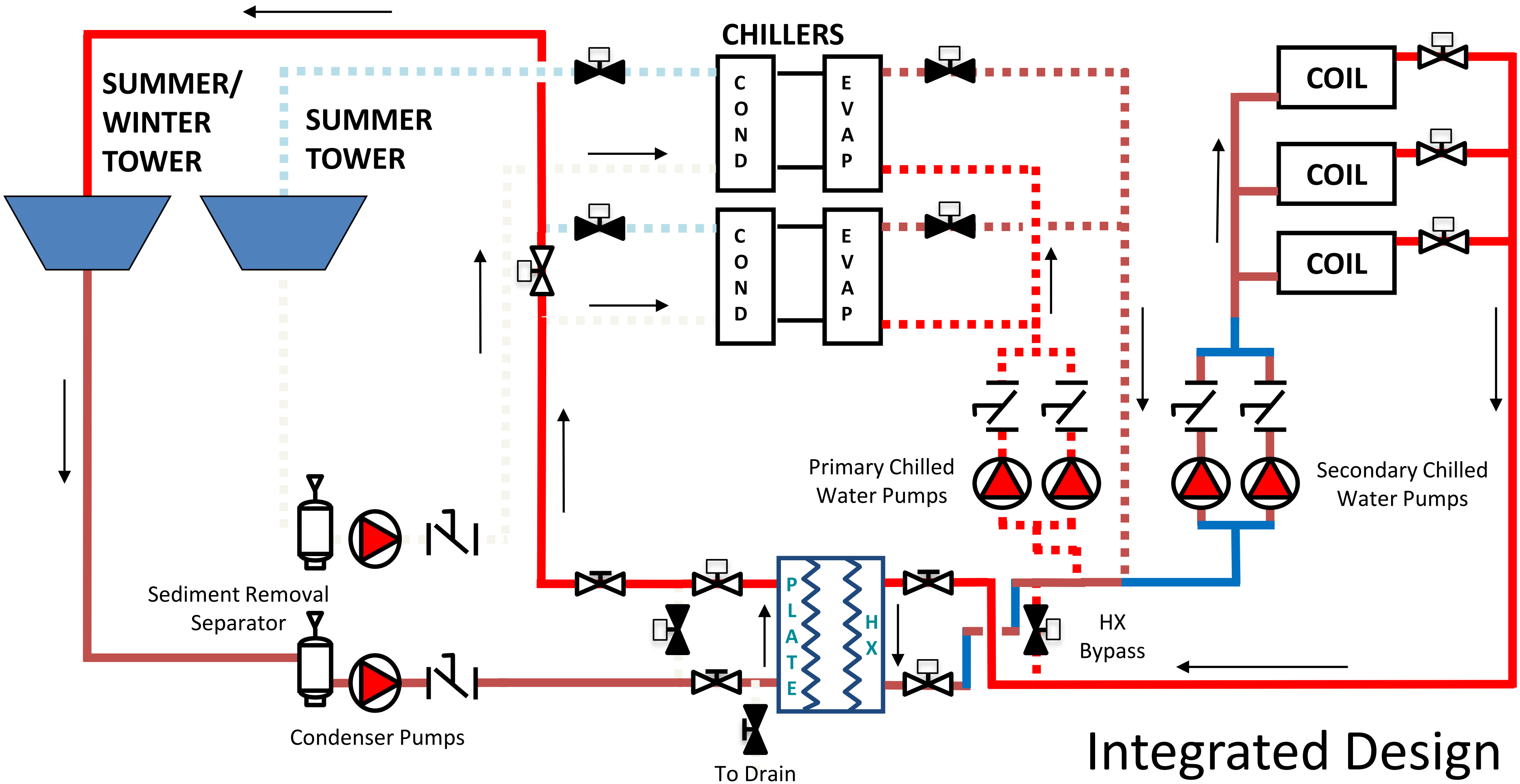
- **Cooling Tower and Heat Exchanger**
  - Two Identical Cooling Towers
    - Each Tower Sized for 50% of Summer Load
    - Winter Load is less than 50% of Summer Load
  - Design Considerations
    - Lower first cost alternative
    - Run Both Towers in Summer Mode
      - Drain One Tower During Winter
    - Run Only Winter Tower in Economizer Mode
      - Freeze Protection Required
    - Run Both Towers when Load Shaving

2 Identical Cooling Towers & Plate & Frame HX
Summer Cycle – Chillers On



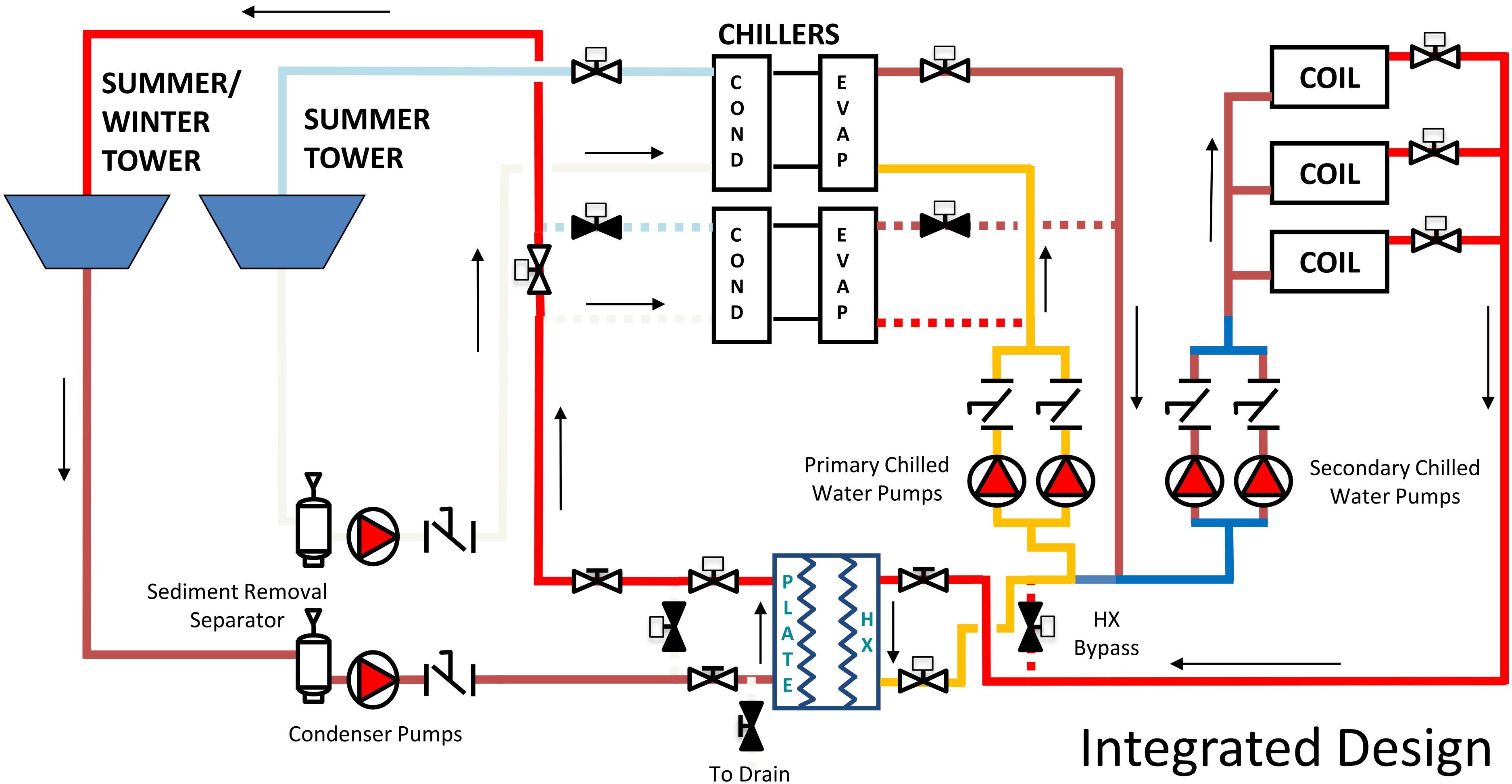
Integrated Design

2 Identical Cooling Towers & Plate & Frame HX
Winter Cycle – Chillers Off – Economizer



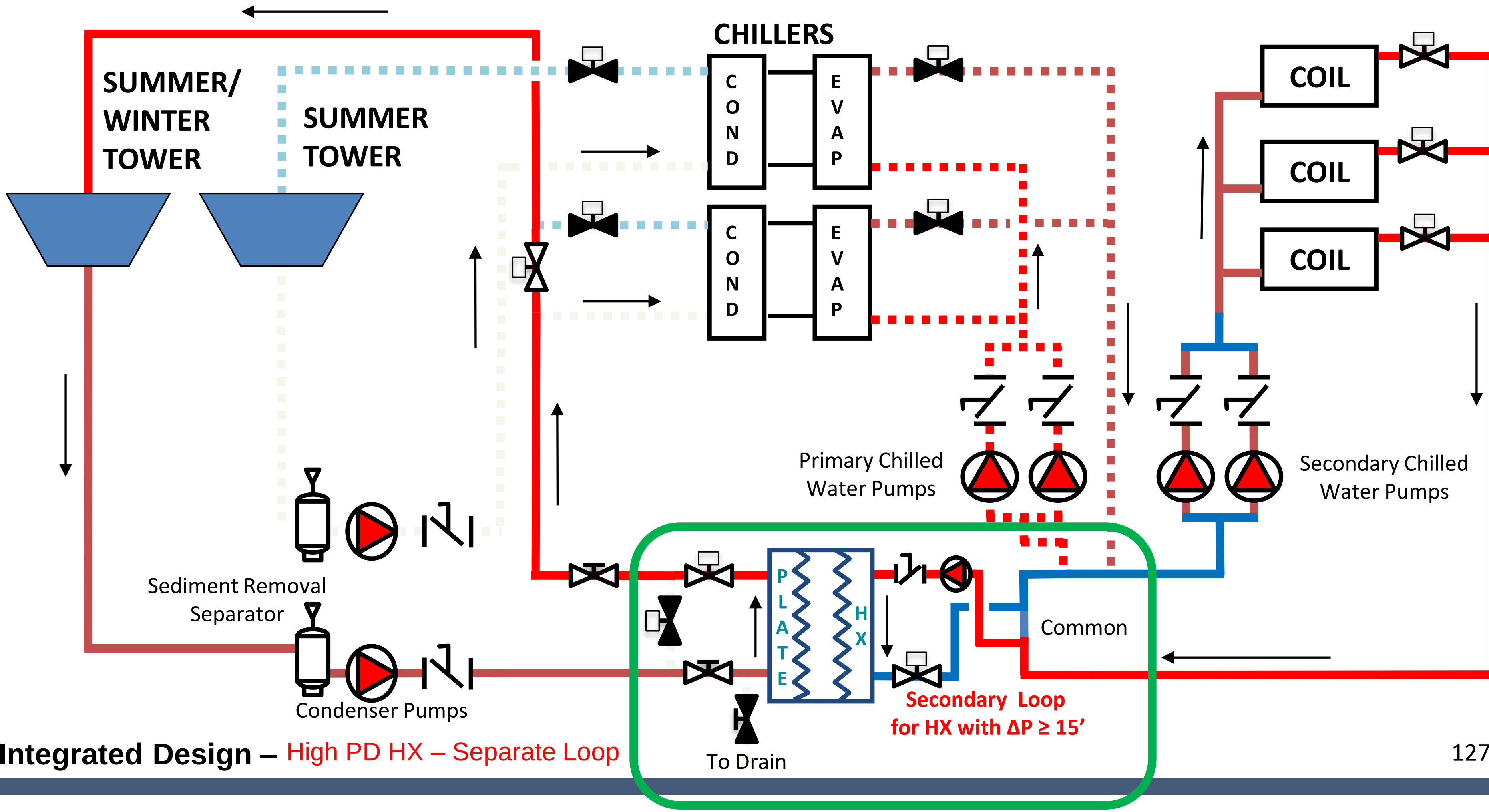
Integrated Design

2 Identical Cooling Towers & Plate & Frame HX
Summer Cycle – Chillers On – Load Shaving



Integrated Design

2 Identical Cooling Towers & Plate & Frame HX Winter Cycle – Chillers Off – Economizer



Expansion Tanks – Hydronic Systems

- Why is a tank needed?
- Absorb system expansion due to temperature change.
- Provides minimum pressure.
  - Keep the system full
  - Vent air bubbles
  - Prevent cavitation at pump, valves
- Provide a reliable system pressure reference

Closed Loop Requirements

- Must be able to rid the system of un-necessary air.
- Prevent loss of water, reduce need for make up and avoid water damage.
- Need to control, and limit, pressure.
  - Think of a “pressure band” with upper and lower limits.
  - Initial pressure is the lower limit.

Pressure Reducing Valve (PRV)

Fills the system from the city water supply.
Establishes minimum fill pressure.

Consider:

- System height above fill point
- Desired residual pressure at the
- Pump NPSHR and location
- Install near expansion tank

Relief Valve

- Needed on boiler and chilled water side to limit system pressure.
- This is the upper limit of the "band"

Air Management in Closed Systems

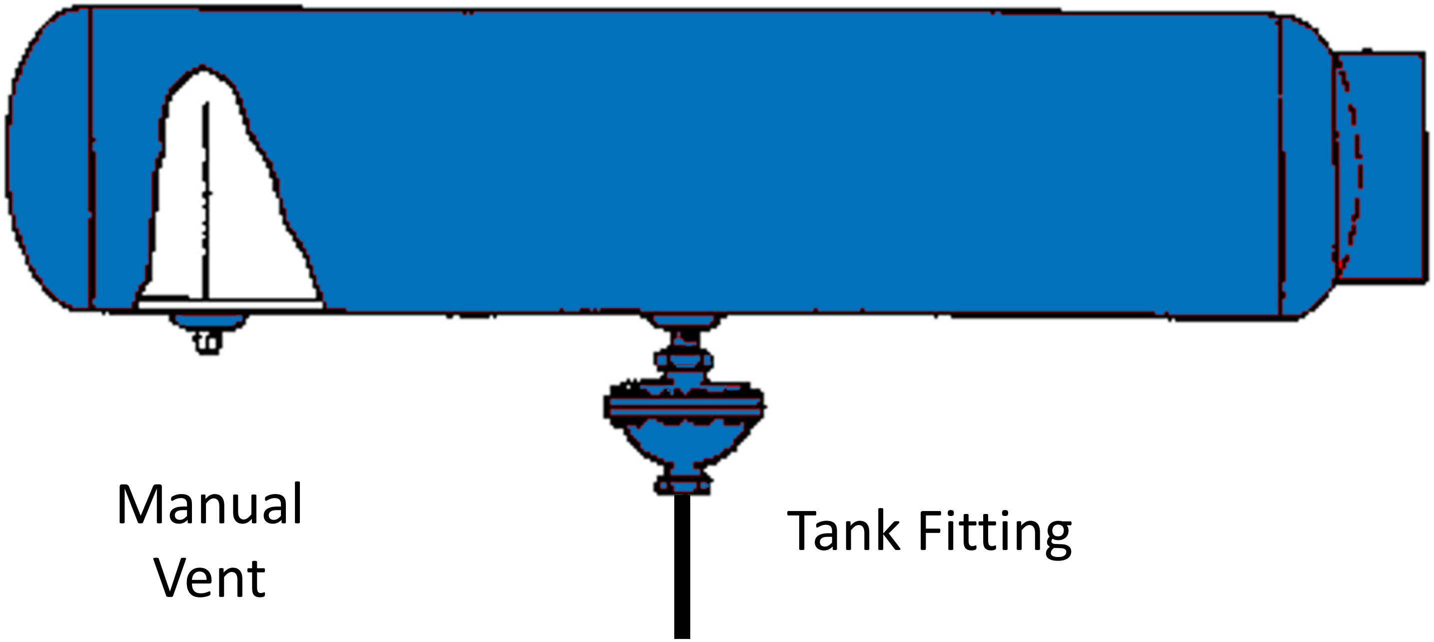
Air Control

- Mechanical pump seal
- Standard tank
- Manual air vents
- An air separator

Air Elimination

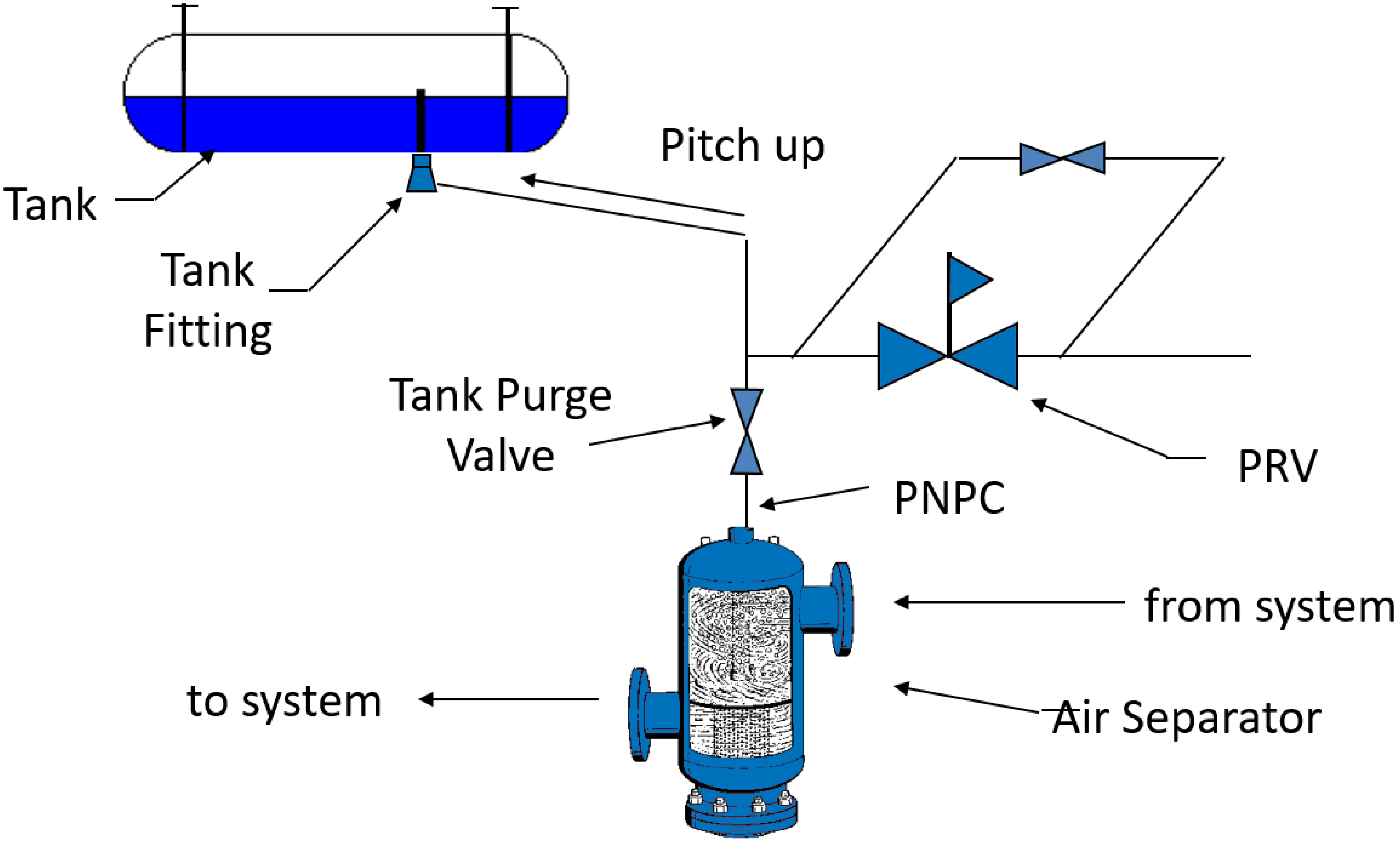
- Mechanical pump seal
- Diaphragm or bladder tank
- Automatic vents
- An air separator

Standard Compression Tank



Used in “Air Control” strategies

Standard Tank Installation



Diaphragm Tank

“Acceptance volume”

Used in “Air Elimination” strategies

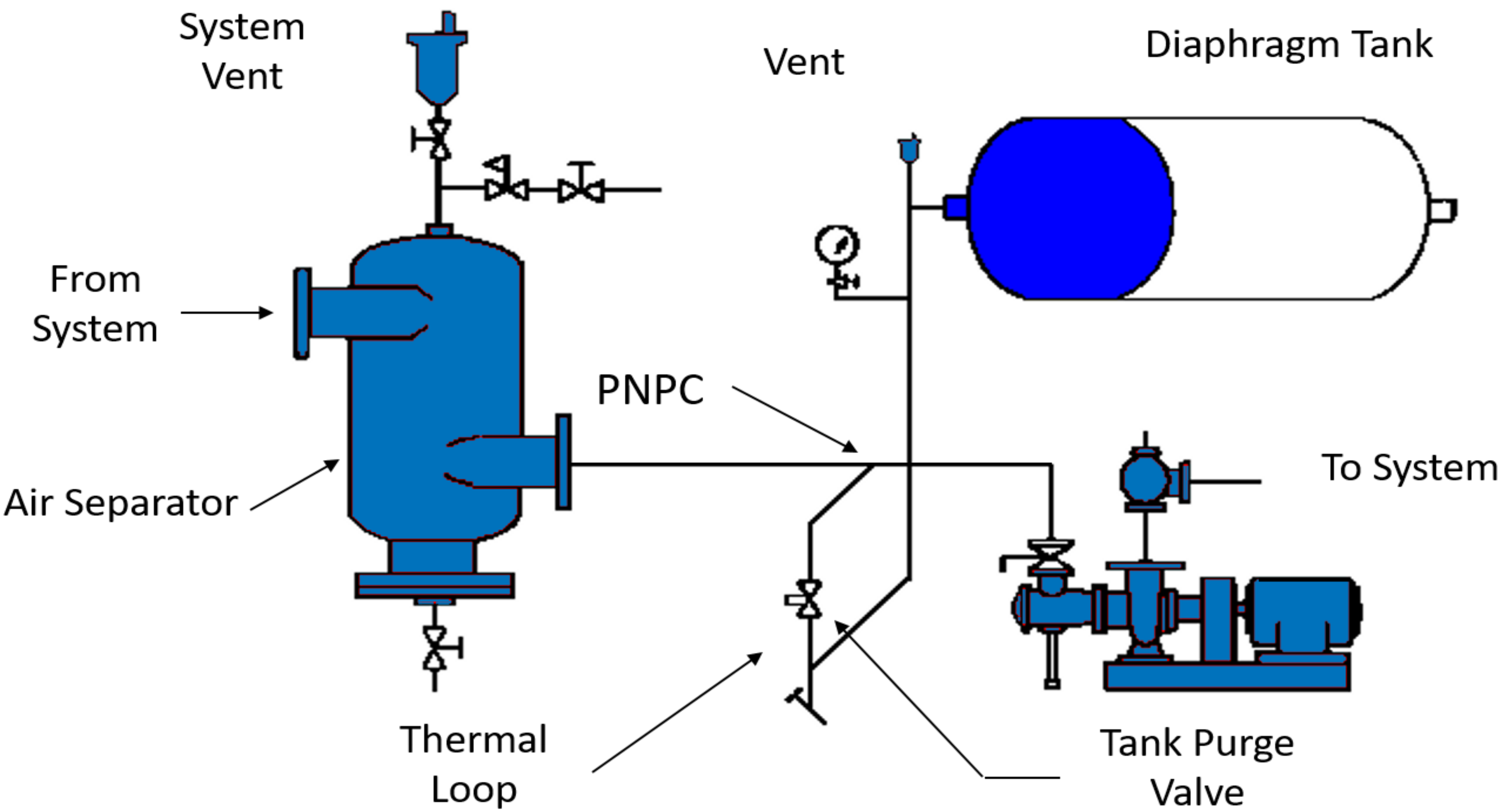
Bladder Tanks

Full Acceptance

Partial Acceptance

Used in “Air Elimination” strategies

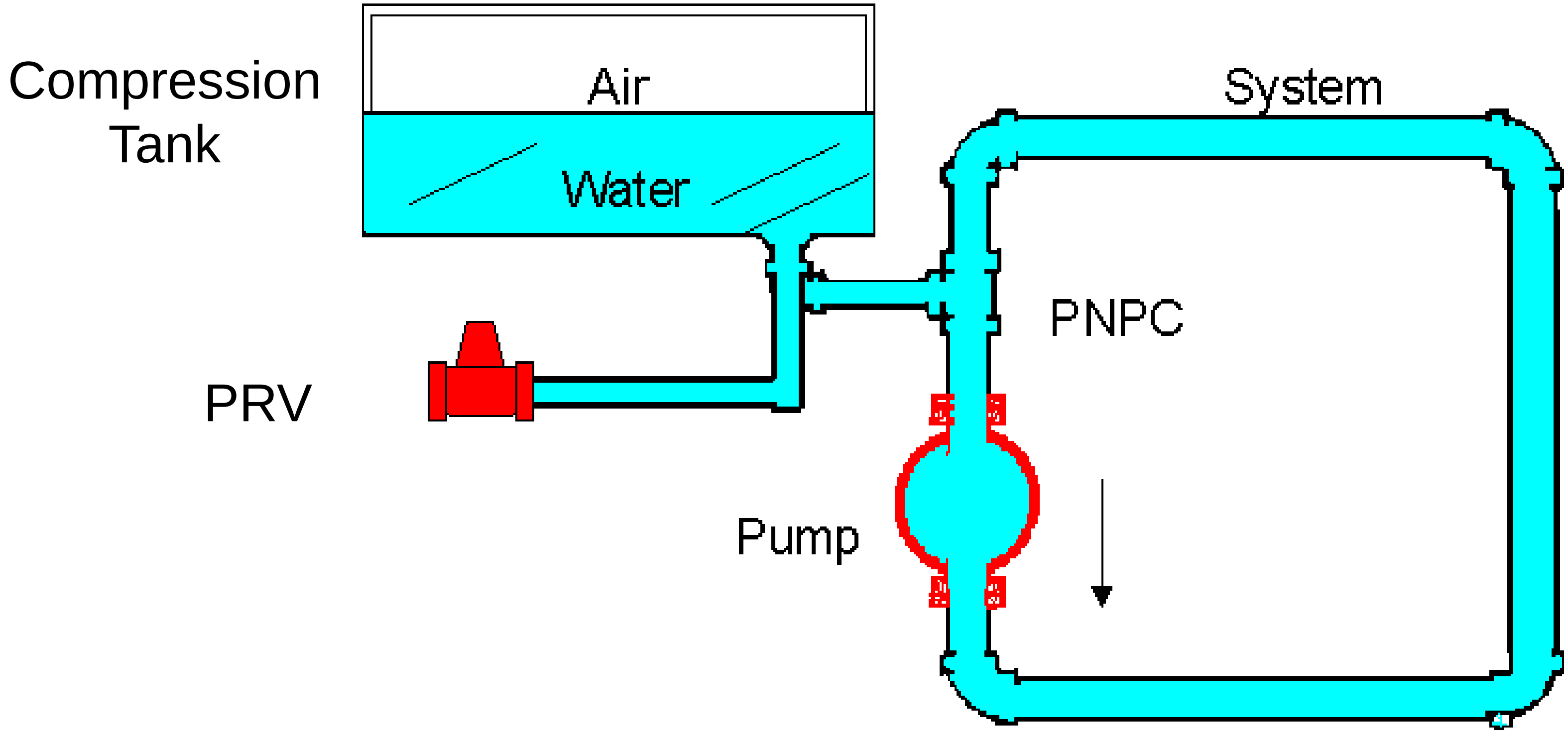
Diaphragm Tank Installation



Tank Sizing and Selection

- Must satisfy two conditions:
  - The volume of the tank must be large enough so that the system operates within the range of the initial fill pressure and the relief valve setting.
  - The tank's acceptance volume must be at least as large as the system's expansion volume.

Tank Location - Installation



PNPC – Point of No Pressure Change

Air Separators

The place we want to remove air:

- Lowest Pressure
- Highest Temperature

Types of Air Separators

- Use centrifugal force
- Use coalescence

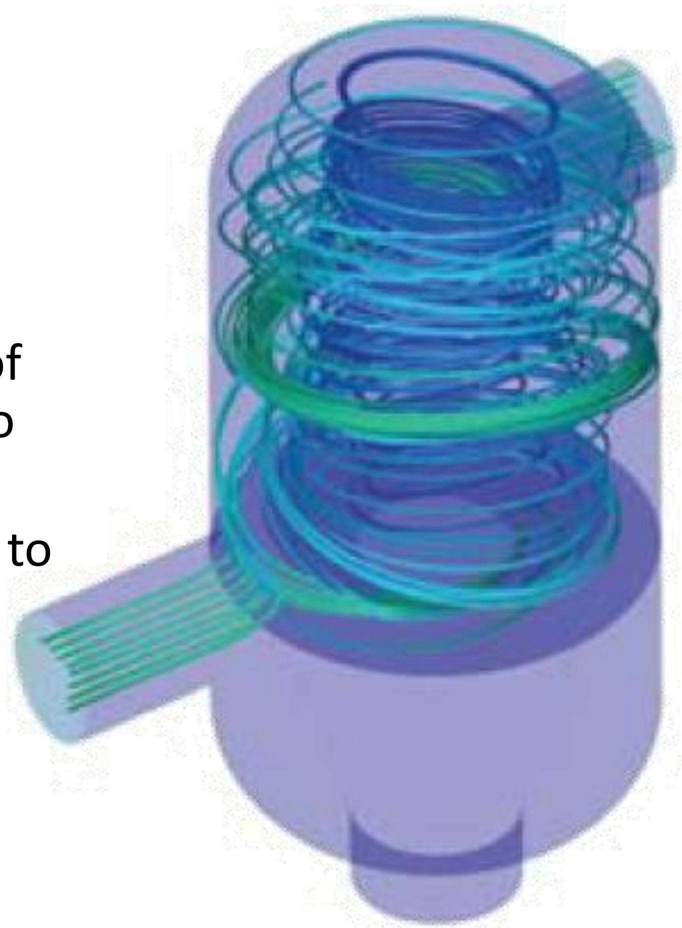
Centrifugal Air Separator

To Standard Tank
or Vent

System Inlet

System Outlet

How Does a Centrifugal Air Separator Work?



Tangential design

- Induces centrifugal action as water enters tank
  - Heavy, air-free water forced to exterior of vessel. Lighter, air-filled water forced into center of tank
  - Separated air collects in center and rises to air vent or compression tank

Velocity reduction

- Tank body sized 3x the inlet/outlet nozzle size
  - Allows air to come out of solution

Coalescing Removal Separator

Velocity Reduction

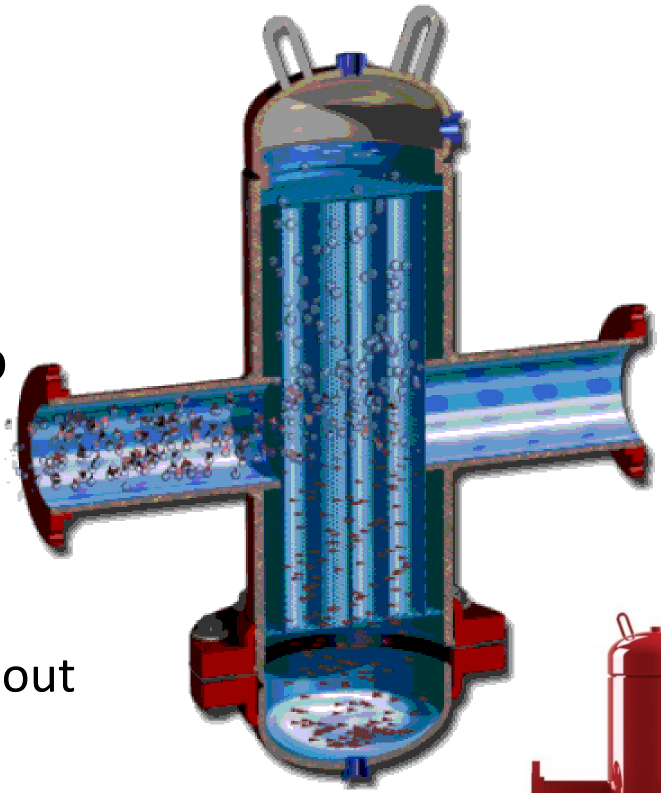
- Tank body 2x inlet/outlet nozzles

Medium inside tank provides surface area for air and sediment to "stick" to

- Medium "pulls" entrained air and sediment out of solution

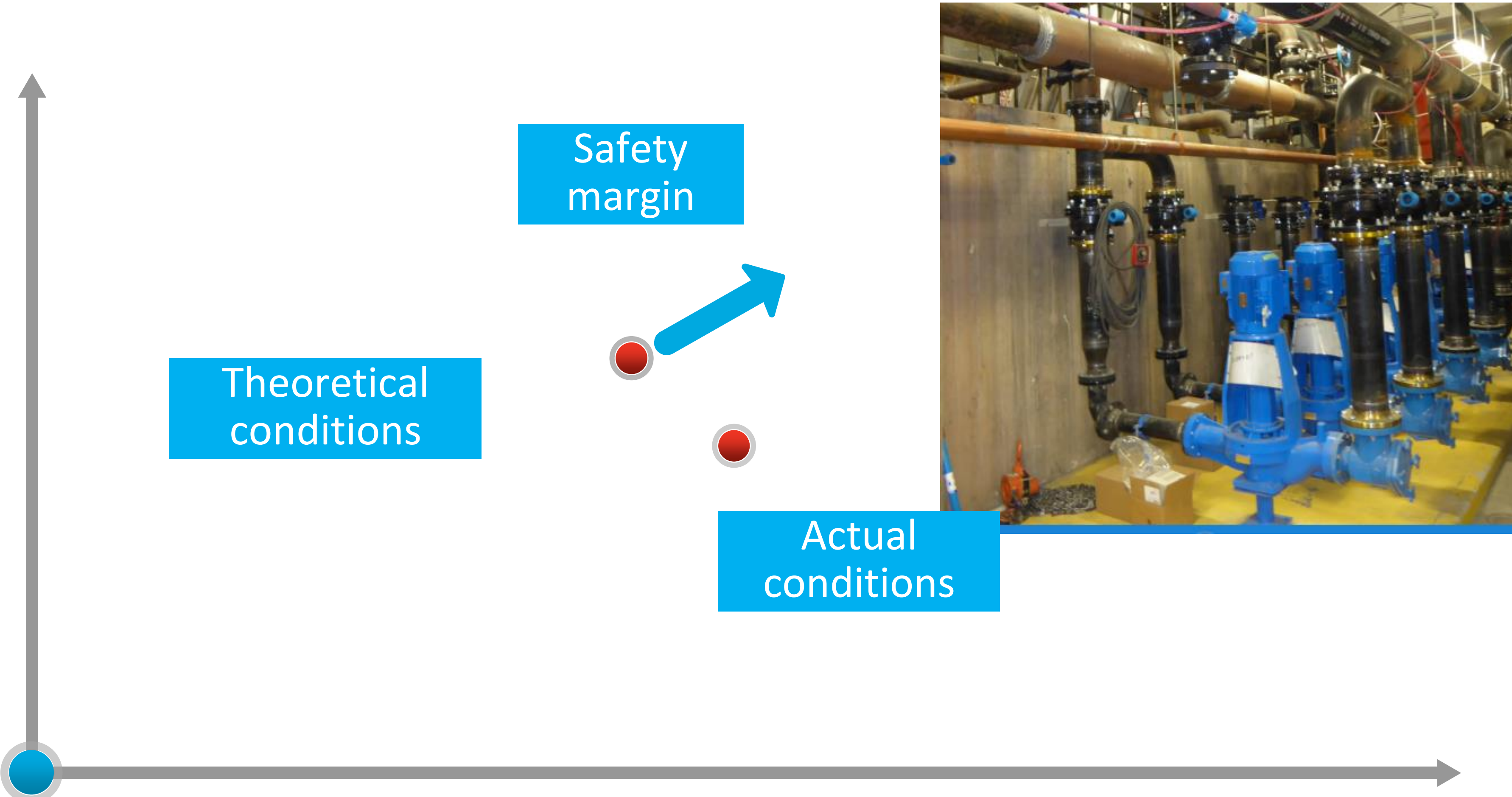
Low inlet velocity critical

- Low fluid speed necessary to "pull" air out of solution
- Coalescing medium increases pressure drop



Fan Coils

Life Cycle Concerns – Design Risk



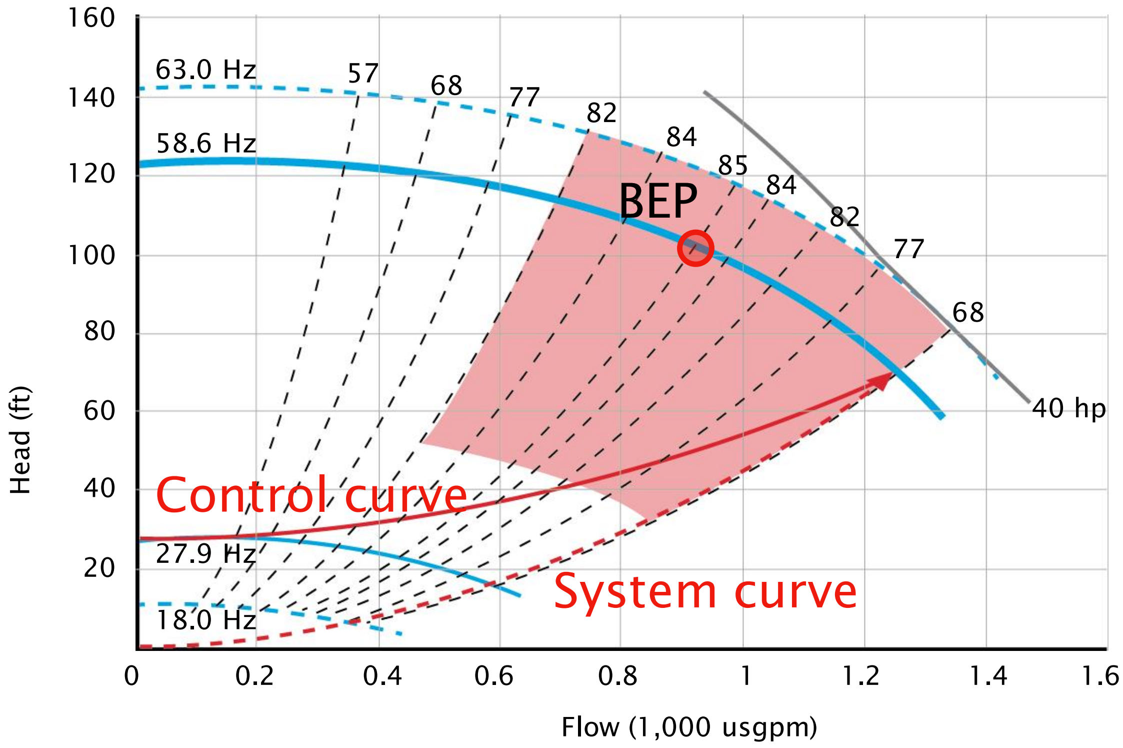
Traditional Pump Selection Energy Savings

	Traditional selection (left of BEP):	Operating point at 50% design flow:
Duty	1250gpm at 70ft	625gpm at 38.5ft
Efficiency	79.1%	67.1%
Power	27.9 bhp	9.06 bhp

67.5%
ENERGY SAVINGS

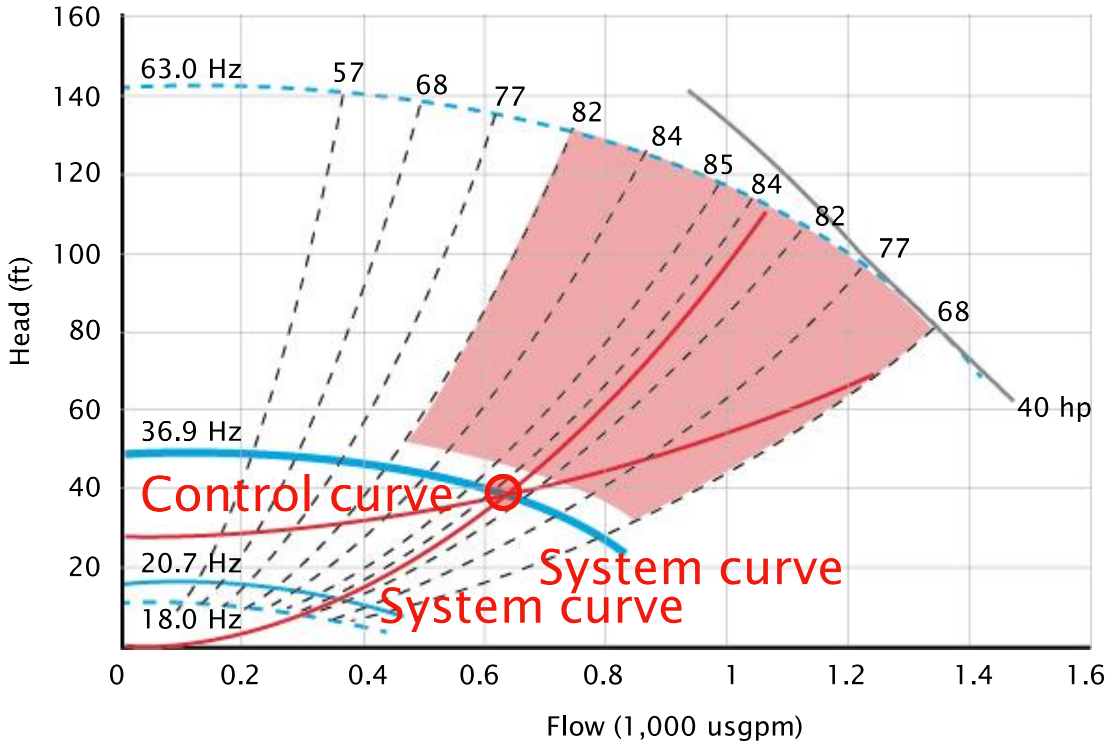
Below ASHRAE 90.1 requirements!

Pump Selection



- Selection to right of BEP
- 1250gpm at 70ft
- 68.1% efficiency
- 32.5bhp

Pump Selection at 50% Flow



- 625gpm at 38.5ft
- 83.2% efficiency
- 7.31bhp

Pump Selection Energy Savings

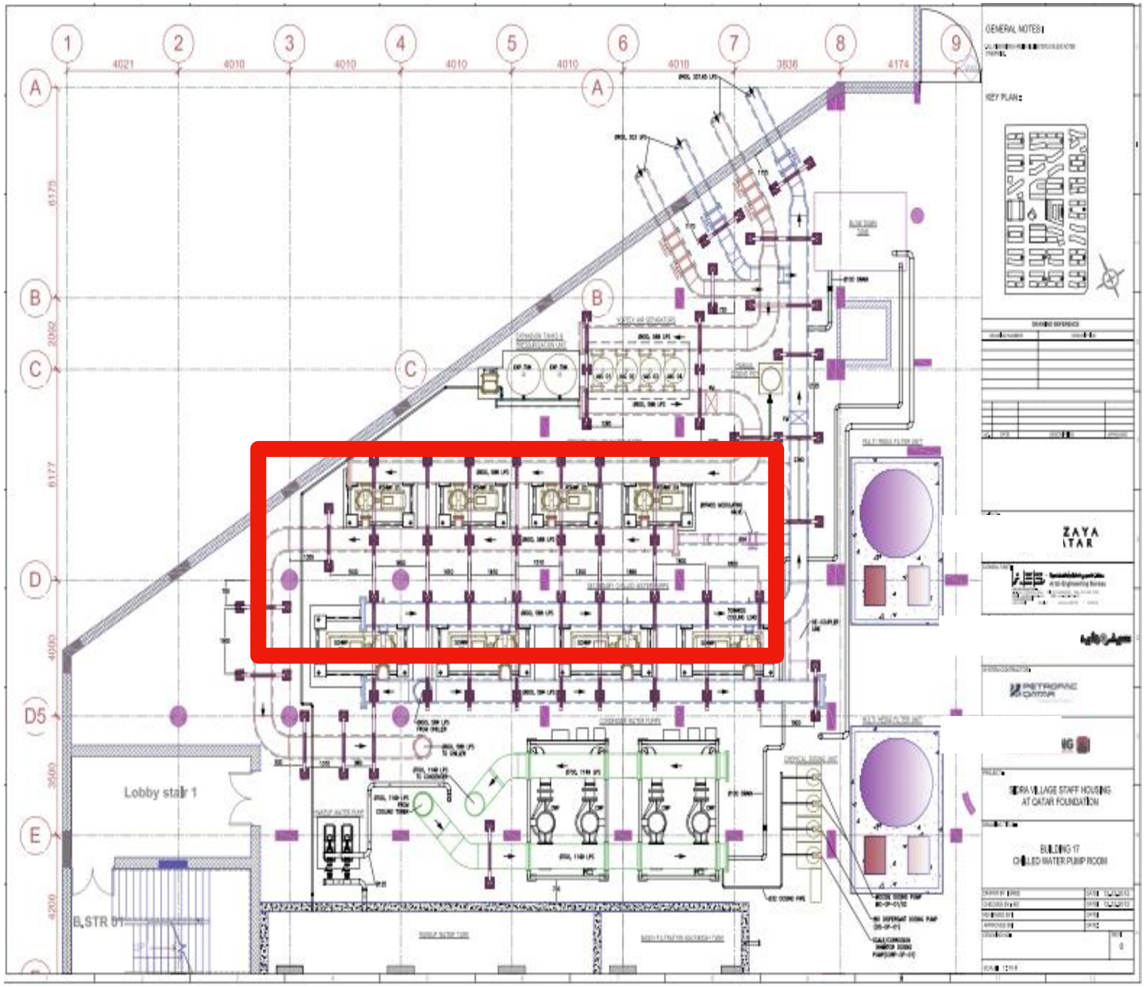
	Pump selection:	Operating point at 50% design flow:
Duty	1250gpm at 70ft	625gpm at 38.5ft
Efficiency	68.1%	83.2%
Power	32.5bhp	7.31bhp

77.5%

ENERGY SAVINGS

Exceeds ASHRAE 90.1 requirements!

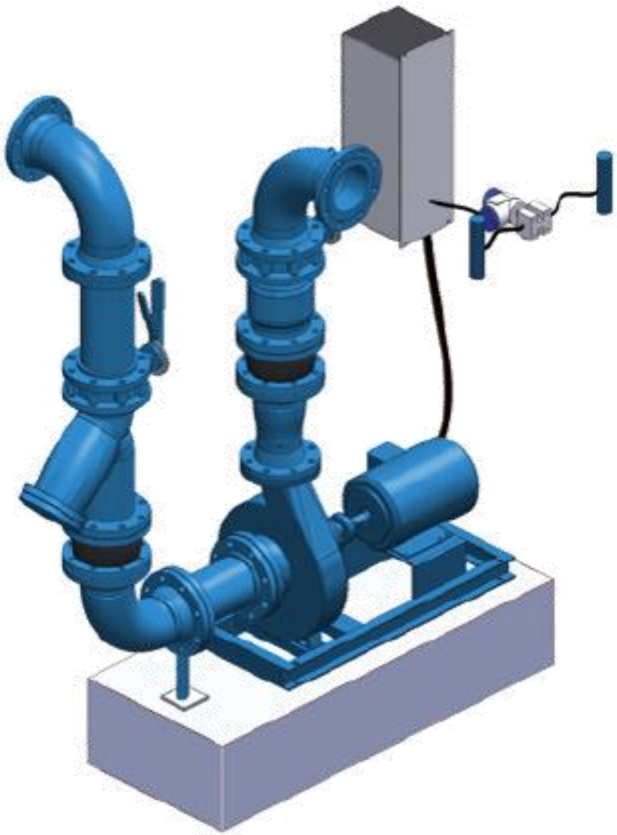
Installed Cost - Space



Installed Cost – Ancillaries and Accessories

- Coupling re-alignment
- Grouting
- Inertia pad
- Concrete base
- Flex connectors

Installed Cost – Ancillaries and Accessories



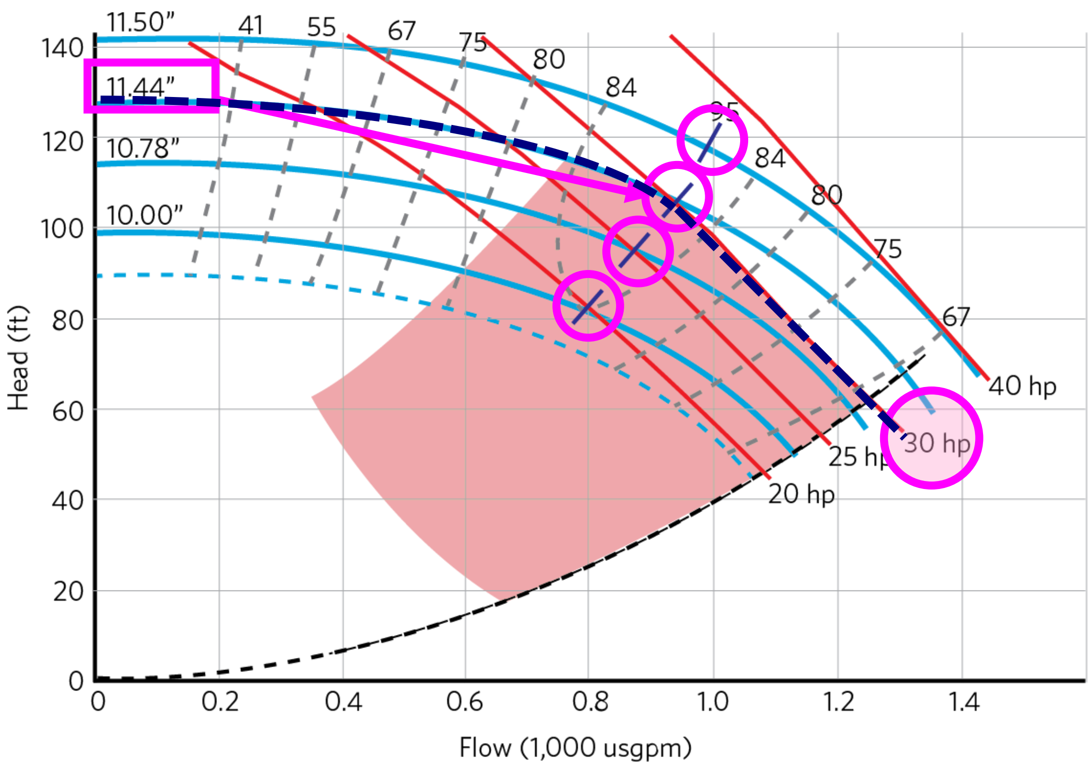
- VFD Mounting and Wiring
- Sensor Acquisition and Installation
- Harmonic and RFI Filtering
- Thermistors and Space Heaters
- Energy and Flow Metering

Other Life Cycle Concerns – Reliability and Maintenance

This is often a lower specification and buying priority

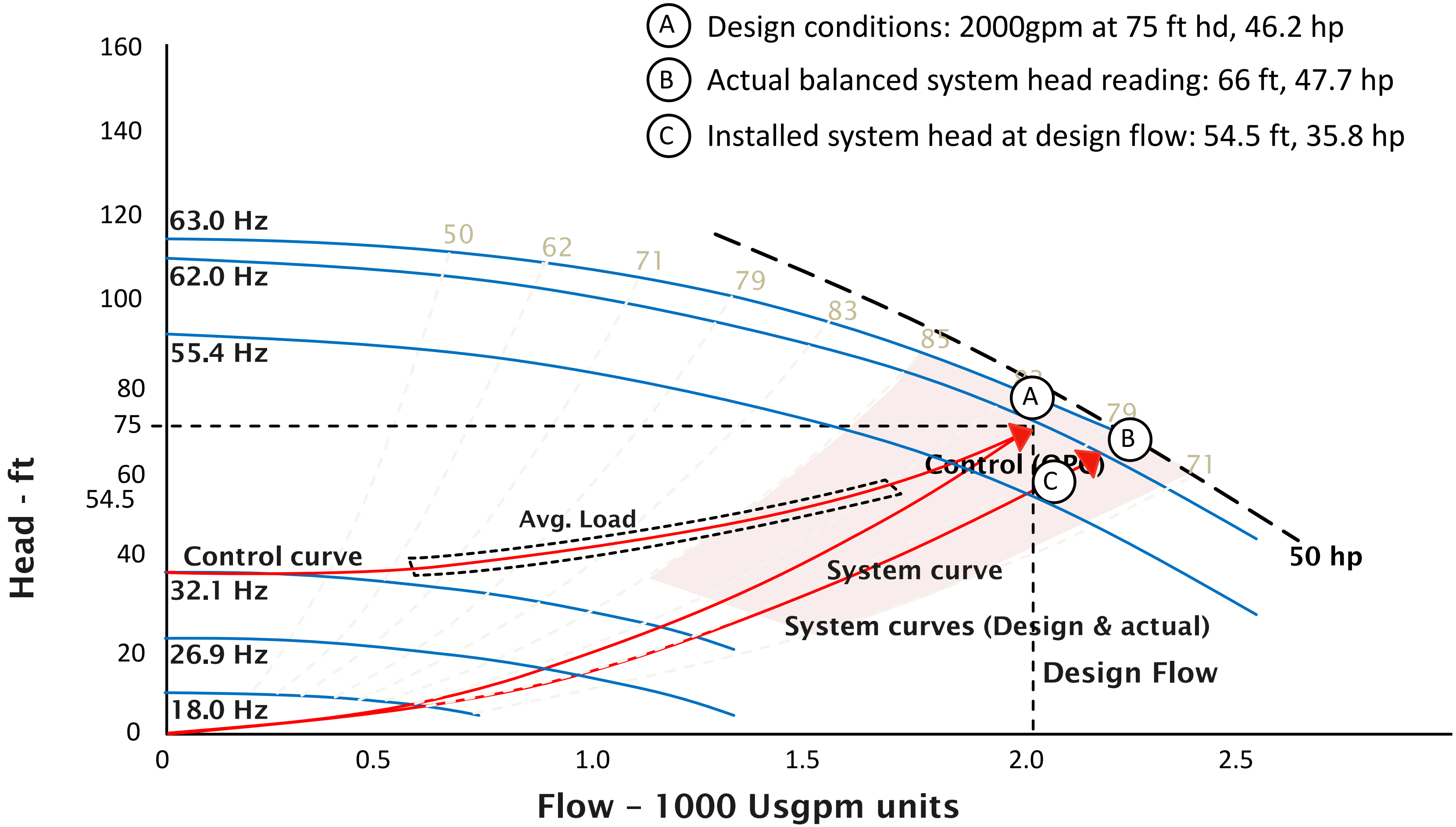
Optimized Capacity and Motor Power

- Impeller trim is optimized to the motor power
- Electronic load limiting ensures that motor power is not exceeded



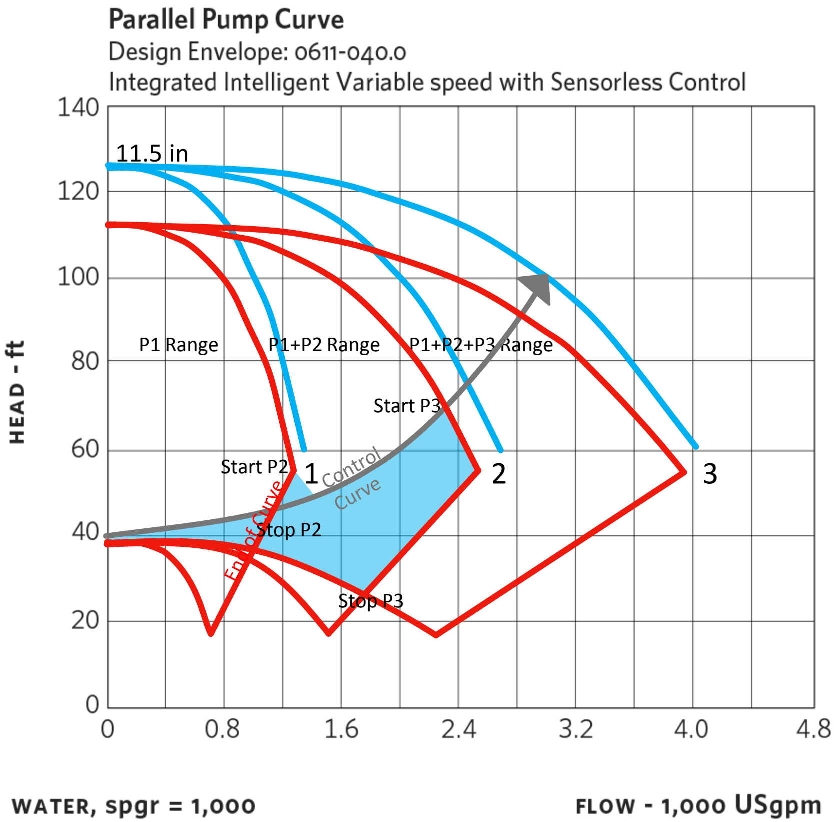
Motor sizing optimized to BEP – no oversized motors

Other Life Cycle Concerns – Ease of Commissioning



Required adjustments are often impractical or delayed, resulting in wasted energy saving opportunities

BMS Parallel Control



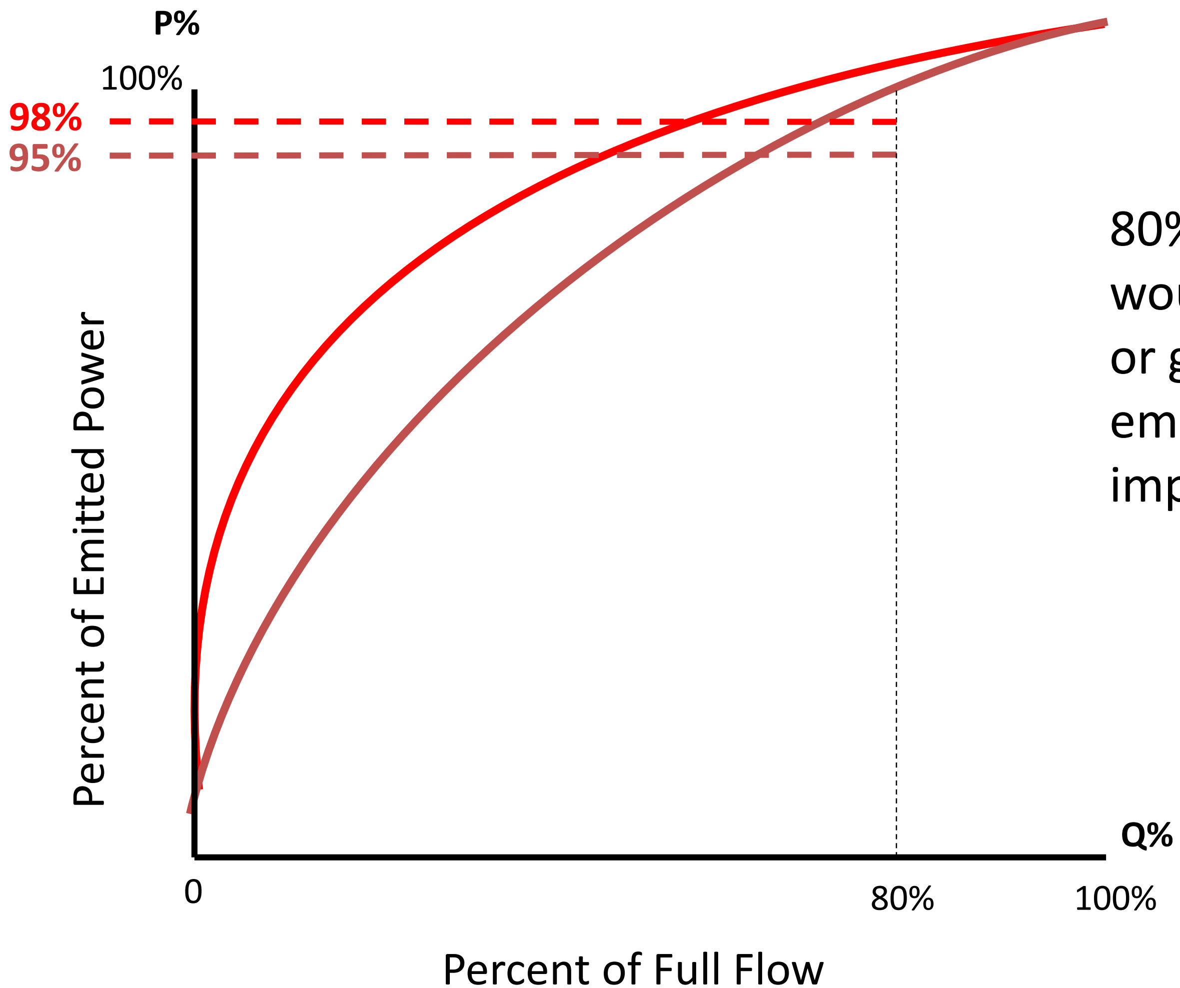
3-pump variable speed curves

Benefits of parallel operation versus traditional BMS parallel pump control

- **Energy savings**
- Typical 3-pump variable flow system / 50% average load / 40hp mtrs
- BMS operating cost* ~ $30, 371
- Parallel Sensorless Pump Control operating cost* ~ $20,092
- 72.5 metric tons CO_2 or equivalent
- Parallel Sensorless pump control saved **34%** energy costs

*Based on $0.10/kWh – 12-months operation – 40% design head min pressure

Redundancy - Impact on Heating or Cooling Output

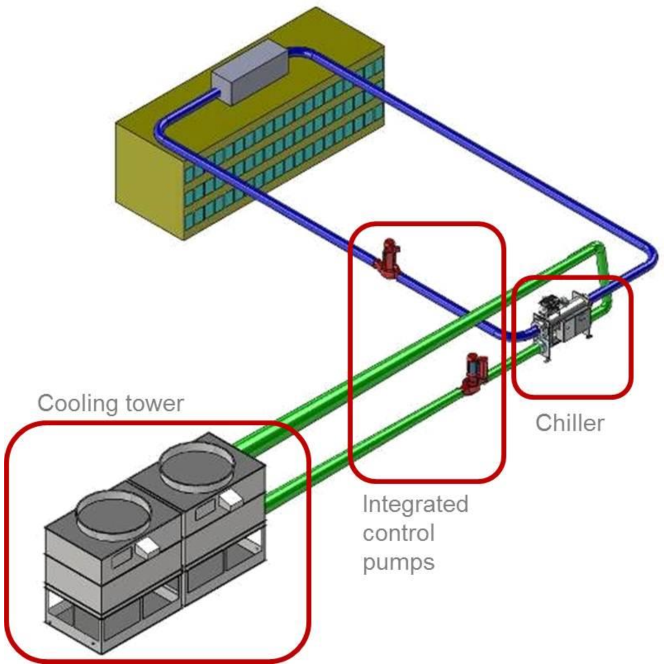


80% Capacity on a design day would still result in approx. 95% or greater heating / cooling coil emission resulting in minimal impact to occupant comfort!

Energy Savings: Chiller and Cooling Tower

Using an all-variable plant:

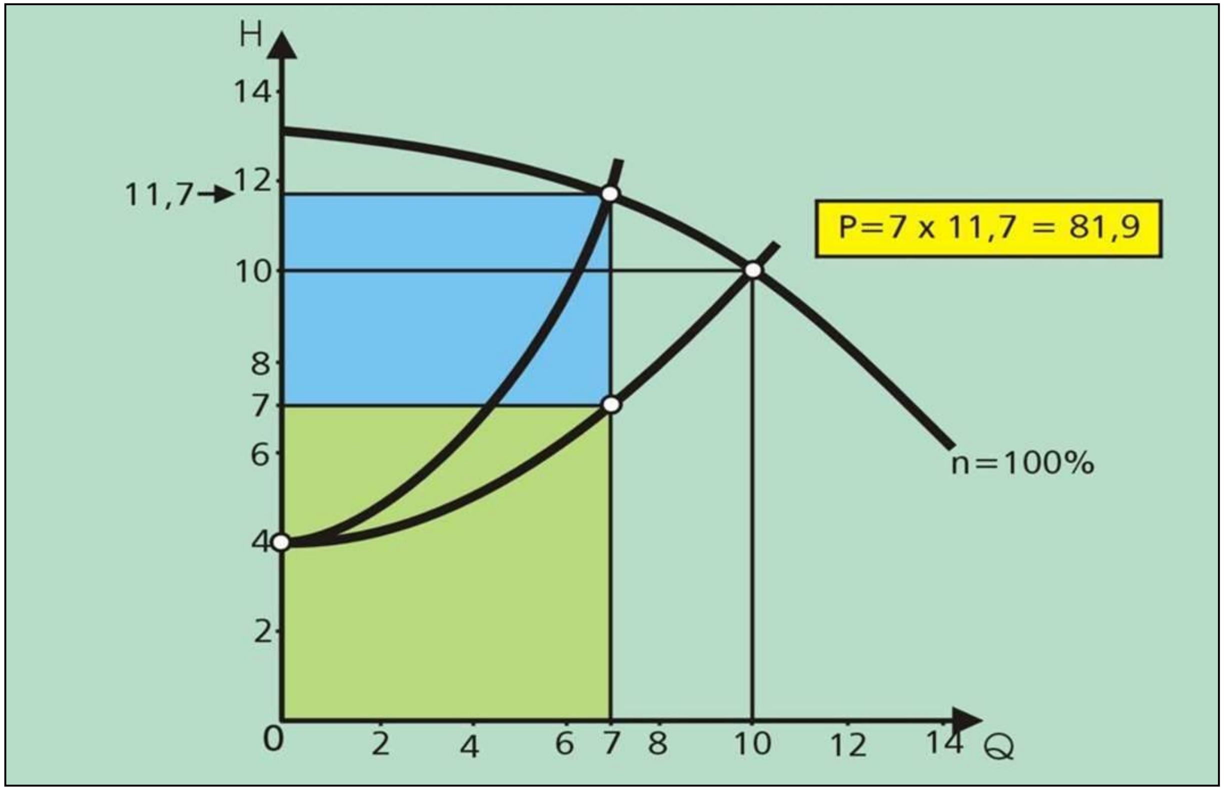
- lowers the chiller's condenser pressure requirement
- lowers the chiller's energy consumption
- enables higher tower performance
- enables better system efficiency through improved balancing of air and water flow ratios



Integrated control pumps can be used with ultra-high-efficiency plant controllers to provide energy savings.

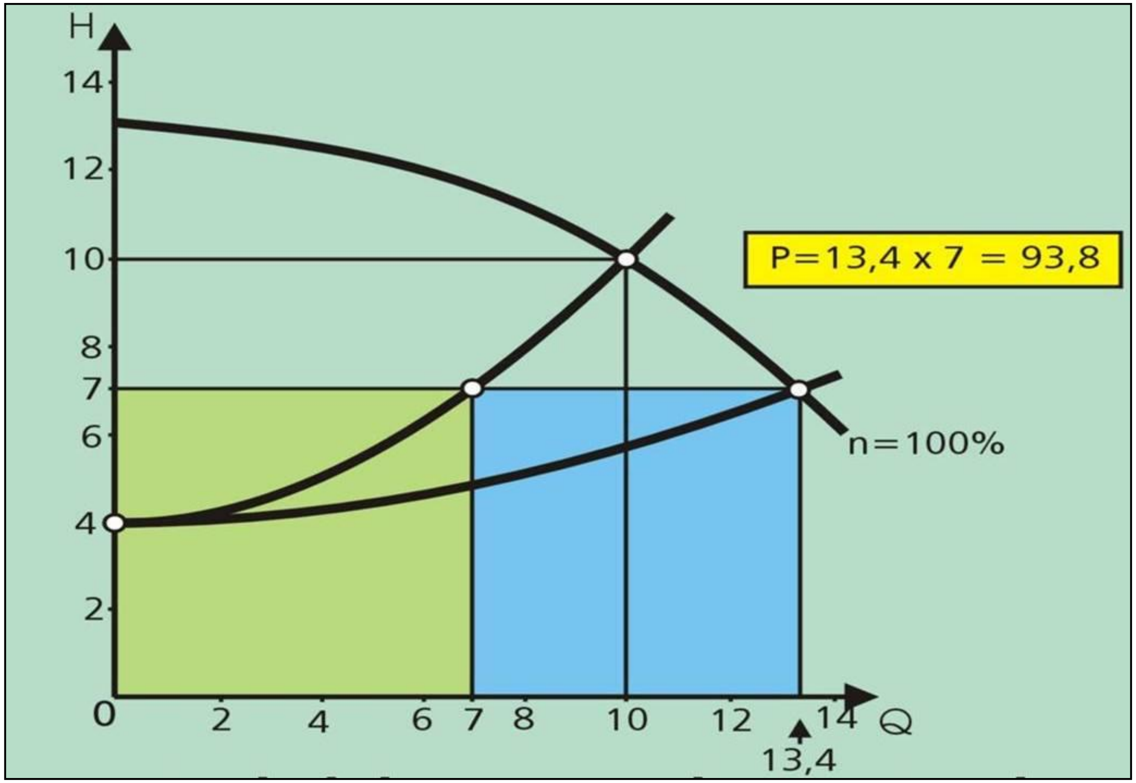
Flow Control & DHW

Throttle Control



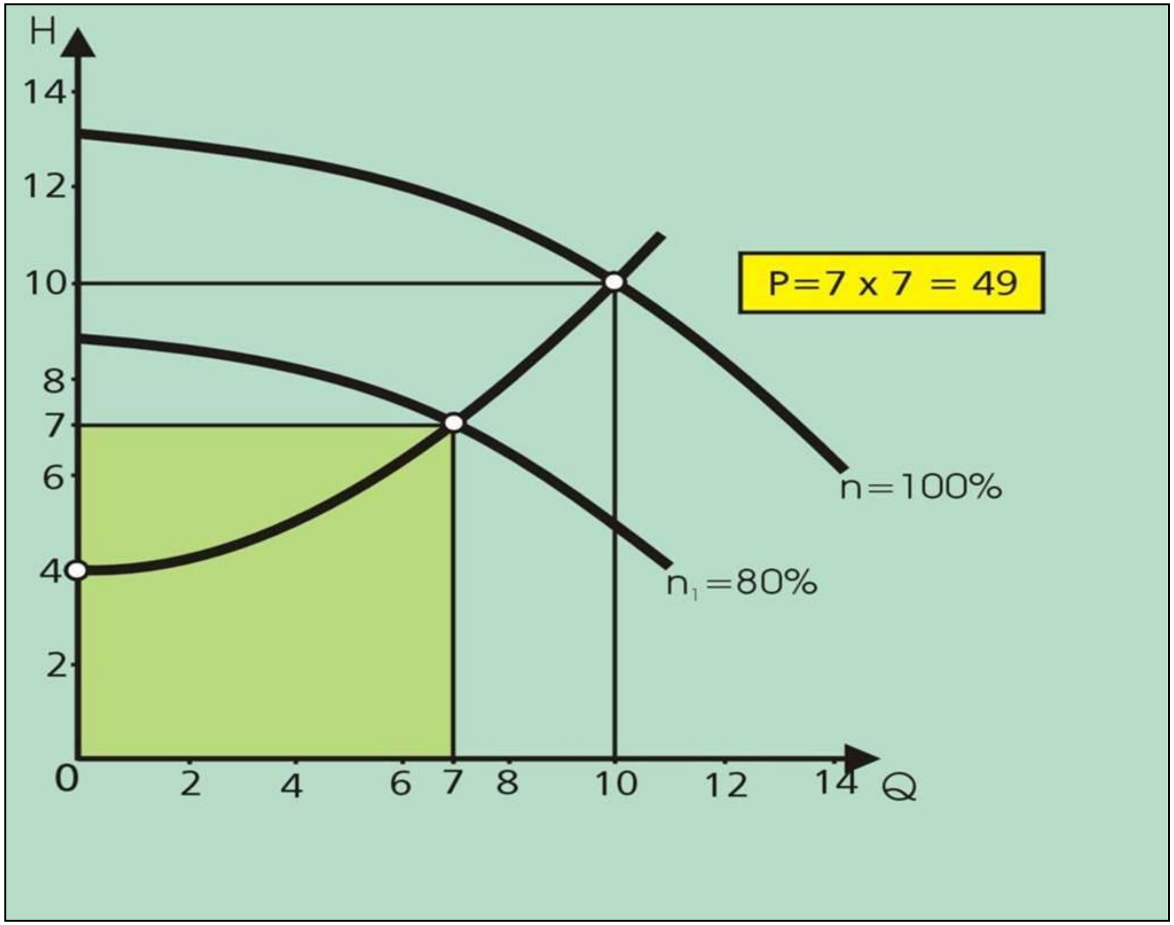
- Valve throttling increases system head resulting in excess power consumption
- Excess energy noted in blue area
- Excess energy impacts equipment reliability

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

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

Change Pump Speed To Match Load

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

Affinity Laws

- **Flow is Proportional to shaft speed**

  $(Q1/Q2) = (N1/N2)$

Pressure is Proportional to square of shaft speed

$(H1/H2) = (N1/N2)^{2}$

Power is Proportional to cube of shaft speed

$(P1/P2) = (N1/N2)^{3}$

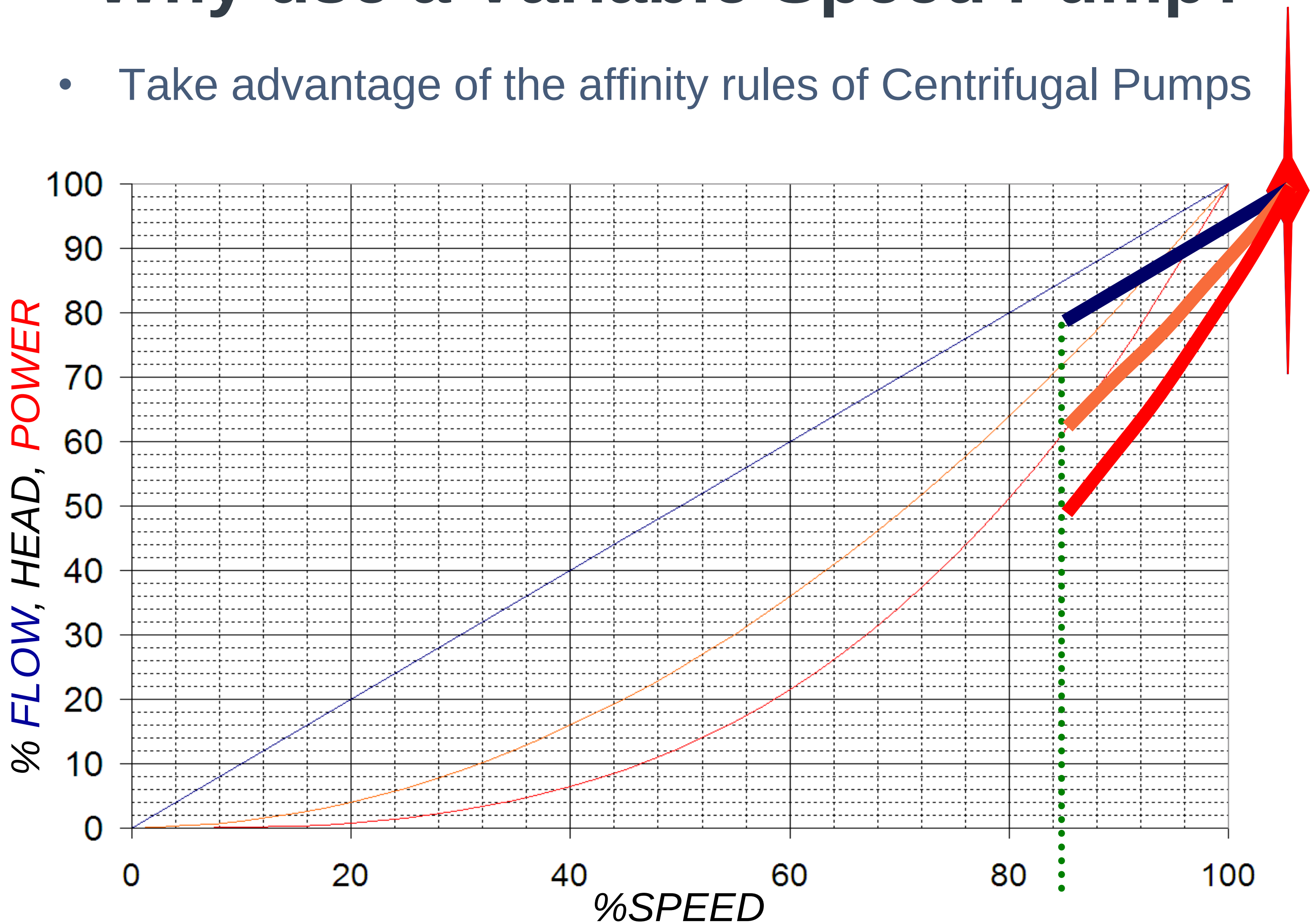
Impact of Affinity Law

RPM	GPM	PSI	HP	% savings
3500	325	65	20	
3250	301.8	56.0	12.8	36%
3000	278.6	47.8	7.9	60%

3000/3500 - 14% reduction = 60% HP reduction

Why use a Variable Speed Pump?

- Take advantage of the affinity rules of Centrifugal Pumps



Traditional Flow Control

Most of the buildings in the 1970s used two basic types of flow control:

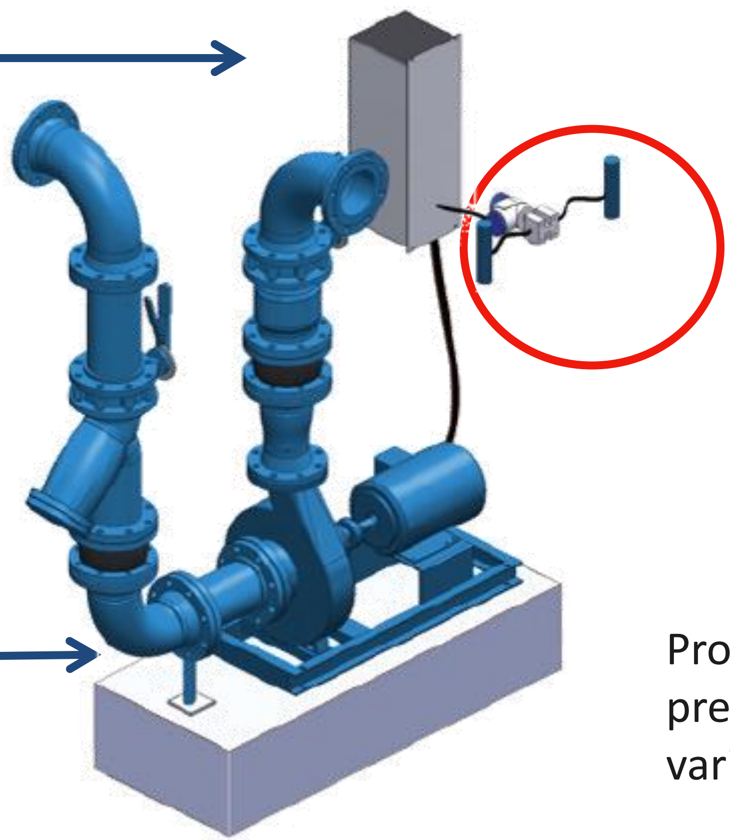
- flow bypasses, or
- throttling discharge valves with trimmed pump impellers.

Bypass arrangements is the least efficient and least used method of flow control.

Throttling control does save energy compared to bypass methods; a variable speed operation can save much more energy.

Traditional Variable Flow Systems with a DP Sensor

Wall-mounted Variable Frequency Drive



Differential Pressure Sensor

Horizontal Base Mounted Pump

Provides variable head pressure in a 2-way valve variable flow system

Modern Control with Differential Pressure Sensor

The building industry has transitioned to using variable speed pumps with two-way valves to achieve variable flow.

Today, a system is composed of the pump, VFD, sensor, and two way valve to control HVAC systems.

Energy Metering Capability

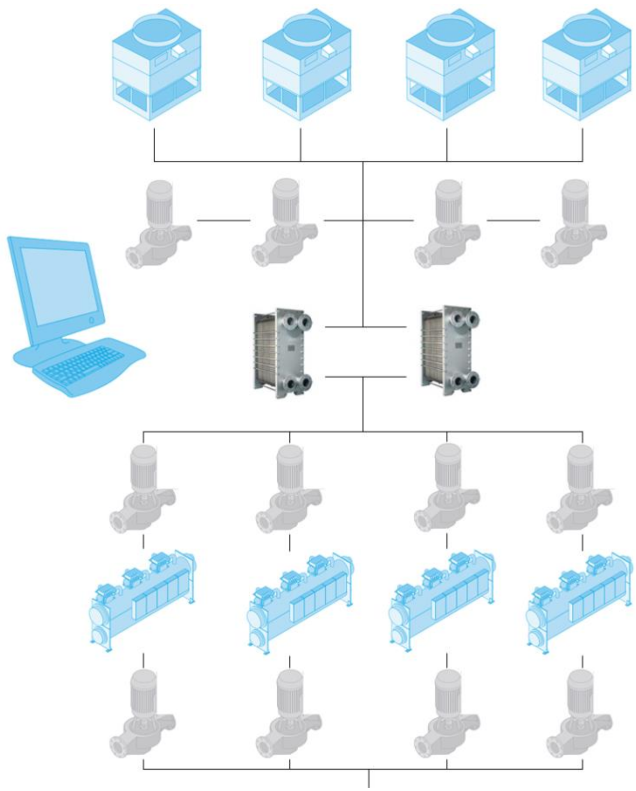
The Variable Speed Drive can be used:

As an energy meter for energy measurement verification, and

For trending analysis towards demand response

Traditional Chiller Plant Control
Process Set-point Based

BMS



Automation Sequence	Traditional Logic
Parallel equipment staging (up/down)	Capacity based sequencing
Equipment speed control	PID feedback control loops
Silo sub-system control	Ambient reset

Integrated Plant Control
Why Should You Be Interested?

Plant Annual energy Savings of **30-60%**

Annual Water Savings on the Cooling Tower of **7-12%**

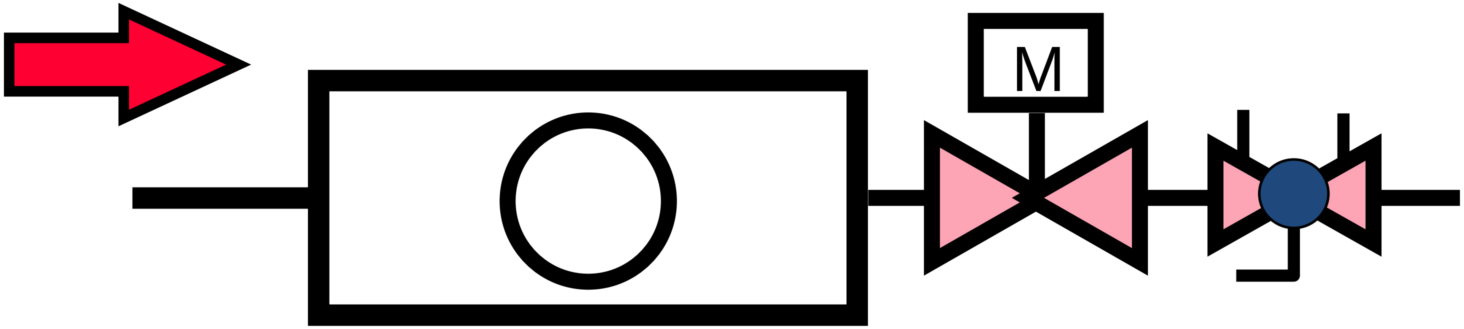
Longer Plant Equipment Life, **20-30%**

Protect your ROI with ECO*PULSE On-board Diagnostic Service saving **5-25%** annual energy costs

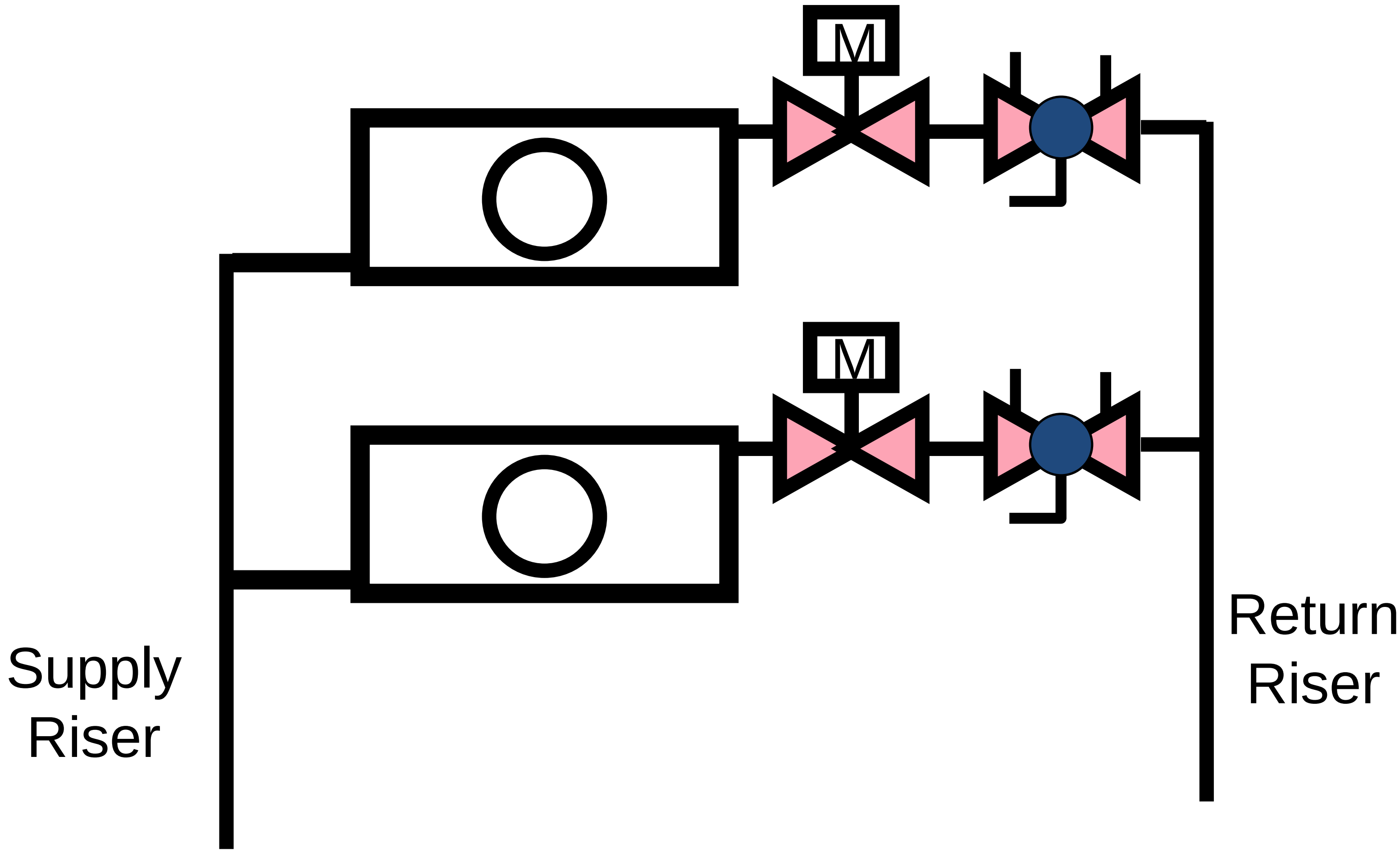
kW-hr	H2O	Life	ROI
↓	↓	↑	↑
30-60%	7-12%	20-30%	5-25%
$	$	$	$

Two-Way Valve Control

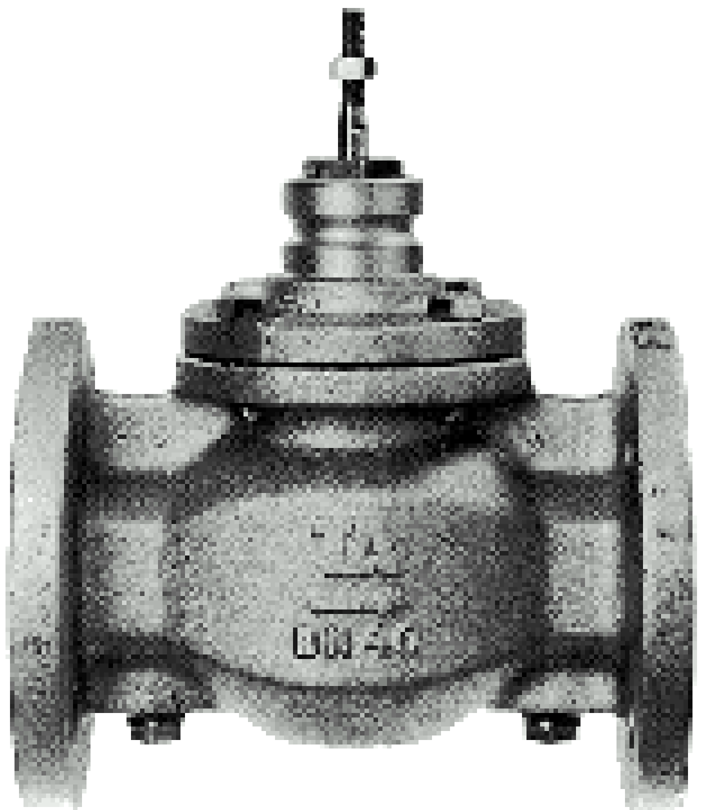
- Variable Flow Through Coil
- Variable Flow Through System

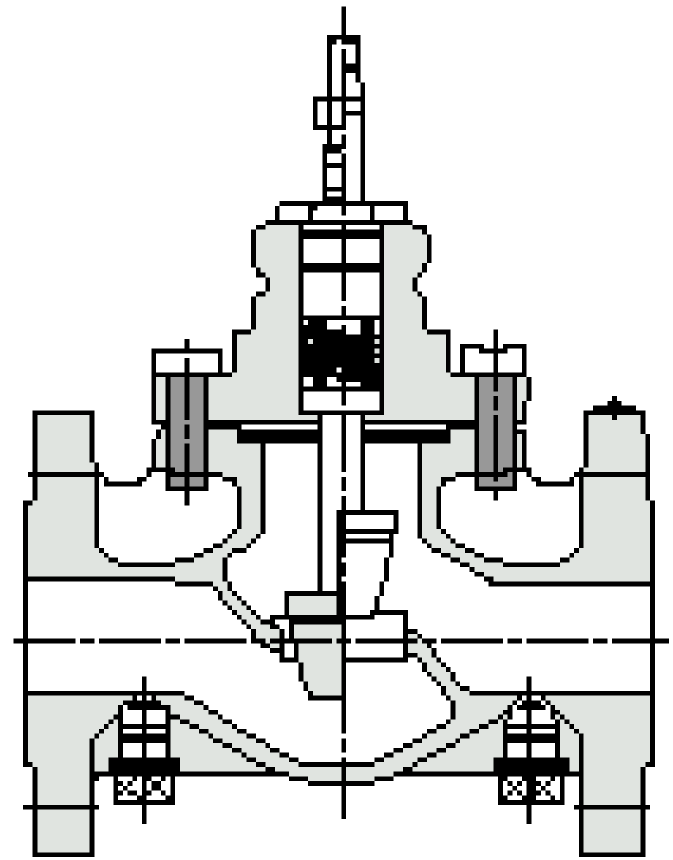


Two-Way Valve Balance

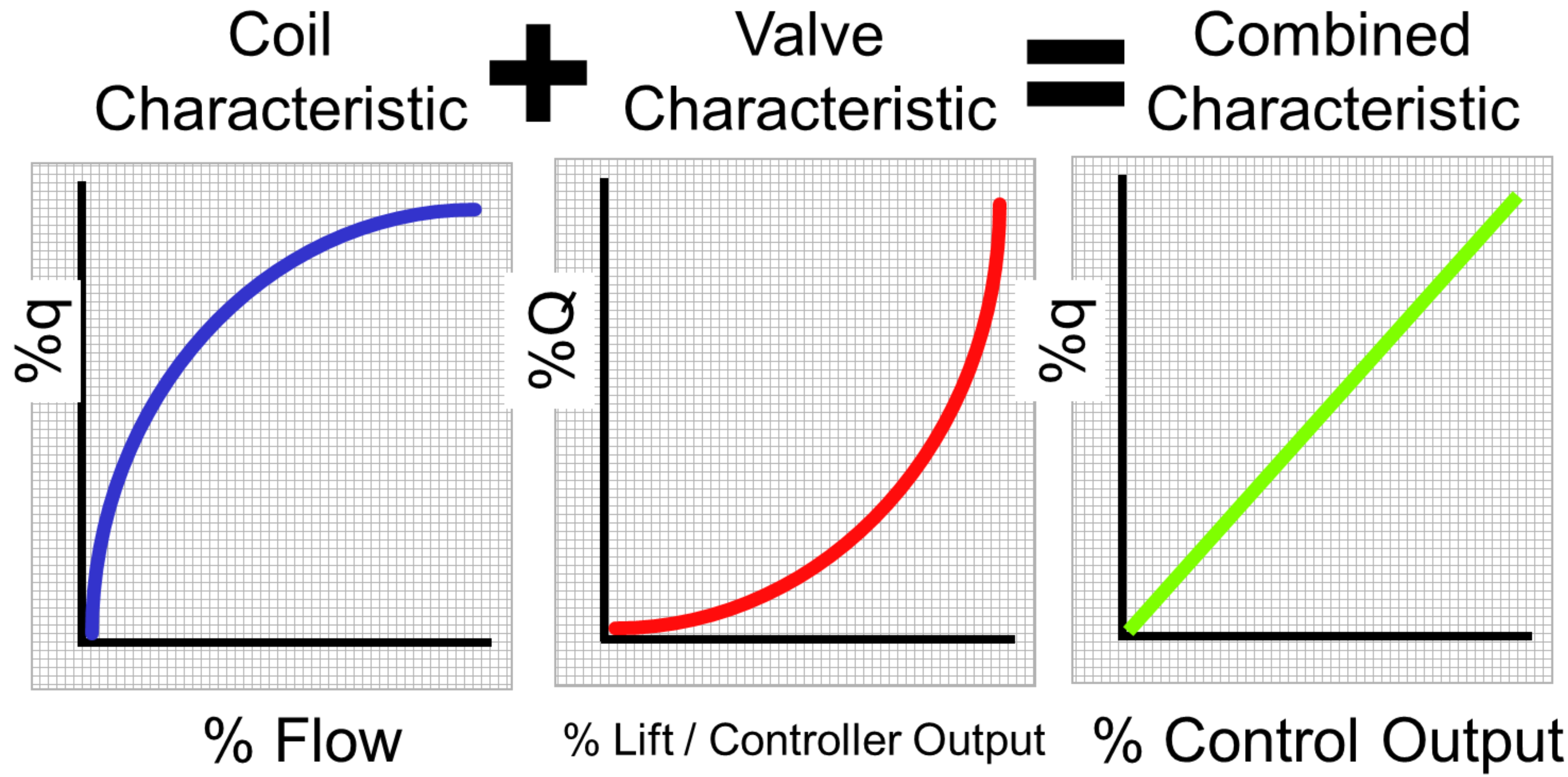


Linear Stem Valves - Globe Valve

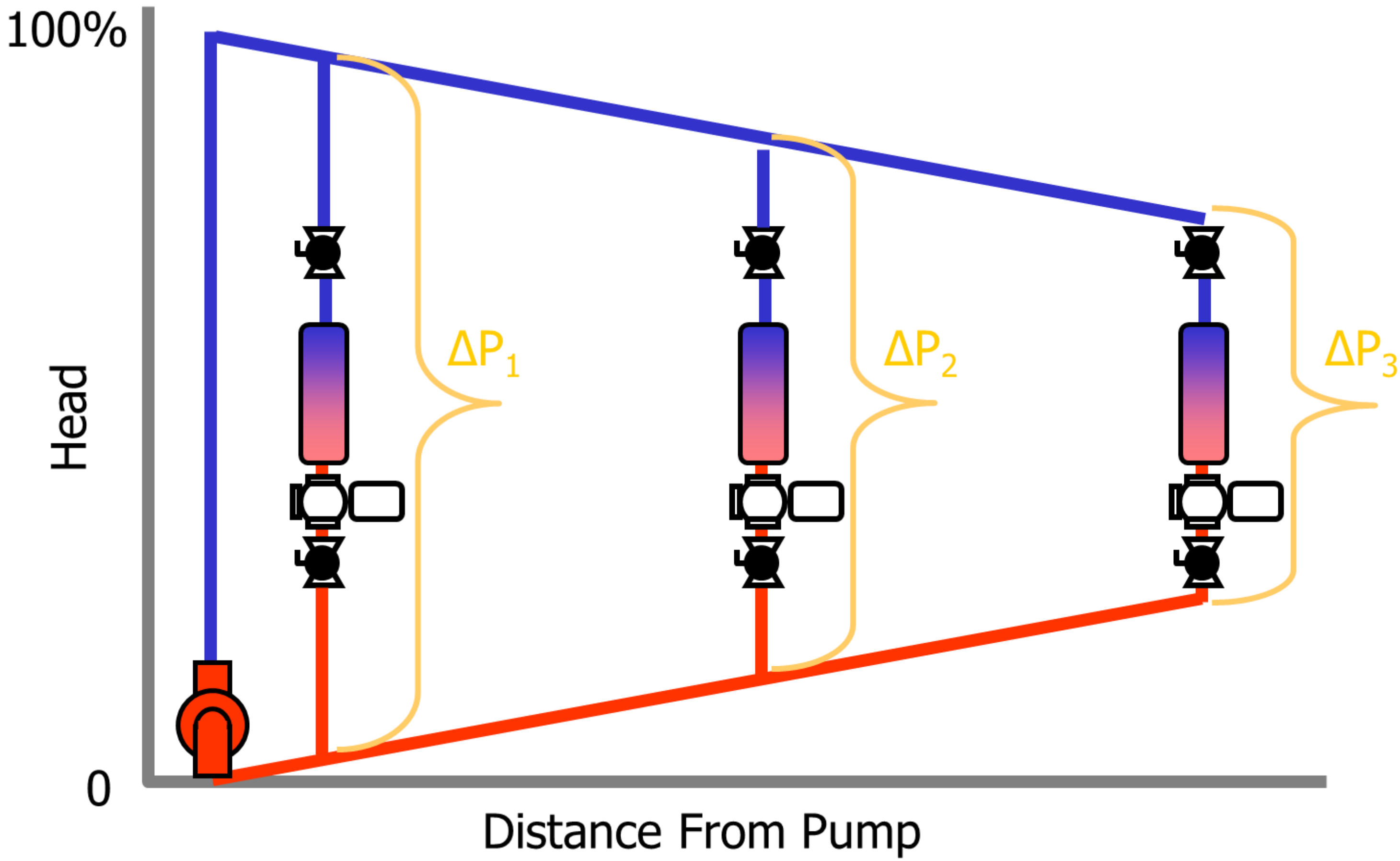




Control Valve Characteristics



Why Balance? Two-Pipe Direct Return Has Unequal Branch Differential Pressures



Flow Is Proportional To ΔP

If all branches require the same design pressure drop:

- Branch 1 gets more flow than 2 or 3
- Branch 2 or 3 may get less than design flow
- Design temperature drops aren’t as predicted
- System will use more pumping horsepower (more flow)

Balancing, The Obvious Answer

- Maximum branch flows need to be controlled
- Balancing valves are one solution
- Pressure independent flow control is another method
  - Prevents overflow conditions in branch

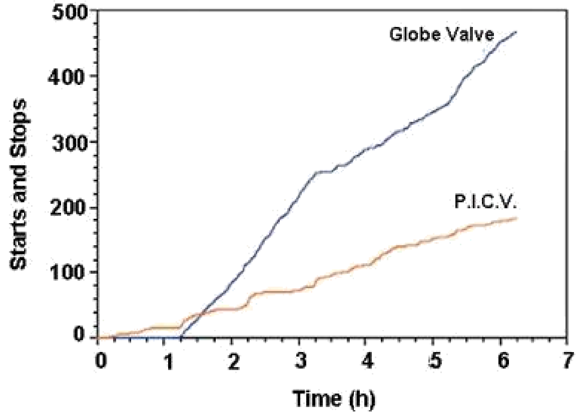
Achieving Flow Control

Two areas of concern:

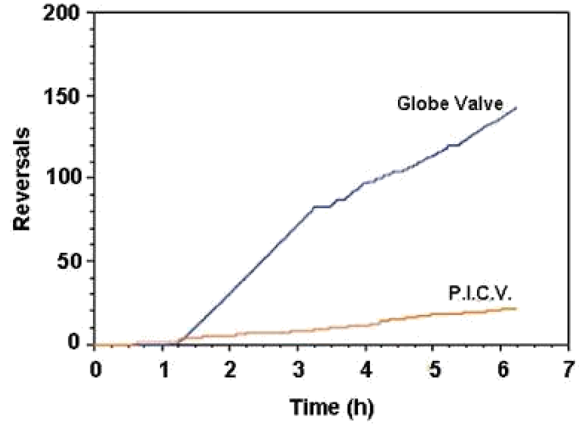
1. Obtaining accurate, stable control of flow in the design range
   - Responsibility – Modulating temperature control valve
2. Preventing excess flow
   - Responsibility – balance device

PICV vs Globe Valve in Operation

(Pressure Independent Control Valve)

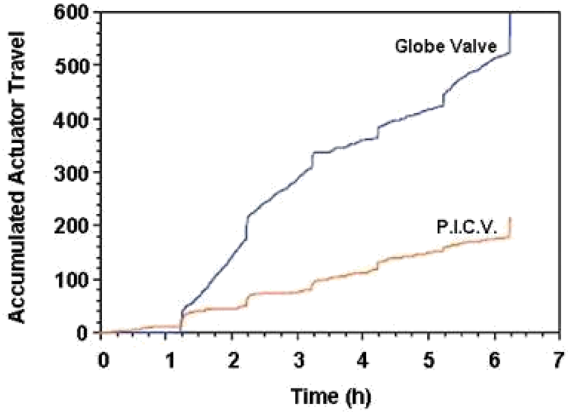


Accumulated Starts and Stops



Accumulated Actuator Reversals

Increased actuator travel and consequent over cooling/heating as the control valve hunts to find the right set point.



Accumulated Actuator Travel

Benefits of PICV

- Pressure Independent Control Valves maintain 100% authority at all times
- Improve system efficiency
- Lower system energy cost
- Provide stable flow and higher ΔT
- An integrated solution - replaces balance and temperature control valves

Takeaways

- Source Equipment
  - **Boilers – Condensing vs Non-condensing**
  - **Chillers – Centrifugal & Rotary Screw**
  - **Head Pressure Control**
- Cooling Towers/Economizer
  - **Good piping design**
  - **Integrated Waterside Economizer (Load Shaving)**
- Expansion Tanks
  - **Air Control vs Air Elimination**
  - **System pressure reference & PNPC**
  - **Cold fill pressure & thermal expansion**

Takeaways

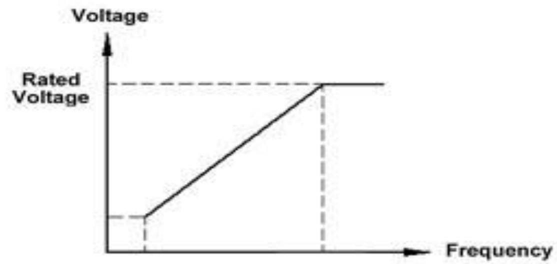
- Air Separators
  - **Install at low pressure and high temperature**
  - **Centrifugal & coalescing air separators**
- Heat Emitters (Fan coils, AHU)
  - **Coil characteristic curves**
- Control Valves
  - **Pressure Dependent vs Pressure Independent**
  - **Inherent Characteristic**
  - **Branch Authority**
- Balance Valves & Automatic Flow Limiters
  - **Pressure Dependent vs Pressure Independent**

Speed Range: Elements

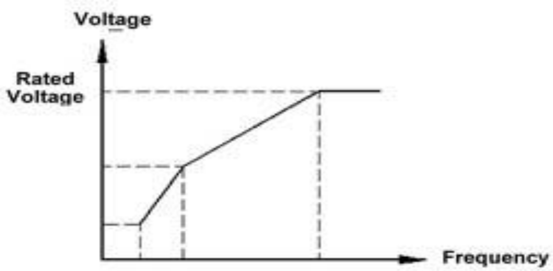
- VFD's typically offer a frequency range of 0 to 60 Hz normal speed. Most applications will only use a portion of the available frequency range.
- An application may only operate at one frequency, or it may operate throughout a range of frequencies, depending on process requirements.
- It is important to understand and define the range of variable speed required, as this may impact the sizing of VFD's and / or Motors.
- The Speed Range (turndown) of Pumps / Motors is usually specified as a ratio of nominal Motor synchronous speed to minimum speed.
- Basically simple division math
    - **2:1 (3600 – 1800 rpm), 4:1 (1800 to 450 rpm), 10:1 (3600 to 360 rpm), etc.**

Operating Principles

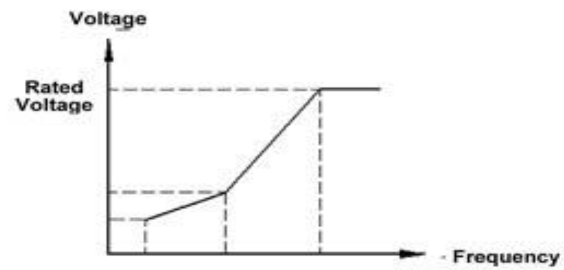
- When a VFD starts a motor, it initially applies a low frequency and voltage to the motor. The initial starting frequency is typically 2 Hz or less.
- The VFD will then ramp up the output frequency and voltage to a desired set point.



[Standard V/F Curve]



[When the startup torque is raised]



[When the startup torque is lowered]

Typical VFD Features

- Adjustable electronic motor overload
- Instantaneous over-current / short circuit protection
- Ground fault (motor circuit)
- Under / over voltage protection
- Under current (no flow / dry run)
- Surge arrestors
- Forward / Reverse operation without the use of contactors
- Multiple Acceleration and Deceleration ramp rates
- Critical frequency avoidance (skip frequencies)
- Multiple stopping modes: Coast, Ramp or Dynamic Brake
- Process variable control
- Power Filters (DC-Chokes, EMI filter, Harmonic filters)
- Programmable Logic Controller

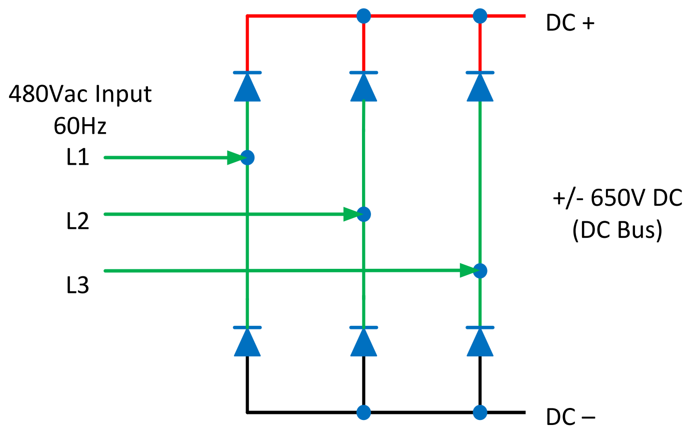
Application Considerations for VFDs

- Pump selection and operating speed range:
  - Verify that the operating points throughout the speed range meet the desired head and flow conditions.
- Maximum and minimum speeds:
  - Verify that the pump and motor can safely operate at these speeds and meet the requirements of the application. For instance, flow or pressure requirements.
- Motor Selection considerations: (Consult the motor manufacturer)
  - Distance motor is located from frequency drive
  - Motor winding insulation class
  - Bearings type: standard versus insulated bearings
  - Protection: Temperature, vibration, shaft grounding brushes
  - Hazardous locations

Application Considerations for VFDs

- Vibration:
  - Any critical / resonant frequencies to avoid
- Pump specific functions:
  - Cavitation protection, pipe fill, pipe burst, pipe blockage, deragging etc.
- Communication

VFD Selection Considerations



Voltage:

- What is the Voltage available on site?
- Does the VFD rated output V = Motor V?
- Single phase input?

Amps:

- Motor Full Load Amps: Is the VFD output rating sufficient?
- Motor Service Factor Amps: Will the motor run into the SF?
- Load type: Variable Torque (110%) or Constant Torque (150%)?

Environment:

- Temperature: Is Enclosure cooling or Heating needed?
- Ingress protection: Dust, moisture, corrosive gas?
- Elevation: More than 3,300ft above sea level?
- Hazardous location: Explosion proof?

VFD Selection Considerations

Motor cable length

- VFD output filters – to protect motors or to avoid nuisance tripping issues:
  - Output sine wave filters
  - dV/dt Filters
  - Common mode filters
- Consider the motor, pump, and drive as a complete system.

Power Source Harmonic level: IEEE 519

- Line reactors
- DC Link chokes
- Active or Passive Harmonic Filter
- 12, 18 or 24 pulse rectifier VFD
- Active front end VFD

VFD Selection Considerations

- Motor FLA amps are best (HP is not as accurate)
- Line Voltage & Phase (480v 3-phase or 230v single)
- Connected load type: Constant Torque / Variable Torque
- Enclosure requirements (NEMA 1, 12, 3R, 4 etc.)
- Motor Nameplate Data (full load current, rpm, etc.)
- Is motor insulation class 1000v or 1600v rated?
- Manual & automatic control signals
- Speed range. Ex. 0-60hz vs over-speeding to 70hz
- Duty Cycle requirements

Summary

- Pump systems are big energy users
- Follow the plan as outlined in this workshop
- Operating (energy) and maintenance comprise 83% of the Life Cycle Cost of a typical pump system
- Look beyond energy savings
- System assessment/optimization should Focus on improving the reliability/efficiency of the system

Thank you for your attendance