Pumps (and Piping)

Design, Performance and Commissioning Issues

Pipes, Valves, and Fittings

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Pipes, Valves and Fittings;

The *System* Part of the Phrase “Pumping System”

Pipe Materials

Pipe Comes in a Variety of Materials

- HVAC
  - Black Iron
  - Cast Iron
  - Copper
  - Brass
  - Plastic
  - Composite/Fiberglass
- Process
  - All the above
  - Stainless
  - Aluminum

Selection Depends On

- Service
- Exposure
- Cost

Pipe Sizes

Sizes are “Nominal”

- My or may not match the outside diameter
- May or may not match the inside diameter
- “Nominal” tends to vary with material
- Multiple wall thicknesses available for each size in most materials

Black Iron Pipe Data

Source - ASHRAE 2012 Systems and Equipment Handbook, Chapter 46, Pipe, Tubes, and Fittings, Table 2

Nominal Size, inches	Pipe OD, inches	Schedule Number or Weight[a]	Wall Thickness, inches	Inside Diameter, inches	Surface Area, square feet		Cross Section, square inches		Weight, pounds/foot		Working Pressure, ASTM A53 B to 400°F[c]		
					Outside, sq.ft.	Inside, sq.ft.	Metal Area	Flow Area	Pipe	Water	Mfg. Process	Joint Type[b]	Rating, psig
1/4	0.54	40 ST	0.088	0.364	0.141	0.095	0.125	0.104	0.424	0.045	CW	T	188
		80 XS	0.119	0.302	0.141	0.079	0.157	0.072	0.535	0.031	CW	T	871
3/8	0.675	40 ST	0.091	0.493	0.177	0.129	0.167	0.191	0.567	0.083	CW	T	203
		80 XS	0.423	0.177	0.111	0.217	0.141	0.738	0.061	CW	T	820	
1/2	0.84	40 ST	0.109	0.622	0.22	0.163	0.25	0.304	0.85	0.131	CW	T	214
		80 XS	0.546	0.22	0.143	0.32	0.234	1.087	0.101	CW	T	753	
3/4	1.05	40 ST	0.113	0.824	0.275	0.216	0.333	0.533	1.13	0.231	CW	T	217
		80 XS	0.742	0.275	0.194	0.433	0.432	1.47	0.187	CW	T	681	
1	1.315	40 ST	0.133	1.049	0.344	0.275	0.494	0.864	1.68	0.374	CW	T	226
		80 XS	0.957	0.344	0.251	0.639	0.719	2.17	0.311	CW	T	642	
1-1/4	1.66	40 ST	0.14	1.38	0.435	0.361	0.669	1.5	2.27	0.647	CW	T	229
		80 XS	1.278	0.435	0.335	0.881	1.28	2.99	0.555	CW	T	594	
1-1/2	1.9	40 ST	0.145	1.61	0.497	0.421	0.799	2.04	2.72	0.881	CW	T	231
		80 XS	1.5	0.497	0.393	1.068	1.77	3.63	0.765	CW	T	576	
2	2.375	40 ST	0.154	2.067	0.622	0.541	1.07	3.36	3.65	1.45	CW	T	230
		80 XS	1.939	0.622	0.508	1.48	2.95	5.02	1.28	CW	T	551	
2-1/2	2.875	40 ST	0.203	2.469	0.753	0.646	1.7	4.79	5.79	2.07	CW	W	533
		80 XS	2.323	0.753	0.608	2.25	4.24	7.66	1.83	CW	W	835	
3	3.5	40 ST	0.216	3.068	0.916	0.803	2.23	7.39	7.57	3.2	CW	W	482
		80 XS	2.9	0.916	0.759	3.02	6.6	10.25	2.86	CW	W	767	
4	4.5	40 ST	0.237	4.026	1.178	1.054	3.17	12.73	10.78	5.51	CW	W	430
		80 XS	3.826	1.178	1.002	4.41	11.5	14.97	4.98	CW	W	695	
6	6.625	40 ST	0.28	6.065	1.734	1.588	5.58	28.89	18.96	12.5	ERW	W	696
		80 XS	5.761	1.734	1.508	8.4	26.07	28.55	11.28	ERW	W	1209	
8	8.625	30	0.277	8.071	2.258	2.113	7.26	51.16	24.68	22.14	ERW	W	526
		40 ST	0.322	7.981	2.258	2.089	8.4	50.03	28.53	21.65	ERW	W	643
		80 XS	0.5	7.625	2.258	1.996	12.76	45.66	43.35	19.76	ERW	W	1106
10	10.75	30	0.307	10.136	2.814	2.654	10.07	80.69	34.21	34.92	ERW	W	485
		40 ST	0.365	10.02	2.814	2.623	11.91	78.85	40.45	34.12	ERW	W	606
		XS	0.5	9.75	2.814	2.552	16.1	74.66	54.69	32.31	ERW	W	887
		80	0.593	9.564	2.814	2.504	18.92	71.84	64.28	31.09	ERW	W	1081
12	12.75	30	0.33	12.09	3.338	3.165	12.88	114.8	43.74	49.68	ERW	W	449
		ST	0.375	12	3.338	3.141	14.58	113.1	49.52	48.94	ERW	W	528
		40	0.406	11.938	3.338	3.125	15.74	111.9	53.48	48.44	ERW	W	583
		XS	0.5	11.75	3.338	3.076	19.24	108.4	65.37	46.92	ERW	W	748
		80	0.687	11.376	3.338	2.978	26.03	101.6	88.44	43.98	ERW	W	1076
14	14	30 ST	0.375	13.25	3.665	3.469	16.05	137.9	54.53	59.67	ERW	W	481
		40	0.437	13.126	3.665	3.436	18.62	135.3	63.25	58.56	ERW	W	580
		XS	0.5	13	3.665	3.403	21.21	132.7	72.04	57.44	ERW	W	681
		80	0.75	12.5	3.665	3.272	31.22	122.7	106.05	53.11	ERW	W	1081
16	16	30 ST	0.375	15.25	4.189	3.992	18.41	182.6	62.53	79.04	ERW	W	421
		40 XS	0.5	15	4.189	3.927	24.35	176.7	82.71	76.47	ERW	W	596
18	18	ST	0.375	17.25	4.712	4.516	20.76	233.7	70.54	101.13	ERW	W	374
		30	0.437	17.126	4.712	4.483	24.11	230.3	81.91	99.68	ERW	W	451
		XS	0.5	17	4.712	4.45	27.49	227	93.38	98.22	ERW	W	530
		40	0.562	16.876	4.712	4.418	30.79	223.7	104.59	96.8	ERW	W	607
20	20	20 ST	0.375	19.25	5.236	5.039	23.12	291	78.54	125.94	ERW	W	337
		30 XS	0.5	19	5.236	4.974	30.63	283.5	104.05	122.69	ERW	W	477
		40	0.593	18.814	5.236	4.925	36.15	278	122.82	120.3	ERW	W	581

a. Numbers are schedule numbers per ASME Standard B36.10M; ST = Standard Weight; XS = Extra Strong.

b. T = Thread; W = Weld

c. Working pressures were calculated per ASME B31.9 using furnace butt-weld (continuous weld, CW) pipe through 4 in. and electric resistance weld (ERW) thereafter. The allowance A has been taken as:

(1) 12.5% of t for mill tolerance on pipe wall thickness, plus

(2) An arbitrary corrosion allowance of 0.025 in. for pipe sizes through NPS 2 and

(3) A thread cutting allowance for sizes through NPS 2.

Because the pipe wall thickness of threaded standard pipe is so small after deducting allowance A, the mechanical strength of the pipe is impaired. It is good practice to limit standard weight threaded pipe pressure to 90 psig for steam and 125 psig for water.

Pipe Joints

Most materials can be joined by a number of methods

- Threads
- Solder
- Braze
- Welding
- Flanges
- Grooved joints
  - Different gaskets for different applications
  - Color = Intended use

Pipe Joints

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- Flanges
- Grooved joints
  - Different gaskets for different applications
  - Color = Intended use
- Flare joints
- Compression joints

Selection determined by

- Material
- Service
- Exposure
- Cost/labor
  - Example – Typical welded joint
    - Cut to length
    - Bevel
    - Align and gap
    - Tack
    - Weld
      - Multiple passes ($c=\pi d$)
      - Chip out flux after each pass

Fitting Pressure Losses

- Fitting pressure losses are also related to velocity
- Commonly used tables have their roots in work that has it's origins in the late 1800's and early 1900's
- Recent ASHRAE research demonstrates
  - Some variation from classic values
  - Fittings in series interact to *reduce* the pressure drop compared to the sum of the losses

$$\Delta h = K \times \left(\frac{V^2}{2 \times g} \right)$$

Where :

Δh = Head loss in ft.w.c.

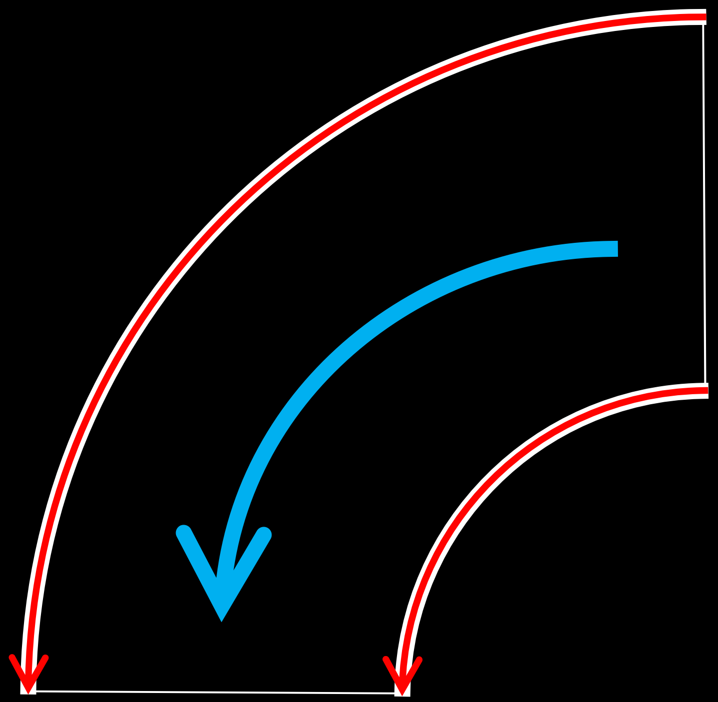
K = Geometry and size dependent loss coefficient

g = Acceleration due to gravity in ft. per sec.^{2}

V = Average velocity in ft. per sec.

- Losses may also be expressed as equivalent feet of pipe
- A common rule of thumb is to estimate the fittings losses as adding another 50% to 100% to the actual length of pipe

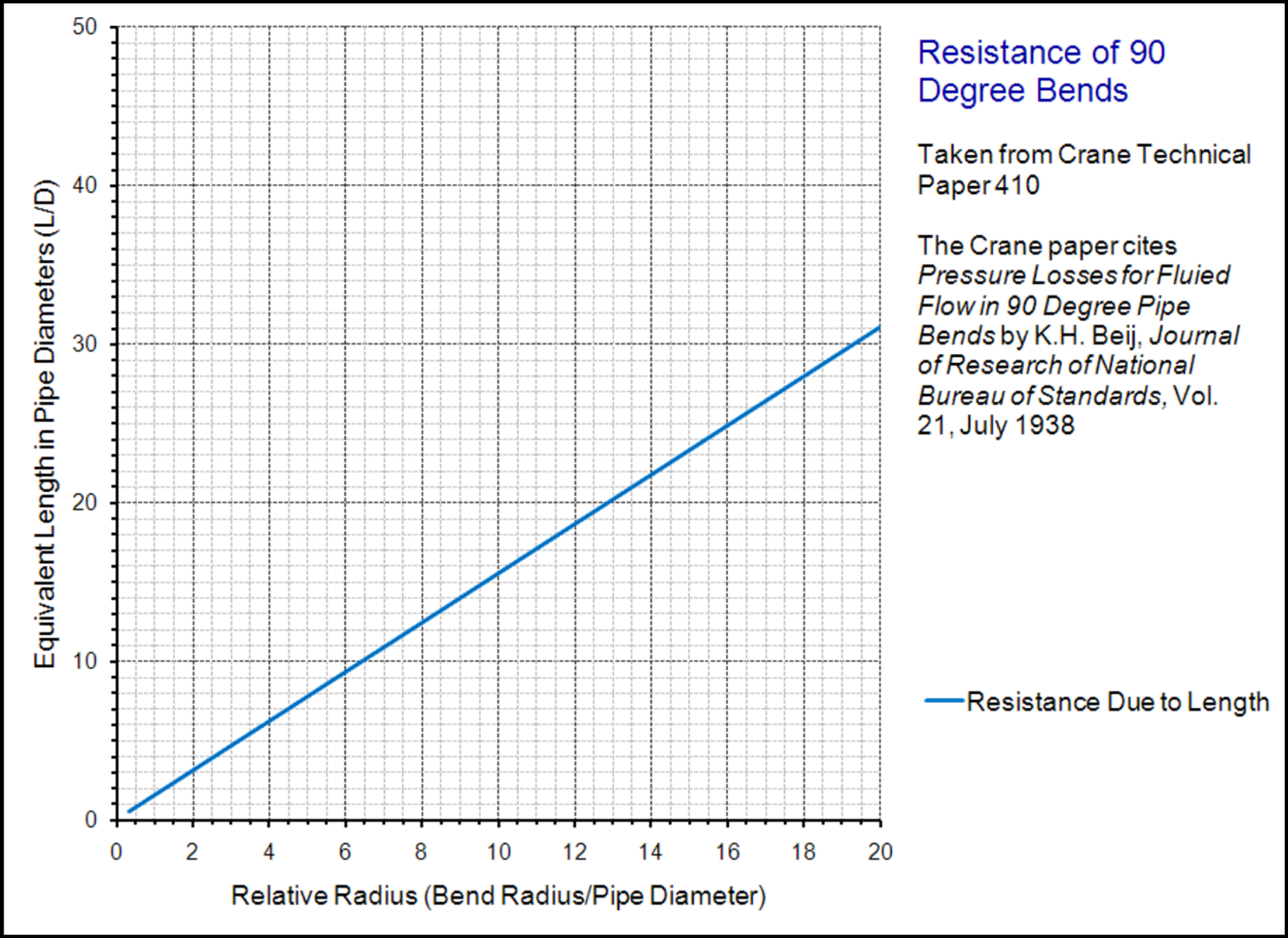
An Interesting Thing about Elbows



One way to think of elbow resistance is to consider it as composed of:

1. Resistance due to interaction with the pipe wall
2. Resistance due to a change in direction

An Interesting Thing about Elbows



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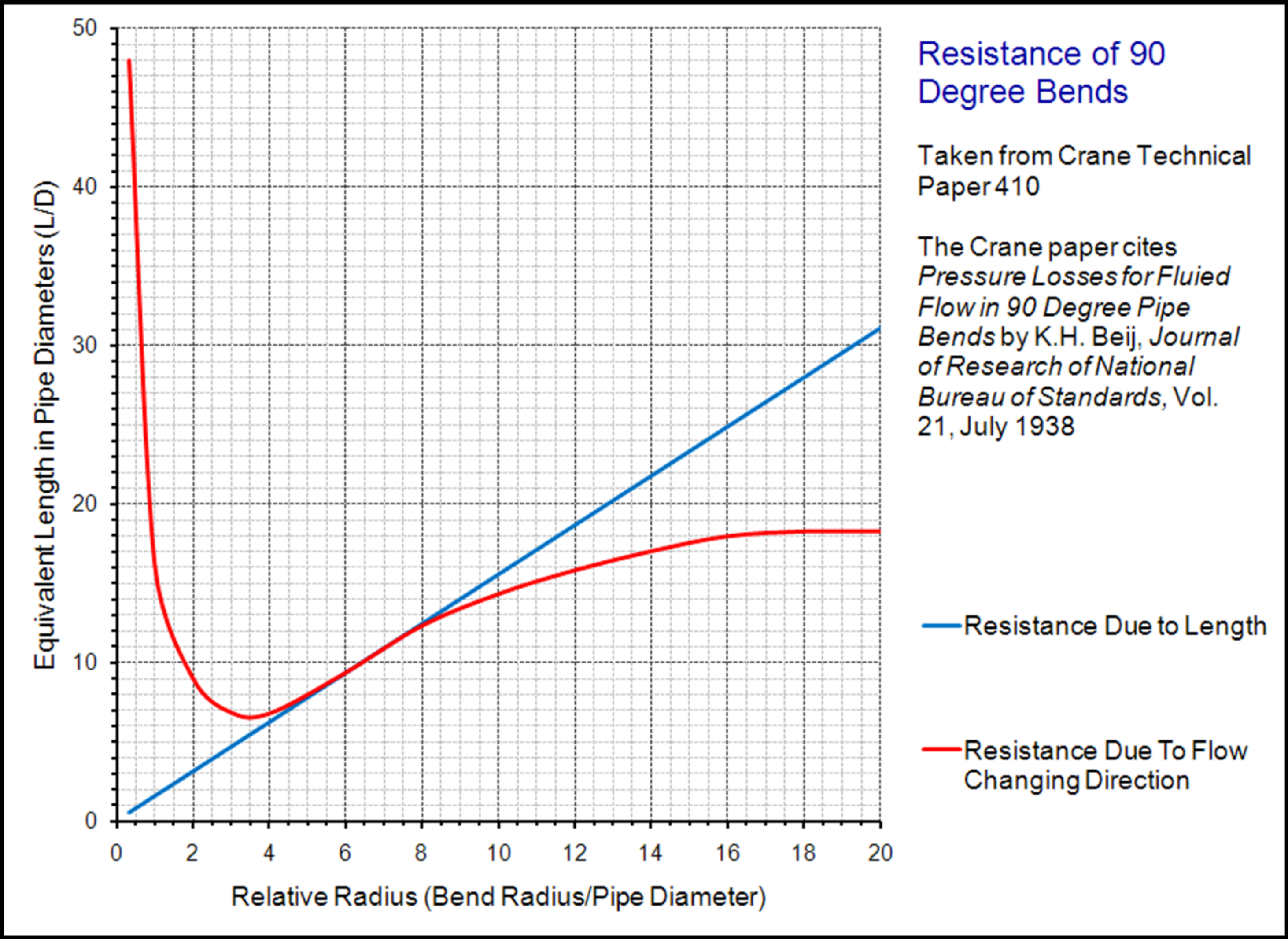

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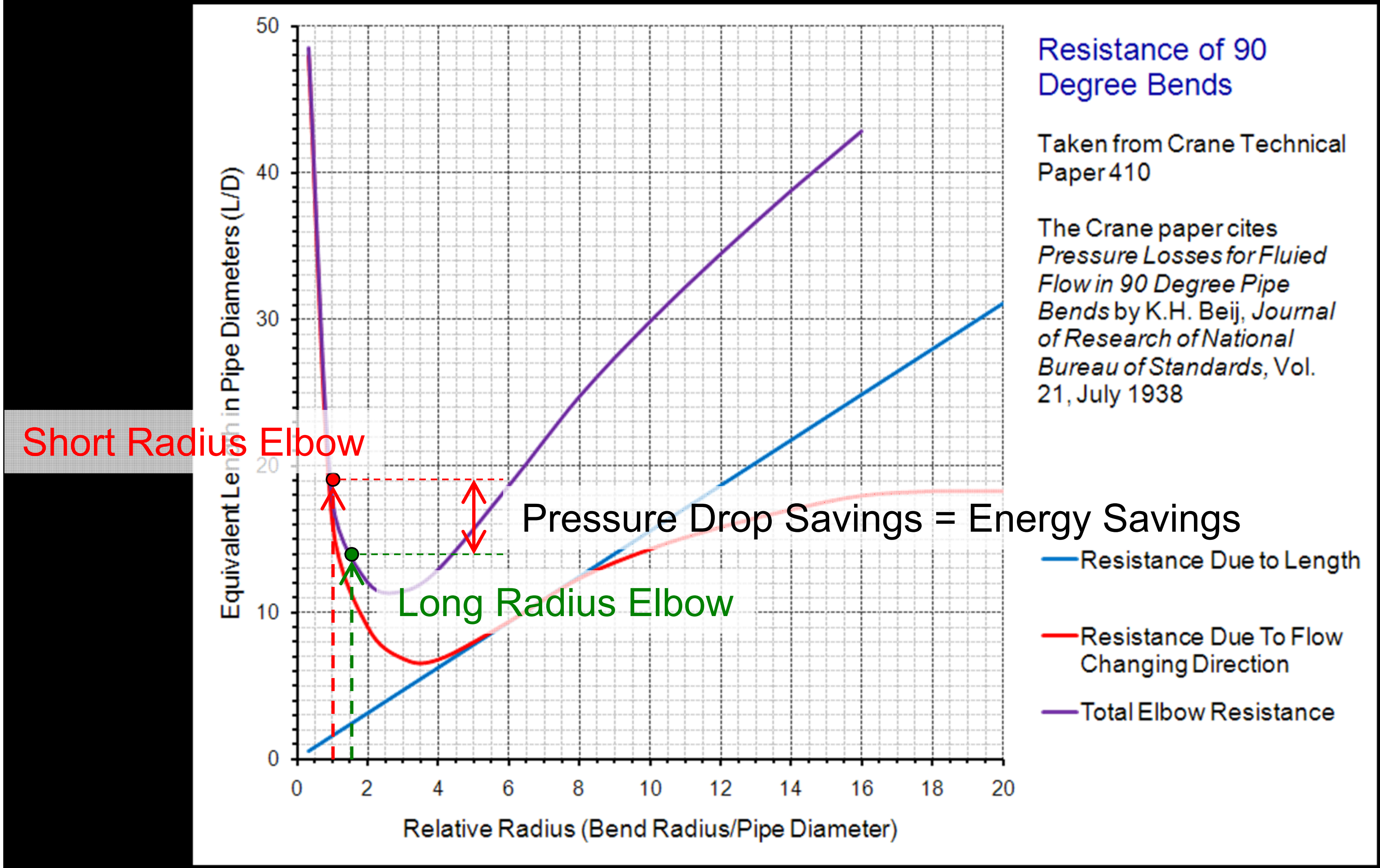
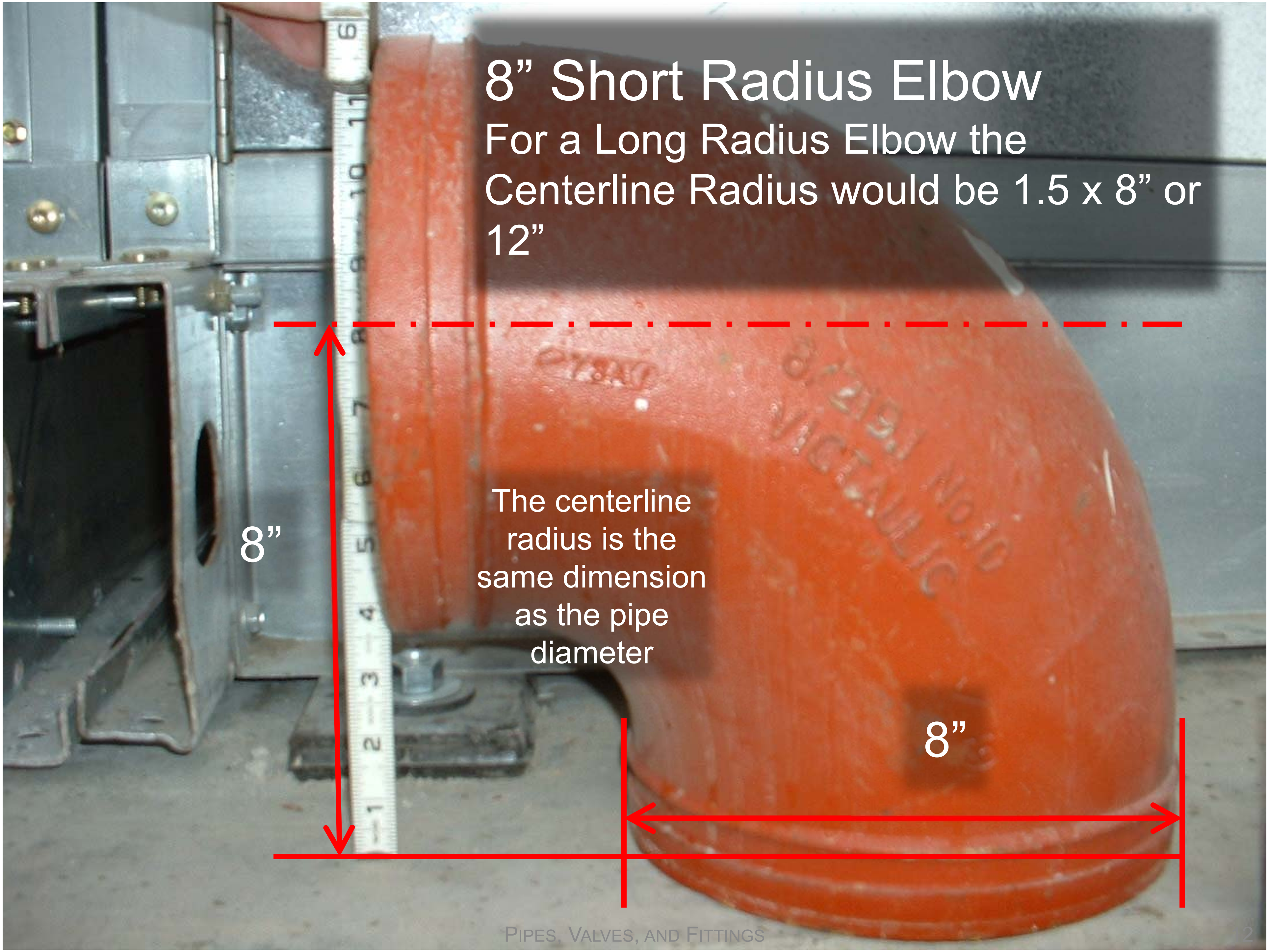



8” Short Radius Elbow
For a Long Radius Elbow the Centerline Radius would be 1.5 x 8” or 12”
The centerline radius is the same dimension as the pipe diameter
8”
8”
VICTAULIC

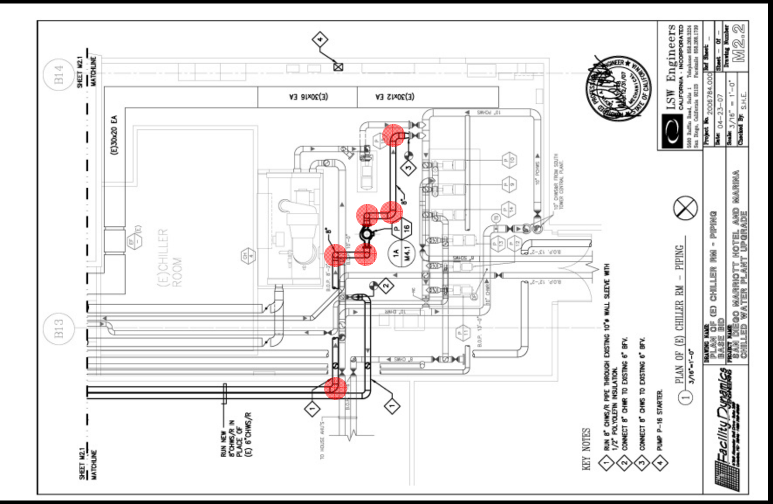
Short Radius vs. Long Radius Elbows

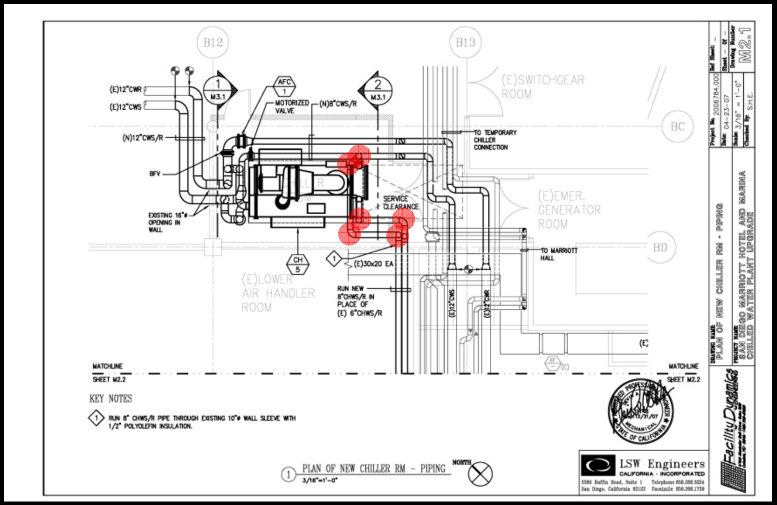
Small differences can add up to significant numbers

Number of elbows = 26

Difference in head for the circuit with long radius versus short radius elbows

- 3+ ft.w.c.
- 9+% difference in pump head (A.K.A. the safety factor)
- .8+ kW
- 7,100 kWh annually

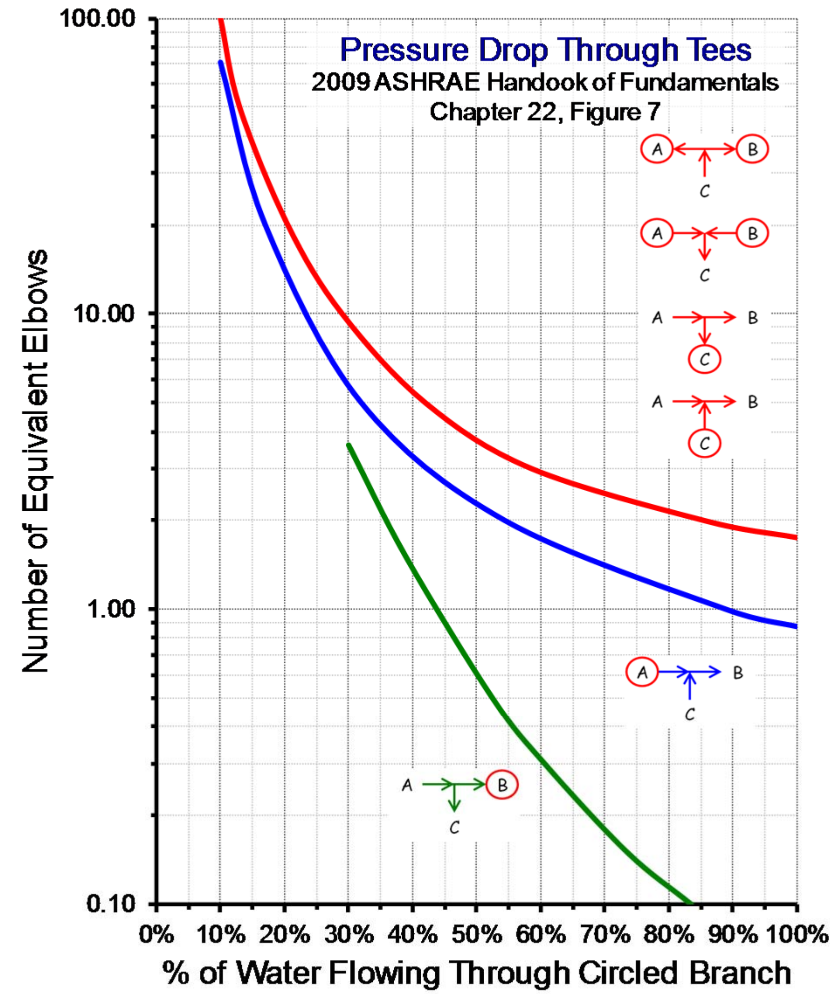




Tees are Interesting Too

Different Flow Paths = Significantly Different Pressure Drops

- Bad thing if you are trying to minimize losses
  - Branching points in distribution mains
  - Areas where noise might be critical
- Good thing if you are trying to balance flow between branches
  - Balancing flow to cooling tower cells
  - Balancing flow to coil banks

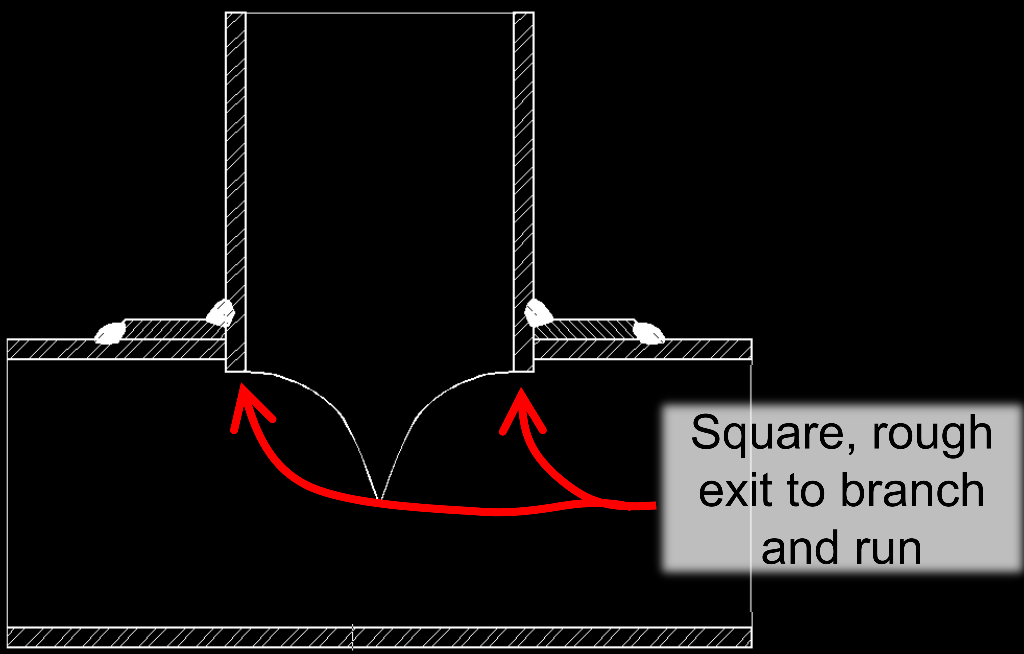


Notes:

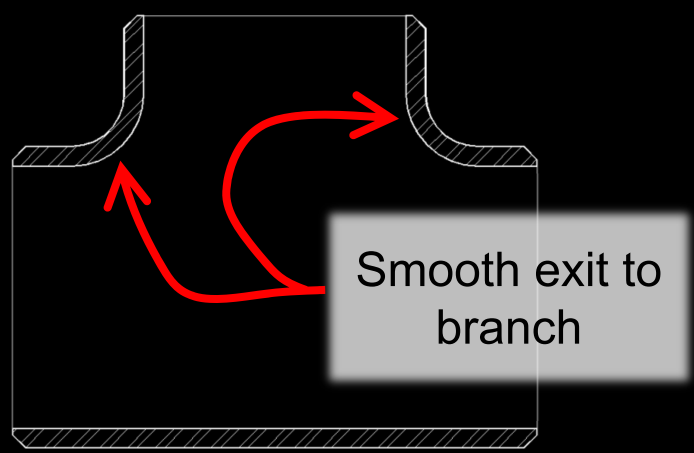
1. Chart is based on straight tees (i.e., branches A, B, and C are the same size).
2. Pressure loss in desired circuit is obtained by selecting the proper curve according to illustrations, determining the flow at the circled branch, and multiplying the pressure loss for the same size elbow at the flow rate in the circled branch by the equivalent elbows indicated.
3. When the size of an outlet is reduced, the equivalent elbows shown in the chart do not apply. Therefore, the maximum loss for any circuit for any flow will not exceed 2 elbow equivalents at the maximum flow occurring in any branch of the tee.
4. Top curve is average of 4 curves, one for each circuit shown.
5. Data from Giesecke and Badgett 1931, 1932.

Construction Impacts Loss Too

Field Fabricated Tee



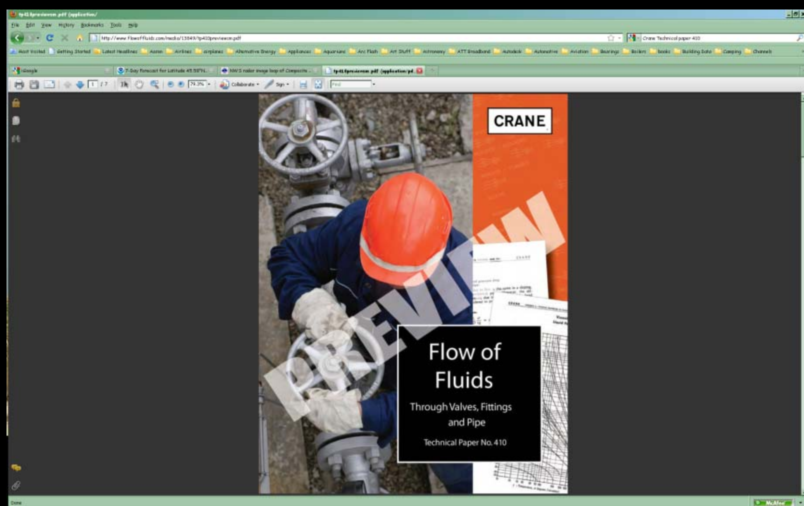
Factory Forged Tee

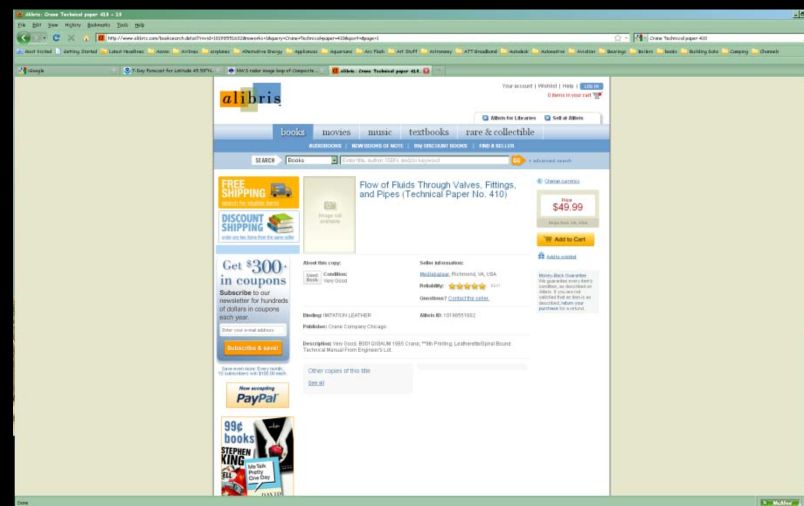


Fittings and Flanges have Pressure Ratings

Pressure Class and Rated Pressure May Not be the Same

Crane Technical Paper 410





Available new for $60 at:

http://www.flowoffluids.com/publications/crane-tp-410.aspx

Available used from $49.99 and up at various used book stores

Service Valves

- Intended to isolate things for service or repair
- Open or Closed
- Bubble Tight shut-off may be important

Gate Valve

Service Valves

- Intended to isolate things for service or repair
- Open or Closed
- Bubble Tight shut-off may be important

Ball Valve

Service Valves

- Intended to isolate things for service or repair
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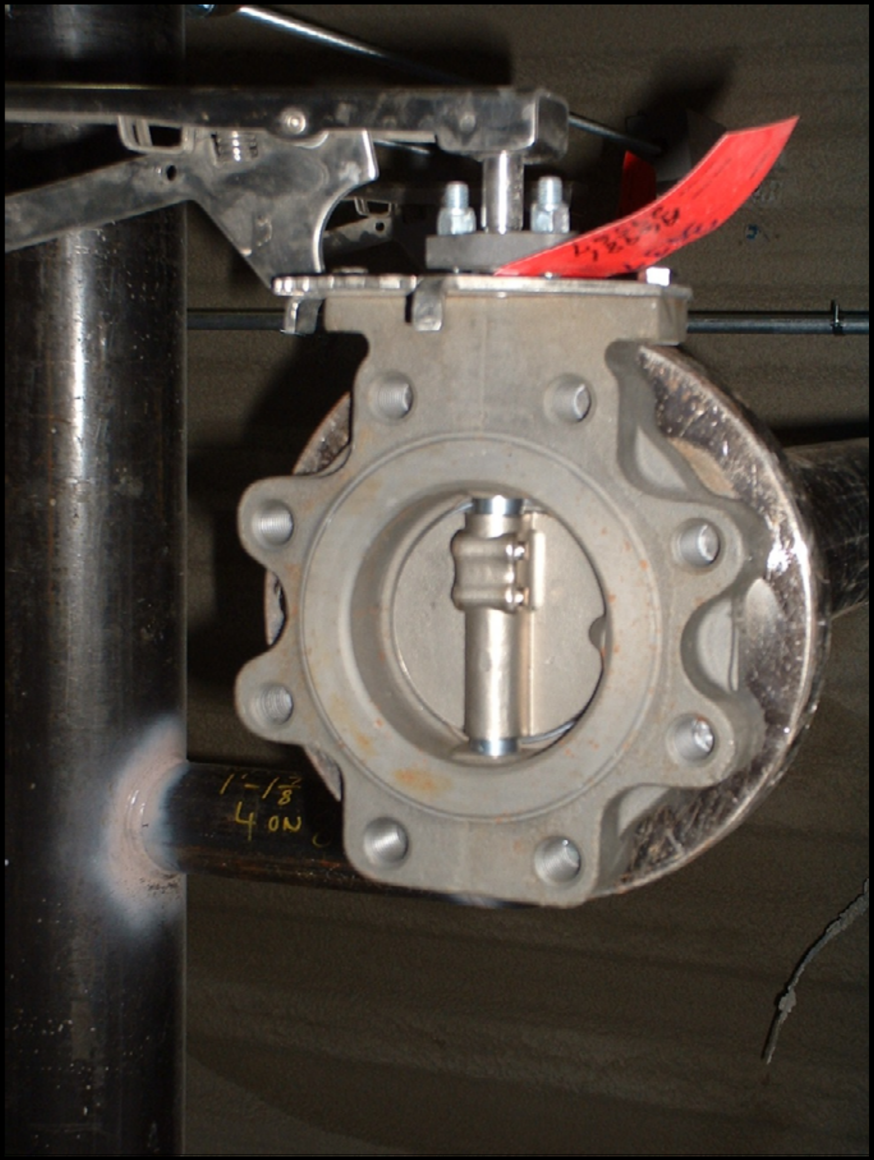

Lug Style Butterfly Valve

Service Valves

- Intended to isolate things for service or repair
- Open or Closed
- Bubble Tight shut-off may be important

Plug Valve

Throttling Valves

- Intended to be used to modulate flow
- Can be “On-Off” but can also have intermediate positions
- Most throttling valves can be used as service valves …
  - Ball valve
  - Butterfly valve
  - Plug valve

  … but not all service valves can be throttling valves
  - Gate valve

Plug Valve

Throttling Valves

- Control valves are automated throttling valves
  - Come in a variety of styles
    - Globe
    - Butterfly
    - Ball
    - Plug
  - Come in a variety of actuator types
    - Pneumatic
      - Piston
      - Diaphragm
    - Electric
      - Gear motor
      - Linear screw
- Need to be properly sized for modulating control
  - Rule of thumb – smaller than the line size

Globe Type Control Valve

Throttling Valves

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    - Butterfly
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- Need to be properly sized for modulating control
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Wafer Style Butterfly Control Valve with Double Acting Pneumatic Actuator

Throttling Valves

- Balancing valves are manually adjusted characterized throttling valves
  - Flow coefficient calibrated to valve position
  - Pressure taps allow valve pressure drop to be measured
  - Pressure drop and flow coefficient can be used to determine flow rate

Bell and Gossett “Circuit Setter” type balance valve

Throttling Valves

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Data logging across a “Circuit Setter” to develop a flow profile

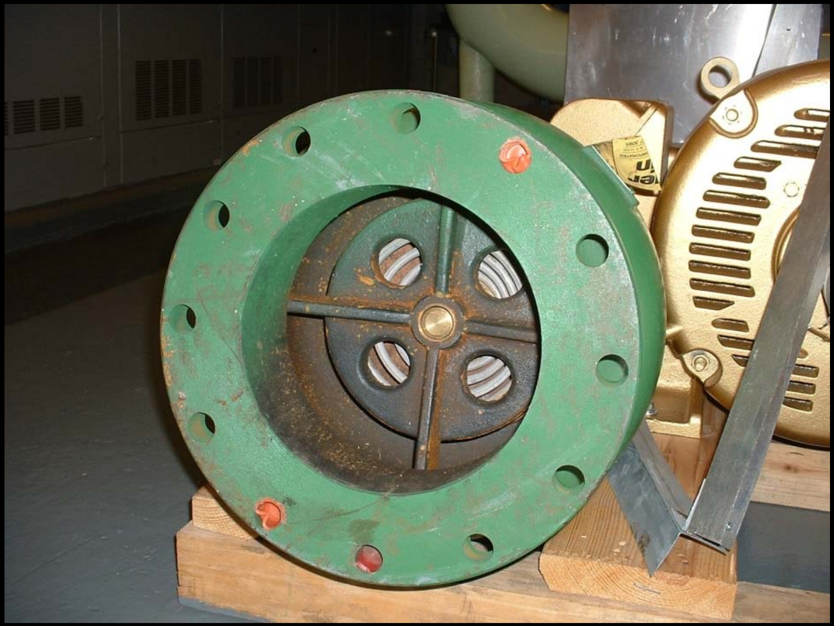
Check Valves

- Intended to prevent reverse flow
- Typically found on the discharge of pumps, especially parallel pumps

Swing Type Check Valve

Check Valves

- Intended to prevent reverse flow
- Typically found on the discharge of pumps, especially parallel pumps



Wafer Type Check Valve – Outlet

Check Valves

- Intended to prevent reverse flow
- Typically found on the discharge of pumps, especially parallel pumps

Wafer Type Check Valve – Inlet

Check Valves

- Intended to prevent reverse flow
- Typically found on the discharge of pumps, especially parallel pumps
- Directional; if you put it in backwards, it won't do its job

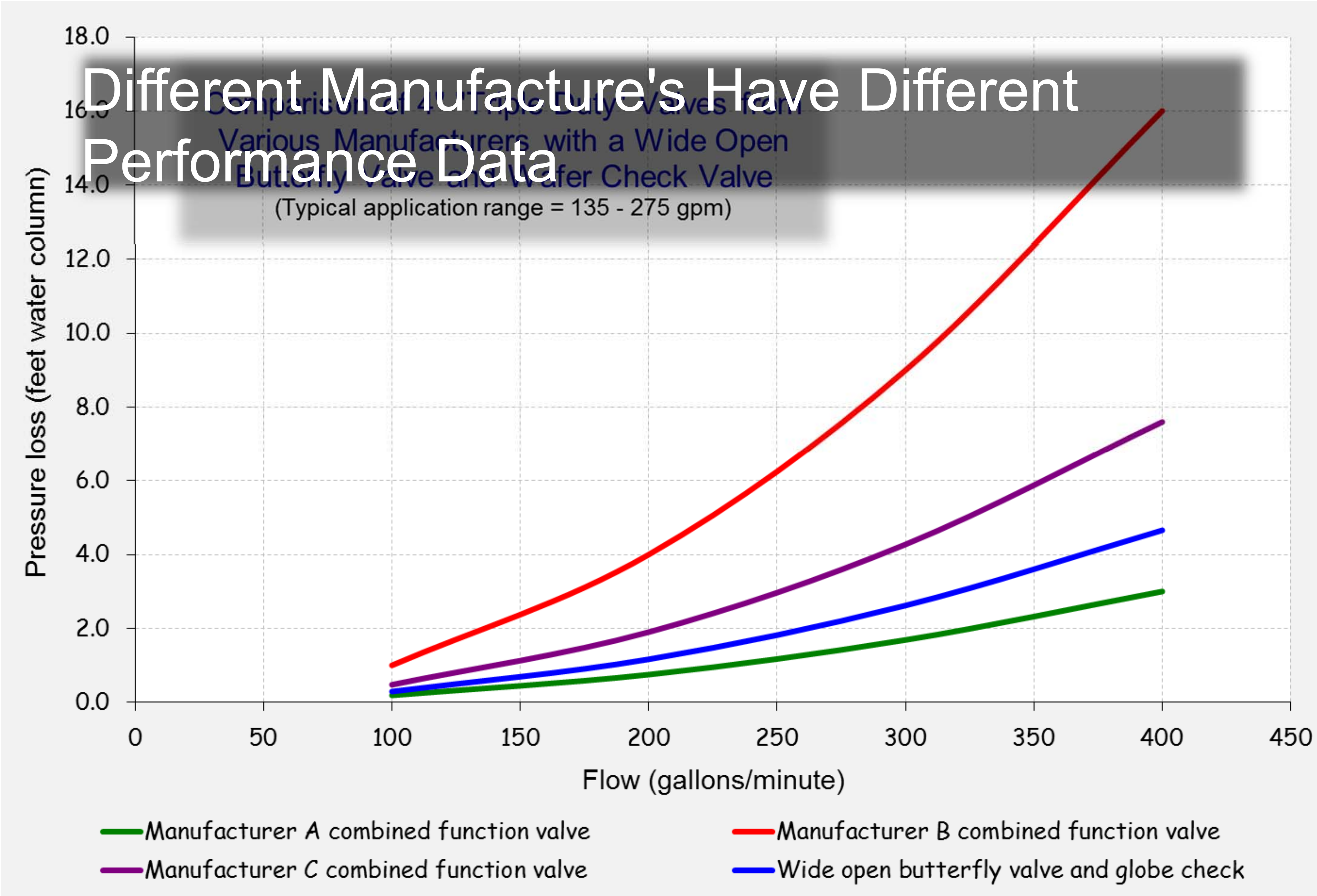
Wafer Type Check Valve – Note Directional Arrow

Valves with Multiple Functions

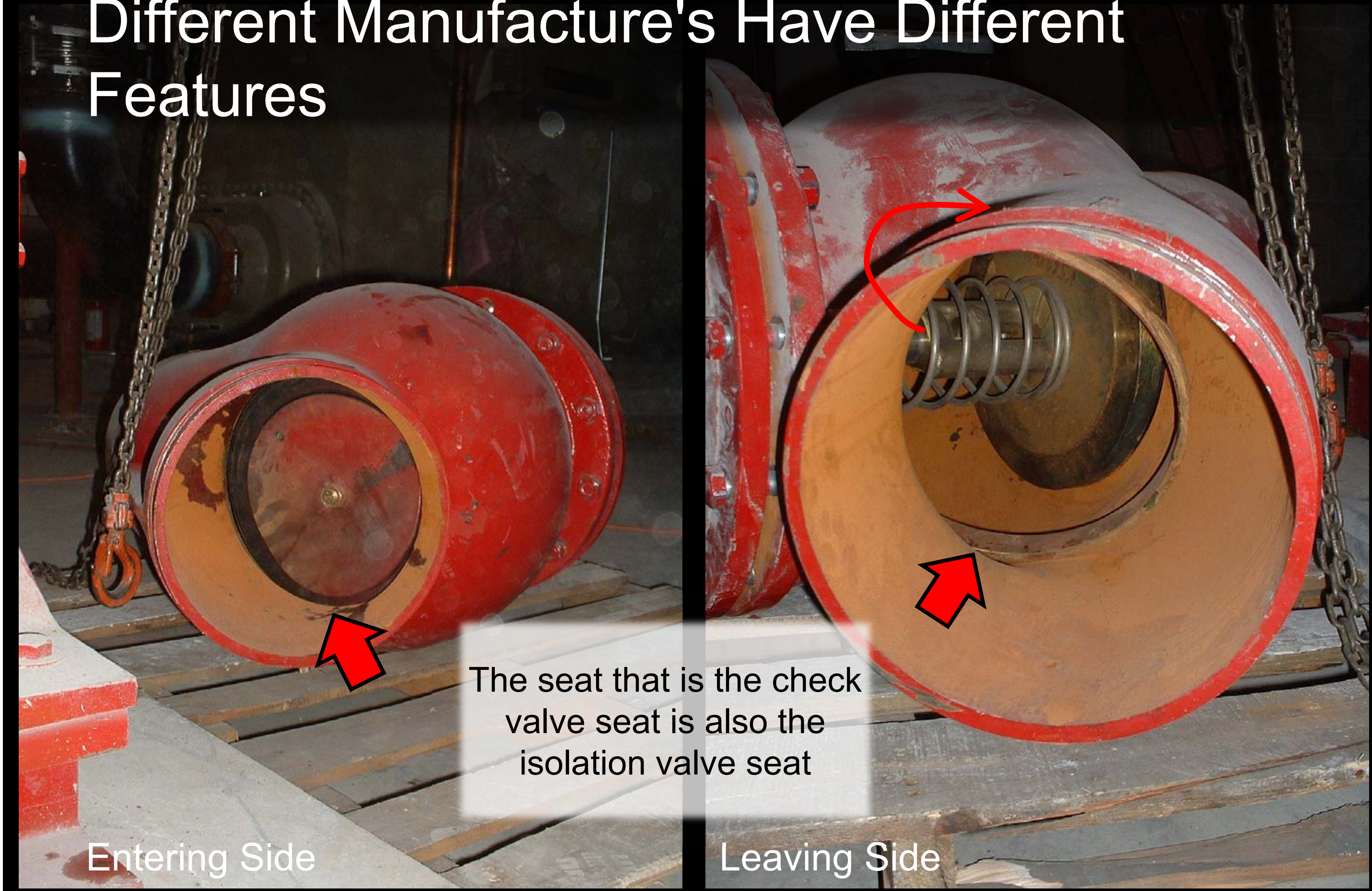
“Triple Duty” Valves

- Throttling
- Isolation
- Check valve

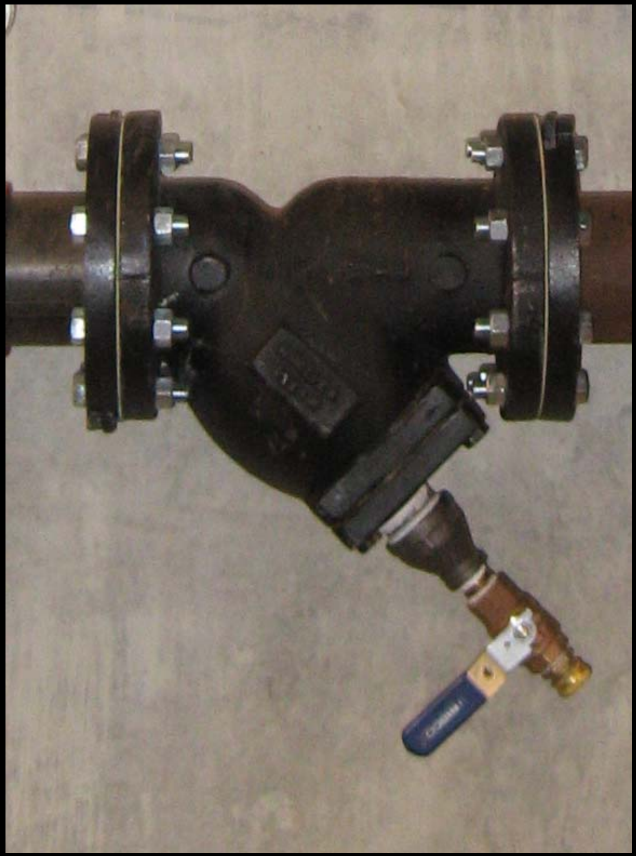
Different Manufacture's Have Different Performance Data

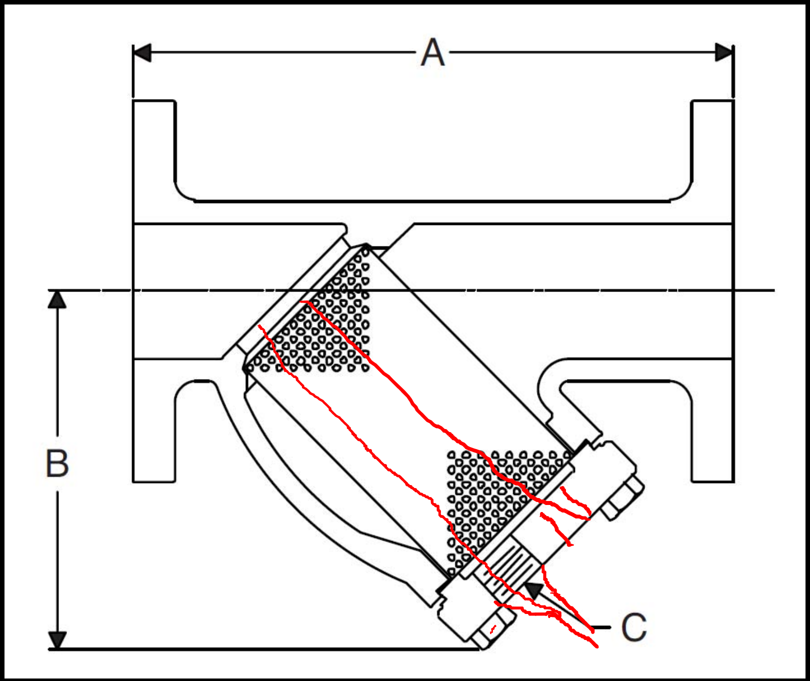


Different Manufacture's Have Different Features



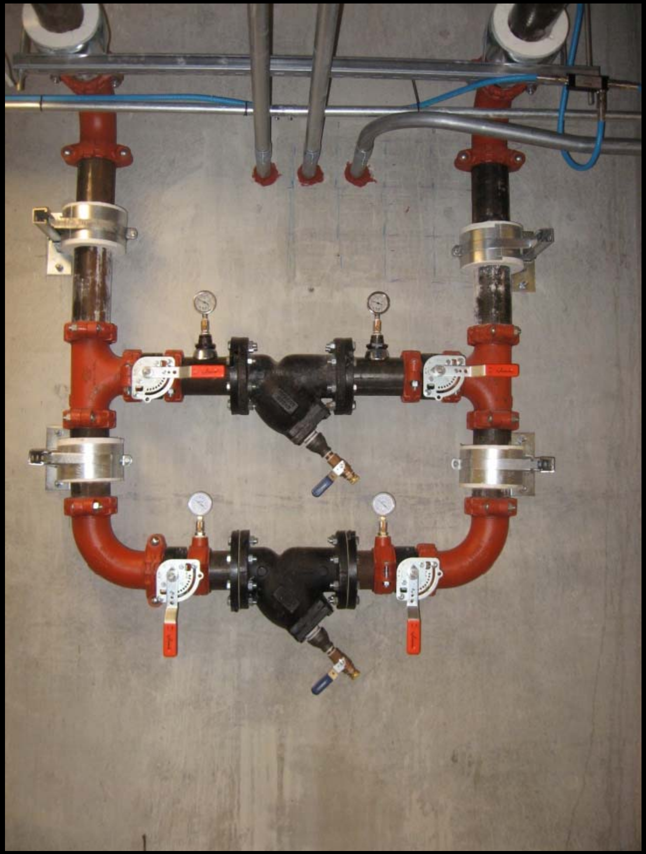
Strainers;
Details Matter

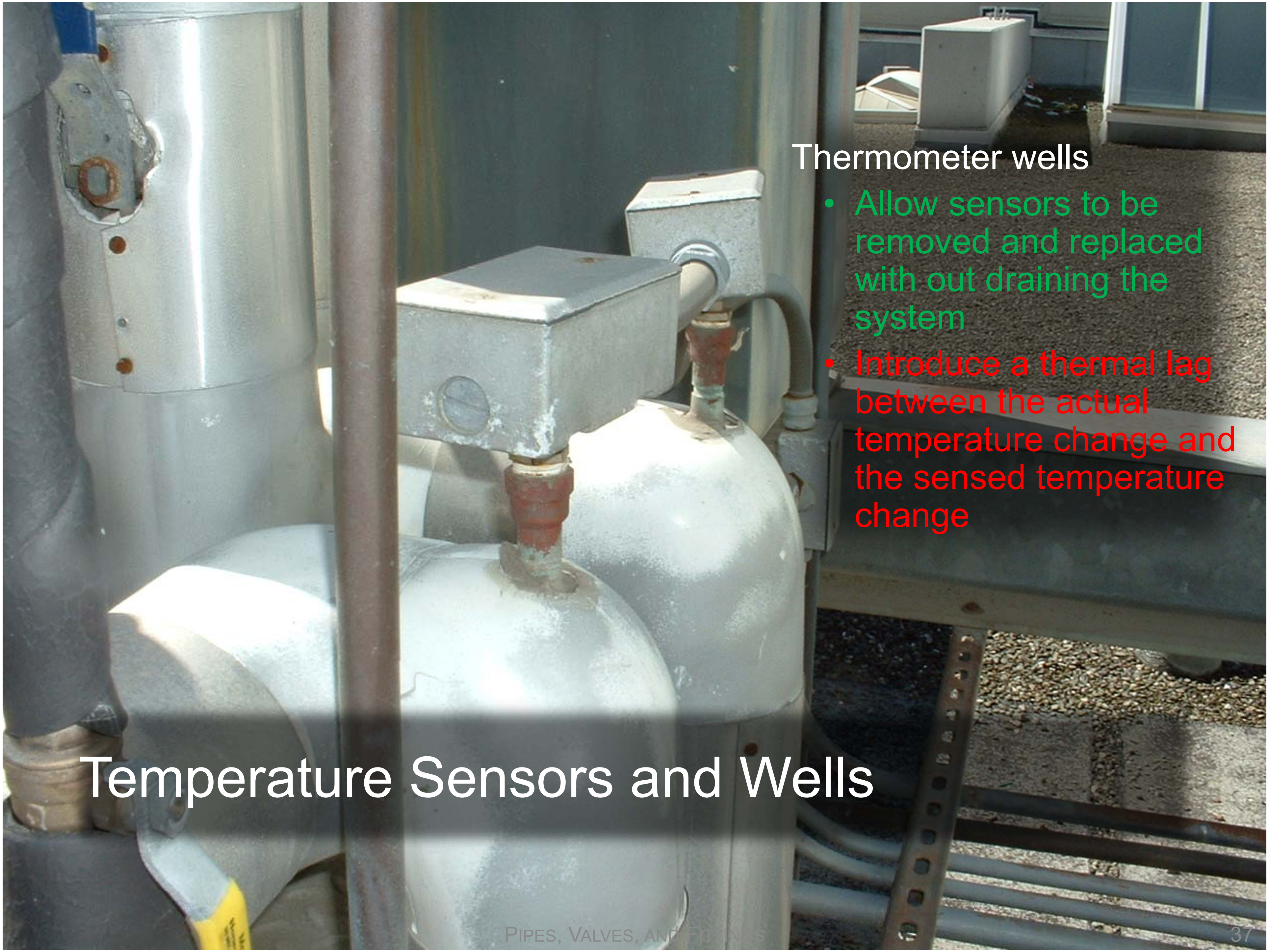




What happens if you put a reducer on the outlet or flip the cover plate so the outlet is on top vs. on the bottom?

Redundant Strainers Allow Uninterrupted Service





Thermometer wells

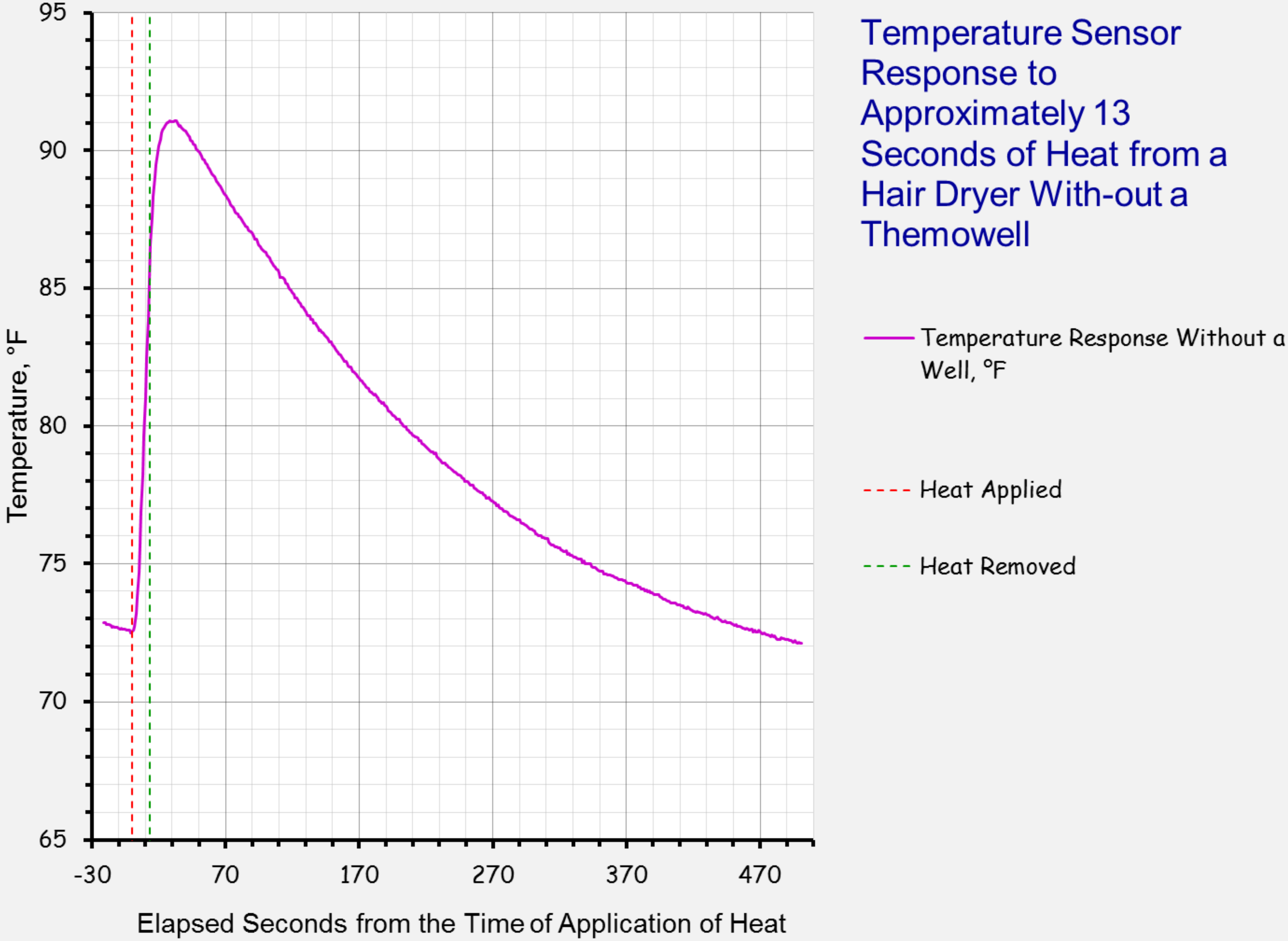
- Allow sensors to be removed and replaced with out draining the system
- Introduce a thermal lag between the actual temperature change and the sensed temperature change

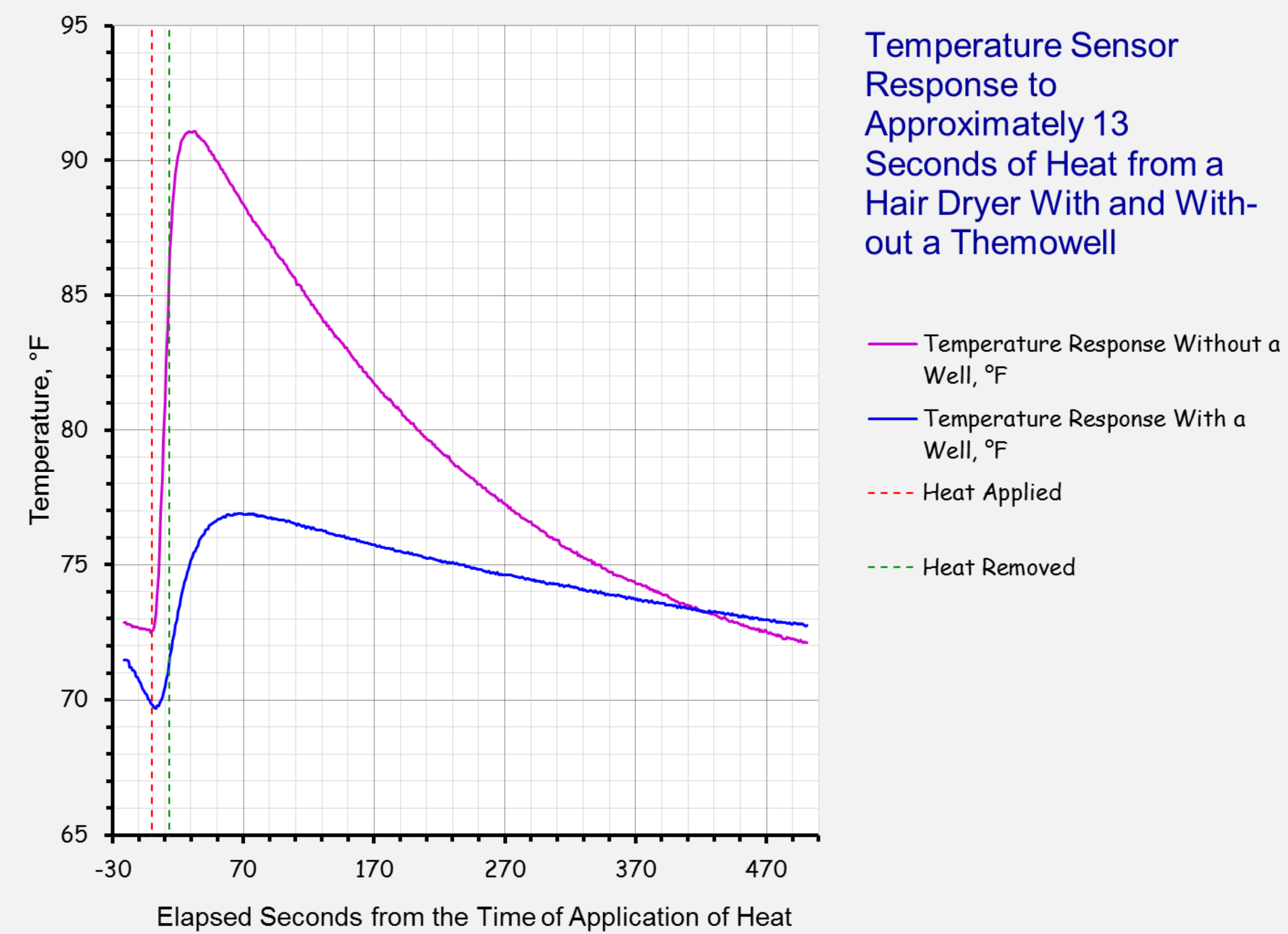
Temperature Sensors and Wells

Insertion Length is Critical

Wells Introduce Lags

Temperature Sensor Response to Approximately 13 Seconds of Heat from a Hair Dryer With-out a Themowell





95
90
85
80
75
70
65
Temperature, °F
-30
70
170
270
370
470
Elapsed Seconds from the Time of Application of Heat
Temperature Sensor Response to Approximately 13 Seconds of Heat from a Hair Dryer With and With-out a Themowell
Temperature Response Without a Well, °F
Temperature Response With a Well, °F
Heat Applied
Heat Removed

Thermal Lags

A Research Experiment by the FDE NW Research Lab

Dr. Riley Sellers; PhD CTK
*LBNL CTPSC **

Hobbes Sellers; Post Doc
Applied Chaos Theory

See *4-20 ma Current Loop Experiments – Thermal Mass Effects* for details

* Doctorate of Philosophy - Canine Treat Kinetics - Lower Buchanan National Labs, Canine Treat Preservation Systems Center

Pressure Testing

Typical Specifications

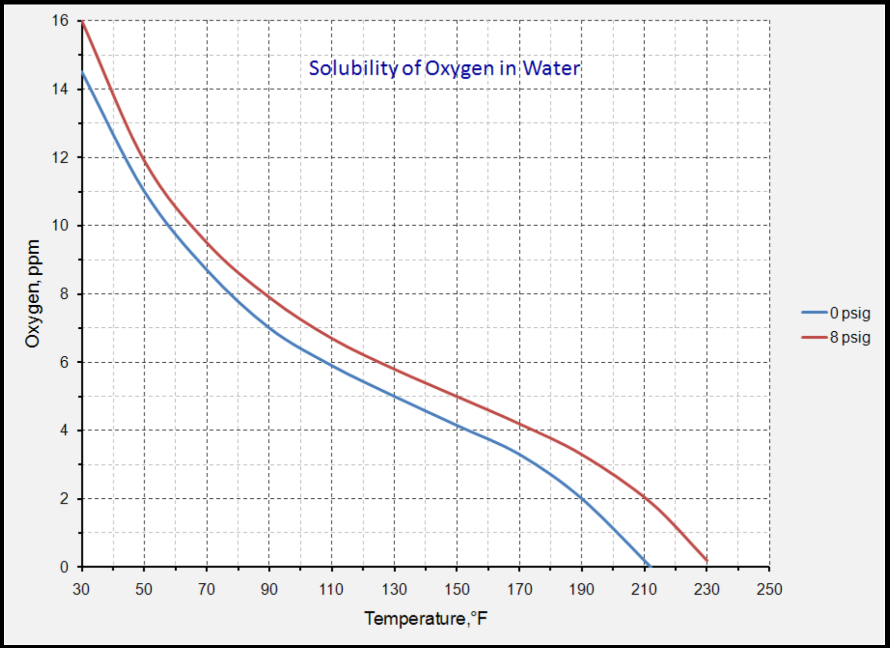
- Test medium (air or water)
- Test pressure
- Test duration
- Allowable variation
  - Temperature compensation

All may be driven by code requirements, especially life safety code requirements for fire protection systems

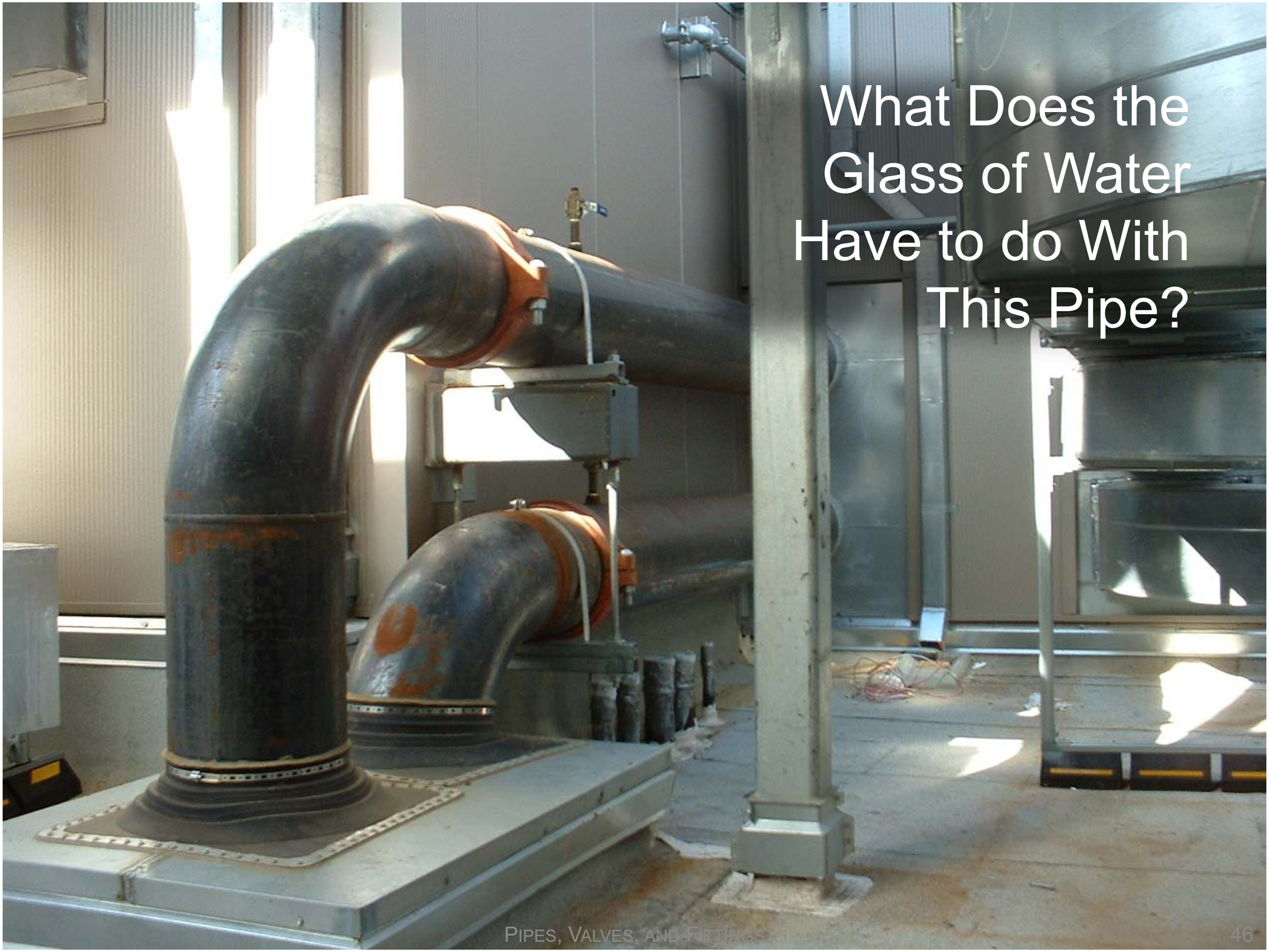
Cleaning

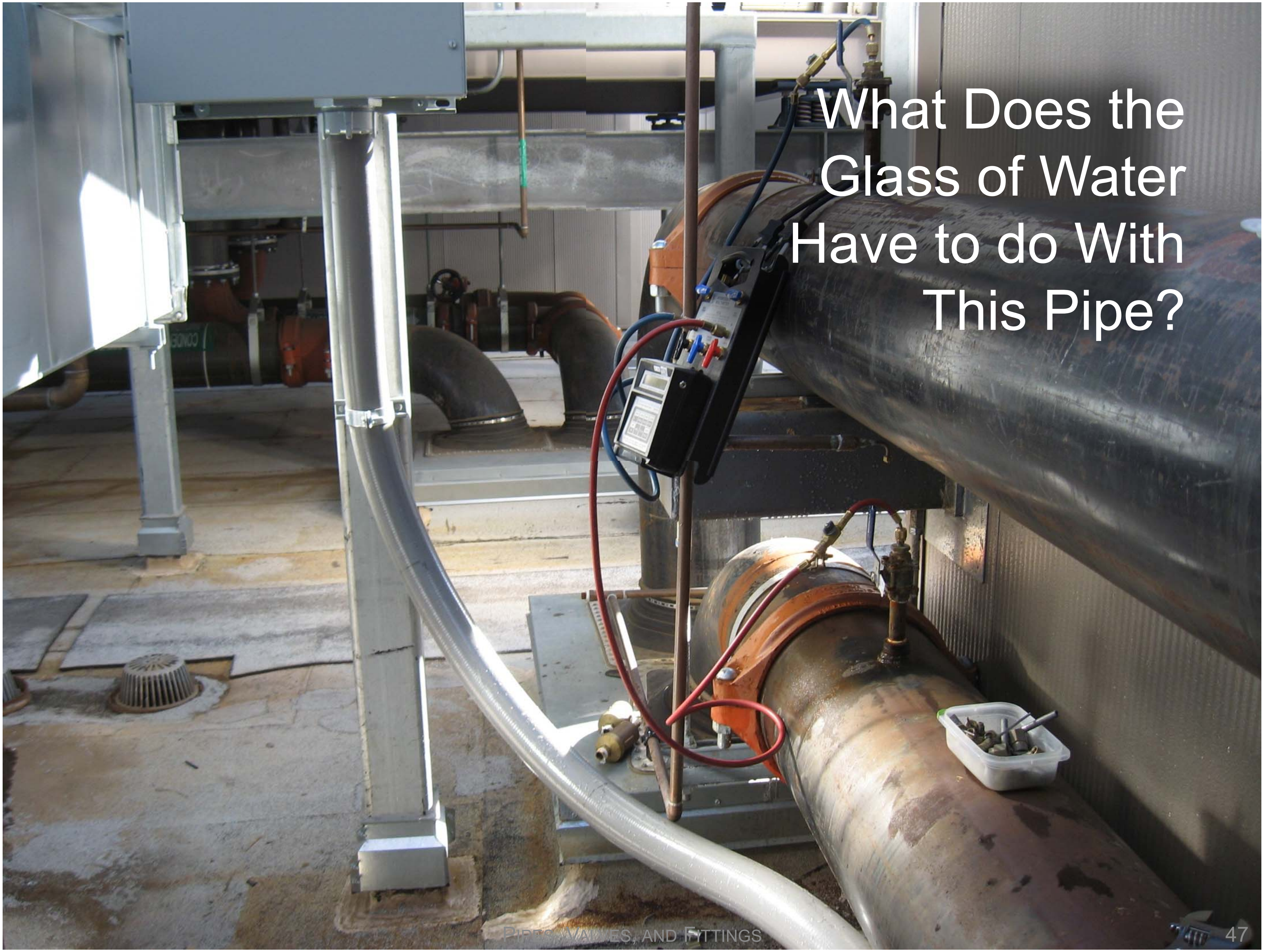
- Step 1
  - Don't let it get dirty
- May be more critical for some applications than others
  - High purity vs. HVAC
  - Refrigeration vs. Water
- Methodology
  - Flushing
  - Circulation of cleaning solution
    - Velocities matter
    - Solution matters
    - Make-up quality matters

Why a Picture of a Glass of Water in a Pump (and Piping) Class



What Does the Glass of Water Have to do With This Pipe?

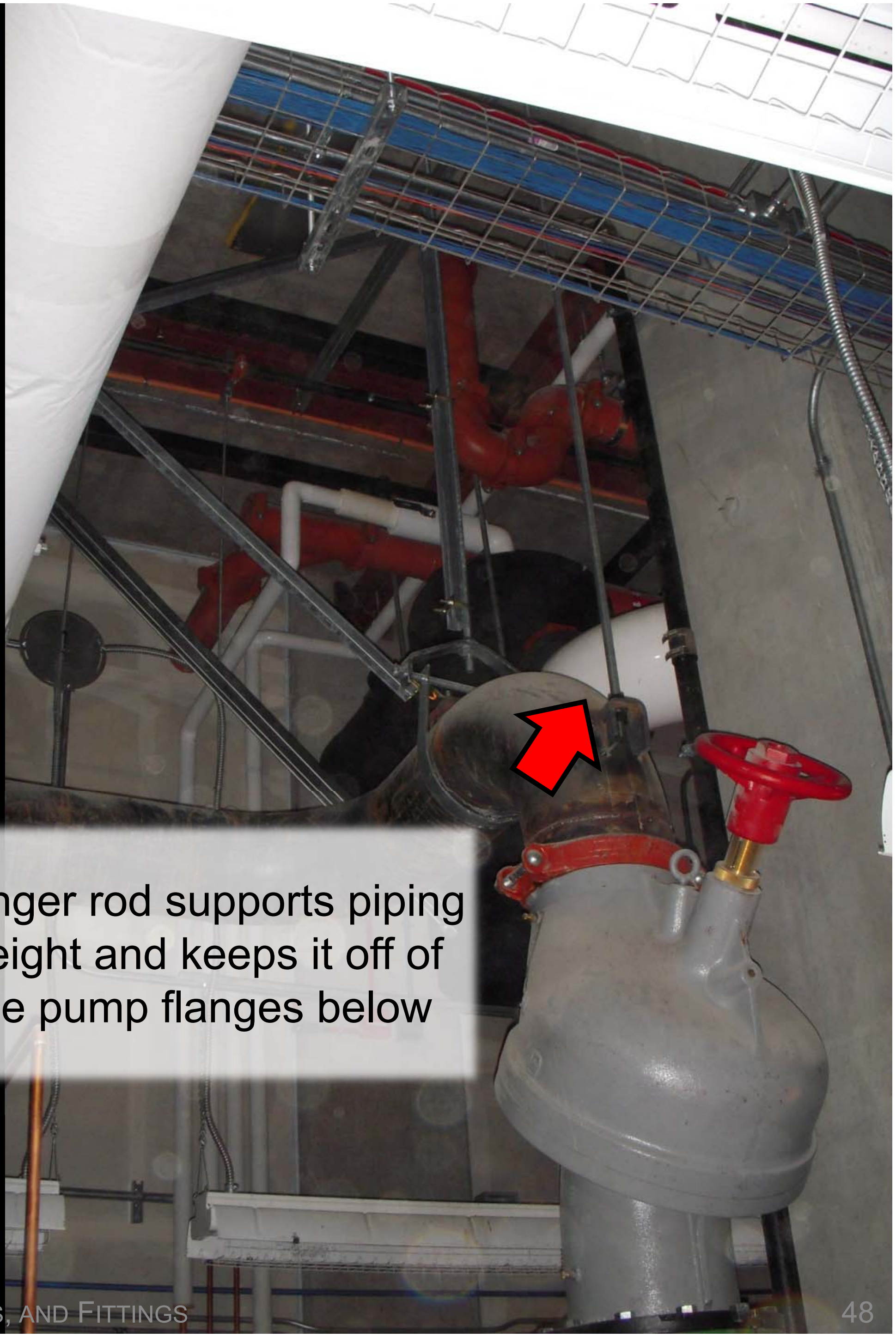




What Does the Glass of Water Have to do With This Pipe?

Hangers

- Need to fully support the weight of the pipe and water
  - No stress on equipment flanges
  - Attachment points sufficient for the imposed loads



Hangers

- Need to fully support the weight of the pipe and water
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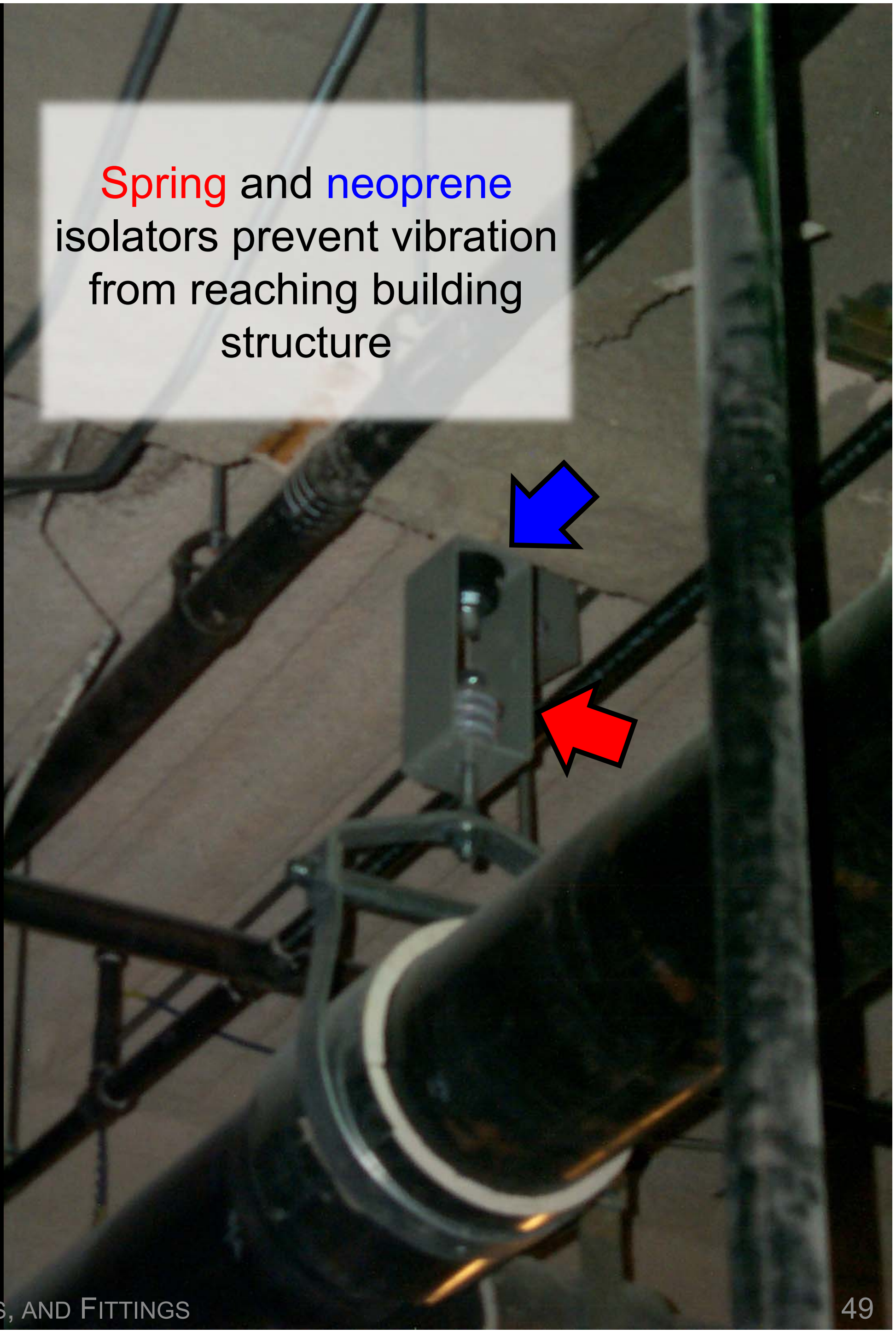
  - Attachment points sufficient for the imposed loads
- Need to constrain and guide movement
  - Vibration isolation



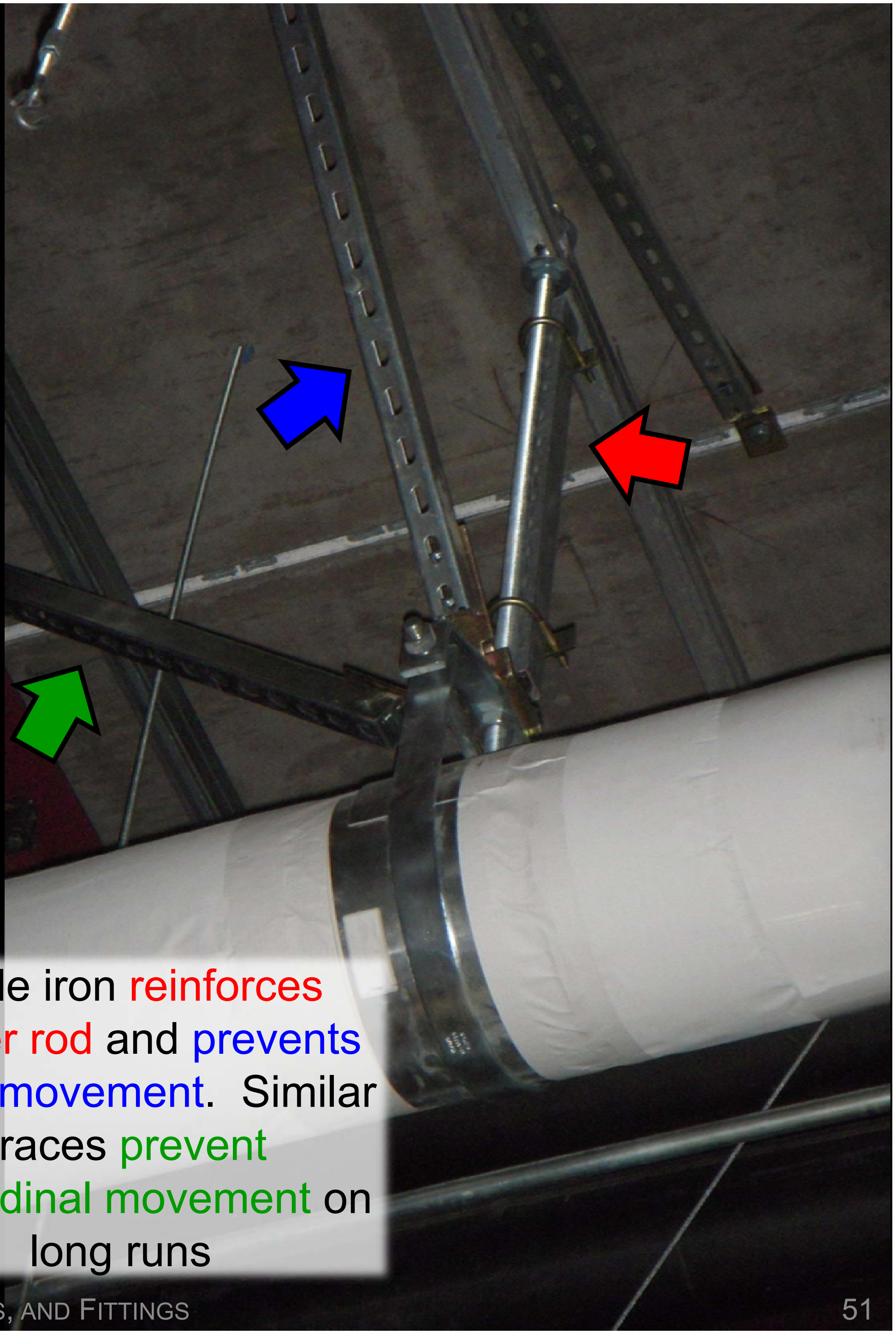
Hangers

- Need to fully support the weight of the pipe and water
  - No stress on equipment flanges
  - Attachment points sufficient for the imposed loads
- Need to constrain and guide movement
  - Vibration isolation
  - Normal operation

The vertical pipe risers in this 450 foot tall high rise can expand 3-4 inches or more when subjected to the temperature change associated with standing empty on a cold day vs. being filled and coming up to operating temperature

Hangers

- Need to fully support the weight of the pipe and water
  - No stress on equipment flanges
  - Attachment points sufficient for the imposed loads
- Need to constrain and guide movement
  - Normal operation
  - Vibration isolation
  - Seismic events



Angle iron reinforces hanger rod and prevents lateral movement. Similar braces prevent longitudinal movement on long runs

Hangers

- Need to fully support the weight of the pipe and water
  - No stress on equipment flanges
  - Attachment points sufficient for the imposed loads
- Need to constrain and guide movement
  - Normal operation
  - Seismic events
  - Vibration isolation
- Need to be coordinated with anchors, guides, and expansion loops

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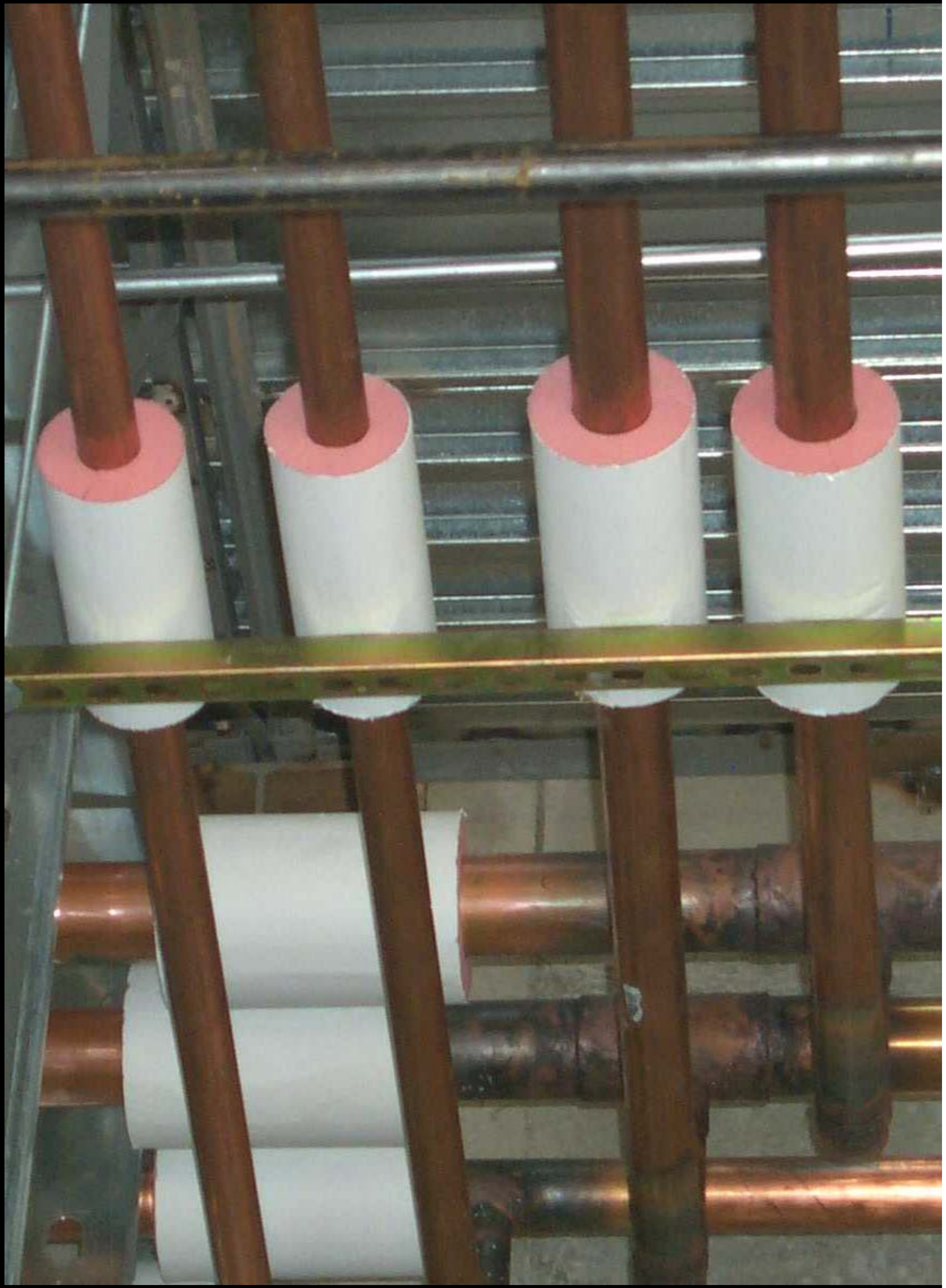
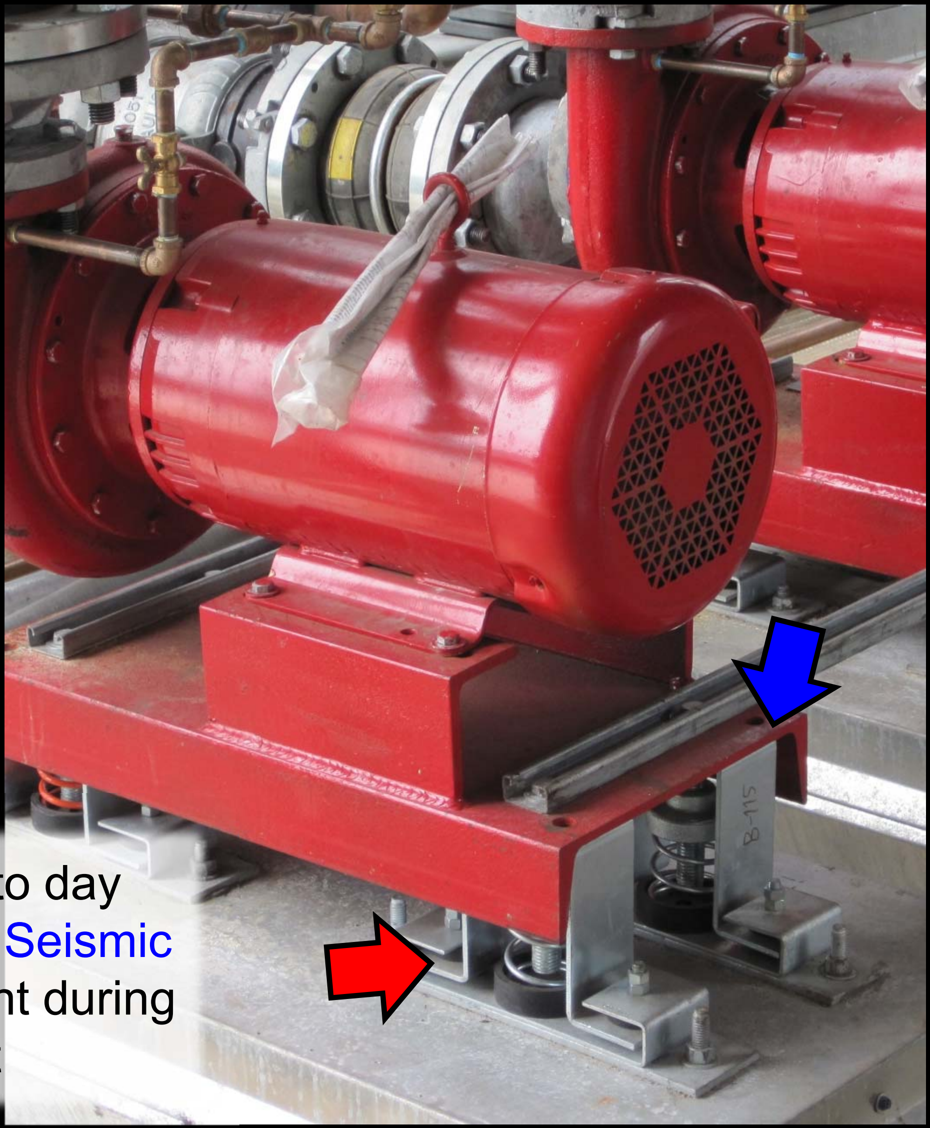
- Need to constrain and guide movement
  - Normal operation
  - Seismic events
  - Vibration isolation
- Need to be coordinated with anchors, guides, and expansion loops
- Need to be coordinated with insulation



Pump Vibration Isolation

Similar Considerations to Hangers

- Isolate pump from structure



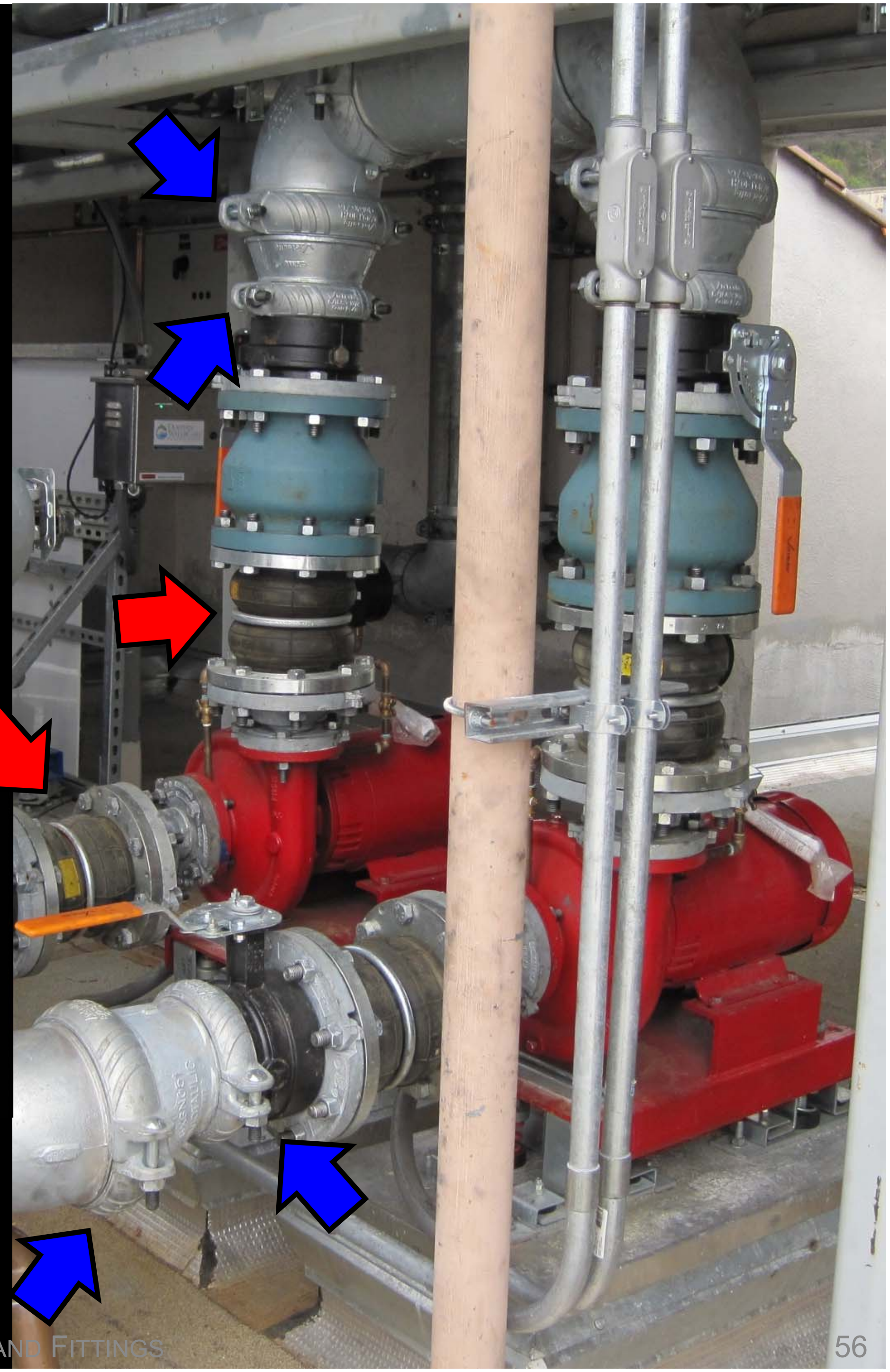
Springs prevent day to day vibration transmission. Seismic snubbers limit movement during a seismic event

Pump Vibration Isolation

Similar Considerations to Hangers

- Isolate pump from structure
- Isolate pump from piping
- Eliminate loads on pump flanges

Flex connectors and mechanical couplings prevent vibration transmission from pumps to the building structure



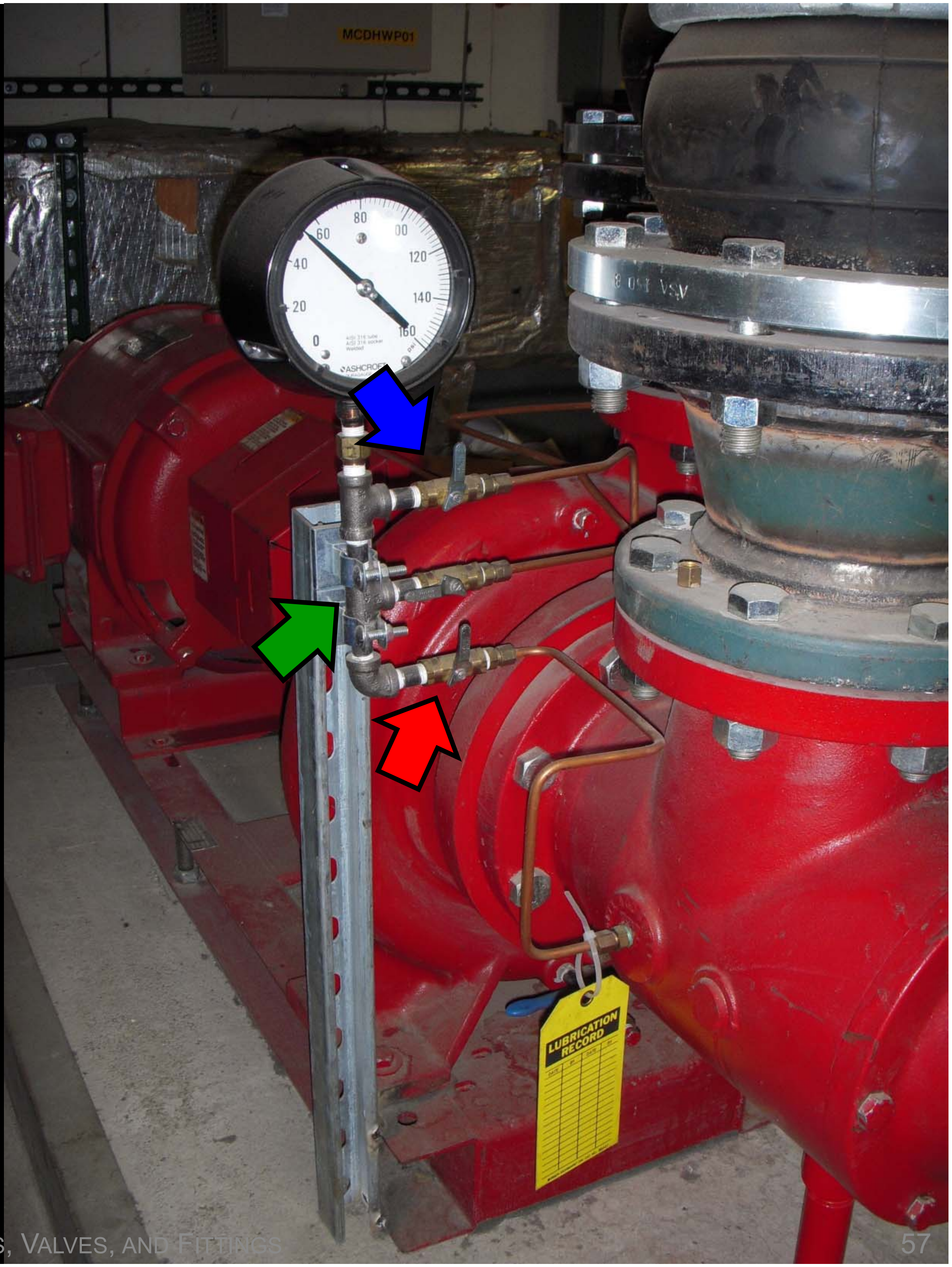
Three valves and one gauge allow:

- Strainer pressure drop,
- Suction pressure, and
- Discharge pressure

to be read with one gauge, thereby eliminating gauge error and saving first cost

Gauge Manifolds

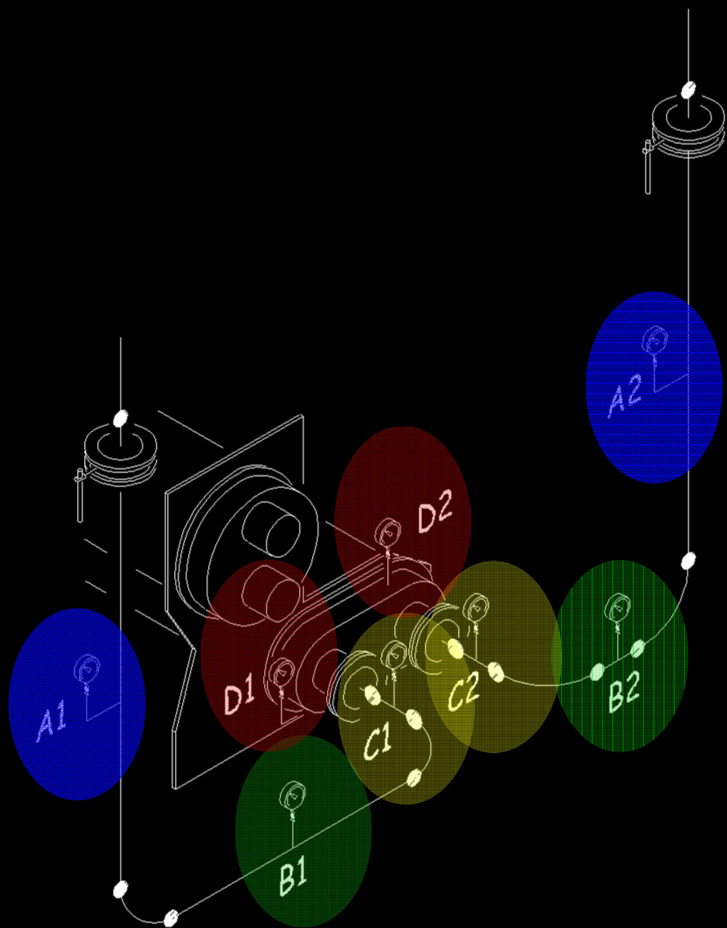
Less is Better



Gauge Manifolds

Less is Better

Small Differences can Make A Big Difference



Flow Based on Differential Pressure			
Location	Pressure Difference, ft.w.c.	Flow Based on Pressure Difference	
		gpm	%
D1 - D2	14.48	1,363	85%
C1 - C2	17.00	1,600	100%
B1 - B2	18.26	1,718	107%
A1 - A2	19.78	1,862	116%

Gauge Manifolds from Hell

A Great Resource for Understanding the Field Side of Piping