Better Plants
U.S. DEPARTMENT OF ENERGY

In-Plant Trainings

Virtual Platform
Session 3 – Controls

Homework Questions

- Let's quickly address some of the Homework responses

Homework Questions

- What's the compression ratio of the single stage compressor below?
  - 13.5 psia inlet pressure
  - 113.5 psia discharge pressure
- assuming 1 atm=13.5 psia, that would be 0 psig inlet and 100 psig discharge

$$\frac{113.5}{13.5} = 8.4 \text{ Ratios}$$

Homework Questions

- Dust wearing inlet modulation valve
- Leaks
- Cold Weather freezing condensate lines
- Compressor loading and unloading frequently
- No wet tank
- Loud screech at 90 to 95% load
- Water in the lines during different times of the year
- losing oil and I think it’s mixing with water on the oil/water separator

Homework Questions

- Compressor room is too warm. Poorly ventilated.
- No bypass piping at filter housing. Causes us to shutdown system to change filters.
- Optimizing compressed air energy use (main compressor in use with two backup compressors)
- Pressure drops at point of use
- Compressor left running during non-operating times
- Potentially oversized receiver tank
- Humidity, loss of pressure, contamination (oil)

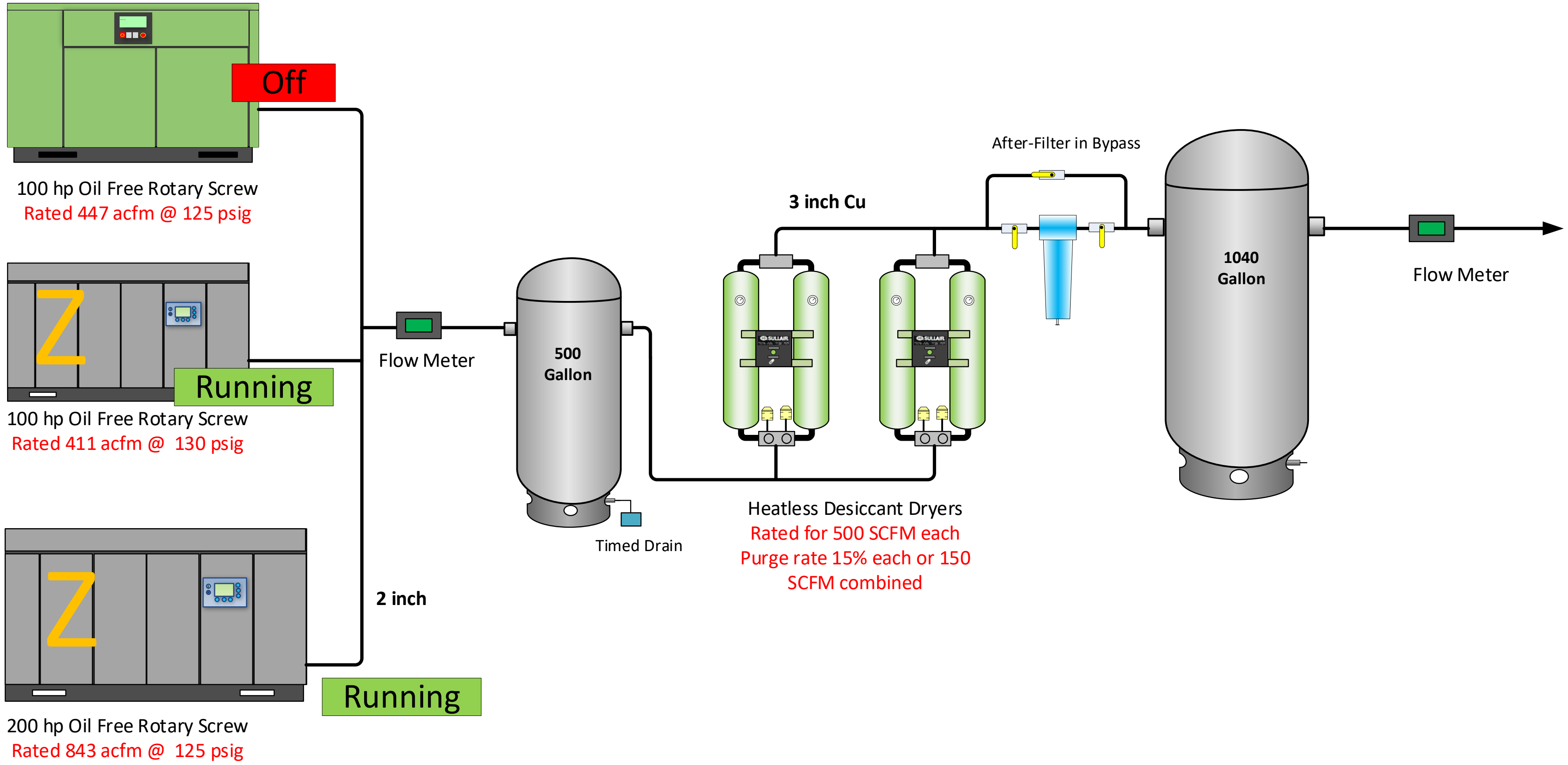
Homework Questions

- High inlet temperature – Usually on cooling of oil or cooling of interstage/discharge coolers
- Water in the system – What solenoids activated systems are people using at compressors, receivers and dryers?
- Dirt/clogged coolers – What options of cleaning solutions other companies utilizing?
- Motor overload
  - Note: Air-cooled screw compressors are used

Homework Questions

- Dryer desiccant power looks like crushed in powered form, which might not be fully drying the air
- There is a continuous hissing sound of our Dryer, so we are not sure of the dryer if it is cycling properly or not.
- We are not sure how much flow each compressor is putting out? One compressor has a rating of 1468 CFM @ 125 PSI and another has 1572 ACFM. But we have put on a flowmeter after dryer which displays close to 1550 CFM. So, we are not sure if our compressors even putting out what they are supposed to? Should we pout flowmeters at discharge of each compressor?

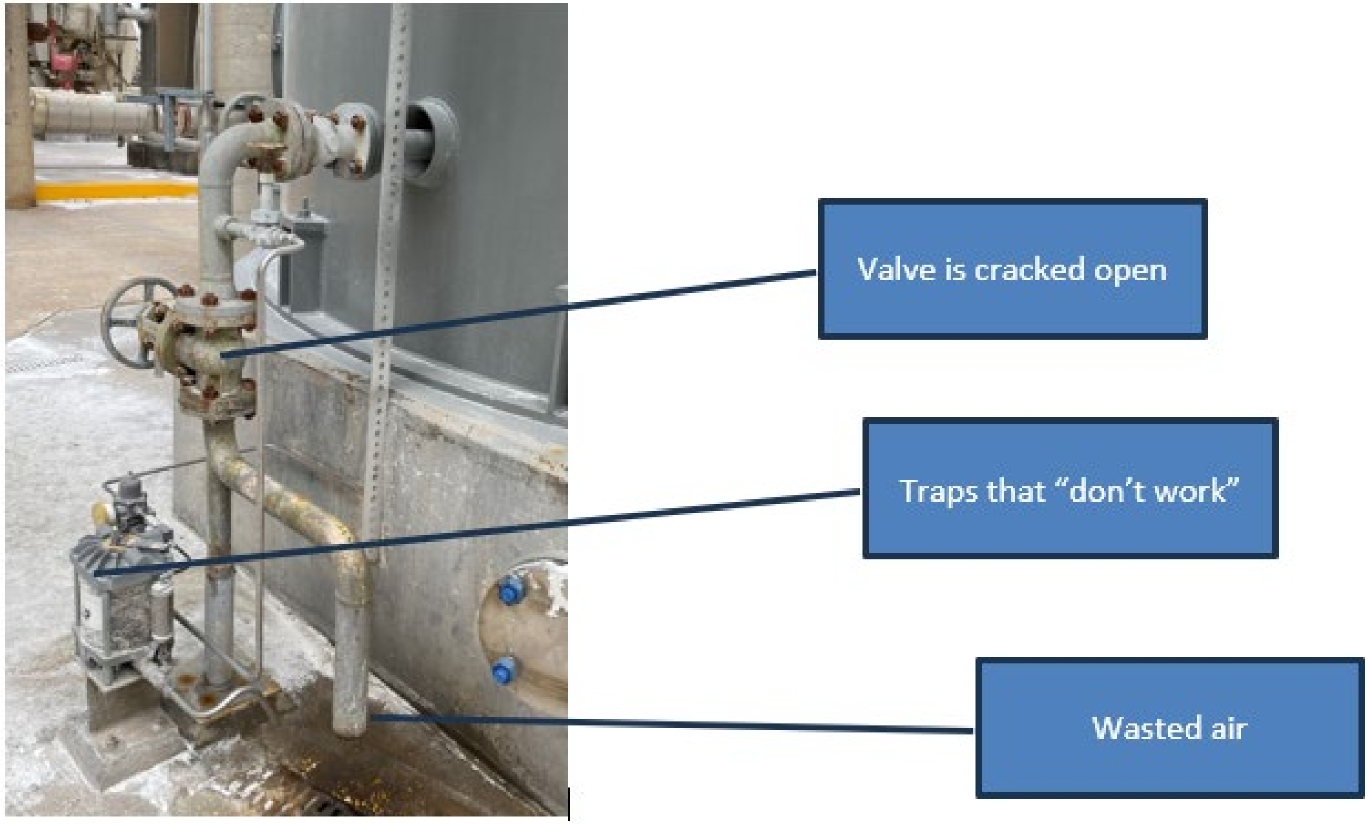
Homework Questions



Homework Questions

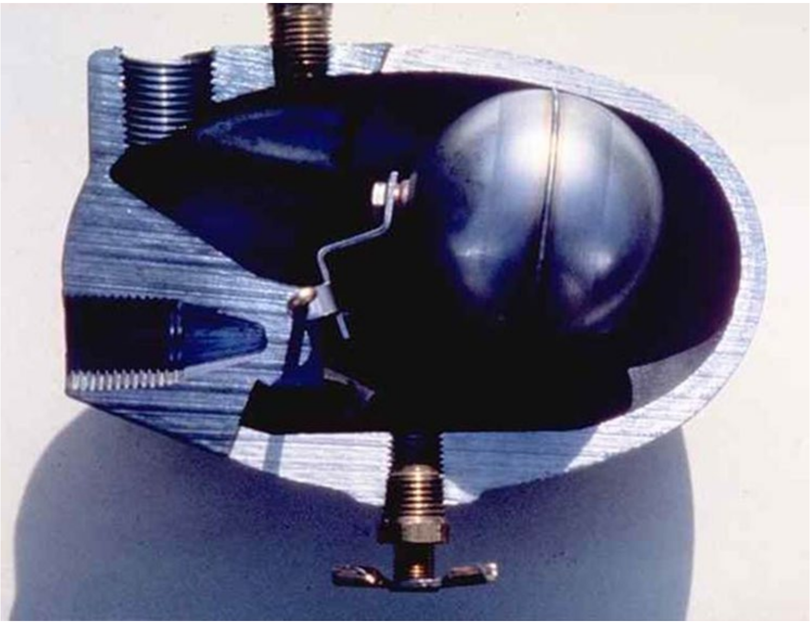
- Condensate traps are insufficient, especially in those shops where centralized package units have been installed.
- The Pressure Drop at dryer end is greater than 6~8 psi probably due to inadequate reduction in dryer inlet and outlet.
- Auto Drain Trap on Wet Receiver gets blocked frequently.
- Line distribution losses are very high throughout the facility.
- We are using black iron piping for our air system which can develop a lot rust overtime.

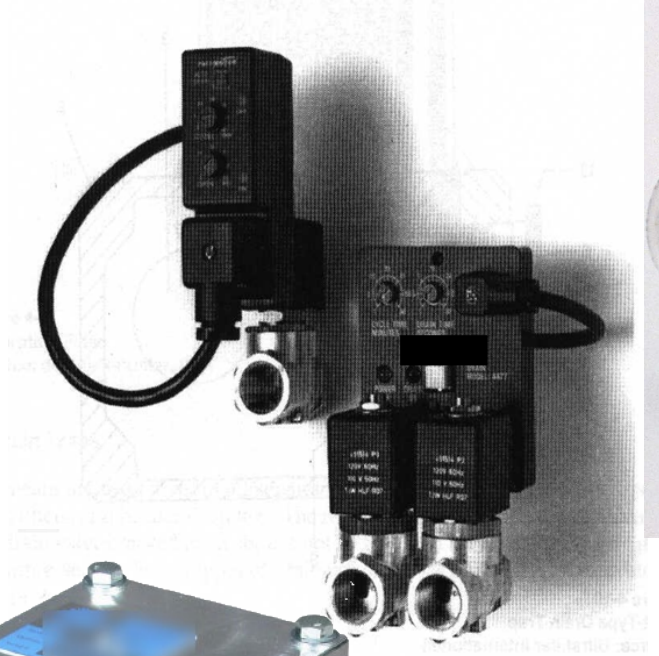
Homework Questions

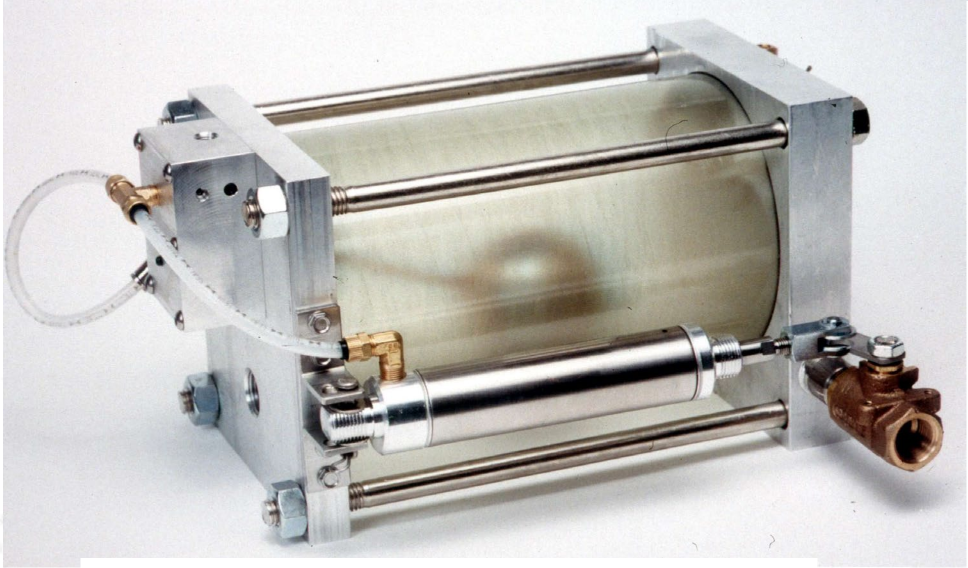


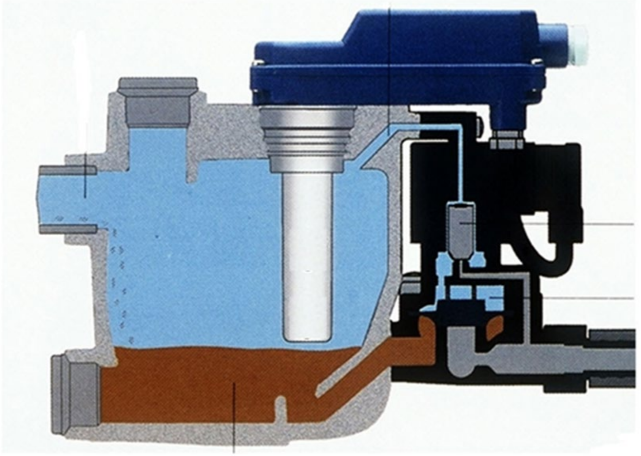
- All condensate traps on dry receivers and moisture separators are bypassed (every single one). This leads to wasted compressed air blowing to atmosphere with condensed water.
- When I ask operations why the traps are bypassed, they tell me: “They don’t work. If we don’t bypass them, water level builds up in the separator and receiver then we get wet air or we trip an interlock on high water level.” The irony is over decades we have added compressed air users, but we have not added one molecule of compressed air capacity. So we don’t have air to waste. Yet we waste it.

Homework Questions

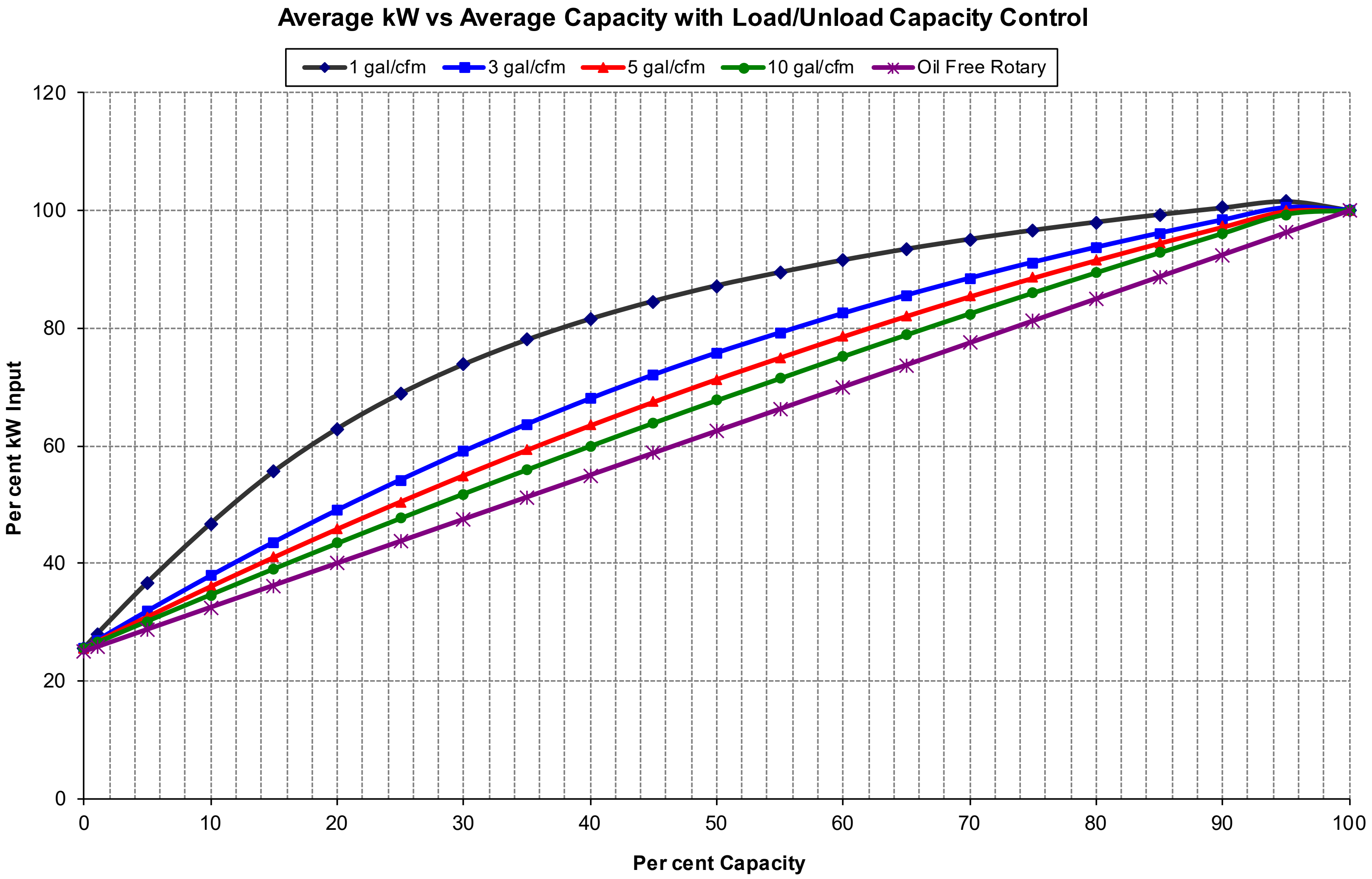






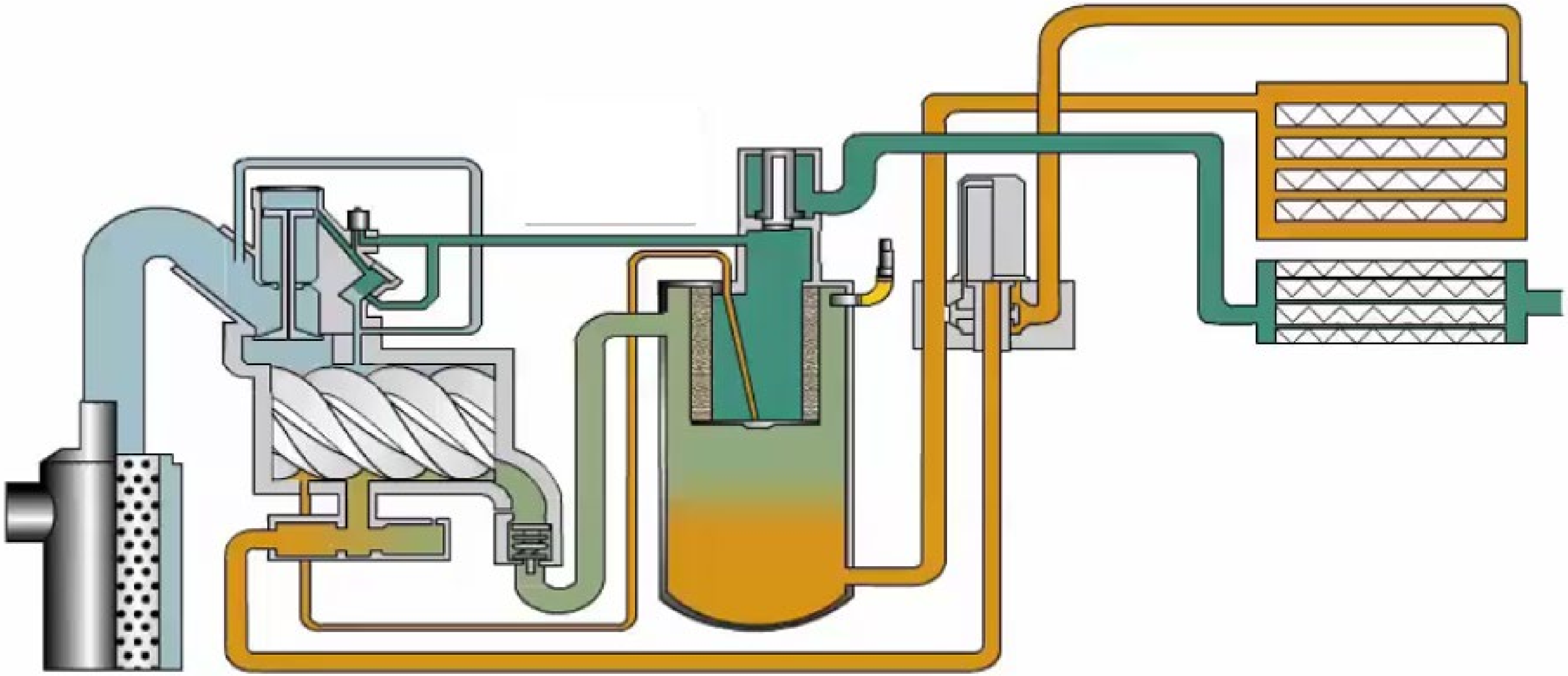


Load/No-load Control Curve

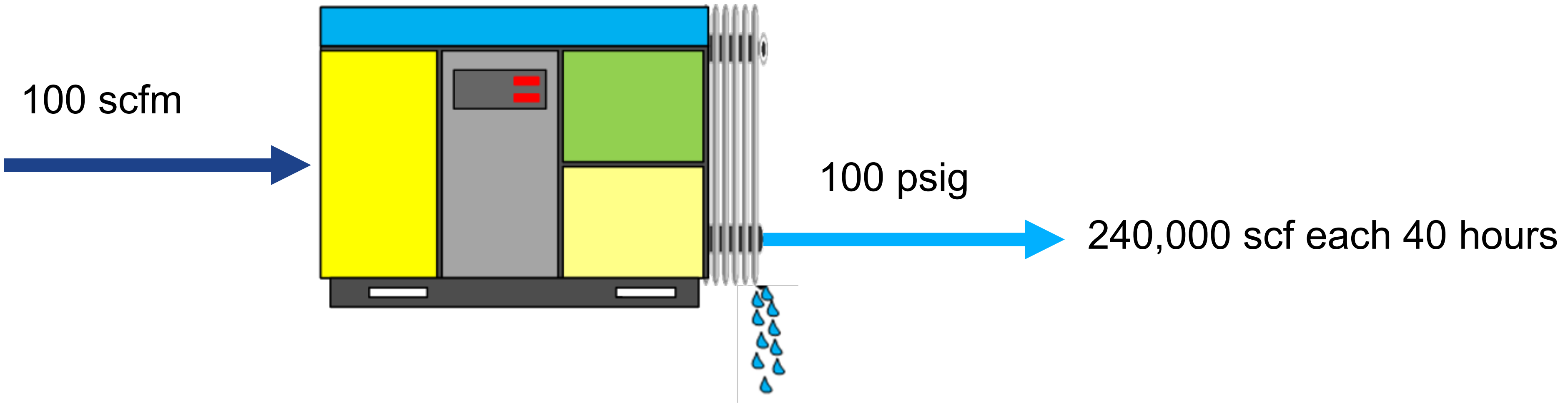


- This graph shows the effect of receiver size on the part load power of a lubricant injected rotary screw compressor with load/unload controls

Rotary Screw



Moisture Content during a 40 HOUR WEEK



- Typical 25 hp compressor produces about 100 SCFM (Standard Cubic Feet Per Minute) at 100 psig.
- During a 40-hour week the compressor would discharge approximately 240,000 SCF into the plant piping system.
- 100 standard cubic feet/min x 60 minutes x 40 hours = 240,000 scf

The Aftercooler Must Work!

Capacity	100	cfm
	102	psi (g)
	80	°F
Air Usage	100	cfm

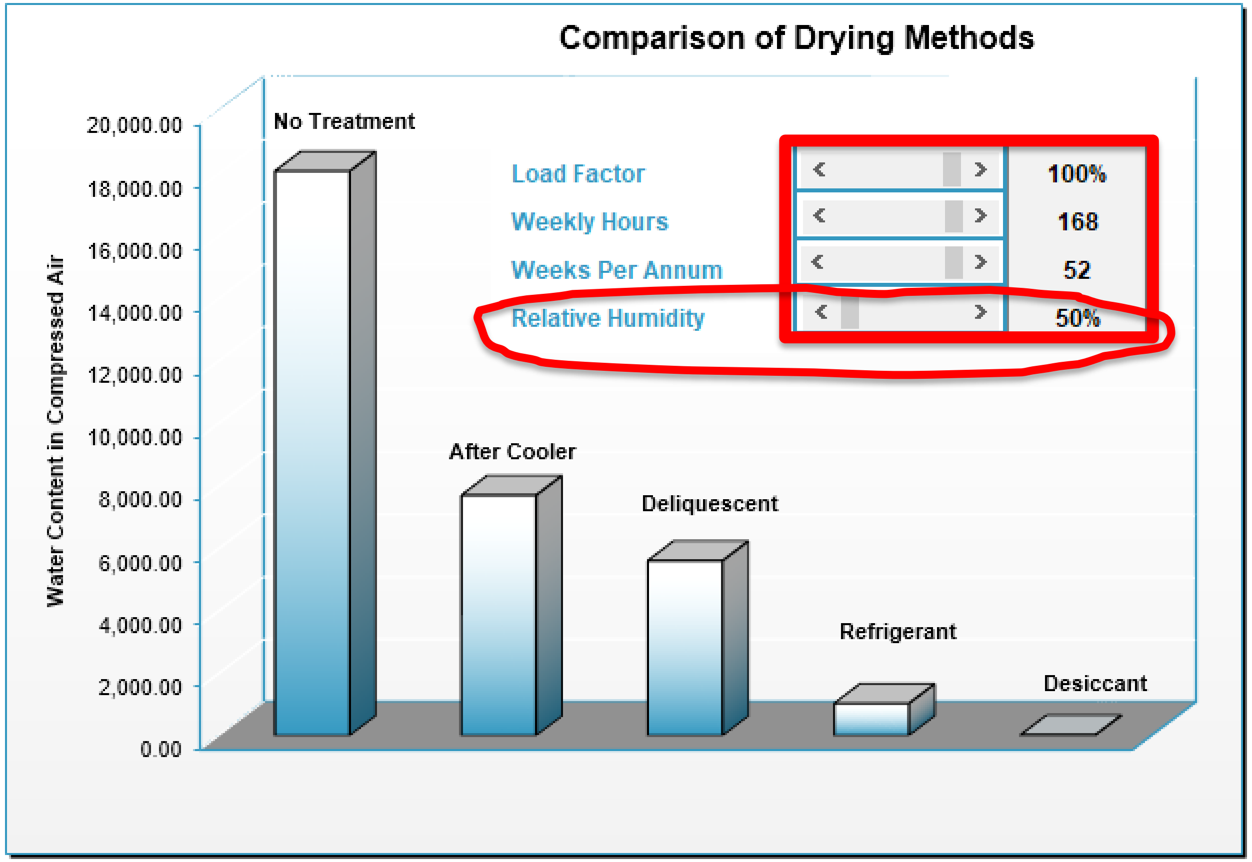
Water Remaining in Compressed Air

Imperial Units

Drying Method	Dewpoint	Gallons Week	Gallons Annum
No Treatment	127°F	76.4	3975.0
After Cooler	98°F	32.6	1693.0
Deliquescent	87°F	23.7	1232.8
Refrigerant	37°F	4.3	225.9
Desiccant	-40°F	0.09	4.8

Metric Units

Drying Method	Dewpoint	Litres Week	Litres Annum
No Treatment	53°C	347.5	18068.2
After Cooler	37°C	148.0	7695.4
Deliquescent	26°C	107.8	5603.7
Refrigerant	3°C	19.7	1026.6
Desiccant	-40°C	0.4	22.0



The Aftercooler Must Work!

Capacity	100	cfm
	102	psi (g)
	80	°F
Air Usage	100	cfm

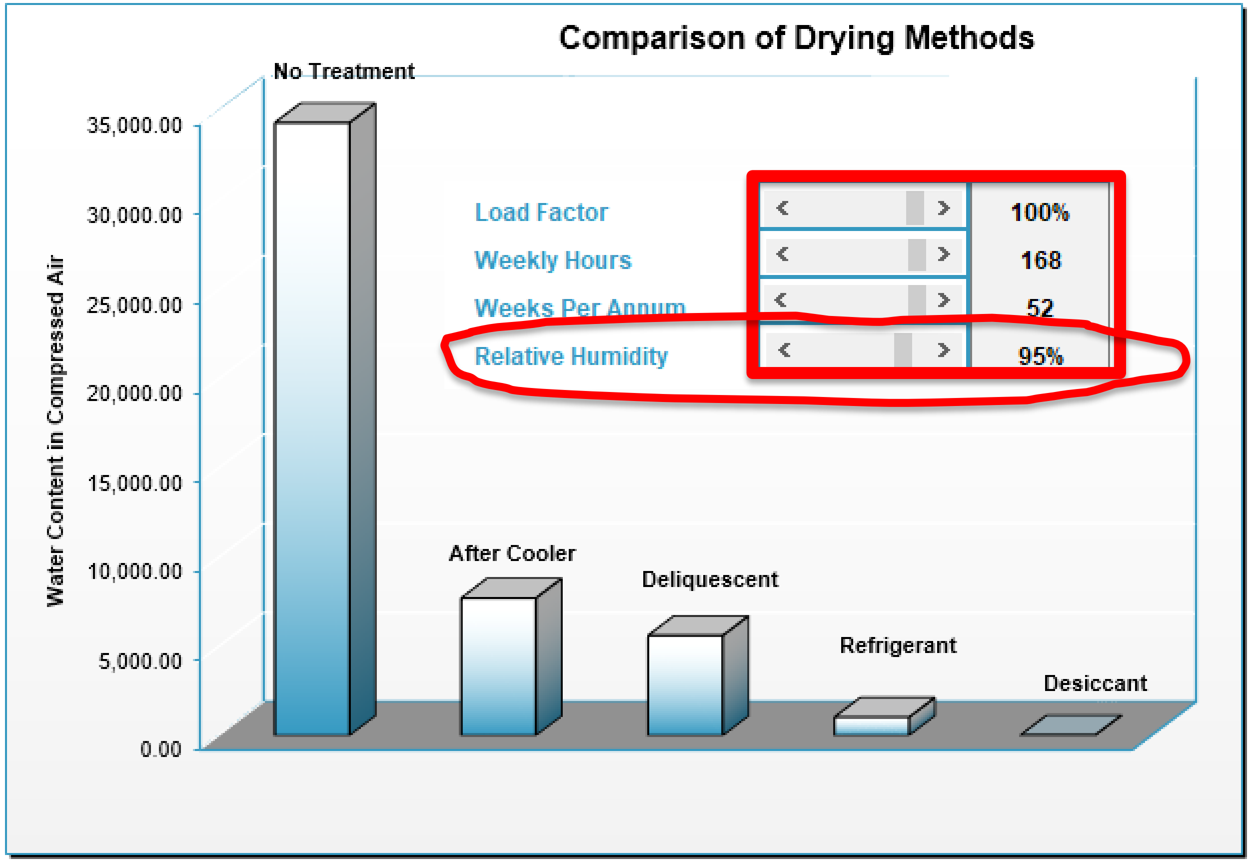
Water Remaining in Compressed Air

Imperial Units

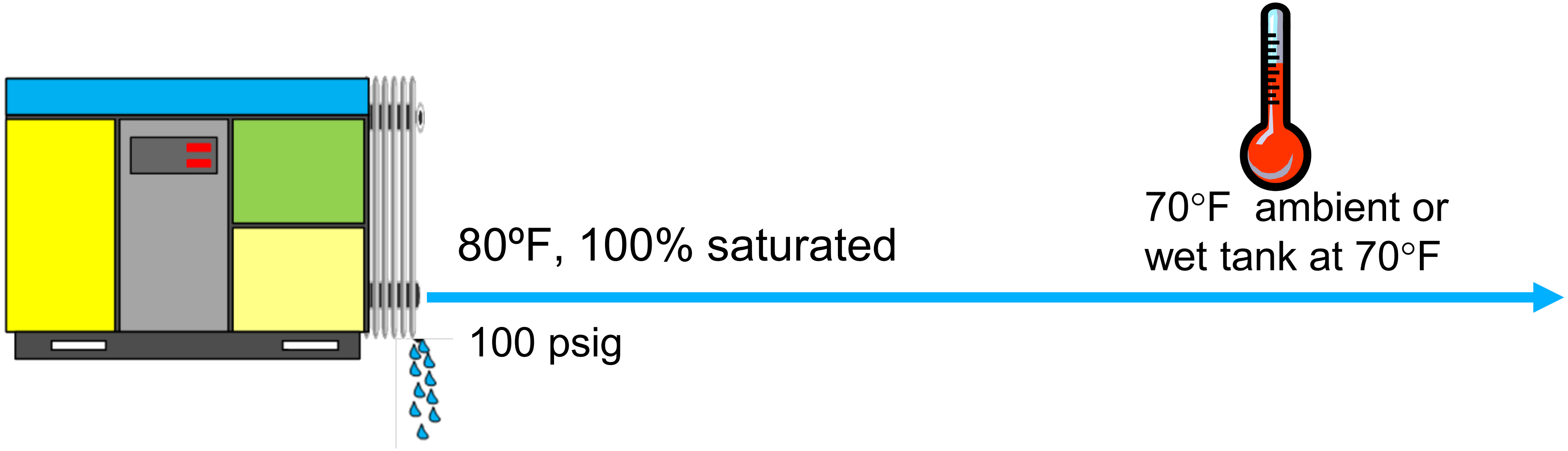
Drying Method	Dewpoint	Gallons Week	Gallons Annum
No Treatment	154°F	145.2	7552.5
After Cooler	98°F	32.6	1693.0
Deliquescent	87°F	23.7	1232.8
Refrigerant	37°F	4.3	225.9
Desiccant	-40°F	0.09	4.8

Metric Units

Drying Method	Dewpoint	Litres Week	Litres Annum
No Treatment	68°C	660.2	34329.5
After Cooler	37°C	148.0	7695.4
Deliquescent	26°C	107.8	5603.7
Refrigerant	3°C	19.7	1026.6
Desiccant	-40°C	0.4	22.0



Moisture Content



- Assume at the aftercooler outlet, the air is 80ºF and saturated.
- Each scf contains 1.42 grains of moisture vapor at 80ºF.
- The air surrounding the airlines is 70ºF.
- Is this 10ºF reduction in temperature enough to cause appreciable condensation ??

MOISTURE CONTENT

- At 80ºF there is 1.42 grains per standard cubic foot.
- At 70ºF a standard cubic foot of free air will still hold 1.03 grains of moisture vapor at 100% relative humidity.
- Making a difference of .39 grains per cubic foot.
- Multiply this by 240,000 standard cubic feet/week.

EQUALS 93,600 GRAINS OF MOISTURE CONDENSING IN ONE WEEK BECAUSE OF A 10 DEGREE REDUCTION IN TEMPERATURE!!

MOISTURE CONTENT

- 7000 grains of water equals one pound or one pint
- 93,600 divided by 7000 equals 13.4 pounds or 13 pints

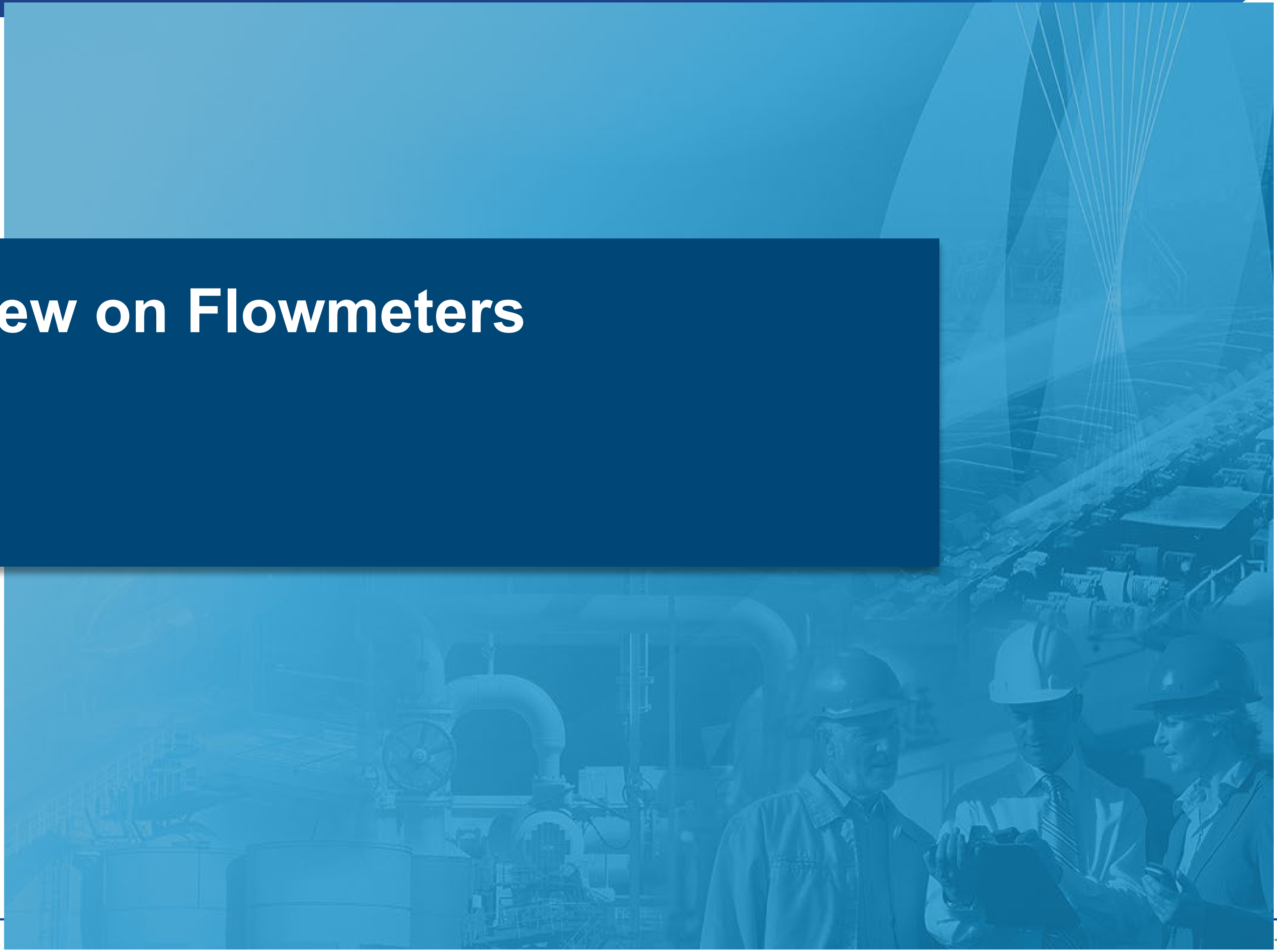
Just a 10° F drop in temperature will allow 13 pints (1.625 gallons) of water to condense into the piping system in 40 hours!

Even with this amount of water removed, the RH is still 100% and the dew point down stream of the aftercooler is now 70° F

Is the Separator and Trap Even Working?

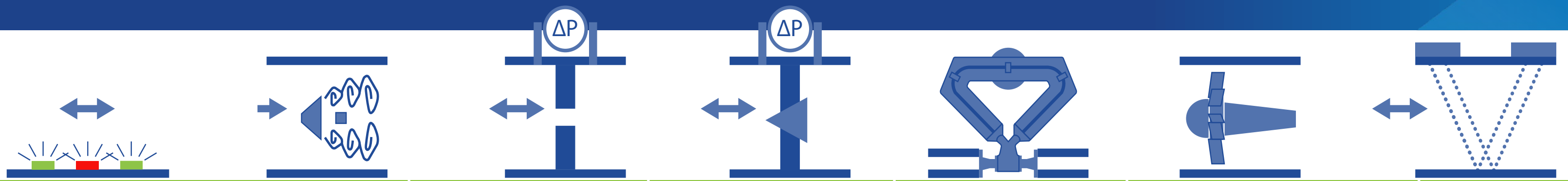
Is the Separator and Trap Even Working?

Week 2



Quick Review on Flowmeters

Types of Meters - Comparisons



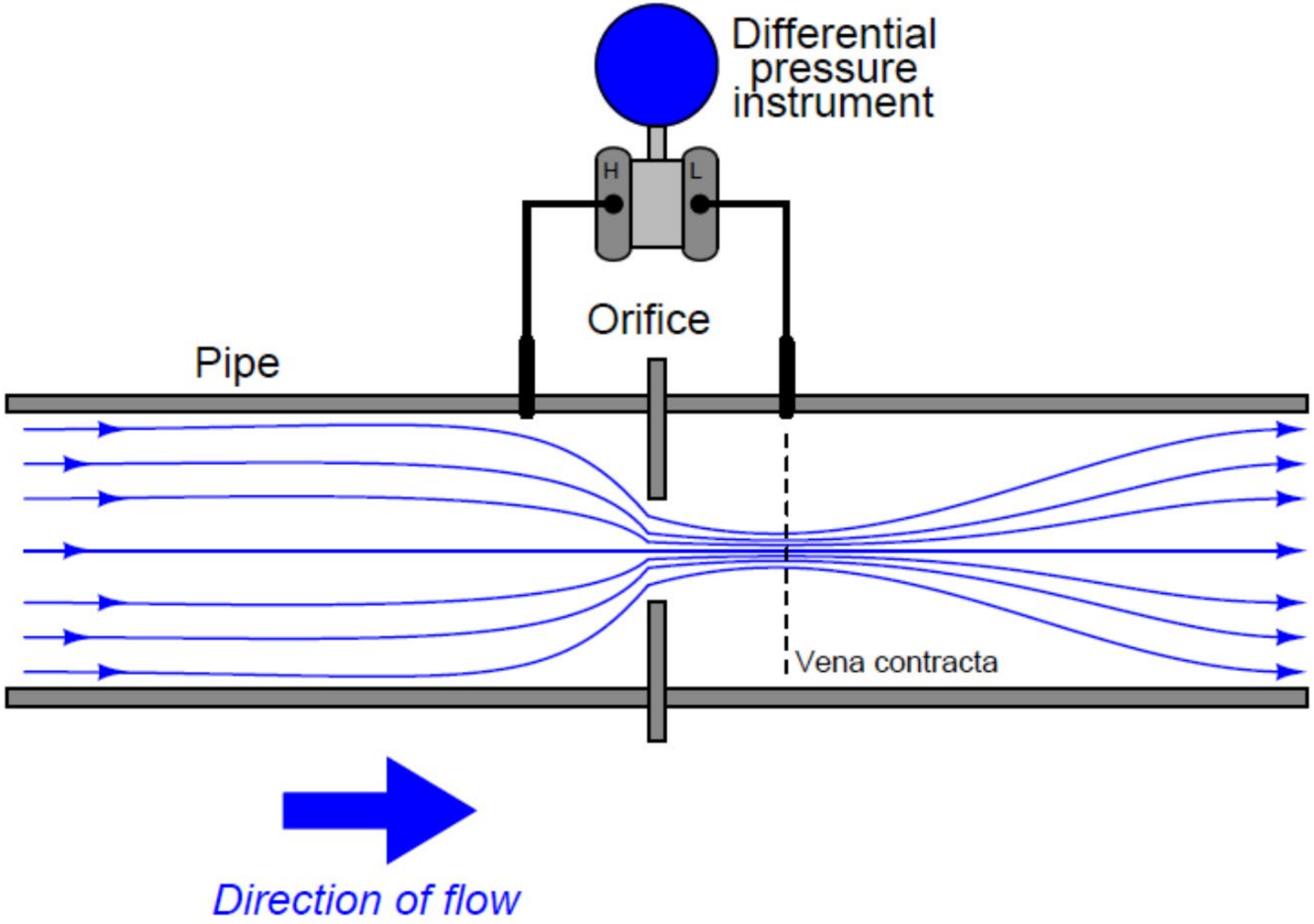
	Thermal	Vortex	DP – Orifice plate	DP – Insertion	Coriolis	Turbine/ rotary displacement	Clamp on ultrason ic
Mass flow	Yes	Optional	Optional	Optional	Yes	Optional	Optional
Meter run	20D	15D	15D	20D	0D	10D	20D
Pressure loss	Low	Medium/hig h	high	Low	Low	Low	Low
Dirty air	Fouling	OK	Clogging	Fouling/Clog	Internal fouling	Faillure	OK
Wet Air	Spikes	OK, spikes	OK	OK, orientation	Yes, but affects reading	Faillure	Spikes
Range	1:250	1:10	1:10	1:10	1:100	1:100	1:100
Accuracy	2%	2%	2%	2%	0.5 .. 1%	0.5…1 %	1%
Purchase price	$	$	$	$S	$$$$	$$	$$$
Maintenance	Medium	Low	Medium	Medium	Low	High	Low

Orifice Plate Flow Meters

These meters are another carry over from fluid engineering.

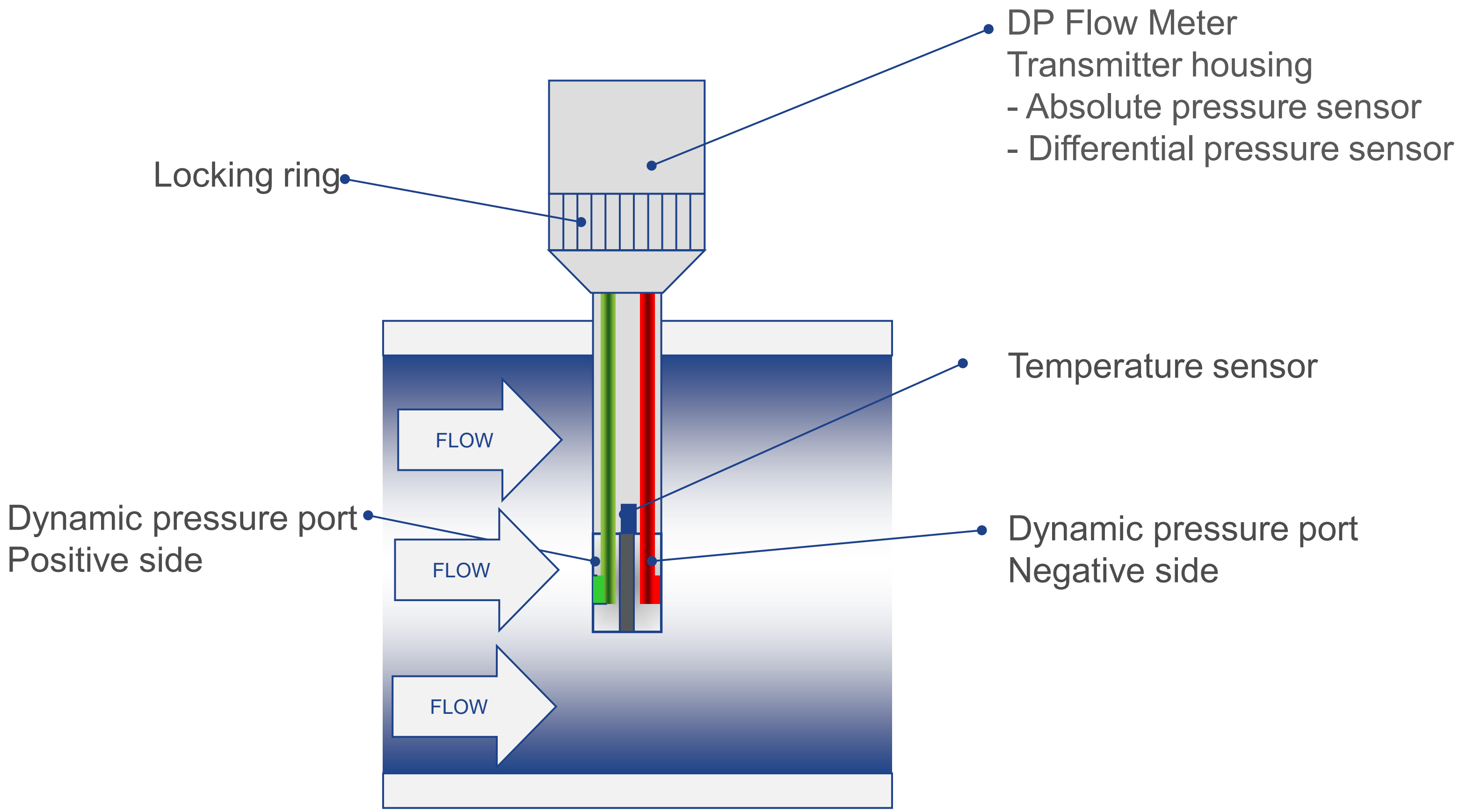
They operate on the physics of a pressure drop being created as a medium flows through an orifice.

The problem with these meters is just that; they, themselves are a pressure drop.



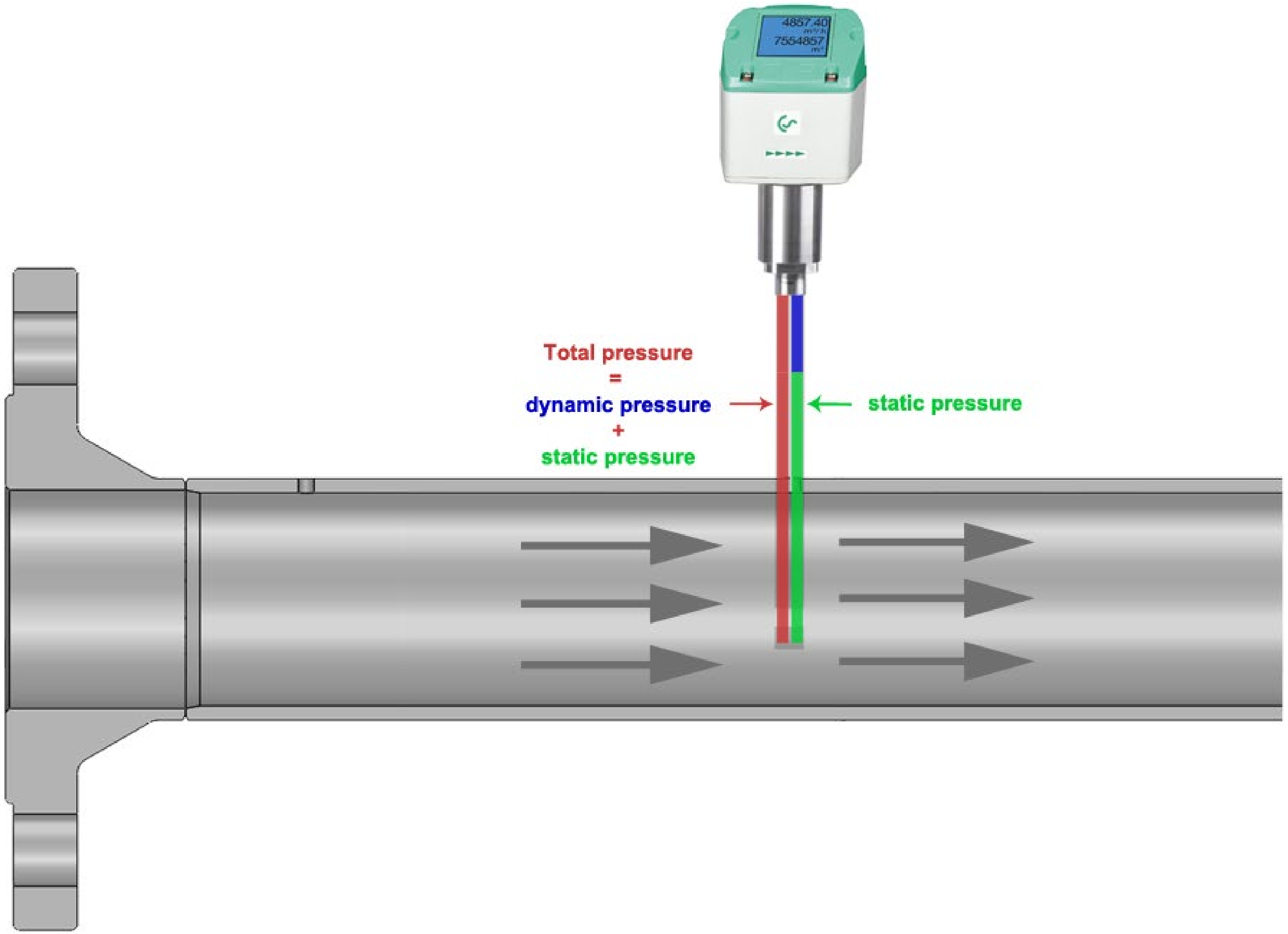
Differential Pressure Technology

- Speed of air creates differential pressure signal over the positive and negative port.
- Low speeds do not generate a stable Dif. Pressure.



Differential Pressure Technology

- Unique sensitivity in the lower measuring range: Measures from as little as 2 m/s and thus covers the complete operating range of variable speed drive (VSD) compressors
- Particularly suitable for extremely high flow rates
- Flow, total consumption, temperature and pressure
- Measurement at high temperatures, max. temperature 180°C (356°F)
- Installation via 1/2″ ball valve under pressure.



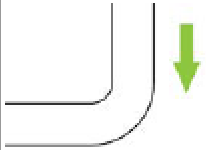
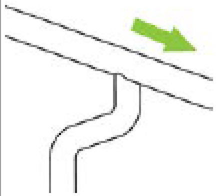
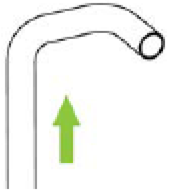
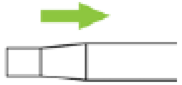
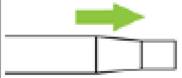
Min and Max Flow per Pipe Size

- DP flow meters have a min and max flow range. Below the minimum range the flow meter will read flaky or no flow, we call this the dead zone, 0 to 20 m/sec (0 to 65 ft/sec).
- In different pipe sizes this dead zone will have a different Q min, see the tables below.

Schedule 40 Standard Seamless Carbon Steel Pipe							
Size (inch)	*DN*	*ID (inch)*	*ID (mm)*	***Min flow (scfm)***	***Max flow (scfm)***	***Min flow (m^3_n/hr)***	***Max flow (m^3_n/hr)***
2	50	2,1	52,5	92	917	**156**	**1559**
3	80	3,1	77,9	202	2021	**343**	**3434**
4	100	4,0	102,3	348	3481	**591**	**5913**
6	150	6,1	154,1	790	7899	**1342**	**13420**
8	200	8,0	202,7	1368	13678	**2324**	**23238**
10	250	10,2	259,1	2234	22341	**3796**	**37957**
12	300	11,9	303,2	3060	30604	**5199**	**51994**
16	400	15,0	381,0	4832	48316	**8209**	**82087**
20	500	18,8	477,8	7599	75994	**12911**	**129110**

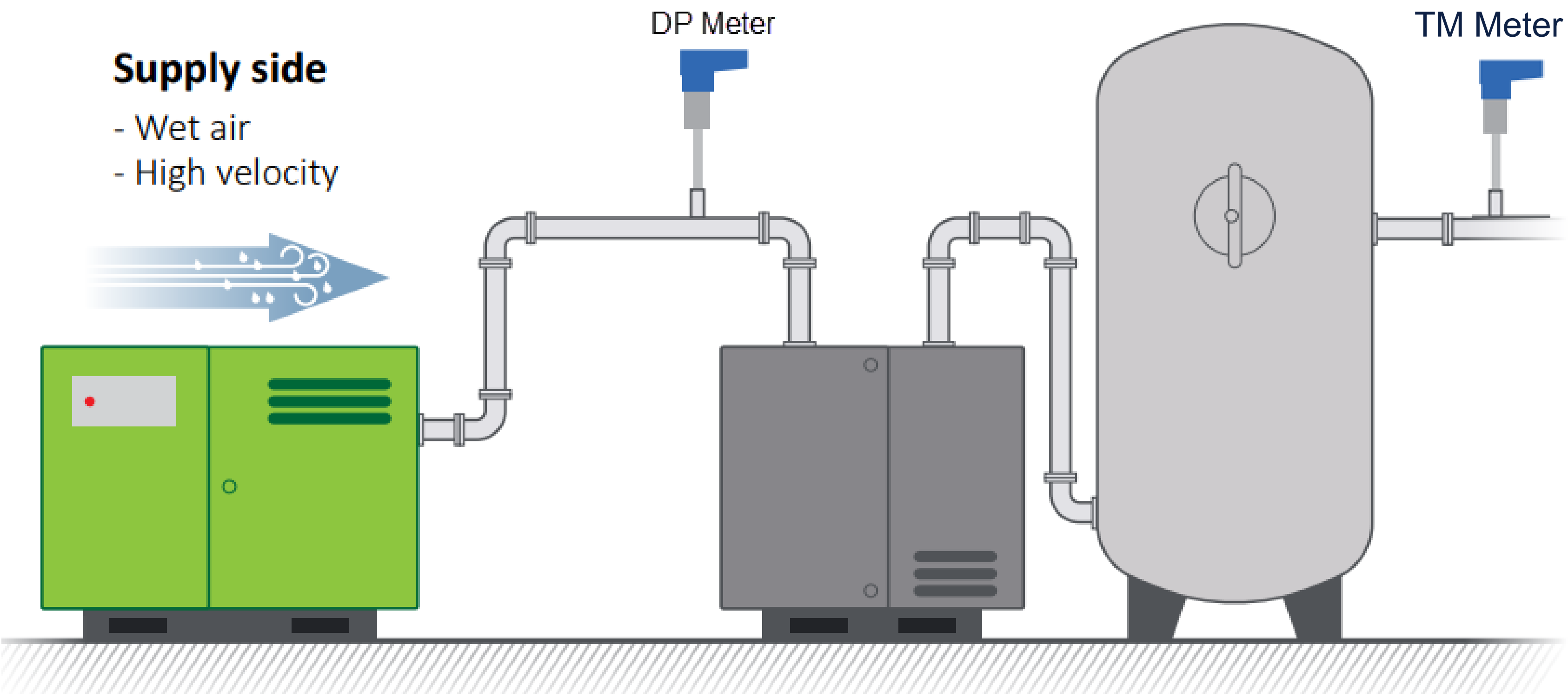
Schedule 10 Standard Seamless Carbon Steel Pipe					
ID (inch)	*ID (mm)*	***Min flow (scfm)***	***Max flow (scfm)***	***Min flow (m^3_n/hr)***	***Max flow (m^3_n/hr)***
2,2	54,8	100	999	**170**	**1697**
3,3	82,8	228	2282	**388**	**3877**
4,3	108,2	390	3897	**662**	**6621**
6,4	161,5	868	8678	**1474**	**14743**
8,3	211,6	1490	14897	**2531**	**25309**
10,4	264,7	2332	23316	**3961**	**39612**
12,4	314,7	3296	32965	**5601**	**56006**
15,6	396,8	5242	52420	**8906**	**89058**
19,6	496,9	8219	82191	**13964**	**139638**

Flow Meter Location

Picture	Description	Upstream length[2]	Downstream length[2]	Effect
	Single elbow	30 * D1	10 * D1	Distorted flow profile
	Complex feed-in situation (header)	40 * D1	10 * D1	Flow profile will be distorted
	Double elbow, multiple elbows following each other	40 * D1	10 * D1	Distorted profile + swirl
	Diameter change from small to large (gradual or instant)	40 * D1	5 *D1	Jet shaped flow
	Diameter change from large to small (gradual change, between 7 and 15 degrees)	10 * D1	5 * D1	Flattened flow profile

DP Insertion Flow Meters

- Insertion style Differential Pressure meter for saturated compressed air flow measurements.
- A differential pressure flow sensor measures bi-directional flow, pressure, temperature and total flow simultaneously.
- They are intended for use in high velocity applications where there is a continuous flow over a minimum value, such as compressor efficiency monitoring.



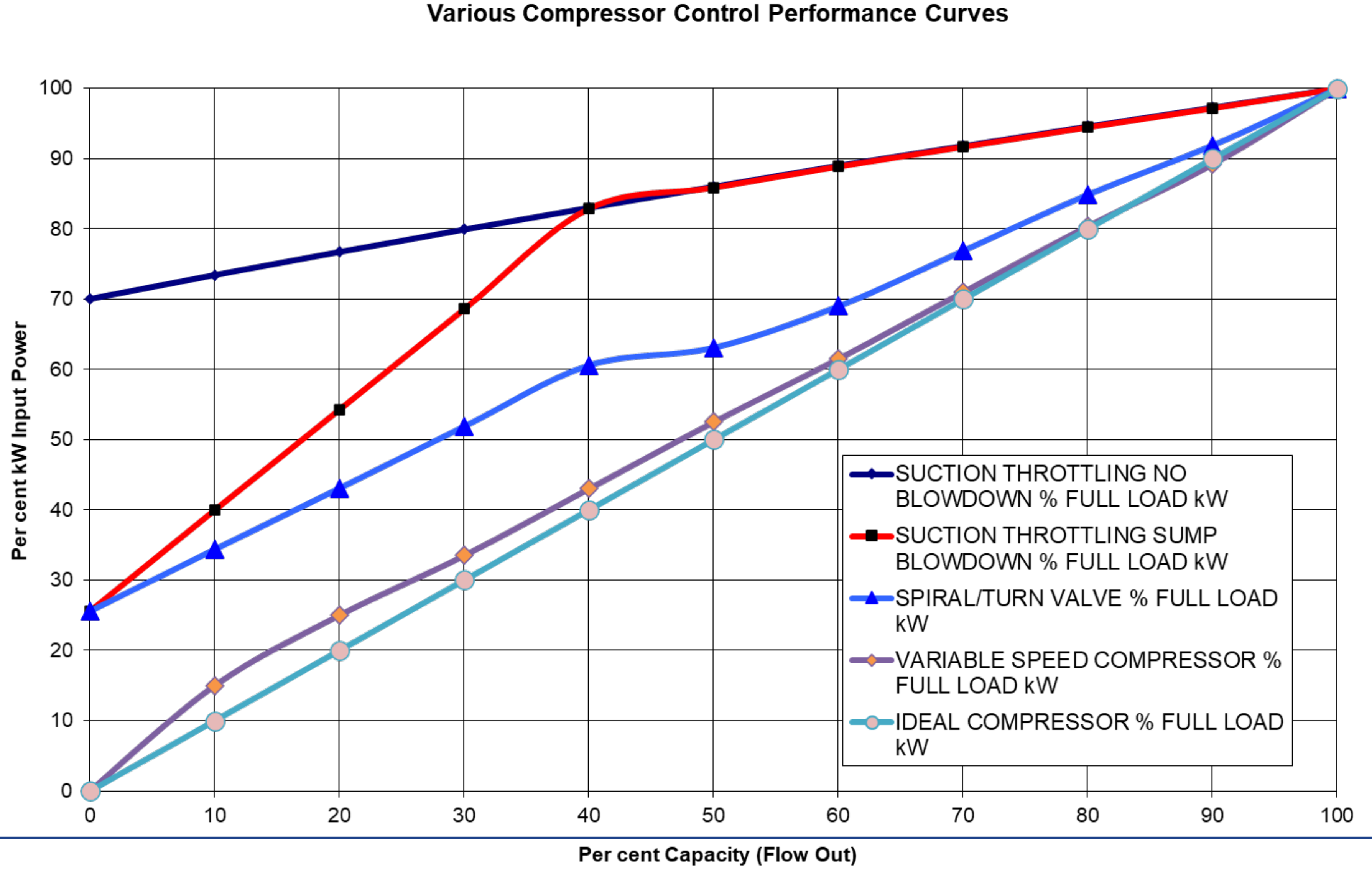
Session 3

Compressor Controls

Compressor Control Types

- Start/Stop
- Load/Unload
- Modulating
- Variable Displacement
- Variable Speed

Performance Curves

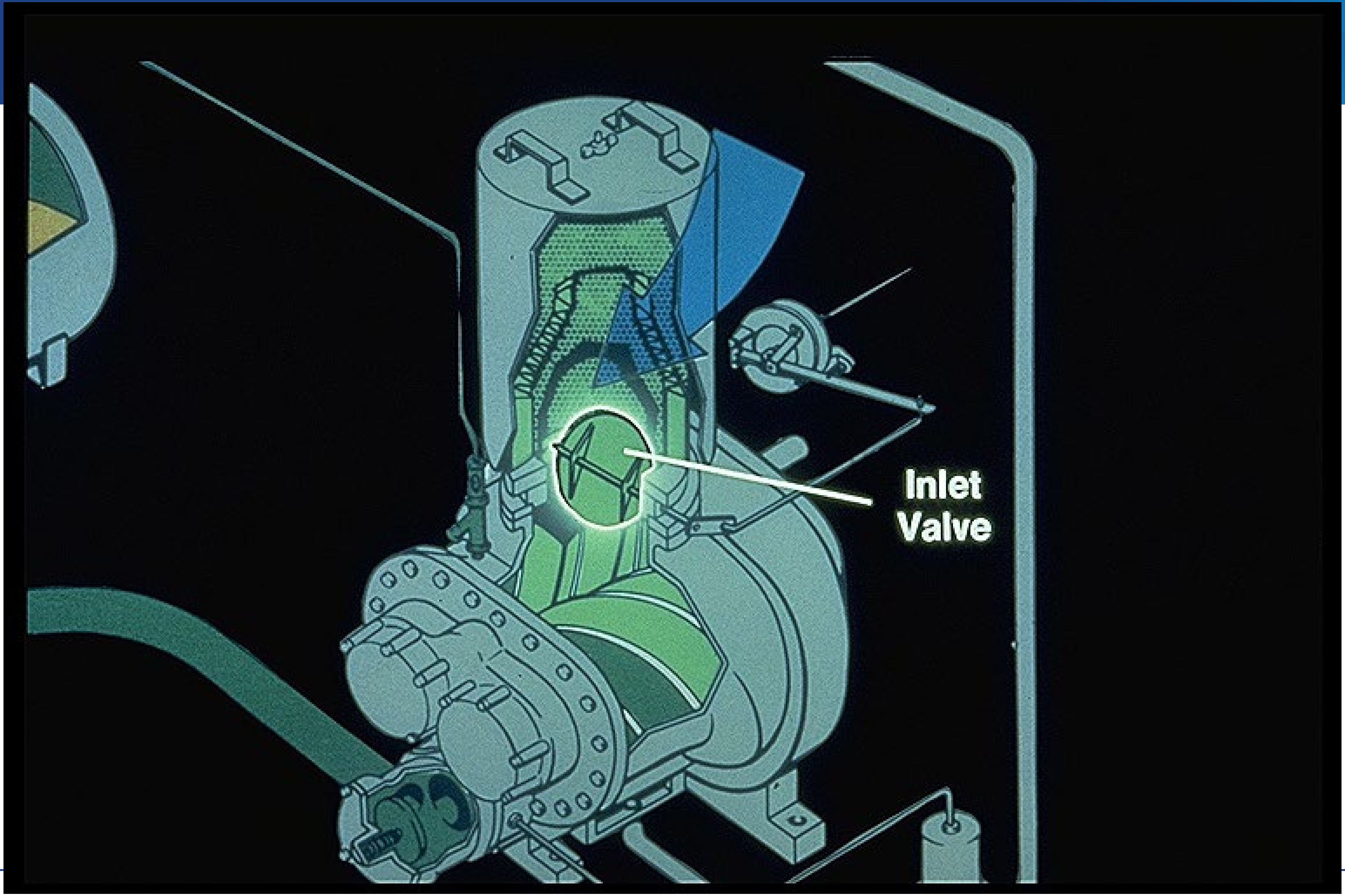


Basic Compressor Design (Air Inlet Controls)

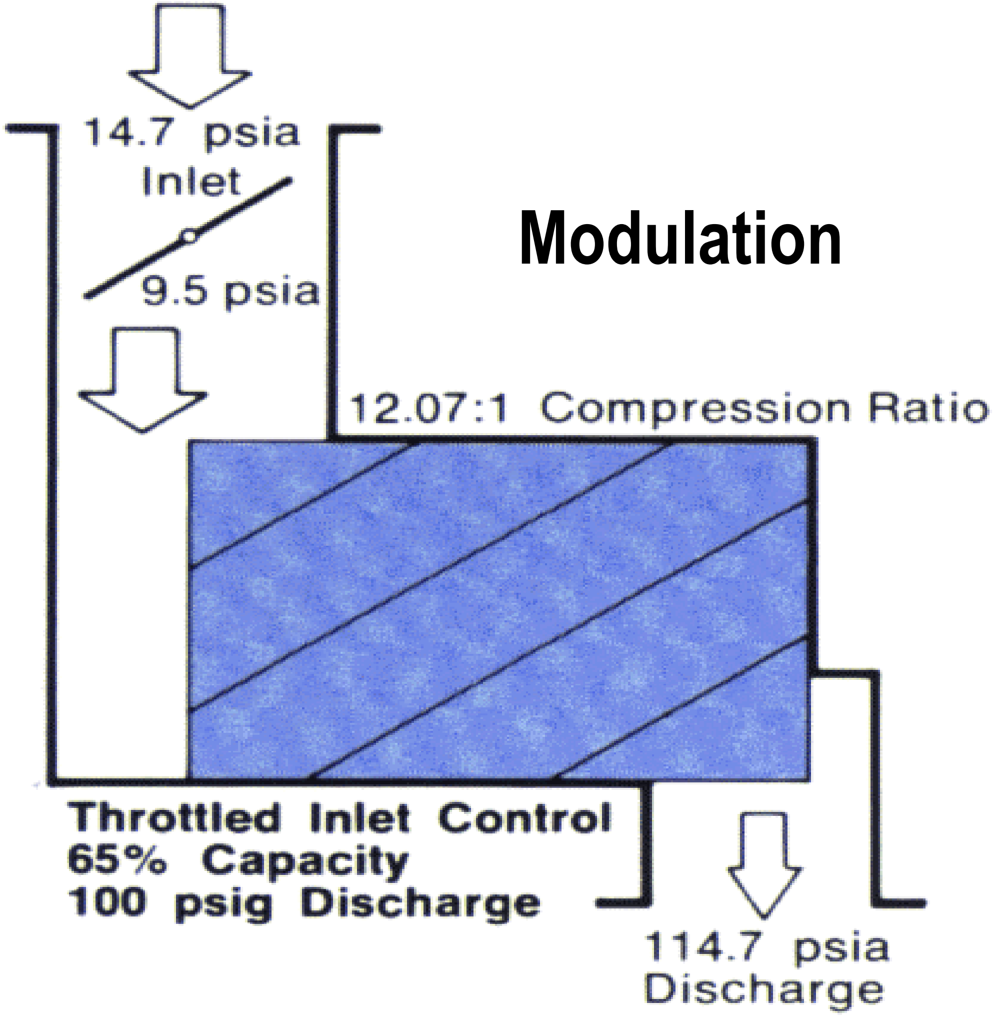
Air Inlet Controls / Regulation Types "their differences"

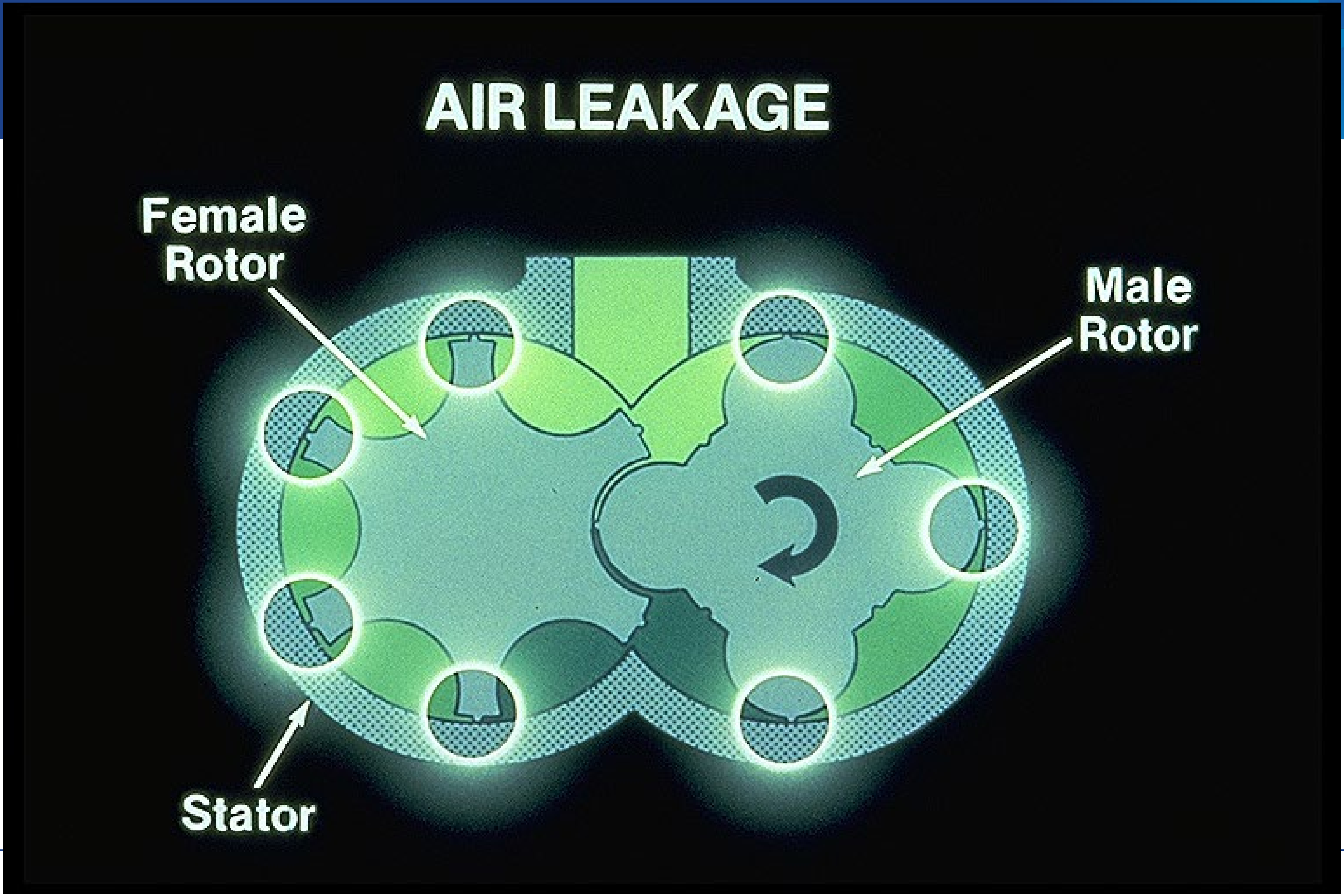
Part Load Performance of Various Regulation Types

	Modulation Control	Rotor Length Adjustment	Full Load / No Load	VSD
% Capacity	% Bhp	% Bhp	% Bhp	% Input kW
100	100	100	100	100
90	97	93	92.5	90
80	94	85	85	80
70	91	78	77.5	70
60	88	72	70	61
50	85	67	62.5	53
40	82	64	55	43.5
30	79	55	47.5	35
20	76	45	40	26
10	73	35	32.5	--
0	70	25	25	--

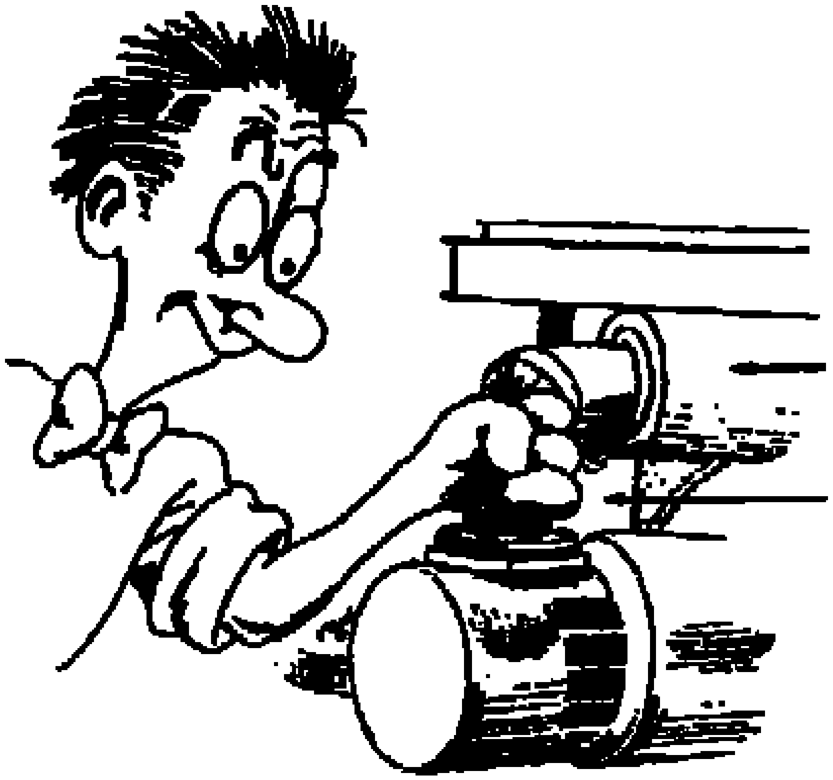

Inlet
Valve

Inlet Throttling



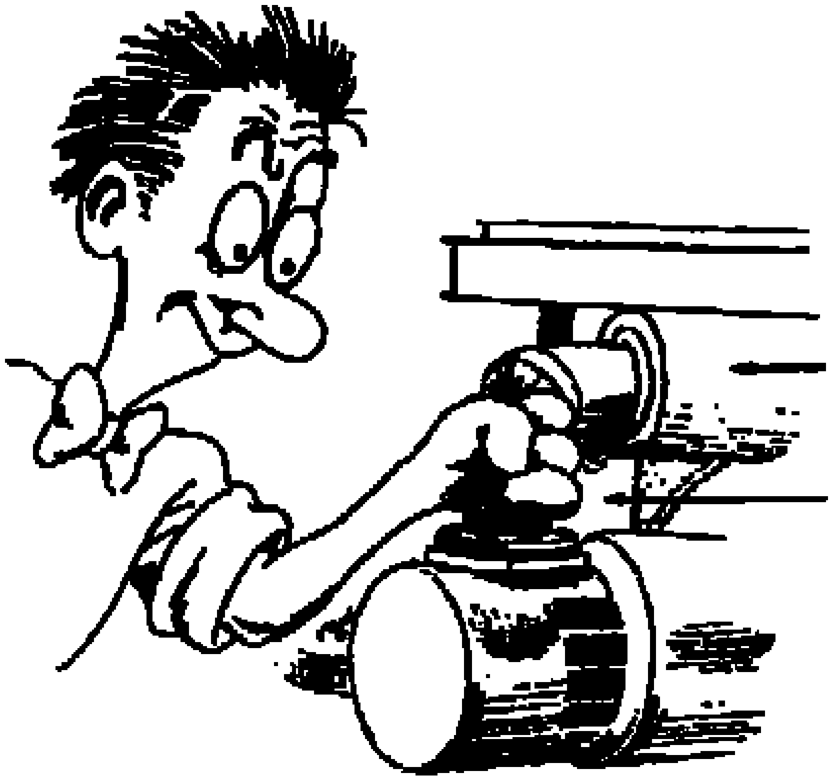

AIR LEAKAGE
Female Rotor
Male Rotor
Stator

Capacity Control by Inlet Throttling



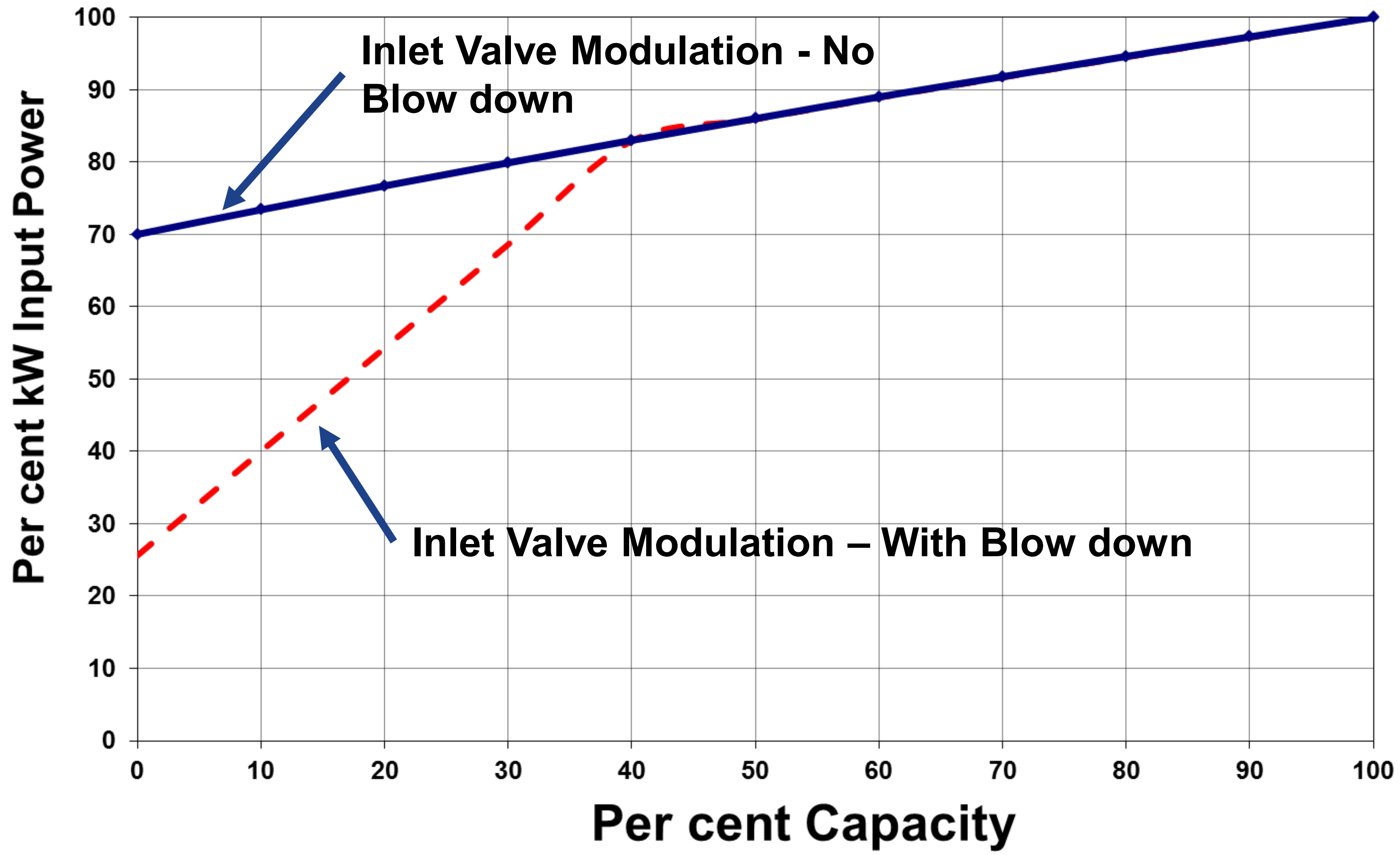
- Atmospheric pressure 14.7 psia
- Intake pressure 9.0 psia
- Discharge pressure 114.7
- Compression ratio: 114.7/9.0 = 12.7 to 1
- End Result?? Increased internal leakage due to a higher compression ratio

Capacity Control by Inlet Throttling



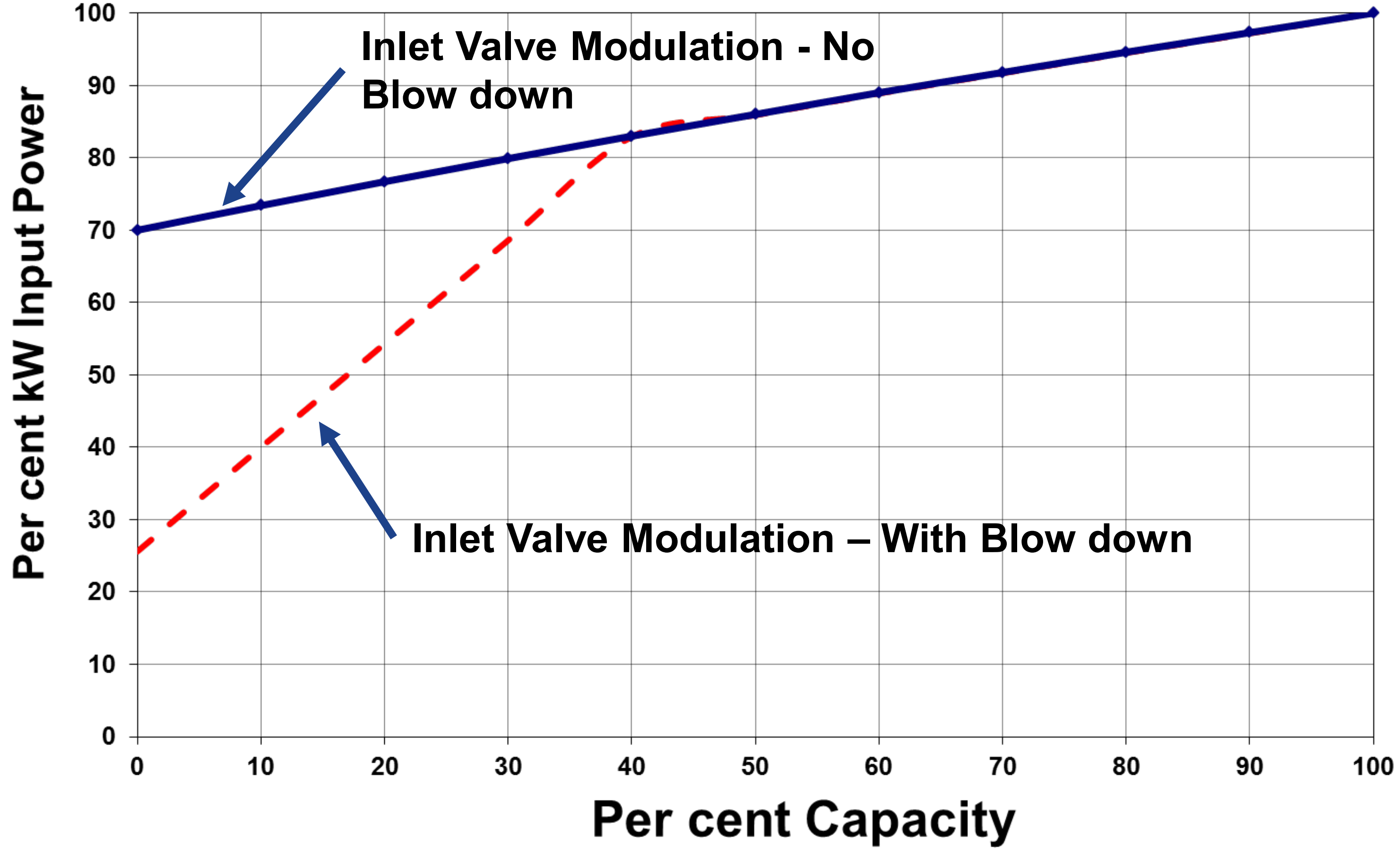
- Varies capacity by throttling (restricting) the inlet flow
- Provides a relatively stable output pressure
- Energy hog… least efficient
- Every 10% reduction in capacity yields only a 3% reduction in power(BHP)
- At zero capacity, power remains at 70% of full load power

Inlet Valve Modulation

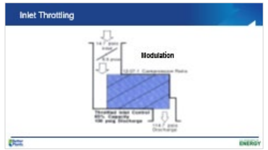


- The example shows a discharge pressure range of 100 - 110 psig.
- As discharge pressure rises from 100 to 110 psig, a proportional pressure regulator provides a control pressure from 0 - 30 psig, to progressively close the inlet valve.
- As the inlet valve closes, the absolute pressure at the inlet of the air end is reduced.

Inlet Valve Modulation



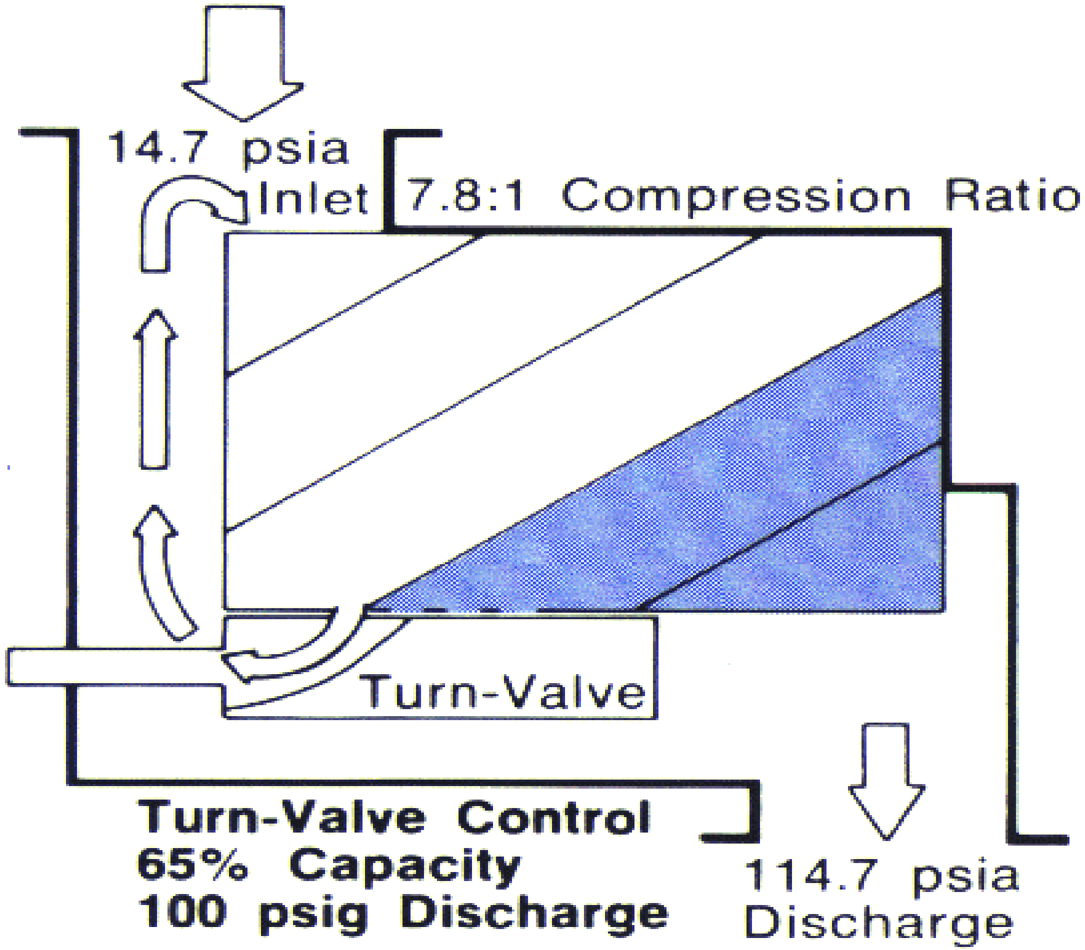
- This reduces the mass flow of air entering the air end in direct proportion to the absolute pressure.
- However, the reduced inlet pressure, with increasing discharge pressure, results in increasing pressure ratio.
- At 40% capacity the pressure ratio will be 124.7/5.88 = 21.21.
- This is why there is not much reduction in the power requirement.



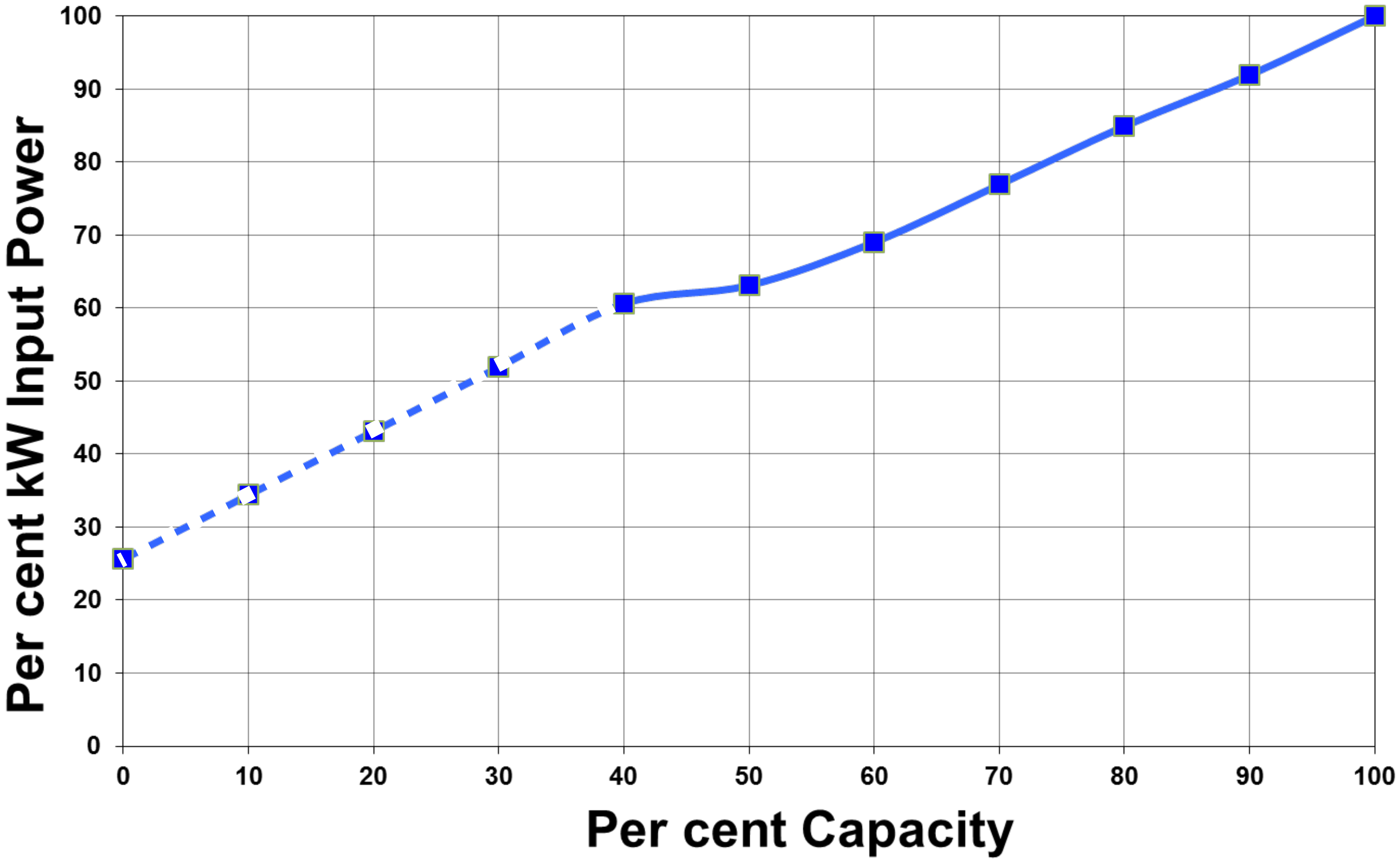
Variable Displacement

- Valves progressively opens ports connecting the compression chamber back to the compressor intake in response to rising discharge pressure.
- This allows some of the intake air to be returned to the compressor inlet before it gets compressed and uses power
- This progressive opening of by-pass ports has the effect of shortening the length of the rotors after the lobes seal without choking the intake and increasing the compression ratio

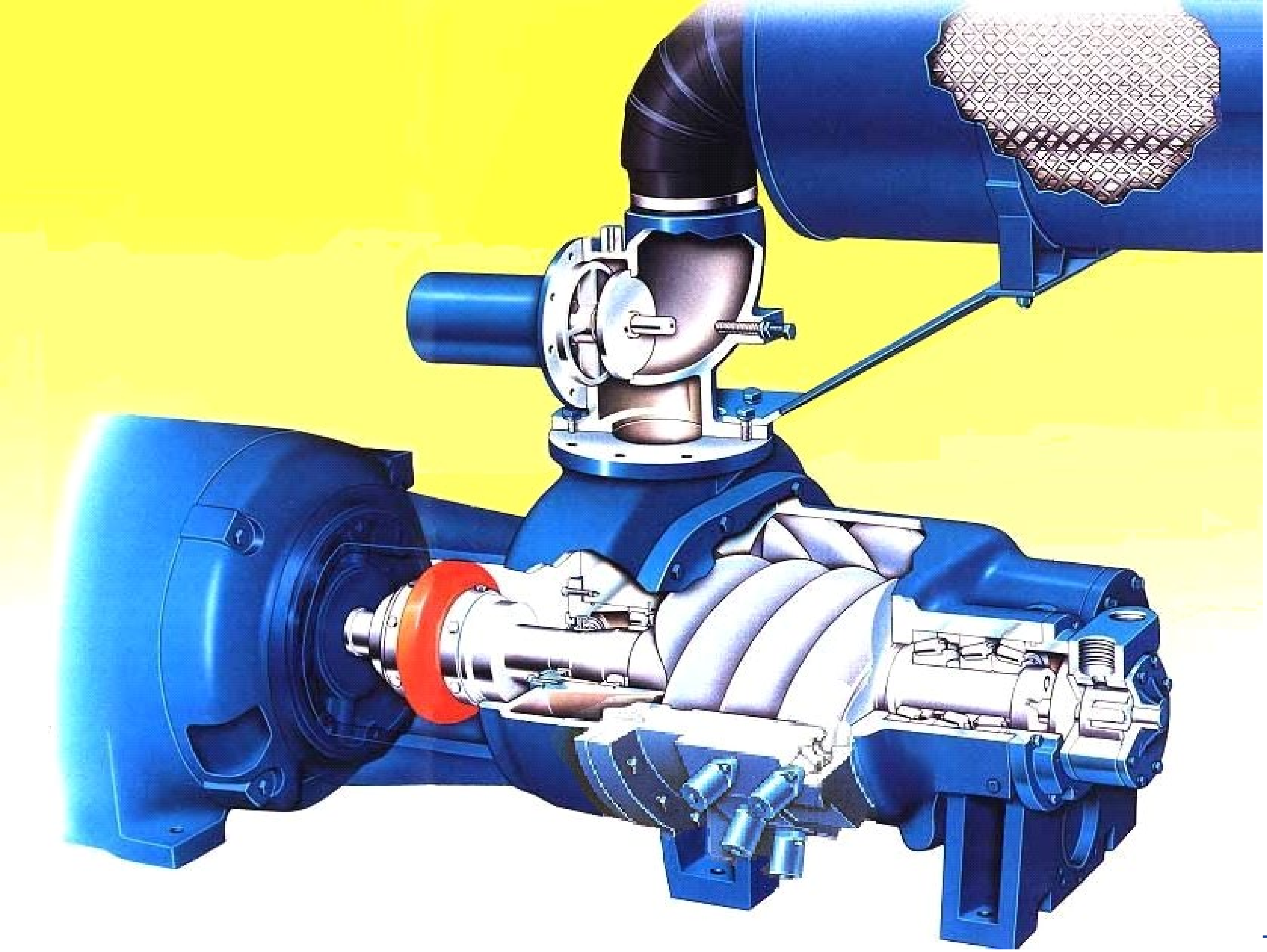
Variable Displacement



Variable Displacement

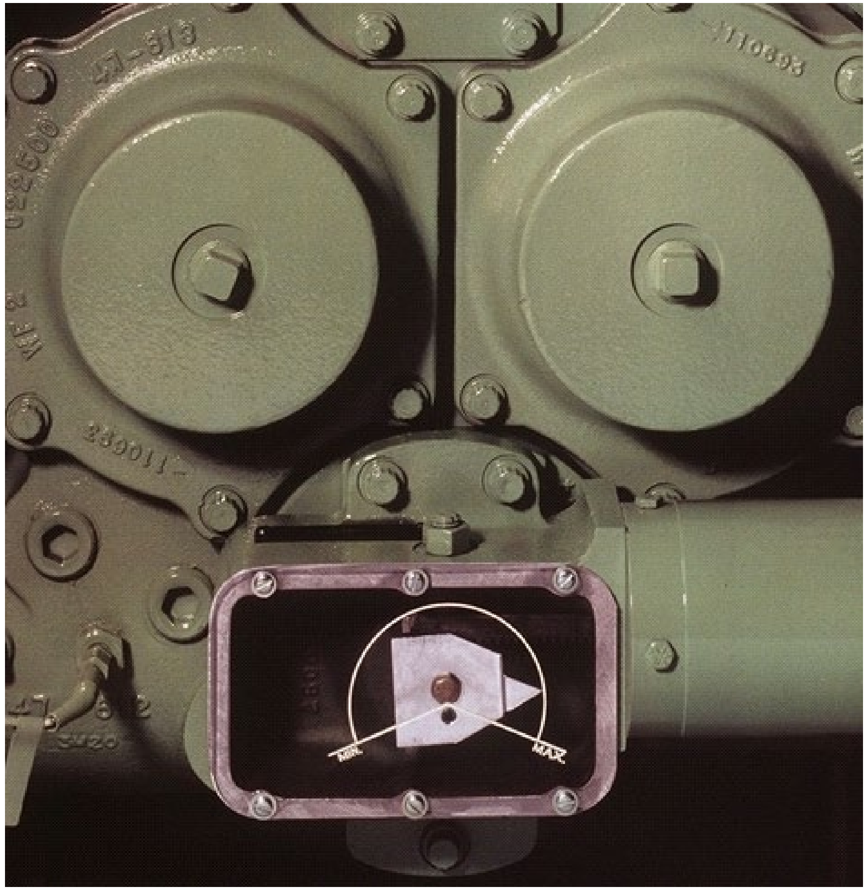


Variable Displacement



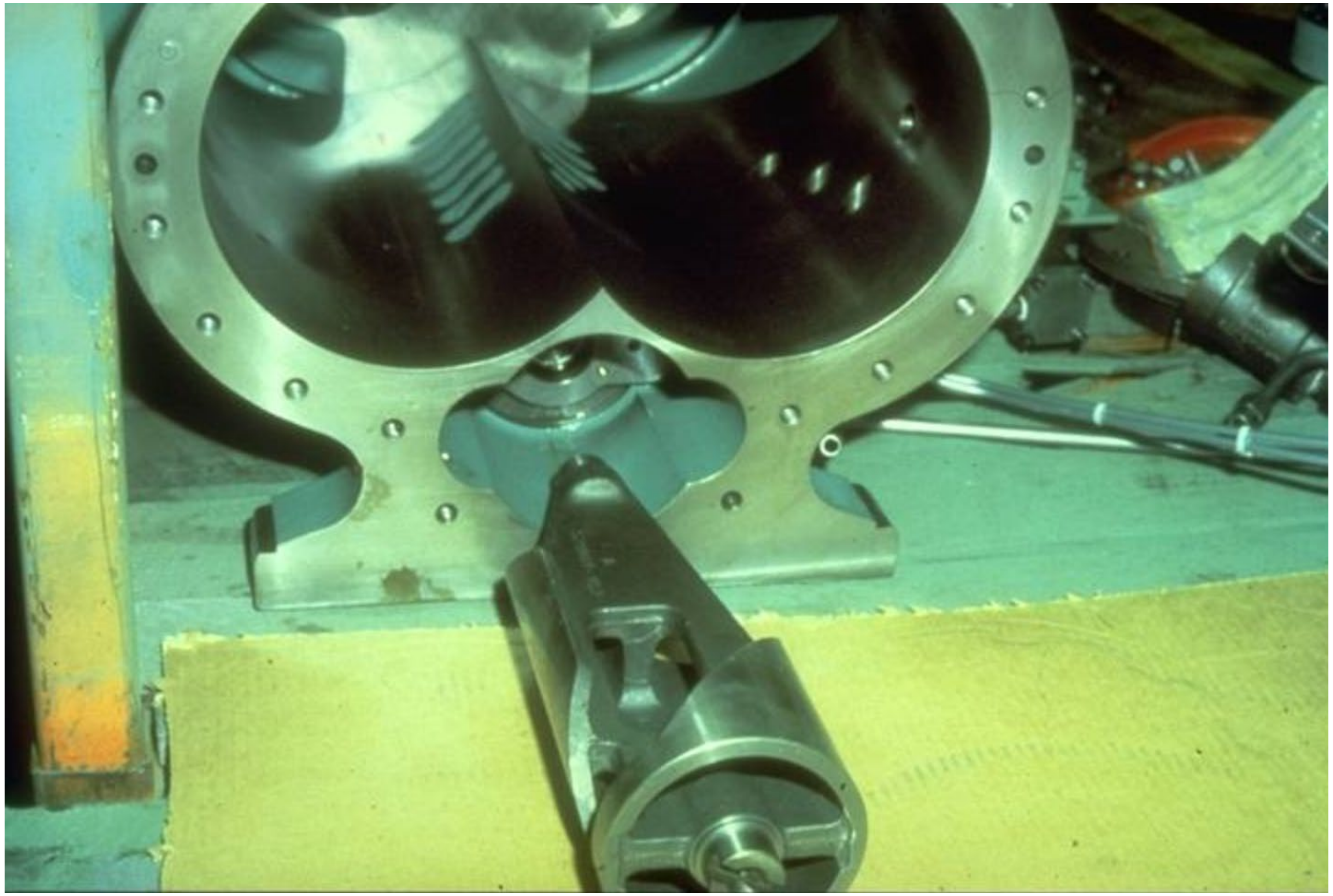
Variable Displacement

Original Version



— UP TO 55% TURN DOWN

Variable Displacement



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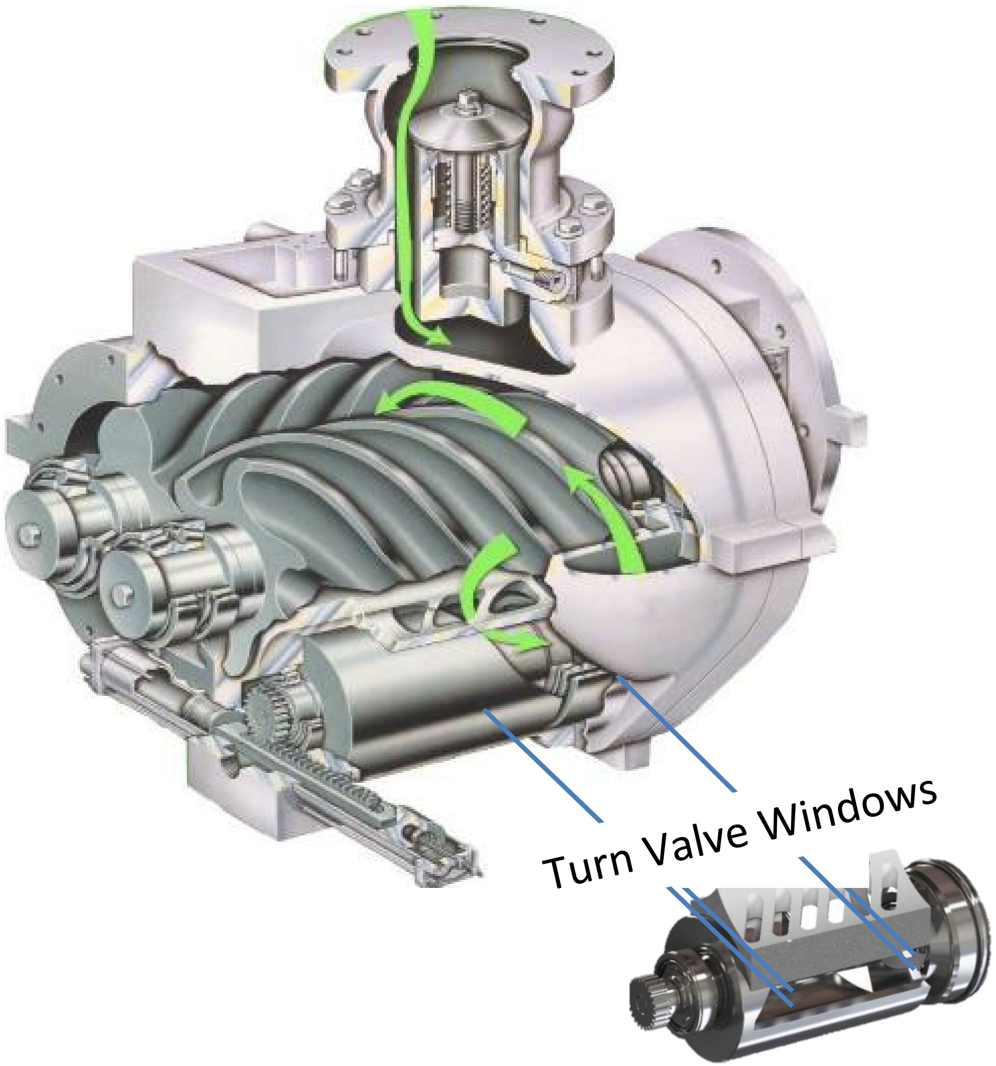
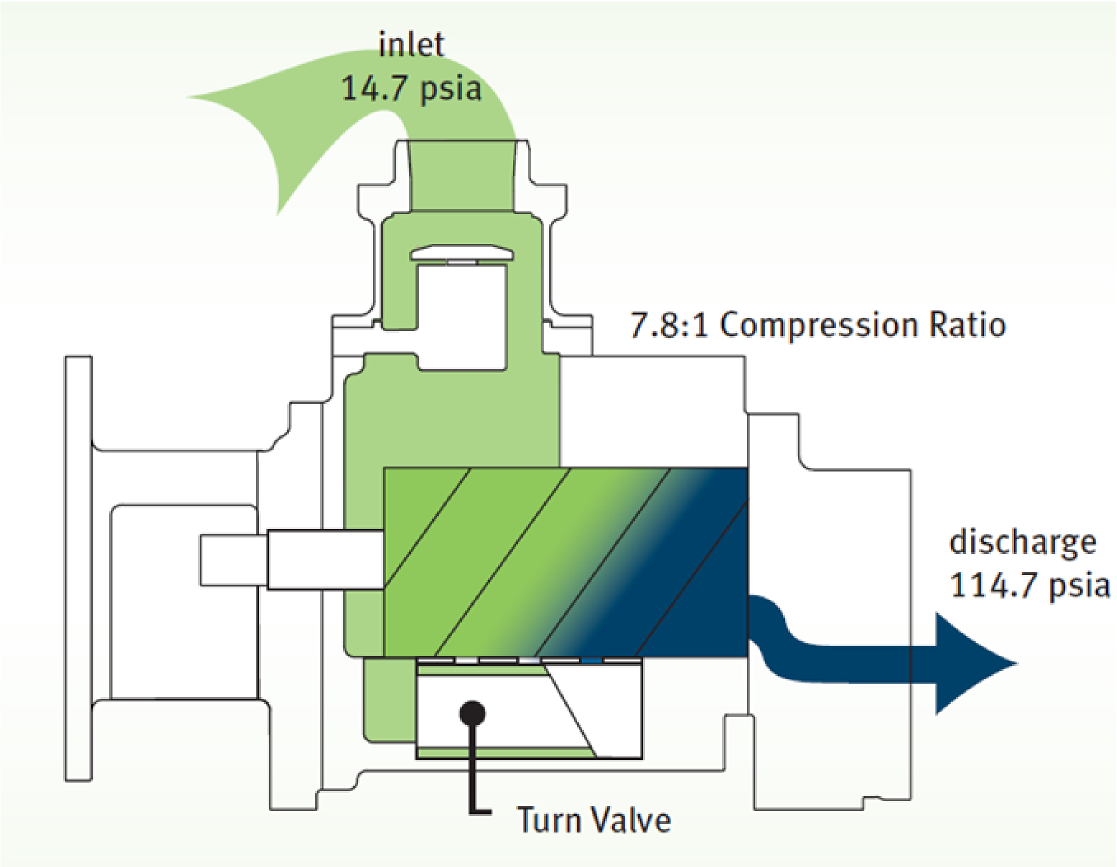
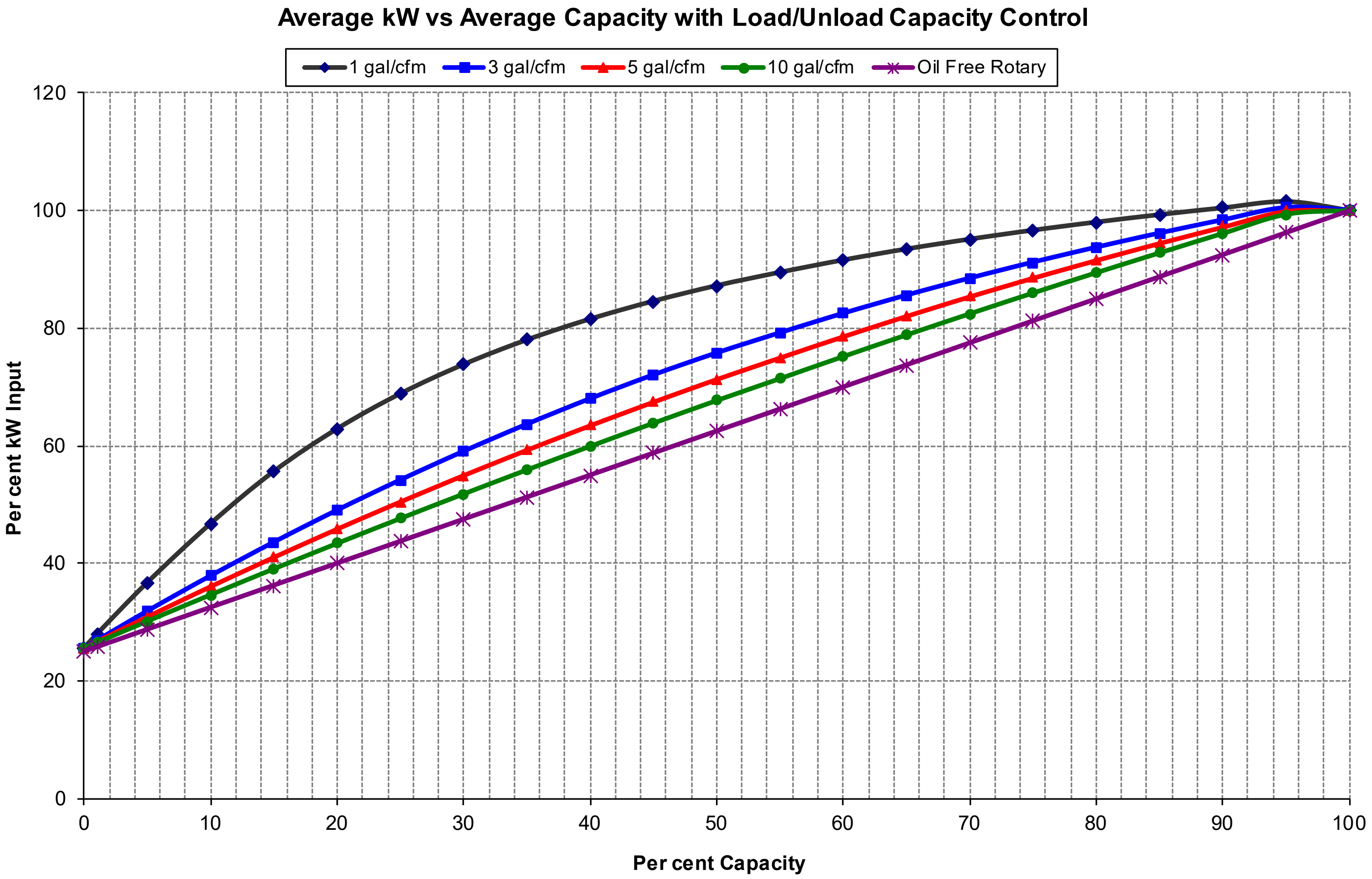




Load/No-load Control Curve

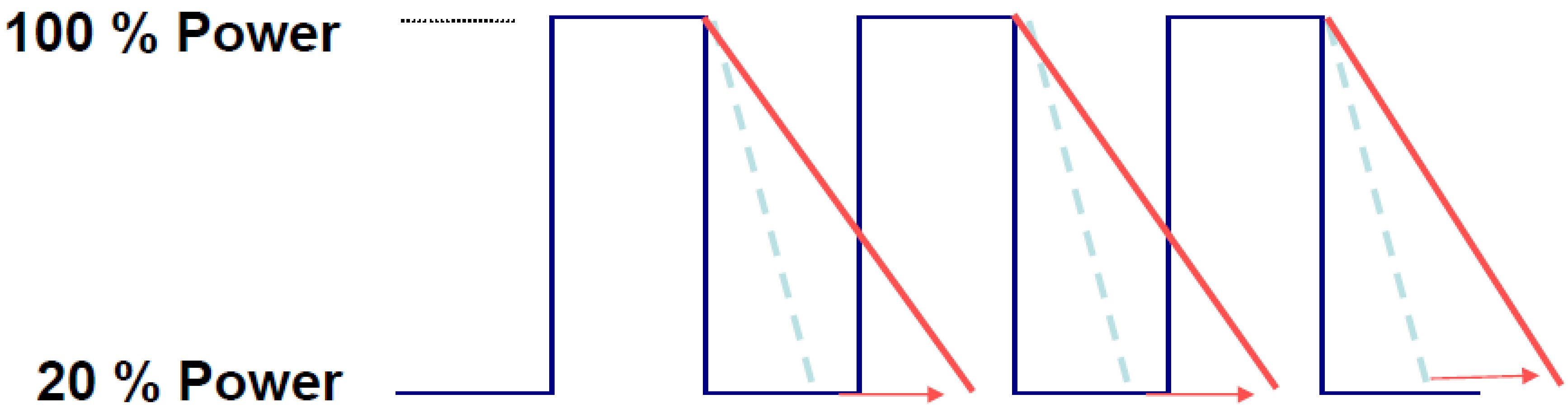


- This graph shows the effect of receiver size on the part load power of a lubricant injected rotary screw compressor with load/unload controls

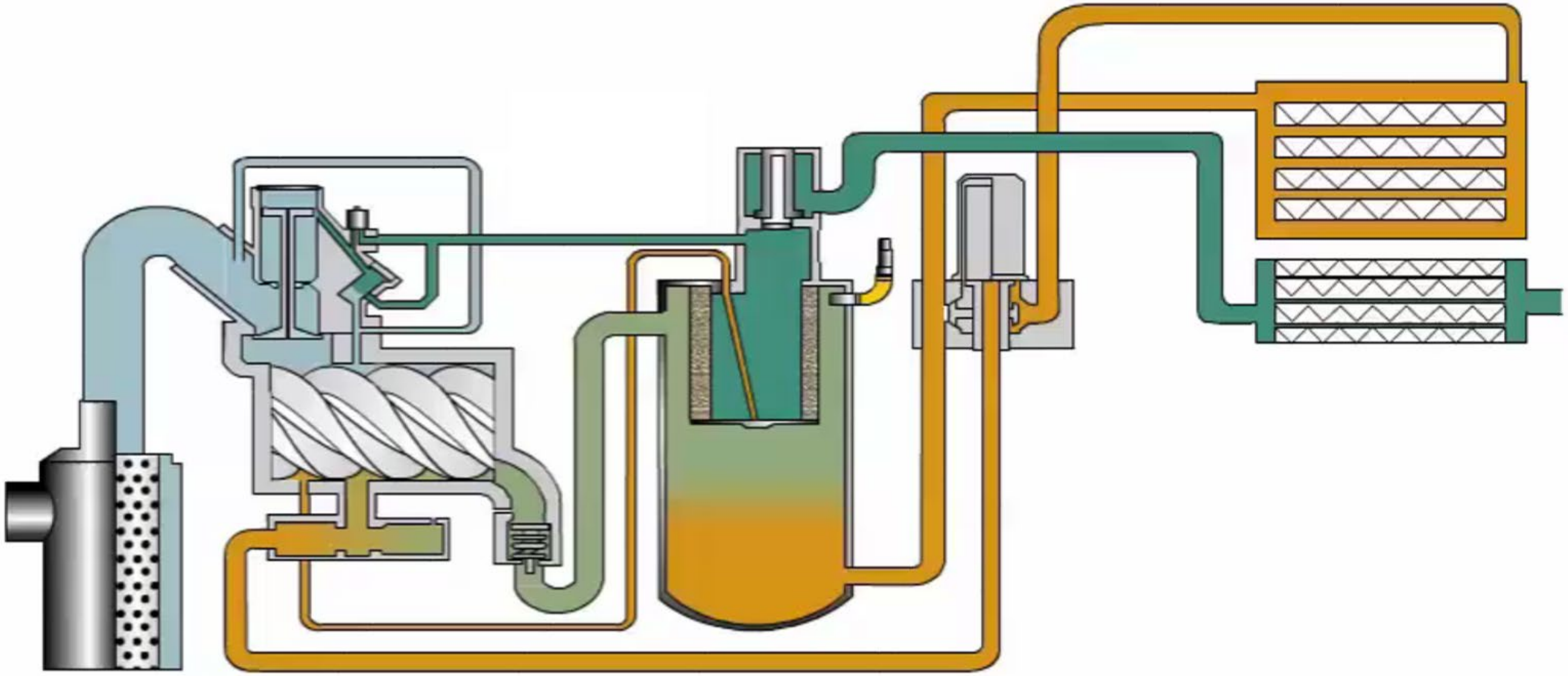
Load/Unload and Storage Size

- It is falsely assumed that a straight line, from full load bhp to unloaded bhp, represents the actual power requirement in this mode of operation.
- Sump blow down times will vary by machine size, but typically this takes in the range of 20 to 60 seconds to prevent foaming of the lubricant with the potential of excessive lubricant carry-over.
- In many cases, the system pressure will fall and the compressor will re-load before the fully unloaded power is realized.

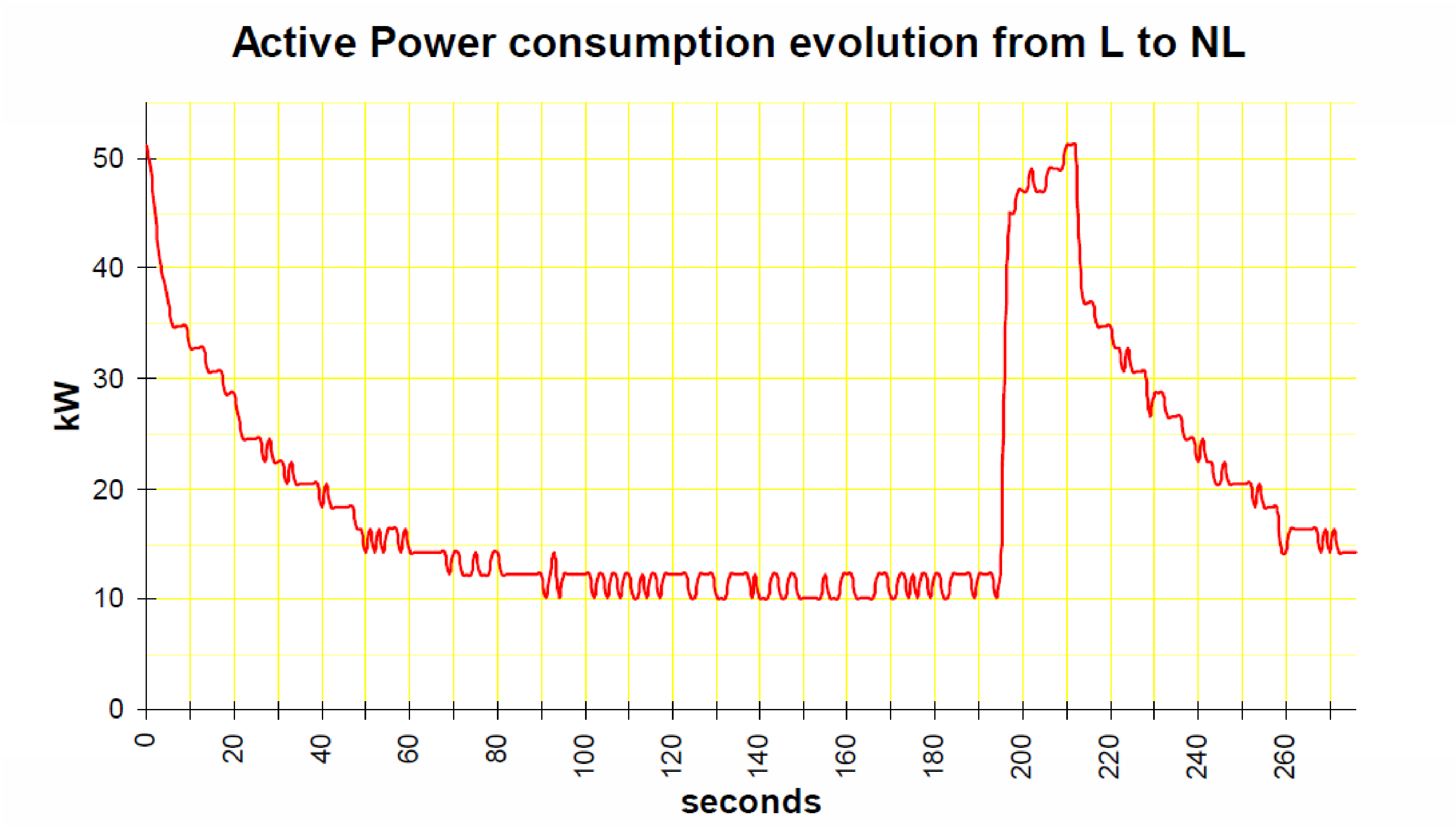
Capacity Control by Load/No-Load



- During blow-off, the compressor is still running against significant back pressure and consuming a lot of power
- Bigger sump vessels lead to longer blow-off times and more energy consumption



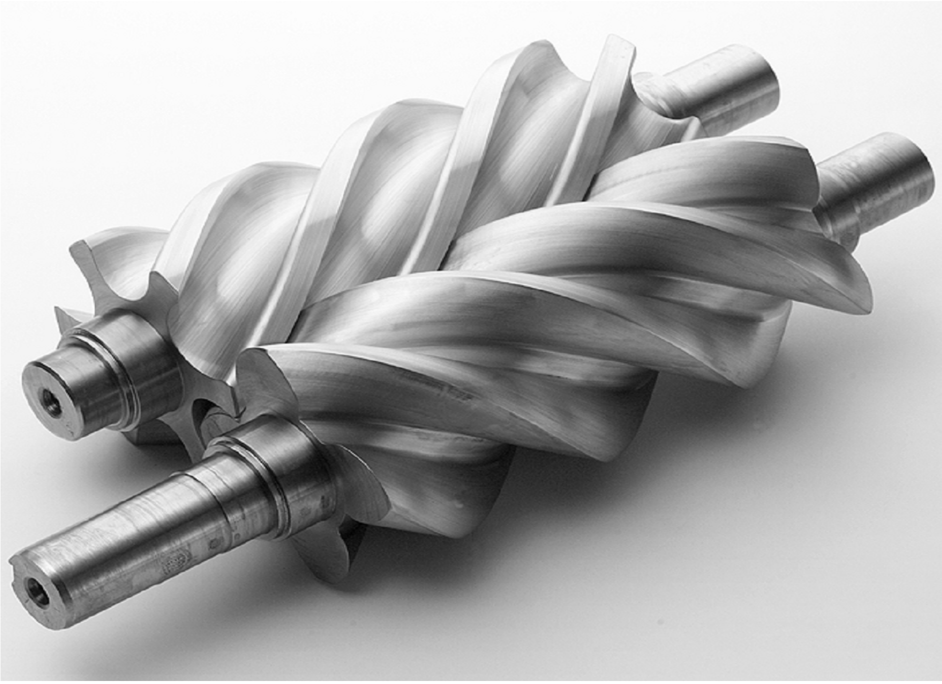
Capacity Control by Load/No-Load

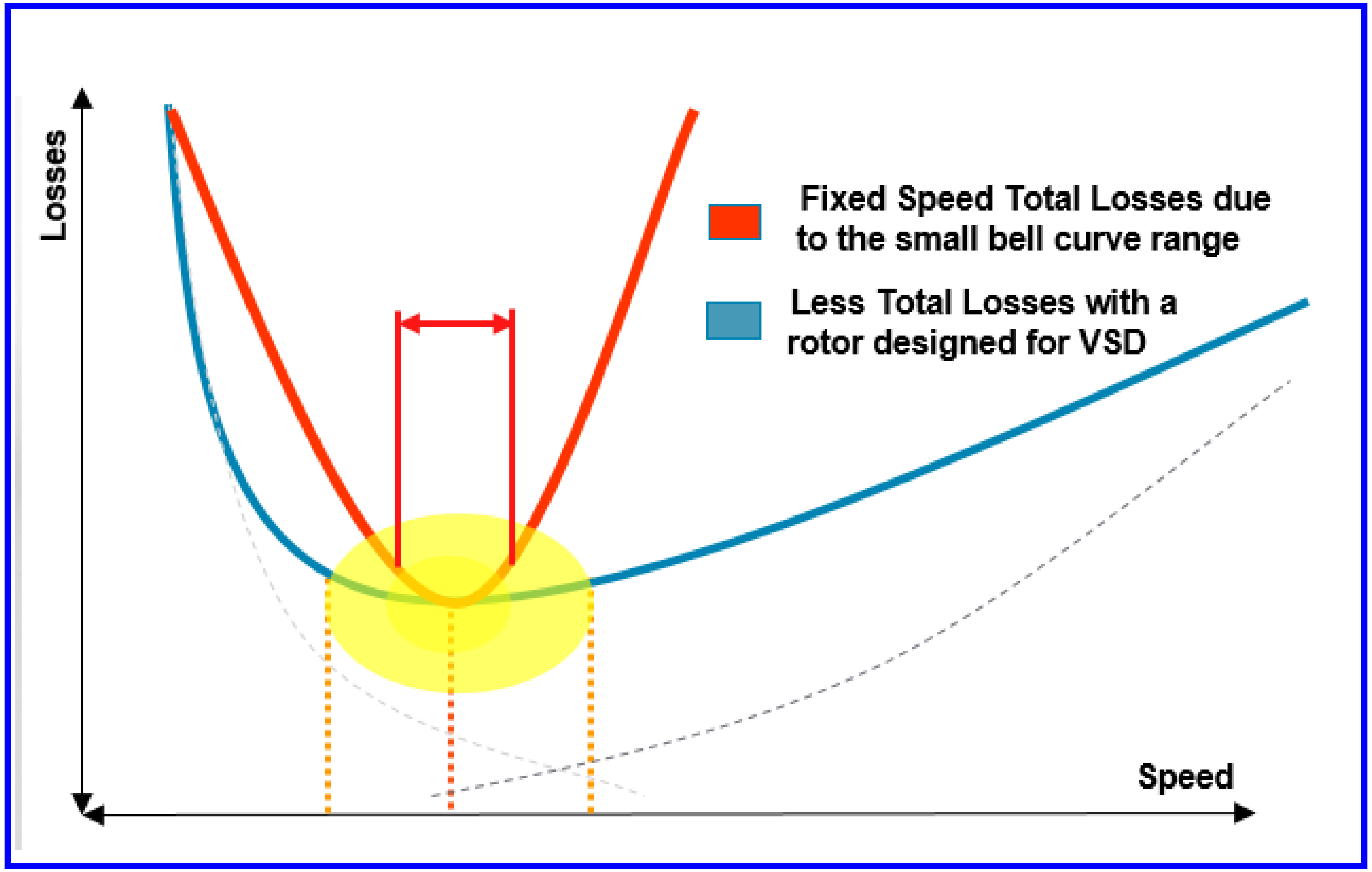


Variable Speed Compressors

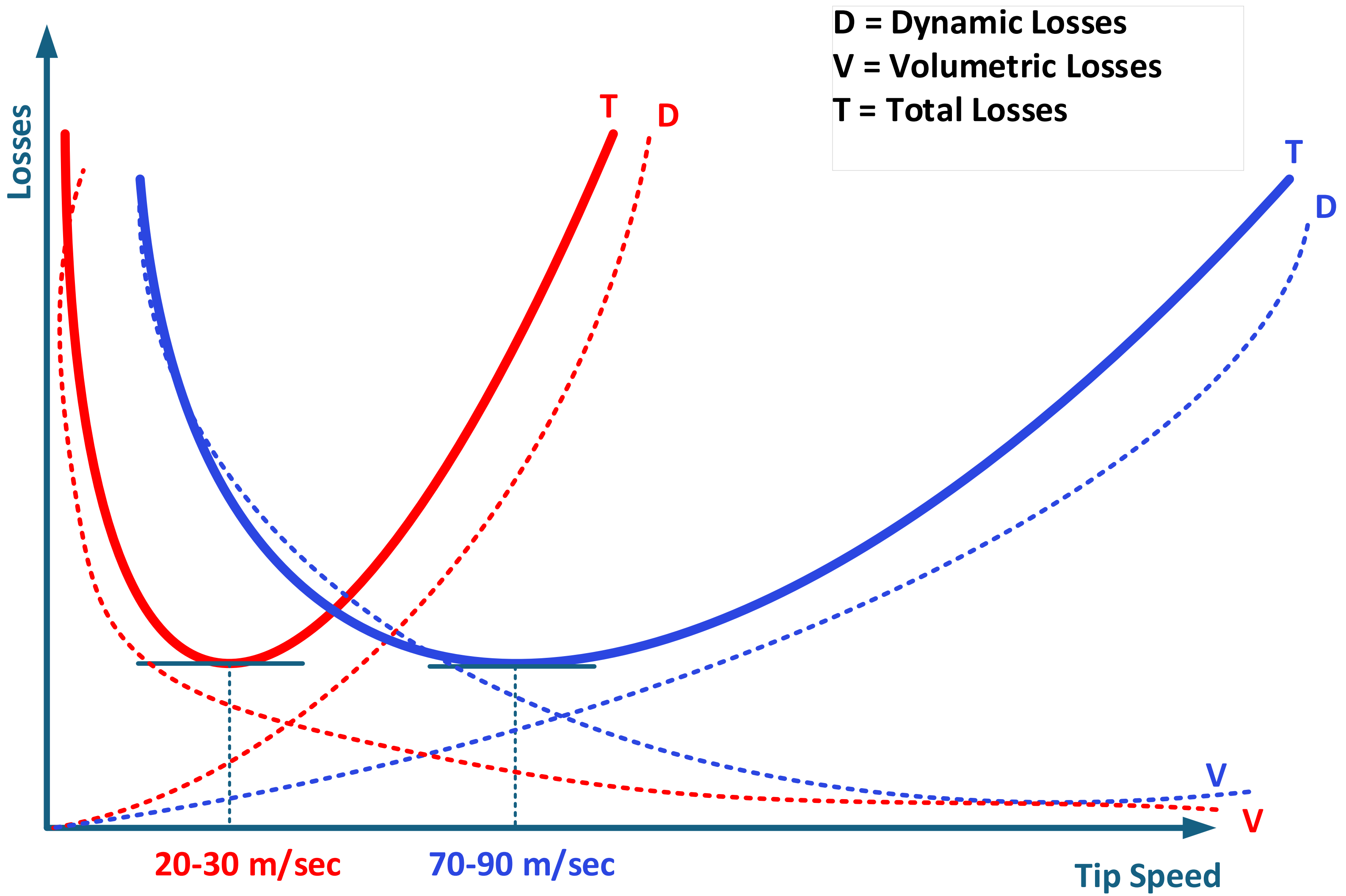
- The most common VSD is the variable frequency drive, which converts 60 Hz alternating current to direct current and then reconverts it to the proper frequency required to turn the drive motor at the desired speed.
- The variable frequency drive is less efficient at full load compared to modulation controls because the electrical conversions usually consume an additional two to four percent more energy.
- Compressor discharge pressure can be held to within +/- 1
- In order to provide efficient VSD regulation over the complete range of the customer's air profile, the VSD operational flow from min to max, needs to be sized so it will always be in its turndown range.

Losses – VSD vs Fixed Speed



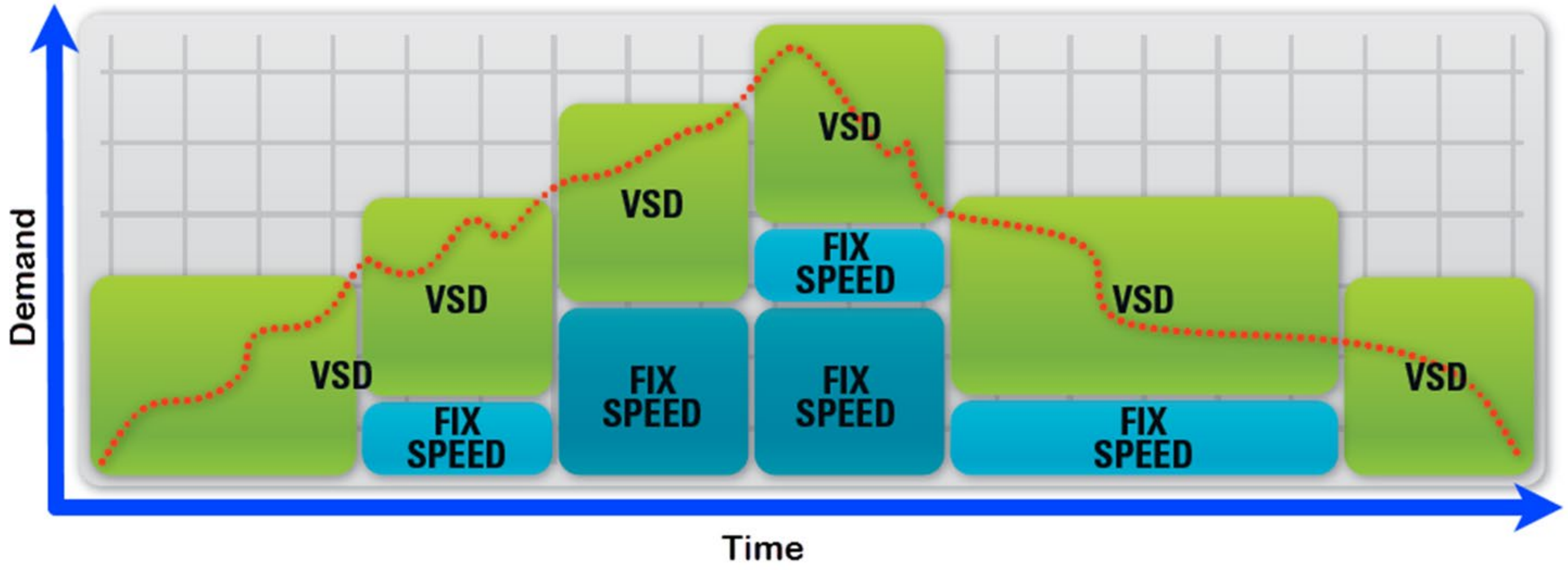


Losses – VSD vs Fixed Speed



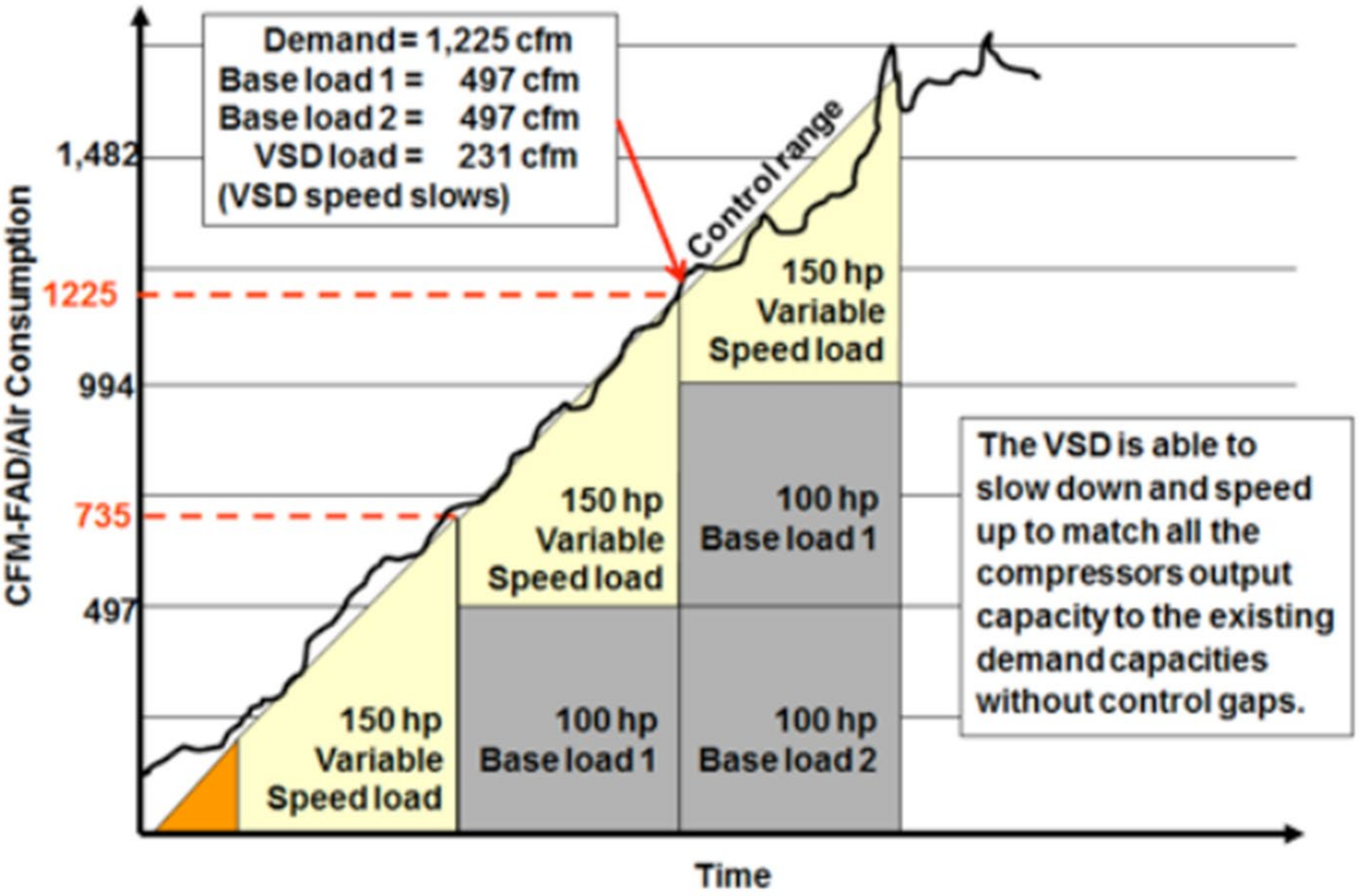
Variable Speed Compressors

- In order to provide efficient VSD regulation over the complete range of the customer's air profile, the range of the VSD from min to max needs to be sized greater than the load/no load machine



Variable Speed Compressors and Control Gap

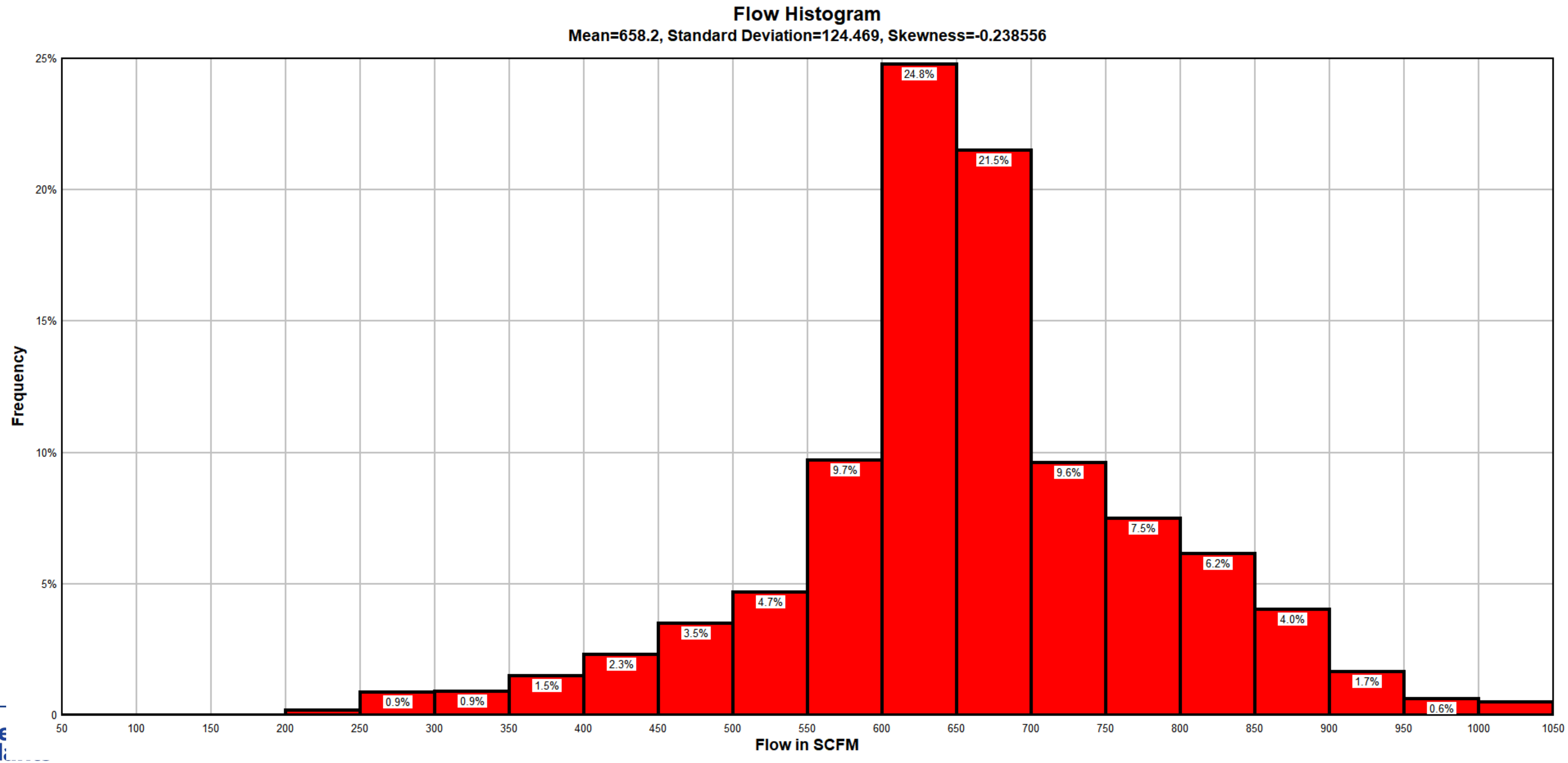
This system can provide a steady operating pressure throughout the flow range of the system as long as the system is properly controlled with a master controller.



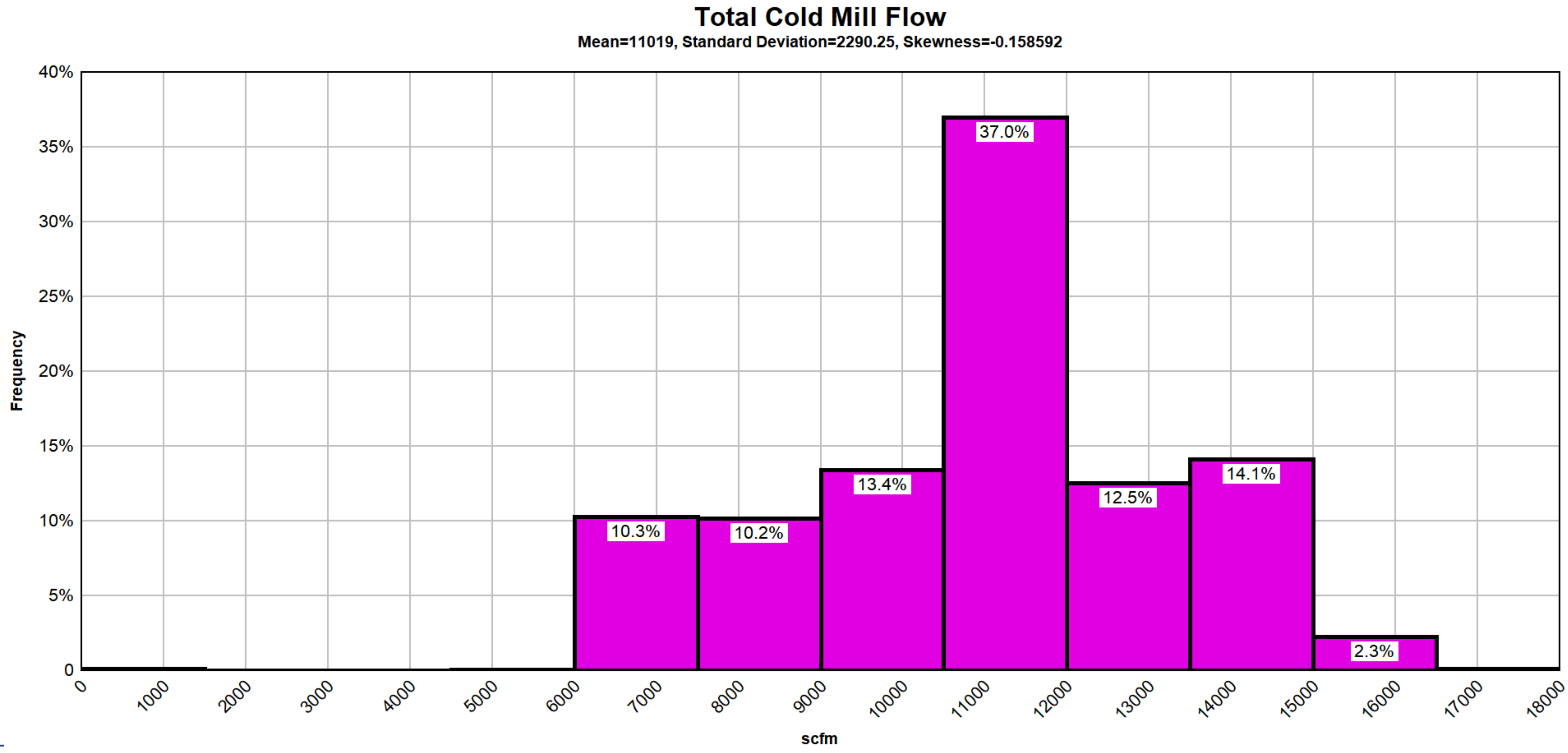
150 hp VSD rated 150-735 cfm
Control Range = 585 cfm

100 hp Fixed Speed rated 497 cfm

How do I know my flow patterns to size a VSD Correctly?



How do I know my flow patterns to size a VSD Correctly?



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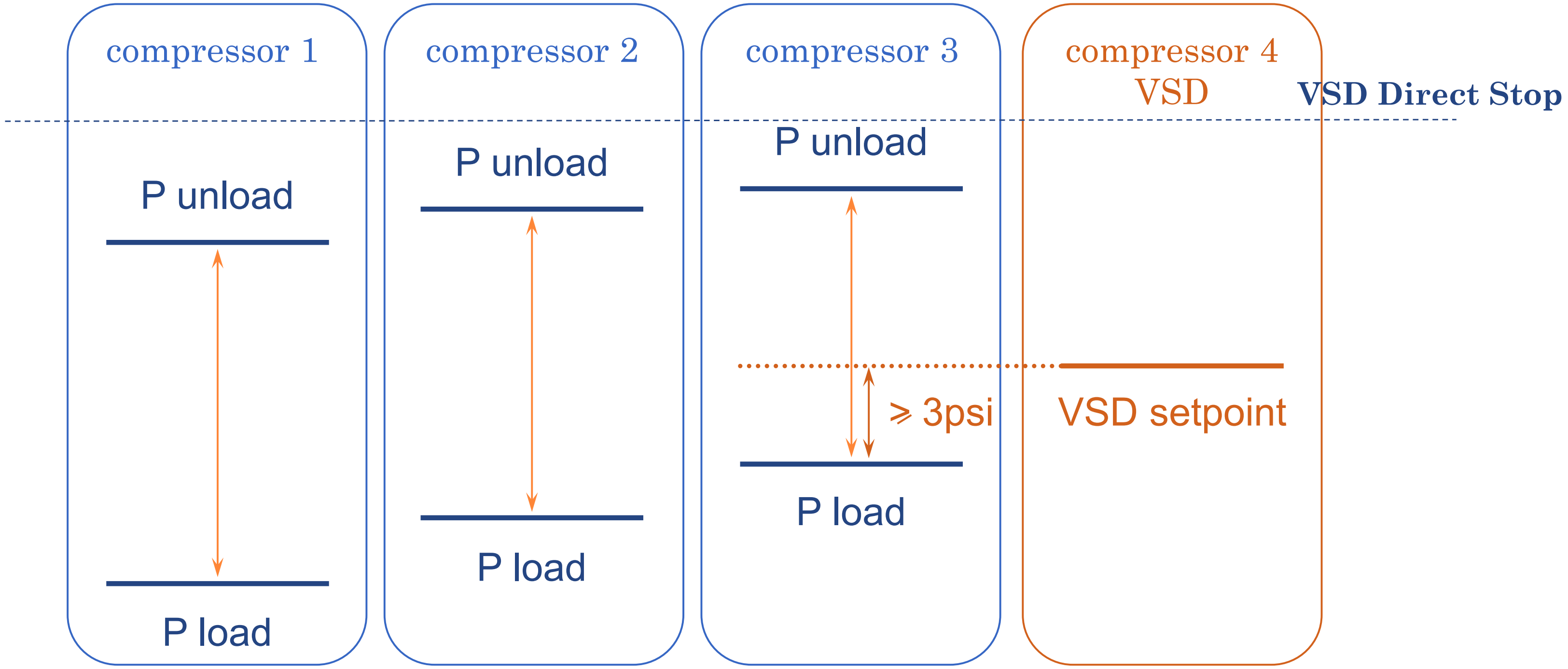
Control Gap and Position

- In order to provide efficient VSD regulation over the complete range of the customer's air profile, the cfm of the VSD needs to be greater than the load/no load machine

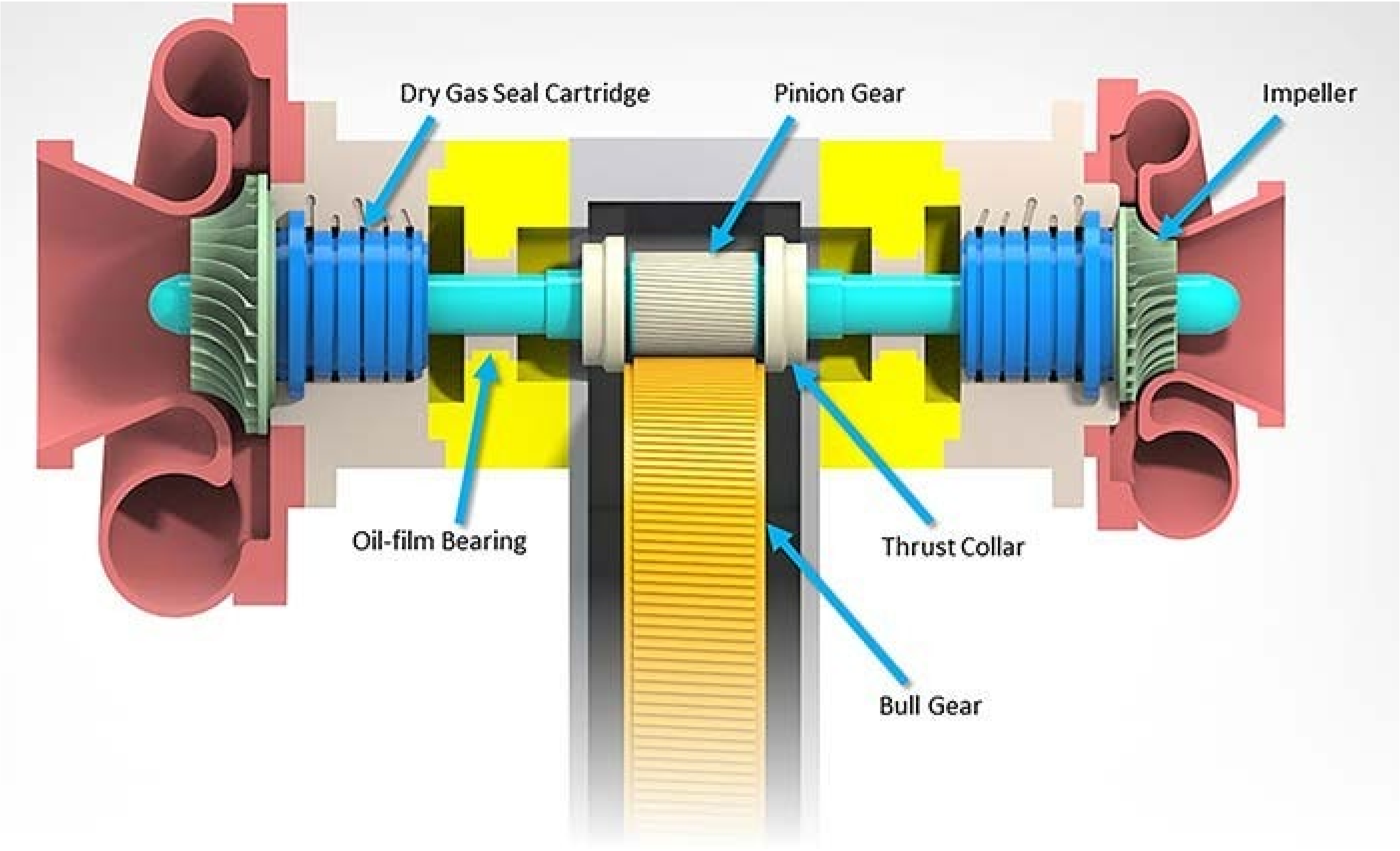


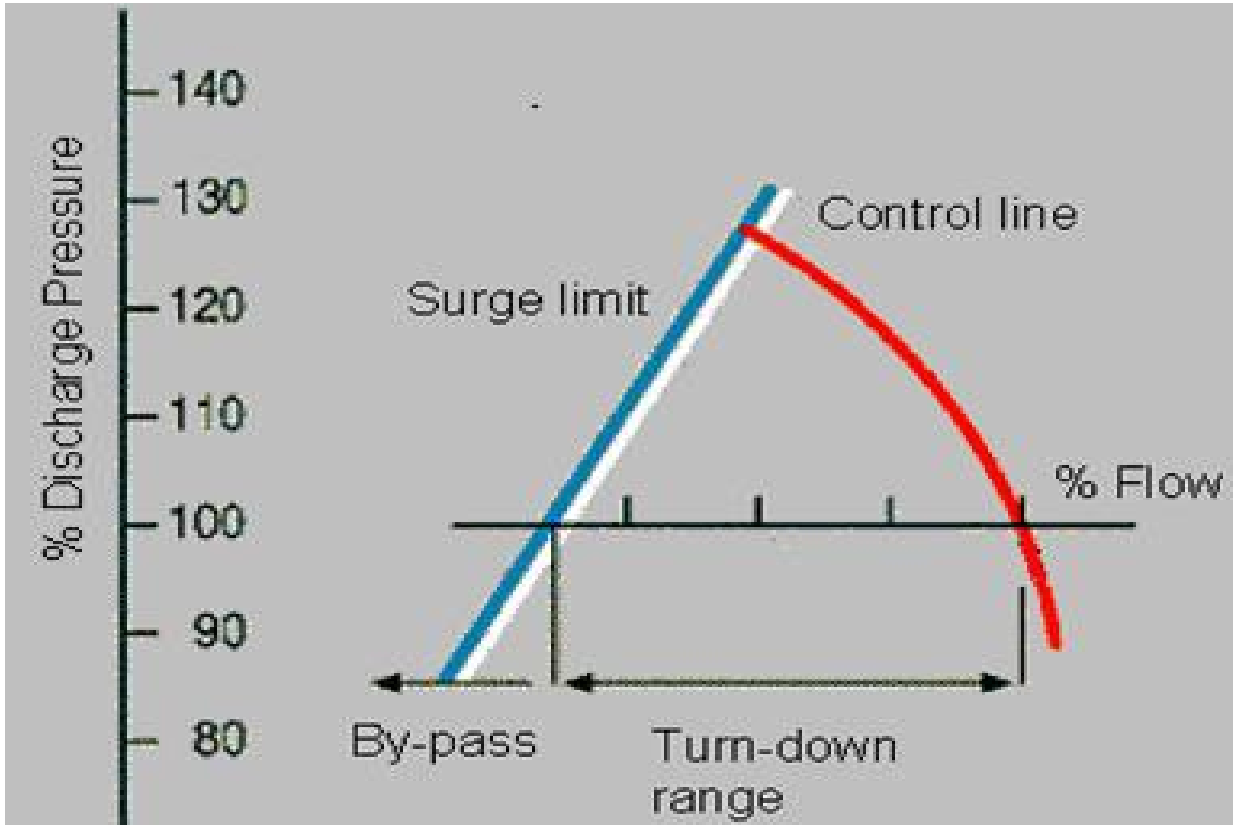
Centrifugal Compressor Control

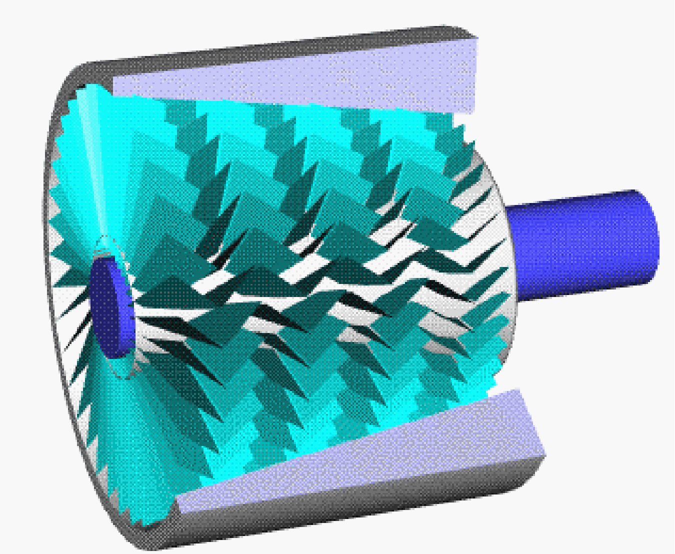
- Performance is affected by inlet conditions and cooling water temperature
- Characteristic curve is determined by impeller design
- Two conditions should be avoided:
  - Surge (flow reversal)
  - Choke (excessive flow vs. frame design)
- Inlet throttle valves modulate the compressor to reduced flow and power but are limited by surge condition
- Blow-off valves control capacity below throttling limit

Centrifugal Compressor Control

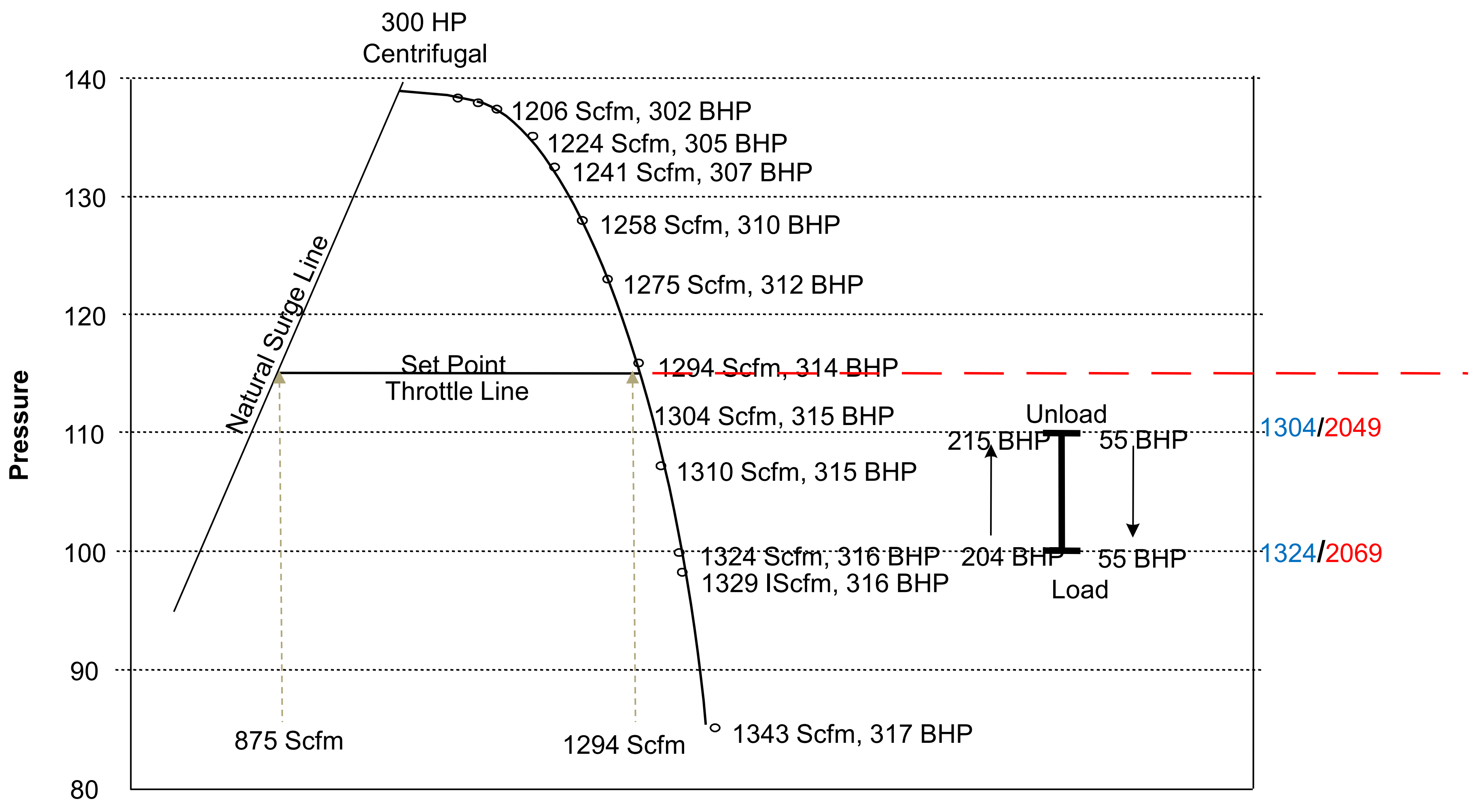
- Centrifugal compressor, "seal air" refers to a pressurized air supply used to maintain a seal between the rotating shaft and the compressor casing, preventing the process gas from escaping into the atmosphere;
- It's a pressurized air barrier that helps keep the high-pressure gas contained within the compressor by creating a positive pressure against the rotating shaft seals.
- No, not all centrifugal compressors require seal air, but some do use dry gas seals that require seal gas.
- Some use wet seals, which use oil, or dry seals, which use a mechanical barrier. Dry gas seals require seal gas to operate



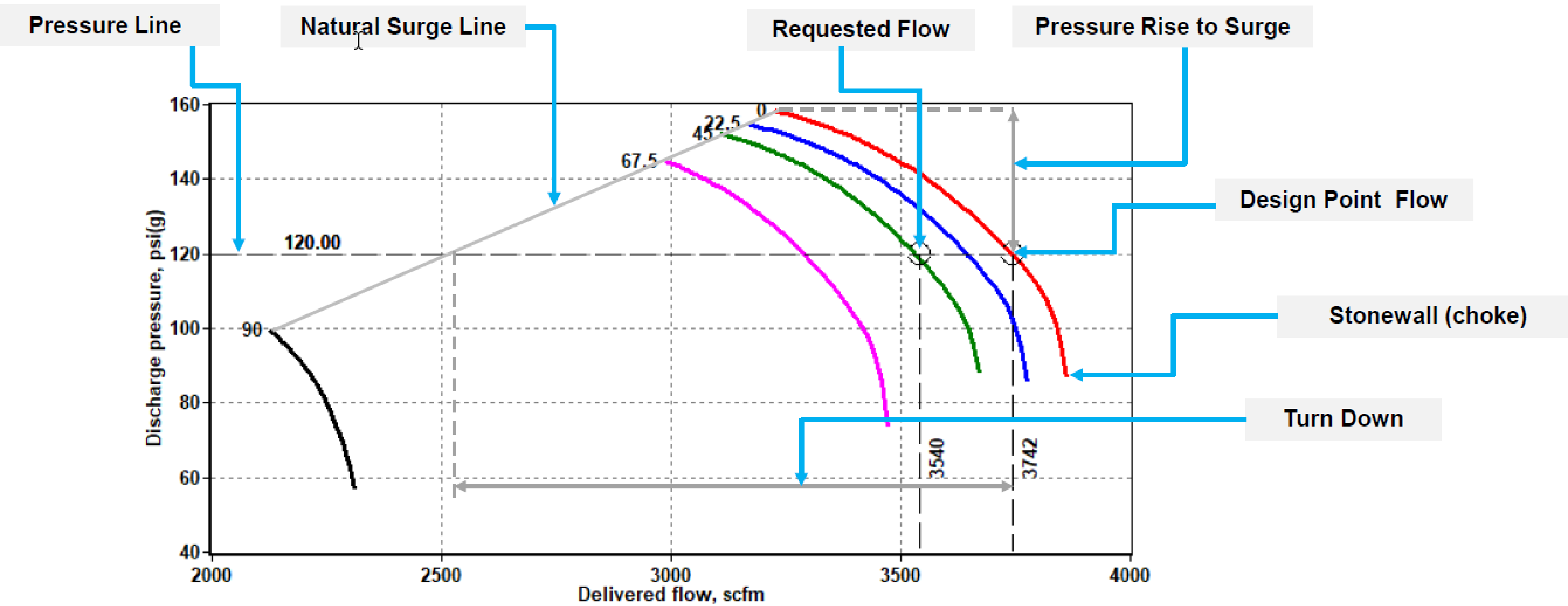

% Discharge Pressure
140
130
120
110
100
90
80
Control line
Surge limit
% Flow
By-pass
Turn-down
range



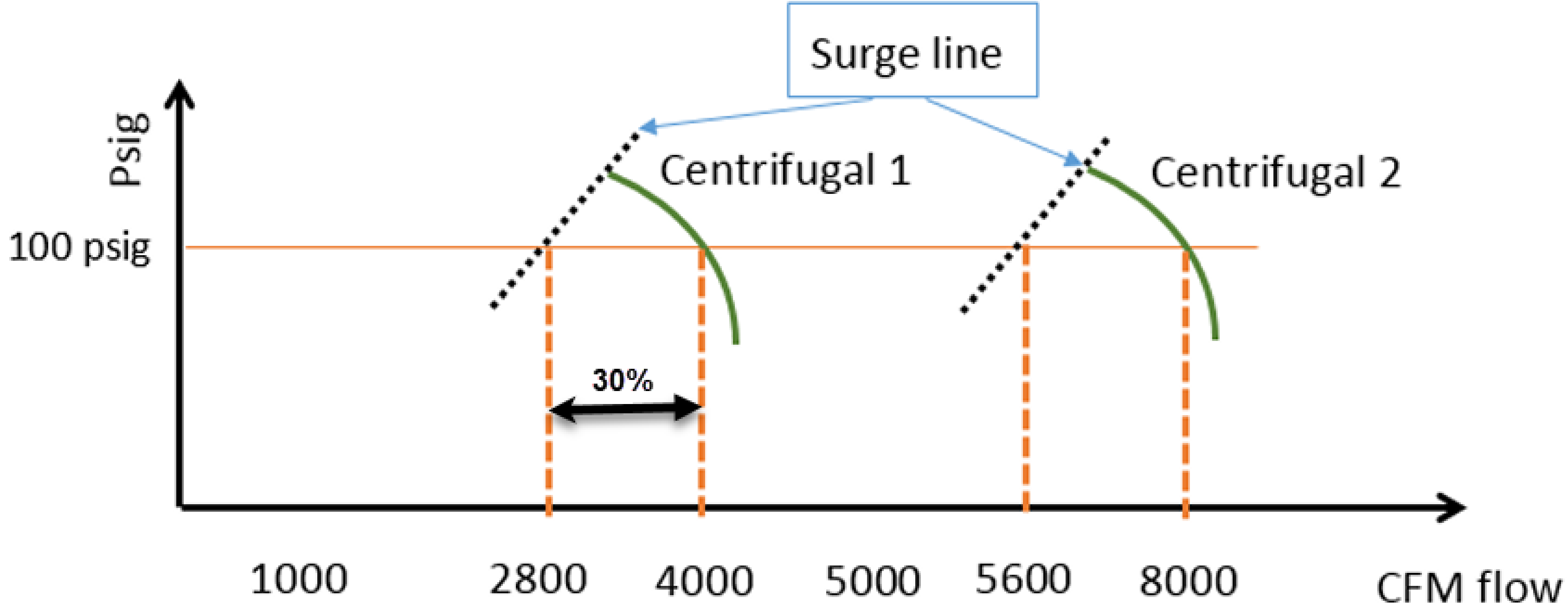
Building the Profile



Centrifugal Compressor Control Common Terms

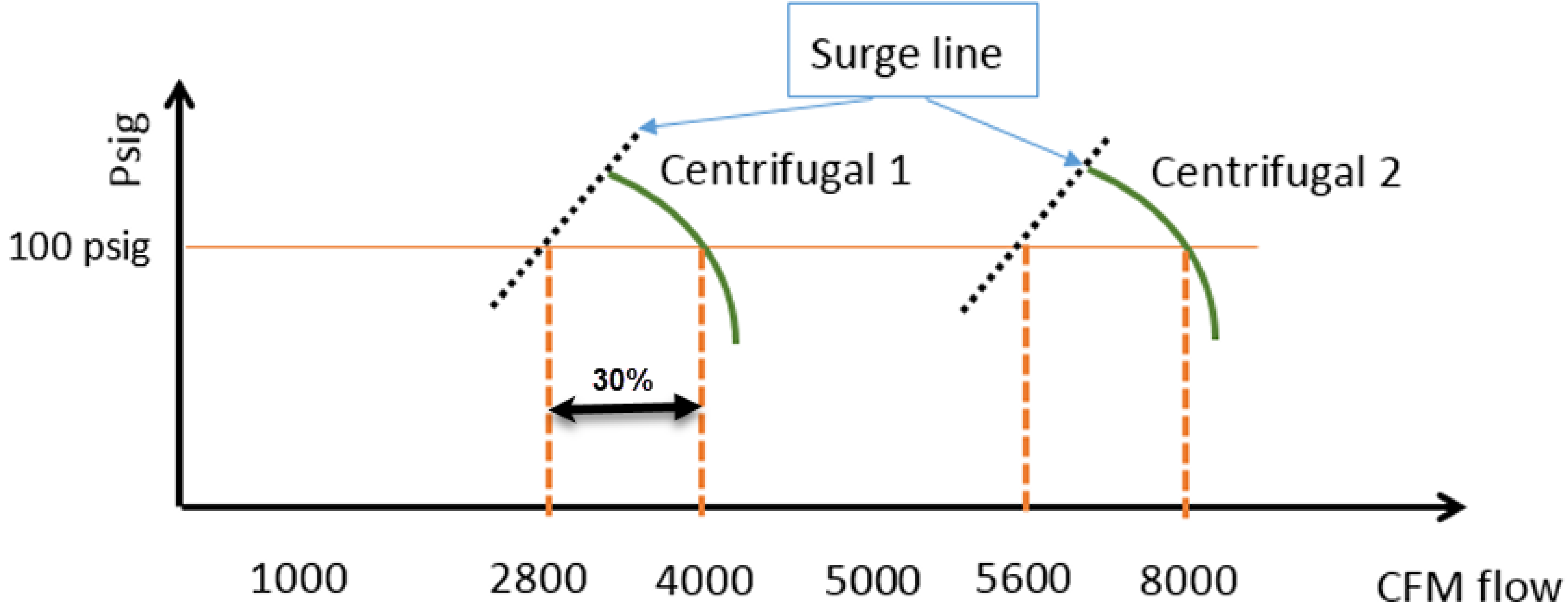


How do I know how to size Centrifugal to my flow Patterns?



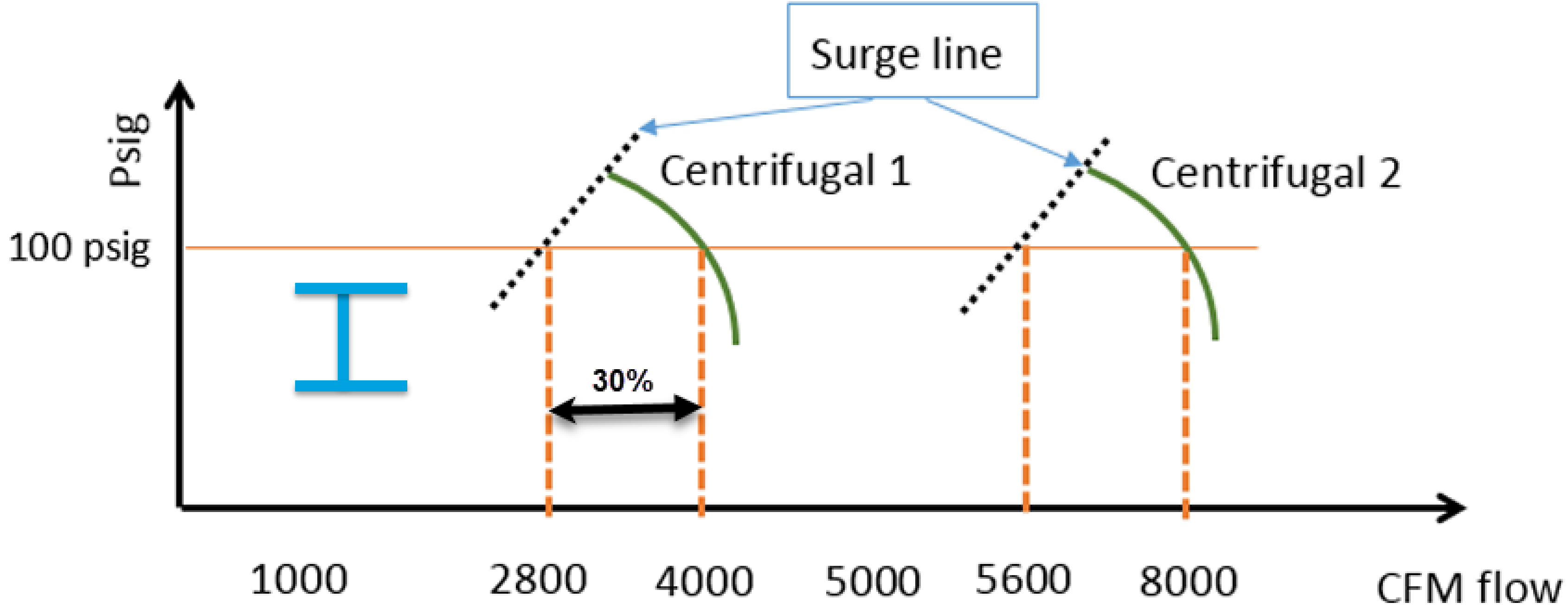
- Plant has 8000 cfm peak demand, 5800 cfm average demand, and 3000 cfm minimum demand during weekends at operating pressure of 100 psig.
- Two 4000 cfm centrifugals with a 30% turndown to 2800 cfm

How do I know how to size Centrifugal to my flow Patterns?



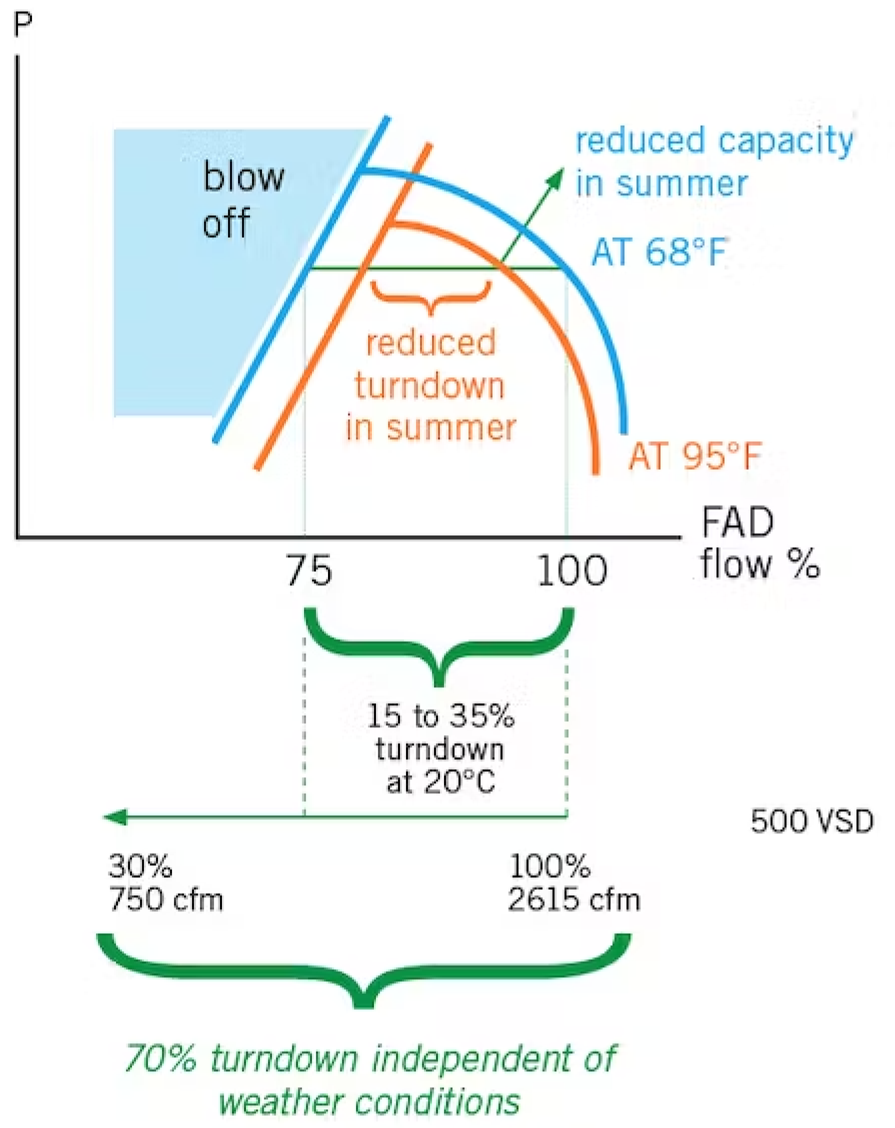
- During peak demand of 8000 cfm, both compressors will run at full load.
- When the flow demand is reduced to the average demand of 5800 cfm, the two centrifugal compressors will close the inlet guide valve and run in its turndown range without exhausting any compressed air to atmosphere.

How do I know how to size Centrifugal to my flow Patterns?



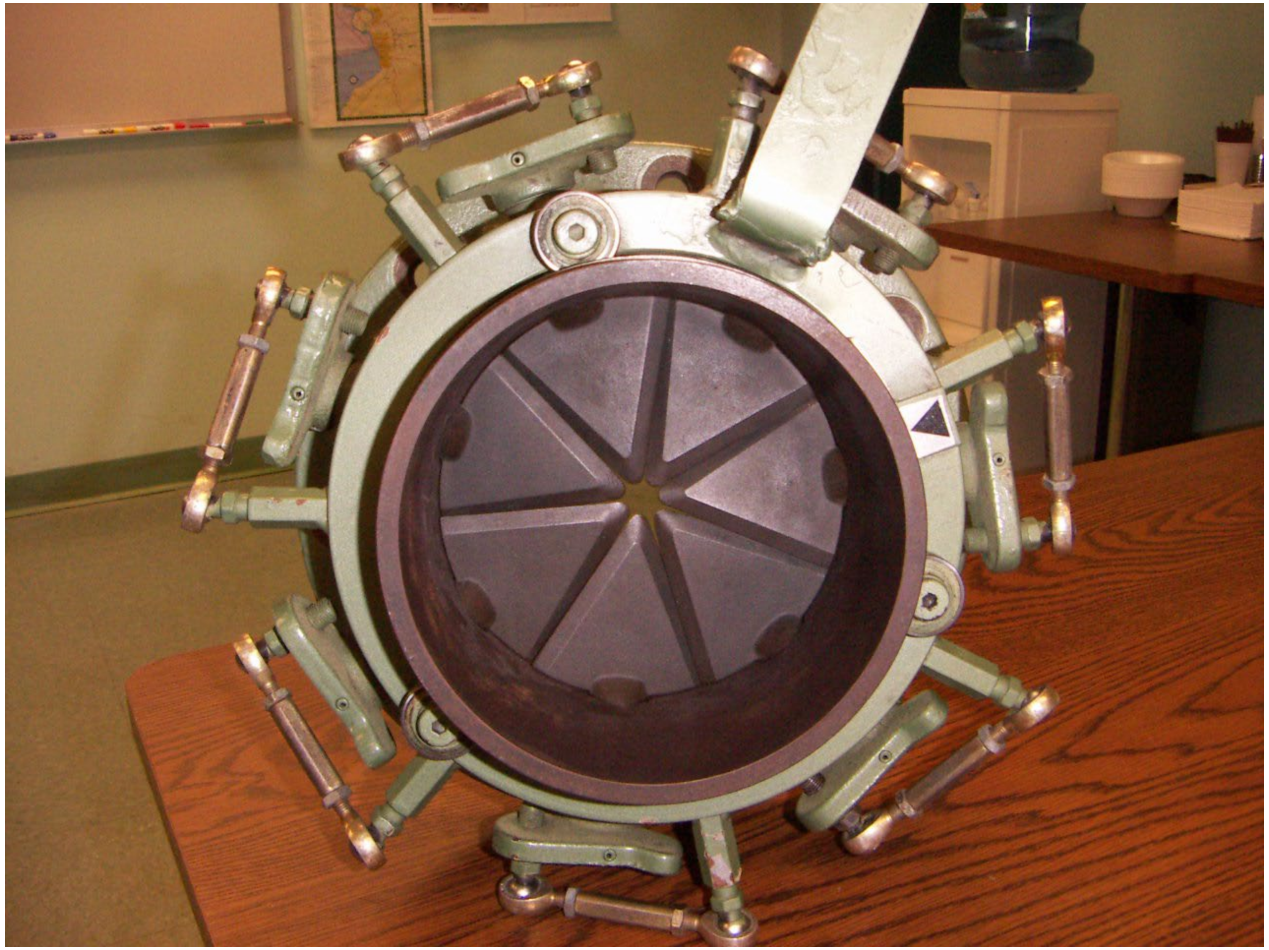
- During the weekend, when the demand reaches to minimum flow of 3000 cfm, one centrifugal compressor will stop and only one compressor will run in its turndown range.
- With this combination, the centrifugal compressors will work most efficiently and save a plant significant energy.
- If flow drops below min flow of the centrifugal, a rotary screw can be added to assist with keeping the plant operating and allowing the centrifugal to stay out of blow down.

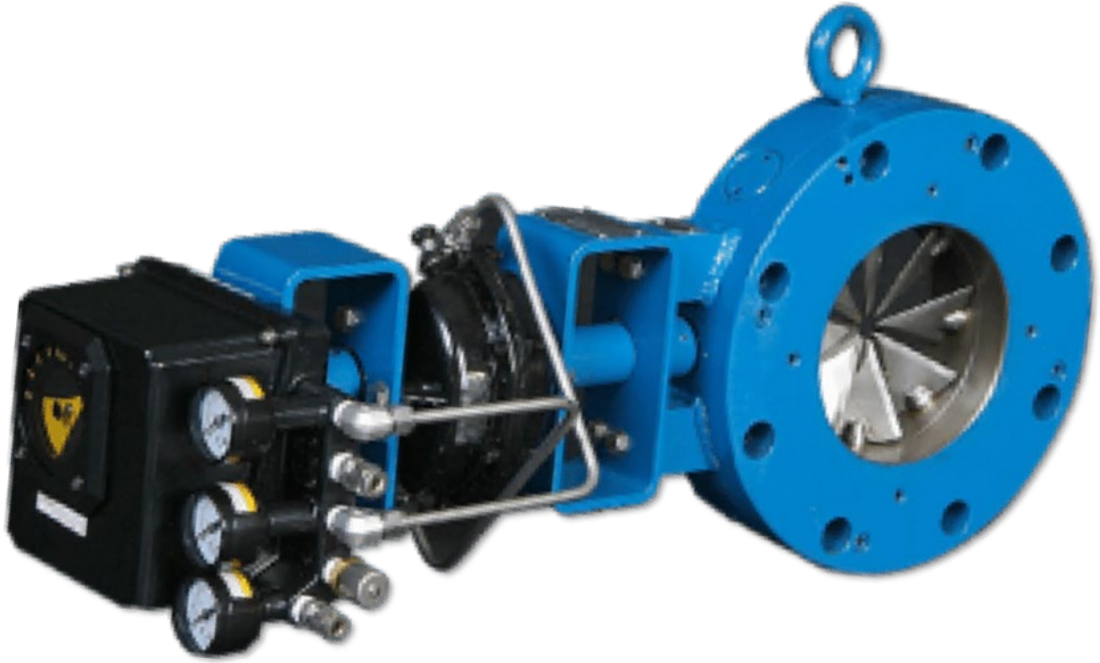
Centrifugal vs VSD Turndown



Inlet Guide Vanes - Open

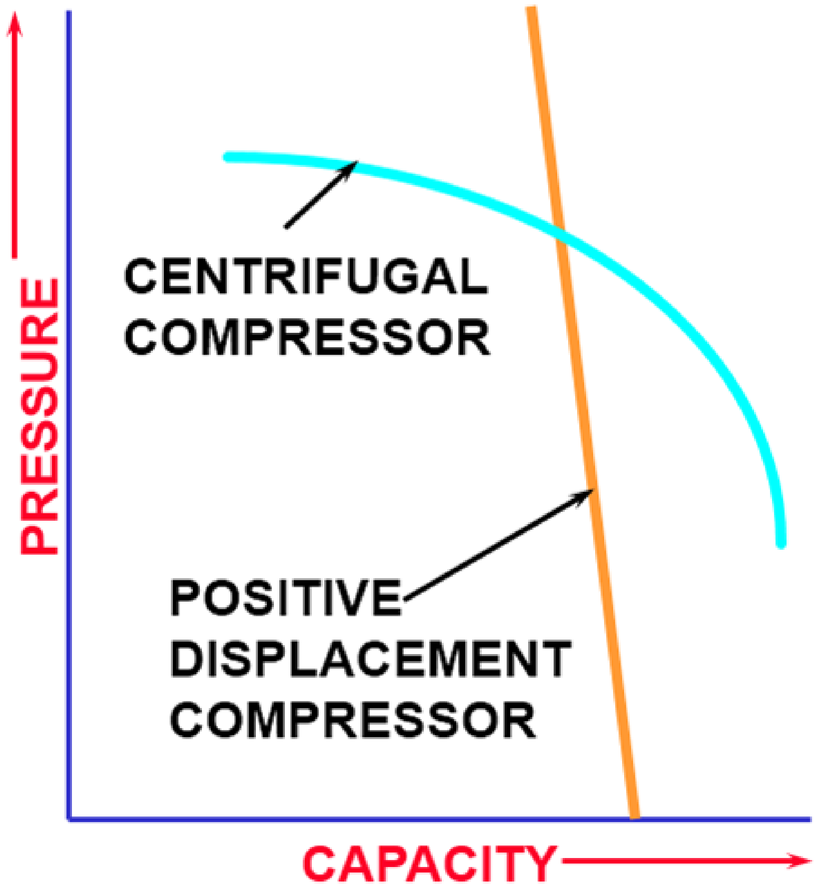
Inlet Guide Vanes - Closed





Centrifugal Compressor Control

The relationship of flow and pressure for dynamic compressors is different from that of positive displacement machines.

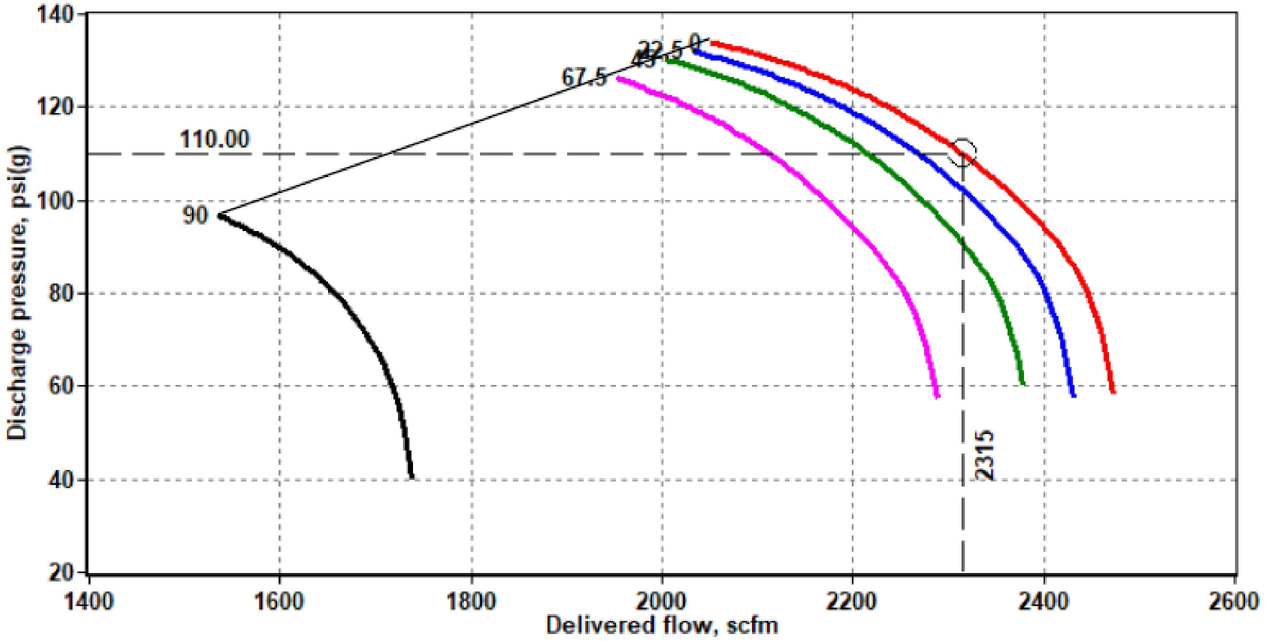


Effects on dynamic compressor performance

- Inlet pressure
- Inlet air temperature
- Cooling water temperature

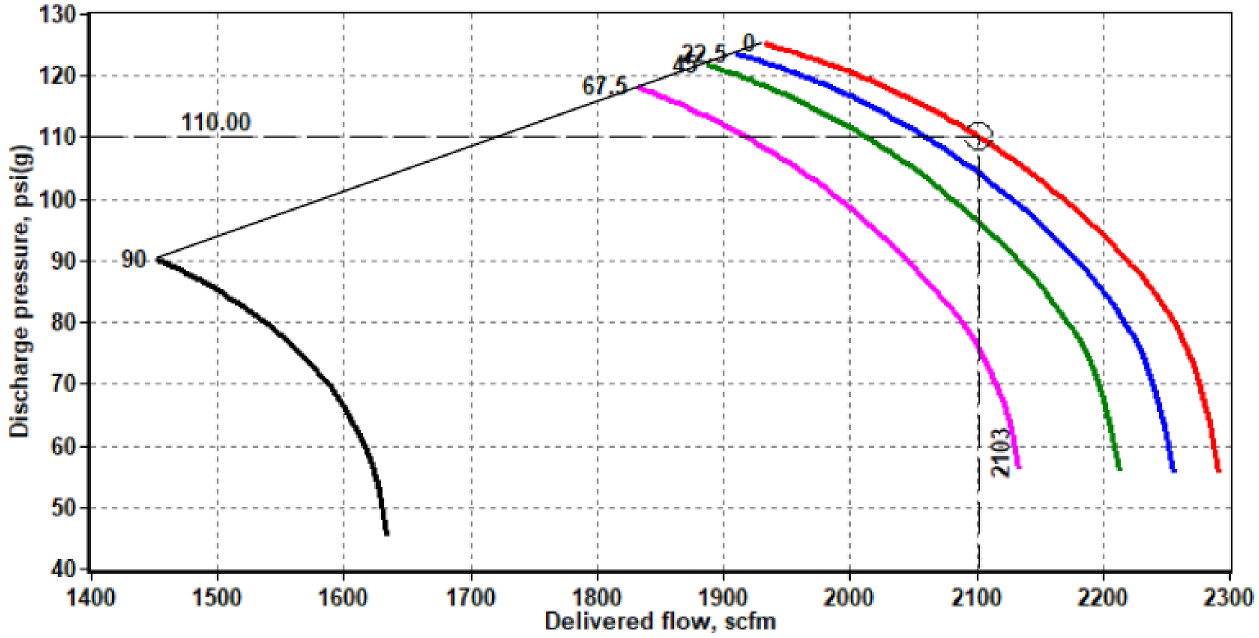
INLET TEMPERATURE CHANGE – EFFECT ON AIR OUTPUT

Capacity at 95^{0}F inlet Temp



2,315 scfm, 497.75 HP, 24 psi rise to surge

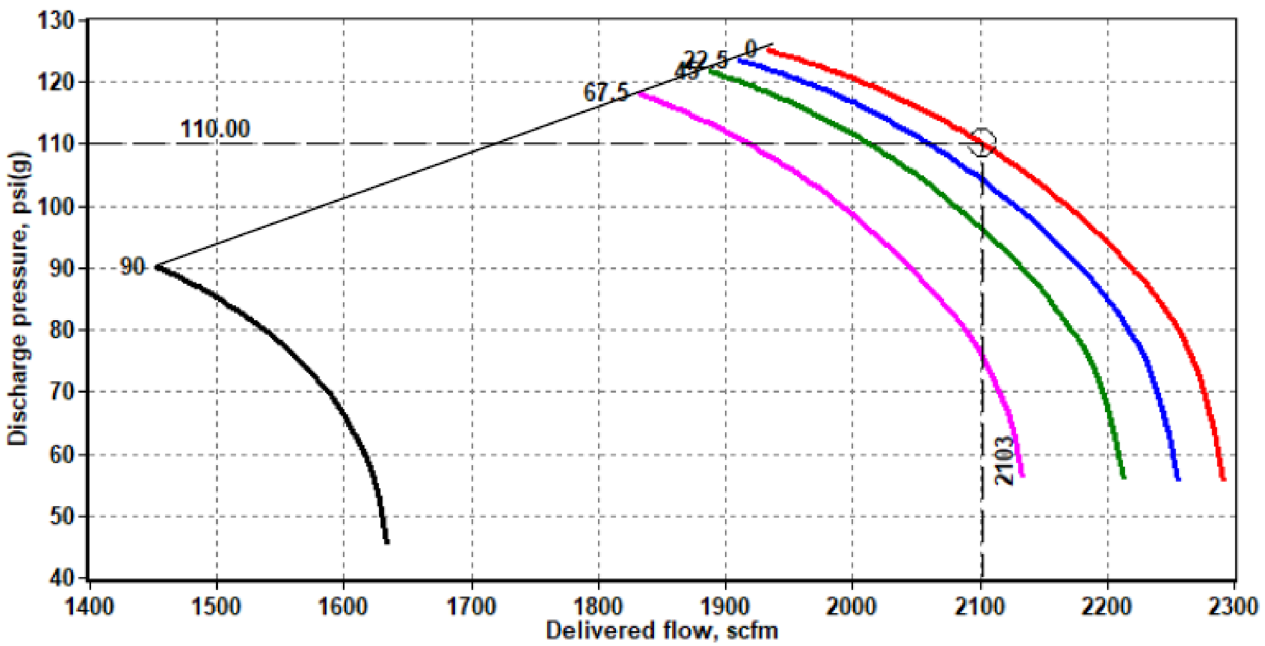
Capacity at 119^{0}F inlet Temp



2,103 scfm, 467.74 HP, 15 psi rise to surge

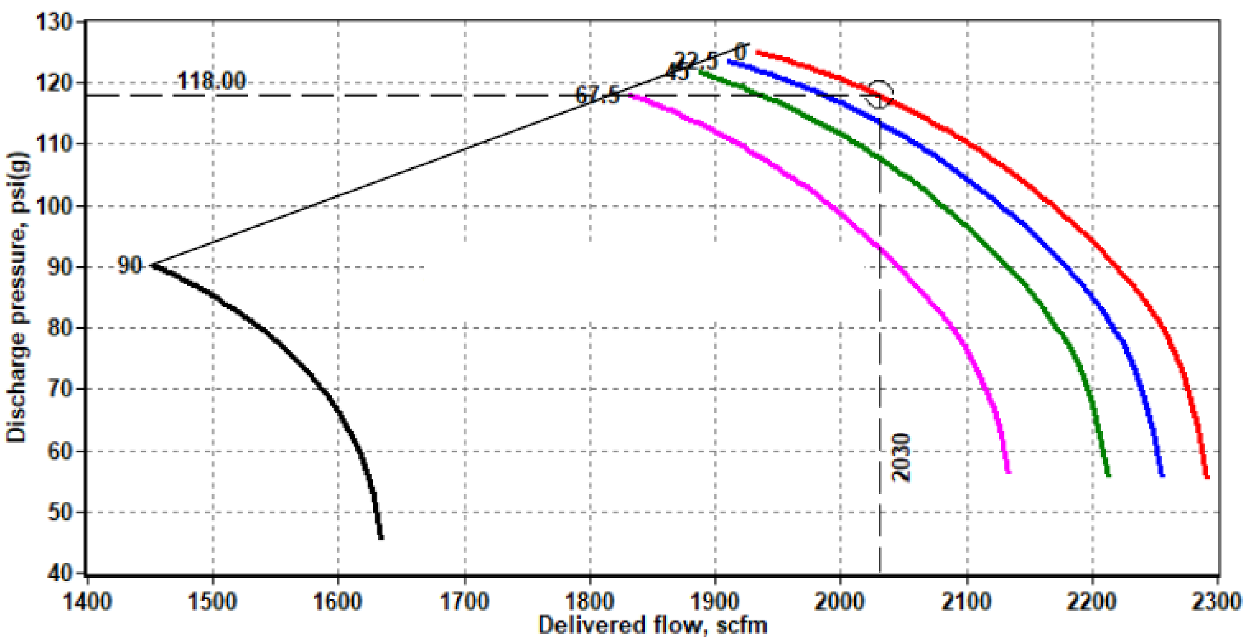
DISCHARGE PRESSURE CHANGE – EFFECT ON AIR OUTPUT

Capacity at 110 psig discharge pressure



2,103 scfm, 467.74 HP, 15 psi rise to surge

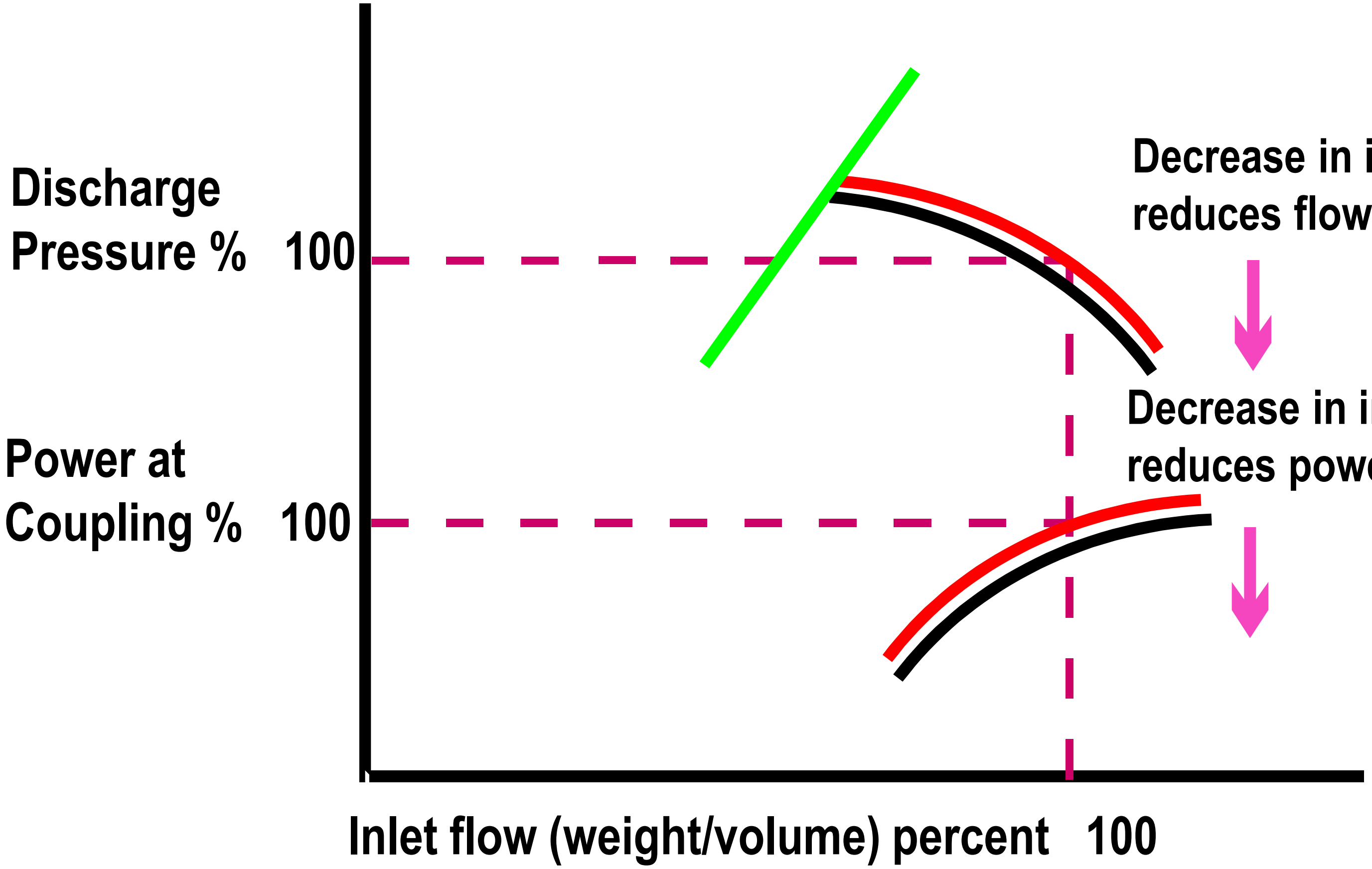
Capacity at 118 psig discharge pressure



2,030 scfm, 464.94 HP, 7 psi rise to surge

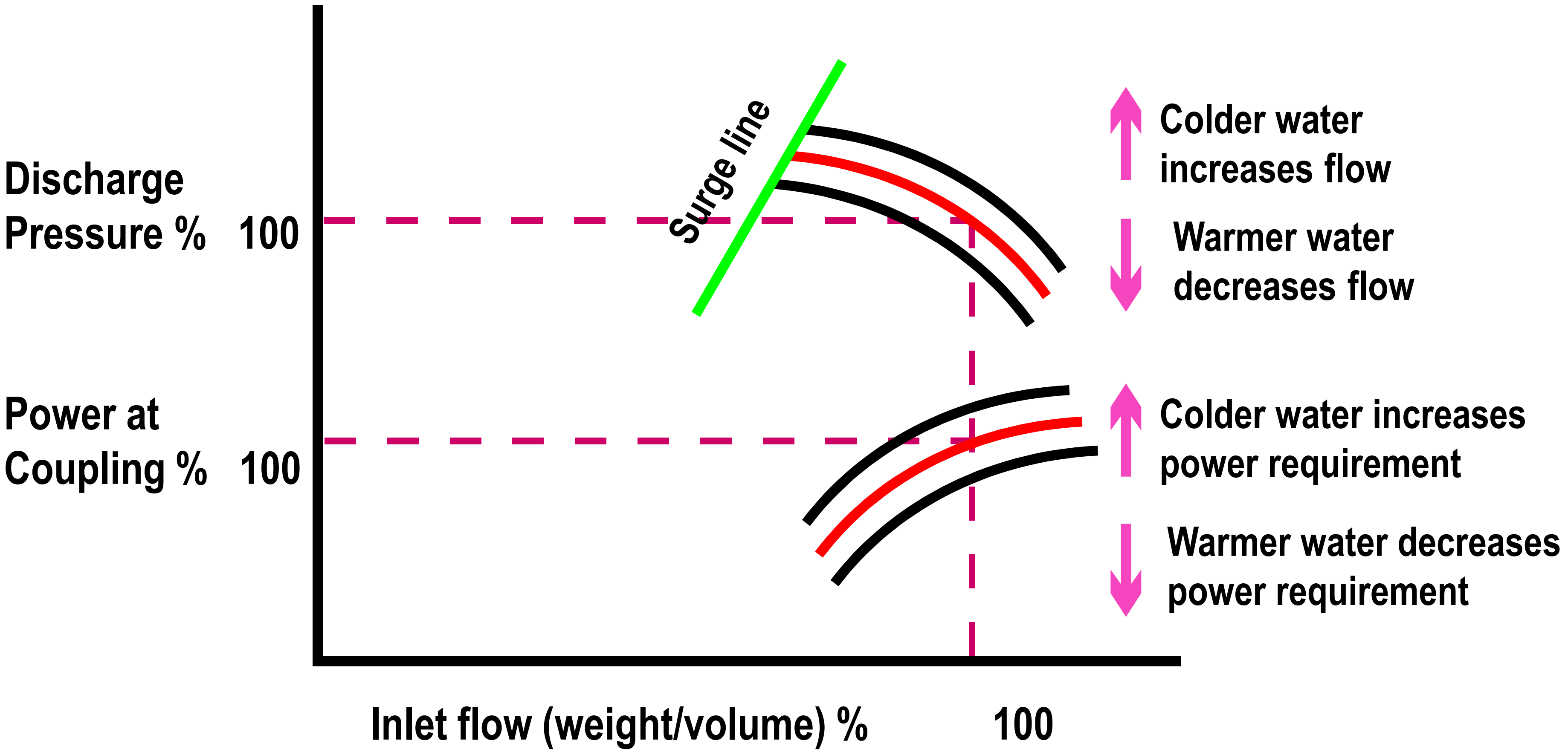
Inlet Pressure Effects On Dynamic Compressor Performance

Inlet pressure



Cooling Water Effects On Dynamic Compressor Performance

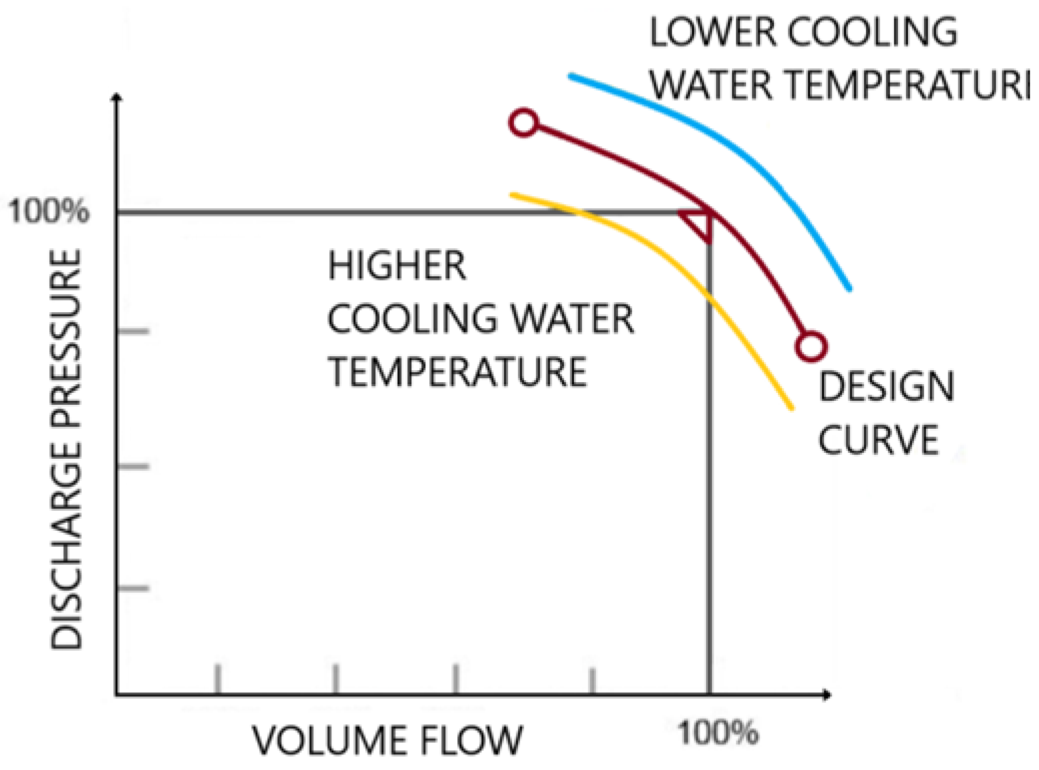
Cooling water temperature



Cooling Water Effects On Dynamic Compressor Performance

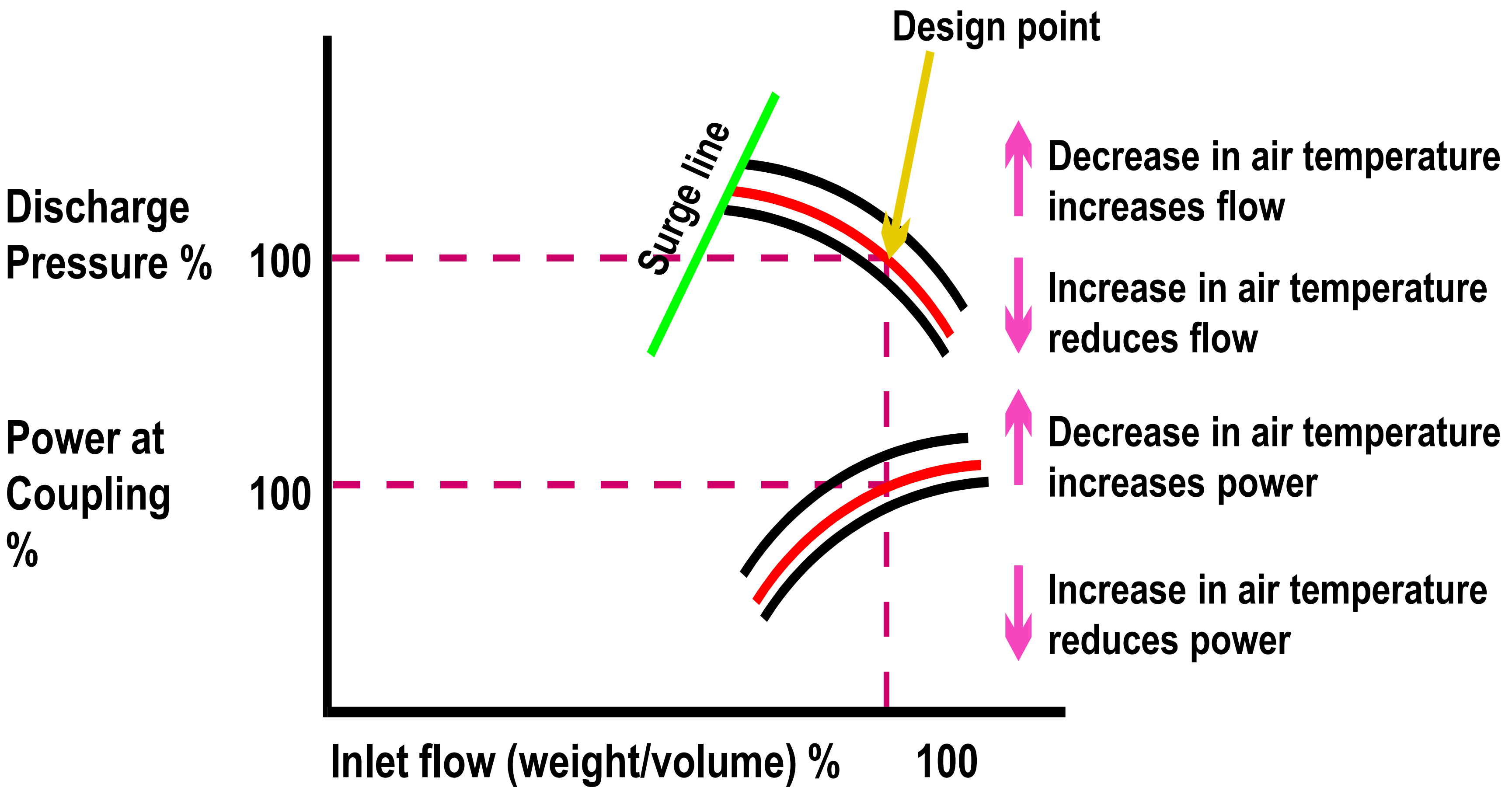
- Mass flow is determined in the first stage of cooling. That is the air that is delivered to the 2nd and 3rd stages.
- The cooler the air delivered, the more mass flow. The hotter the air delivered, the less mass flow. Manufacturers can redraw the performance curve on a centrifugal with various water temperatures so you can actually see the difference in flow.

Cooling water temperature

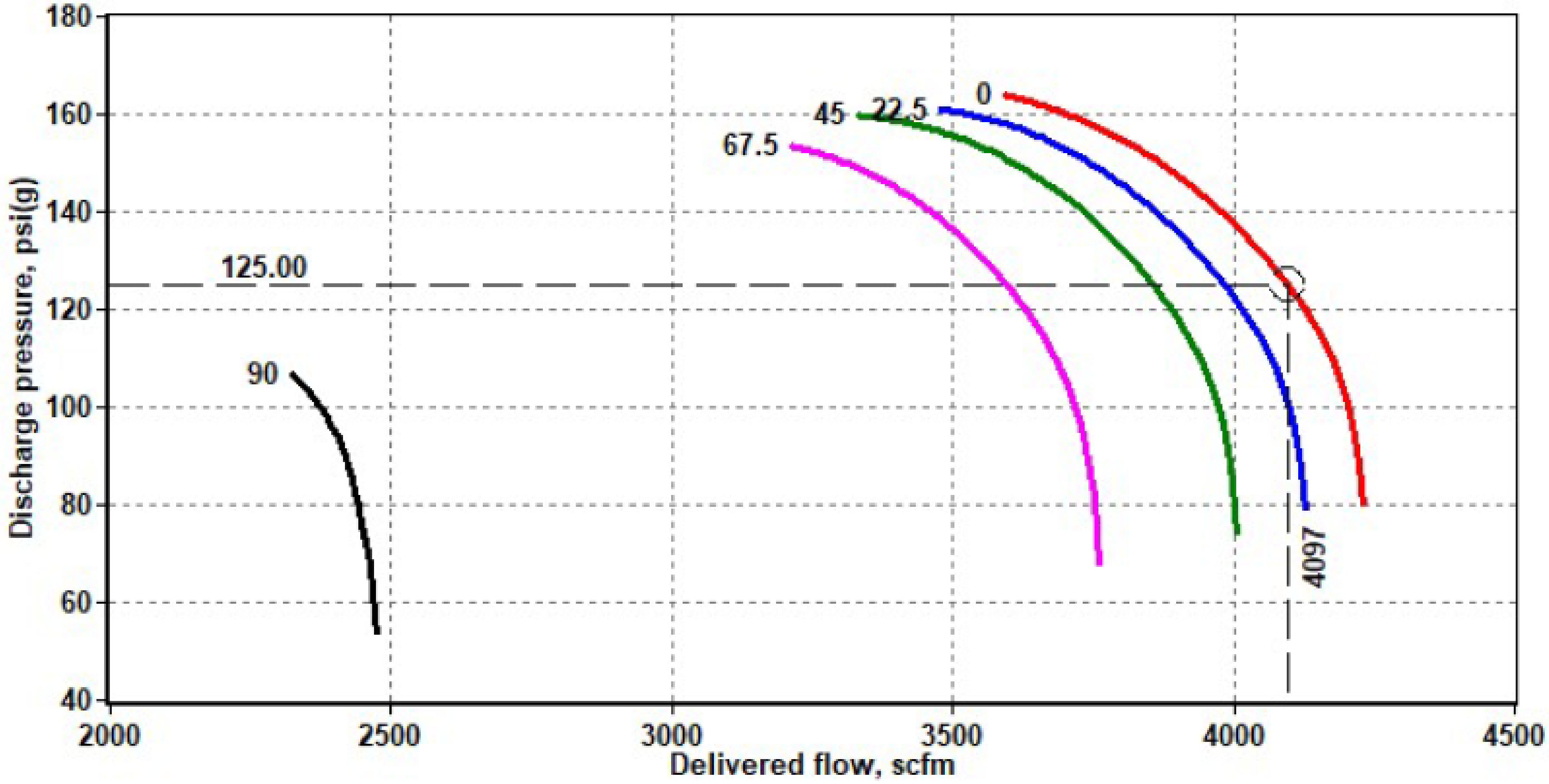


Inlet Air Temperature Effects On Dynamic Compressor Performance

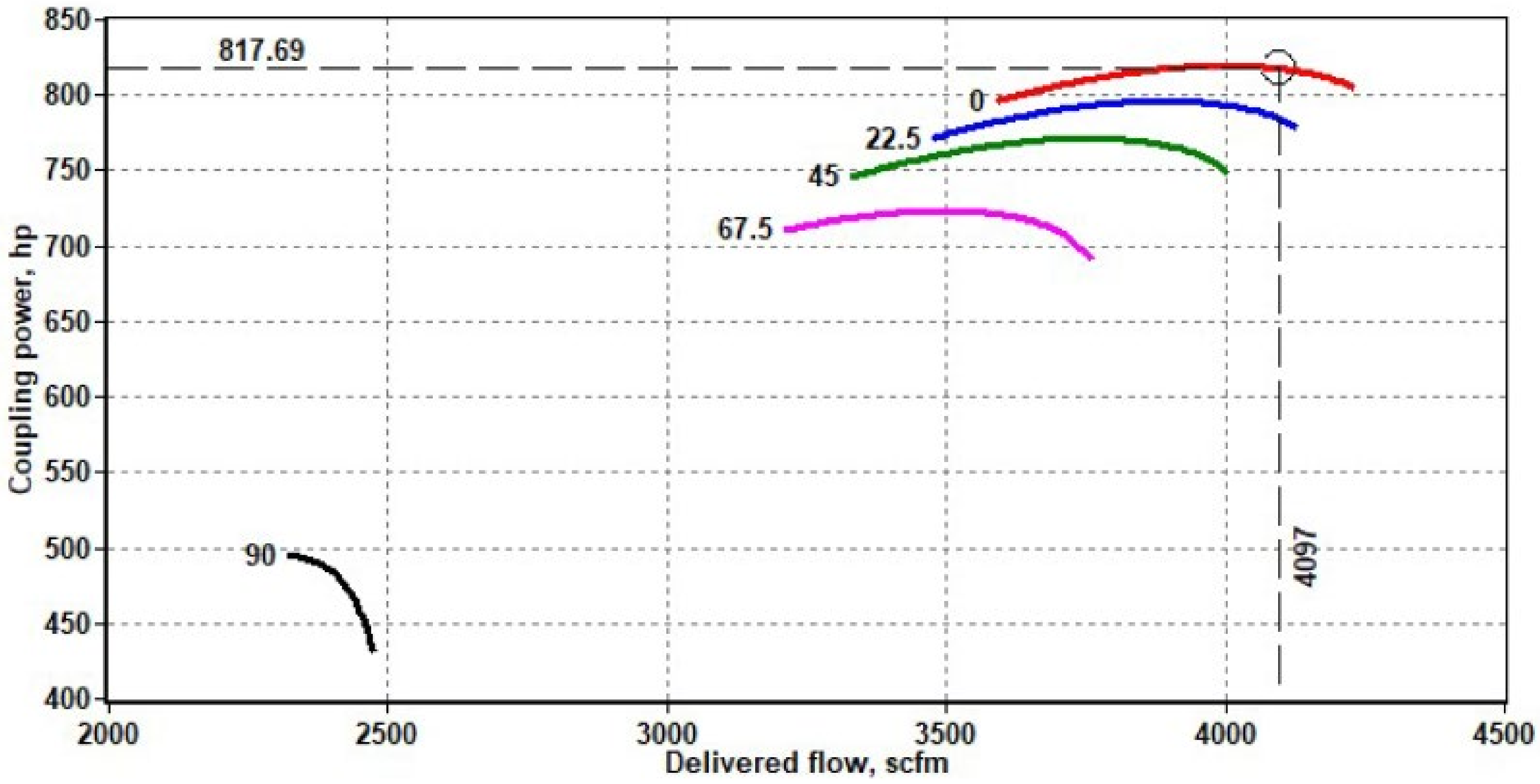
Inlet air temperature influence



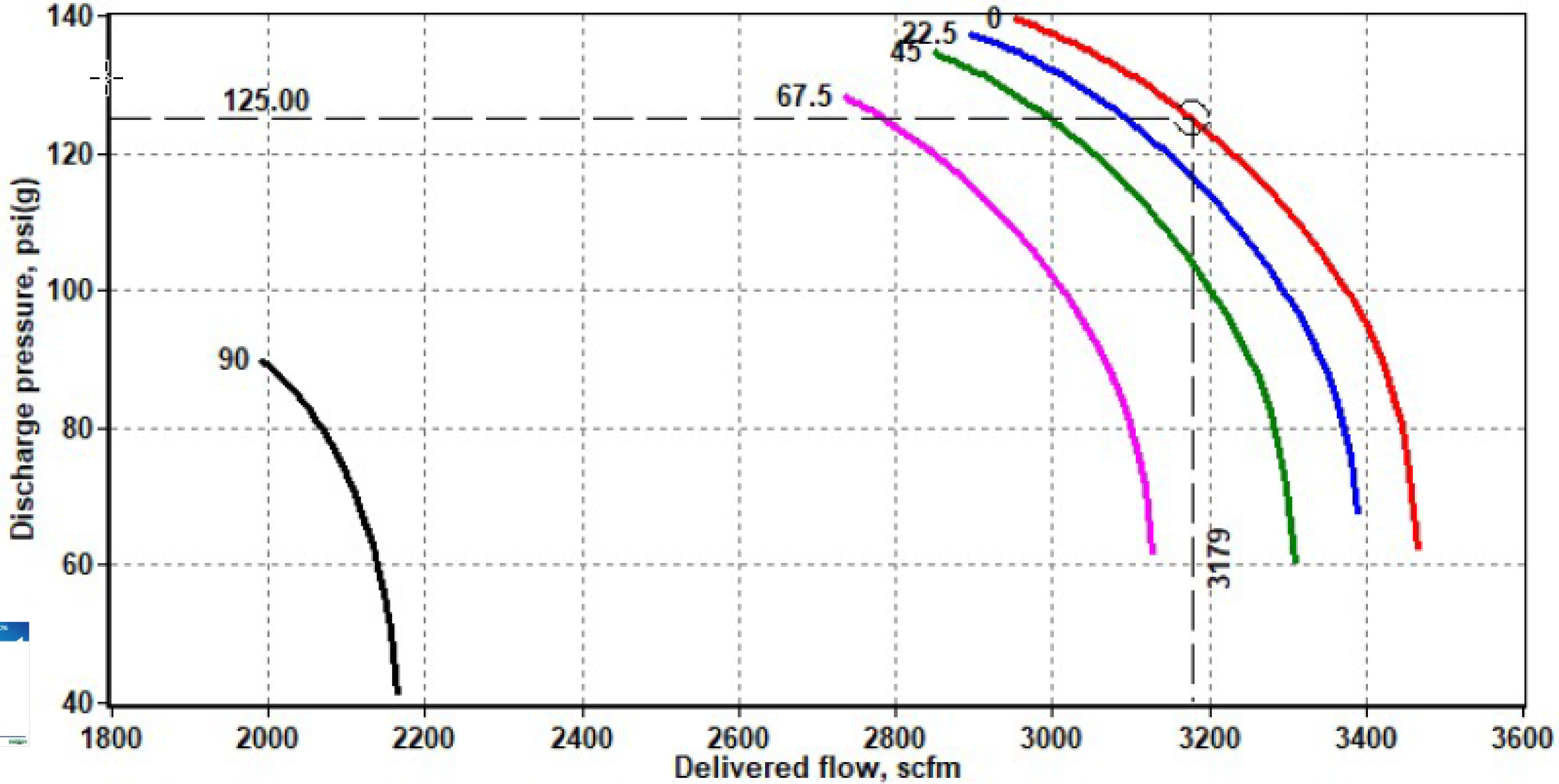
Curve showing air compressor performance at a 34°F inlet,60% RH, 77°F Coolant and 125 psig discharge pressure:

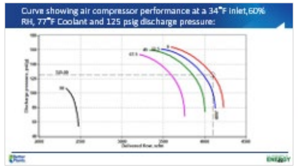


Curve showing air compressor horse power at a 34°F inlet,60% RH, 77°F Coolant and 125 psig discharge pressure:

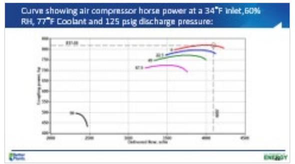


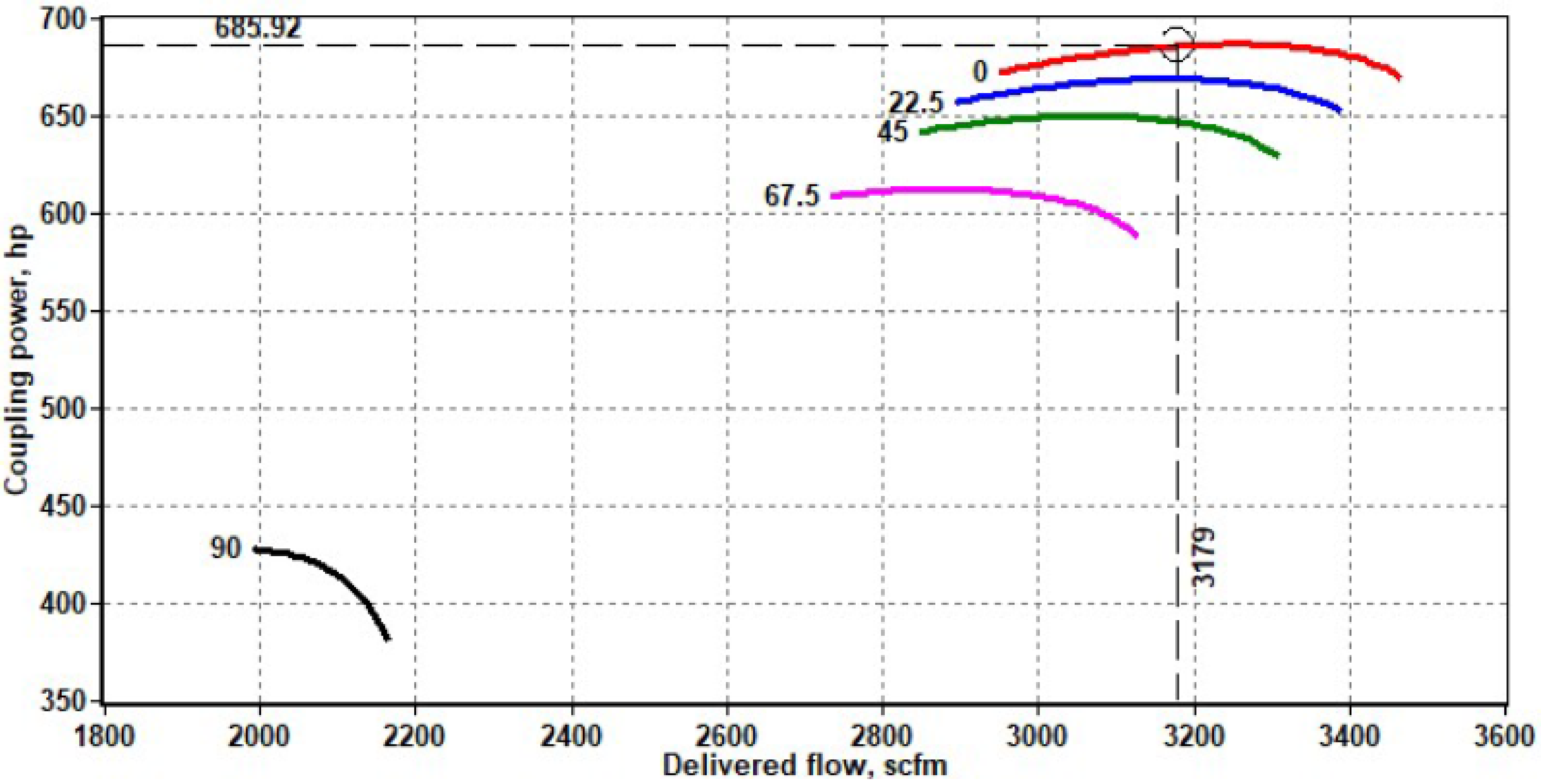
Curve showing air compressor performance at a 104°F inlet,100% RH, 77°F Coolant and 125 psig discharge pressure:





Curve showing air compressor horsepower at a 104°F inlet, 100% RH, 77°F Coolant and 125 psig discharge pressure:





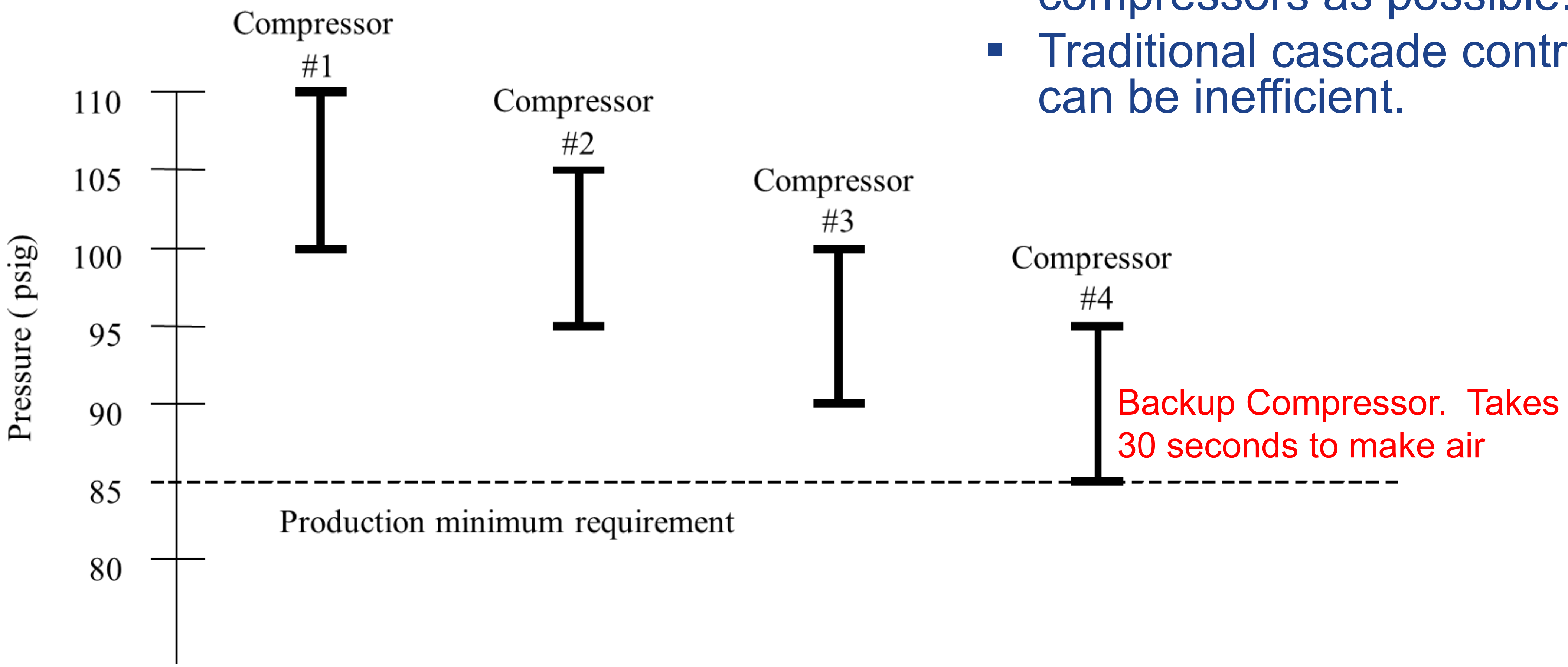
Multiple Compressor Controls

- Maintains a consistent air pressure in the network within tight parameters.
- Simple installation process.
- Compatible with various types of compressors.
- Improved service intervals lead to reduced maintenance costs.
- Option for prioritizing old machines over new ones.
- Staggered start times: Avoid starting two or more machines simultaneously to prevent high current spikes.
- Base load compressors can pre-fill a network to mitigate load peaks.

Multiple Compressor Control

- Very simple user interface = minimum user training.
- Machines are used more efficiently.
- Energy reduction = immediately saves money.
- Full compressor & network status feed- back.
- Programmable pressure schedule.
- PC monitoring & analysing possibilities.

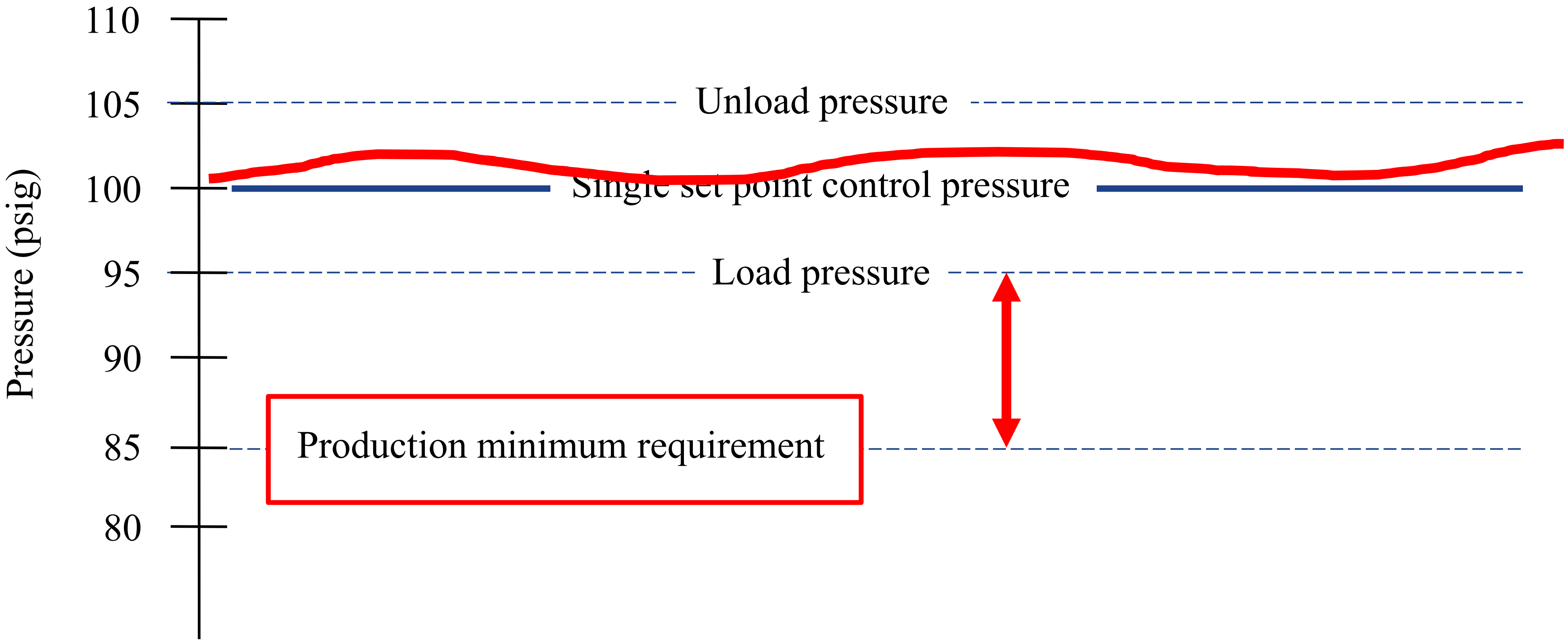
Cascade Compressor Control



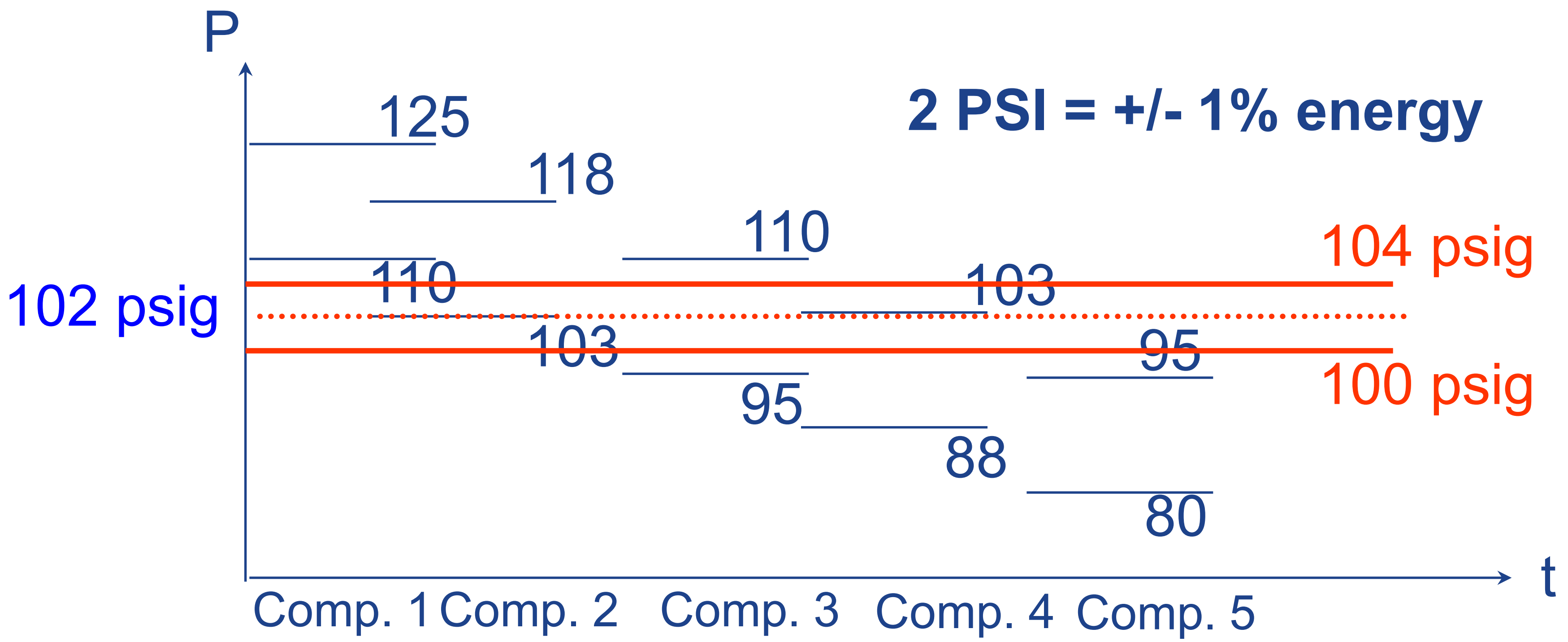
- Base load as many compressors as possible.
- Traditional cascade control can be inefficient.

Master Controls

- Basic single set point control scheme



Master Control Basics

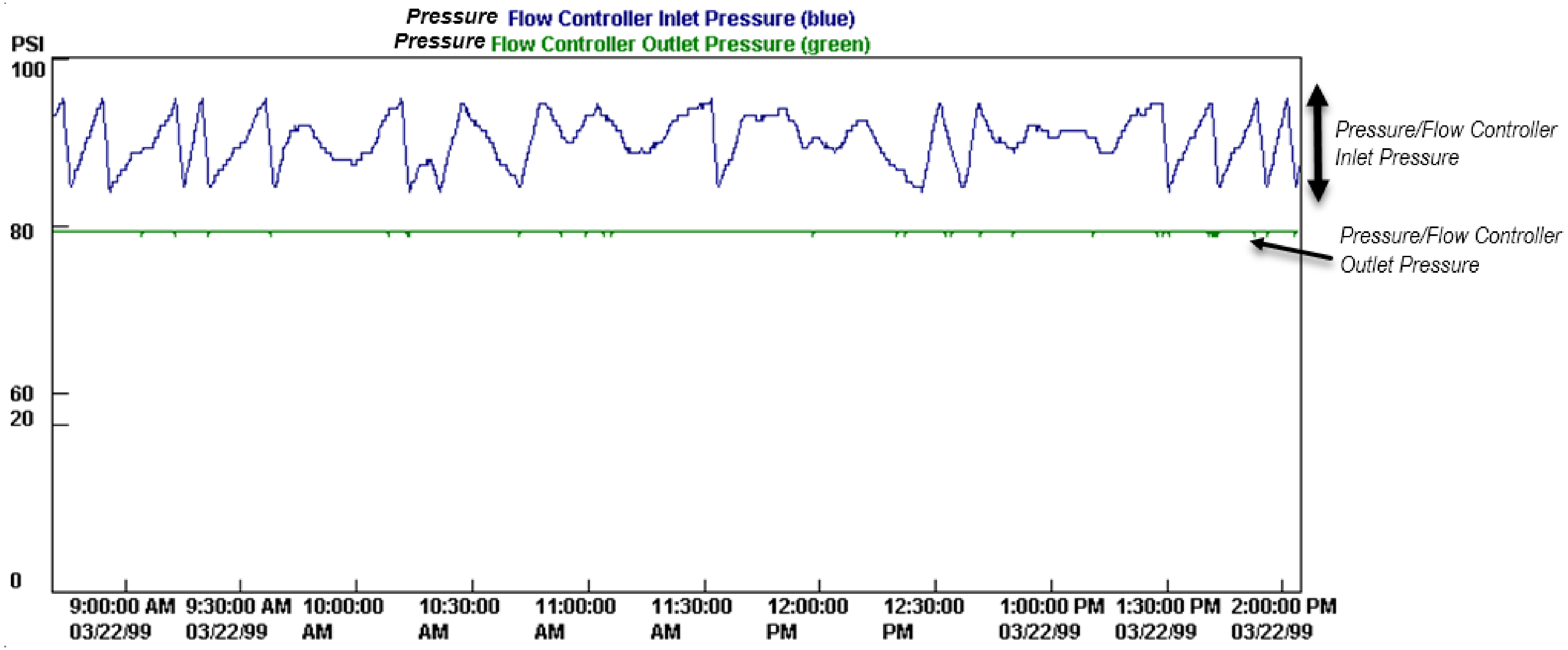


Cascaded Pressure Switches Vs Master

Pressure/Flow Controllers

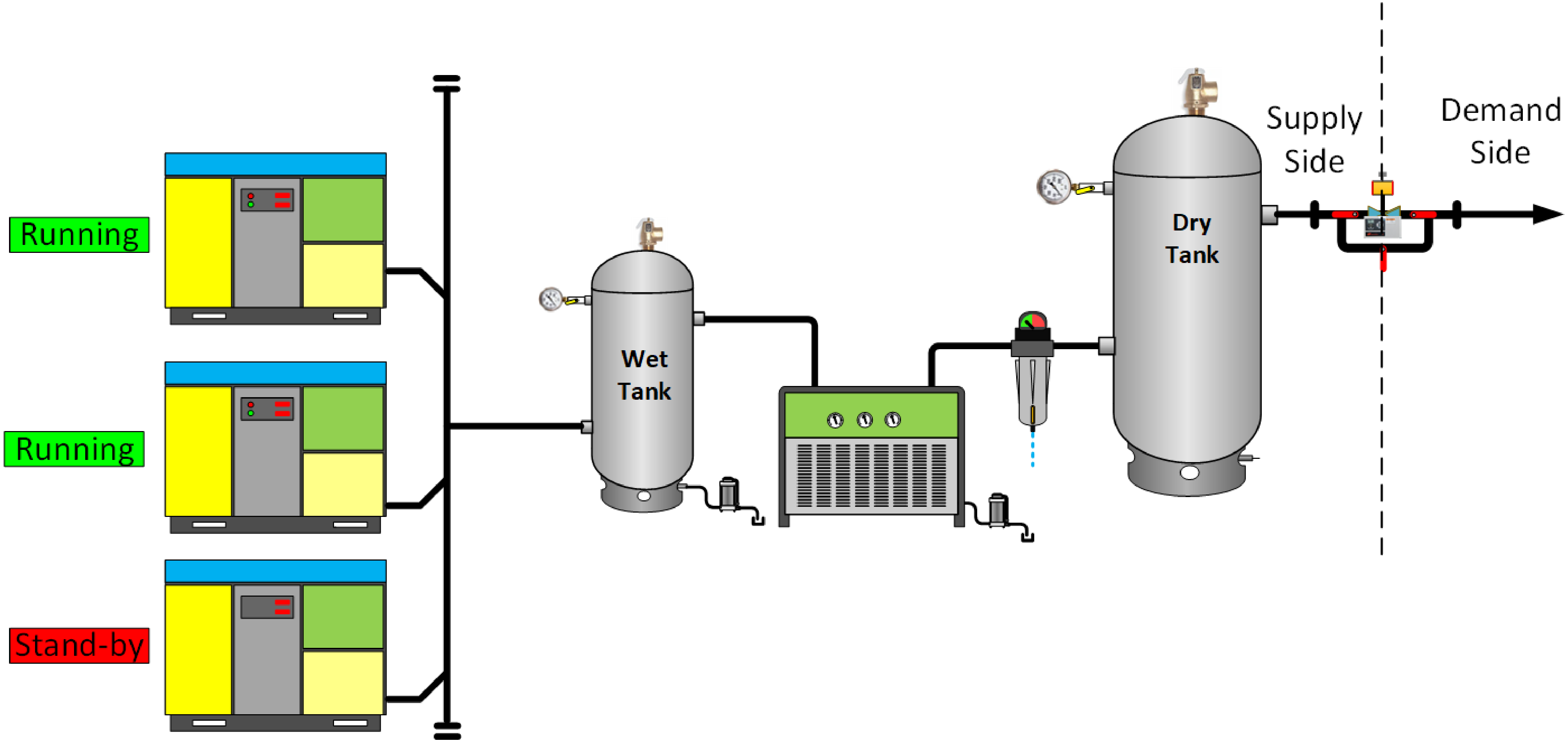
- Primary function: Stabilize pressure regardless of demand
- Most compressor controls cause 3-10 psi swings
- Multiple compressors can compound the system pressure swings
- Pressure/flow controllers typically hold pressure to production within ± 1% of set point
- The following graph is from a system with 9 compressors totaling over 6,000 hp – pressure is set at 79 psig

Pressure/Flow Controllers

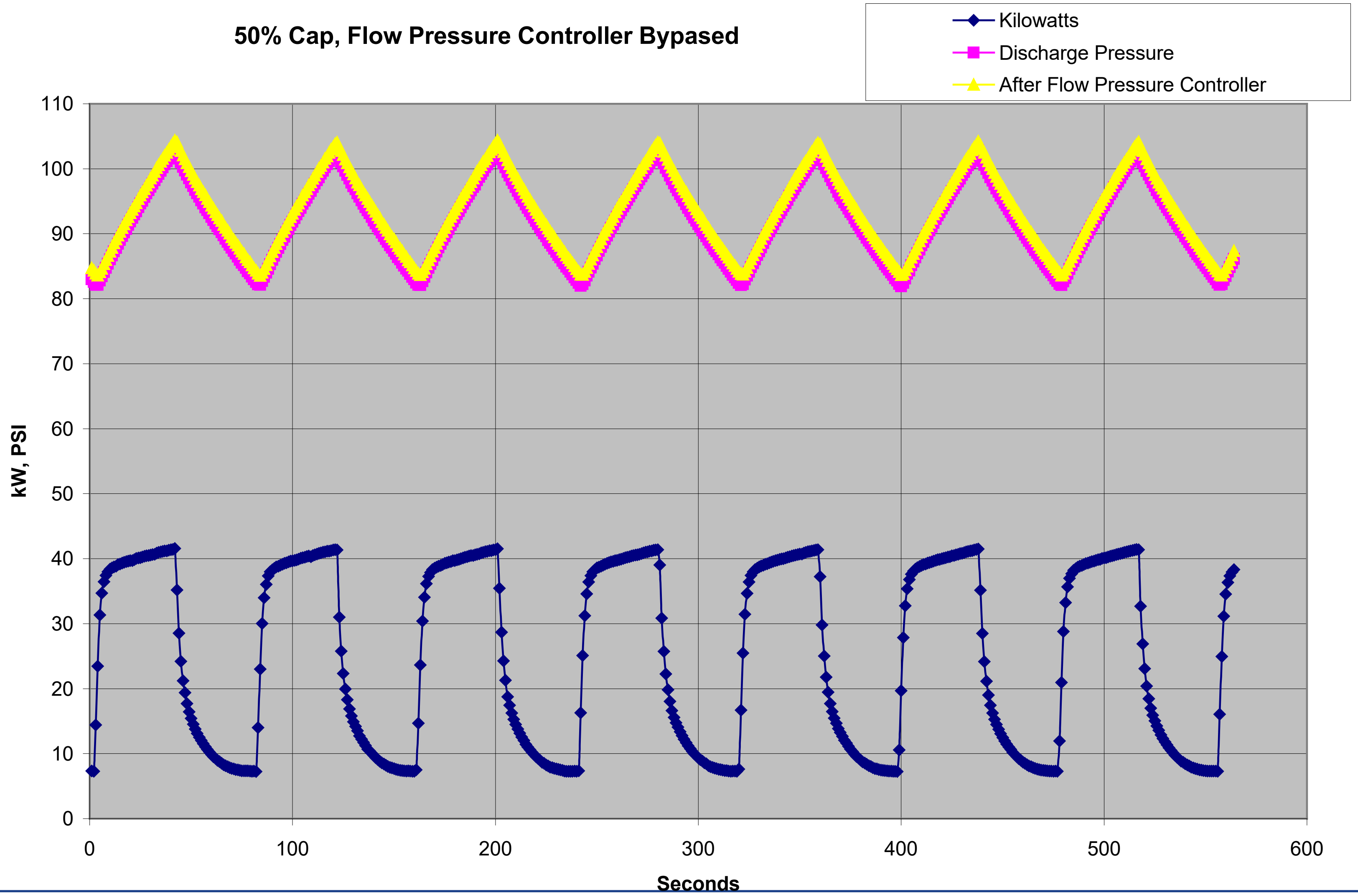


- The compressor discharge pressure varies about 10 psi as the trim compressor loads and unloads to meet plant demand.
- The pressure to the plant is kept at a constant 79 psig.

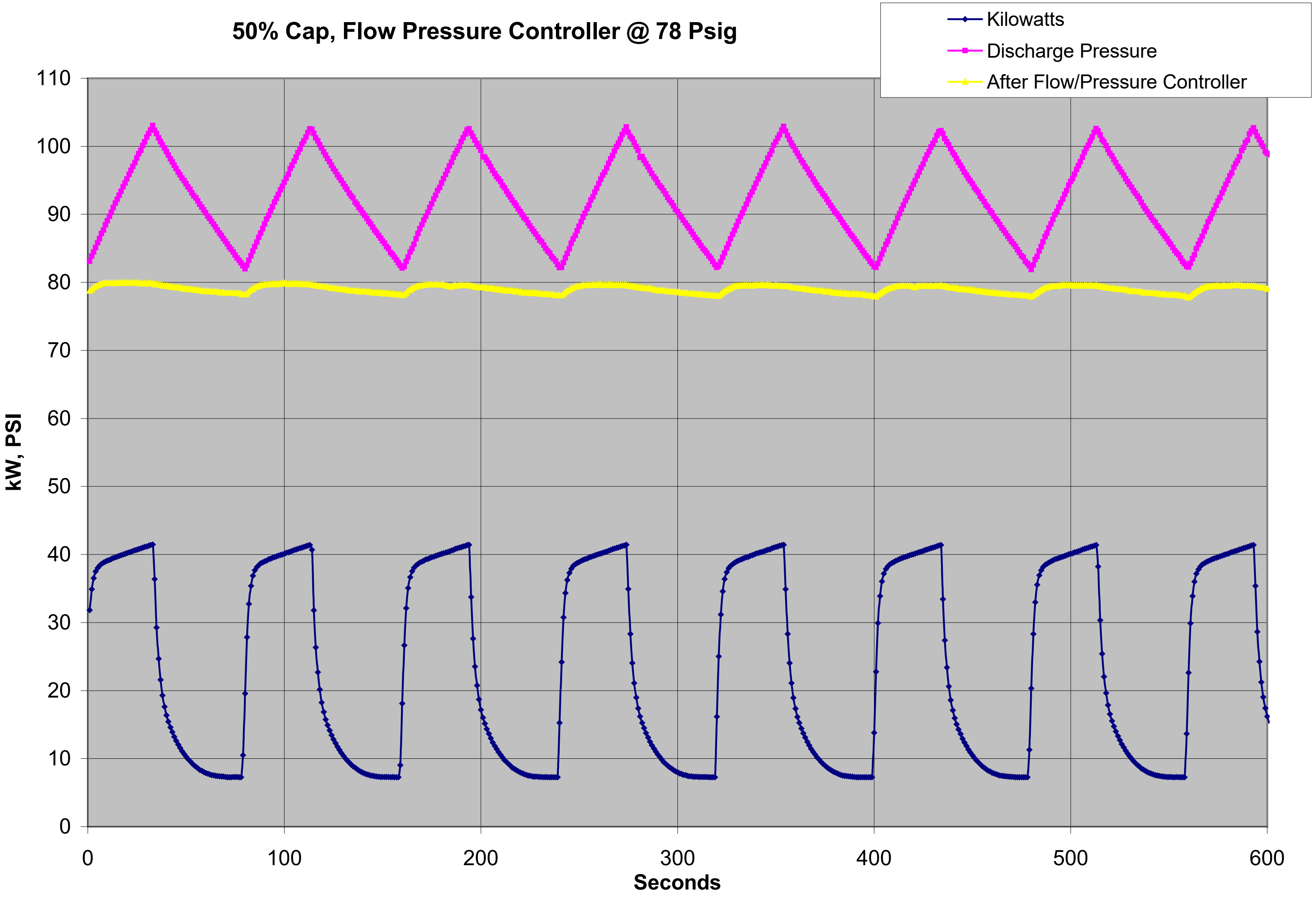
Best Practice with Pressure Flow Controller



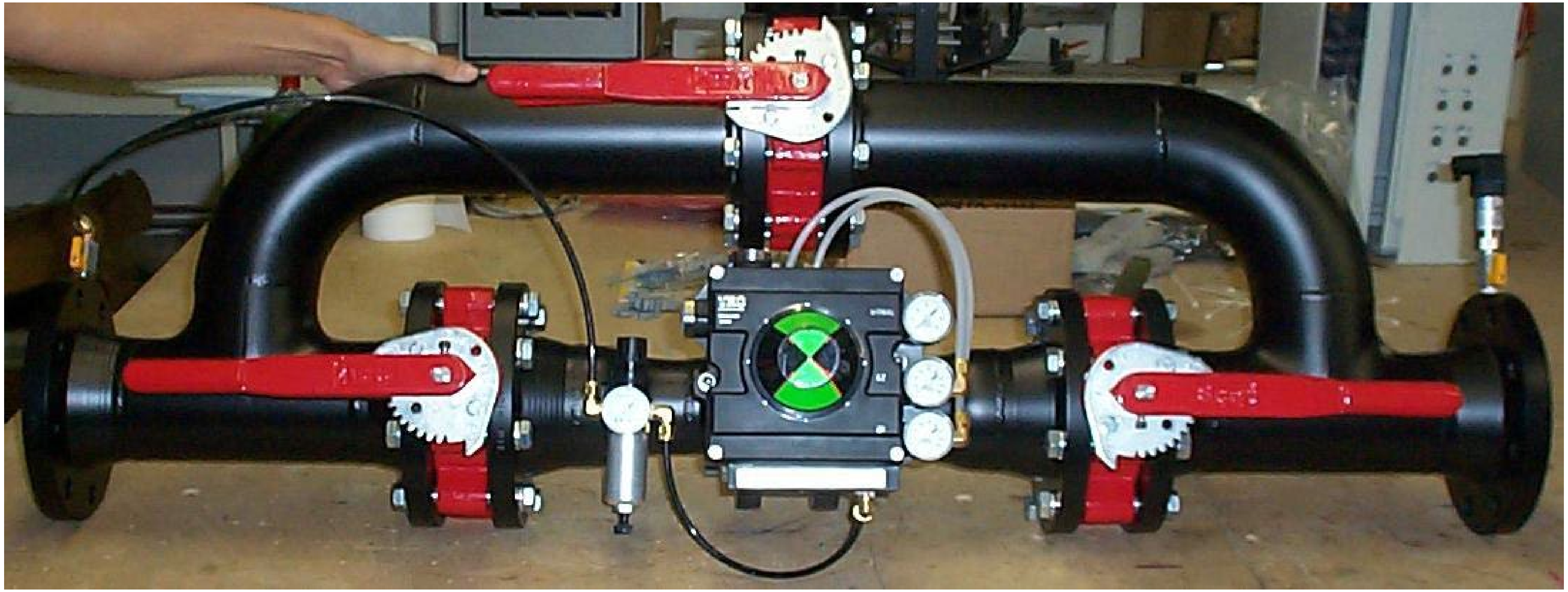
Pressure/Flow Controllers



Pressure/Flow Controllers

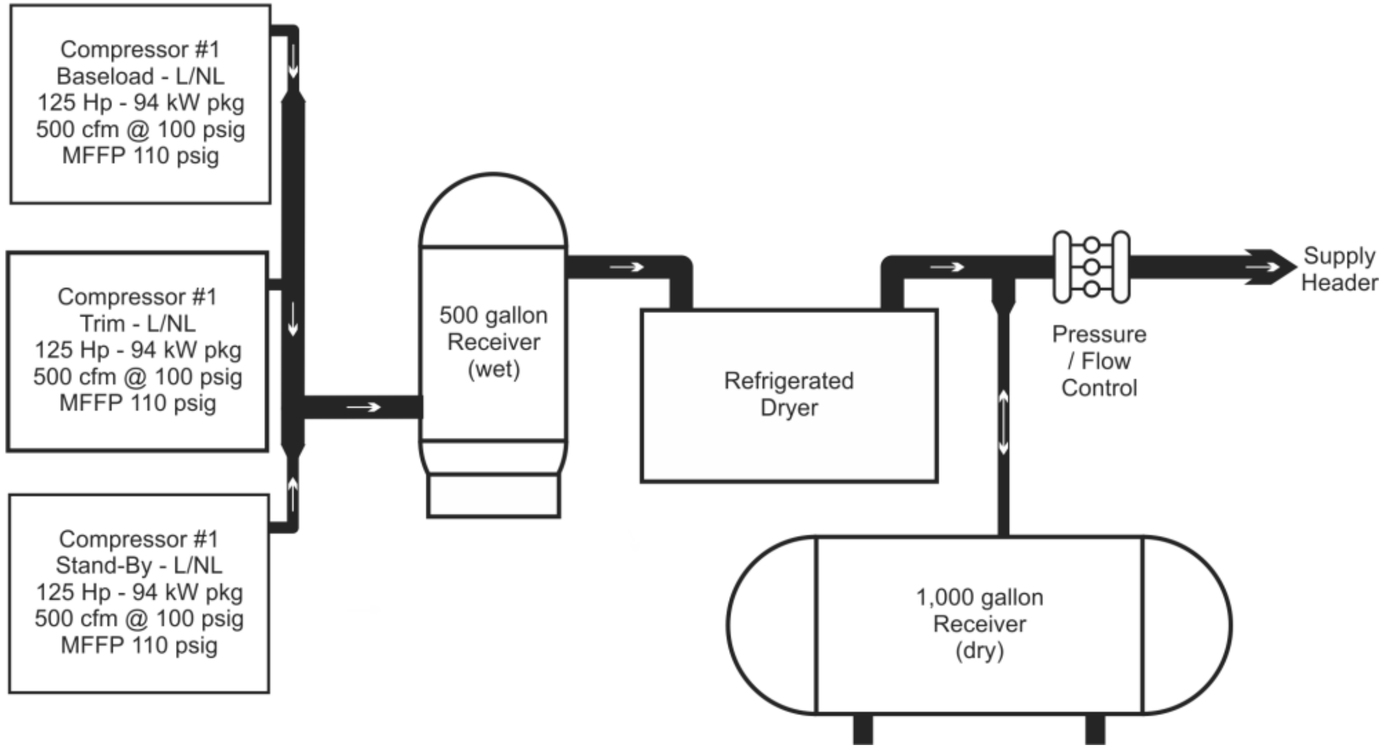


Pressure/Flow Controllers



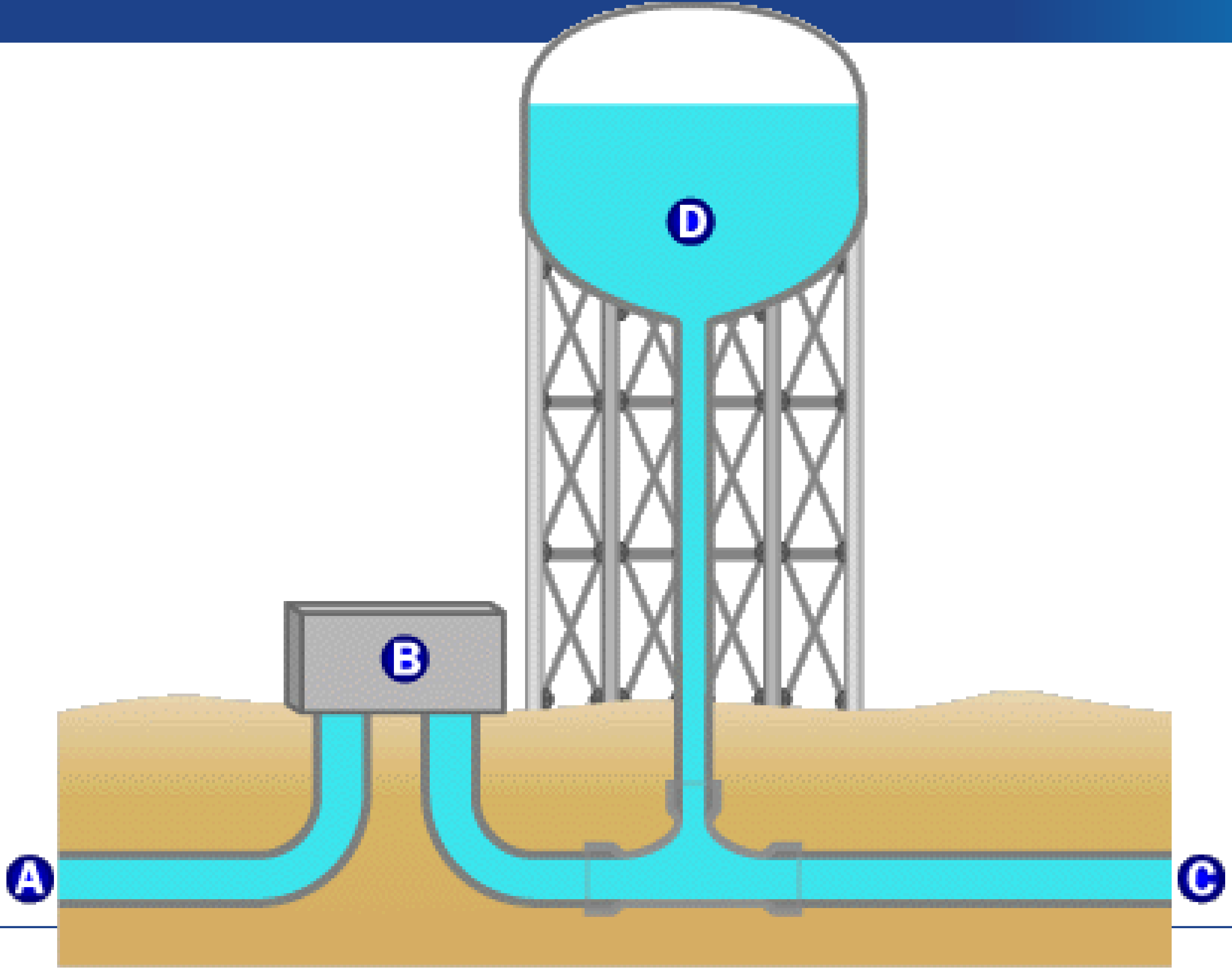
Pressure/Flow Controllers

Pressure/Flow Controllers



- A typical block diagram of a pressure/flow controller in a compressed air system with one point of entry (single compressor room)

Pressure/Flow Controllers



Primary Storage

Controls Summary

- Create a control strategy:
  - ✓ Know how your controls work
  - ✓ Realize the pros and cons of different controls
  - ✓ Recognize how controls affect part load efficiency
  - ✓ Understand how storage affects the effectiveness of control strategies

Session 3

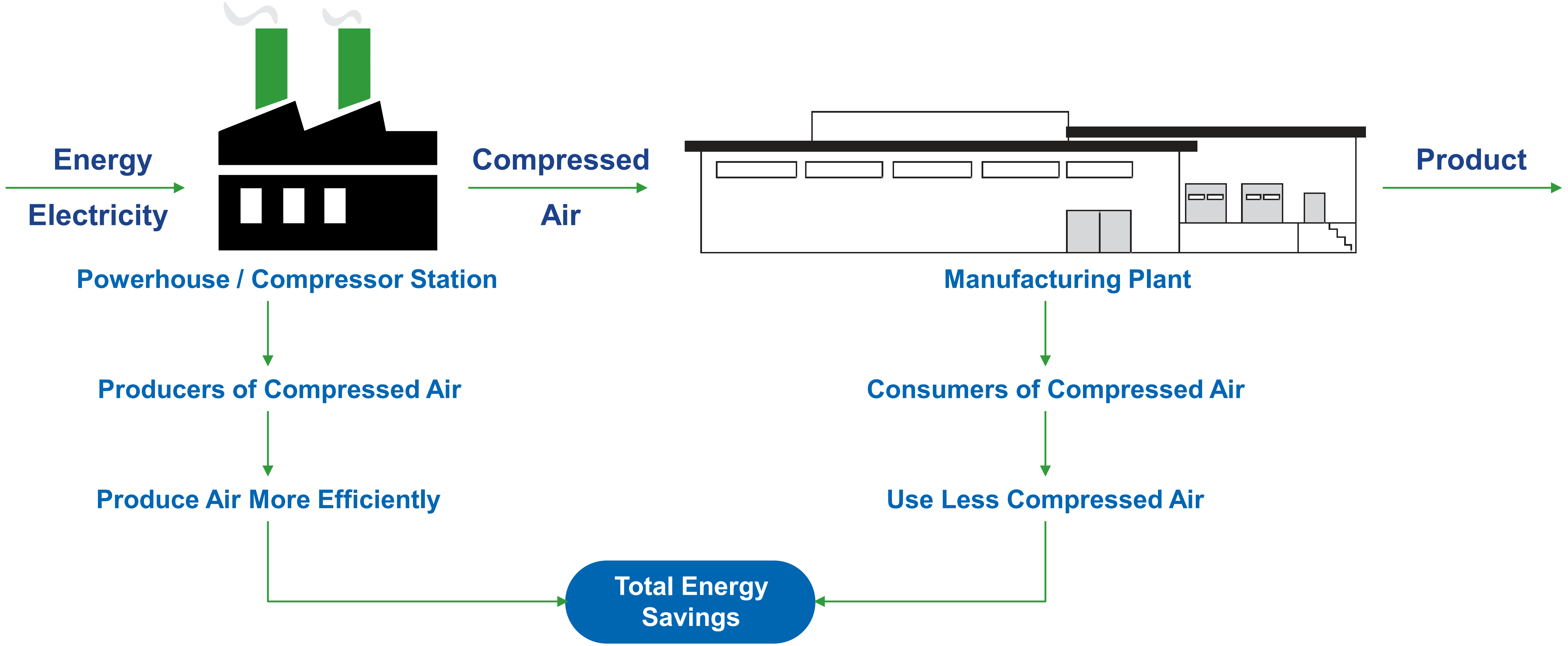
Logtool, and the MEASUR Tool

Why AIRMaster+?

- ~90% of energy input to compressor never reaches tools (waste heat, drying, etc.)
- Leaks +pressure drops remove air energy before reaching tools--sometimes >50%
- Poor or improperly adjusted controls leave several compressors operating a part load
- System assessments can be an arduous task using spreadsheets that must be modified for each job
- MEASUR provides a systematic approach to assessing compressed air systems, analyzing collected data, and reporting results

What Can This Tool Help Me With?

There are two basic ways to reduce the energy consumption of a compressed air system: produce compressed air more efficiently; and consume less compressed air.

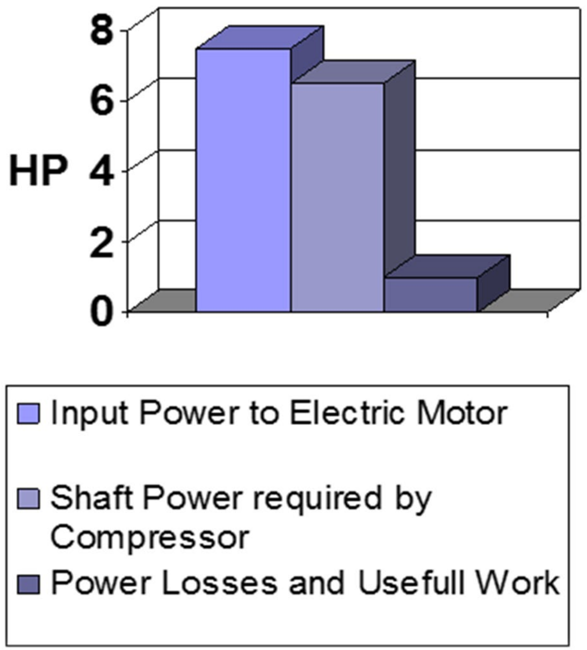


What Can This Tool Help Me With?

- Produce more efficiently
  - Improve Compressor Control
  - Type of Compressor Control
- Use less compressed air
  - Reduce System Pressure
  - Reduce Air Demand
  - How does compressed air support production?

Compressed Air Versus Other Energy Sources

- 1 hp air motor = 7-8 hp of electrical power
  - 30 scfm @ 90 psig is required by the air motor
  - 6 - 7 bhp at compressor shaft required for 30 scfm
  - 7 - 8 hp electrical power required for this
- Annual energy cost for a 1 hp air motor versus a 1 hp electric motor, 5-day per week, 2 shift operation, $0.05/kWh
- $ 1,164 vs. $ 194



MEASUR Features

- MEASUR is an open-source software tool used to analyze industrial compressed air systems:
- Simulates existing and modified compressed air system operation
- Models part load system operation
- Assigns electrical utility energy schedules
- Enters 24-hour metered airflow or power data
- Is not a substitute for an experienced auditor!

Energy Efficiency Measures

1. Reduce Air Leaks
2. Improve End Use Efficiency
3. Reduce System Air Pressure
4. Use Unloading Controls
5. Adjust Cascading Set Points
6. Use Automatic Sequencer
7. Reduce Run Time
8. Add Primary Receiver Volume

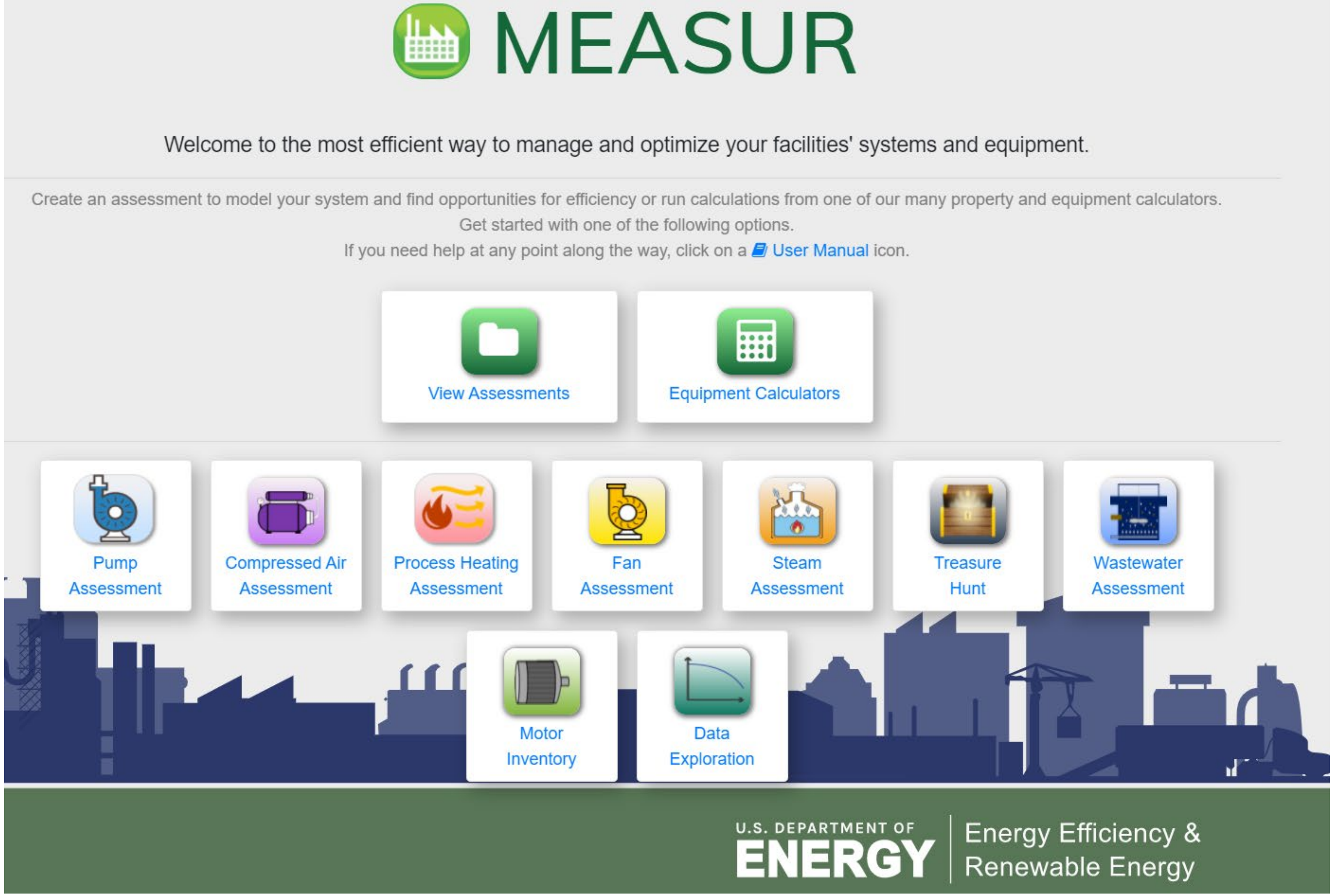
Why LogTool?

- LogTool is a public domain tool developed by SBW Consulting with support from the Compressed Air Challenge™.
- It is designed to assist in the analysis of compressed air system performance measurements.
- It was a companion tool for Airmaster+ available from the US DOE and CAC.

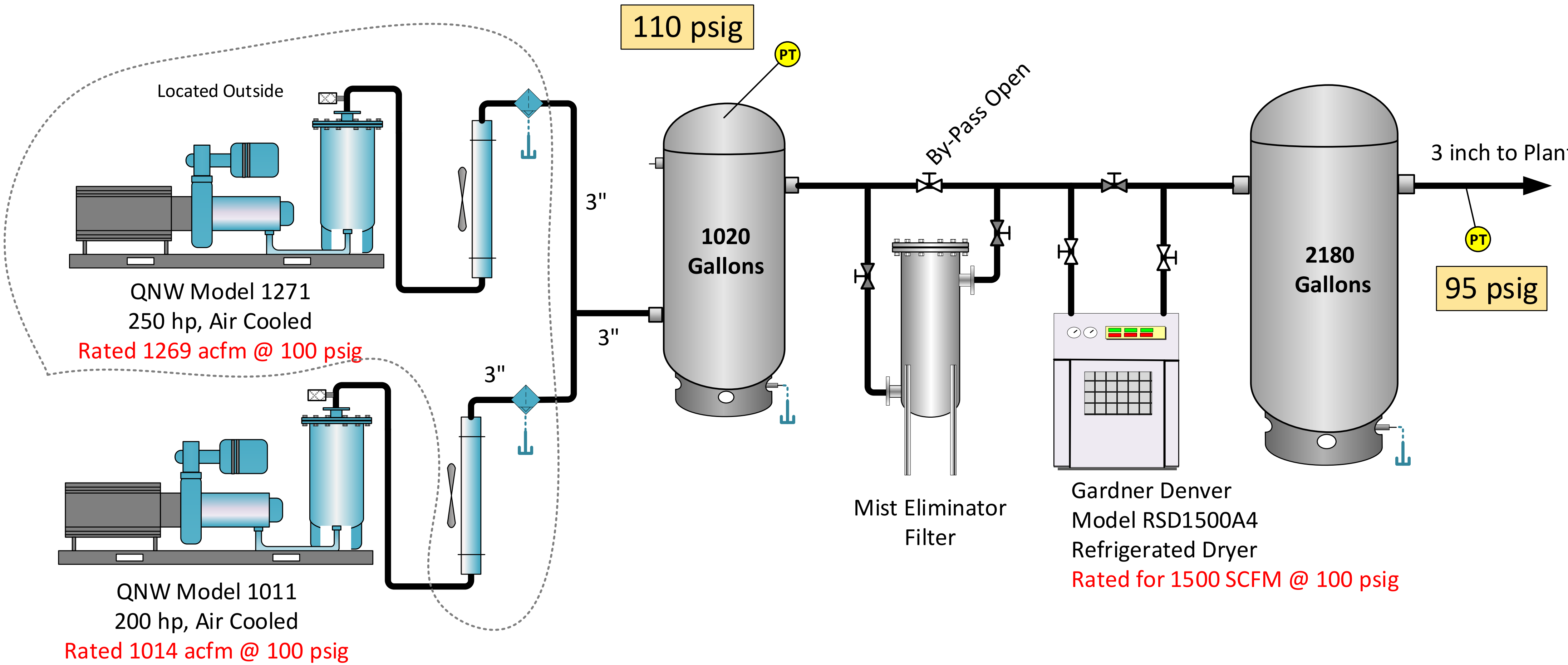
LogTool is Designed To:

- Import data which is exported from different types of data loggers.
- Select logger data channels and modify their properties.
  - e.g., name, type, units, etc.
- View data values for one or more logger channels.
- Display trend plots on one or two Y axis.
- Display scatter plots.
- Display daytype plots in the format that is needed for AIRMaster+

MEASUR Main Menu



Box Plant Company Example



Baseline Info

- 200 hp baseloaded compressor rated 1014 acfm using modulated inlet control
- 250 hp trim compressor rated 1269 acfm using modulated inlet control operating at 40% output
- Production is 24/6 with Sundays off
- Average flow during Monday to Saturday is 1500 cfm
- Baseline energy is 2,587,516 kWh or $174,657 using $.0675/kWh
- Leakage is estimated to be about 600 cfm based on leak down test

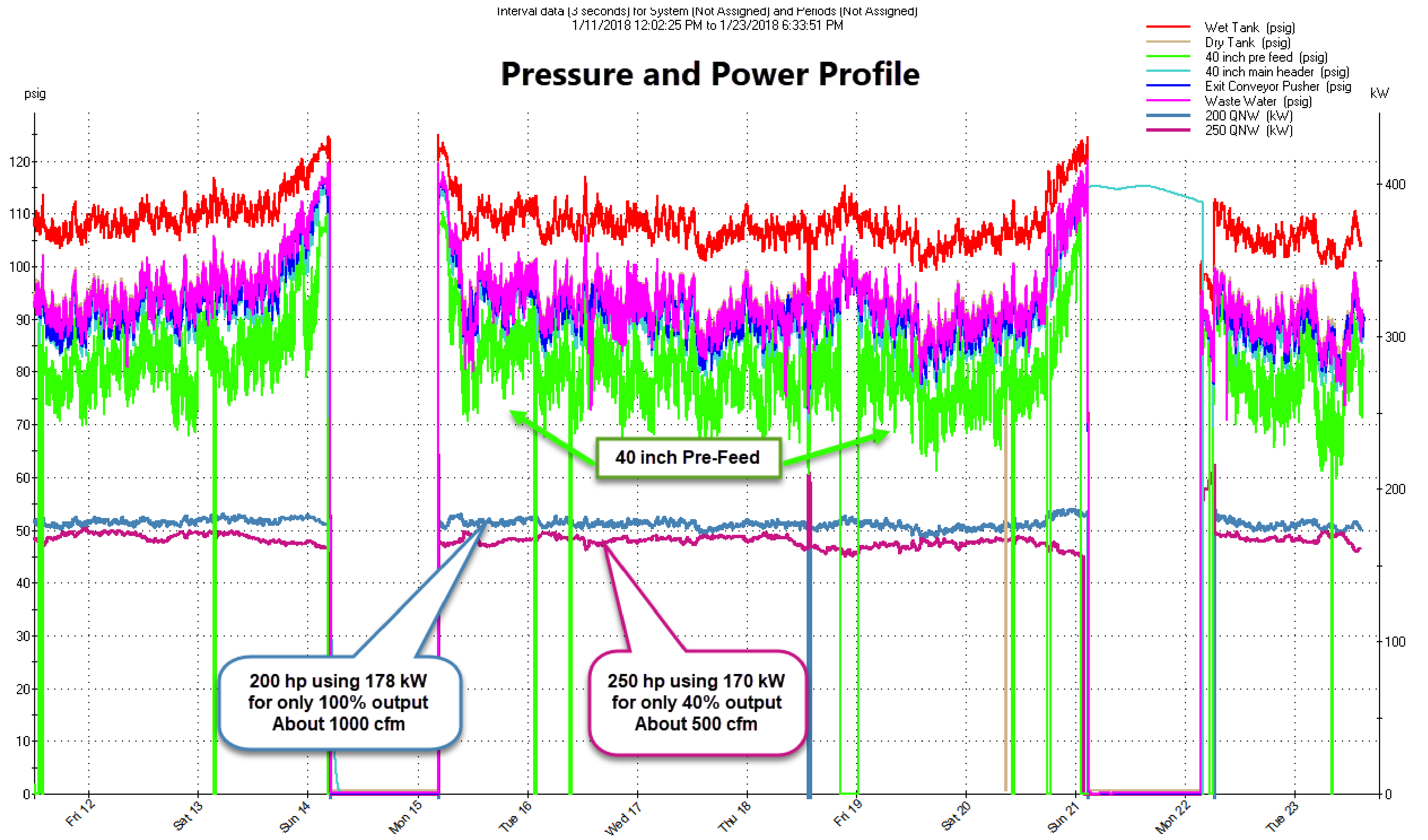
Baseline Info

- Air Operated Diaphragm Pumps (AOD) are in use and can be replaced with electric driven pumps made to pump heavy viscous fluids such as glue
- 3-inch pipe is used in the compressor room to handle almost 1500 scfm of flow. This is borderline undersized and is creating additional pressure drop.
- Both compressors must run to support production. Neither one by itself can run production. There is no redundancy at this plant for compressed air.

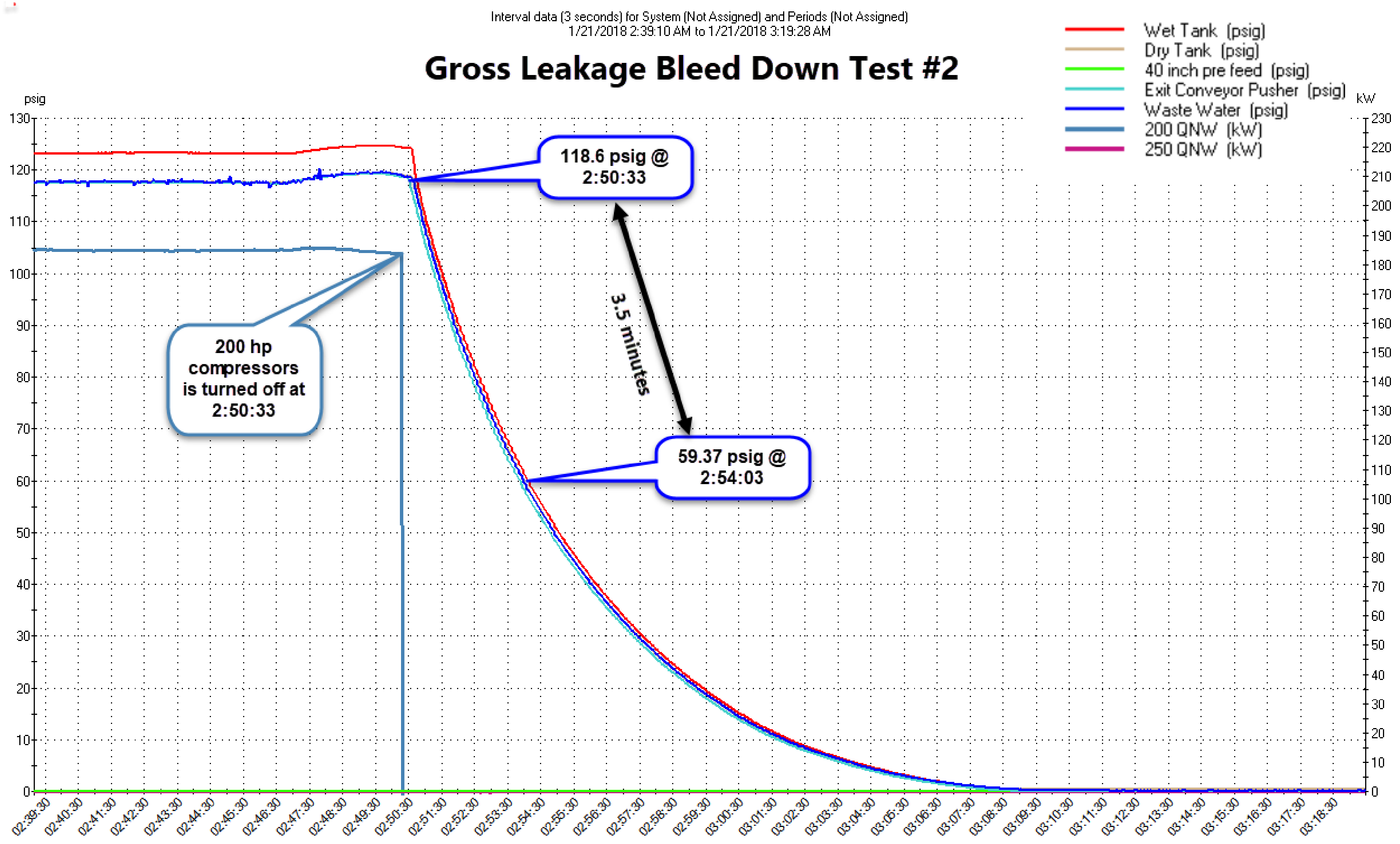
Table 4.7 Loss of Air Pressure Due to Friction

Cu ft Free Air Per Min	Equivalent Cu ft Compressed Air Per Min	Nominal Diameter, In.											
		1/2	3/4	1	1 1/4	1 1/2	2	3	4	6	8	10	12
10	1.28	6.50	.99	0.28									
20	2.56	25.9	3.90	1.11	0.25	0.11							
30	3.84	58.5	9.01	2.51	0.57	0.26							
40	5.12	....	16.0	4.45	1.03	0.46							
50	6.41	....	25.1	9.96	1.61	0.71	0.19						
60	7.68	....	36.2	10.0	2.32	1.02	0.28						
70	8.96	....	49.3	13.7	3.16	1.40	0.37						
80	10.24	....	64.5.	17.8	4.14	1.83	0.49						
90	11.52	....	82.8	22.6	5.23	2.32	0.62						
100	12.81	....	....	27.9	6.47	2.86	0.77						
125	15.82	....	....	48.6	10.2	4.49	1.19						
150	19.23	....	....	62.8	14.6	6.43	1.72	0.21					
175	22.40	....	....	....	19.8	8.72	2.36	0.28					
200	25.62	....	....	....	25.9	11.4	3.06	0.37					
250	31.64	....	....	....	40.4	17.9	4.78	0.58					
300	38.44	....	....	....	58.2	25.8	6.85	0.84	0.20				
350	44.80	....	....	....	....	35.1	9.36	1.14	0.27				
400	51.24	....	....	....	....	45.8	12.1	1.50	0.35				
450	57.65	....	....	....	....	58.0	15.4	1.89	0.46				
500	63.28	....	....	....	....	71.6	19.2	2.34	0.55				
600	76.88	....	....	....	....	....	27.6	3.36	0.79				
700	89.60	....	....	....	....	....	37.7	4.55	1.09				
800	102.5	....	....	....	....	....	49.0	5.89	1.42				
900	115.3	....	....	....	....	....	62.3	7.6	1.80				
1,000	128.1	....	....	....	....	....	76.9	9.3	2.21				
1,500	192.3	....	....	....	....	....	....	21.0	4.9	0.57			
2,000	256.2	....	....	....	....	....	....	37.4	8.8	0.99	0.24		

LogTool Trend Plot



LogTool Trend Plot



Bleed Down Test Calculation

Cfm Leakage =	[V x (P1 - P2) x 1.25]/(T x 14.7)						
Where	V=	453.9	Cu ft				
	P1=	118.66	Psig				
	P2 =	59.33	Psig				
	T =	3.50	Minute				
Cfm Leakage =	654.34						
% Leakage =	Measured cfm leakage/total cfm output of plant compressors						
% Leakage =	**32.3%**	Assuming 4cfm/hp and total HP of 450					

$$\text{Leakage (cfm free air)} = \left[\frac{V_{cf} \times (P_1 - P_2)}{T_m \times P_a}\right] \times 1.25$$

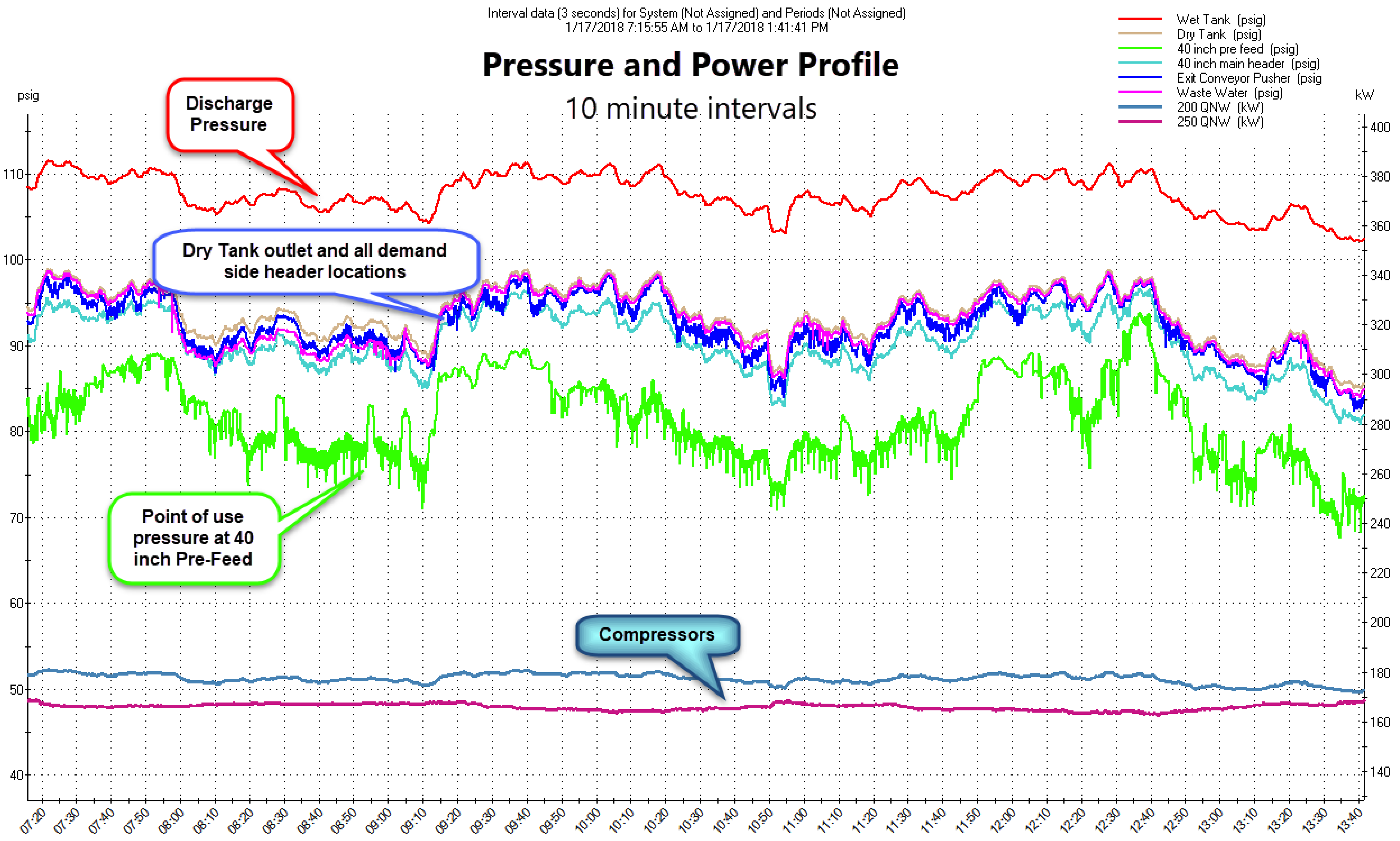
Bleed Down Using MEASUR

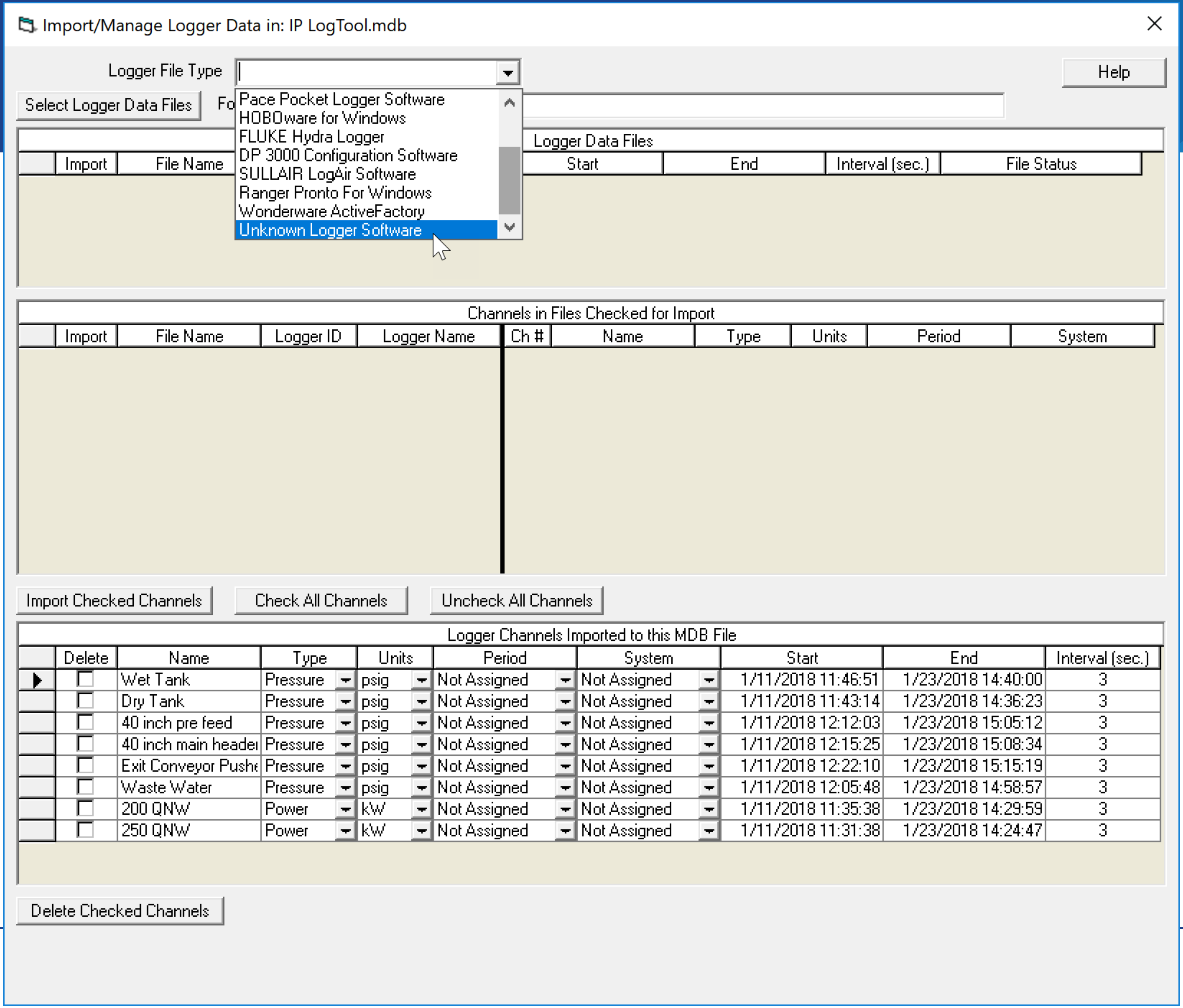
BLEED TEST

Total System Volume	453.9	ft^3
Atmospheric Pressure	14.7	psia
Normal Operating Pressure	118.66	psig
Test Pressure	59.33	psig
Time	3.5	min

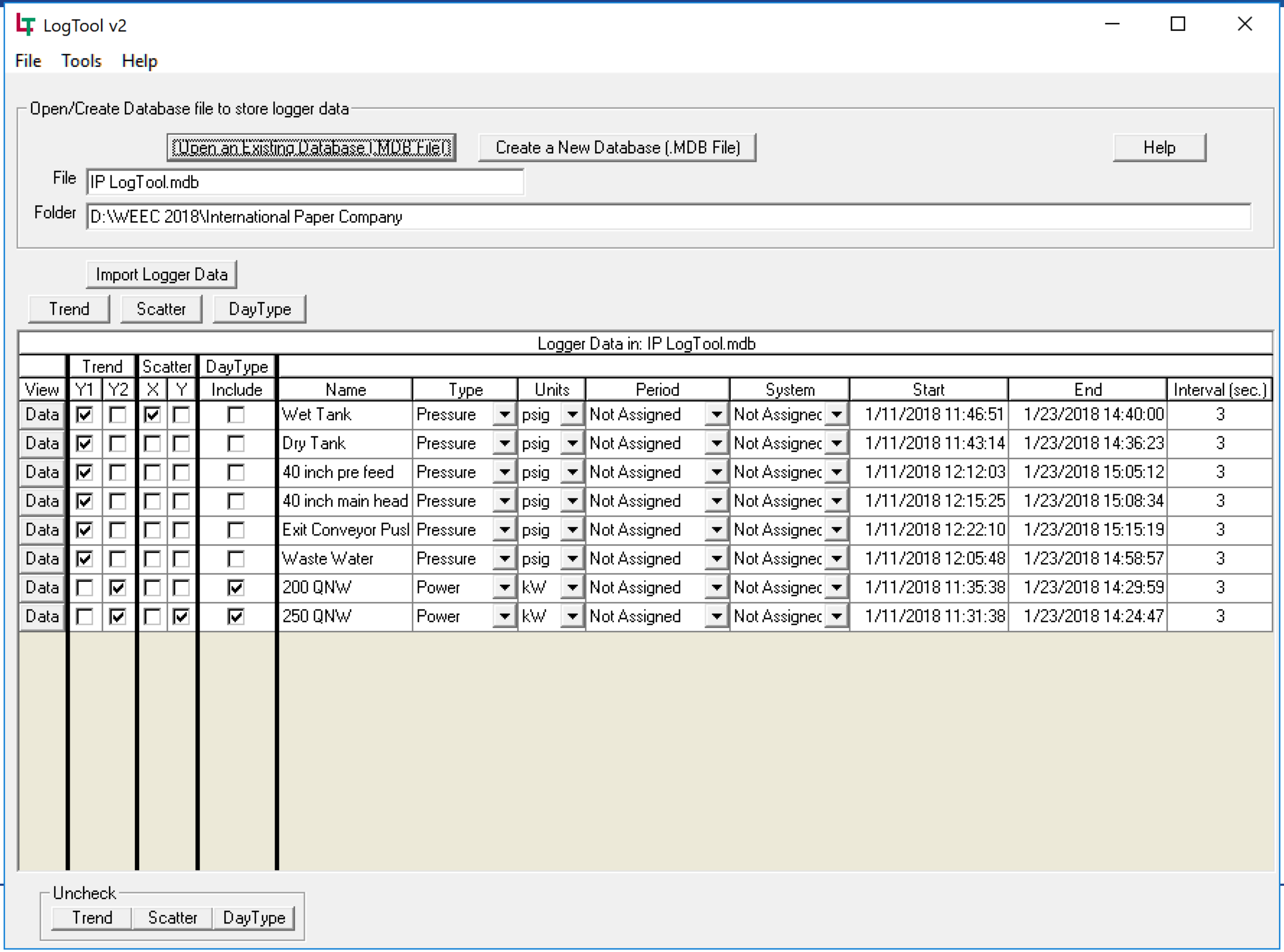
Leakage **654.27 CFM**

LogTool Trend Plot



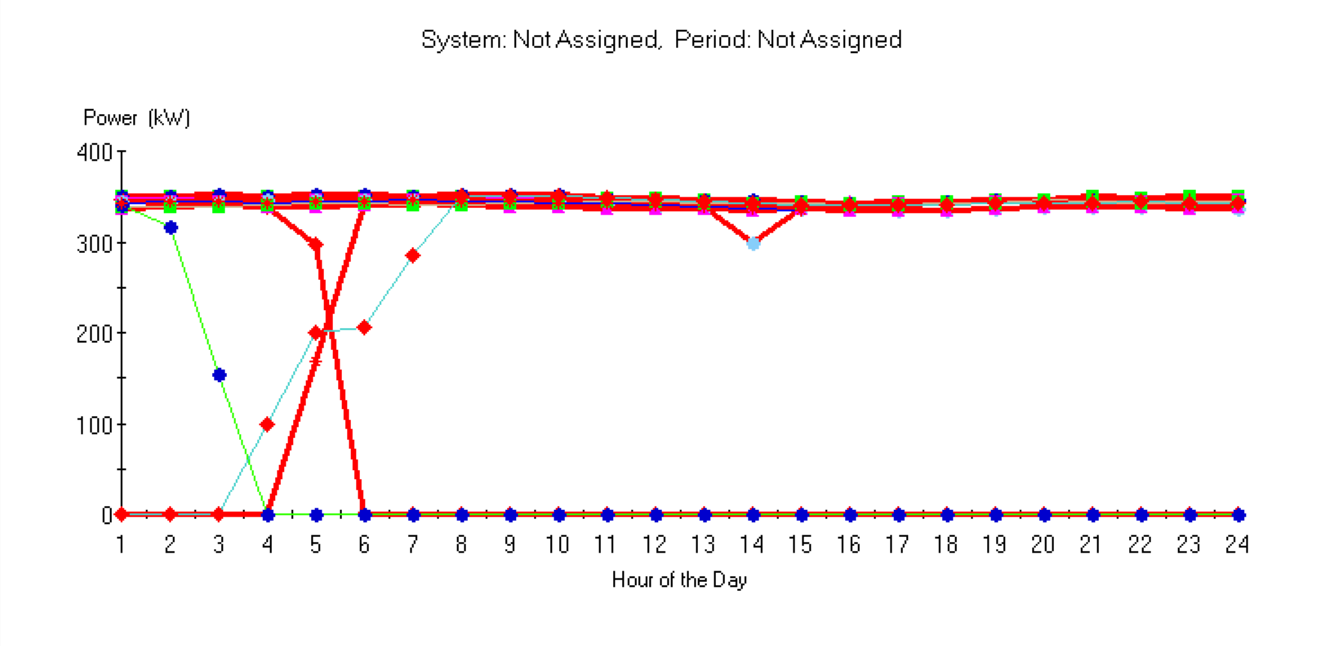

Import/Manage Logger Data in: IP LogTool.mdb
Logger File Type
Help
Select Logger Data Files
Pace Pocket Logger Software
HOBOware for Windows
FLUKE Hydra Logger
DP 3000 Configuration Software
SULLAIR LogAir Software
Ranger Pronto For Windows
Wonderware ActiveFactory
Unknown Logger Software
Logger Data Files
Import | File Name | Start | End | Interval (sec.) | File Status
Channels in Files Checked for Import
Import | File Name | Logger ID | Logger Name | Ch # | Name | Type | Units | Period | System
Import Checked Channels
Check All Channels
Uncheck All Channels
Logger Channels Imported to this MDB File
Delete | Name | Type | Units | Period | System | Start | End | Interval (sec.)
Wet Tank | Pressure | psig | Not Assigned | Not Assigned | 1/11/2018 11:46:51 | 1/23/2018 14:40:00 | 3
Dry Tank | Pressure | psig | Not Assigned | Not Assigned | 1/11/2018 11:43:14 | 1/23/2018 14:36:23 | 3
40 inch pre feed | Pressure | psig | Not Assigned | Not Assigned | 1/11/2018 12:12:03 | 1/23/2018 15:05:12 | 3
40 inch main header | Pressure | psig | Not Assigned | Not Assigned | 1/11/2018 12:15:25 | 1/23/2018 15:08:34 | 3
Exit Conveyor Pusher | Pressure | psig | Not Assigned | Not Assigned | 1/11/2018 12:22:10 | 1/23/2018 15:15:19 | 3
Waste Water | Pressure | psig | Not Assigned | Not Assigned | 1/11/2018 12:05:48 | 1/23/2018 14:58:57 | 3
200 QNW | Power | kW | Not Assigned | Not Assigned | 1/11/2018 11:35:38 | 1/23/2018 14:29:59 | 3
250 QNW | Power | kW | Not Assigned | Not Assigned | 1/11/2018 11:31:38 | 1/23/2018 14:24:47 | 3
Delete Checked Channels

LogTool Main Menu



Enter LogTool Data Into AIRMaster

DayType Analysis



Right click on data points to select day type. Left click to highlight the trace.

Click a date to highlight profile in graph.

Date	Day	Day Type
Jan-11-2018	Thu	Excluded Days
Jan-12-2018	Fri	Production
Jan-13-2018	Sat	Production
Jan-14-2018	Sun	Sunday
Jan-15-2018	Mon	Monday
Jan-16-2018	Tue	Production
Jan-17-2018	Wed	Production
Jan-18-2018	Thu	Production
Jan-19-2018	Fri	Production
Jan-20-2018	Sat	Production
Jan-21-2018	Sun	Excluded Days
Jan-22-2018	Mon	Excluded Days
Jan-23-2018	Tue	Excluded Days

Plot Day Type ...

All Days

Remove Day Type...

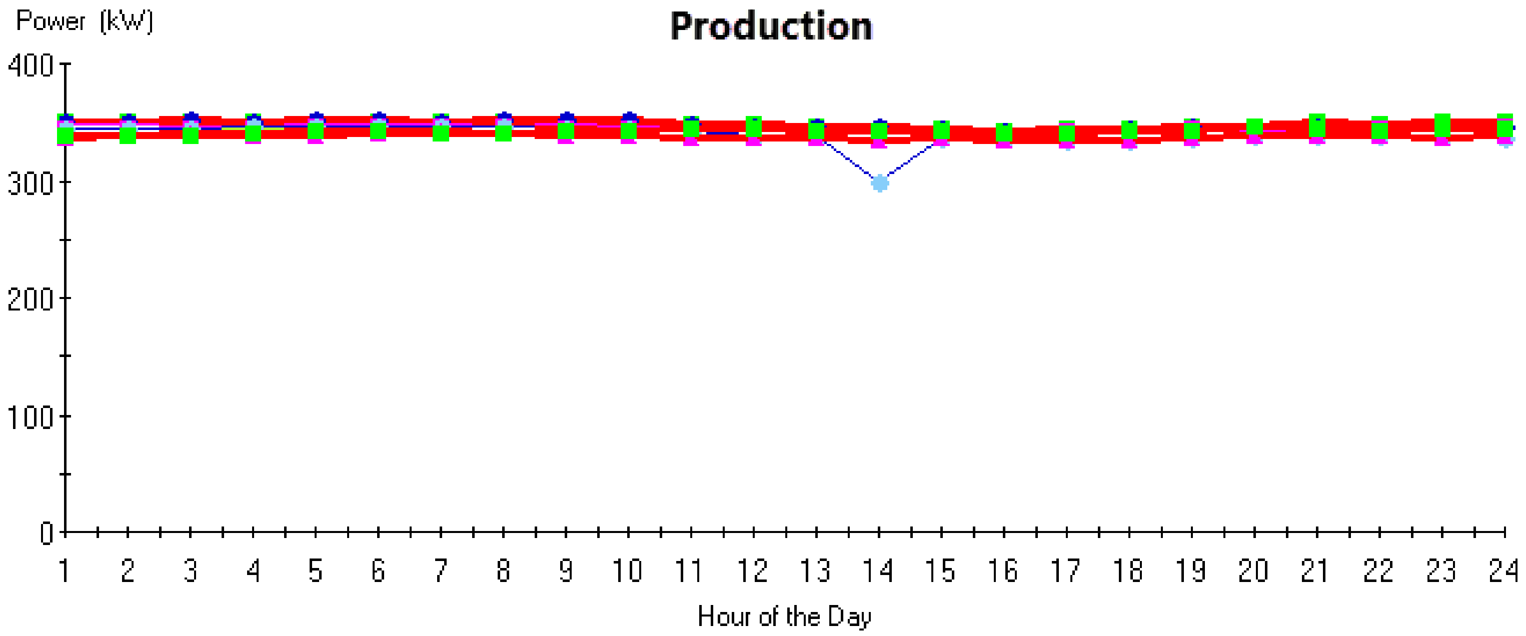
Caution: Day profiles can be similar even though different equipment, e.g., compressors, is operating. Use Trend Plots to examine the details of equipment operation before determining whether days should be assigned to the same daytype.

Create System DayType Profiles | Copy Plot to ClipBoard | Copy Profiles to ClipBoard | Help

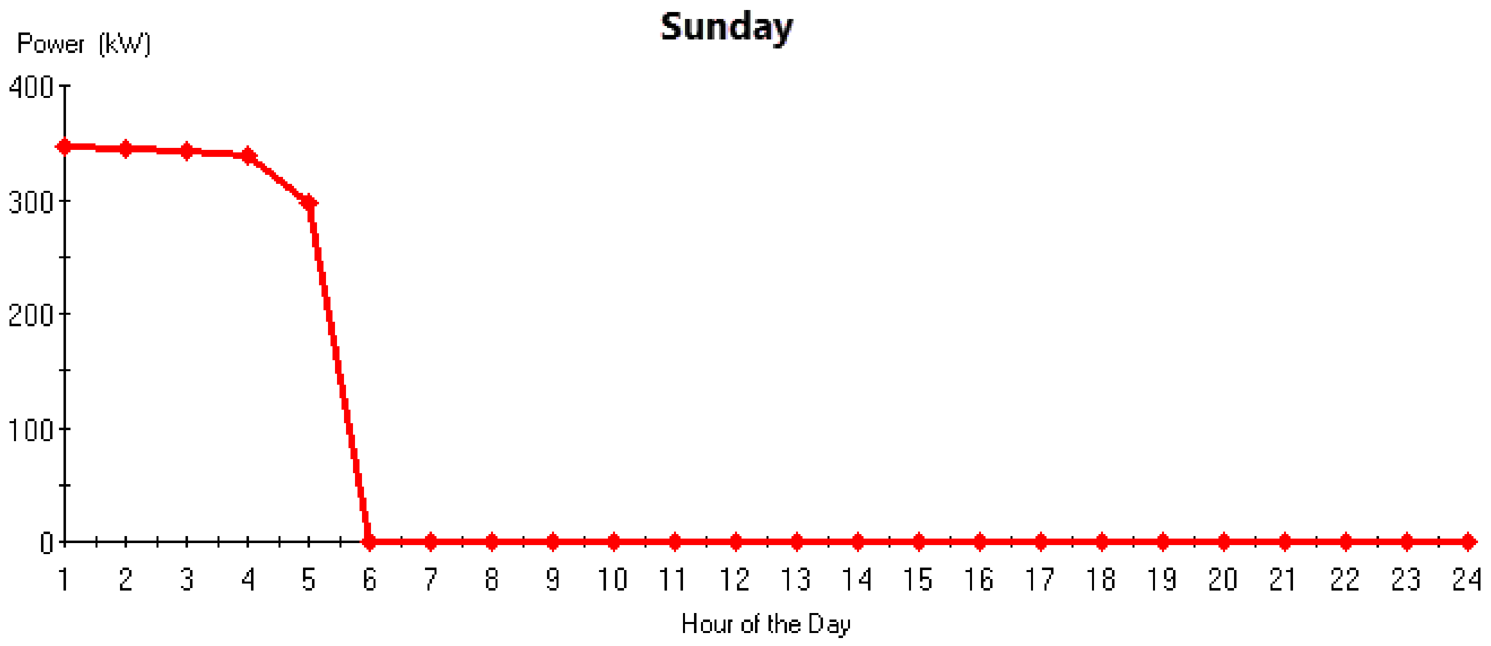
System DayType Profiles

DayTypeName	ChannelName	Hr_01	Hr_02	Hr_03	Hr_04	Hr_05	Hr_06	Hr_07
Monday	200 QNW	0.00	0.00	0.00	0.00	84.55	175.88	177.13
Monday	250 QNW	0.00	0.00	0.00	0.00	83.80	164.18	163.56
Production	200 QNW	178.12	178.25	177.86	177.11	177.67	178.09	177.97
Production	250 QNW	166.54	166.81	167.49	168.31	168.50	168.50	168.40
Sunday	200 QNW	181.76	180.51	179.20	176.98	154.17	0.00	0.00
Sunday	250 QNW	165.56	163.78	162.43	161.83	143.08	0.00	0.00

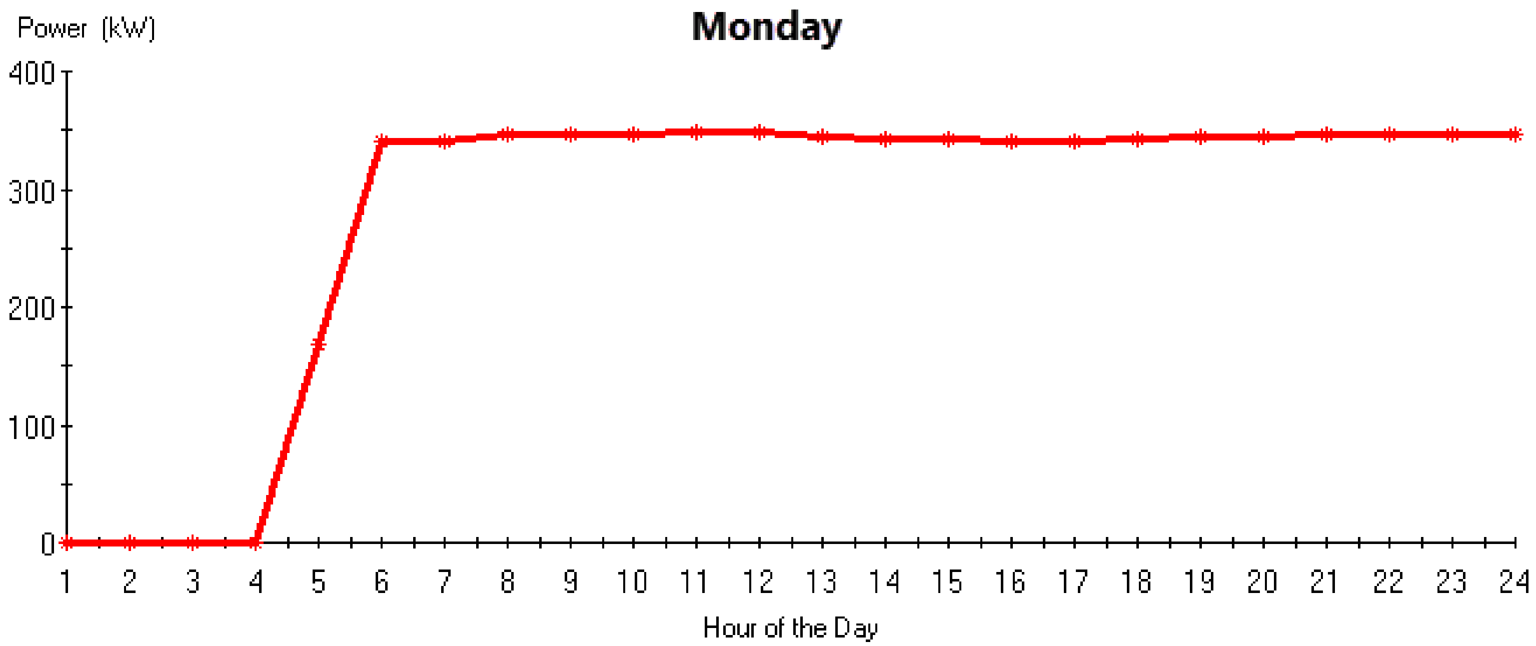
DayType Profiles



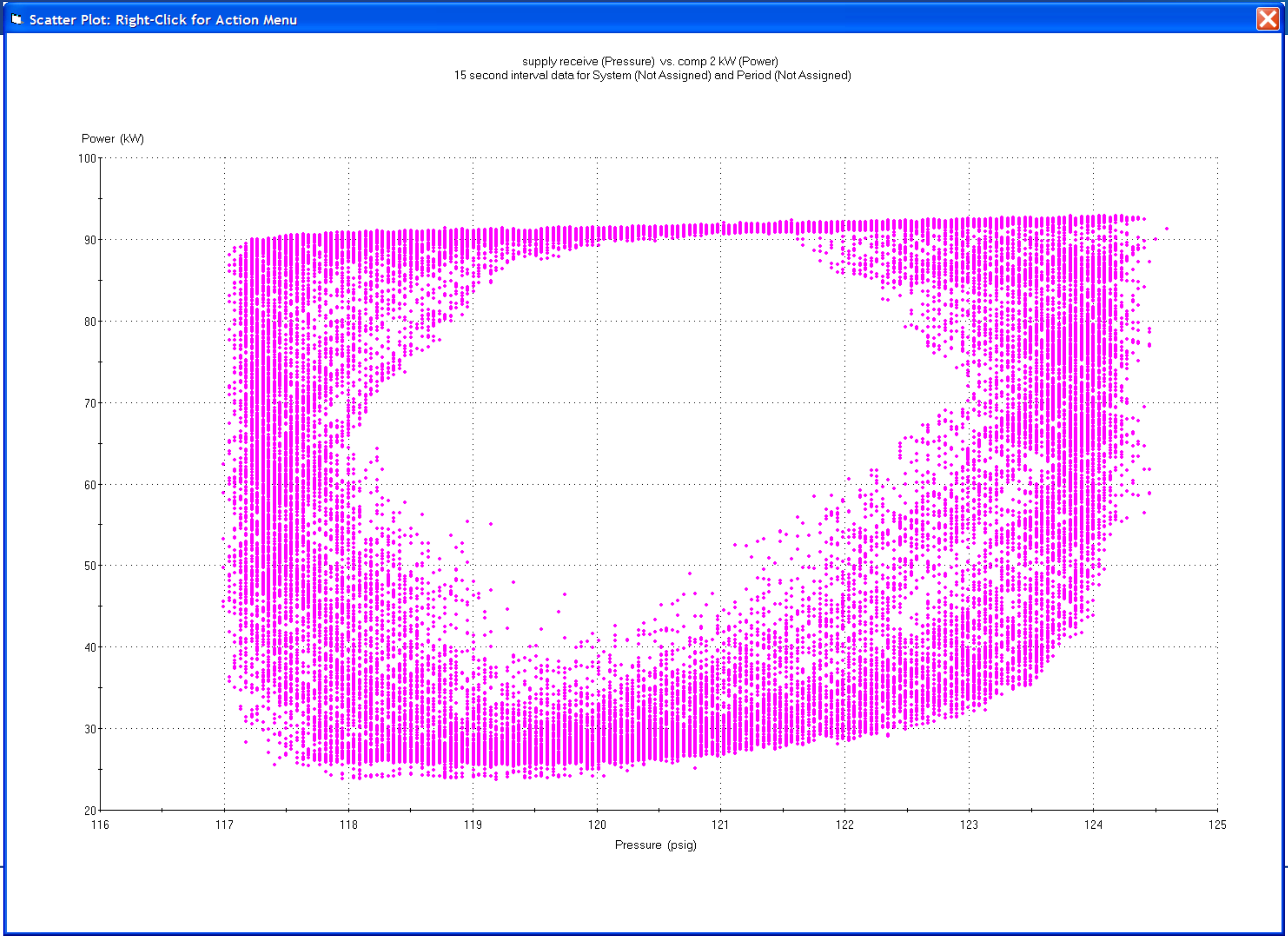
DayType Profiles



DayType Profiles



LogTool Scatter Plot



MEASUR Tool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Energy Efficiency & Renewable Energy
Add New
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Coca Cola v2
Coca Cola v2
Coca Cola v2
Coca Cola
Cleveland Cliffs Burns Harbor
Lockheed Martin
New Assessment
Lockheed Martin
International Paper
International Paper
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Lennox
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MEASUR
Welcome to the most efficient way to manage and optimize your facilities' systems and equipment.
Create an assessment to model your system and find opportunities for efficiency or run calculations from one of our many property and equipment calculators.
Get started with one of the following options.
If you need help at any point along the way, click on a User Manual icon.
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Compressed Air Assessment
Process Heating Assessment
Fan Assessment
Steam Assessment
Treasure Hunt
Wastewater Assessment
Motor Inventory
Pump Inventory
Data Exploration
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

MEASUR Tool

Compressed Air Calculators

Compressed Air Reduction
This calculator is used to quantify the energy savings associated with reducing compressed air usage.

Compressed Air Pressure Reduction
This calculator is used to quantify the energy savings associated with reducing compressed air system pressure.

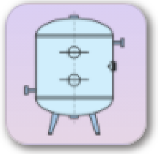
Actual to Standard Airflow
The calculator converts ACFM (Actual cubic feet per minute) to SCFM (Standard cubic feet per minute) and vice versa for the given conditions using either ASME standard conditions or CAGI/ISO standard conditions.

Leak Loss Estimator - Bag Method
Estimates the leakage losses in a compressed air system using the bag method

Pneumatic Air Requirement
Estimate the quantity of air required by a specific single acting or a double acting piston cylinder compressor

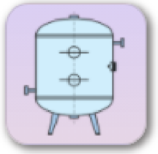
Compressed Air - Leak Survey
Used to quantify the energy savings associated with reducing compressed air leaks.

MEASUR Tool



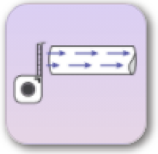
Receiver Tank Sizing

Calculate the required size of the receiver tank



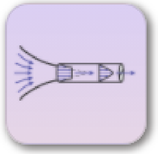
Usable Air Capacity

Estimate the quantity of compressed air that is available for use



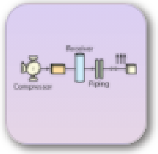
Pipe Sizing

Determine pipe diameter when the volumetric flow velocity, pressure, and design velocity are known



Velocity in the Piping

Estimate the velocity of compressed air throughout system piping



System Capacity

Determine total capacity of compressed air system or specific pipes and receiver tanks

Operation Costs

Estimate the cost of operation of the compressor in both fully and partially loaded instances

Let's compare to old Log Tool

Data Exploration

Setup Day Type Analysis Visualization

1 Import Data | 2 **Select Header Row** | 3 Refine Data | 4 Map Date and Time

Select a header row and advance to the next file

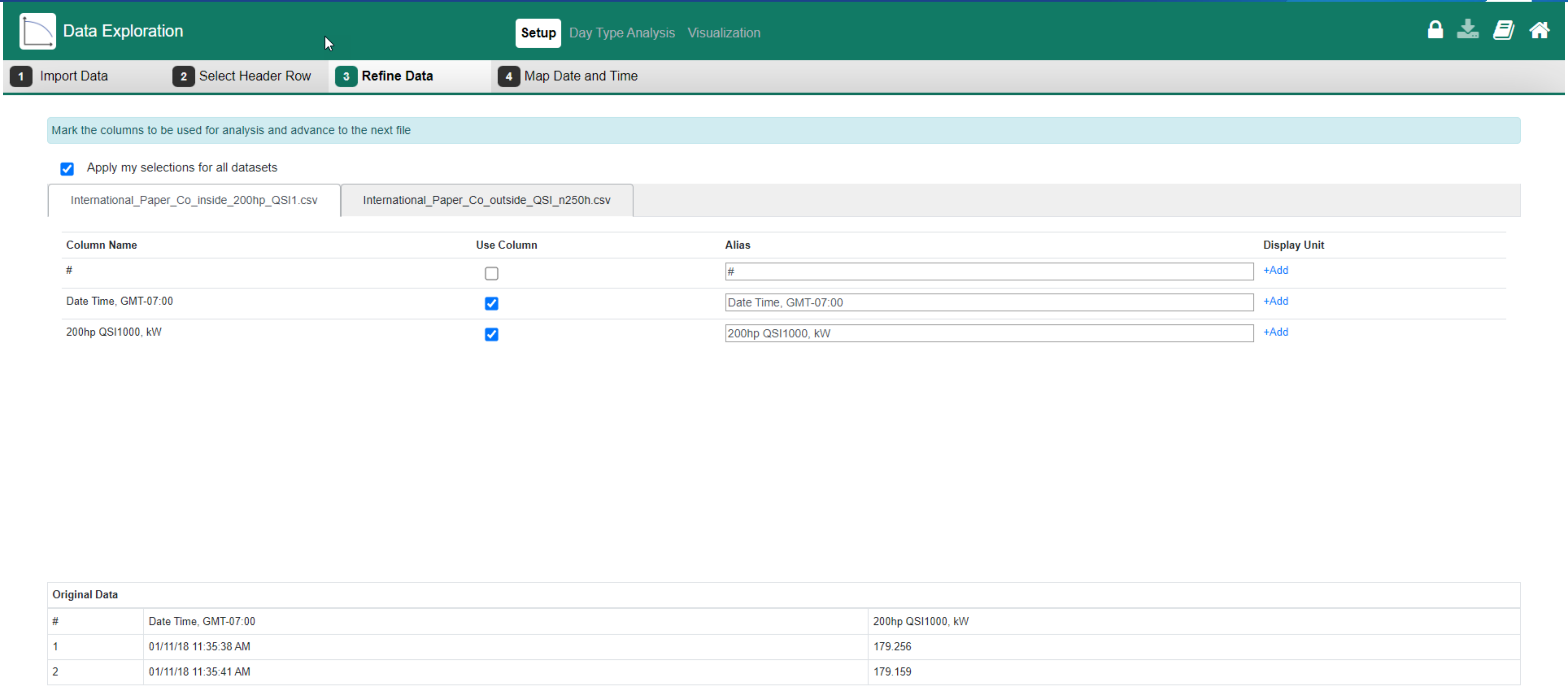
☑ Apply my selections for all datasets

International_Paper_Co_inside_200hp_QSI1.csv | International_Paper_Co_outside_QSI_n250h.csv

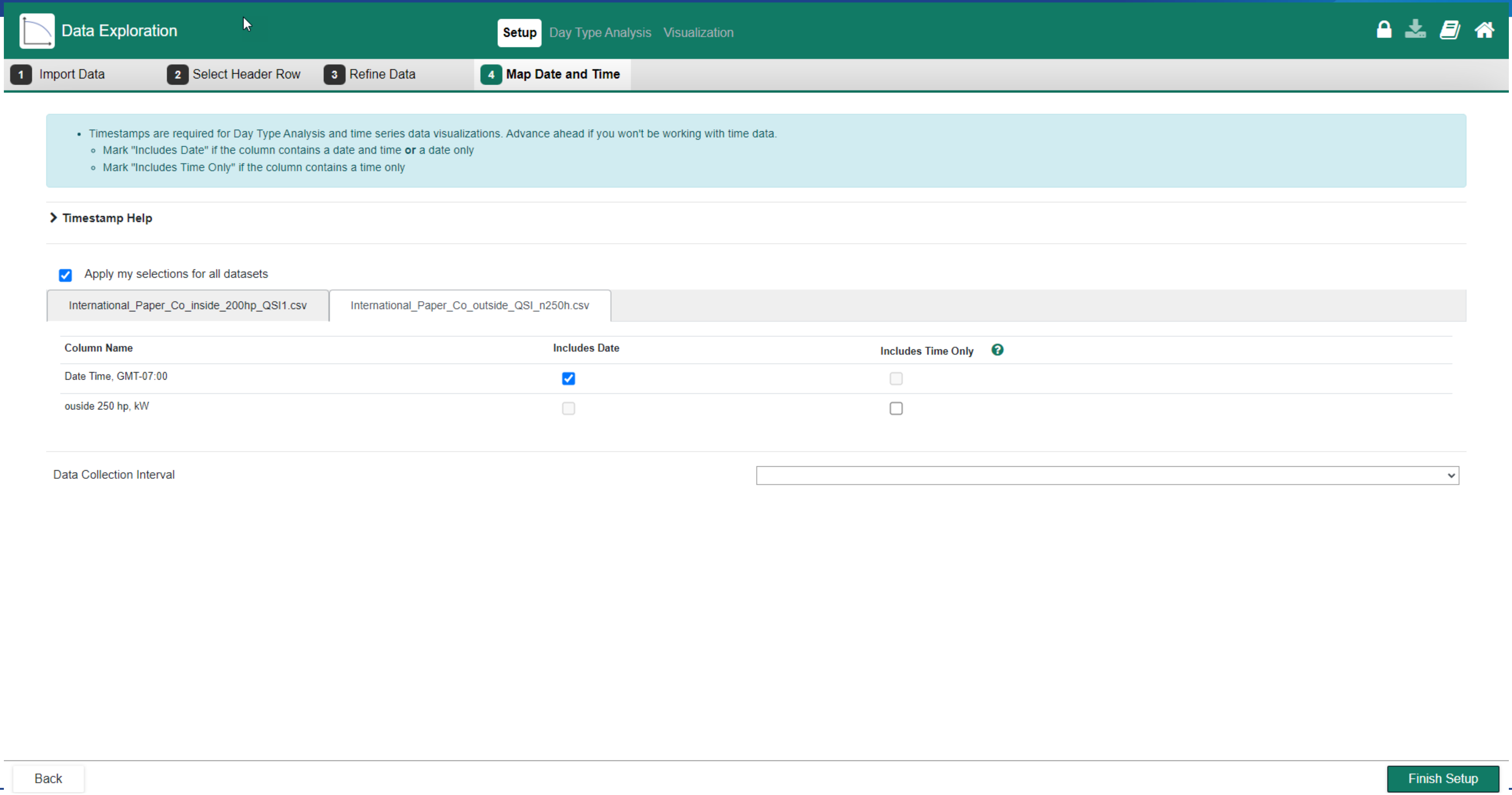
Select Header Row

○	Plot Title: International Paper Co inside 200hp QSI1		
◉	#	Date Time, GMT-07:00	200hp QSI1000, kW
○	1	01/11/18 11:35:38 AM	179.256
○	2	01/11/18 11:35:41 AM	179.159
○	3	01/11/18 11:35:44 AM	179.061
○	4	01/11/18 11:35:47 AM	178.964
○	5	01/11/18 11:35:50 AM	179.159
○	6	01/11/18 11:35:53 AM	179.256
○	7	01/11/18 11:35:56 AM	179.451
○	8	01/11/18 11:35:59 AM	179.354
○	9	01/11/18 11:36:02 AM	179.451

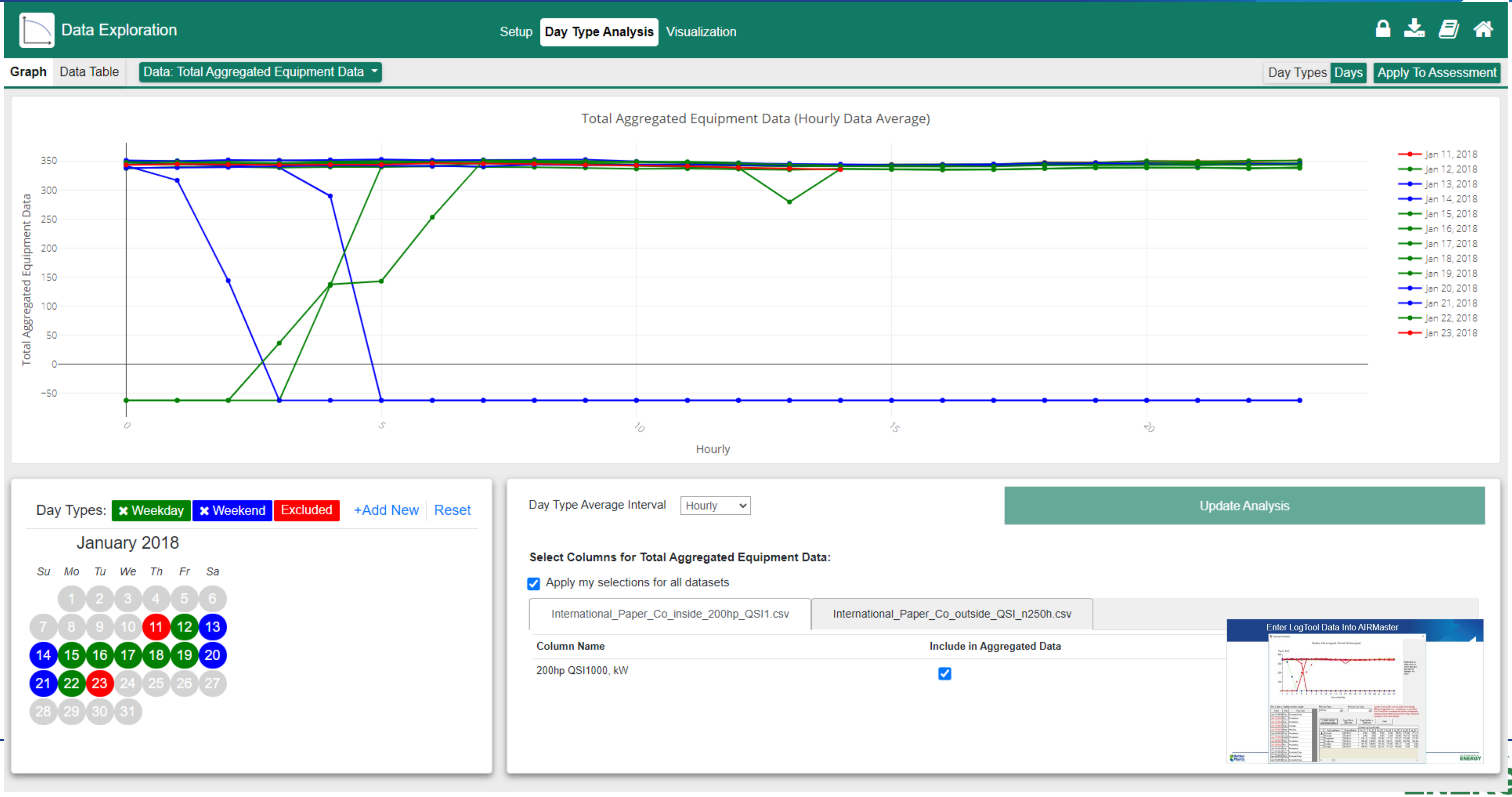
Let's compare to old Log Tool



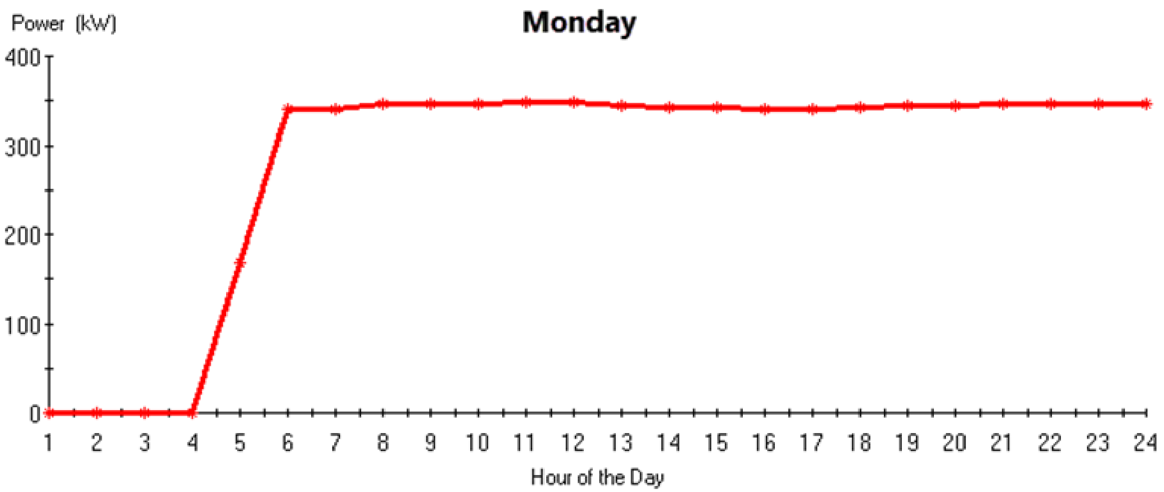
Let's compare to old Log Tool

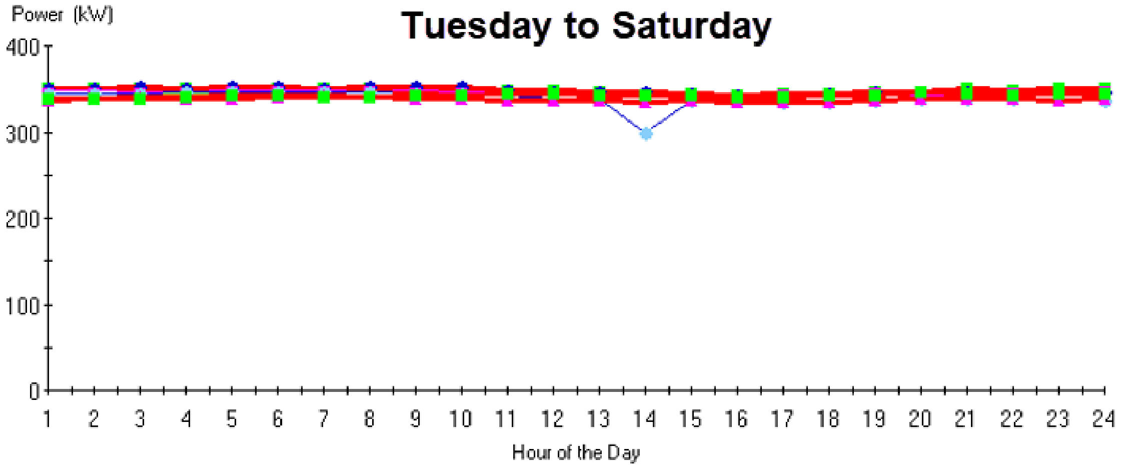


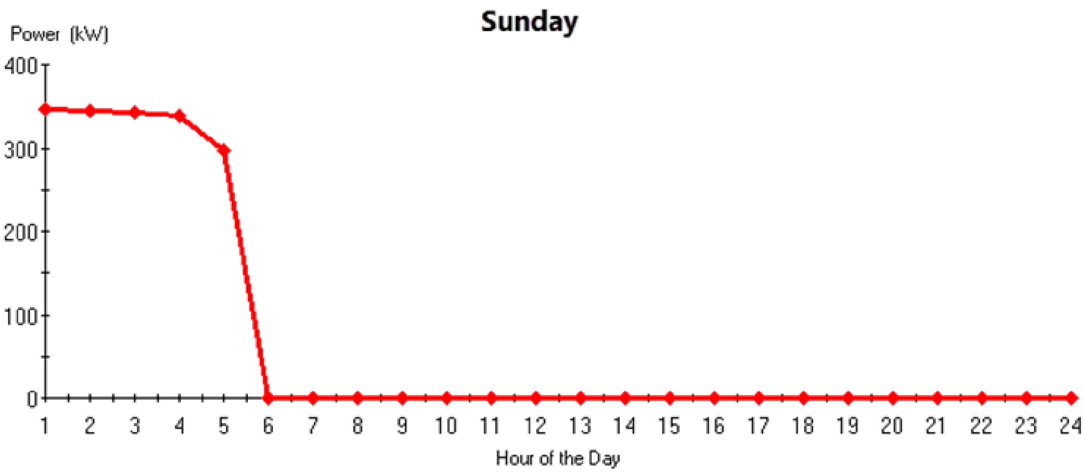
Let's compare to old Log Tool



Day Types


Monday
Power (kW)
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of the Day


Tuesday to Saturday
Power (kW)
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of the Day


Sunday
Power (kW)
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of the Day

Let's compare to old Log Tool

Data Exploration

Setup | **Day Type Analysis** | Visualization

Graph | **Data Table** | Data: Total Aggregated Equipment Data

Display Selected | Display All | Day Types | Days | Apply To Assessment

Day Type Summaries (Total Aggregated Equipment Data)

	0	1	2	3	4	5	6	7	8	9	10	11
Weekday	228.377	228.905	228.787	242.79	286.037	316.346	332.26	346.52	346.149	345.545	344.301	343.832
Weekend	344.453	337.26	294.106	242.105	230.29	142.398	141.889	141.907	142.721	142.478	142.019	141.54
Excluded	343.151	344.6	343.84	343.205	343.652	343.678	345.983	345.427	344.92	343.188	342.499	343.677

	12	13	14	15	16	17	18	19	20	21	22	23
Weekday	342.328	332.301	340.319	340.034	339.788	340.325	342.196	342.645	343.561	343.737	343.301	343.897
Weekend	140.985	140.712	140.507	139.788	139.802	140.537	141.008	141.615	141.356	140.843	141.28	141.524
Excluded	341.853	340.265	338.766	343.887	344.11	343.776	347.291	347.341	349.506	349.346	349.406	350.719

Copy Table

Day Summaries (Total Aggregated Equipment Data)

	0	1	2	3	4	5	6	7	8	9	10	11
Weekday												
Jan 12, 2018	350.503	350.457	349.767	350.922	349.444	350.735	350.126	349.697	348.726	347.911	348.143	348.613
Jan 15, 2018	-62.48	-62.481	-62.479	-62.48	135.607	340.068	340.692	346.157	347.243	347.519	348.732	347.609
Jan 16, 2018	347.61	347.97	347.122	346.248	347.541	347.869	347.655	346.948	347.811	345.907	343.795	343.826
Jan 17, 2018	344.128	344.633	344.586	344.258	346.296	347.187	345.95	346.432	344.017	345.032	342.959	343.33
Jan 18, 2018	344.129	344.662	345.205	345.692	346.339	346.123	346.506	345.632	345.089	344.363	341.707	339.446
Jan 19, 2018	337.229	339.573	339.789	338.727	339.595	339.627	341.793	339.637	339.3	338.219	336.391	336.754
Jan 22, 2018	-62.479	-62.48	-62.48	36.16	137.439	142.81	253.096	351.139	350.856	349.867	348.384	347.243
Weekend												
Jan 13, 2018	351.026	349.585	351.782	351.001	351.894	352.74	351.297	351.961	352.383	352.372	349.311	346.937
Jan 14, 2018	347.315	344.282	341.634	338.817	289.6	-62.48	-62.481	-62.479	-62.48	-62.48	-62.482	-62.481
Jan 20, 2018	337.969	338.586	339.17	341.079	342.147	341.811	341.216	340.627	343.462	342.497	343.729	344.185
Jan 21, 2018	341.5	316.585	143.837	-62.476	-62.479	-62.478	-62.478	-62.48	-62.48	-62.478	-62.48	-62.48
Excluded												
Jan 11, 2018												346.218
Jan 23, 2018	343.151	344.6	343.84	343.205	343.652	343.678	345.983	345.427	344.92	343.188	342.499	341.135

	12	13	14	15	16	17	18	19	20	21	22	23
Weekday												
Jan 12, 2018	346.908	343.422	343.798	343.359	343.994	344.688	346.835	347.03	350.133	349.088	350.24	350.696
Jan 15, 2018	345.048	343.513	341.95	341.139	340.554	341.815	343.719	344.359	345.83	346.652	346.369	346.135
Jan 16, 2018	342.966	340.637	341.396	342.32	341.424	341.937	343.92	343.374	343.997	345.062	343.421	344.827
Jan 17, 2018	341.718	340.763	341.098	341.488	341.749	342.284	344.047	344.131	344.641	344.578	344.717	345.682
Jan 18, 2018	338.237	279.357	336.221	335.939	335.253	335.215	337.038	338.875	338.816	338.304	338.122	337.499
Jan 19, 2018	336.199	334.947	336.405	335.468	334.589	335.592	337.082	337.984	338.112	338.727	336.751	339.25
Jan 22, 2018	345.219	343.466	341.363	340.524	340.952	340.747	342.73	342.761	343.397	343.746	343.488	343.188
Weekend												
Jan 13, 2018	345.905	345.548	344.381	343.145	343.407	344.375	346.107	344.937	346.216	345.54	345.22	346.343
Jan 14, 2018	-62.48	-62.48	-62.48	-62.488	-62.483	-62.48	-62.48	-62.479	-62.479	-62.48	-62.48	-62.48
Jan 20, 2018	342.992	342.259	342.607	340.974	340.766	342.729	342.885	346.484	344.162	342.792	344.86	344.712
Jan 21, 2018	-62.477	-62.479	-62.481	-62.48	-62.481	-62.478	-62.479	-62.48	-62.476	-62.48	-62.479	-62.48
Excluded												
Jan 11, 2018	345.07	343.465	342.276	343.887	344.11	343.776	347.291	347.341	349.506	349.346	349.406	350.719
Jan 23, 2018	338.636	337.064	335.257									

Copy Table

Day Types: Weekday | Weekend | Excluded | +Add New | Reset

January 2018

Day Type Average Interval: Hourly

Update Analysis

Select Columns for Total Aggregated Equipment Data:

Setup Profile | Profile Summary Table | Profile Summary Graphs

VSD
Selected Scenario

View / Add Scenarios

SELECT POTENTIAL ADJUSTMENT PROJECTS

Select potential adjustment projects to explore opportunities to increase efficiency and the effectiveness of your system.

Add New Scenario

Modification Name: VSD

Reduce Run Time | *Supply* — 1

Implementation Cost: 106700 $

Day Type: Weekday

	Capacity acfm	Shutdown Timer	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
200 hp QNW	933 acfm	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
250 hp QNW	1261 acfm	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
New Compressor	1141 acfm	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Available Airflow			933	933	933	933	933	2,074	2,074	2,074	2,074	2,074	2,074	2,074	2,074
Required Airflow			705	708	709	775	907	1,085	1,347	1,526	1,527	1,524	1,524	1,521	1,513
Power, kW			159.5	159.7	159.8	164.1	172.7	244.1	300.9	357.7	357.8	357.6	357.6	357.4	344.2

Reduce Air Leaks | *Demand* — 2

Implementation Cost: 5000 $

Leak Flow: 600 acfm

Leak Reduction: 50 %

Improve End Use Efficiency | *Demand* — Off

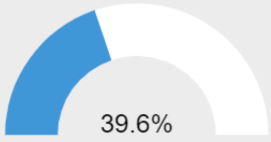
Reduce System Air Pressure | *Supply* — Off

Add Primary Receiver Volume | *Supply* — Off

MODIFICATION RESULTS | PERFORMANCE PROFILE | HELP | NOTES

All Day Types

	Baseline	VSD
Percent Savings (%)	— —	



	Baseline	VSD
Flow Reallocation Energy Savings	— —	391,627 kWh
Reduce Air Leaks Energy Savings	— —	585,745 kWh
Reduce Run Time Energy Savings	— —	-233,967 kWh
Peak Demand	**346.6 kW**	**273.86 kW**
Annual Energy	**2,620,045 kWh**	**1,876,639 kWh**
Annual Emission Output Rate	**1,050,821 tonne CO_2**	**752,664 tonne CO_2**
Peak Demand Savings	— —	**72.74 kW**
Annual Energy Savings	— —	**743,405 kWh**
Annual Emission Savings	— —	**298,158 tonne CO_2**
Flow Reallocation Savings	— —	$25,847.38
Reduce Air Leaks Savings	— —	$55,352.94
Reduce Run Time Savings	— —	-$22,109.88
Peak Demand Cost	**$0.00**	**$0.00**
Annual Energy Cost	**$247,594.21**	**$177,342.40**
Annual Cost	**$247,594.21**	**$177,342.40**
Peak Demand Cost Savings	— —	**$0.00**
Annual Energy Cost Savings	— —	**$70,251.80**
Annual Cost Savings	— —	**$70,251.80**

Next Week Session 4 – Air Treatment

- Compressed air must be dried. This is an undeniable statement of fact.
  - Today's modern industry can no longer tolerate the problems of wet, dirty compressed air.
  - Wet air causes rust, pitting, blockages, and freeze-ups, with resultant component failure and product rejection.
  - Wet air is a major contributor of downtime, causing millions of dollars of lost production.

Homework for Week 3 – Compressor Controls

- Explain each of the following control methods:
  - Start/Stop
  - Load/Unload
  - Modulating
  - Variable Displacement
  - Variable Speed
  - Sequencer
  - Master Compressor Controller?
  - Pressure Flow Control?

Questions?