Better Plants
U.S. DEPARTMENT OF ENERGY

In-Plant Trainings

Virtual Platform
Session 3 – Controls

Homework Questions from week 2

- What's the compression ratio of the single stage compressor listed below:
    - 13.5 psia inlet pressure
    - 113.5 psia discharge pressure

Homework Questions from week 2

- What's the compression ratio of the single stage compressor listed below:
    - 13.5 psia inlet pressure
    - 113.5 psia discharge pressure

Homework Questions from week 2

- What are some problems you are experiencing related to your compressed air system?
- Examples on next slide

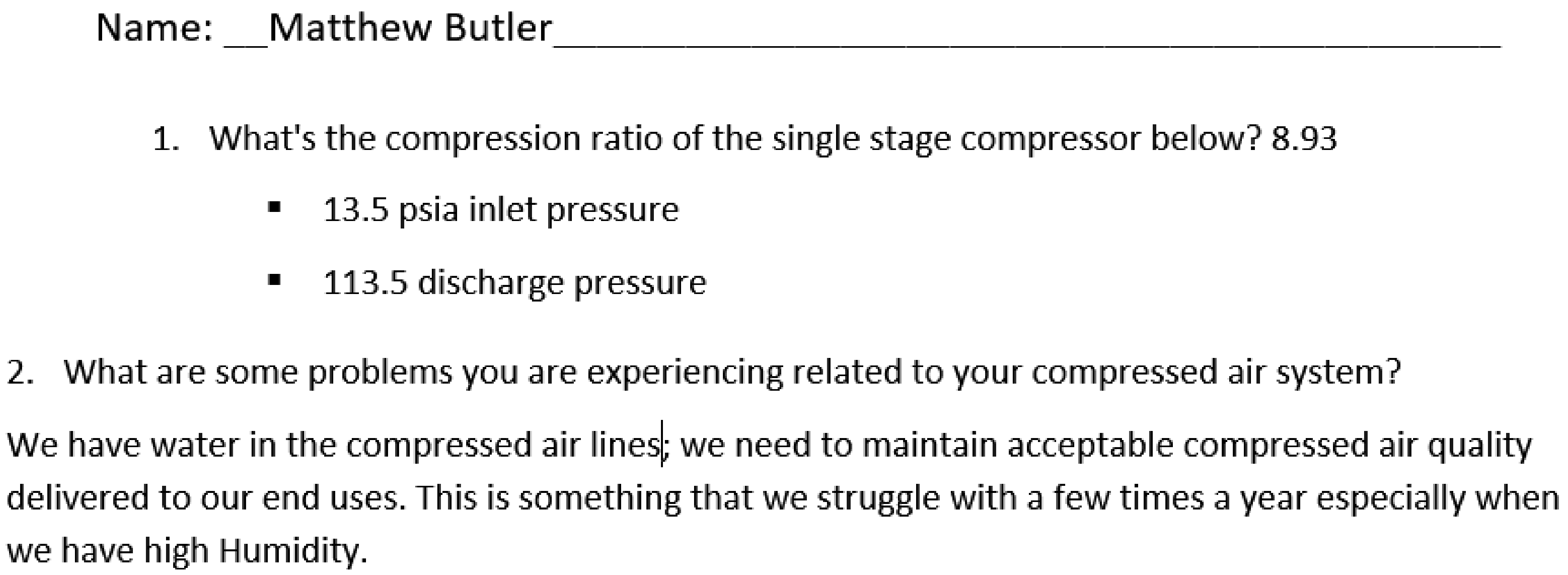
Homework Questions from week 2

- We need to improve the reliability of the compressed air system in supporting manufacturing operations.
- Production interruptions occur which are a result of poor compressed air system performance; we need to minimize production downtime.
- Product quality is being affected by poor compressed air system performance; we need to reduce our scrap rate.
- Our automated equipment which is operated by compressed air will not achieve its full capacity throughput: we need to know if this is a compressed air related issue.
- We are expanding our production facility and consequently need to expand our existing compressed air system to accommodate the new flows; we want to know if our existing compressors can handle it.
- We are replacing older air compressors and want to investigate new more efficient type compressors; we want to improve system efficiency and reduce energy costs.
- We have recently eliminated production equipment which used compressed air but the compressors are still using the same energy as before: we need to reduce the compressed air demand.
- Low pressure occurs on a system wide basis and occasionally impacts production.
- Low pressure occurs on a localized basis (point of use).
- Pressure fluctuations frequently occur; we need to maintain more stable air pressure.
- We have water in the compressed air lines; we need to maintain acceptable compressed air quality delivered to our end uses.
- Oil in the compressed air lines is contaminating our end product.

Homework Questions from week 2

- What's the compression ratio of the single stage compressor below?
  - 13.5 psia inlet pressure
  - 113.5 psia discharge pressure
- Is discharge pressure psig or psia?
- If it is psia, $\frac{113.5}{13.5} = 8.4$

Homework Questions



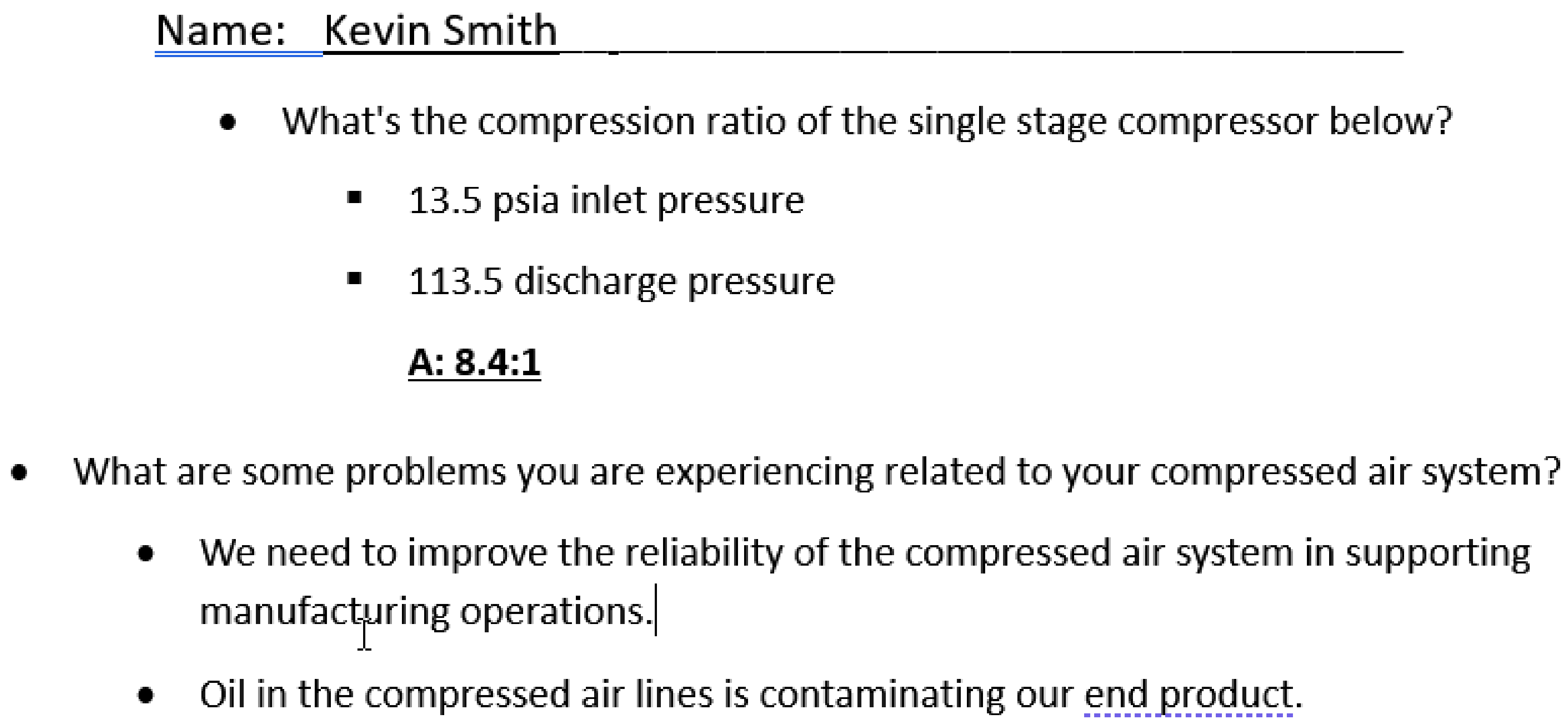
Name: __Matthew Butler____

1. What's the compression ratio of the single stage compressor below? 8.93
   - 13.5 psia inlet pressure
   - 113.5 discharge pressure

2. What are some problems you are experiencing related to your compressed air system?

We have water in the compressed air lines; we need to maintain acceptable compressed air quality delivered to our end uses. This is something that we struggle with a few times a year especially when we have high Humidity.

Homework Questions



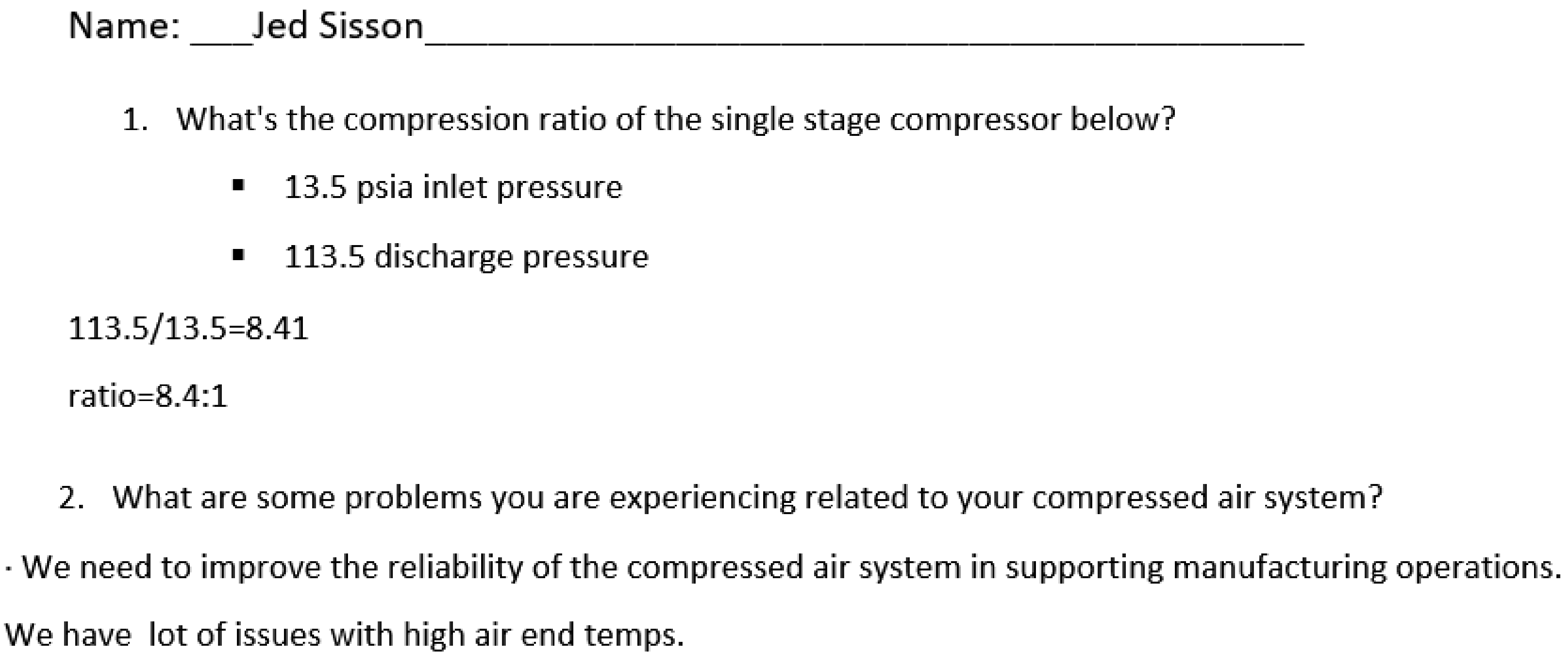
Name: Kevin Smith

- What's the compression ratio of the single stage compressor below?
  - 13.5 psia inlet pressure
  - 113.5 discharge pressure

  A: 8.4:1

- What are some problems you are experiencing related to your compressed air system?
  - We need to improve the reliability of the compressed air system in supporting manufacturing operations.
  - Oil in the compressed air lines is contaminating our end product.

Homework Questions



Name: ___Jed Sisson____

1. What's the compression ratio of the single stage compressor below?
   - 13.5 psia inlet pressure
   - 113.5 discharge pressure

113.5/13.5=8.41

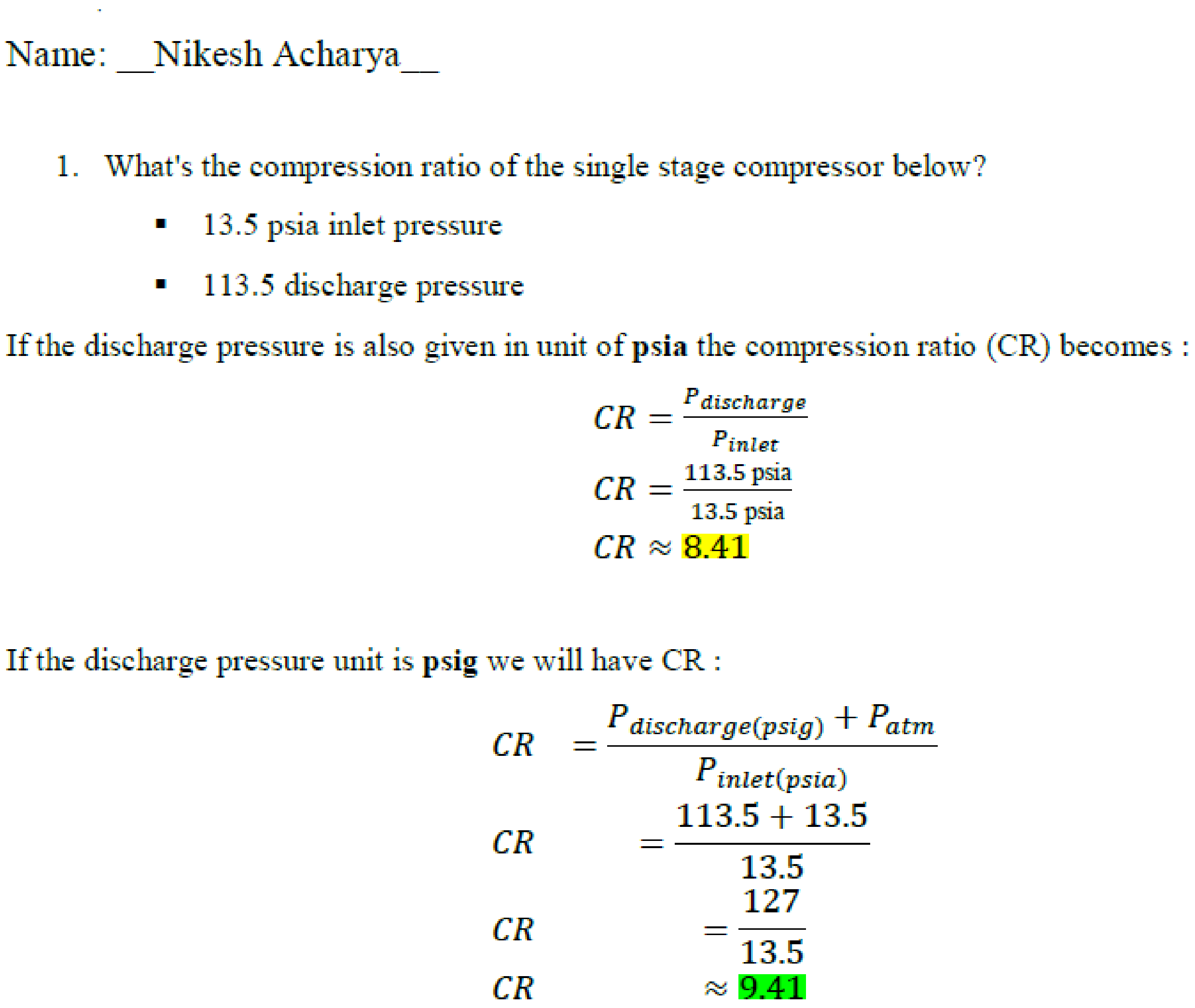
ratio=8.4:1

2. What are some problems you are experiencing related to your compressed air system?

· We need to improve the reliability of the compressed air system in supporting manufacturing operations.

We have lot of issues with high air end temps.

Homework Questions



Name: __Nikesh Acharya__

1. What's the compression ratio of the single stage compressor below?
   - 13.5 psia inlet pressure
   - 113.5 discharge pressure

If the discharge pressure is also given in unit of **psia** the compression ratio (CR) becomes :

$$CR = \frac{P_{discharge}}{P_{inlet}}$$

$$CR = \frac{113.5 \text{ psia}}{13.5 \text{ psia}}$$

$$CR \approx 8.41$$

If the discharge pressure unit is **psig** we will have CR :

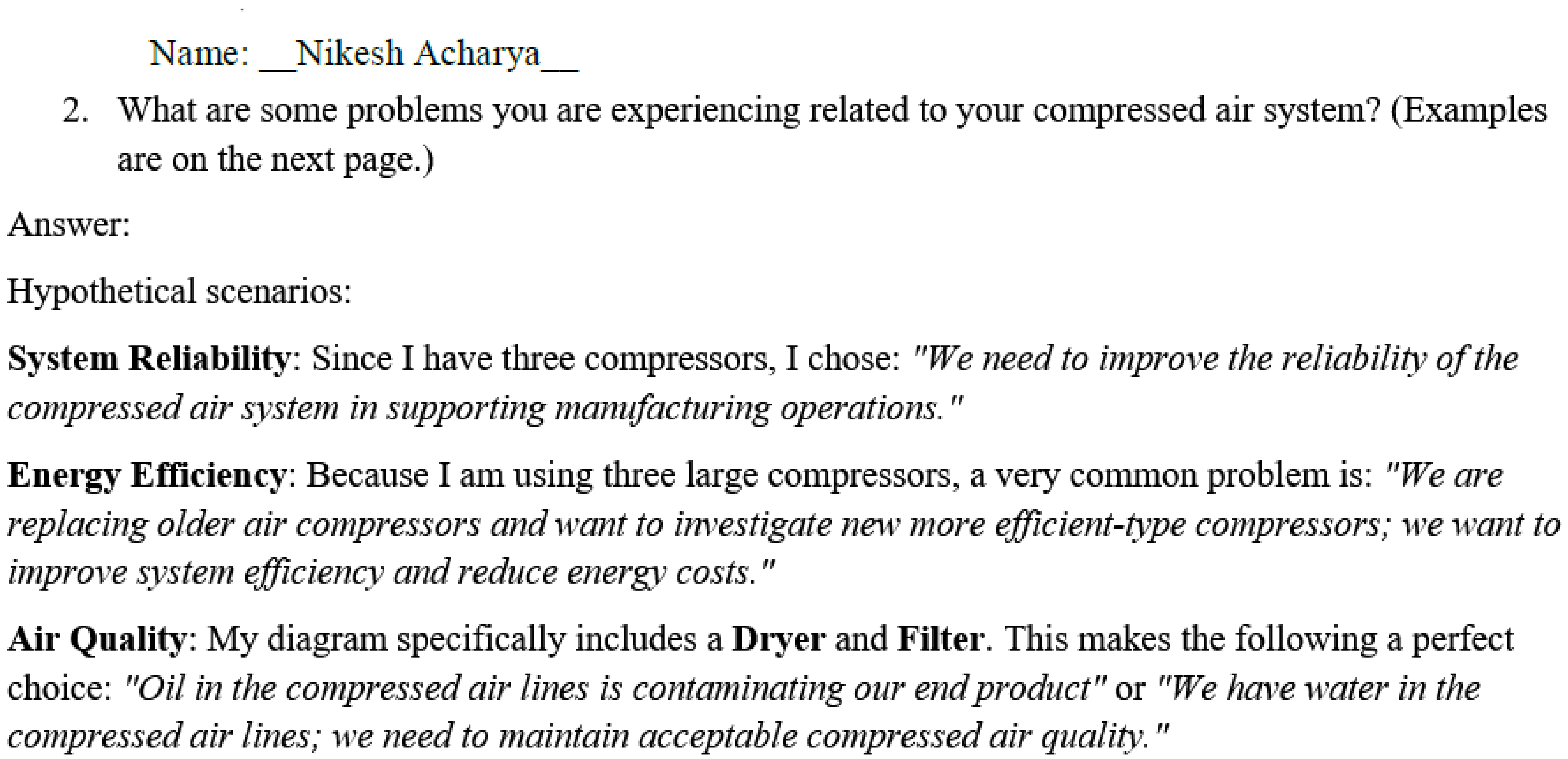
$$CR = \frac{P_{discharge(psig)} + P_{atm}}{P_{inlet(psia)}}$$

$$CR = \frac{113.5 + 13.5}{13.5}$$

$$CR = \frac{127}{13.5}$$

$$CR \approx 9.41$$

Homework Questions



Name: __Nikesh Acharya__

2. What are some problems you are experiencing related to your compressed air system? (Examples are on the next page.)

Answer:

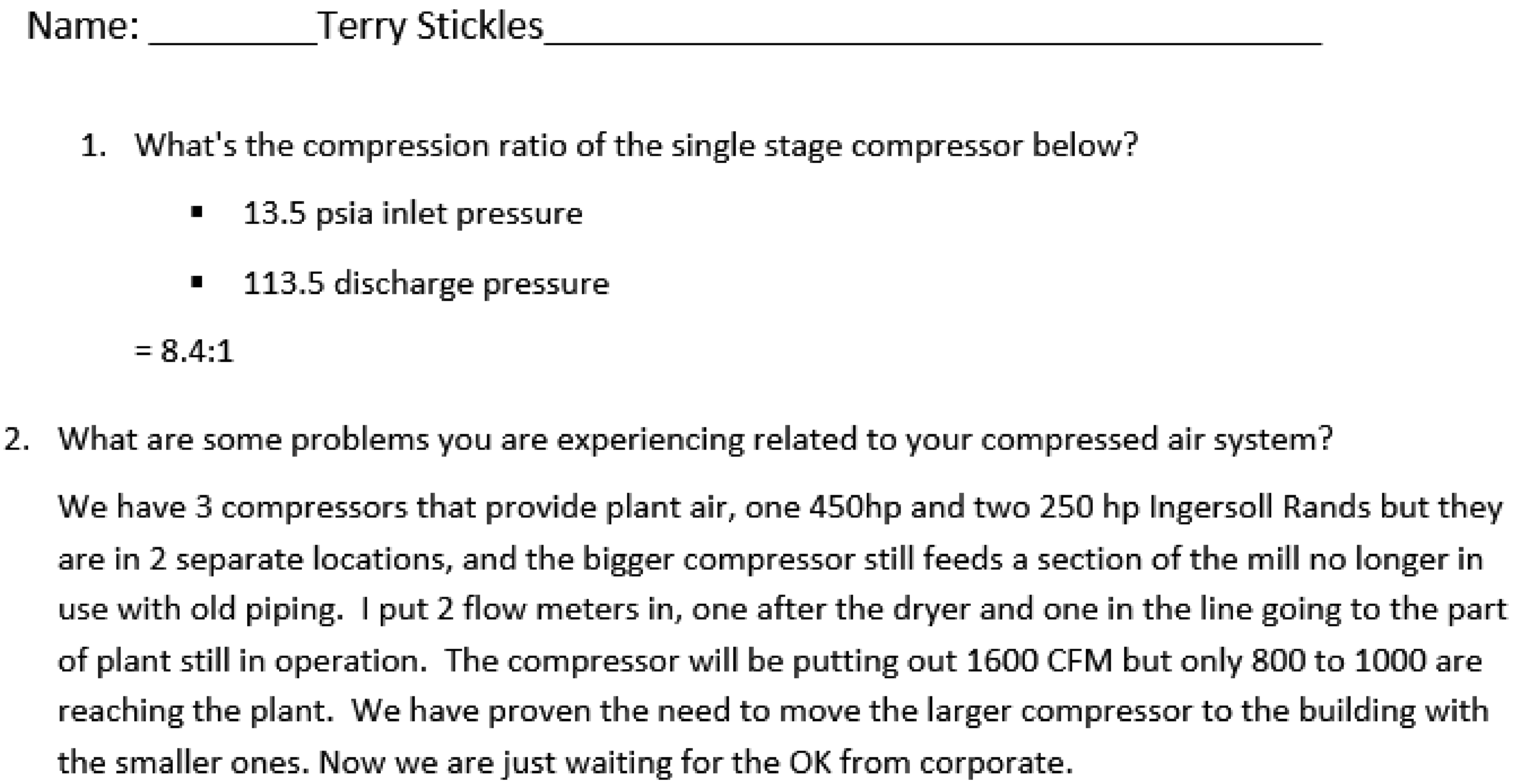
Hypothetical scenarios:

System Reliability: Since I have three compressors, I chose: *"We need to improve the reliability of the compressed air system in supporting manufacturing operations."*

Energy Efficiency: Because I am using three large compressors, a very common problem is: *"We are replacing older air compressors and want to investigate new more efficient-type compressors; we want to improve system efficiency and reduce energy costs."*

Air Quality: My diagram specifically includes a **Dryer** and **Filter**. This makes the following a perfect choice: *"Oil in the compressed air lines is contaminating our end product"* or *"We have water in the compressed air lines; we need to maintain acceptable compressed air quality."*

Homework Questions



Name: _________Terry Stickles____

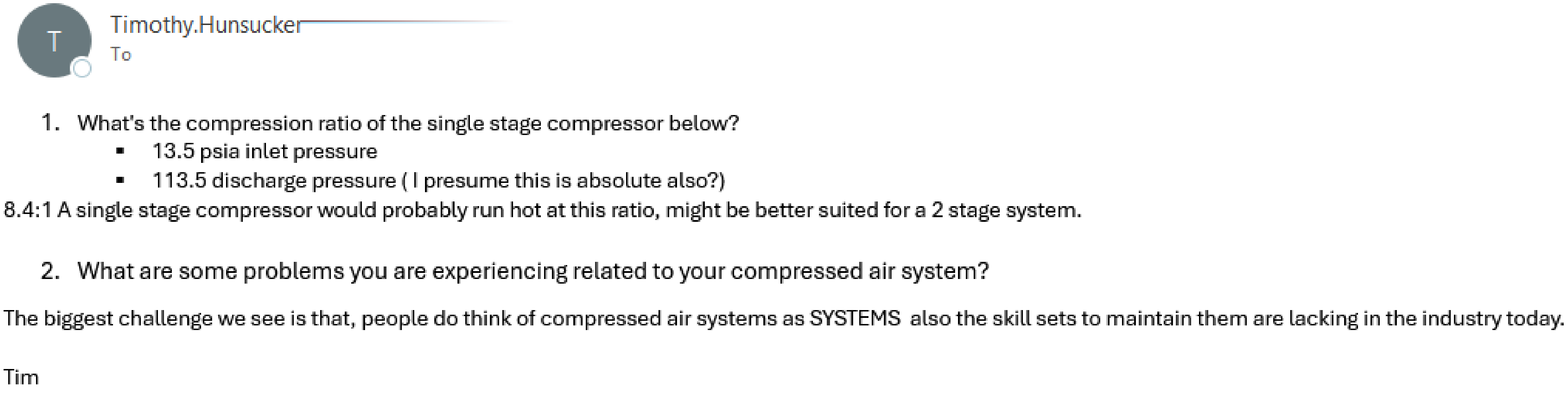
1. What's the compression ratio of the single stage compressor below?
   - 13.5 psia inlet pressure
   - 113.5 discharge pressure

   = 8.4:1

2. What are some problems you are experiencing related to your compressed air system?

   We have 3 compressors that provide plant air, one 450hp and two 250 hp Ingersoll Rands but they are in 2 separate locations, and the bigger compressor still feeds a section of the mill no longer in use with old piping. I put 2 flow meters in, one after the dryer and one in the line going to the part of plant still in operation. The compressor will be putting out 1600 CFM but only 800 to 1000 are reaching the plant. We have proven the need to move the larger compressor to the building with the smaller ones. Now we are just waiting for the OK from corporate.

Homework Questions



Timothy.Hunsucker

To

1. What's the compression ratio of the single stage compressor below?
   - 13.5 psia inlet pressure
   - 113.5 discharge pressure (I presume this is absolute also?)

8.4:1 A single stage compressor would probably run hot at this ratio, might be better suited for a 2 stage system.

2. What are some problems you are experiencing related to your compressed air system?

The biggest challenge we see is that, people do think of compressed air systems as SYSTEMS also the skill sets to maintain them are lacking in the industry today.

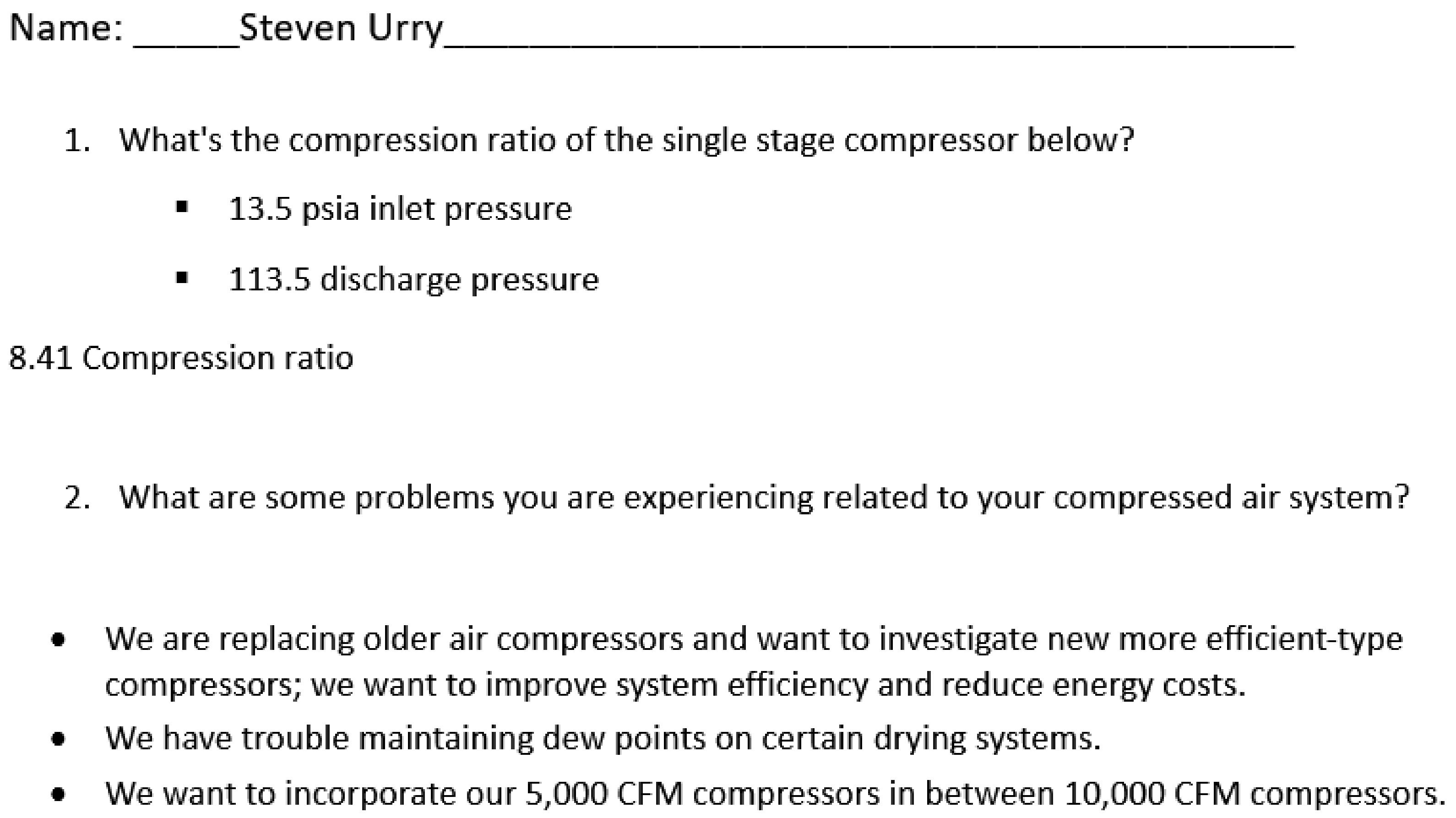
Tim

Homework Questions

Name: ____**Rowan Bender**______________________________

- What's the compression ratio of the single stage compressor below?
  - 13.5 psia inlet pressure
  - 113.5 discharge pressure
  - $\frac{113.5\ psia}{13.5\ psia} = \mathbf{8.4}$
- What are some problems you are experiencing related to your compressed air system? (Examples are on the next page.)
  - **Large pressure drop across the system.**
    - i. Large pressure drop between our wet and dry headers (6psig)
    - ii. Large pressure drop from dry header to farthest end use point (13.5 psig)
  - **Inability to meet high demand scenarios**
    - i. Current practice is wet receivers with no dry receivers. When a high demand event occurs air is pulling pulled through the filters/mist eliminators/dryer and not at a fast enough rate to maintain a stable air pressure for production.
  - Looking **to improve system efficiency** by replacing fixed speed compressors with VFD compressors.

Homework Questions



Name: ______Steven Urry____

1. What's the compression ratio of the single stage compressor below?
   - 13.5 psia inlet pressure
   - 113.5 discharge pressure

8.41 Compression ratio

2. What are some problems you are experiencing related to your compressed air system?

- We are replacing older air compressors and want to investigate new more efficient-type compressors; we want to improve system efficiency and reduce energy costs.
- We have trouble maintaining dew points on certain drying systems.
- We want to incorporate our 5,000 CFM compressors in between 10,000 CFM compressors.

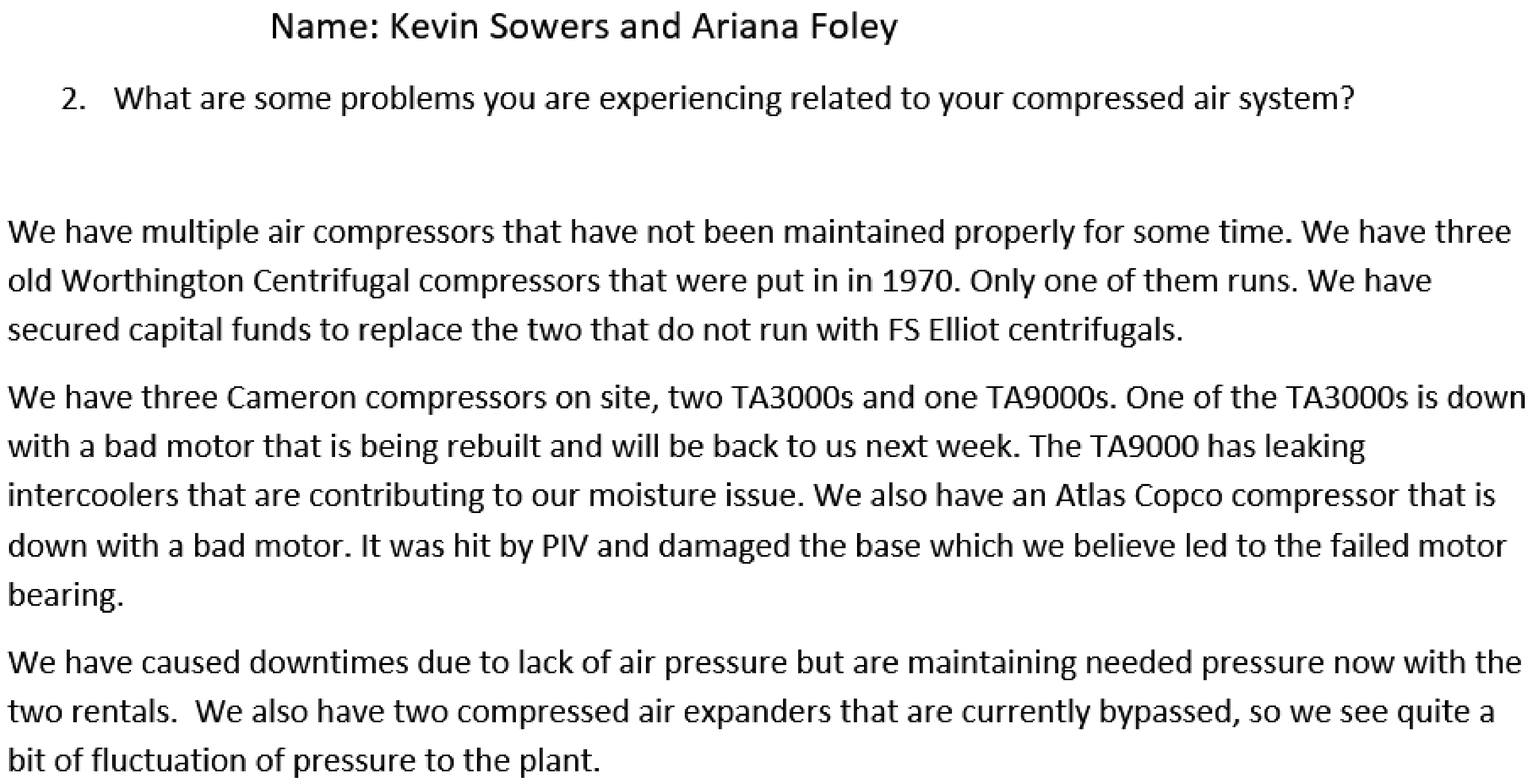
Homework Questions

Name: Kevin Sowers and Ariana Foley

1. What's the compression ratio of the single stage compressor below?
    - 13.5 psia inlet pressure
    - 113.5 discharge pressure

113.5/13.5 = 8.4 to 1

Homework Questions



Name: Kevin Sowers and Ariana Foley

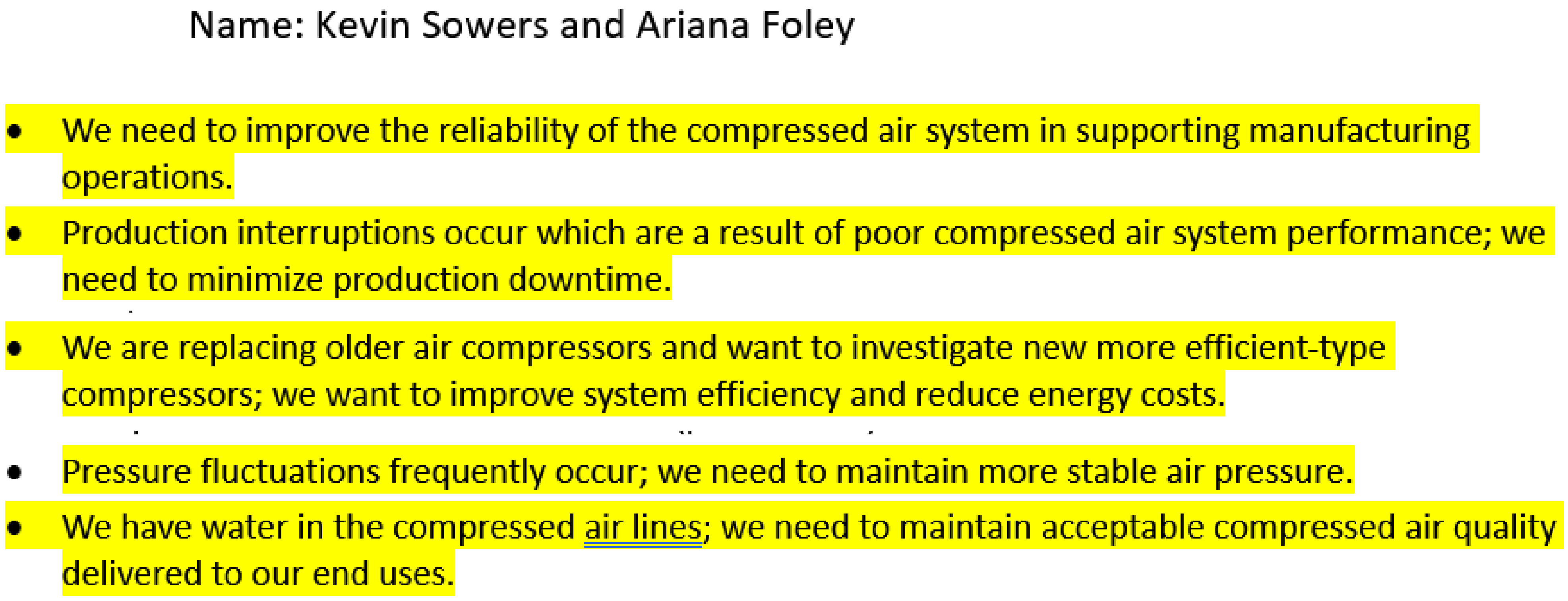
2. What are some problems you are experiencing related to your compressed air system?

We have multiple air compressors that have not been maintained properly for some time. We have three old Worthington Centrifugal compressors that were put in in 1970. Only one of them runs. We have secured capital funds to replace the two that do not run with FS Elliot centrifugals.

We have three Cameron compressors on site, two TA3000s and one TA9000s. One of the TA3000s is down with a bad motor that is being rebuilt and will be back to us next week. The TA9000 has leaking intercoolers that are contributing to our moisture issue. We also have an Atlas Copco compressor that is down with a bad motor. It was hit by PIV and damaged the base which we believe led to the failed motor bearing.

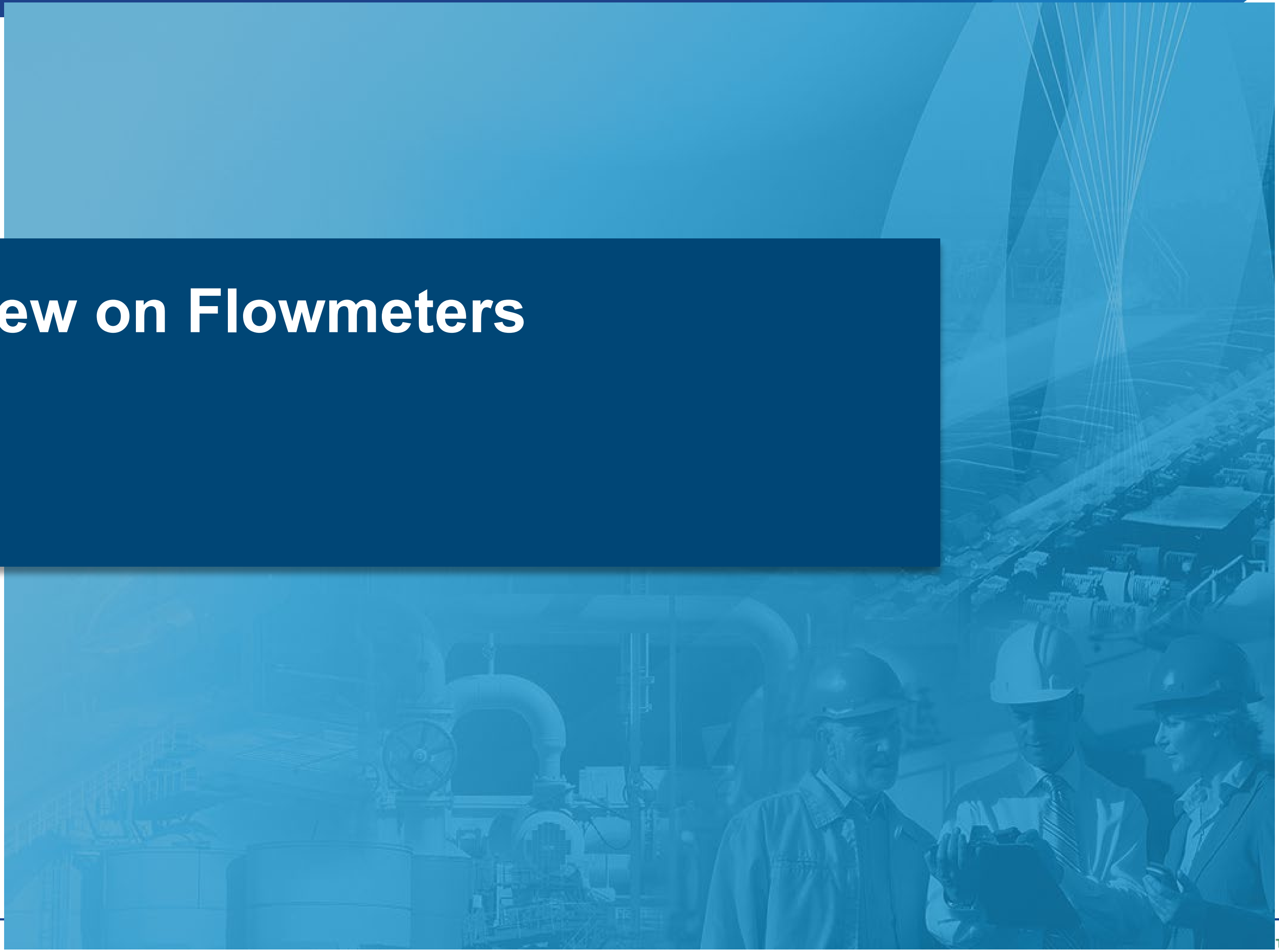
We have caused downtimes due to lack of air pressure but are maintaining needed pressure now with the two rentals. We also have two compressed air expanders that are currently bypassed, so we see quite a bit of fluctuation of pressure to the plant.

Homework Questions



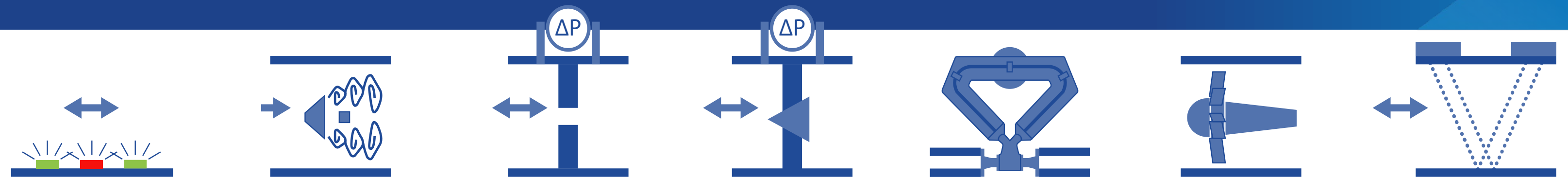
Name: Kevin Sowers and Ariana Foley

- We need to improve the reliability of the compressed air system in supporting manufacturing operations.
- Production interruptions occur which are a result of poor compressed air system performance; we need to minimize production downtime.
- We are replacing older air compressors and want to investigate new more efficient-type compressors; we want to improve system efficiency and reduce energy costs.
- Pressure fluctuations frequently occur; we need to maintain more stable air pressure.
- We have water in the compressed air lines; we need to maintain acceptable compressed air quality delivered to our end uses.



Quick Review on Flowmeters

Types of Meters - Comparisons



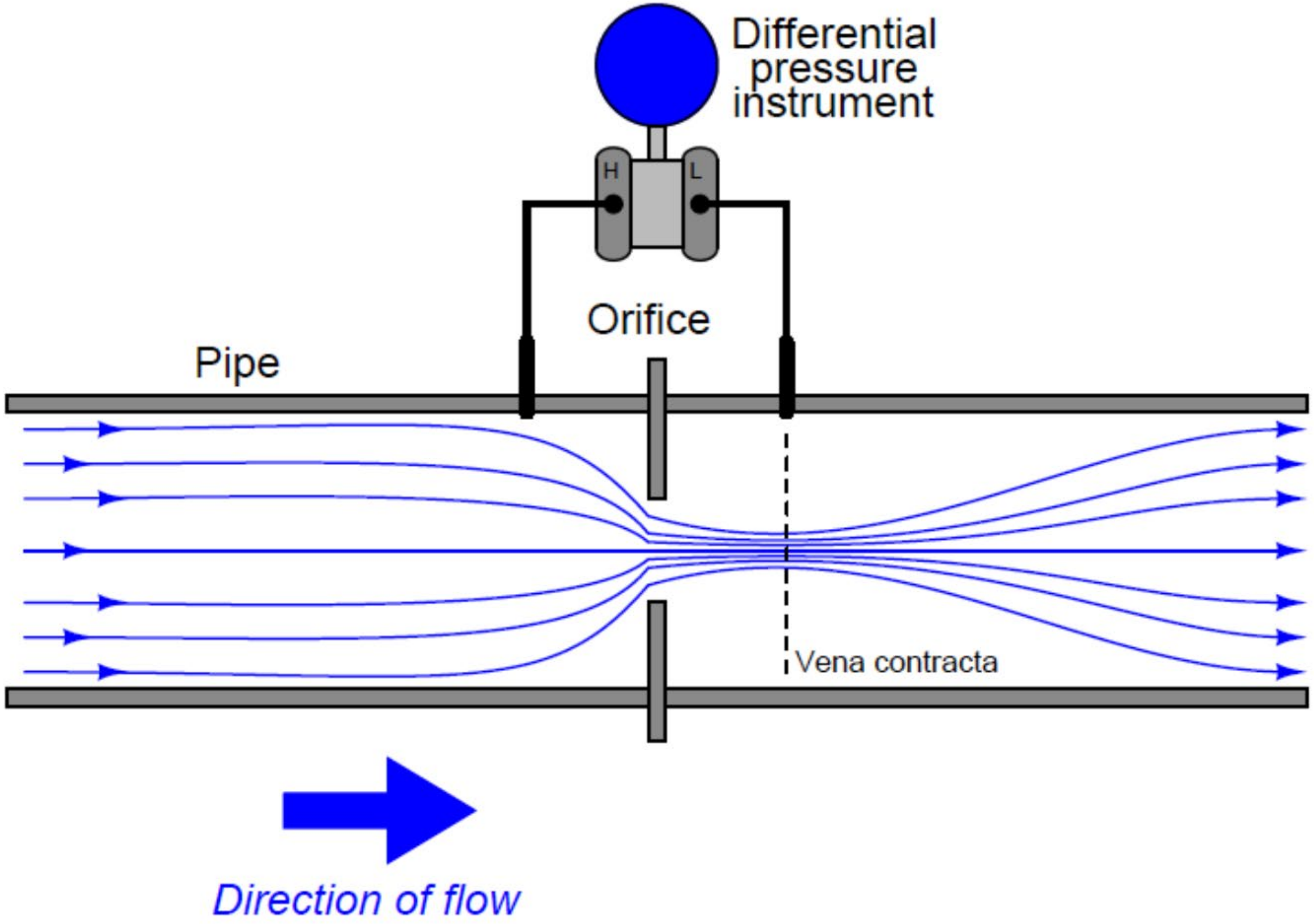
	Thermal	Vortex	DP – Orifice plate	DP – Insertion	Coriolis	Turbine/ rotary displacement	Clamp on ultrasonic
Mass flow	Yes	Optional	Optional	Optional	Yes	Optional	Optional
Meter run	20D	15D	15D	20D	0D	10D	20D
Pressure loss	Low	Medium/high	high	Low	Low	Low	Low
Dirty air	Fouling	OK	Clogging	Fouling/Clog	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.

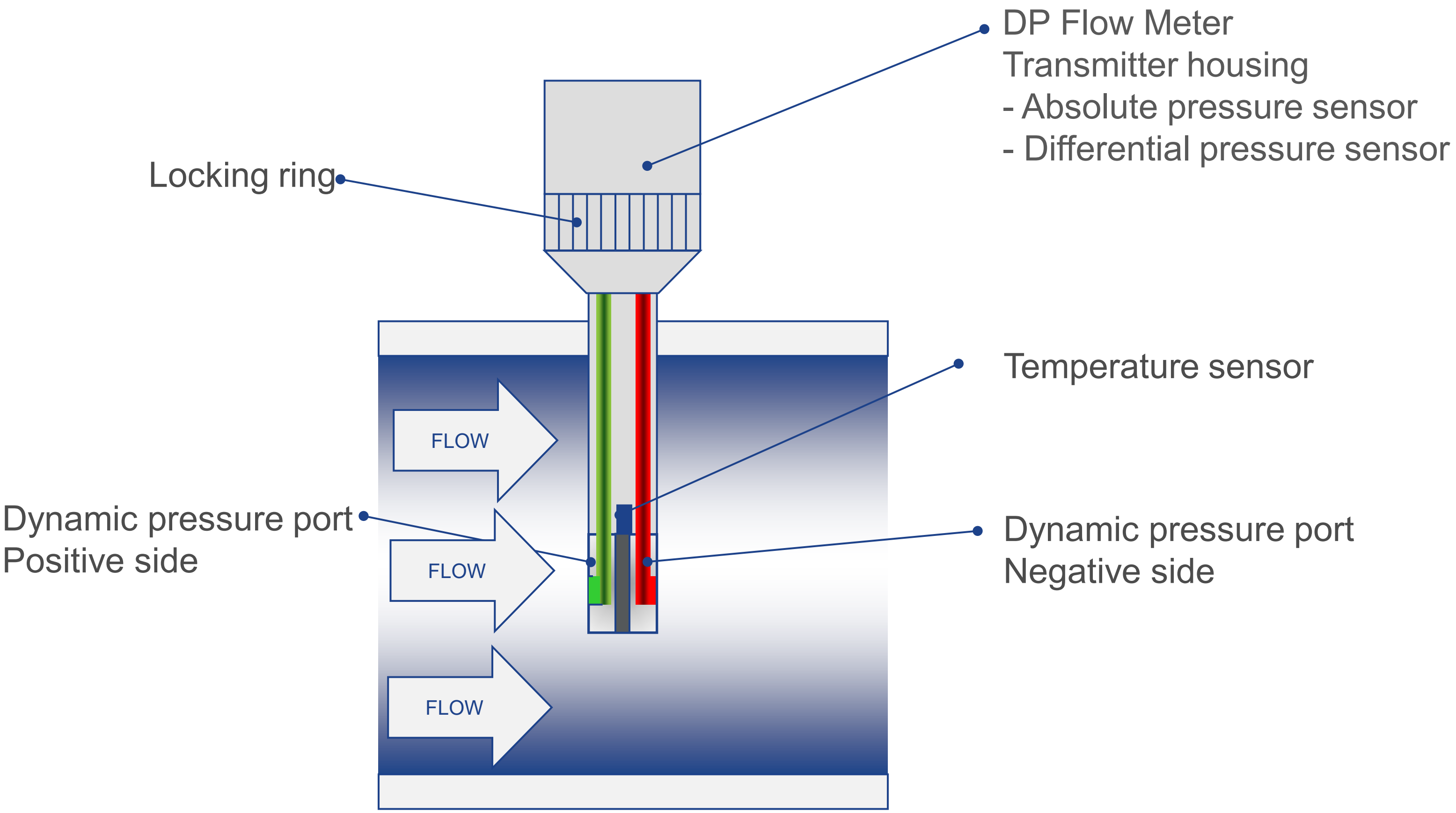
They operate on the physics of a pressure drop being created as a medium flows through an orifice.

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


Differential pressure instrument
H
L
Orifice
Pipe
Vena contracta
Direction of flow

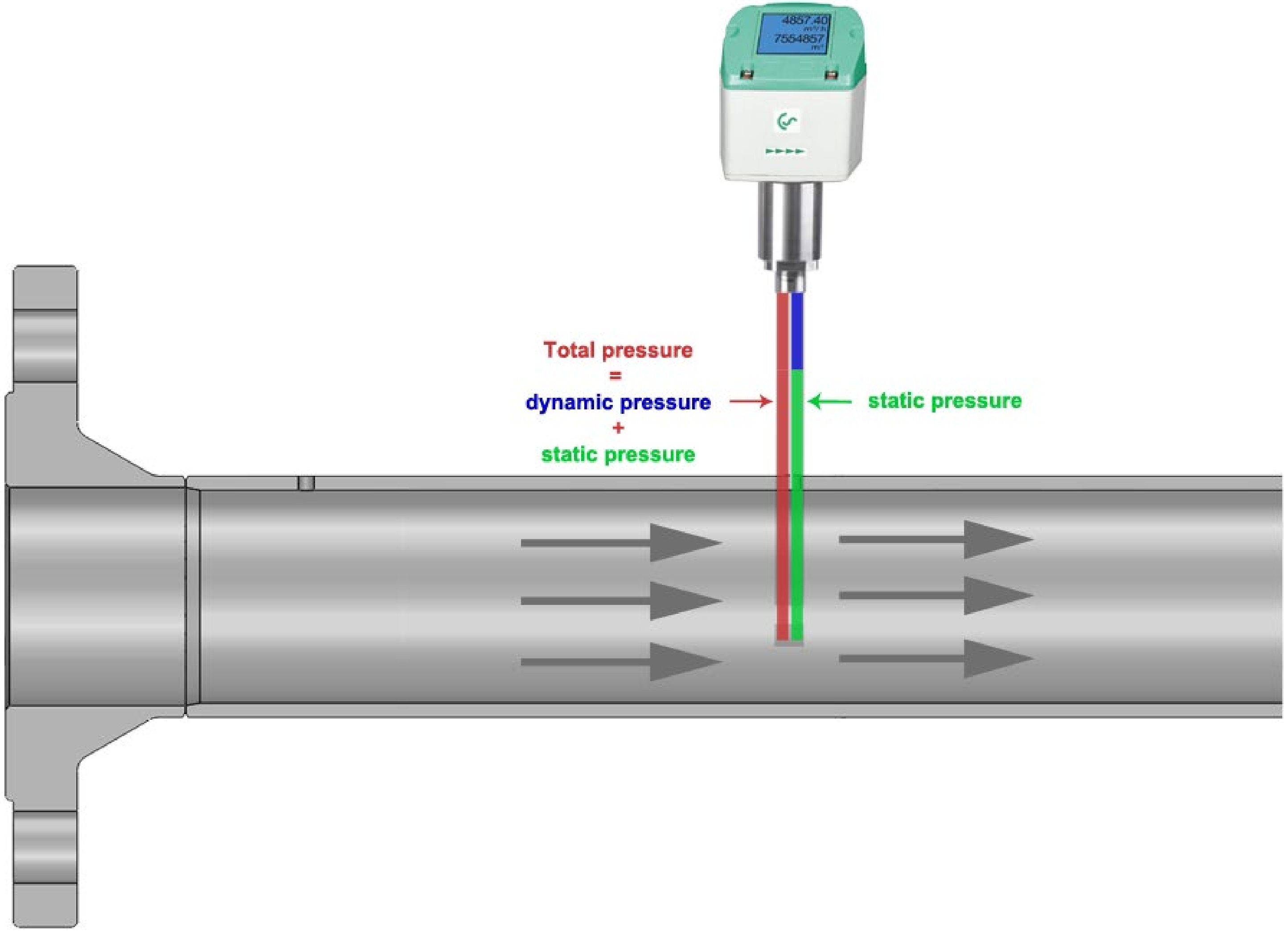
Differential Pressure Technology

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


DP Flow Meter
Transmitter housing
- Absolute pressure sensor
- Differential pressure sensor
Locking ring
Temperature sensor
FLOW
FLOW
FLOW
Dynamic pressure port
Positive side
Dynamic pressure port
Negative side

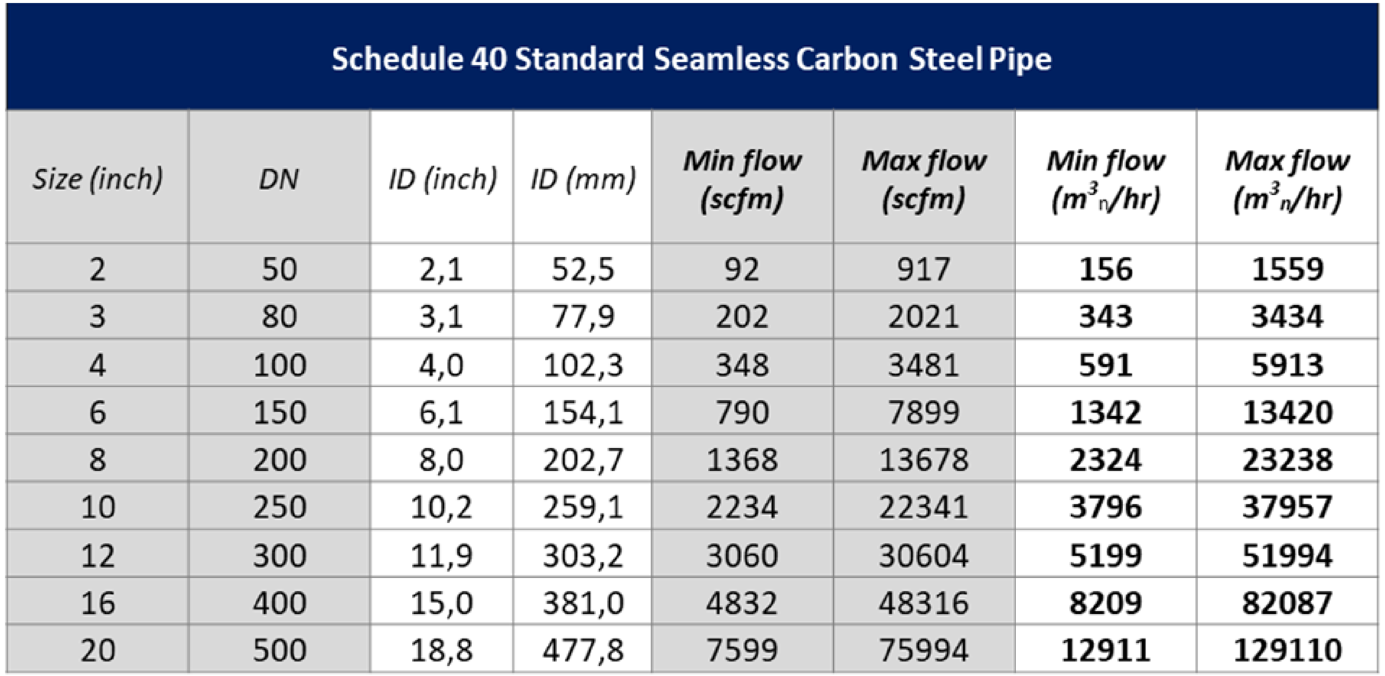
Differential Pressure Technology

- 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
- Installation via 1/2″ ball valve under pressure.


4857.40
7554857
Total pressure
=
dynamic pressure
+
static pressure
static pressure

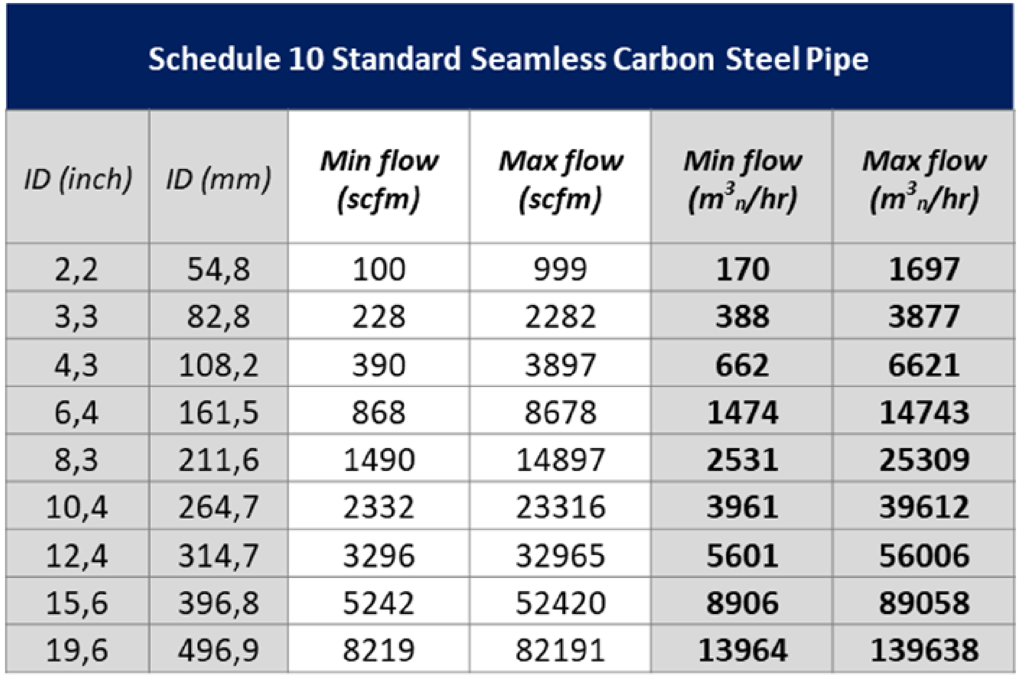
Min and Max Flow per Pipe Size

- 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

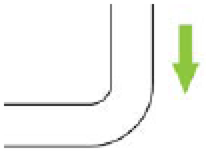
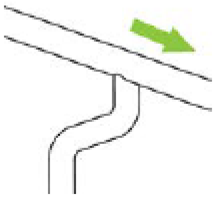
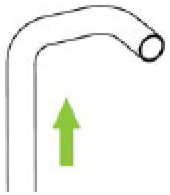
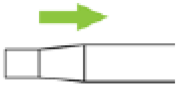
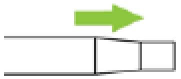
Size (inch)	*DN*	*ID (inch)*	*ID (mm)*	***Min flow (scfm)***	***Max flow (scfm)***	***Min flow (m^3_n/hr)***	***Max flow (m^3_n/hr)***
2	50	2,1	52,5	92	917	**156**	**1559**
3	80	3,1	77,9	202	2021	**343**	**3434**
4	100	4,0	102,3	348	3481	**591**	**5913**
6	150	6,1	154,1	790	7899	**1342**	**13420**
8	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

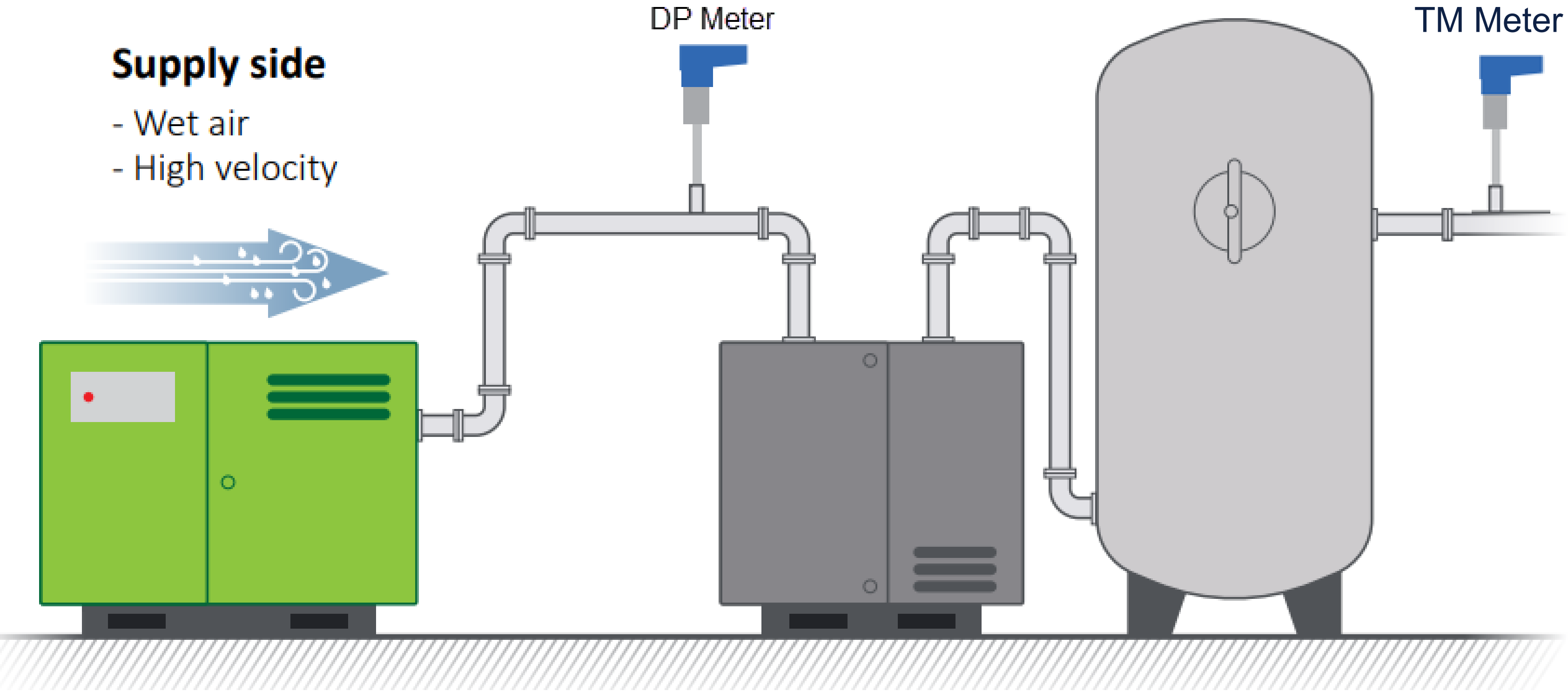
ID (inch)	*ID (mm)*	***Min flow (scfm)***	***Max flow (scfm)***	***Min flow (m^3_n/hr)***	***Max flow (m^3_n/hr)***
2,2	54,8	100	999	**170**	**1697**
3,3	82,8	228	2282	**388**	**3877**
4,3	108,2	390	3897	**662**	**6621**
6,4	161,5	868	8678	**1474**	**14743**
8,3	211,6	1490	14897	**2531**	**25309**
10,4	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.


Supply side
- Wet air
- High velocity
DP Meter
TM Meter

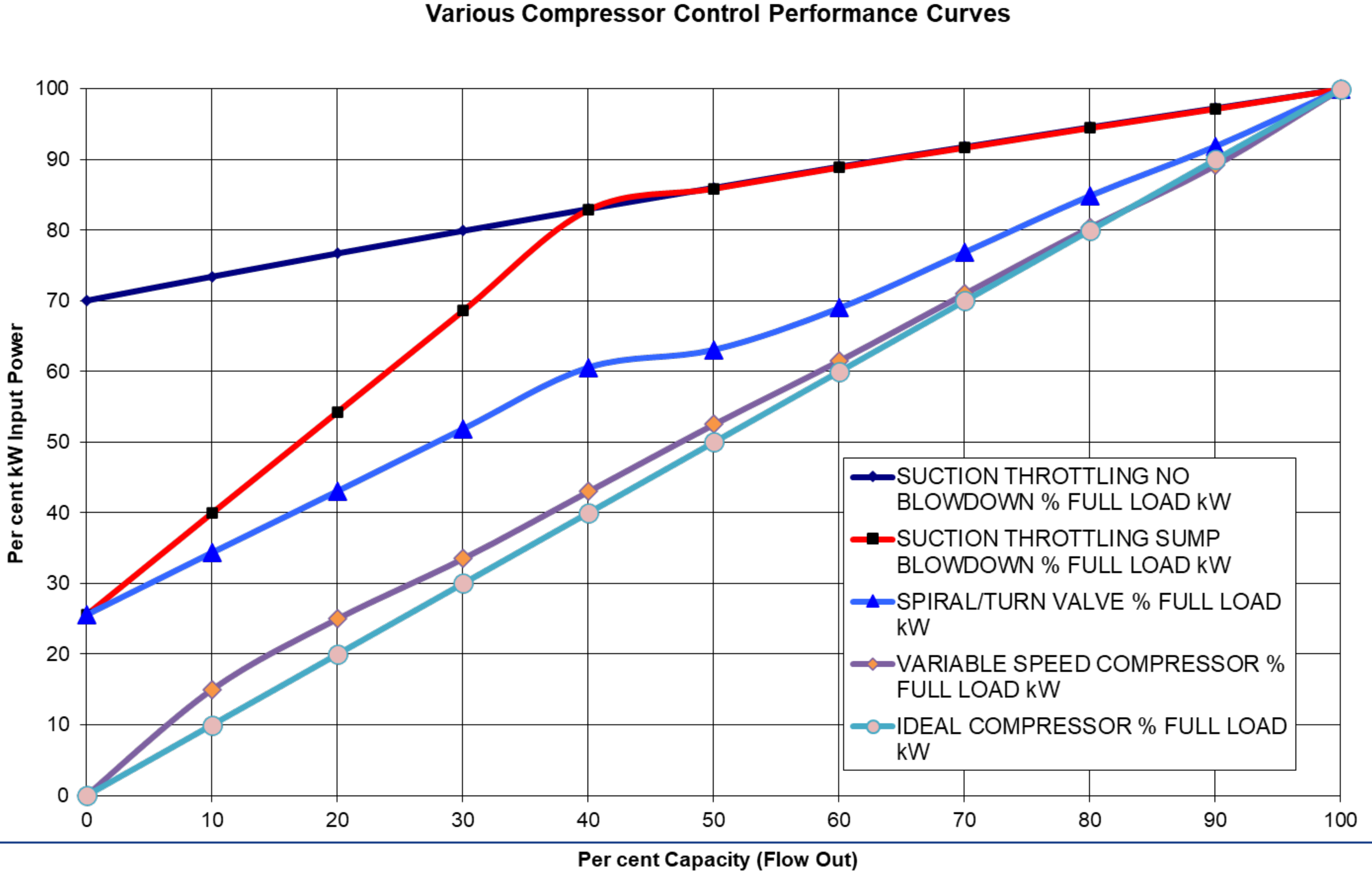
Session 3

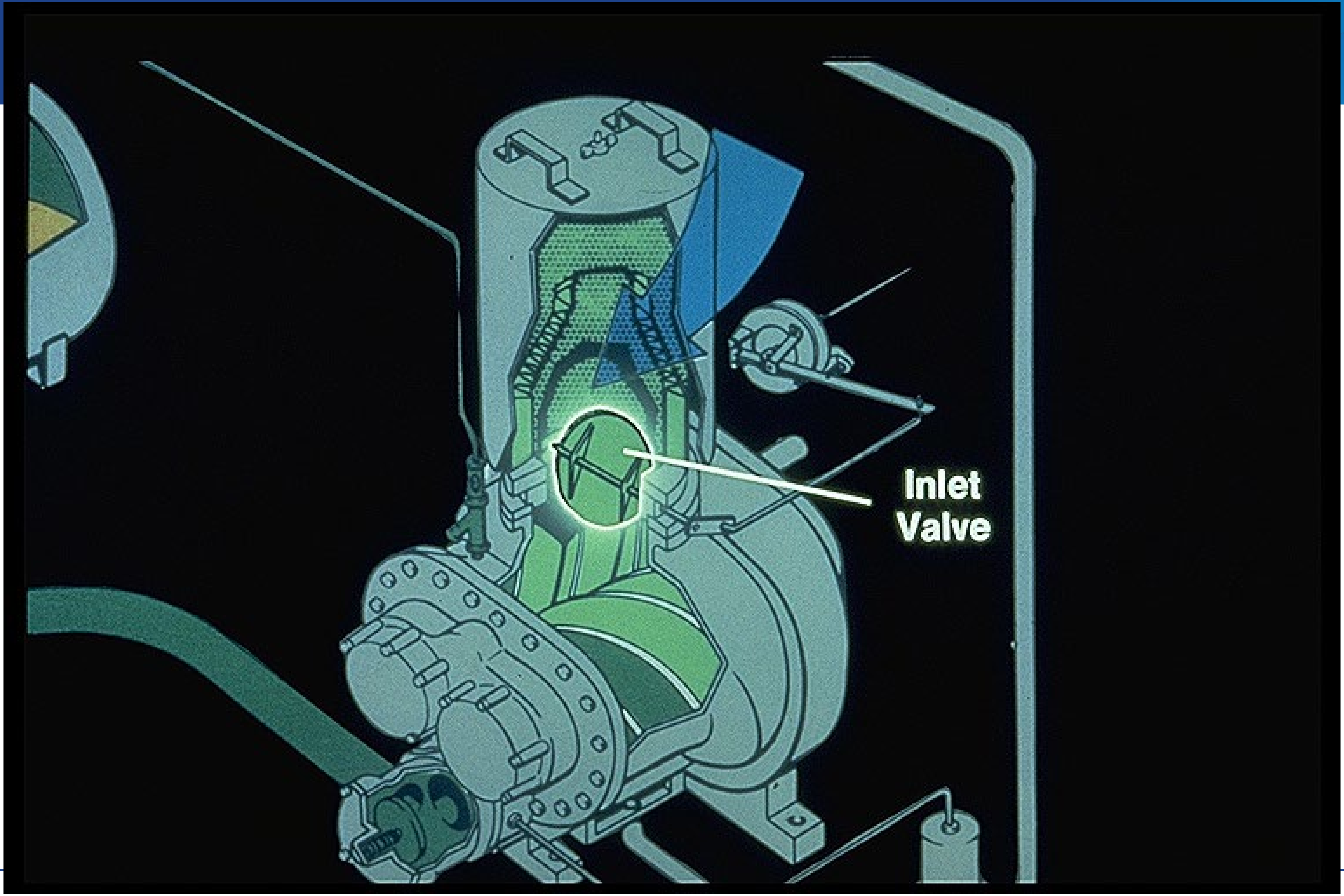
Compressor Controls

Compressor Control Types

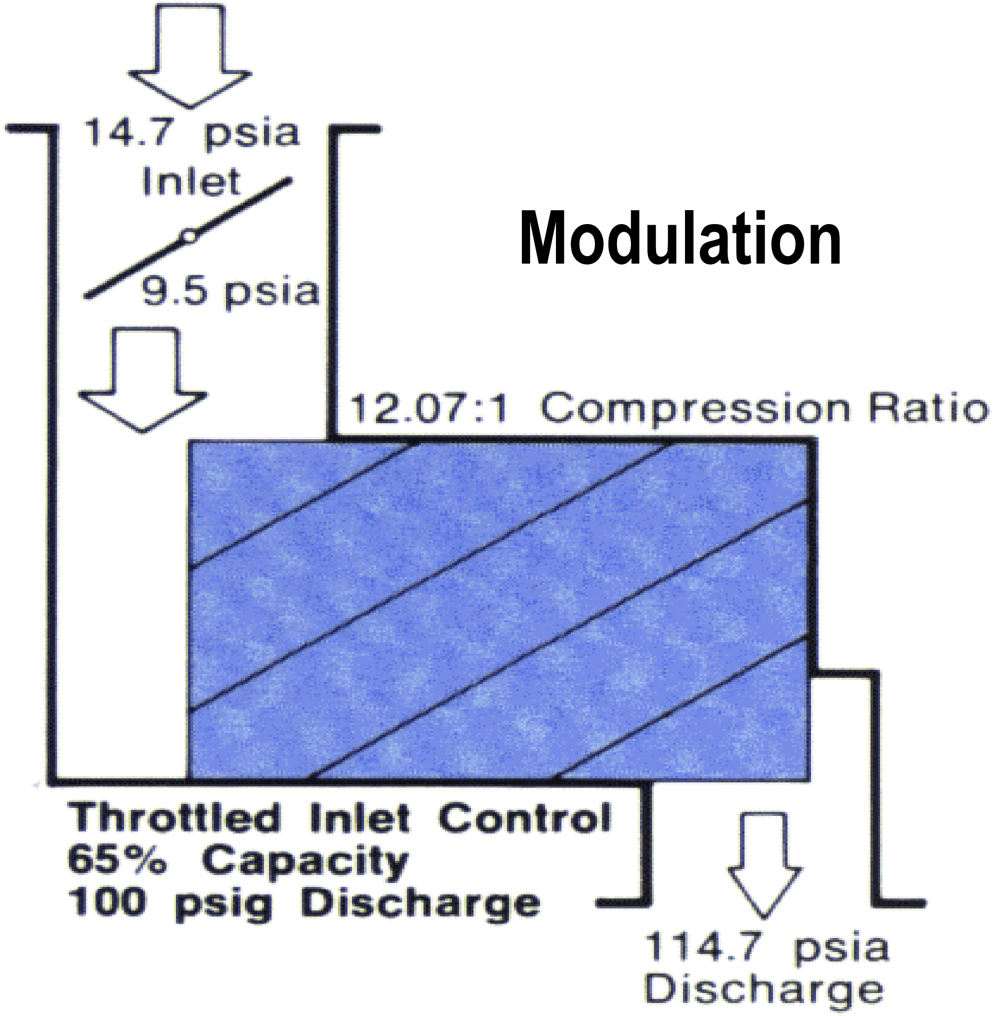
- Start/Stop
- Load/Unload
- Modulating
- Variable Displacement
- Variable Speed

Performance Curves

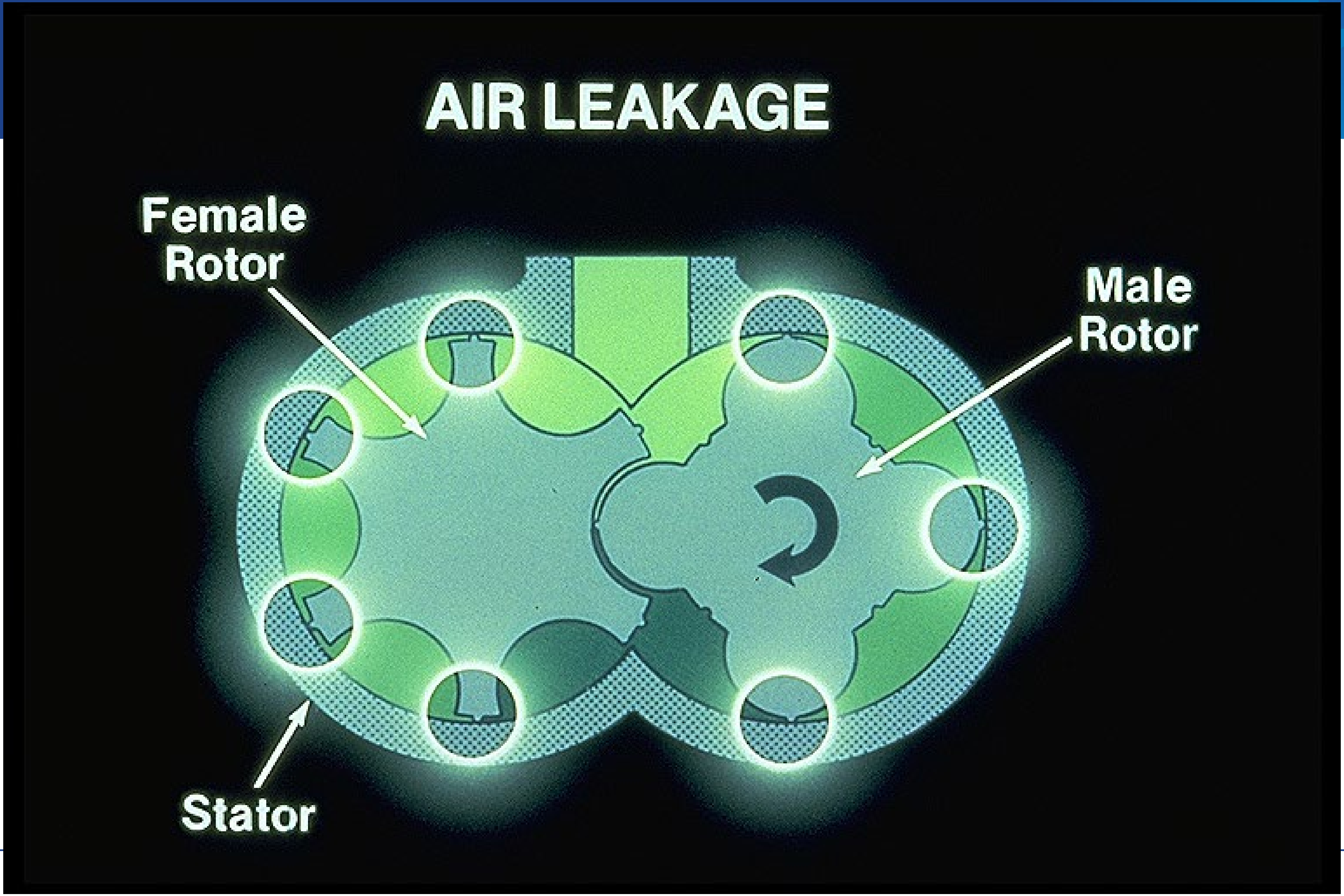



Inlet Valve

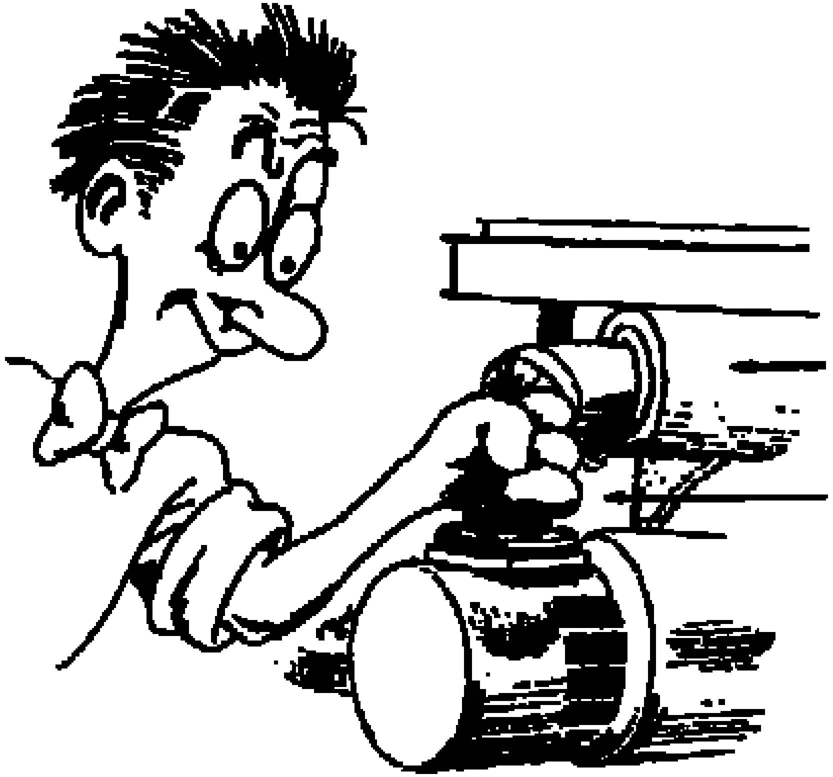
Inlet Throttling


14.7 psia
Inlet
9.5 psia
12.07:1 Compression Ratio
Throttled Inlet Control
65% Capacity
100 psig Discharge
114.7 psia
Discharge

Modulation

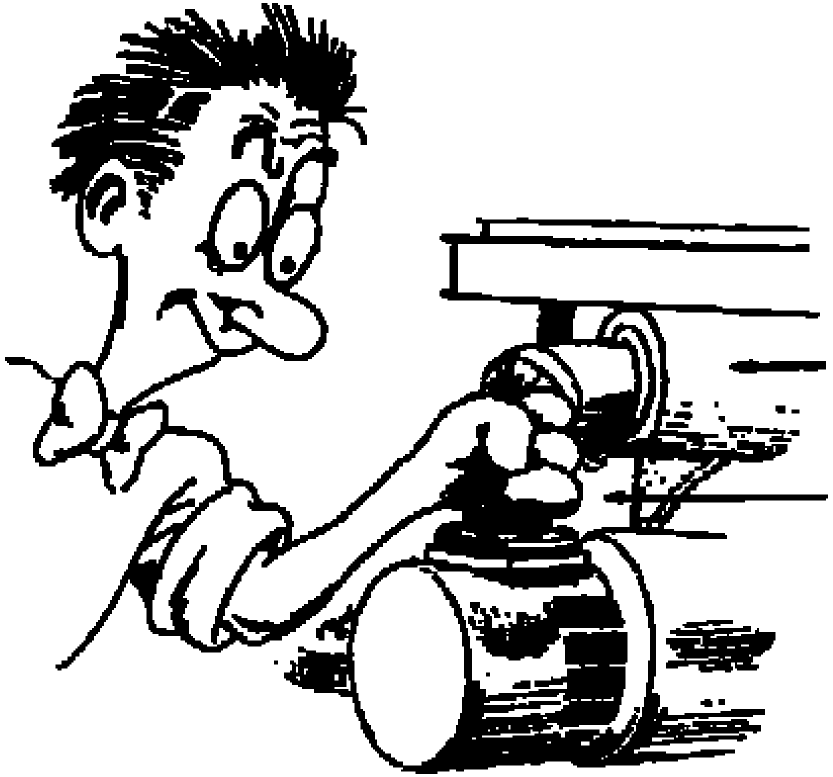

AIR LEAKAGE
Female Rotor
Male Rotor
Stator

Capacity Control by Inlet Throttling



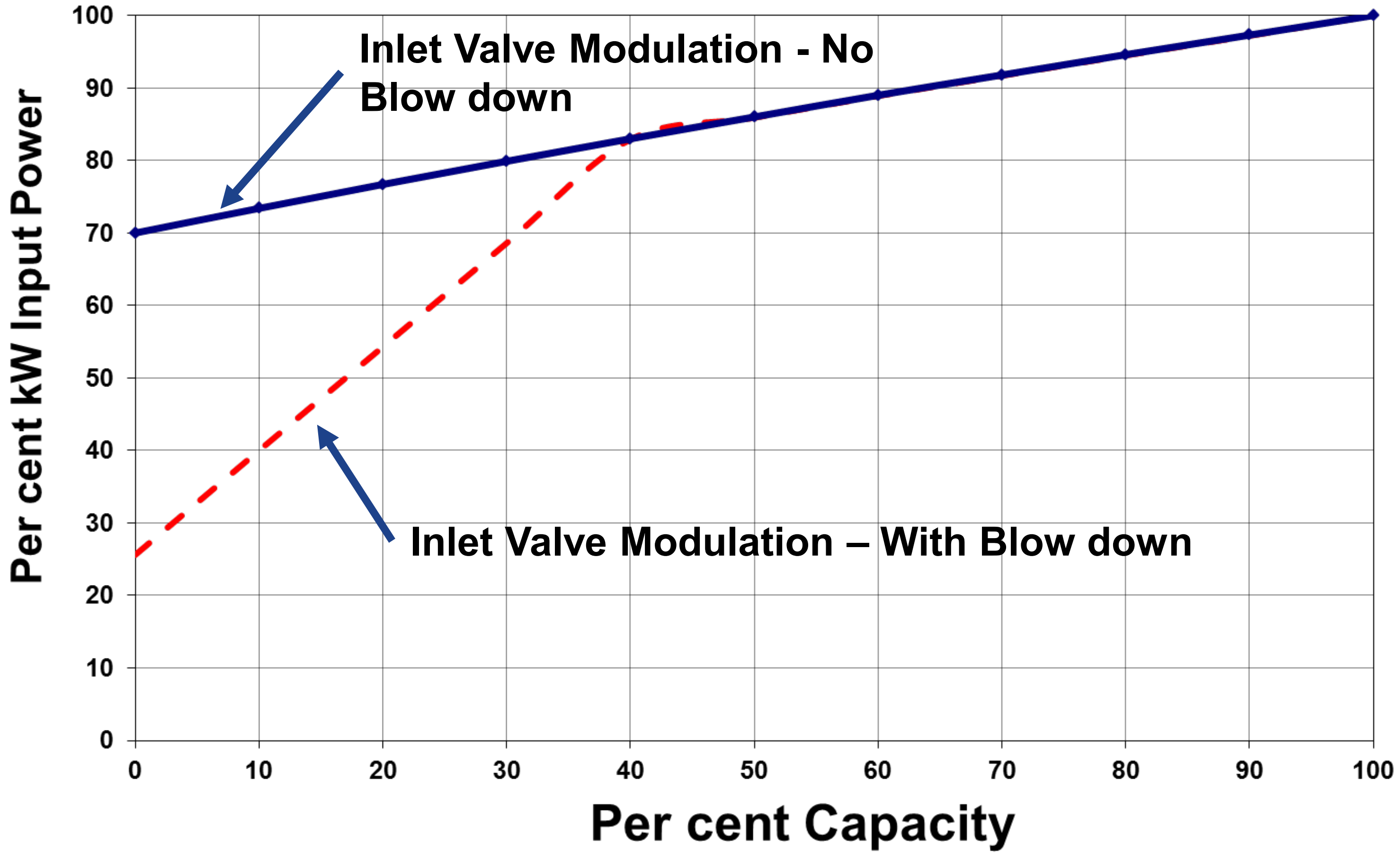
- Atmospheric pressure 14.7 psia
- Intake pressure 9.0 psia
- Discharge pressure 114.7
- Compression ratio: 114.7/9.0 = 12.7 to 1
- End Result?? Increased internal leakage due to a higher compression ratio

Capacity Control by Inlet Throttling



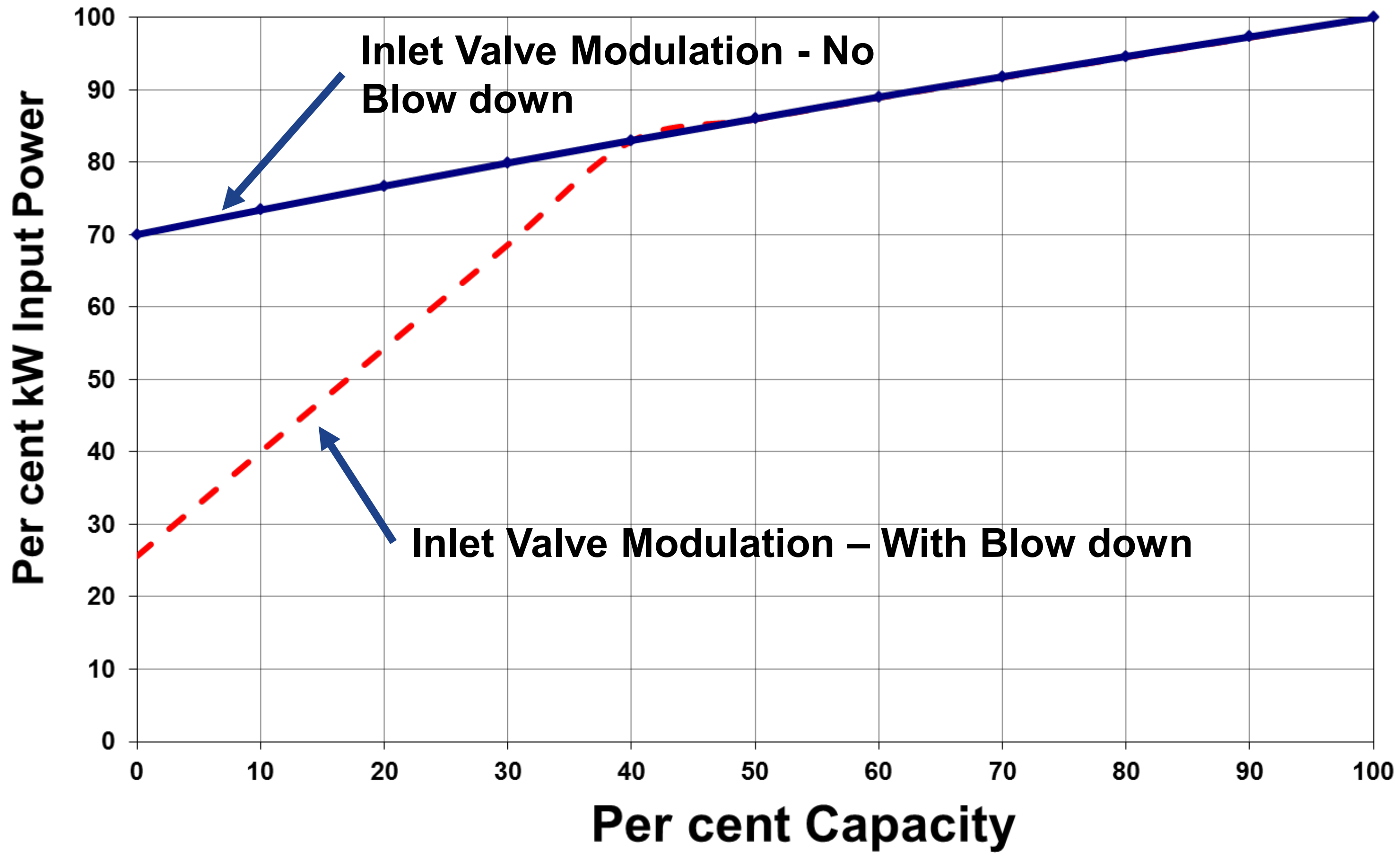
- Varies capacity by throttling (restricting) the inlet flow
- Provides a relatively stable output pressure
- Energy hog… least efficient
- Every 10% reduction in capacity yields only a 3% reduction in power(BHP)
- At zero capacity, power remains at 70% of full load power

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

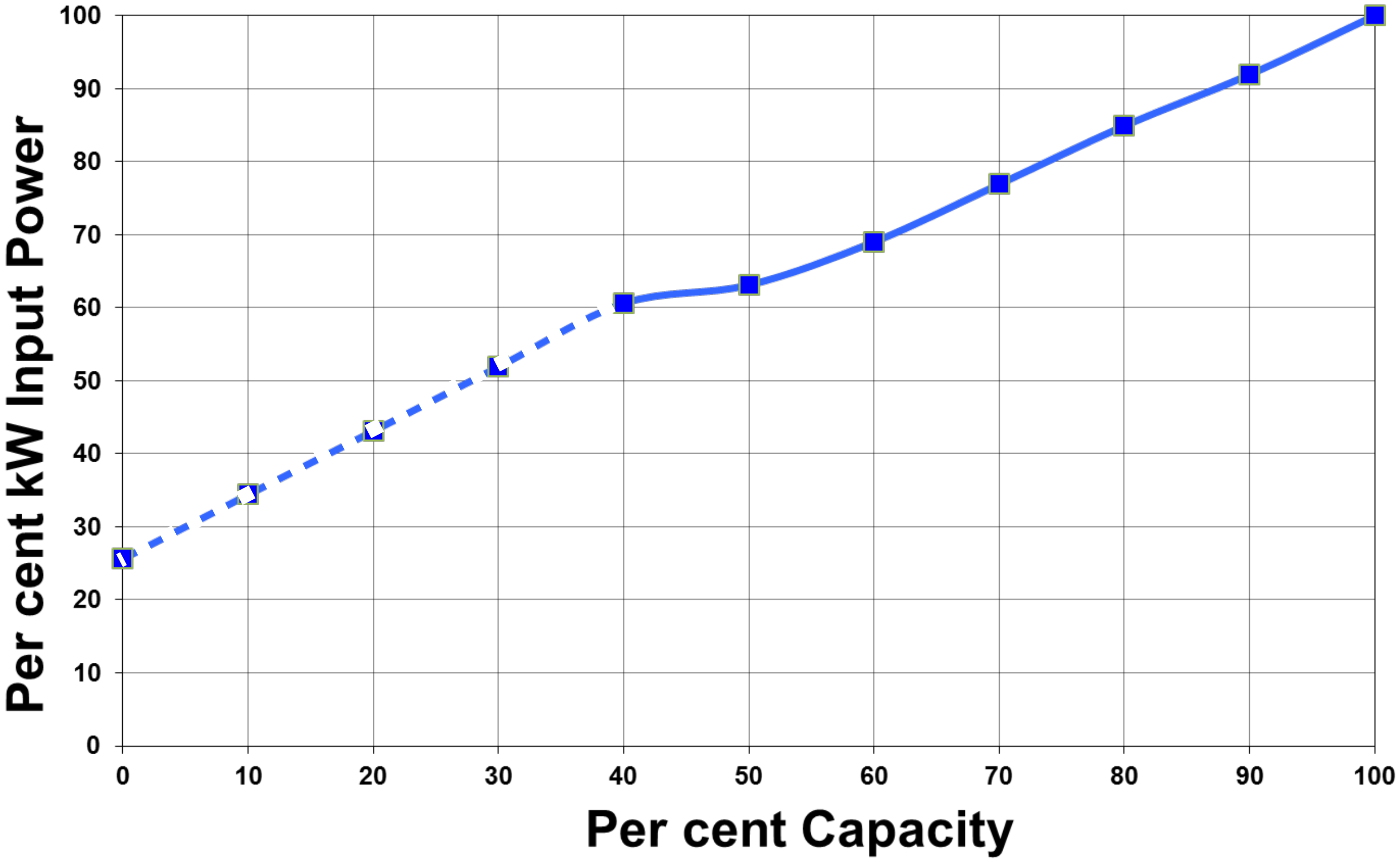


- This reduces the mass flow of air entering the air end in direct proportion to the absolute pressure.
- However, the reduced inlet pressure, with increasing discharge pressure, results in increasing pressure ratio.
- At 40% capacity the pressure ratio will be 124.7/5.88 = 21.21.
- This is why there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

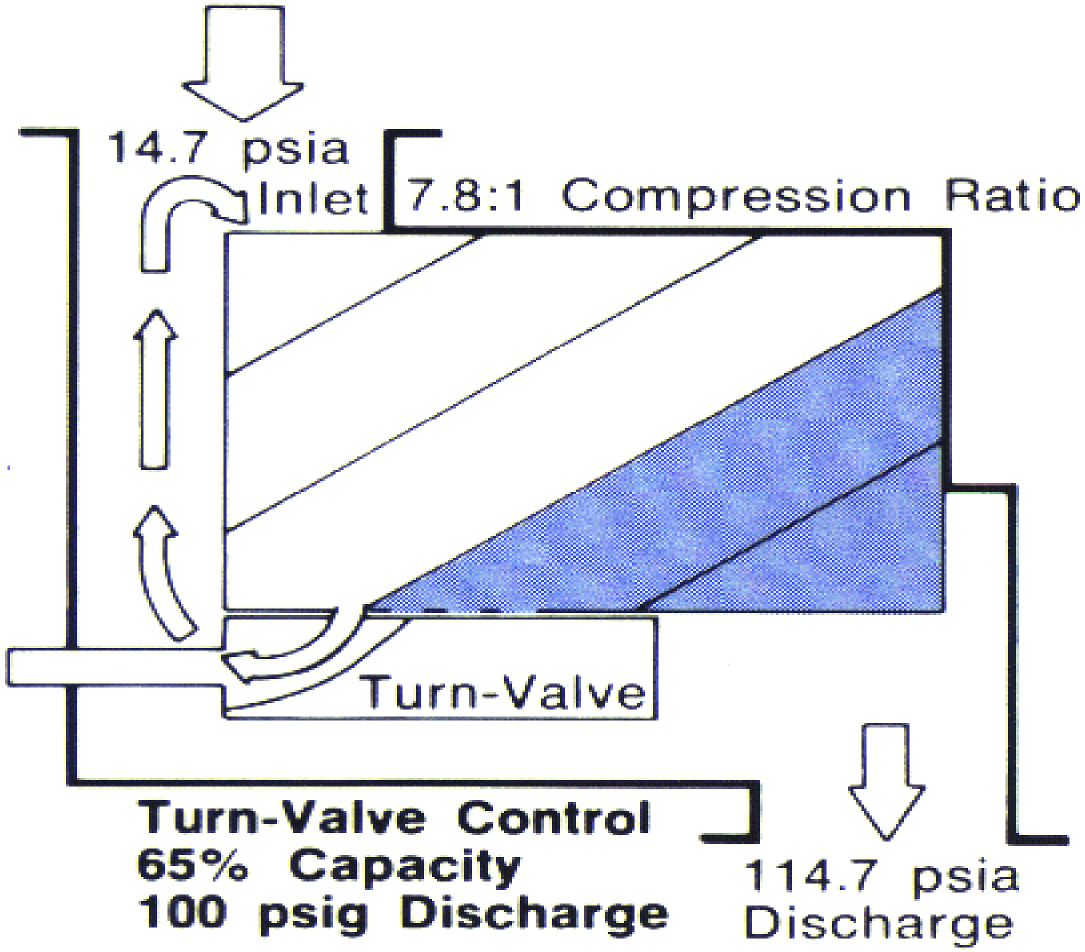
Variable Displacement

- 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

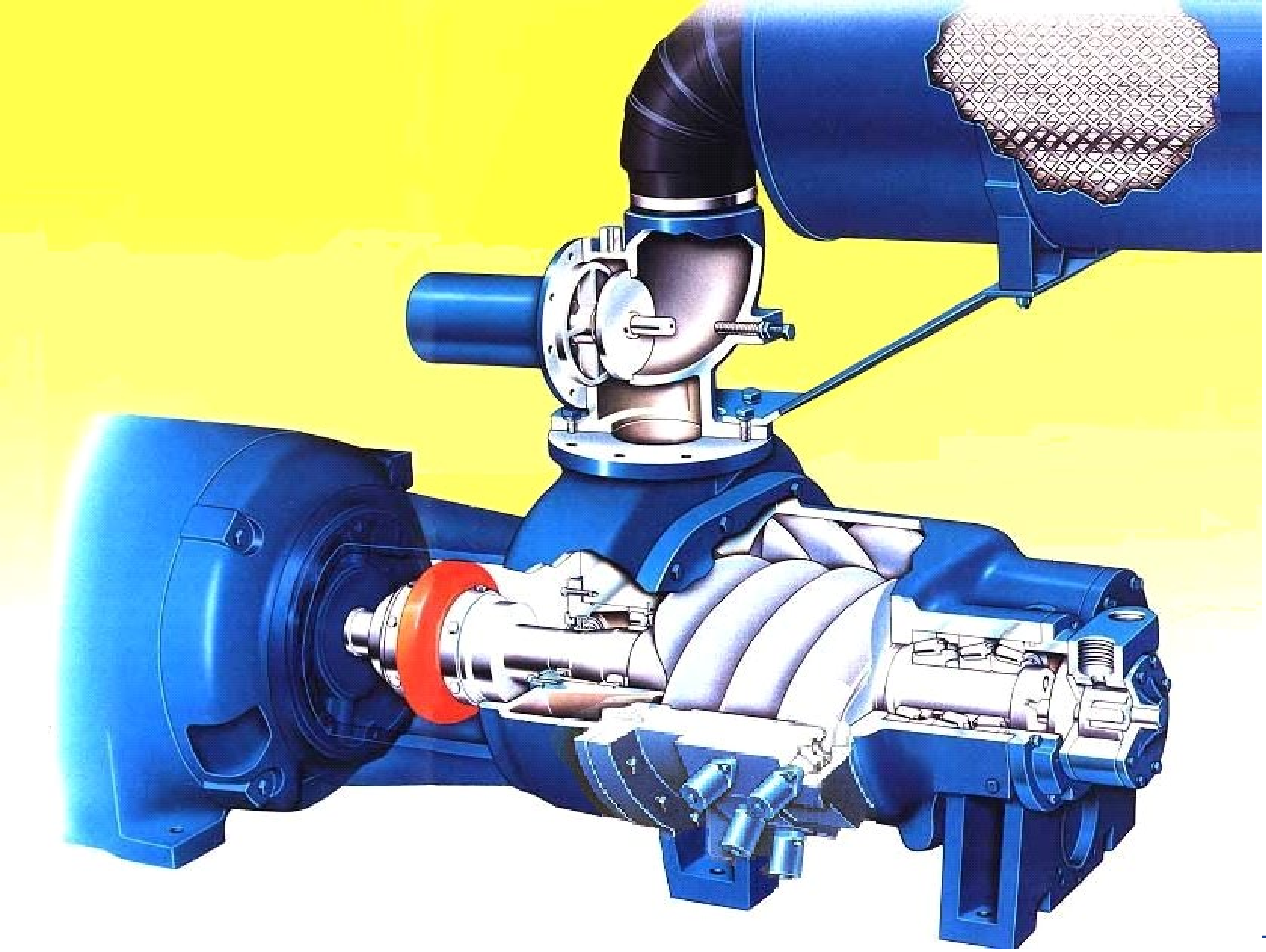
Variable Displacement



Variable Displacement

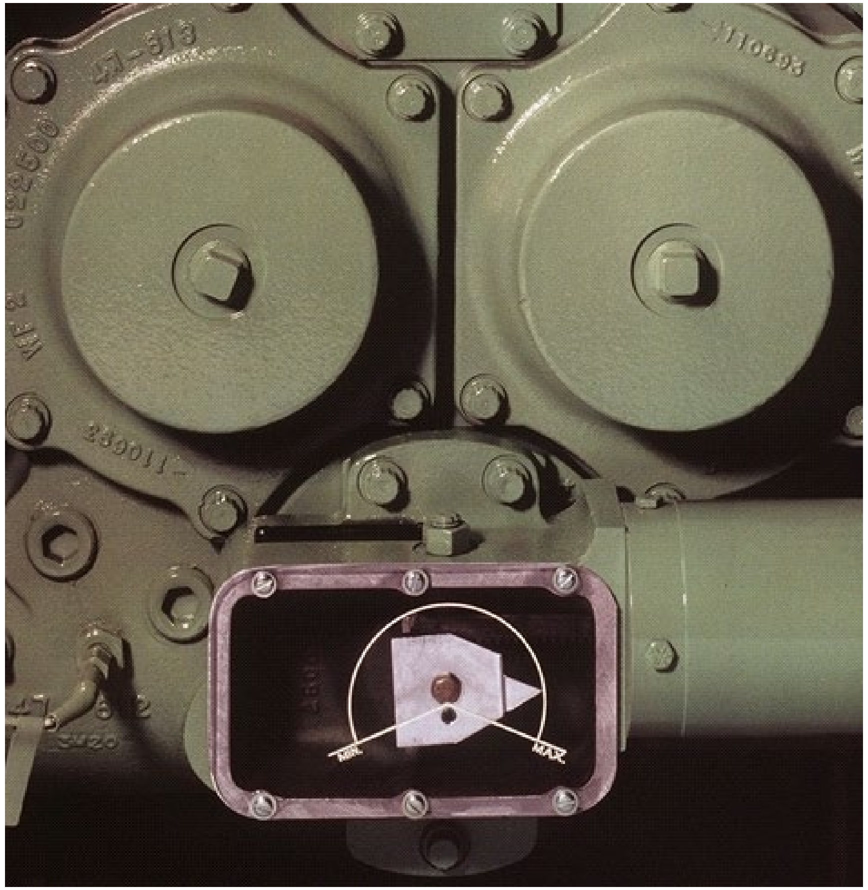

14.7 psia
Inlet
7.8:1 Compression Ratio
Turn-Valve
Turn-Valve Control
65% Capacity
100 psig Discharge
114.7 psia
Discharge

Variable Displacement



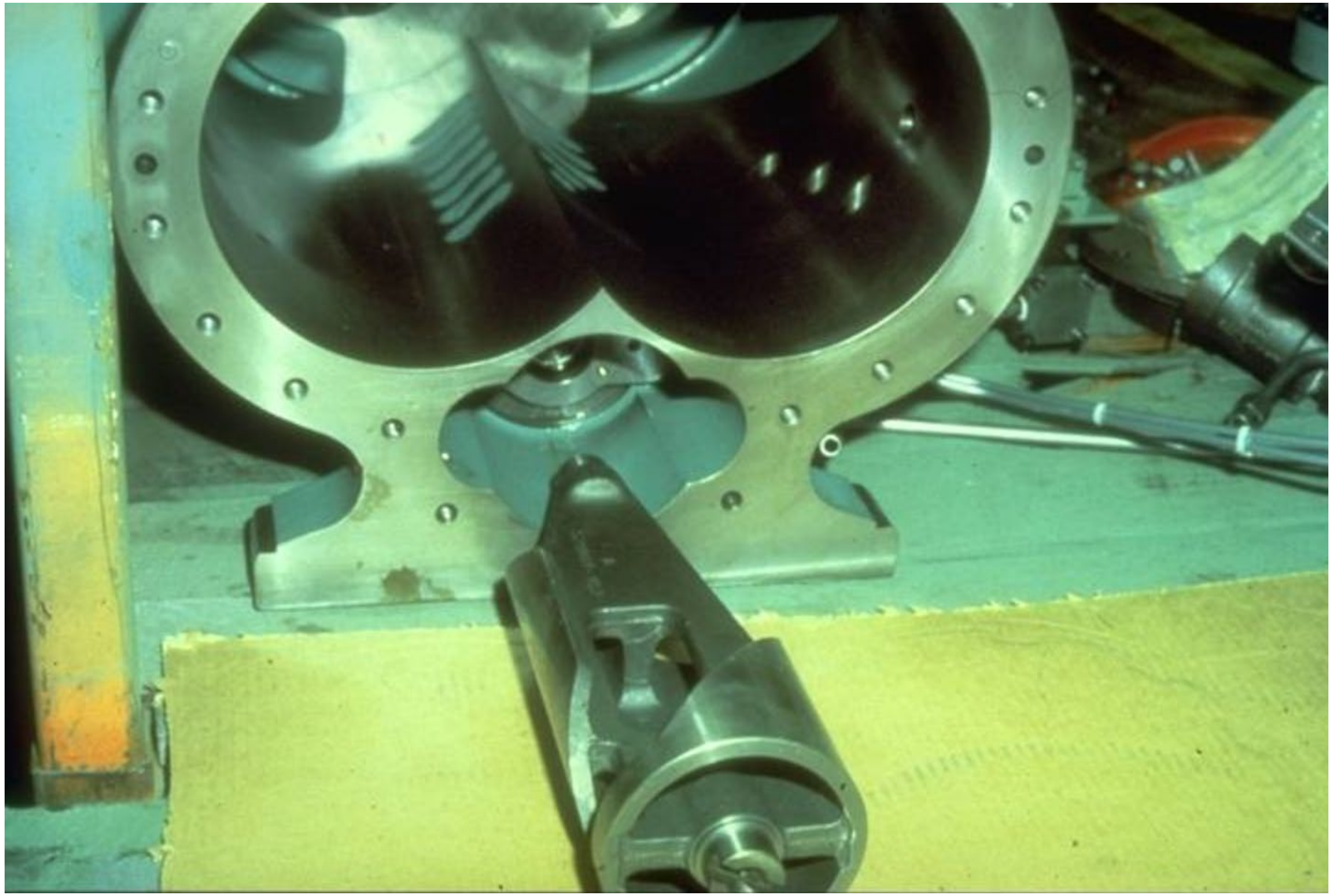
Variable Displacement

Original Version

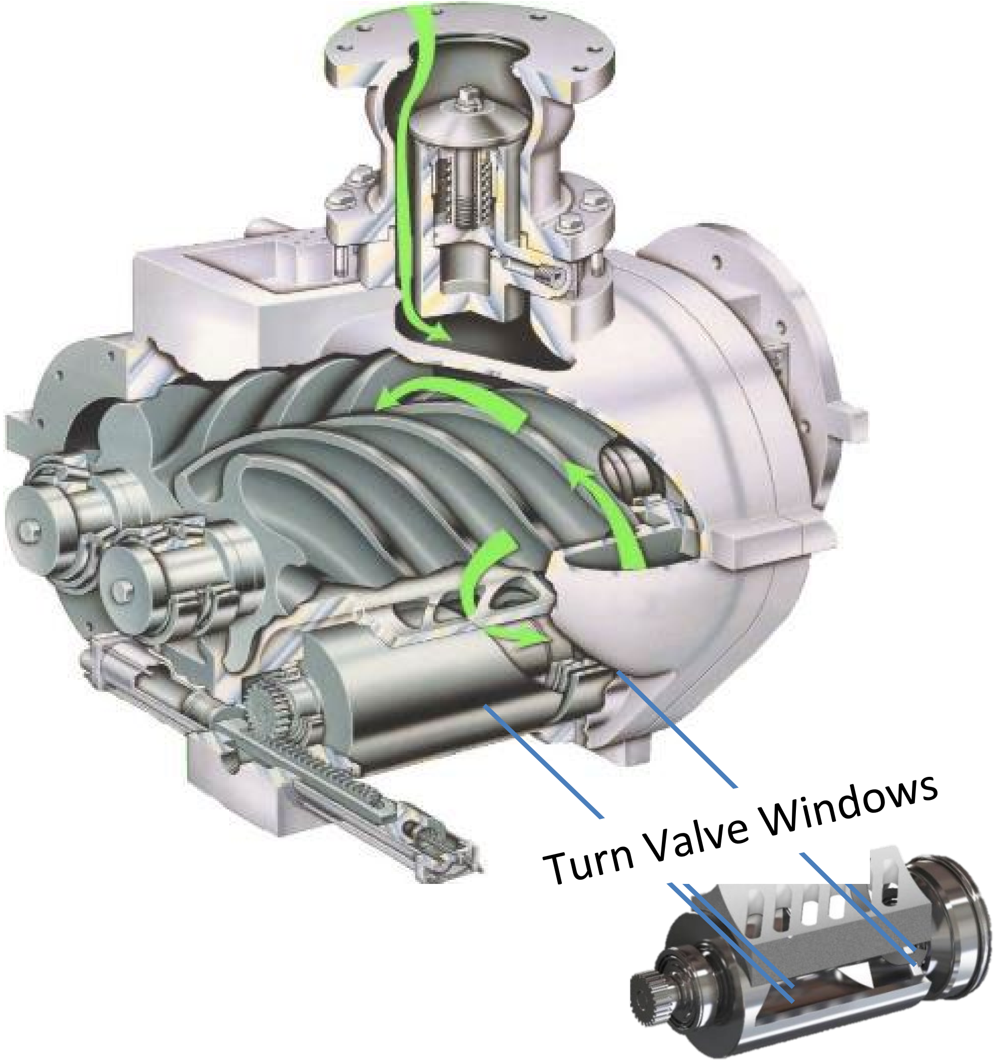


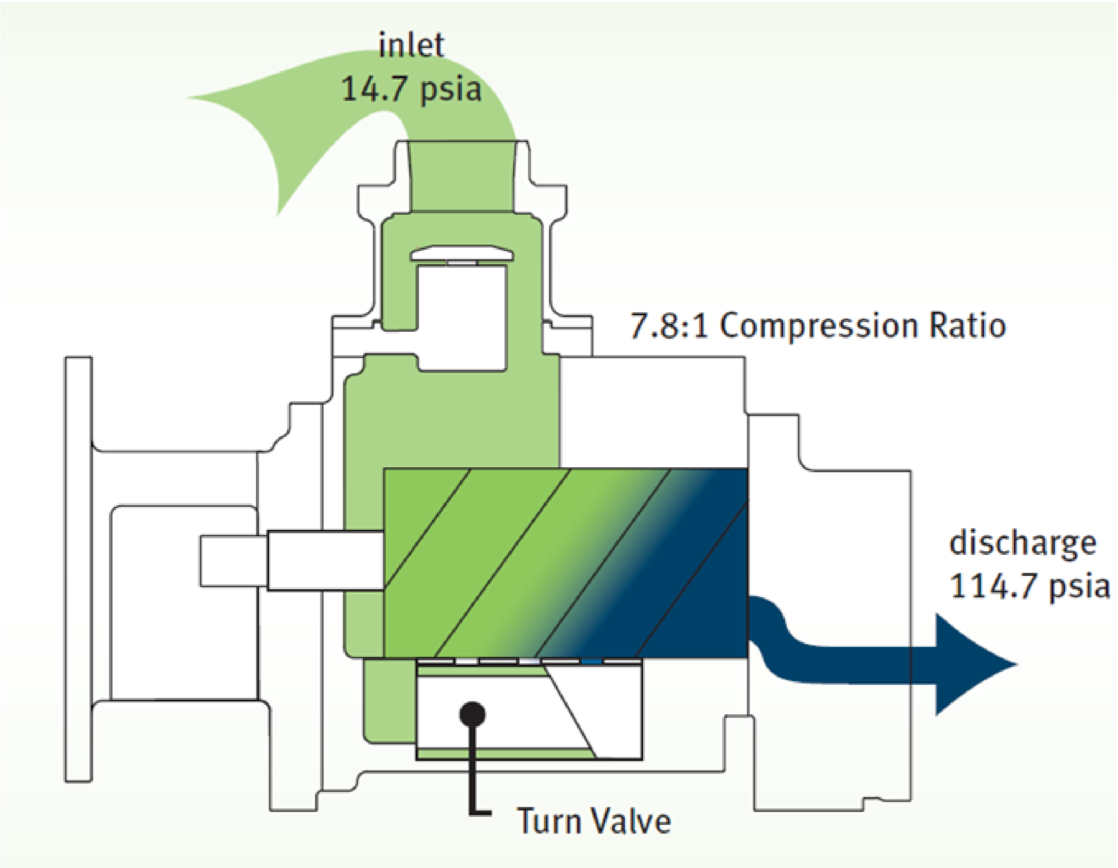
— UP TO 55% TURN DOWN

Variable Displacement

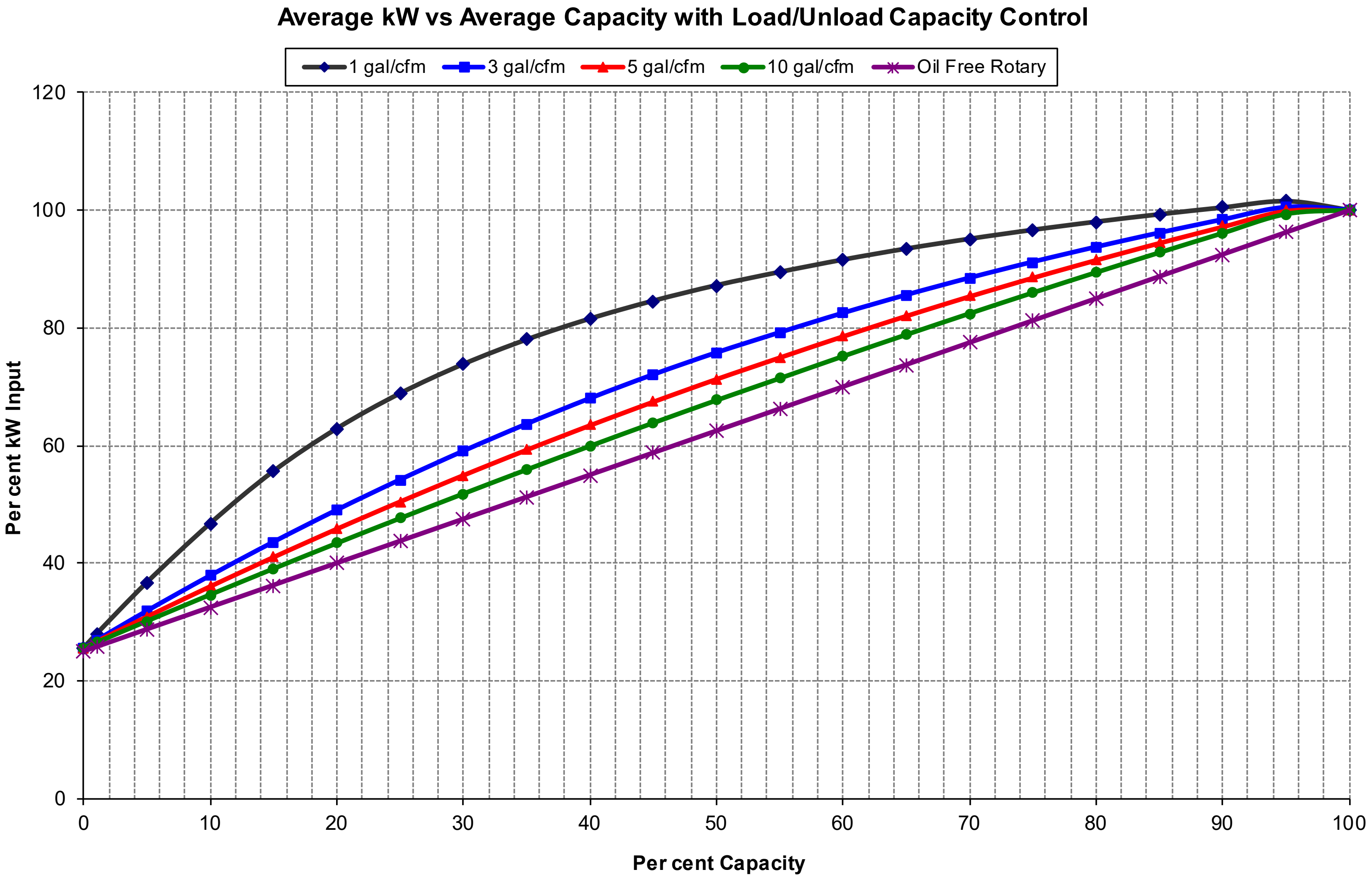


Variable Displacement


Turn Valve Windows


inlet
14.7 psia
7.8:1 Compression Ratio
discharge
114.7 psia
Turn Valve

Load/No-load Control Curve

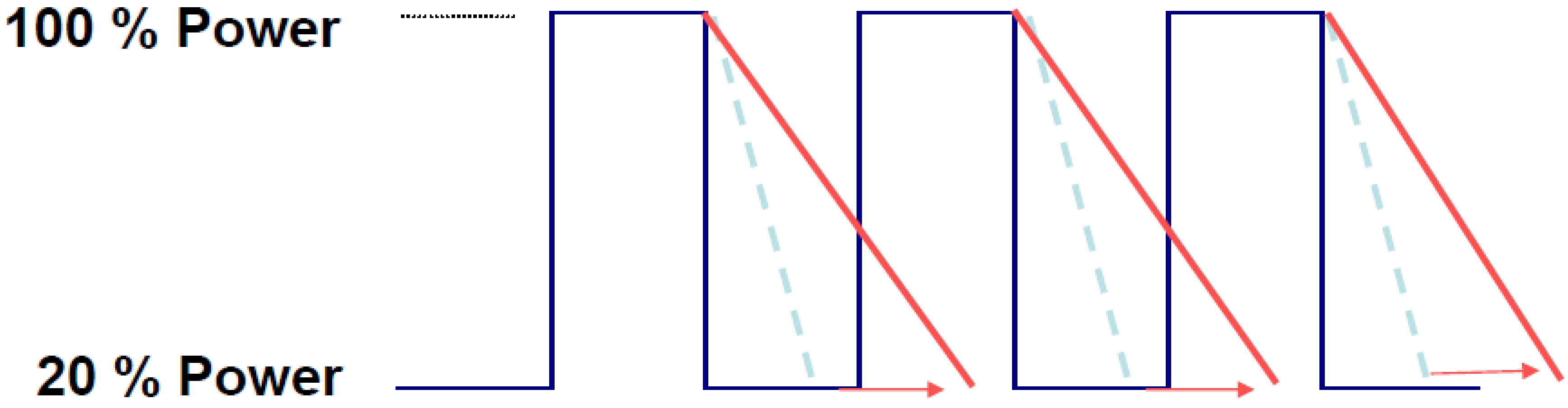


- This graph shows the effect of receiver size on the part load power of a lubricant injected rotary screw compressor with load/unload controls

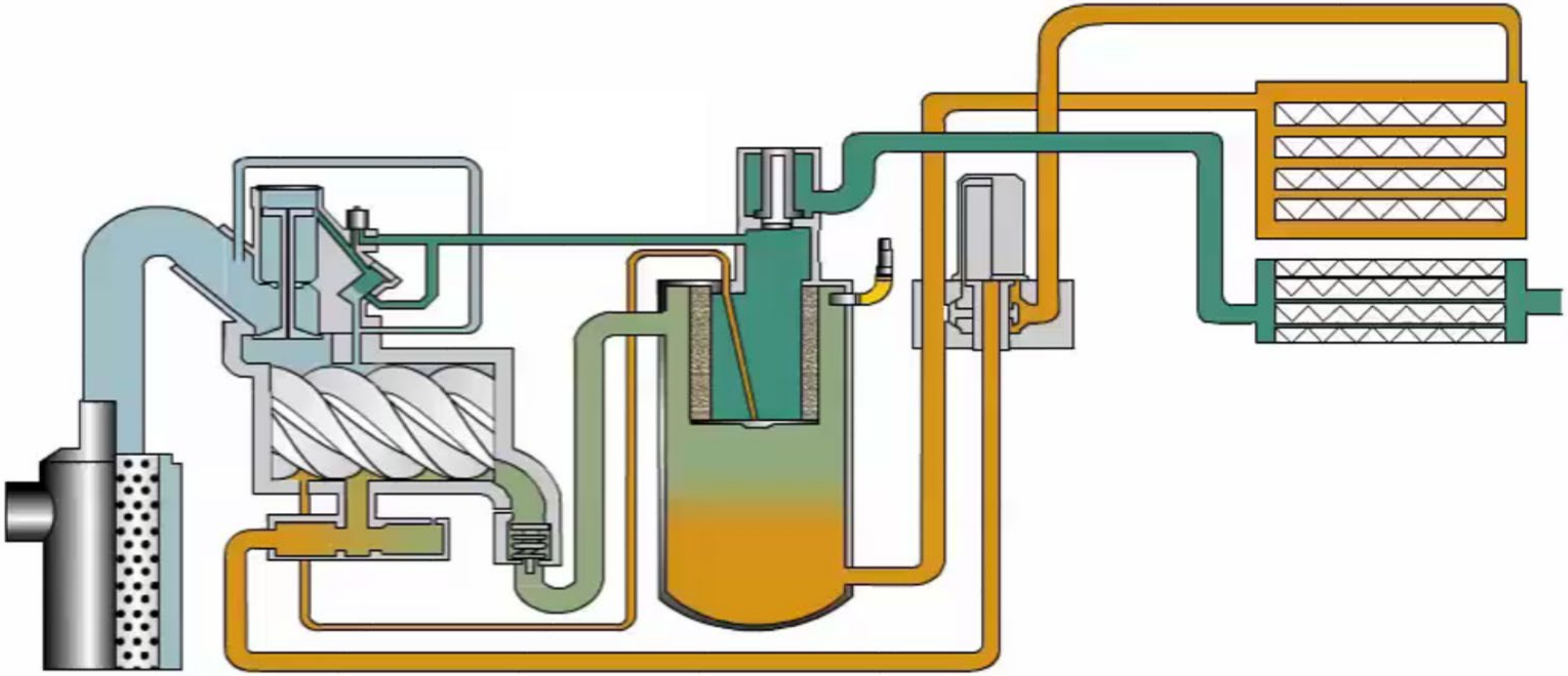
Load/Unload and Storage Size

- 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.

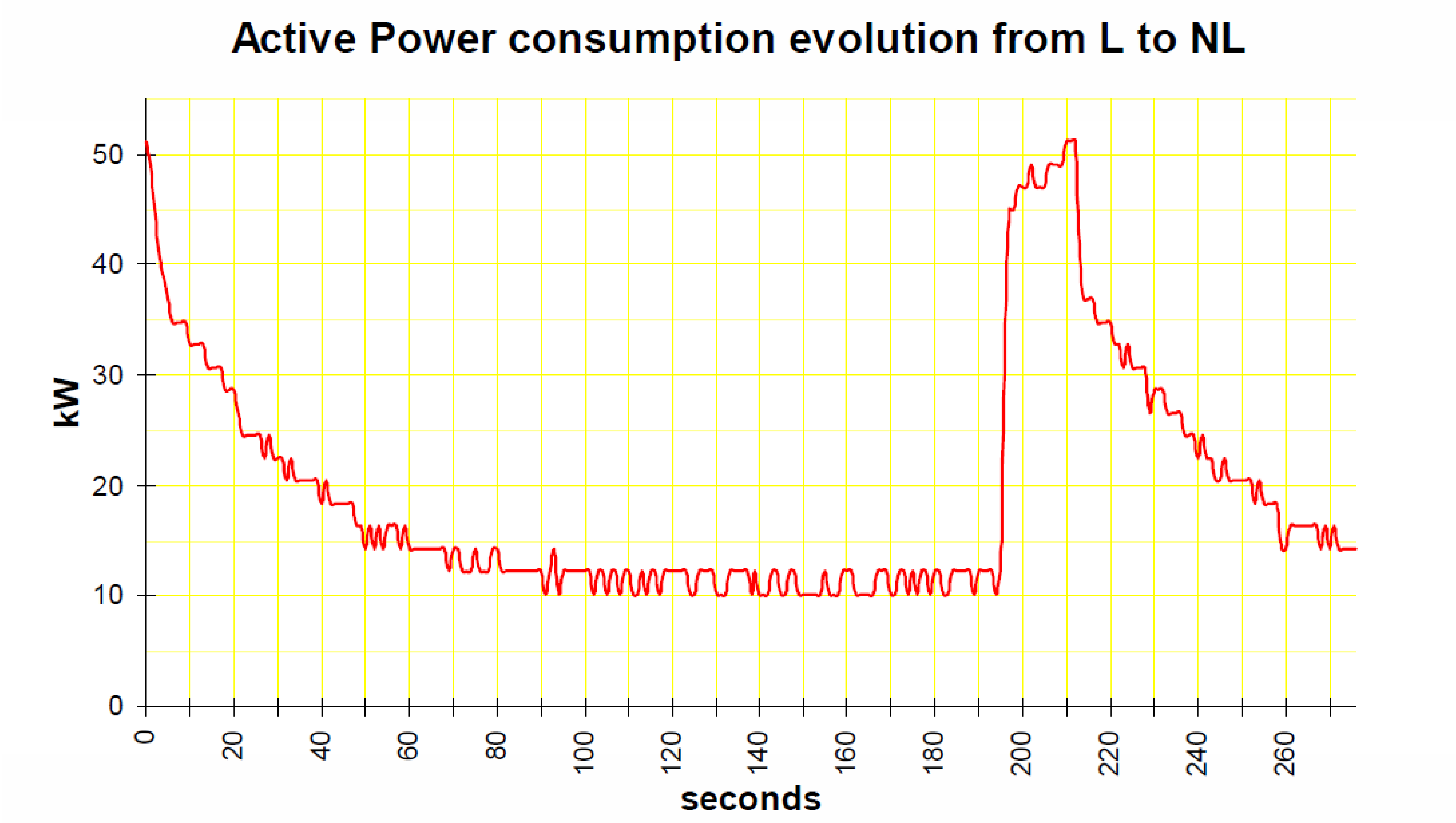
Capacity Control by Load/No-Load



- 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



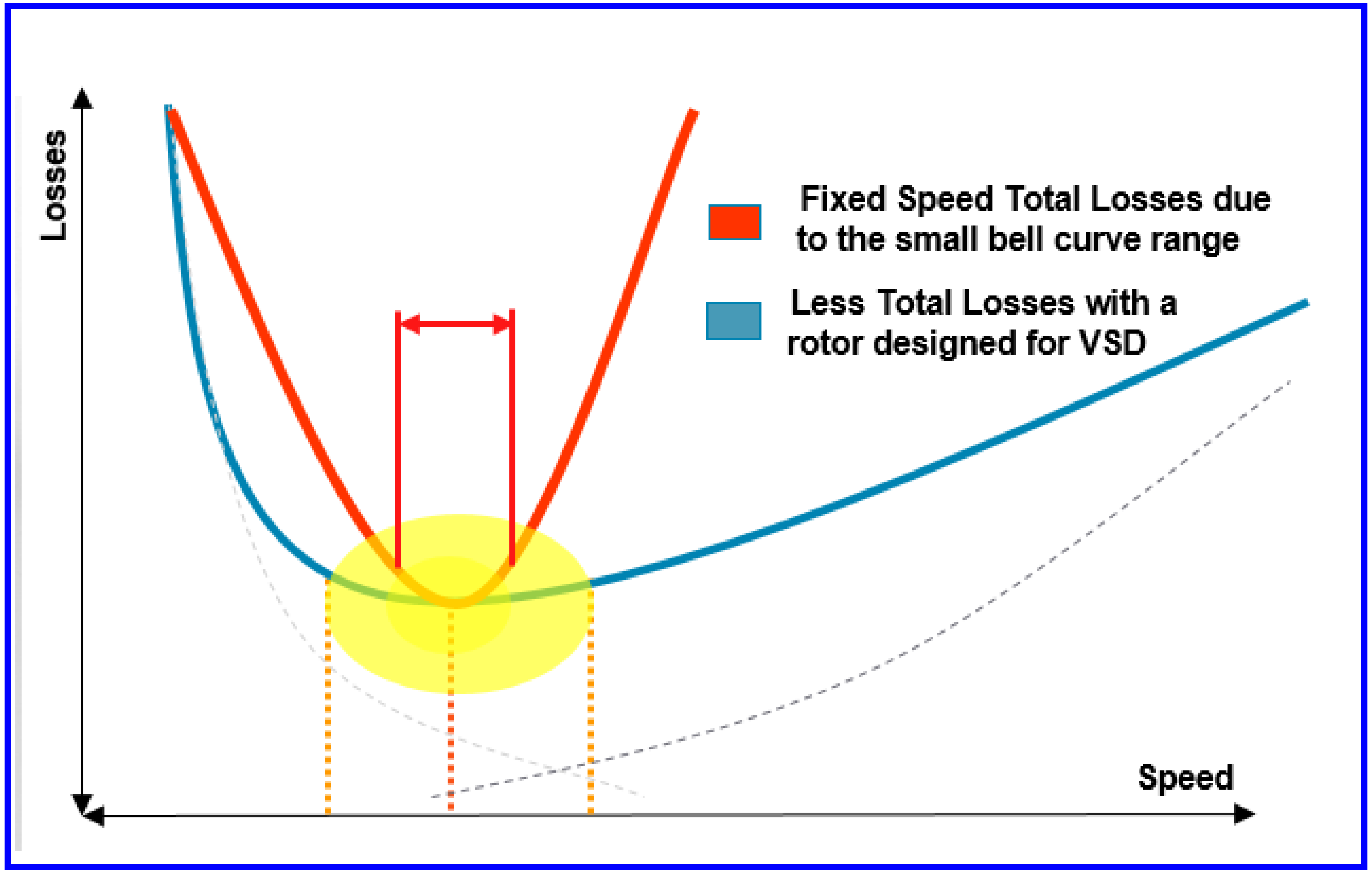
Capacity Control by Load/No-Load



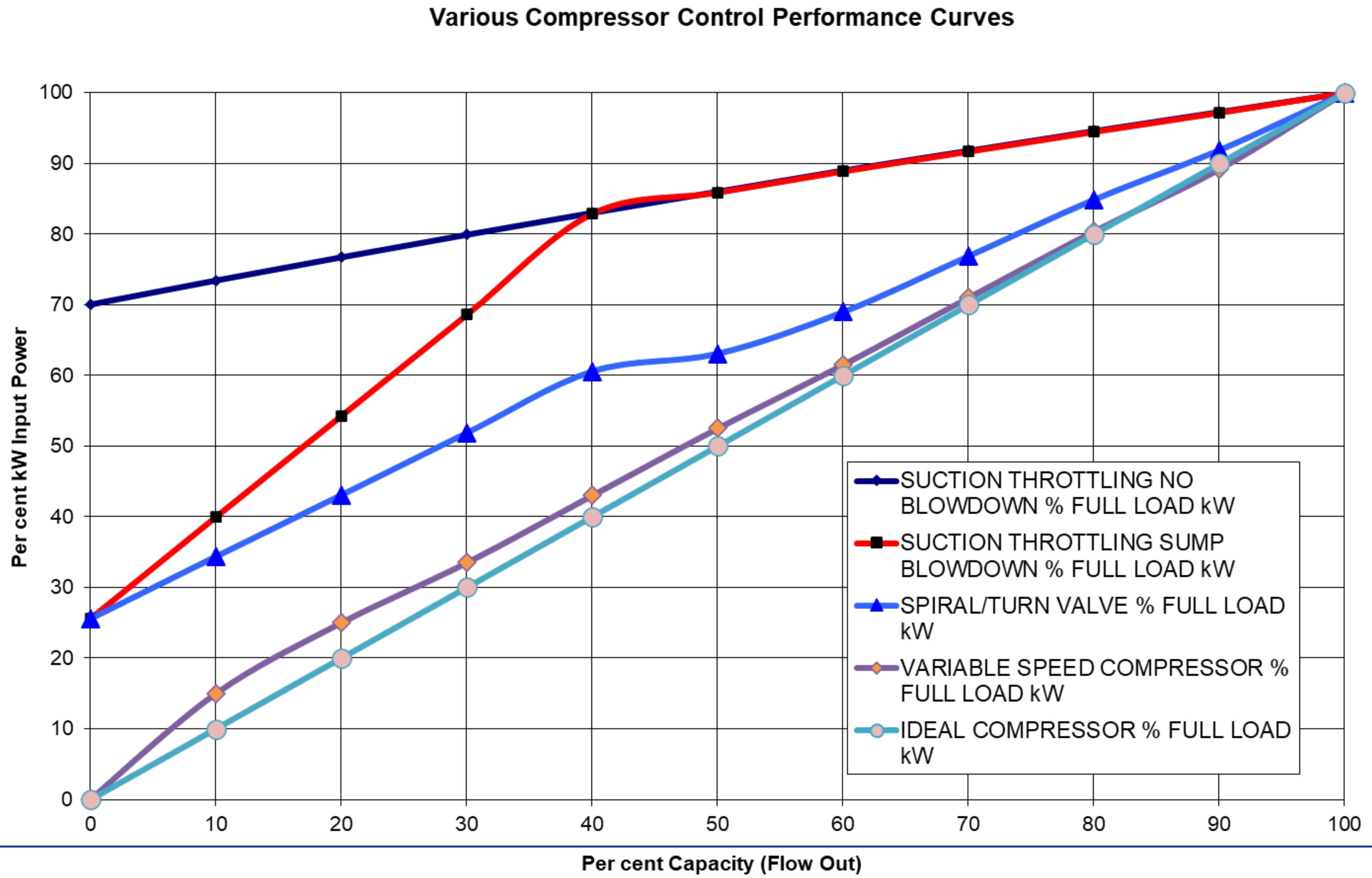
Variable Speed Compressors

- Efficient means of rotary compressor capacity control,
- Integrated variable frequency AC or
- Switched reluctance DC drives.
- 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.

Variable Speed



Performance Curves



Variable Speed Compressors

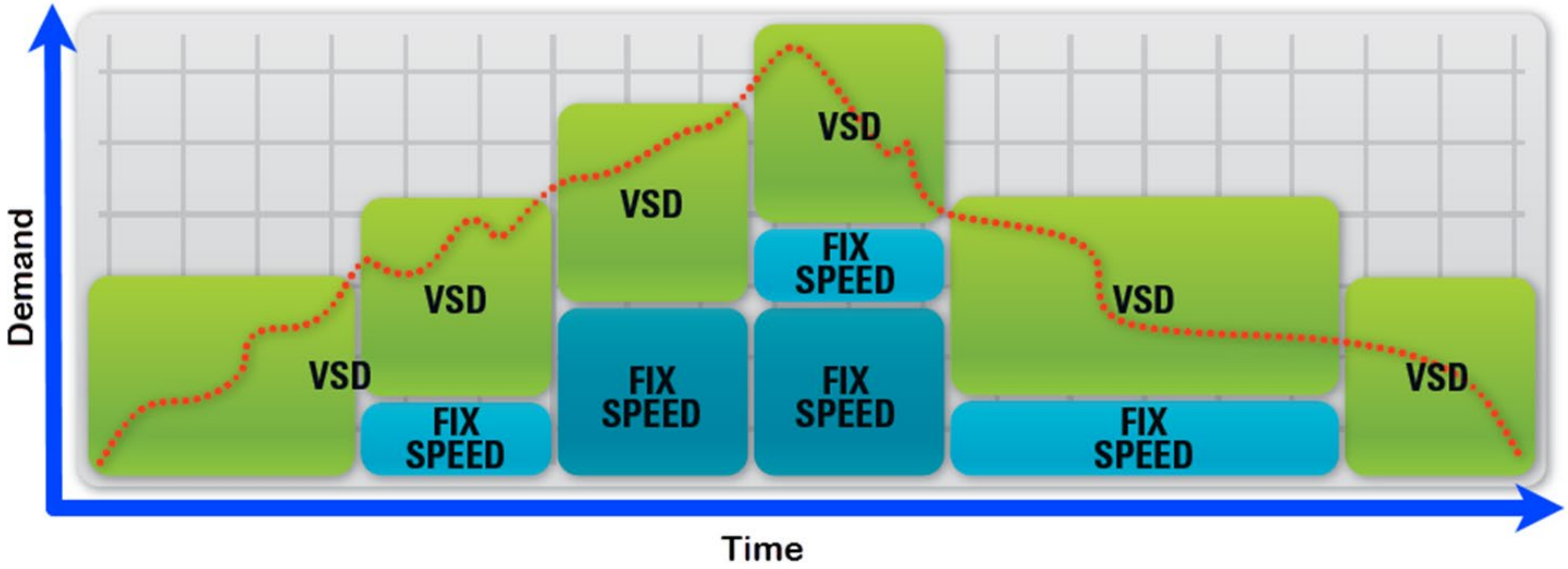
- The most common VSD is the variable frequency drive, which converts 60 Hz alternating current to direct current and then reconverts it to the proper frequency required to turn the drive motor at the desired speed.
- The variable frequency drive is less efficient at full load compared to modulation controls because the electrical conversions usually consume an additional two to four percent more energy.

Variable Speed Compressors

- VSD (variable speed drive) and VFD (variable frequency drive) are used interchangeably
- VFD is only one of the VSD technologies available.

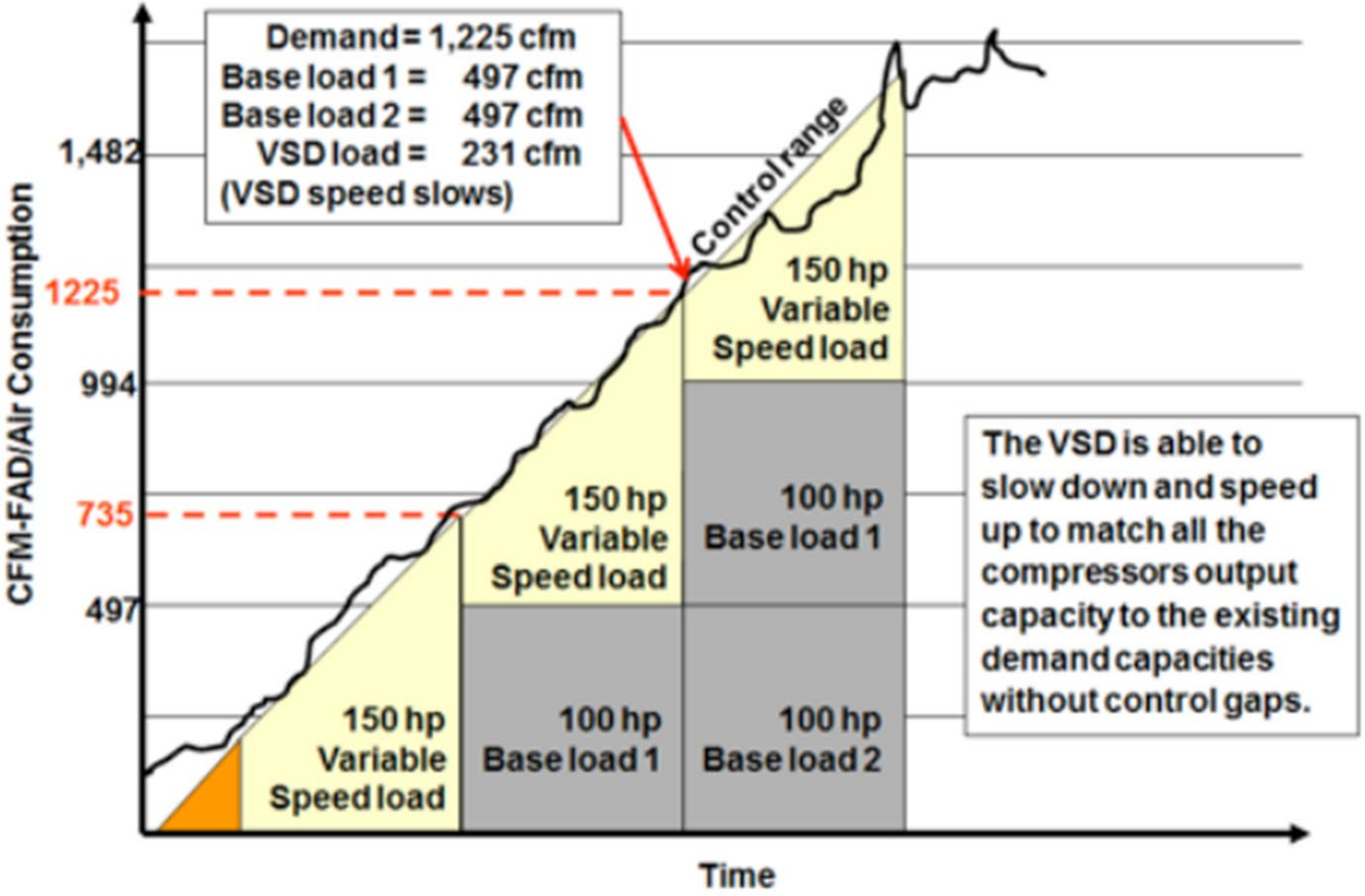
Variable Speed Compressors

- 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

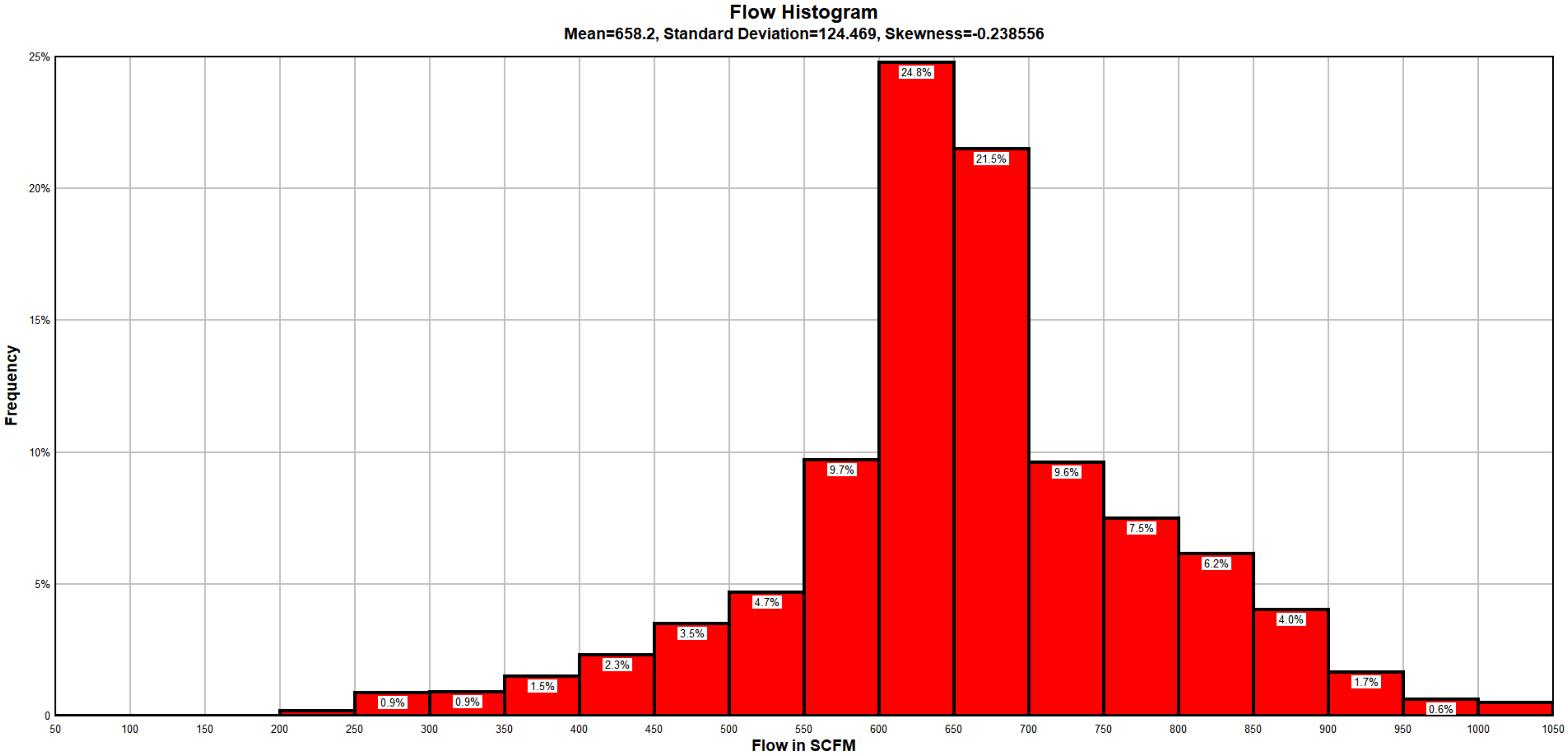

Demand
VSD
VSD
FIX SPEED
VSD
FIX SPEED
VSD
FIX SPEED
FIX SPEED
VSD
FIX SPEED
VSD
Time

Variable Speed Compressors and Control Gap

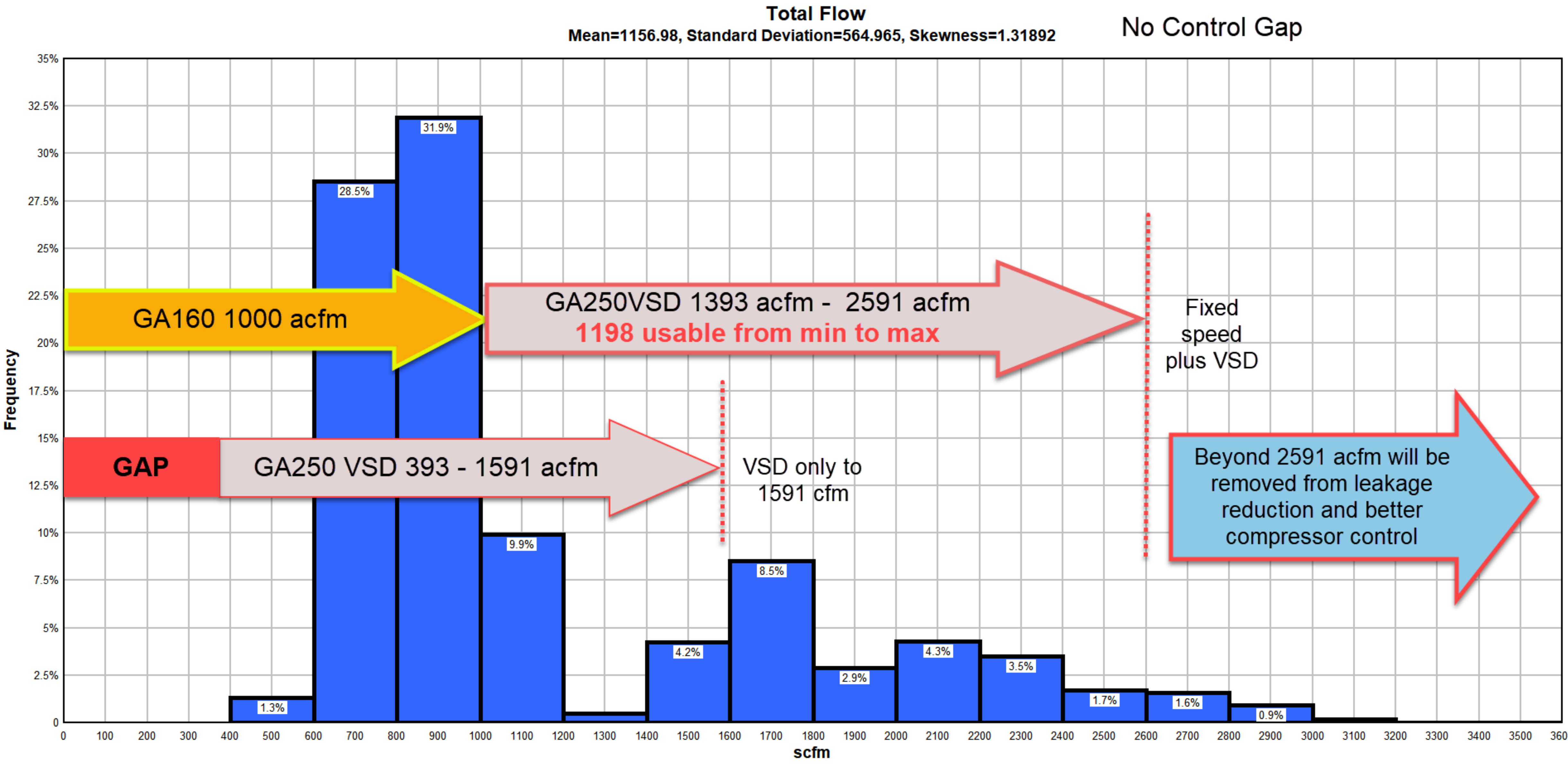
This system can provide a steady operating pressure throughout the flow range of the system as long as the system is properly controlled with a master controller.



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



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



No Control Gap

GA160 1000 acfm

GA250VSD 1393 acfm - 2591 acfm

1198 usable from min to max

Fixed speed plus VSD

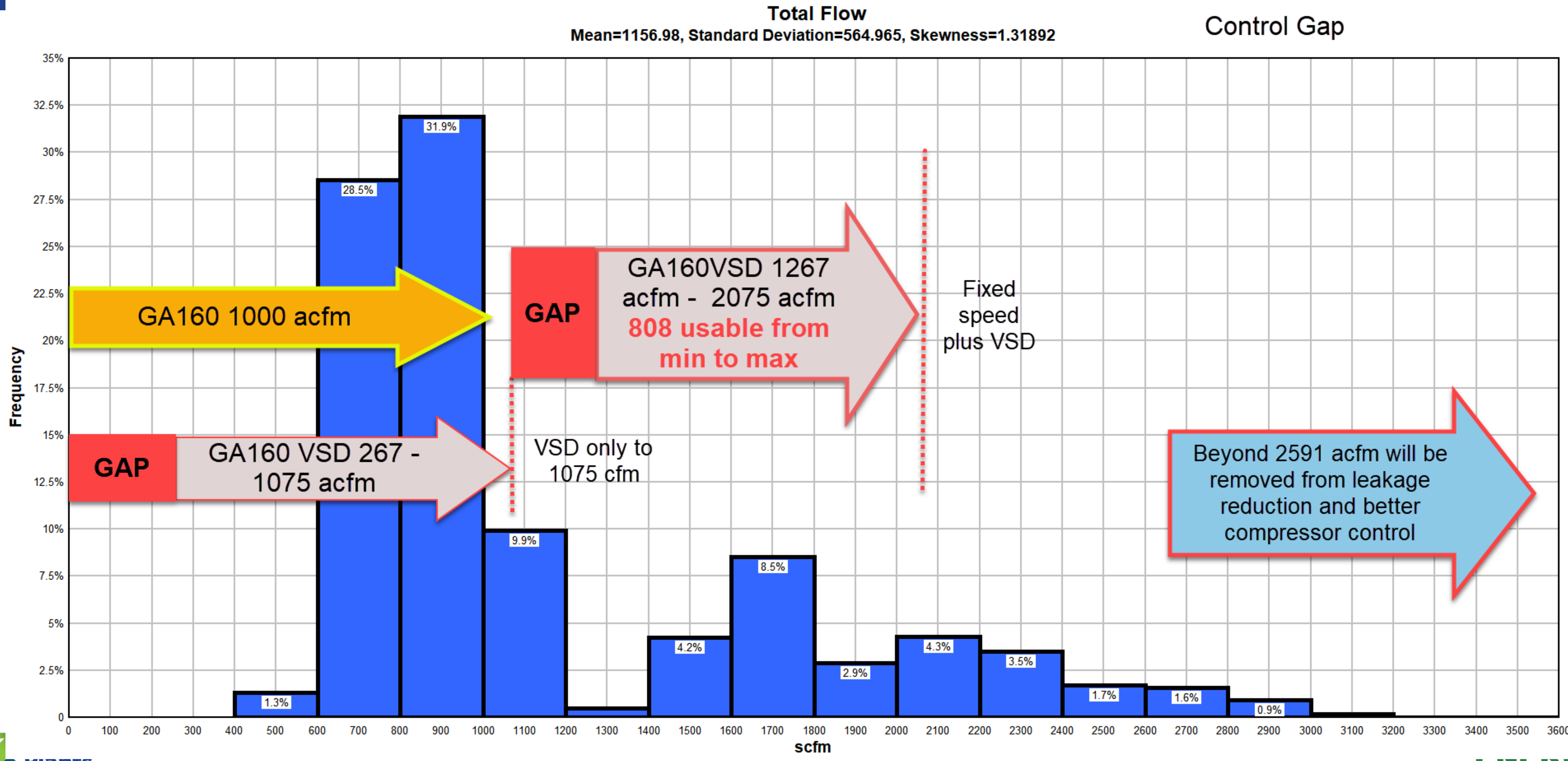
GAP

GA250 VSD 393 - 1591 acfm

VSD only to 1591 cfm

Beyond 2591 acfm will be removed from leakage reduction and better compressor control

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



Total Flow

Mean=1156.98, Standard Deviation=564.965, Skewness=1.31892

Control Gap

GA160 1000 acfm

GAP

GA160VSD 1267 acfm - 2075 acfm

808 usable from min to max

Fixed speed plus VSD

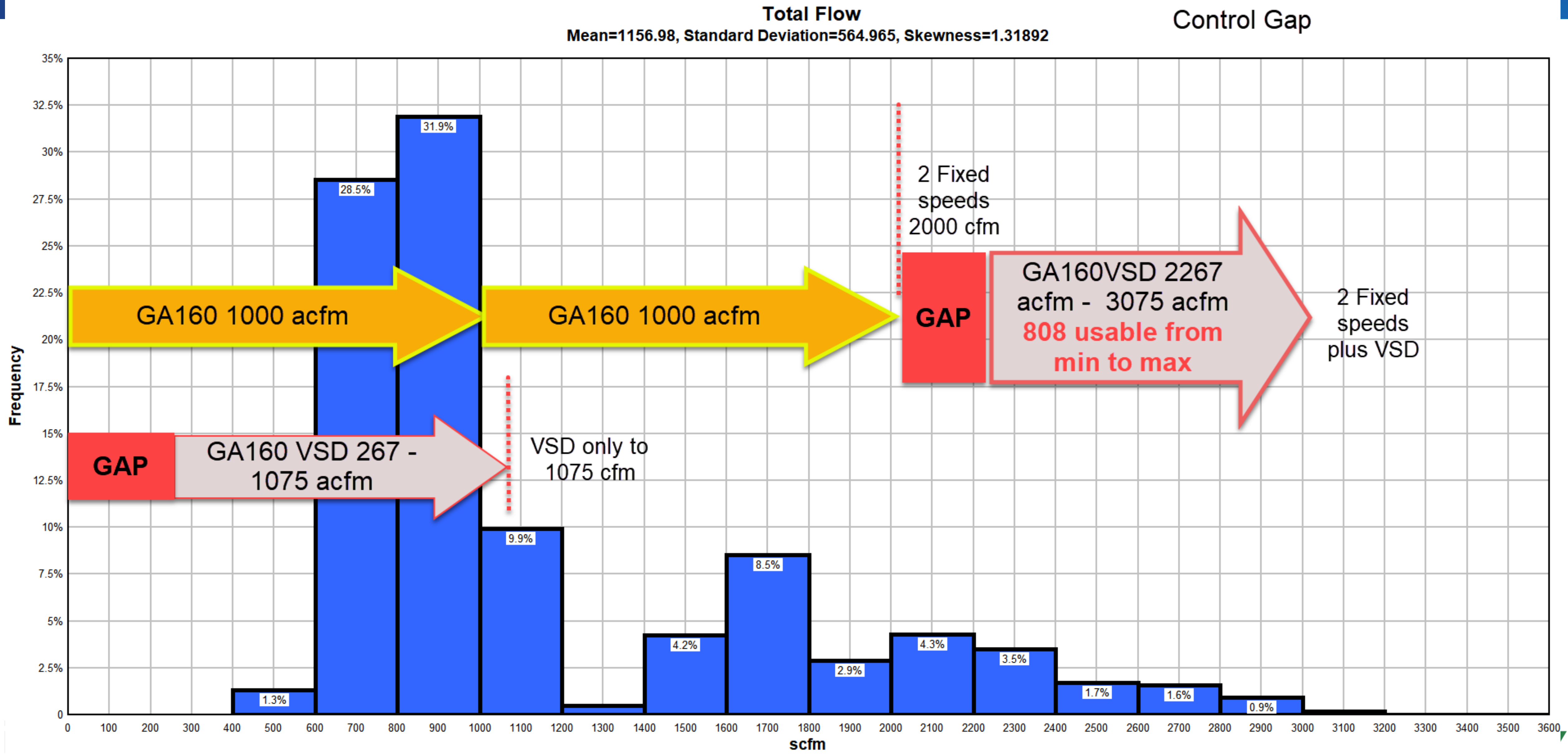
GAP

GA160 VSD 267 - 1075 acfm

VSD only to 1075 cfm

Beyond 2591 acfm will be removed from leakage reduction and better compressor control

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



Total Flow

Mean=1156.98, Standard Deviation=564.965, Skewness=1.31892

Control Gap

GA160 1000 acfm

GA160 1000 acfm

GAP

GA160 VSD 267 - 1075 acfm

VSD only to 1075 cfm

2 Fixed speeds 2000 cfm

GAP

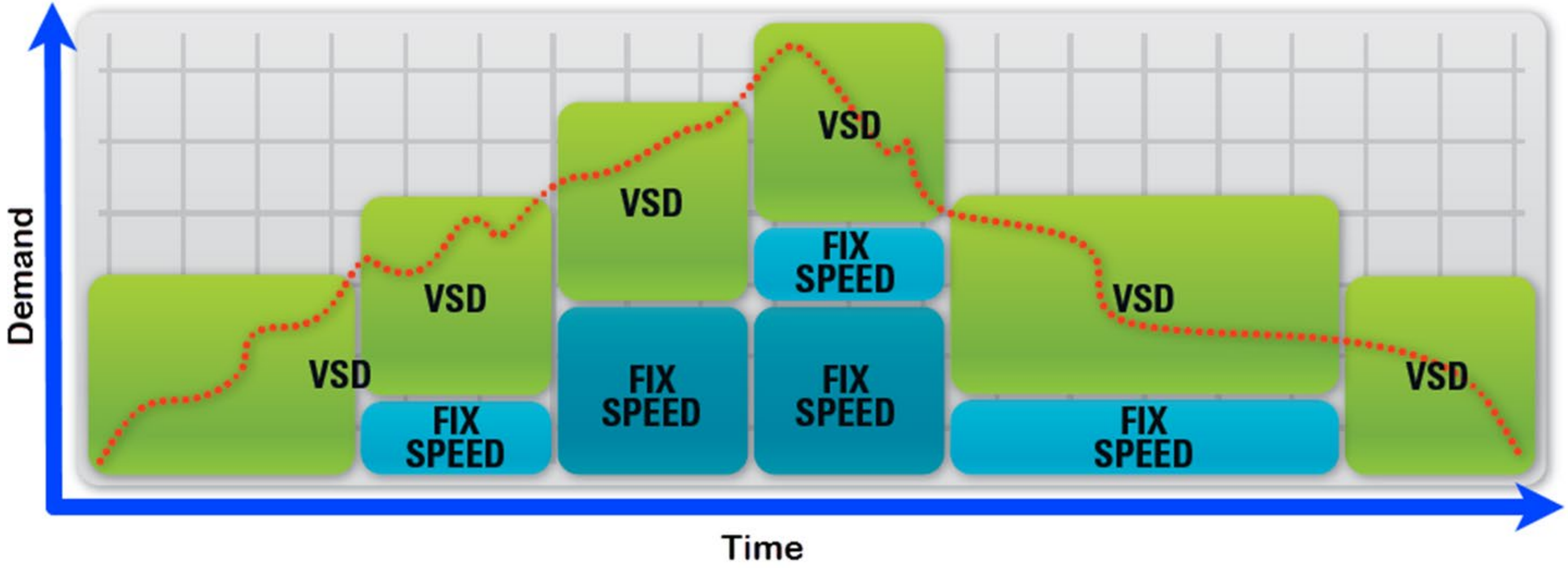
GA160VSD 2267 acfm - 3075 acfm

808 usable from min to max

2 Fixed speeds plus VSD

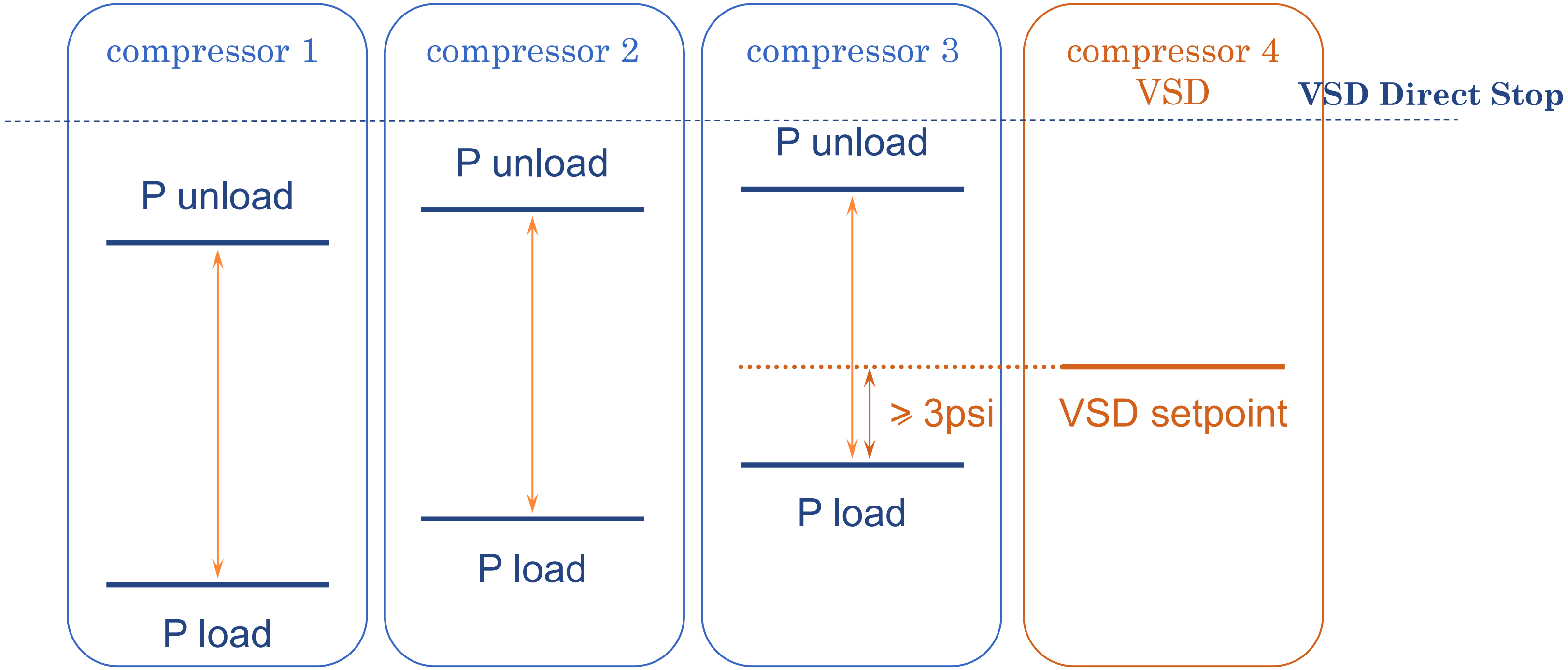
Variable Speed Compressors

- 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


Demand
VSD
VSD
FIX SPEED
VSD
FIX SPEED
VSD
FIX SPEED
FIX SPEED
VSD
FIX SPEED
VSD
Time

Control Gap and Position

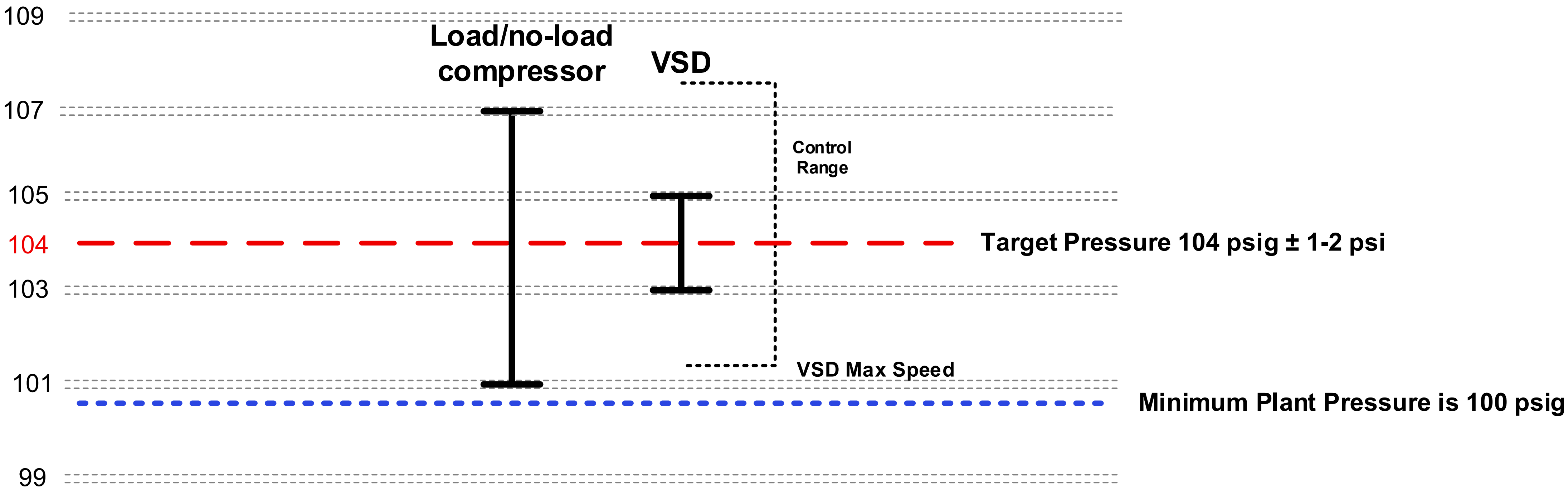
- In order to provide efficient VSD regulation over the complete range of the customer's air profile, the cfm of the VSD needs to be greater than the load/no load machine


compressor 1
P unload
P load
compressor 2
P unload
P load
compressor 3
P unload
> 3psi
P load
compressor 4
VSD
VSD Direct Stop
VSD setpoint

Control Gap and Position – Example Settings

- Assume minimum plant pressure: 100 psig
- Chosen header target : 104 psig

Set fixed-speed load/unload around the VSD setpoint -- The fixed-speed machine should only come in when the VSD is near max speed and can't keep up.

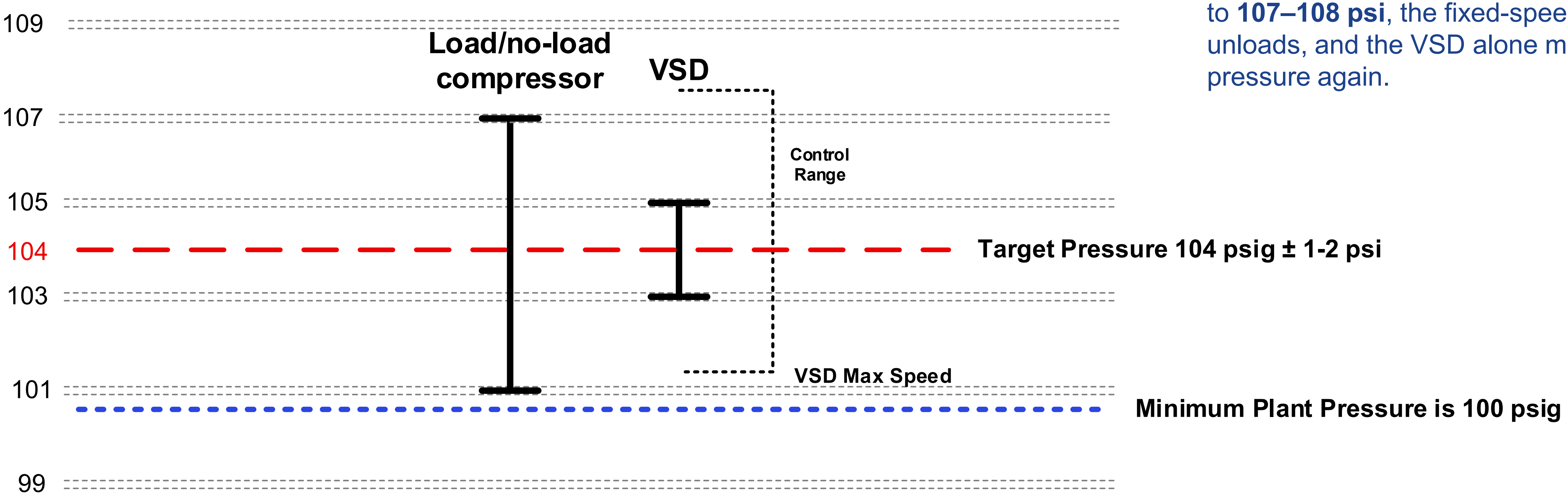


109
107
105
104
103
101
99
Load/no-load compressor
VSD
Control Range
Target Pressure 104 psig ± 1-2 psi
VSD Max Speed
Minimum Plant Pressure is 100 psig

Control Gap and Position – Example Settings

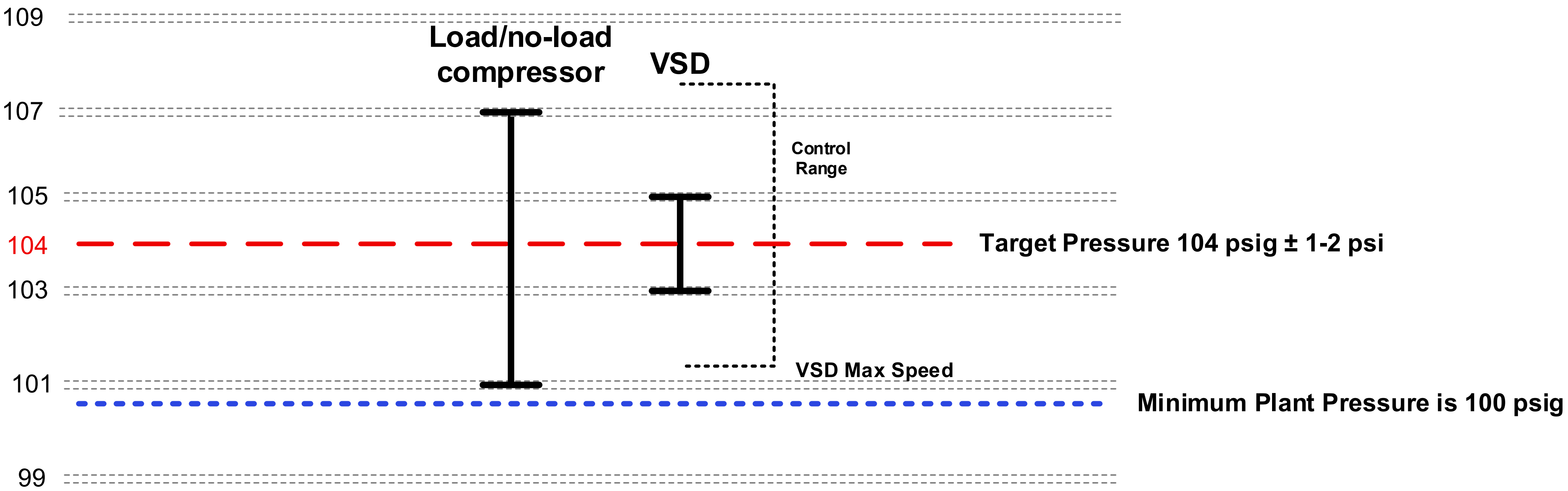
- Set VSD compressor setpoint at 104 psig
- Control band: 103–105 psi (or as tight as the controller allows)
- Fixed speed compressor load 100-101 psig and unload 107 – 108 psig

The **VSD does all the trimming** between ~101–107 psi.
When demand rises and pressure falls toward **100–101 psi**, the fixed-speed unit loads and shares the base load.
When demand drops and pressure rises to **107–108 psi**, the fixed-speed unit unloads, and the VSD alone maintains pressure again.


109
107
105
104
103
101
99
Load/no-load compressor
VSD
Control Range
VSD Max Speed
Target Pressure 104 psig ± 1-2 psi
Minimum Plant Pressure is 100 psig

Control Gap and Position – Example Settings

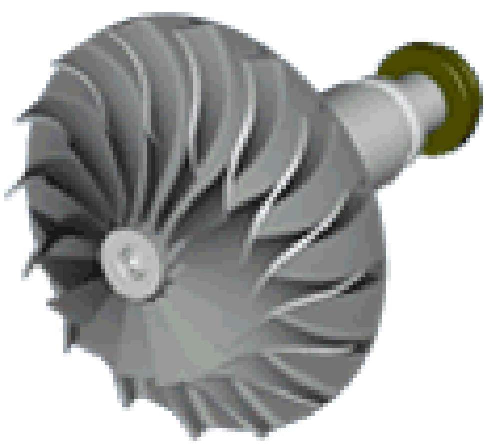
- Result:
  - Most of the time, the VSD alone holds ~104 psi.
  - When demand spikes, pressure drifts down toward 101 psi → fixed-speed loads.
  - When demand falls, pressure drifts up to 107–108 psi → fixed-speed unloads, VSD trims again.

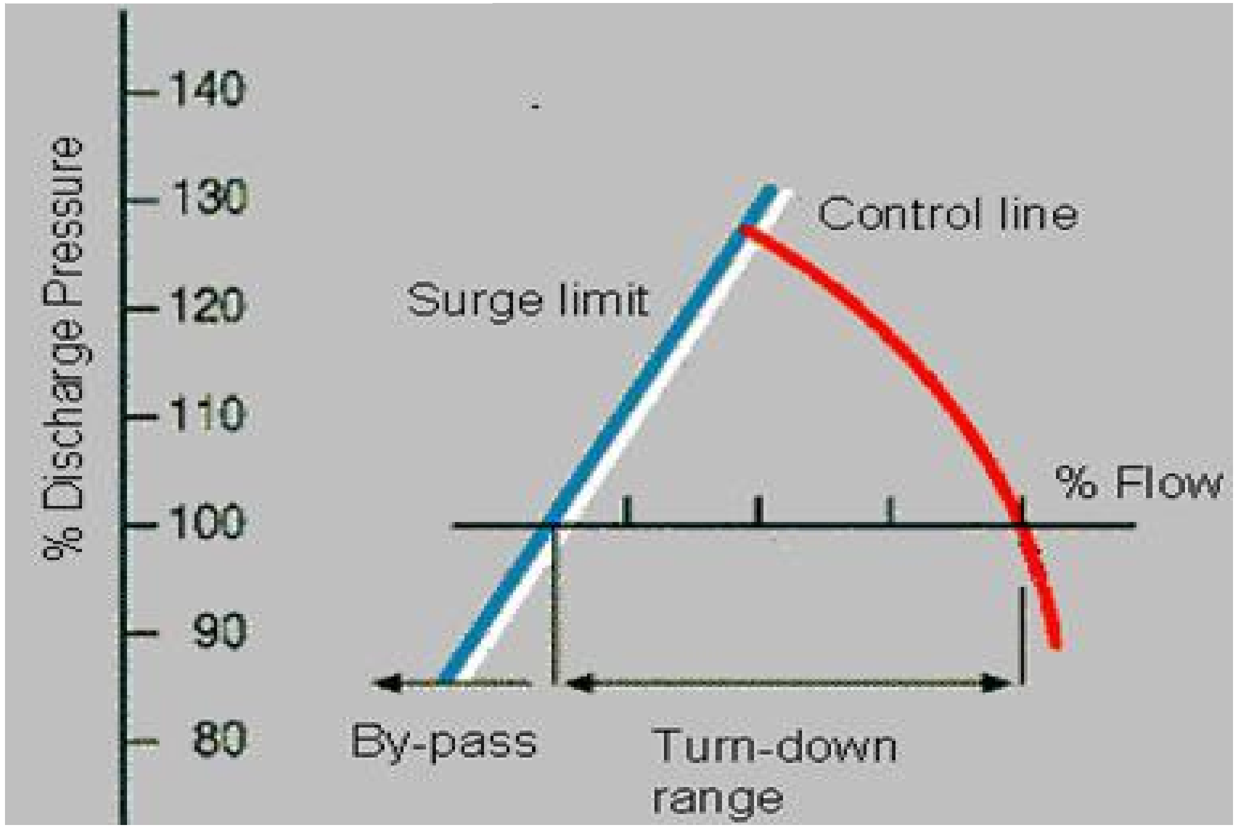


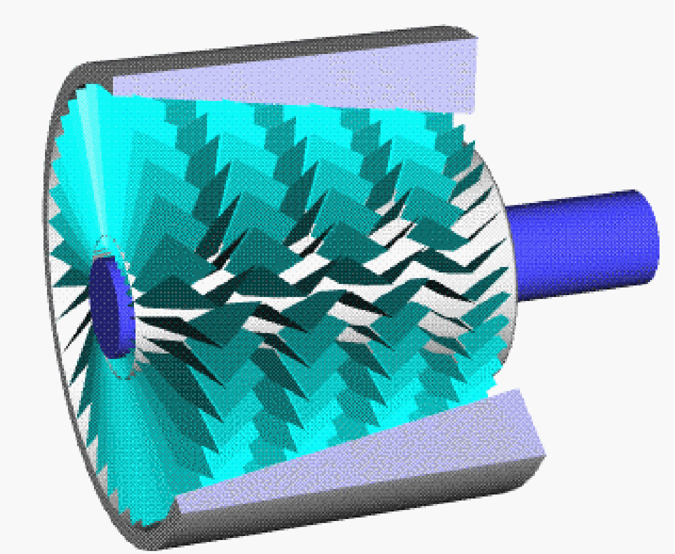
109
107
105
104
103
101
99
Load/no-load compressor
VSD
Control Range
VSD Max Speed
Target Pressure 104 psig ± 1-2 psi
Minimum Plant Pressure is 100 psig

Centrifugal Compressor Control

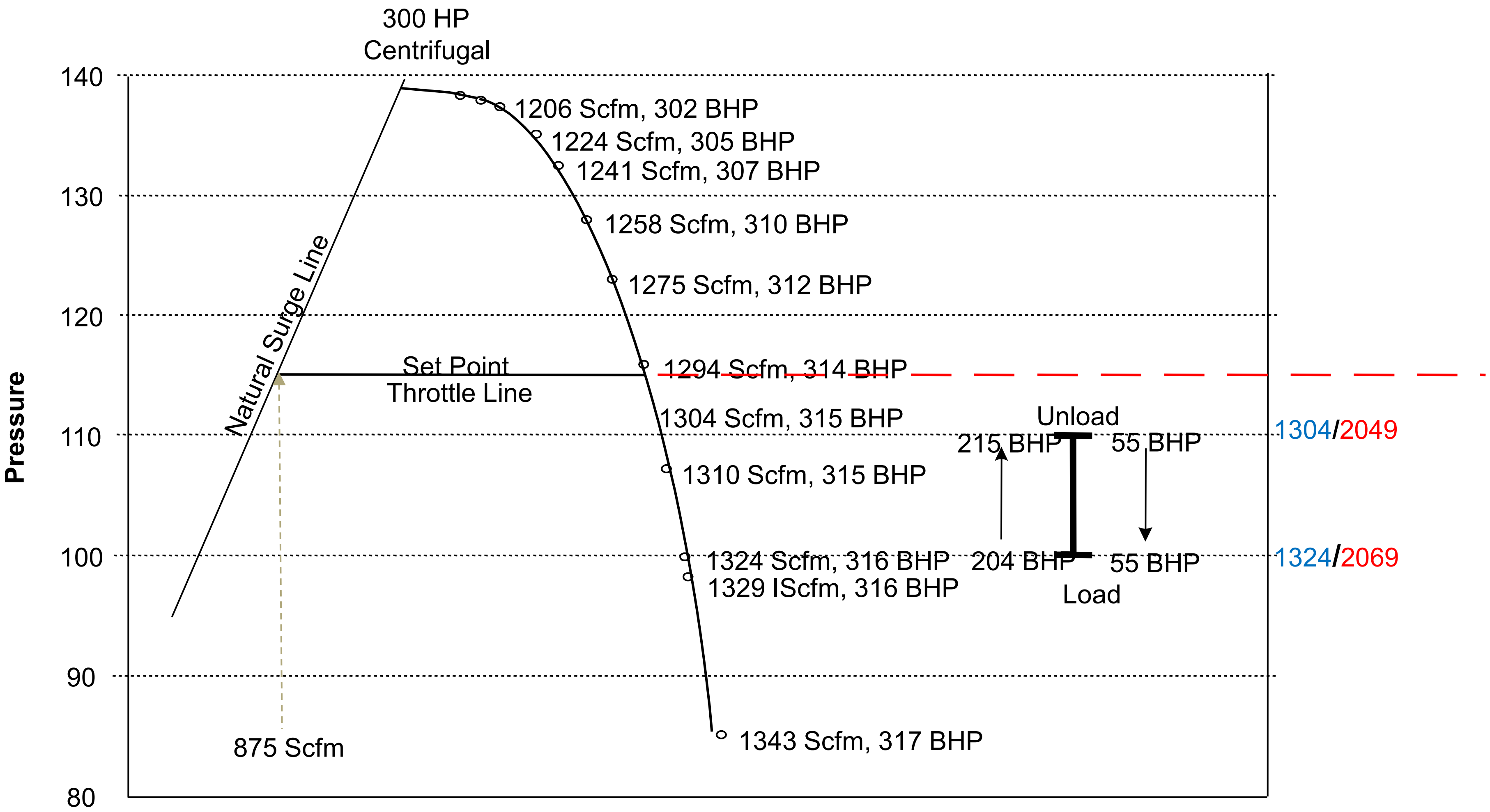
- Performance is affected by inlet conditions and cooling water temperature
- Characteristic curve is determined by impeller design
- Two conditions should be avoided:
  - Surge (flow reversal)
  - Choke (excessive flow vs. frame design)
- Inlet throttle valves modulate the compressor to reduced flow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



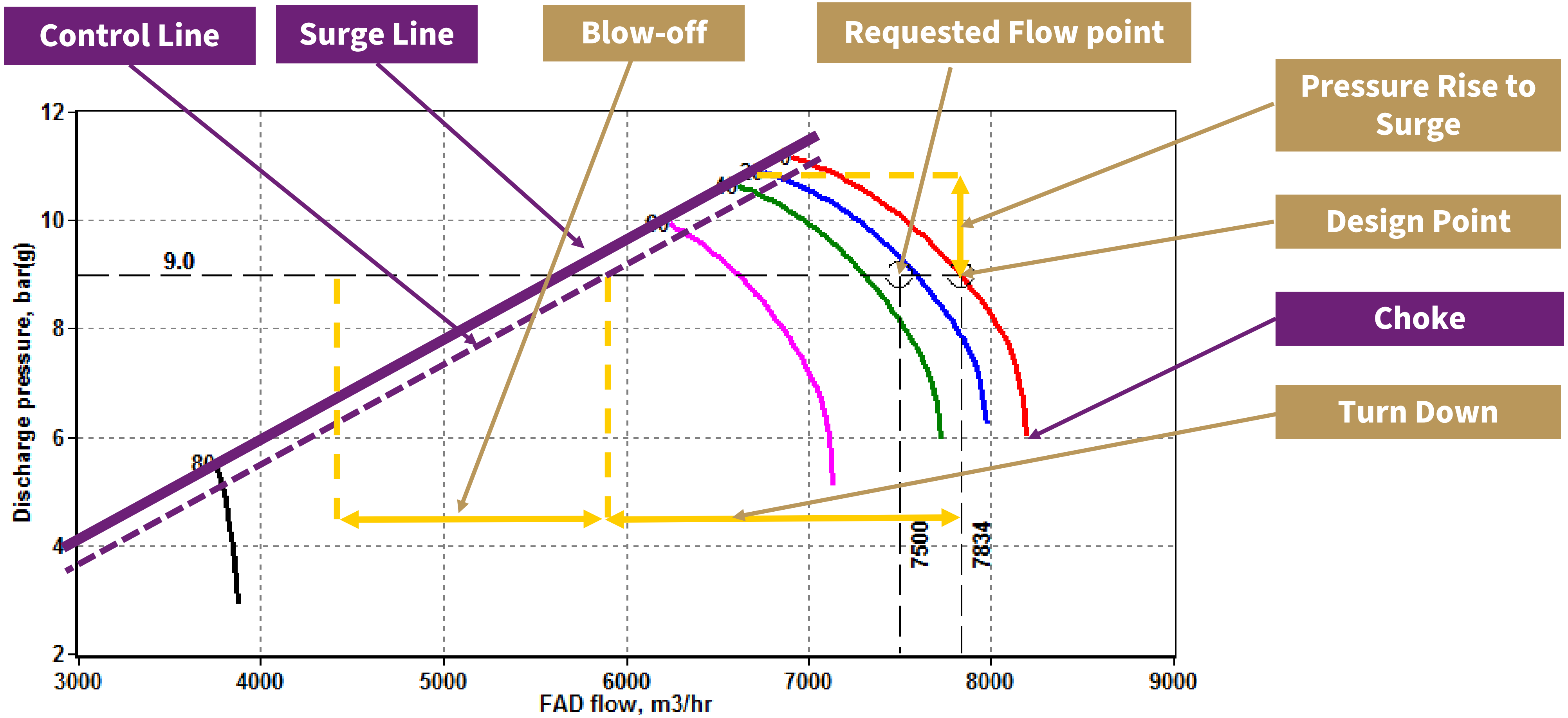

% Discharge Pressure
140
130
120
110
100
90
80
Control line
Surge limit
% Flow
By-pass
Turn-down range



Building the Profile



Centrifugal Compressor Control Common Terms



Control Line

Surge Line

Blow-off

Requested Flow point

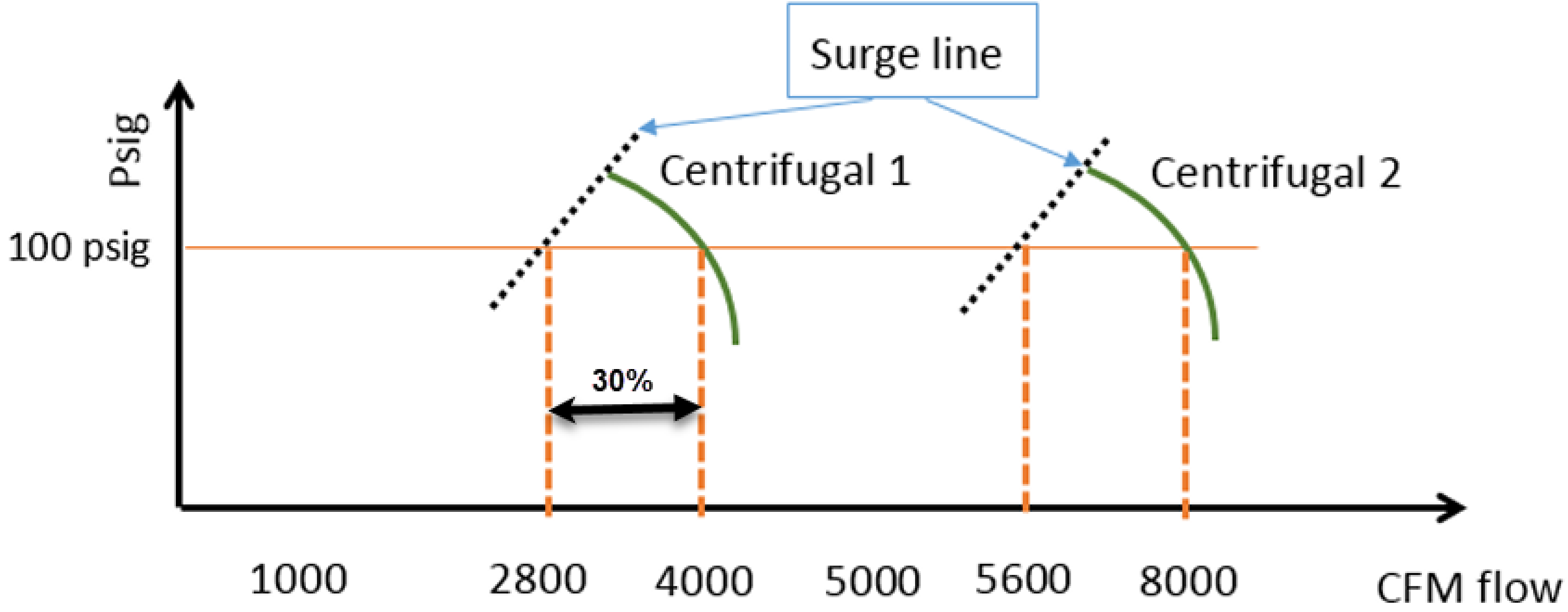
Pressure Rise to Surge

Design Point

Choke

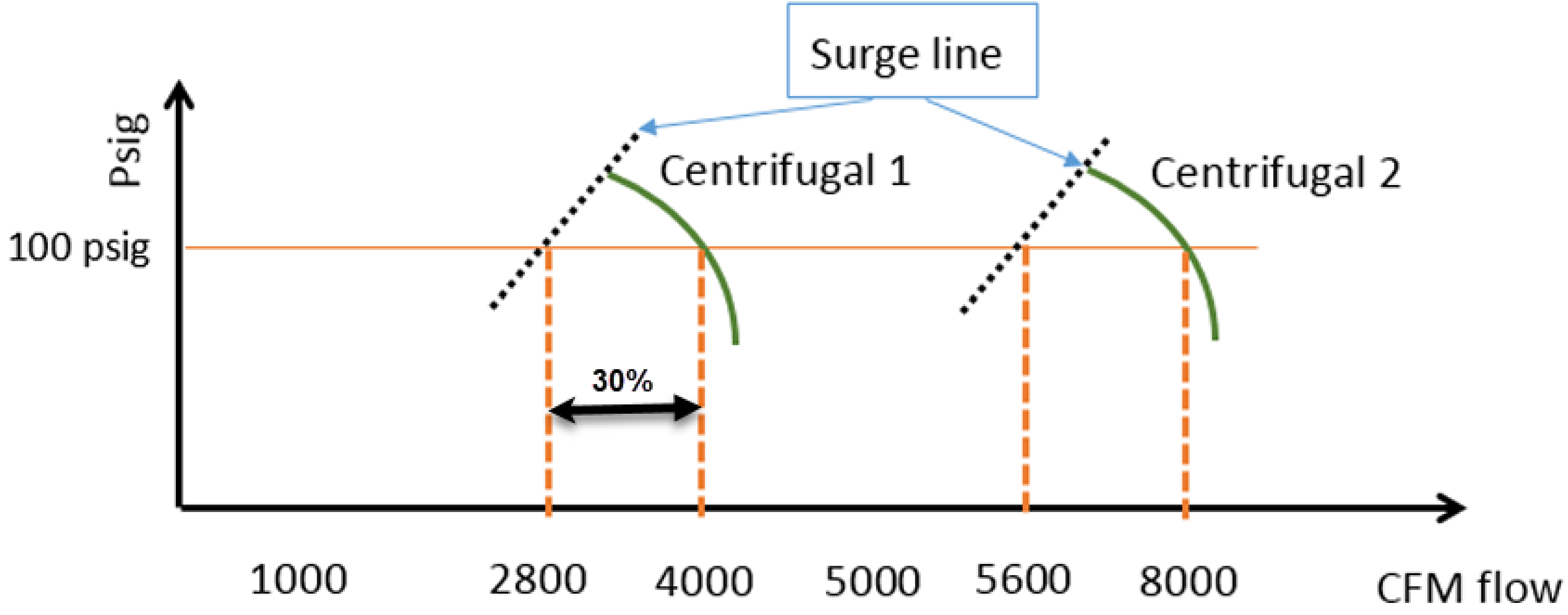
Turn Down

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



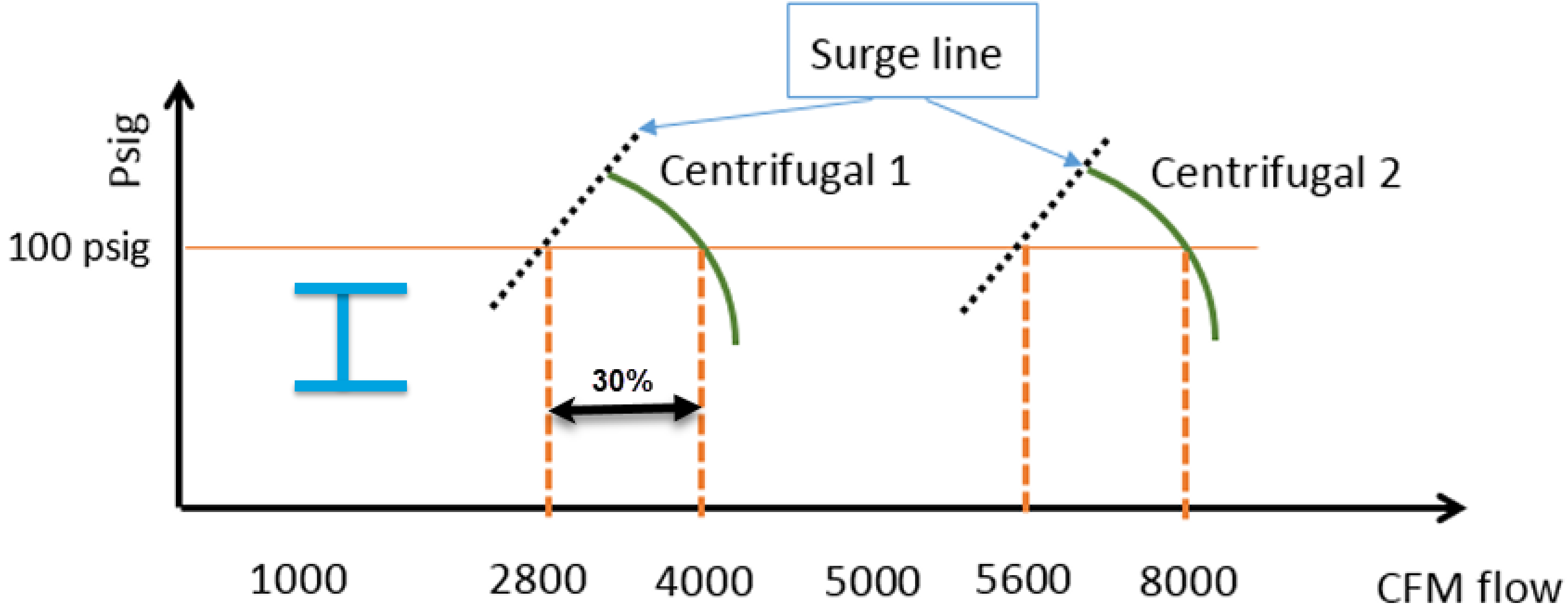
- Plant has 8000 cfm peak demand, 5800 cfm average demand, and 3000 cfm minimum demand during weekends at operating pressure of 100 psig.
- Two 4000 cfm centrifugals with a 30% turndown to 2800 cfm

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



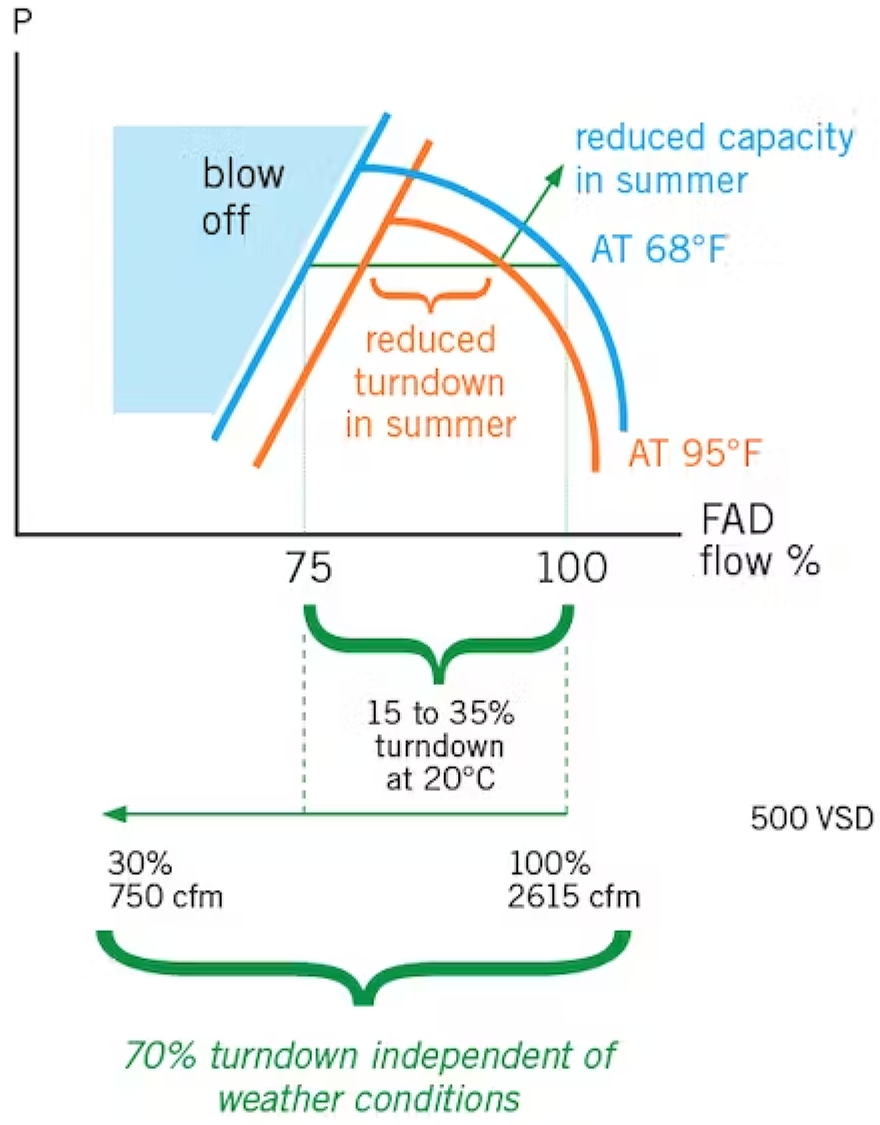
- During peak demand of 8000 cfm, both compressors will run at full load.
- When the flow demand is reduced to the average demand of 5800 cfm, the two centrifugal compressors will close the inlet guide valve and run in its turndown range without exhausting any compressed air to atmosphere.

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

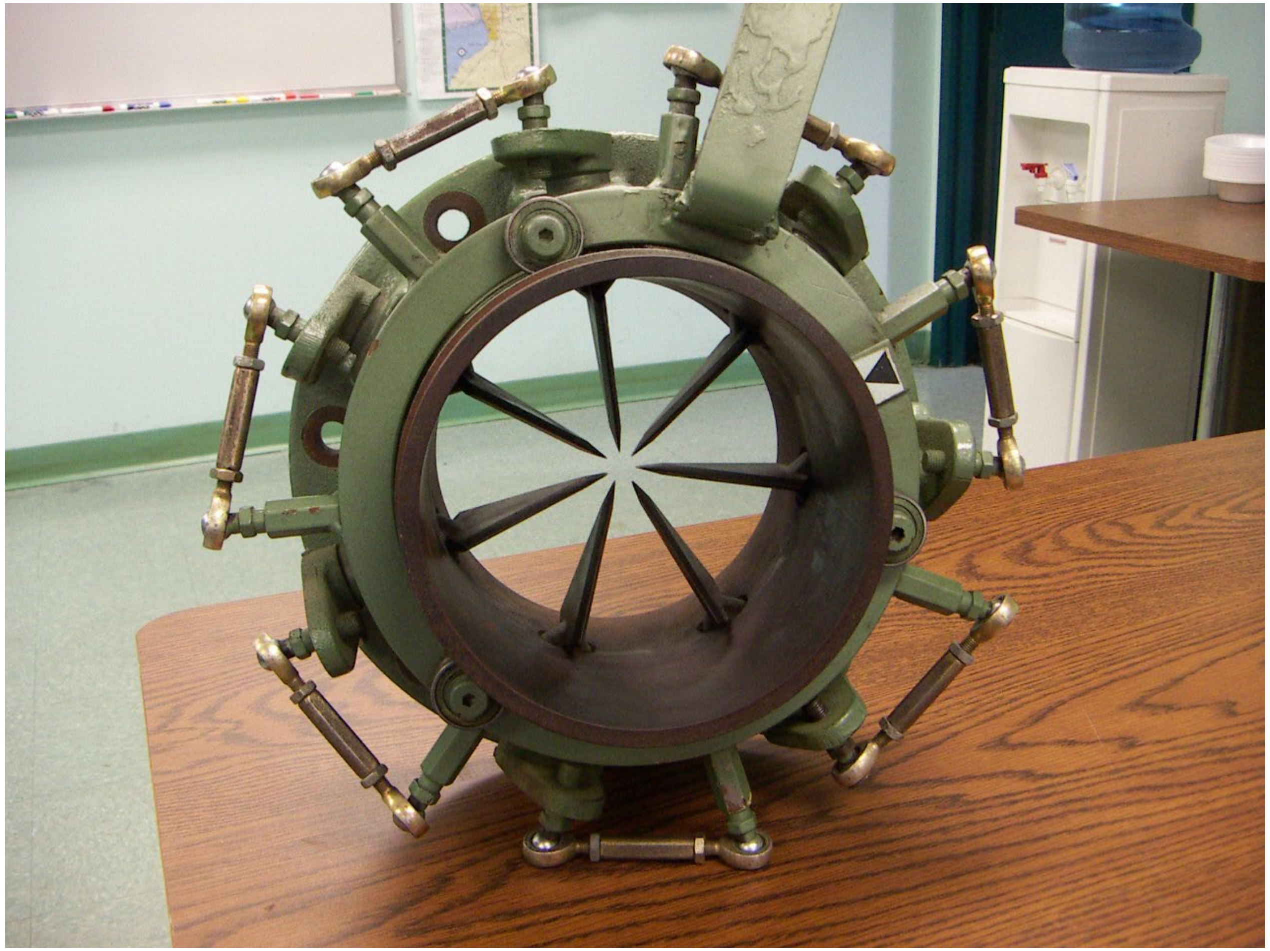


- During the weekend, when the demand reaches to minimum flow of 3000 cfm, one centrifugal compressor will stop and only one compressor will run in its turndown range.
- With this combination, the centrifugal compressors will work most efficiently and save a plant significant energy.
- If flow drops 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.

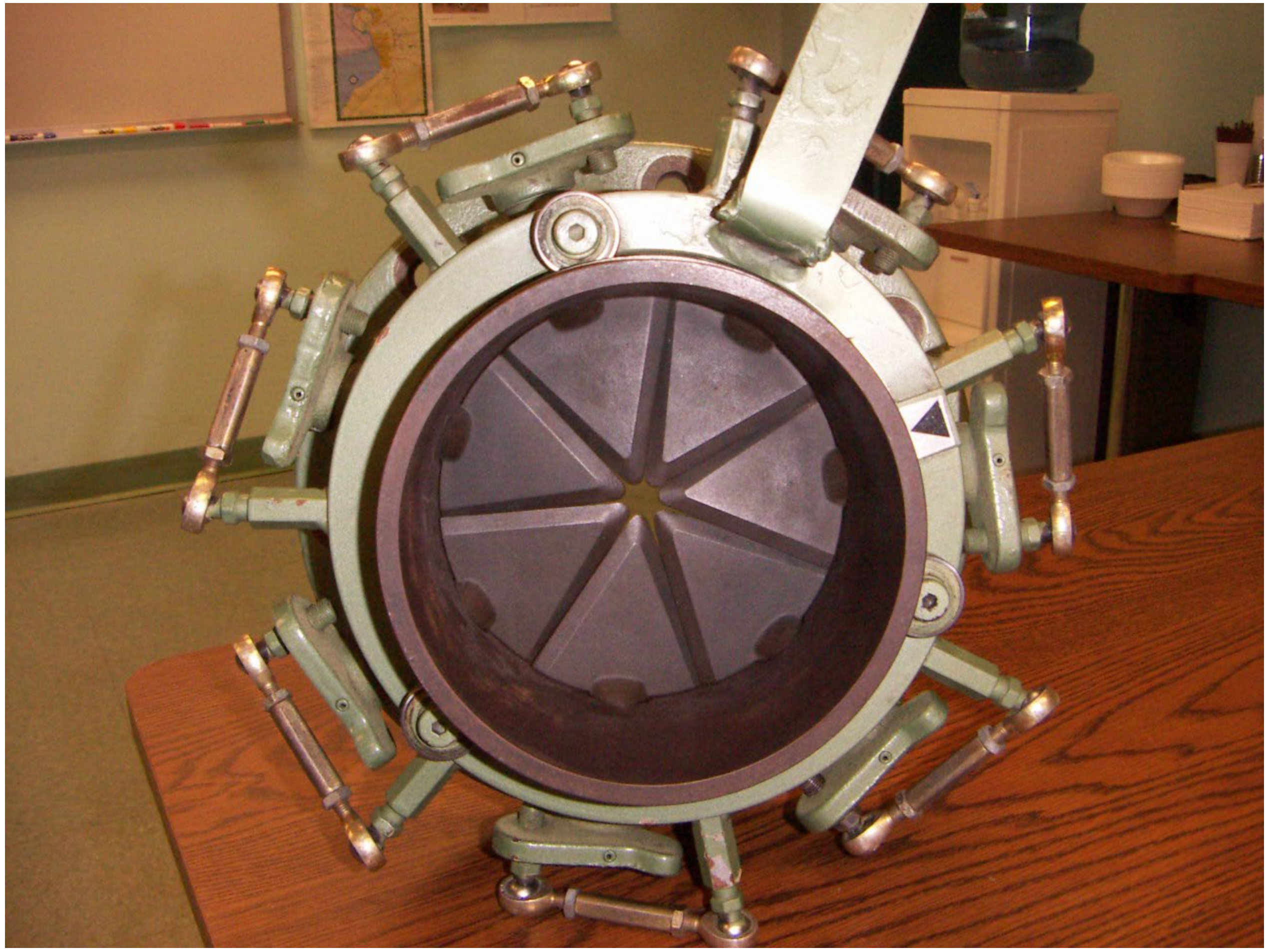
How do I know how to size Centrifugal to my flow Patterns?


P
blow off
reduced capacity in summer
AT 68°F
reduced turndown in summer
AT 95°F
FAD flow %
75
100
15 to 35% turndown at 20°C
500 VSD
30%
750 cfm
100%
2615 cfm
70% turndown independent of weather conditions

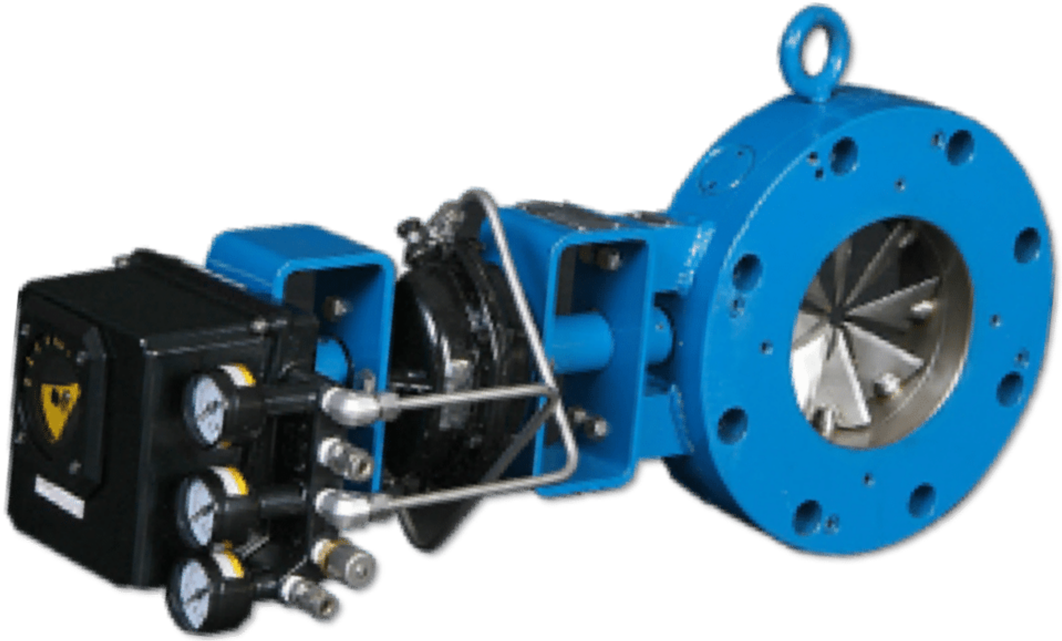
Inlet Guide Vanes - Open



Inlet Guide Vanes - Closed



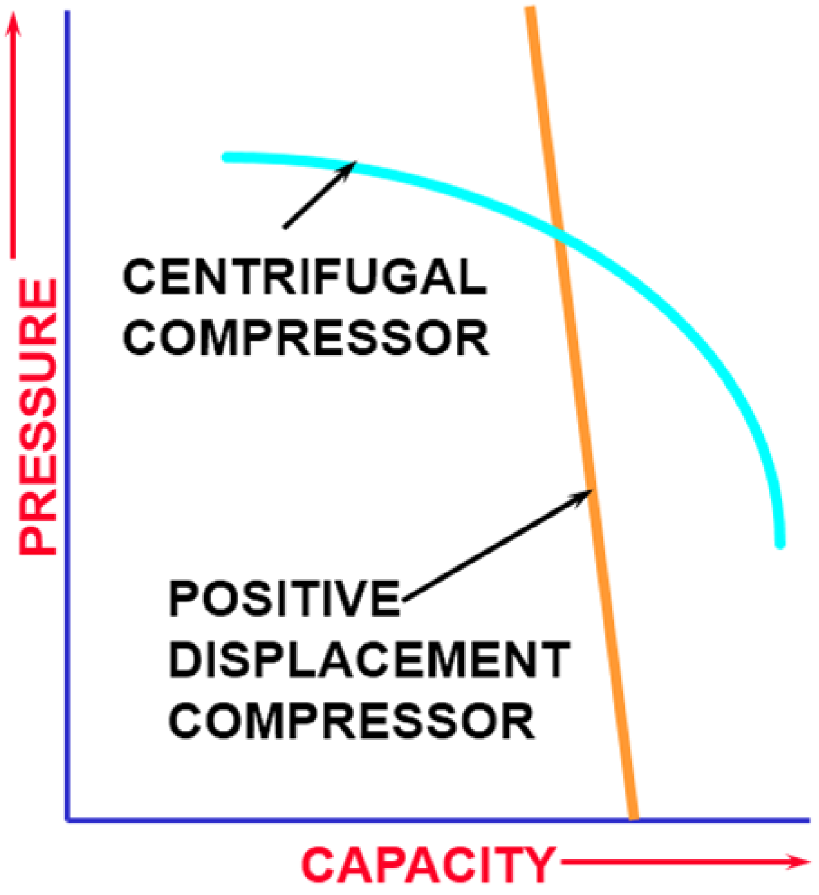
Inlet Guide Vanes



- This valve positioner consists of a common housing that contains a 4 – 20 mA current to pressure (I/P) transducer that controls the attached pilot valve operated air to actuator assembly.
- The positioner will output 0 to 65 psi (448 kPa) to the actuator from an air signal.
- The air signal provided by the positioner is proportional to the microcontroller 4 – 20 mA output.
- The actuator provides the power to drive the valve open or closed in proportion to the microprocessor output control signal.

Centrifugal Compressor Control

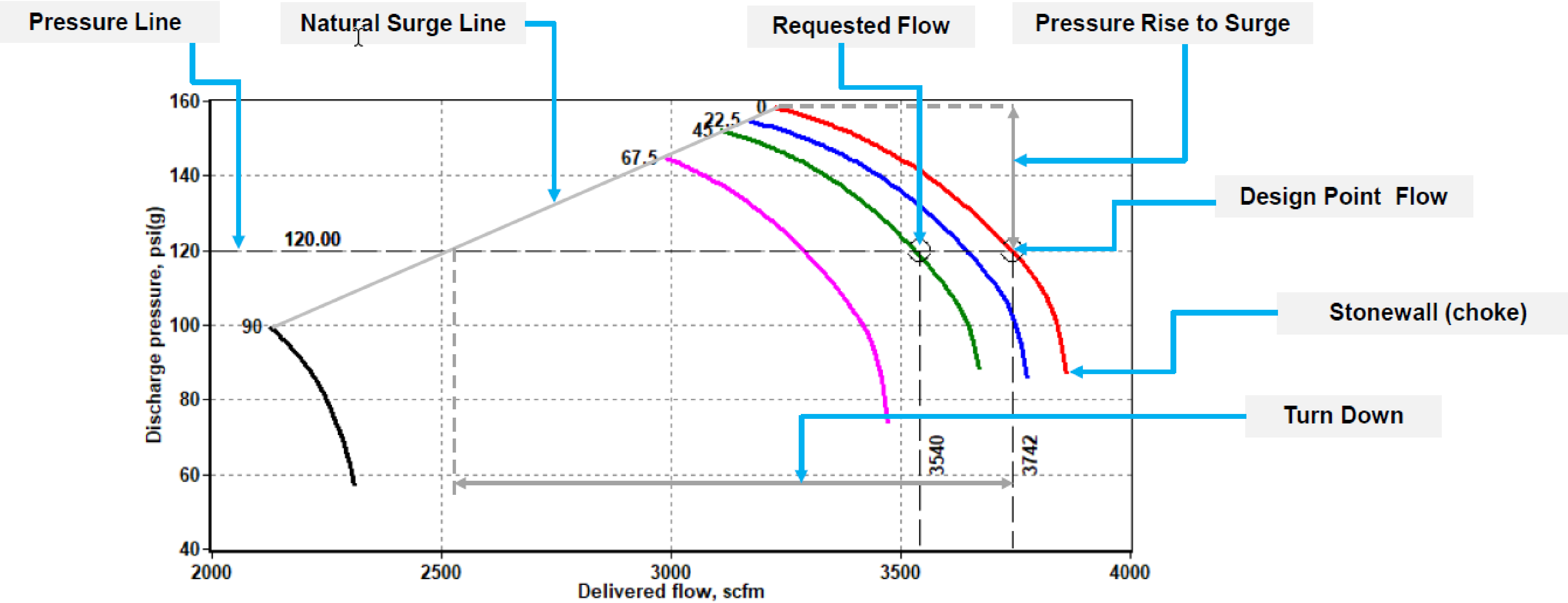
The relationship of flow and pressure for dynamic compressors is different from that of positive displacement machines.



Effects on dynamic compressor performance

- Inlet pressure
- Inlet air temperature
- Cooling water temperature

Centrifugal Performance



Pressure Line

Natural Surge Line

Requested Flow

Pressure Rise to Surge

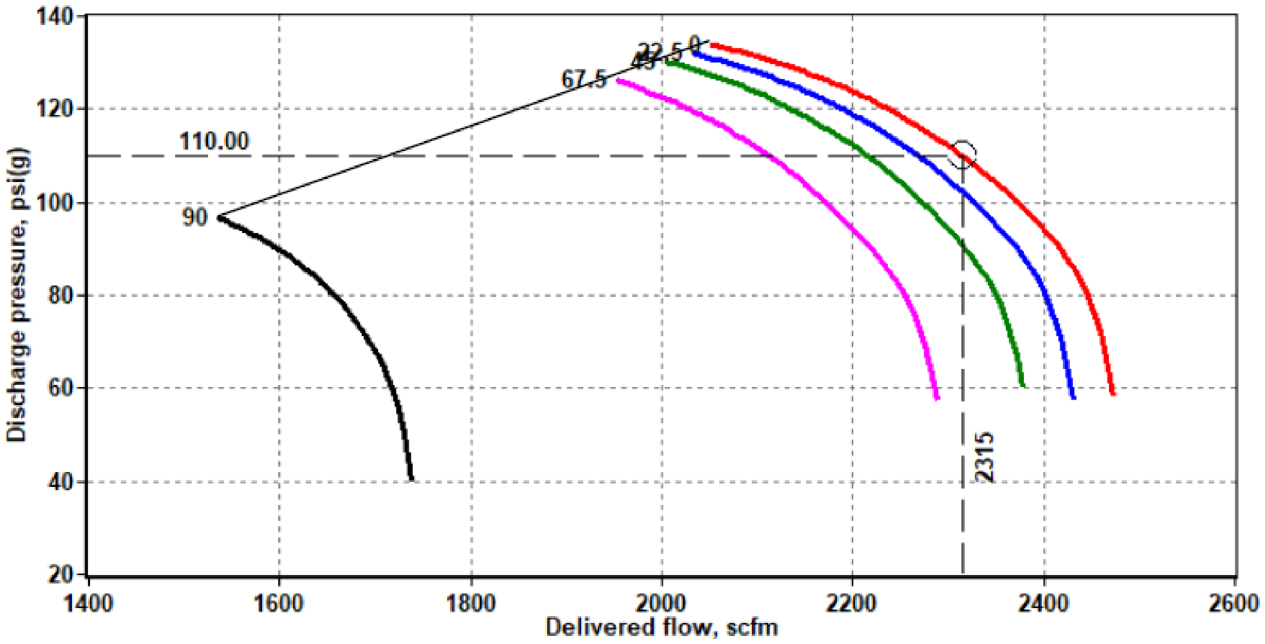
Design Point Flow

Stonewall (choke)

Turn Down

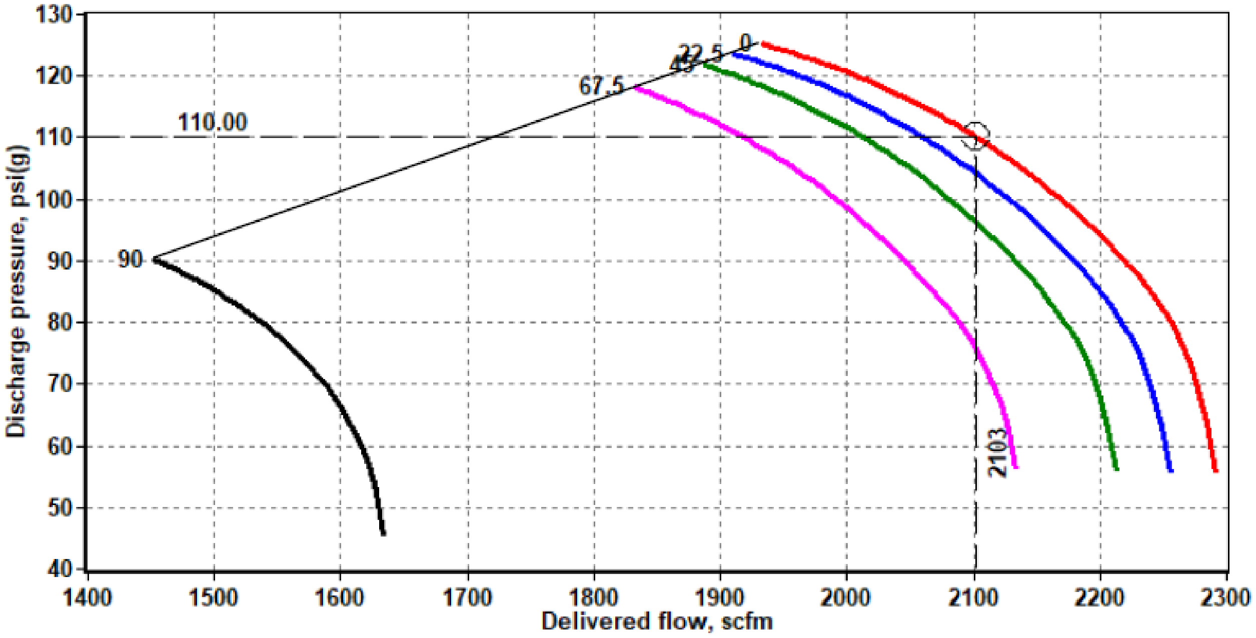
INLET TEMPERATURE CHANGE – EFFECT ON AIR OUTPUT

Capacity at 95^{0}F inlet Temp



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

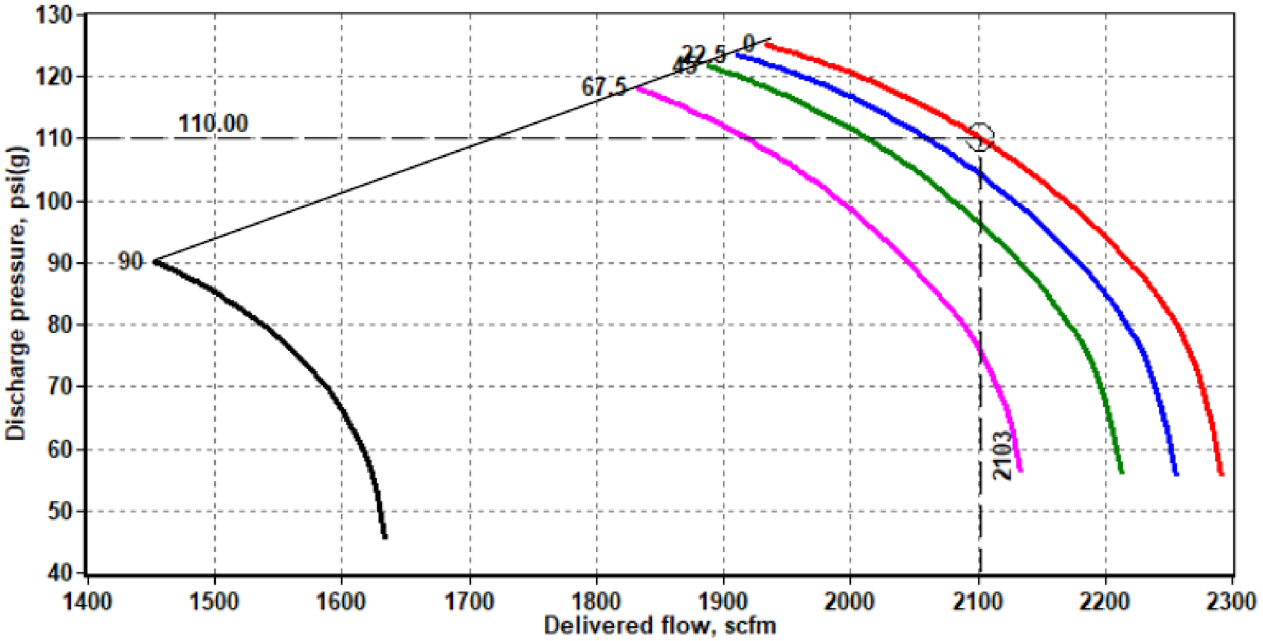
Capacity at 119^{0}F inlet Temp



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

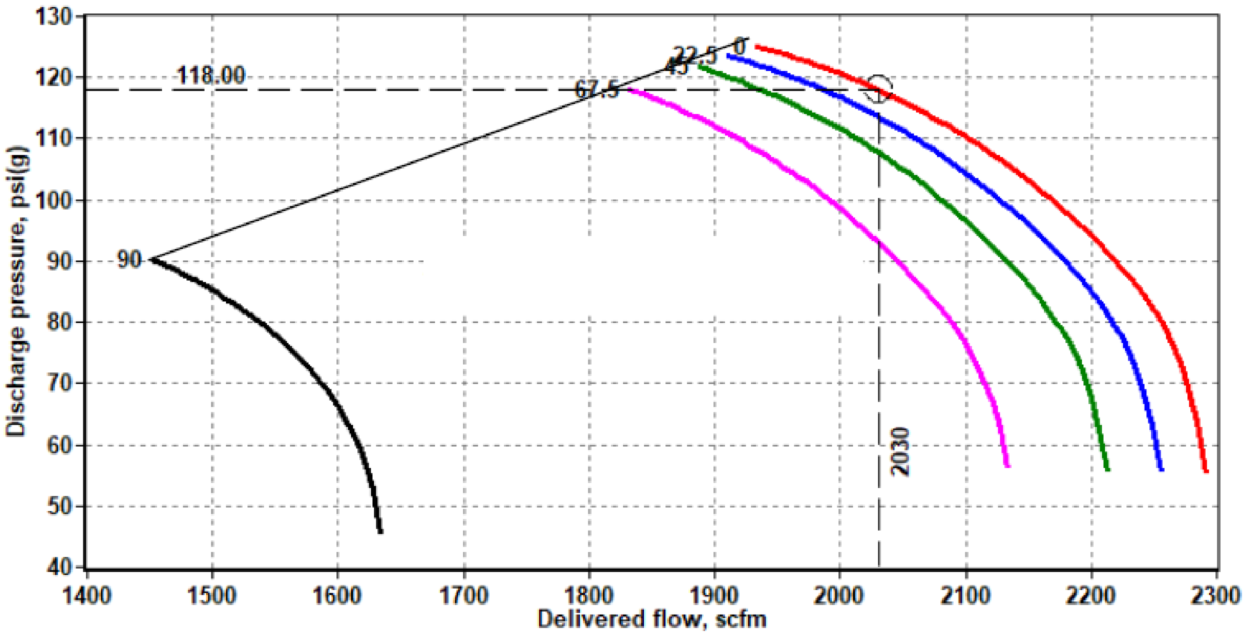
DISCHARGE PRESSURE CHANGE – EFFECT ON AIR OUTPUT

Capacity at 110 psig discharge pressure



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

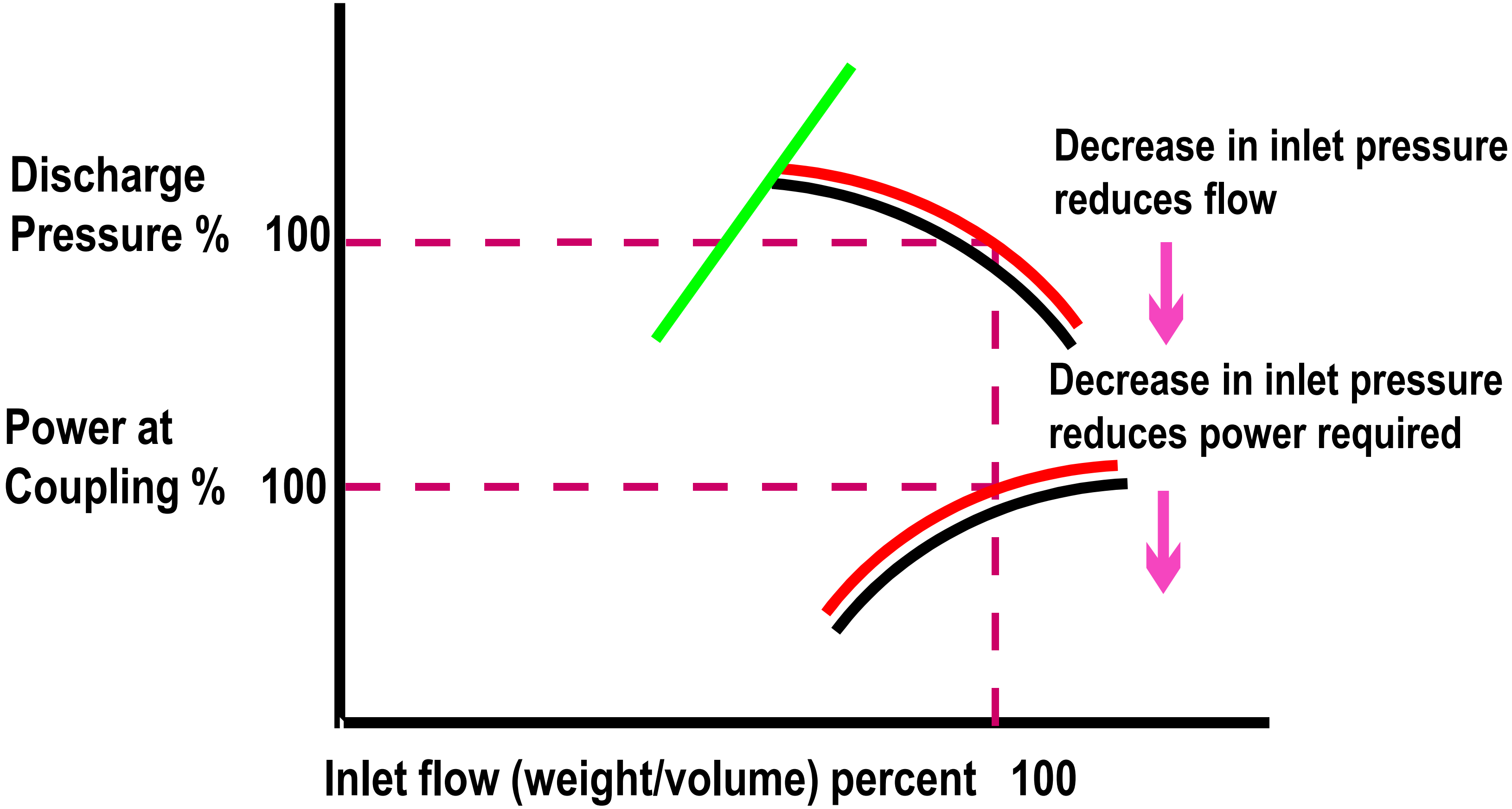
Capacity at 118 psig discharge pressure



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

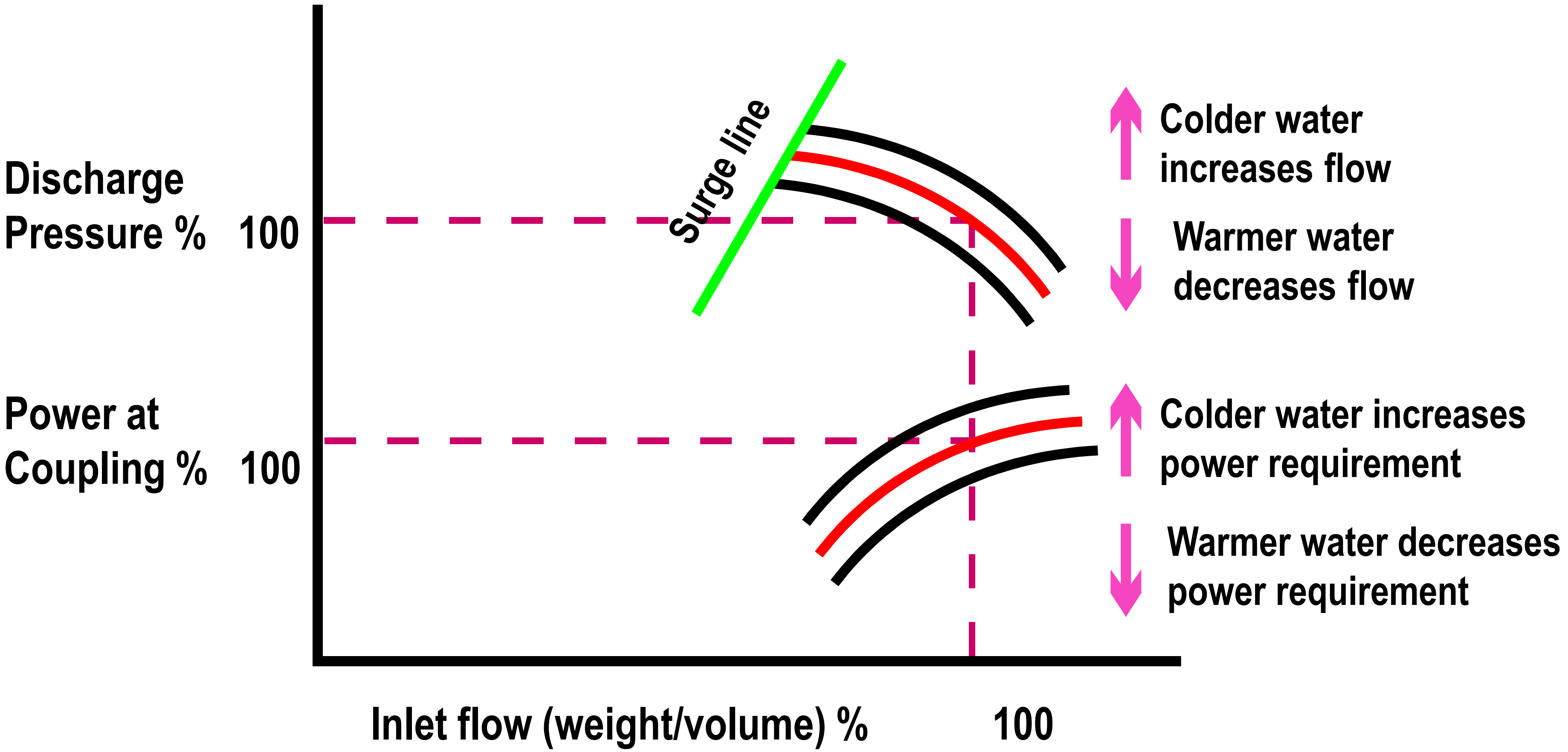
Inlet Pressure Effects On Dynamic Compressor Performance

Inlet pressure



Cooling Water Effects On Dynamic Compressor Performance

Cooling water temperature



Colder water increases flow

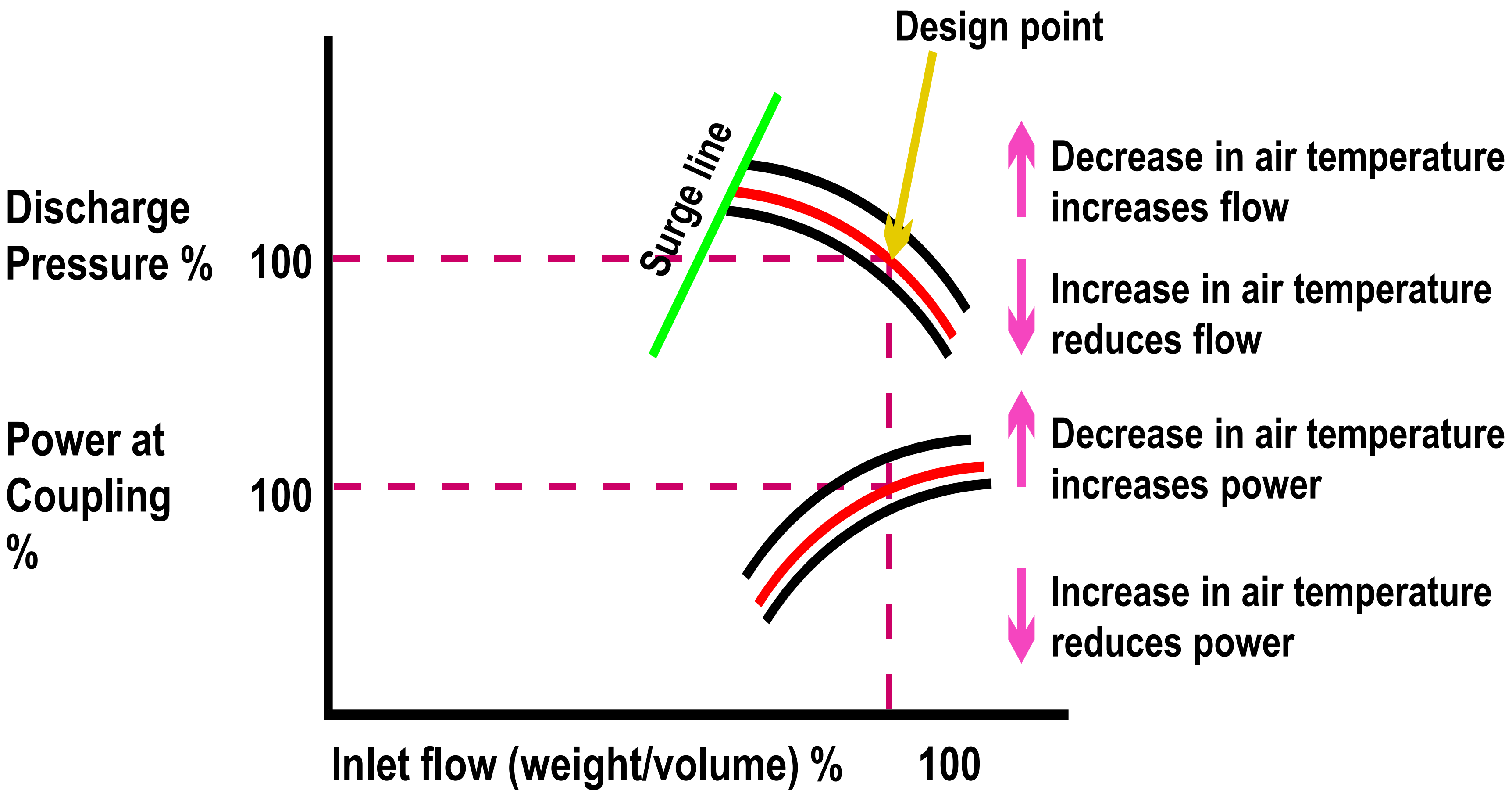
Warmer water decreases flow

Colder water increases power requirement

Warmer water decreases power requirement

Inlet Air Temperature Effects On Dynamic Compressor Performance

Inlet air temperature influence



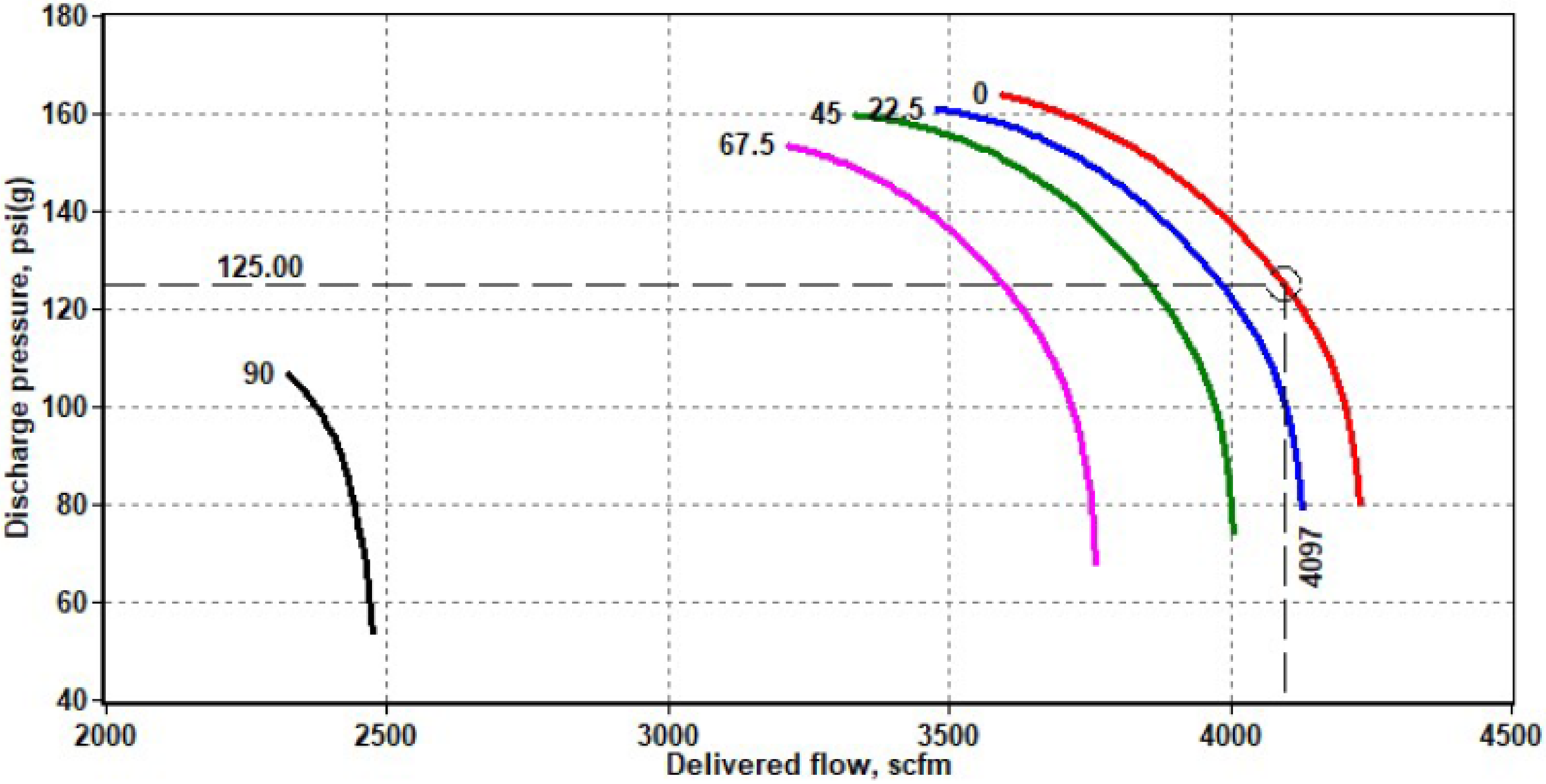
↑ Decrease in air temperature increases flow

↓ Increase in air temperature reduces flow

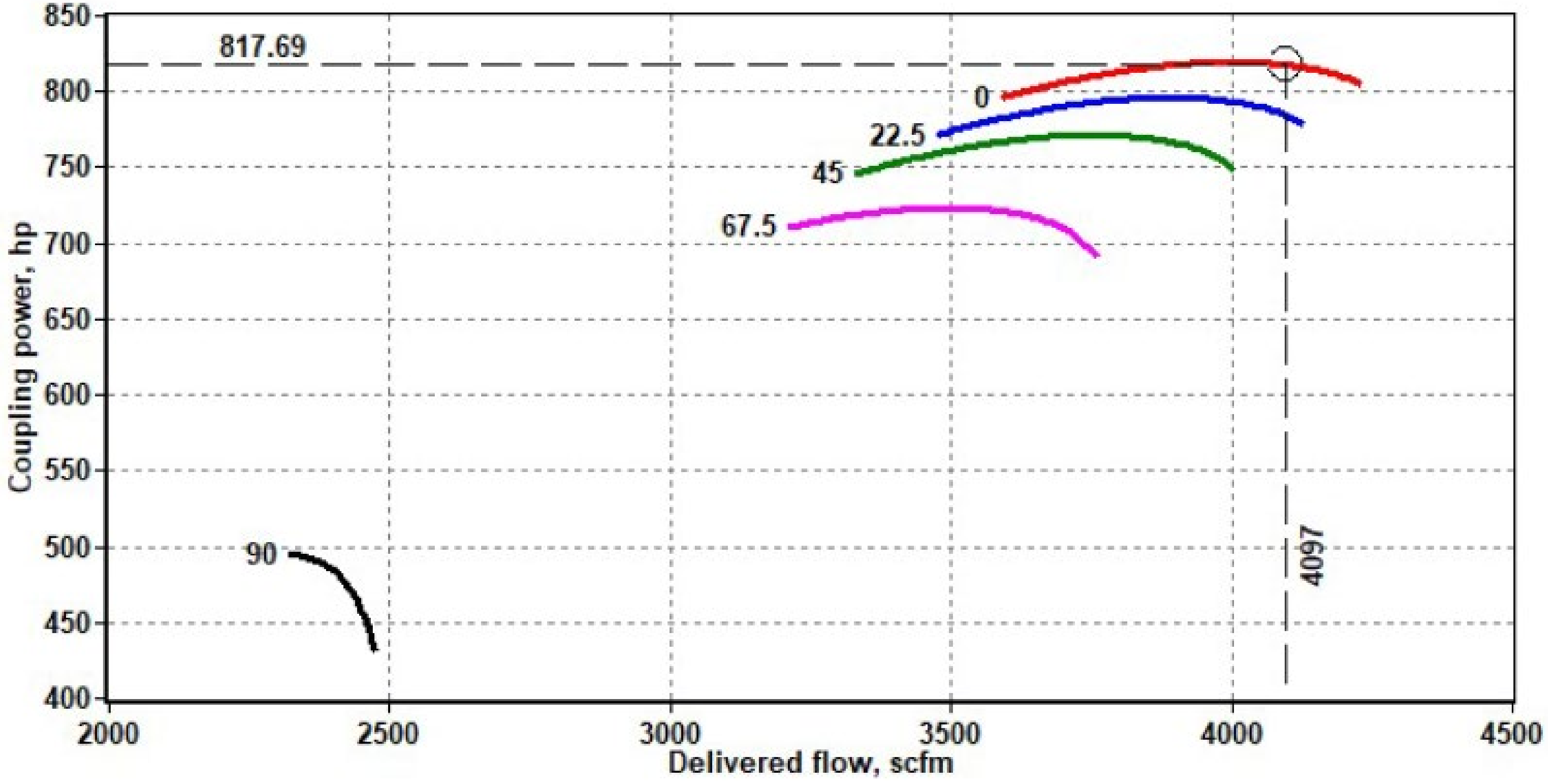
↑ Decrease in air temperature increases power

↓ Increase in air temperature reduces power

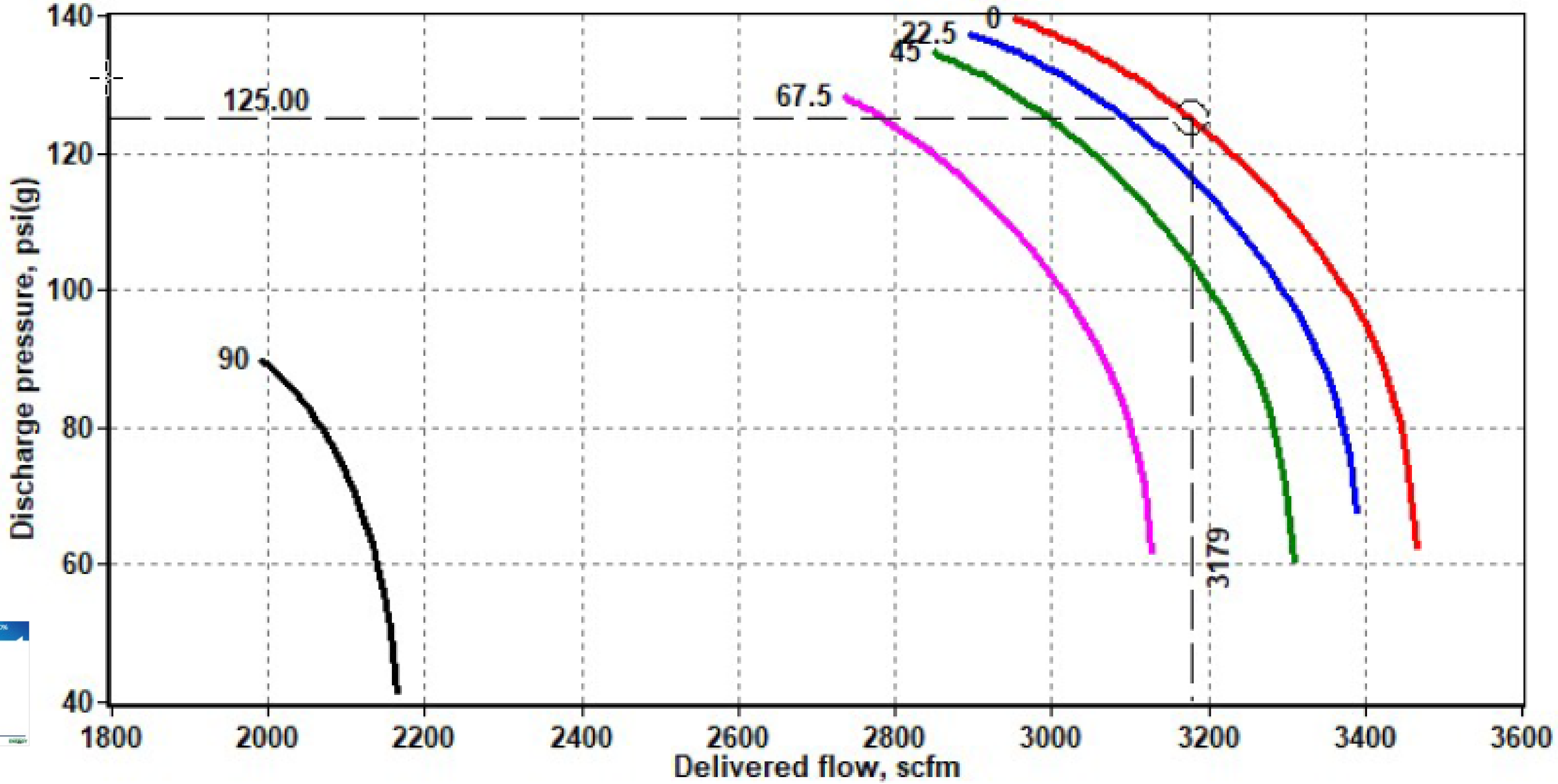
Curve showing air compressor performance at a 34°F inlet,60% RH, 77°F Coolant and 125 psig discharge pressure:

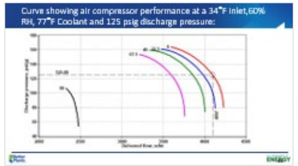


Curve showing air compressor horse power at a 34°F inlet,60% RH, 77°F Coolant and 125 psig discharge pressure:

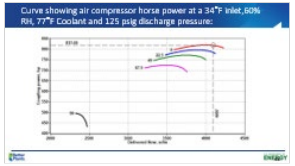


Curve showing air compressor performance at a 104°F inlet,100% RH, 77°F Coolant and 125 psig discharge pressure:

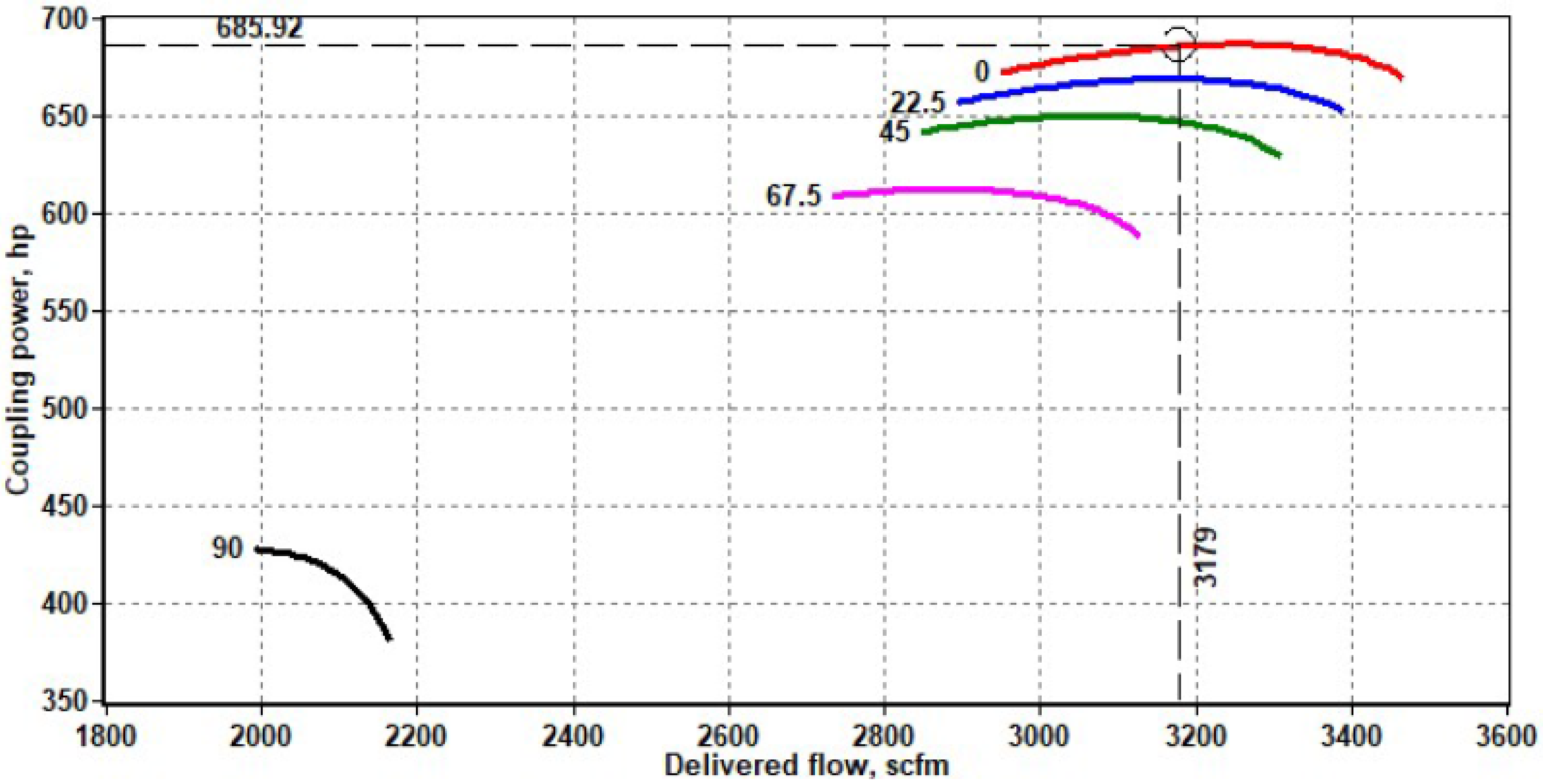



Curve showing air compressor performance at a 34°F inlet,60% RH, 77°F Coolant and 125 psig discharge pressure:

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



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



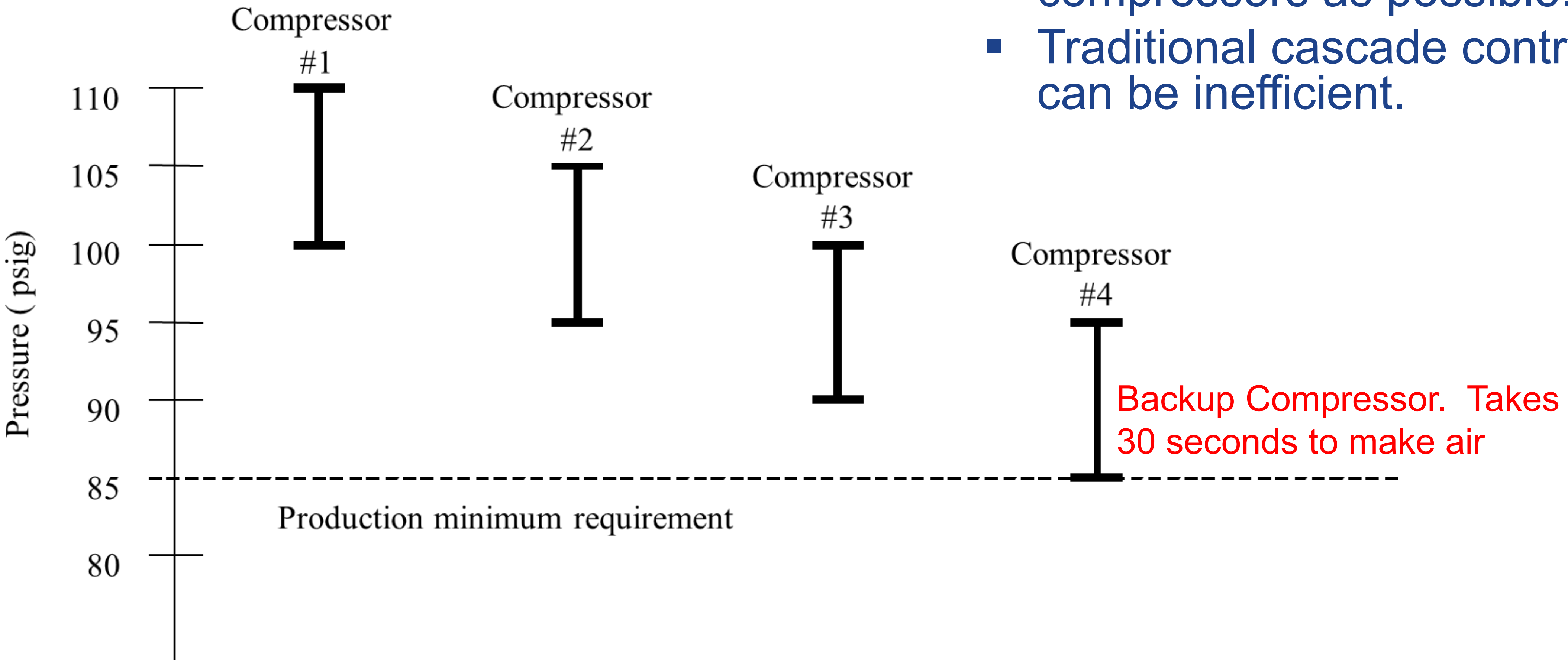
Multiple Compressor Control

- Holds a constant air pressure in the network within narrow limits.
- Easy to install.
- Connectable to all kinds of compressors.
- Optimisation of service intervals = lower service cost.
- Priority selection : old versus new machines.
- Delayed start : NEVER start two machines or more at the same time => high current peaks are avoided.
- Base load compressors can fill a net in advance to avoid 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

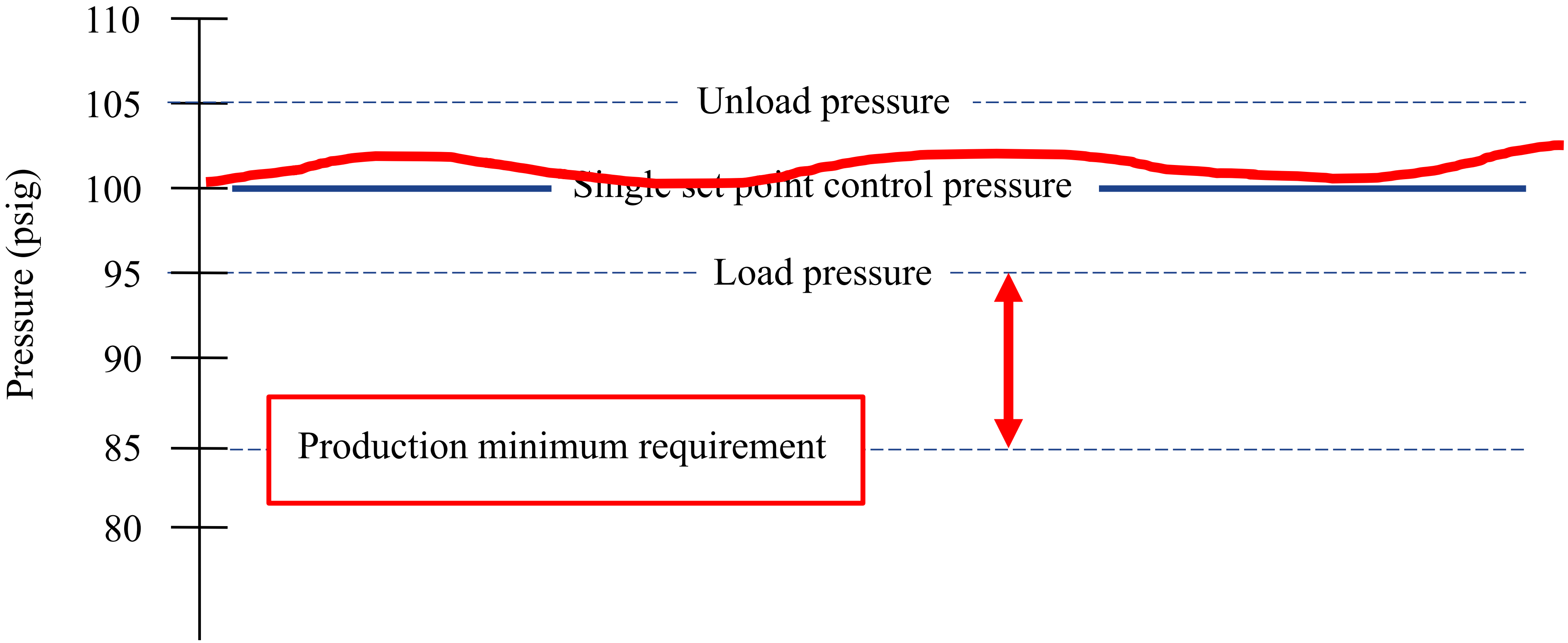


Backup Compressor. Takes 30 seconds to make air

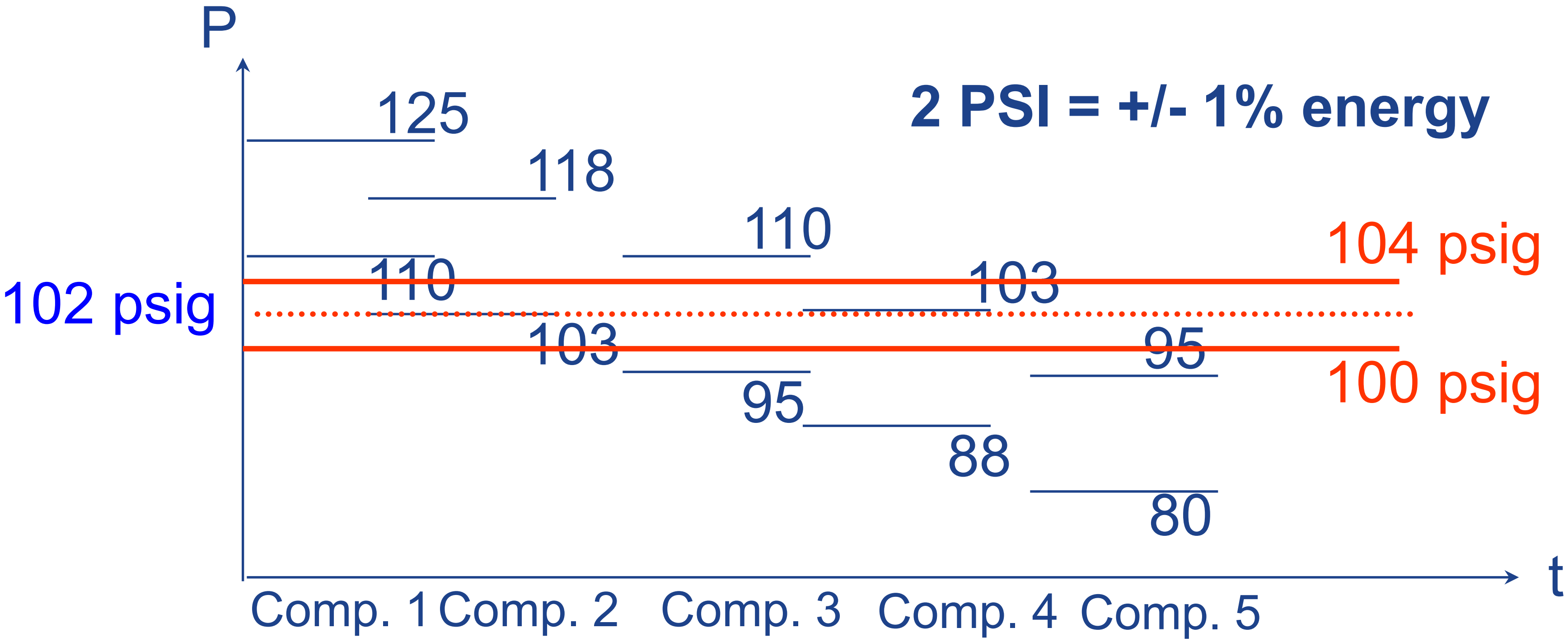
- Base load as many compressors as possible.
- Traditional cascade control can be inefficient.

Master Controls

- Basic single set point control scheme



Master Control Basics

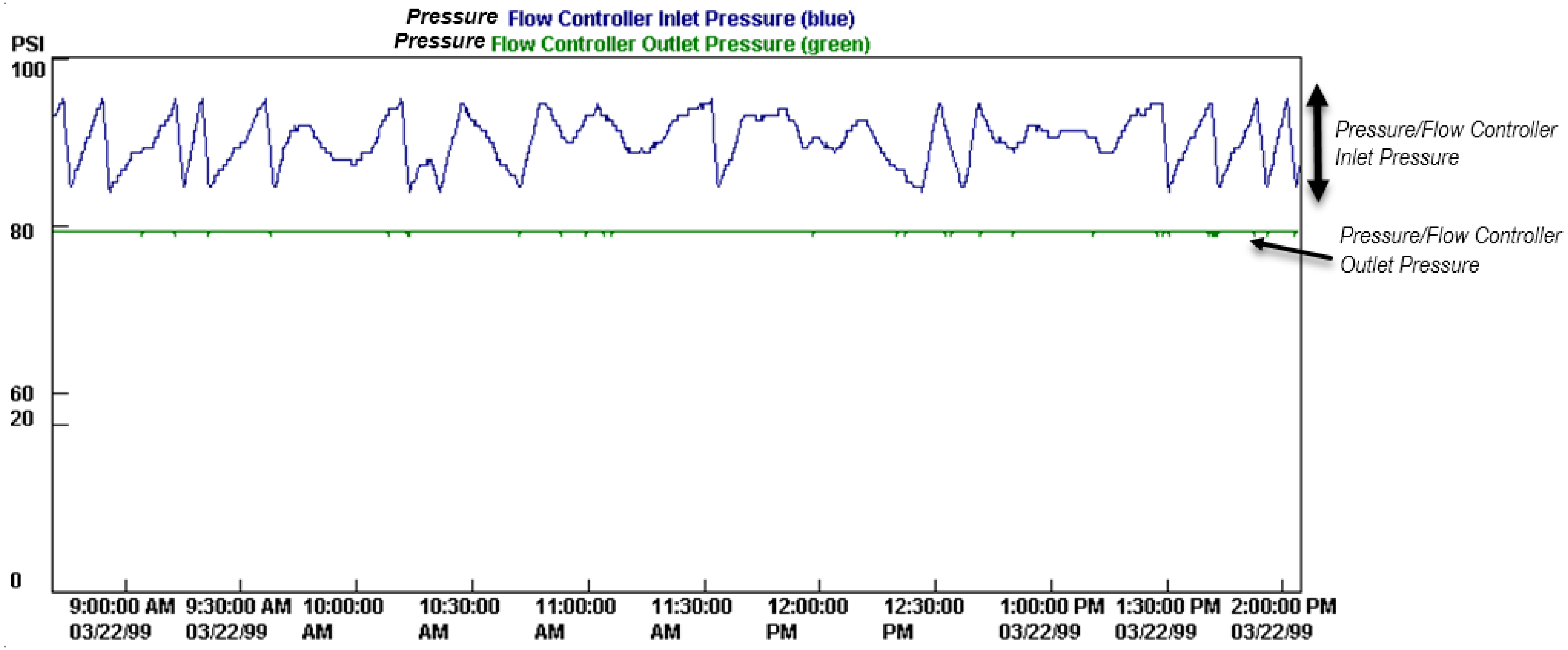


Cascaded Pressure Switches Vs Master

Pressure/Flow Controllers

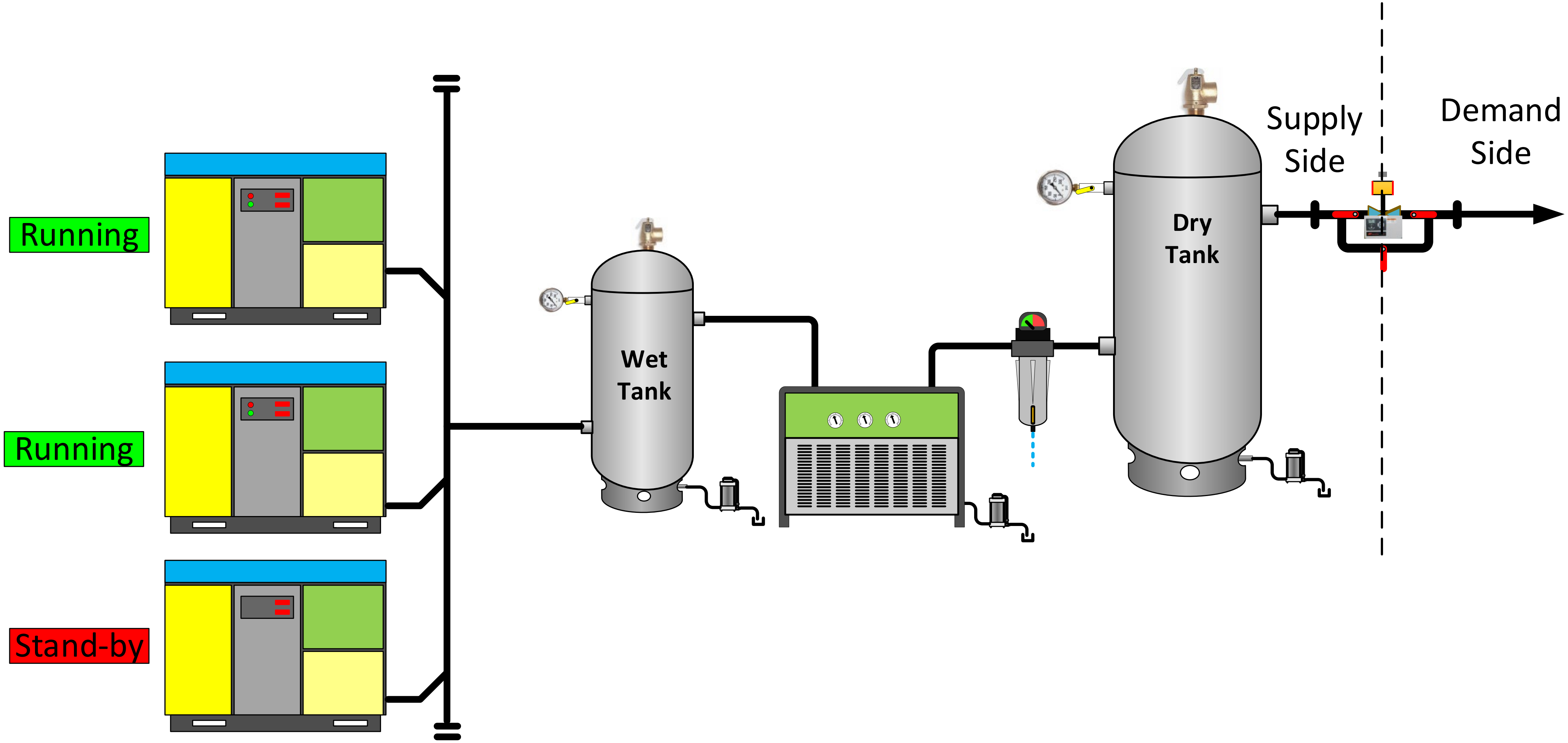
- Primary function: Stabilize pressure regardless of demand
- Most compressor controls cause 3-10 psi swings
- Multiple compressors can compound the system pressure swings
- Pressure/flow controllers typically hold pressure to production within ± 1% of set point
- The following graph is from a system 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.

Pressure Flow Controllers


Running
Running
Stand-by
Wet Tank
Dry Tank
Supply Side
Demand Side

Useful Storage (Reviewed at a later session)

- Useful Storage = Capacity to Store x Allowable Pressure Drop

$$\frac{V_{cf}}{P_a} \times \Delta P$$

Given a 660 gallon tank and the pressure can drop 10 psi

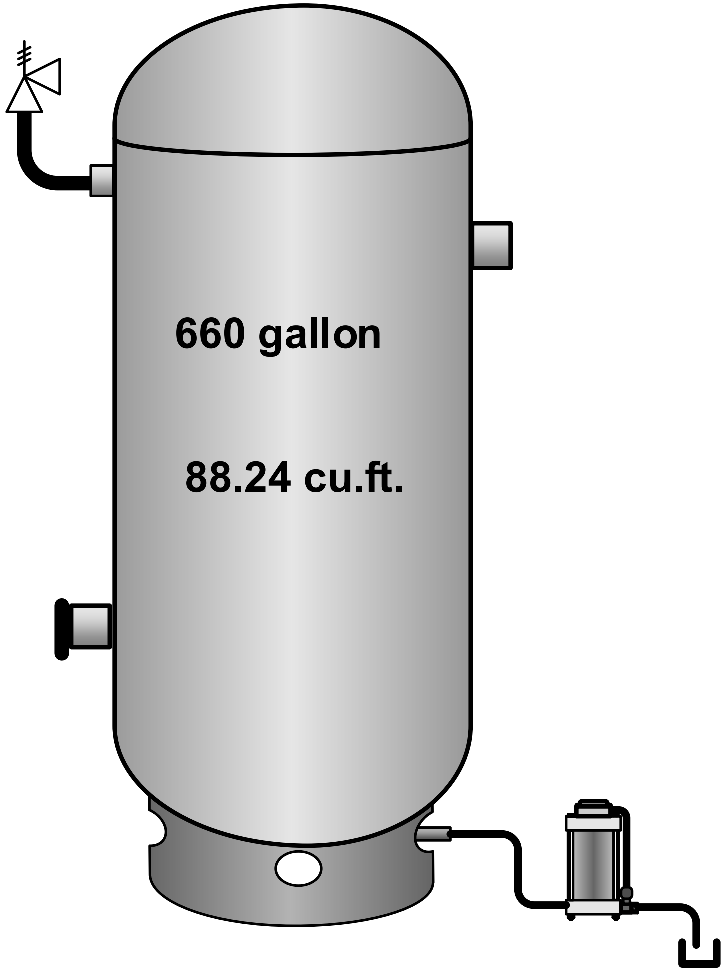
What is the usable (useful) storage?

660 gallons / 7.48 gal/cuft =88.24 cubic feet

88.24 cuft / 14.5 psia = **6.09 cuft /psia**

6.09 cuft /psia x 10 psia =

= 60.9 cuft of usable storage



https://measur.ornl.gov/calculators/compressed-air-list

Useful Storage

- Useful Storage = Capacity to Store x Allowable Pressure Drop

$$\frac{V_{cf}}{P_a} \times \Delta P$$

Given a 5000 gallon tank with pressure in at 100 and pressure out at 80

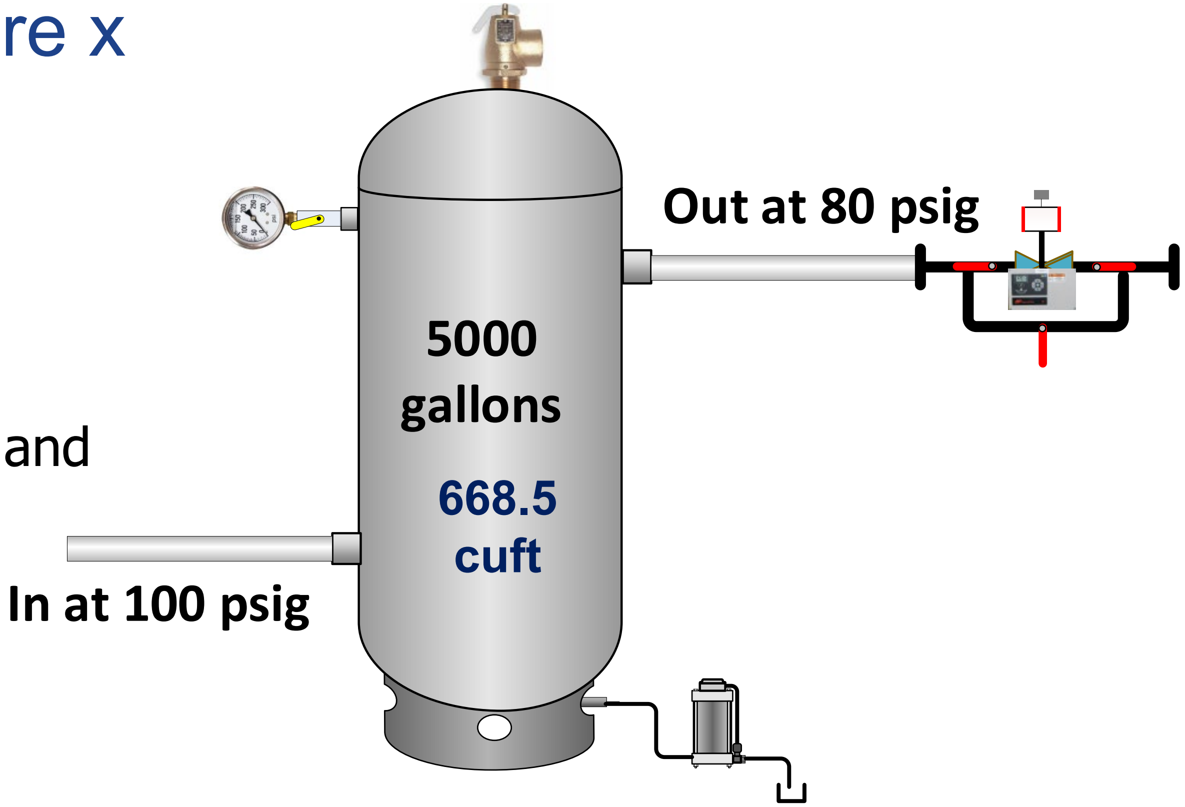
What is the usable (useful) storage?

5000 gallons / 7.48 gal/cuft =668.5 cubic feet

668.5 cuft / 14.5 psia = **46.1 cuft /psia**

46.1 cuft /psia x 20 psia =

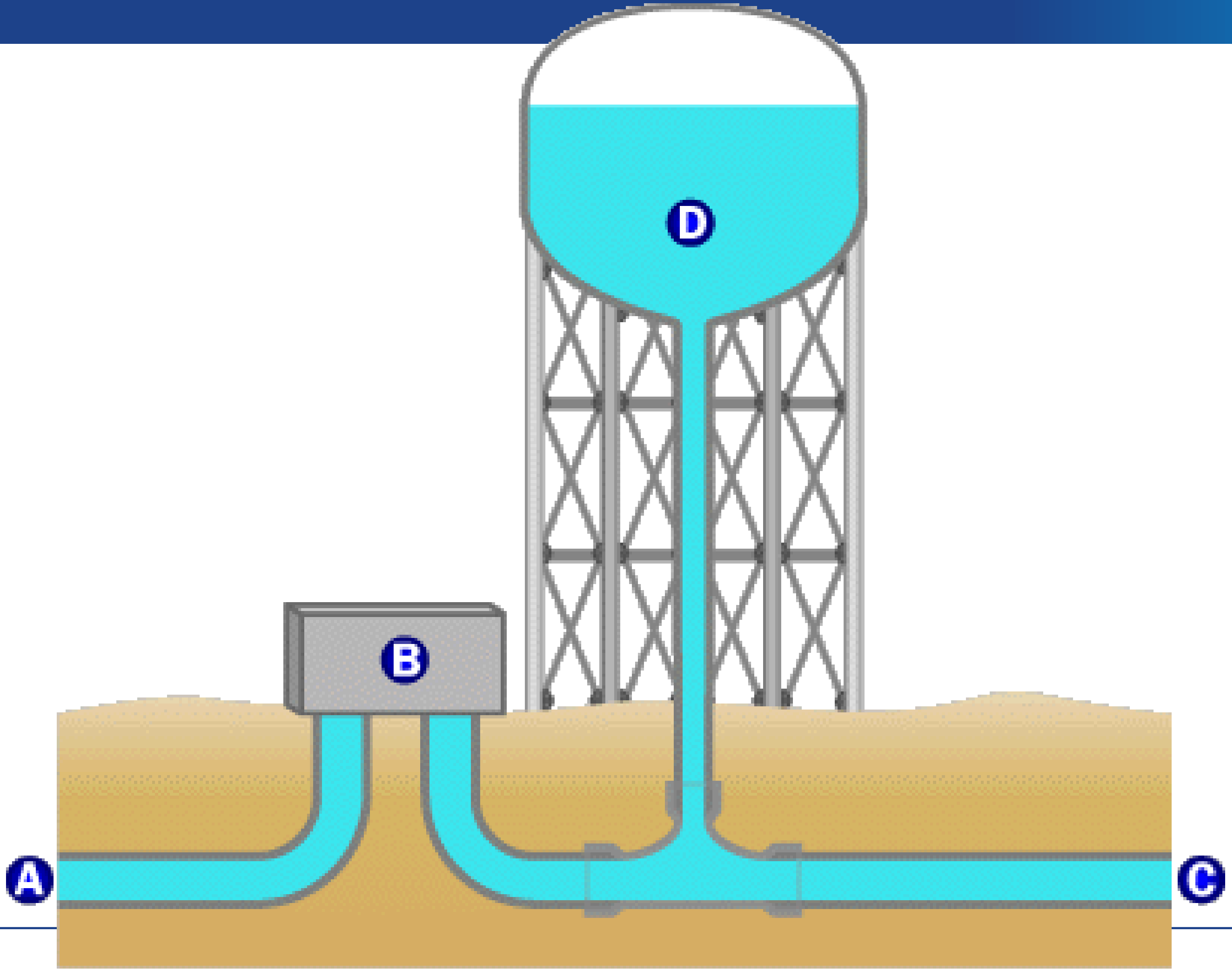
= 922 cuft of usable storage



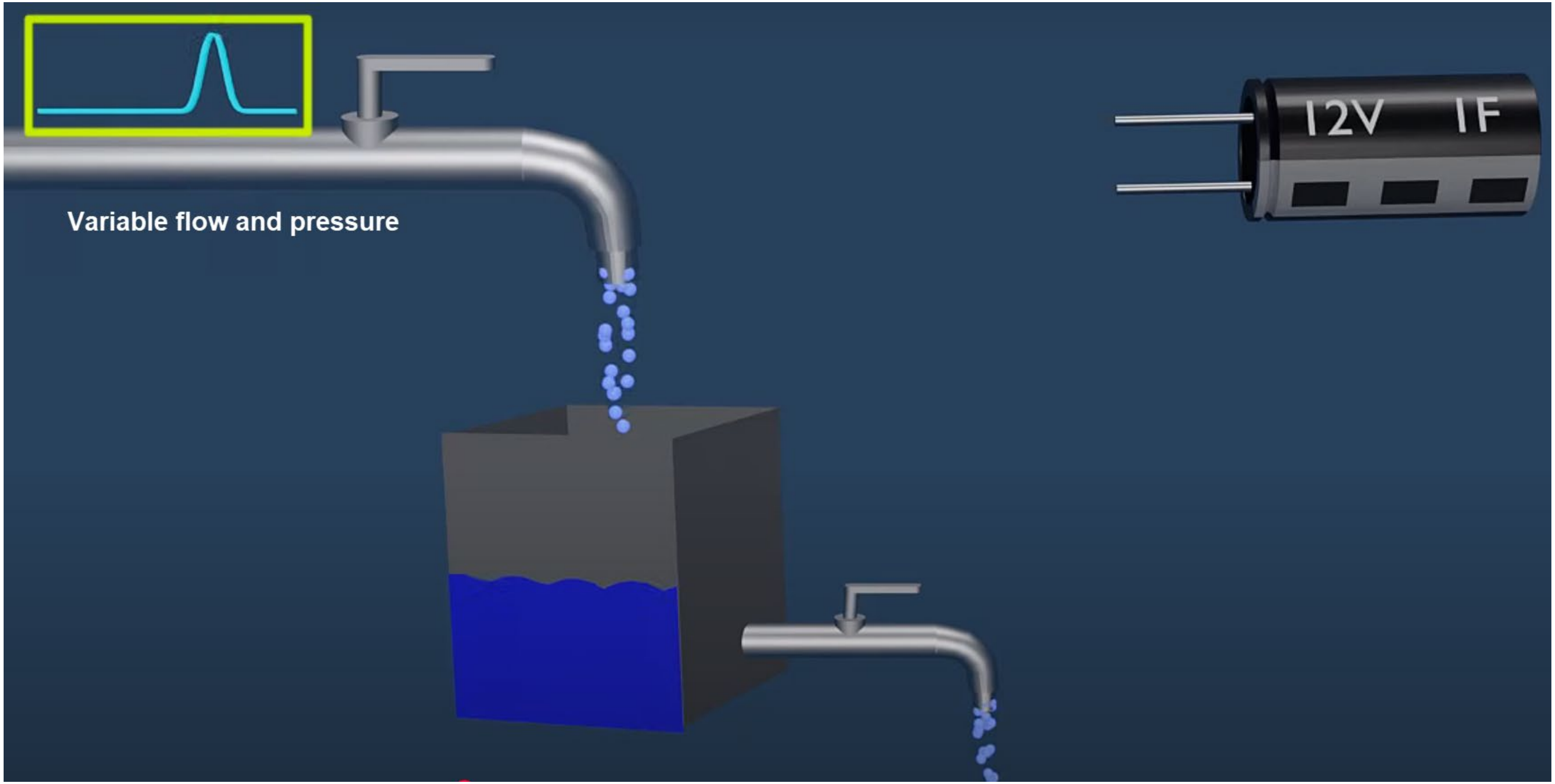
$$Solving\ For\ S_{refill} = \frac{V_{cf} \times (P_1 - P_2)}{T_m \times 14.7} \qquad Solving\ For\ S_{refill} = \frac{668.5_{cf} \times (20)}{T_m \times 14.7}$$

https://measur.ornl.gov/calculators/compressed-air-list

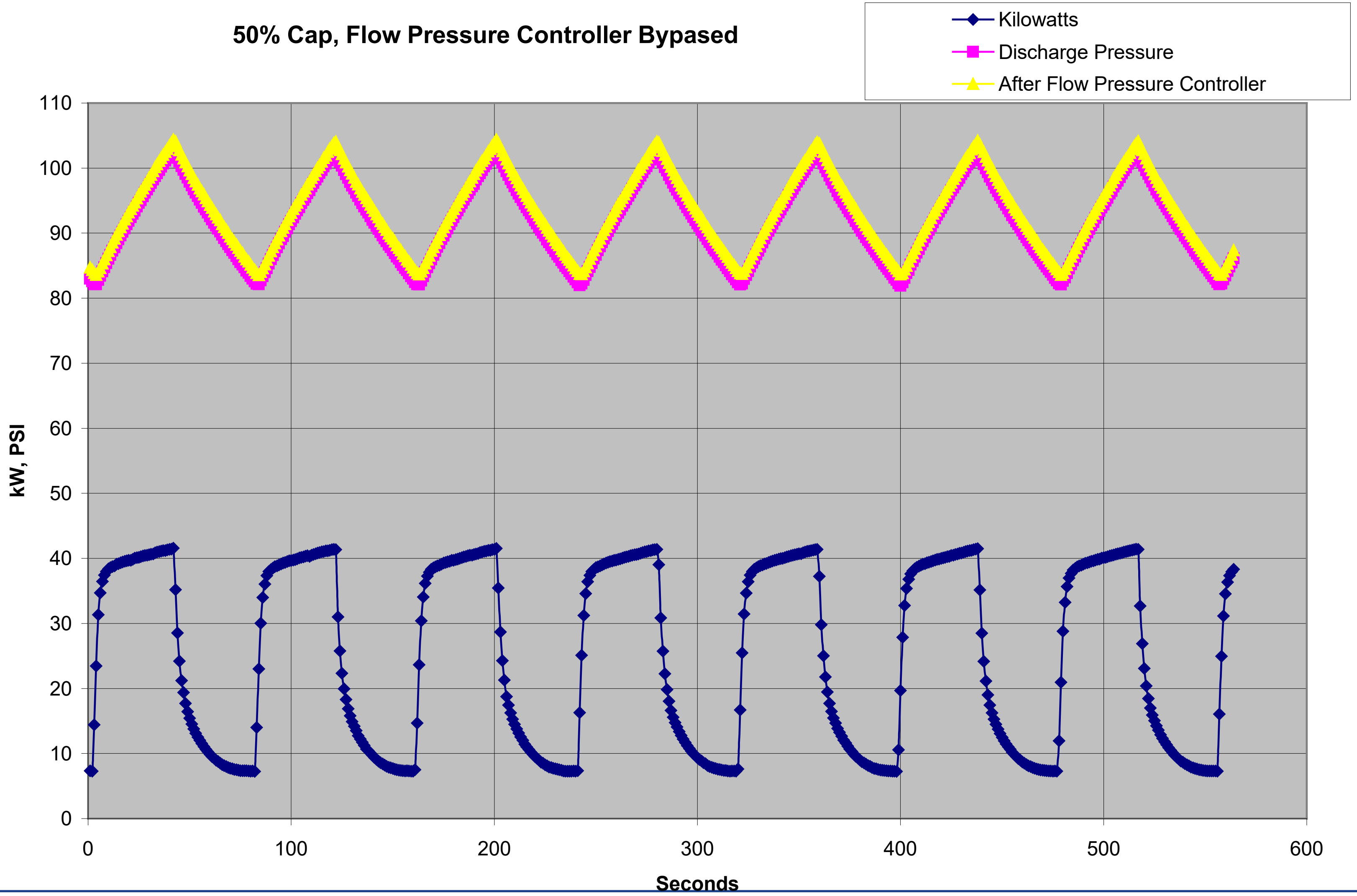
Pressure/Flow Controllers



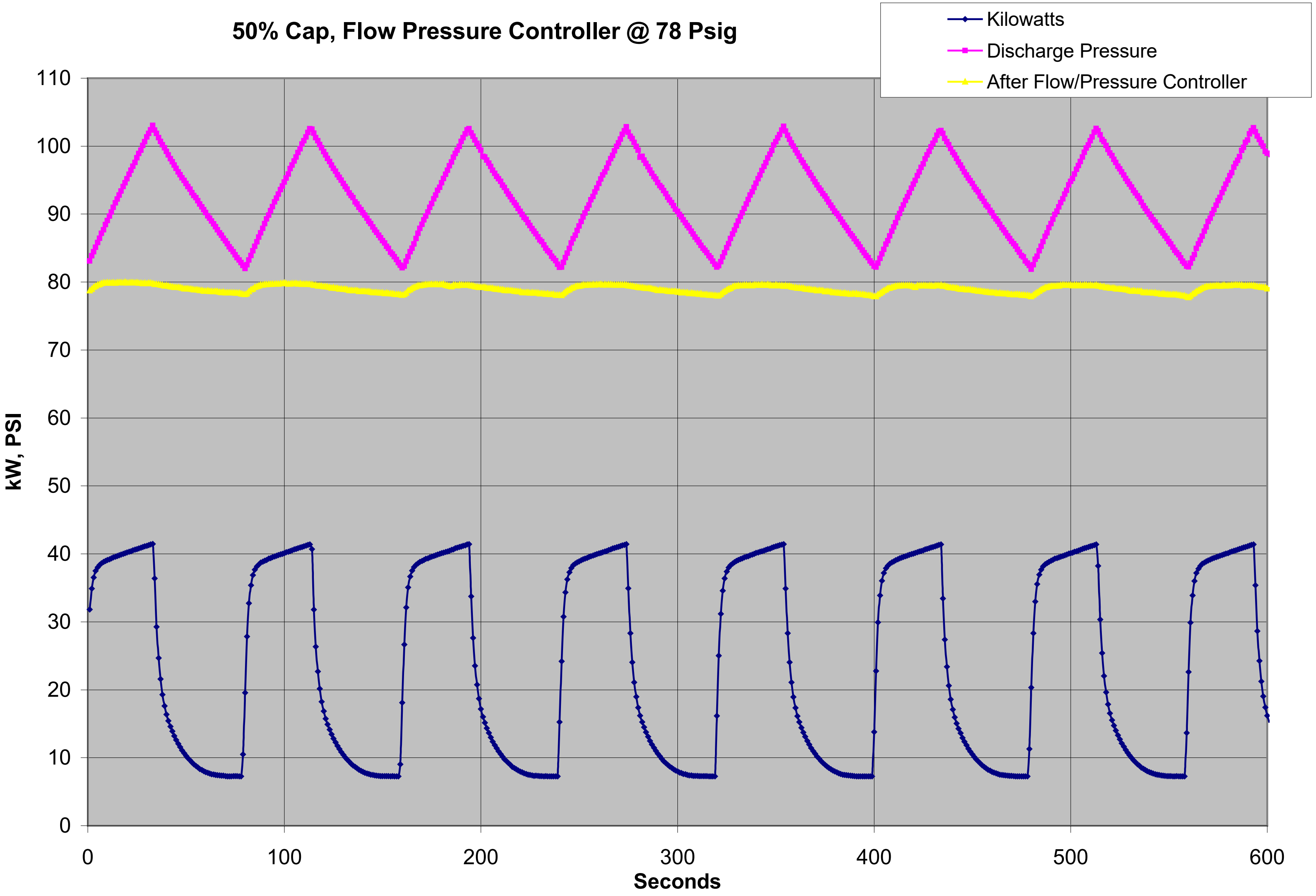
Pressure Flow Controller


Variable flow and pressure
12V
1F

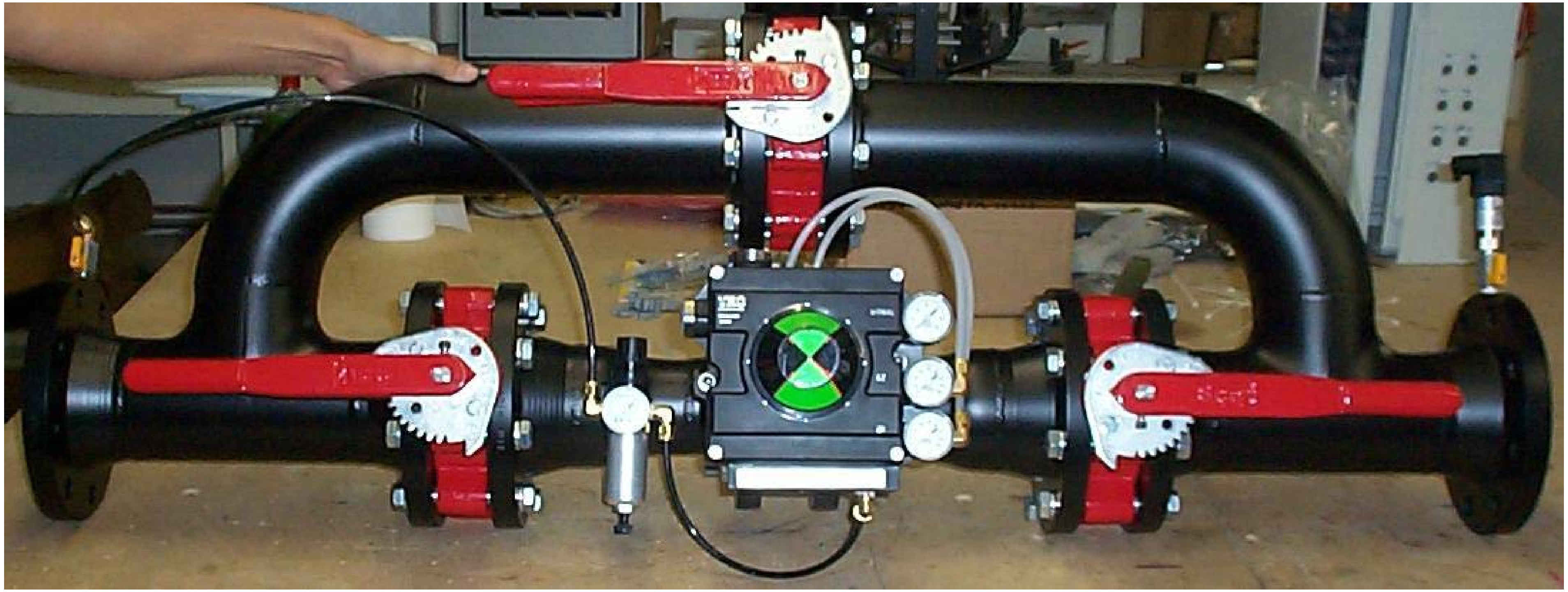
Pressure/Flow Controllers



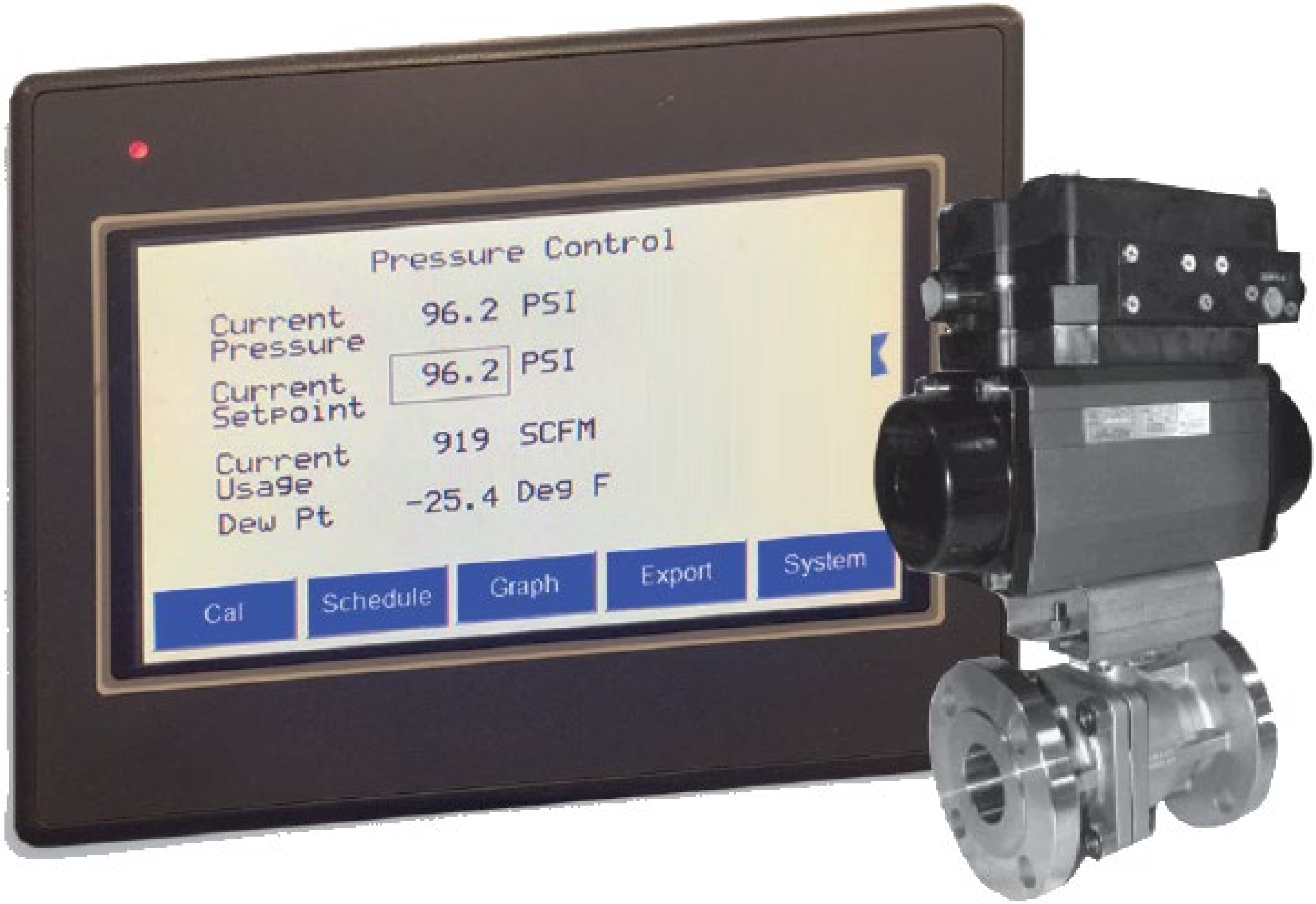
Pressure/Flow Controllers



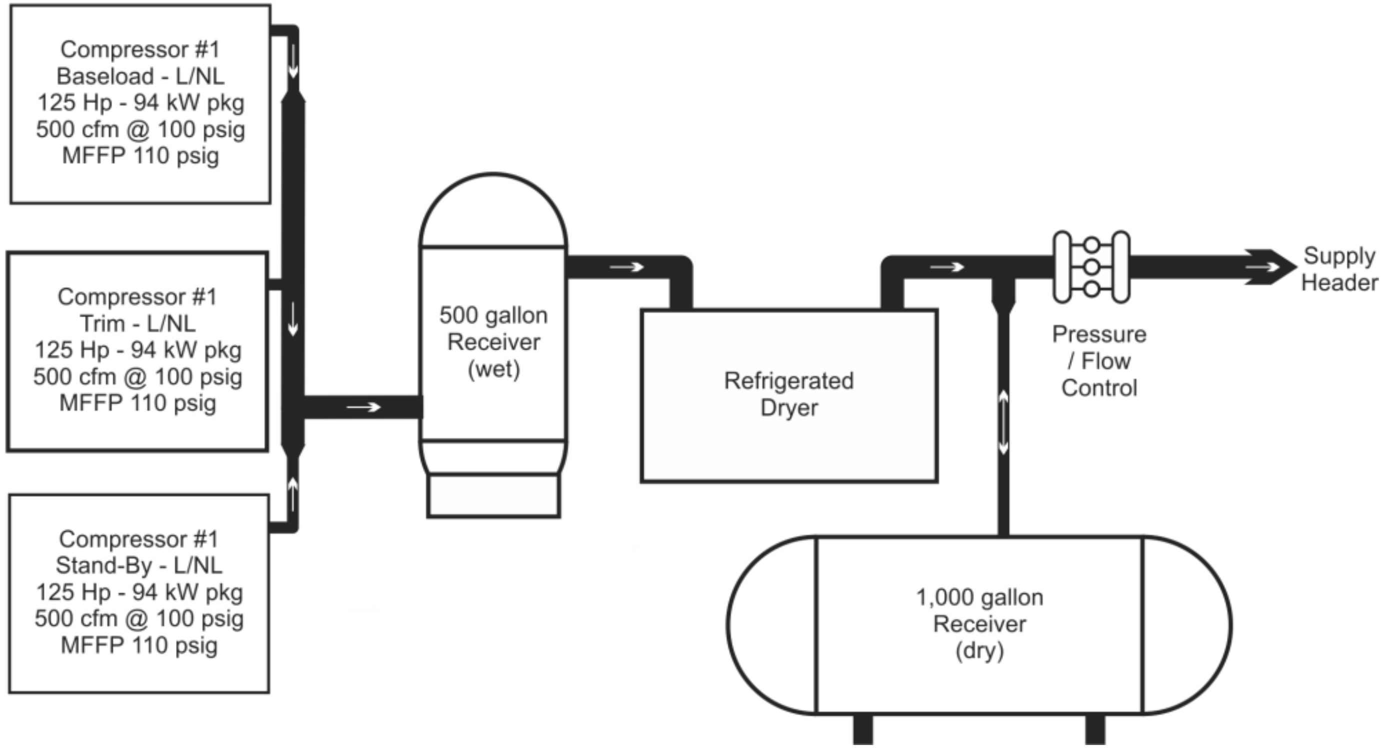
Pressure/Flow Controllers



Pressure/Flow Controllers


Pressure Control
Current Pressure
96.2 PSI
Current Setpoint
96.2 PSI
Current Usage
919 SCFM
Dew Pt
-25.4 Deg F
Cal
Schedule
Graph
Export
System

Pressure/Flow Controllers

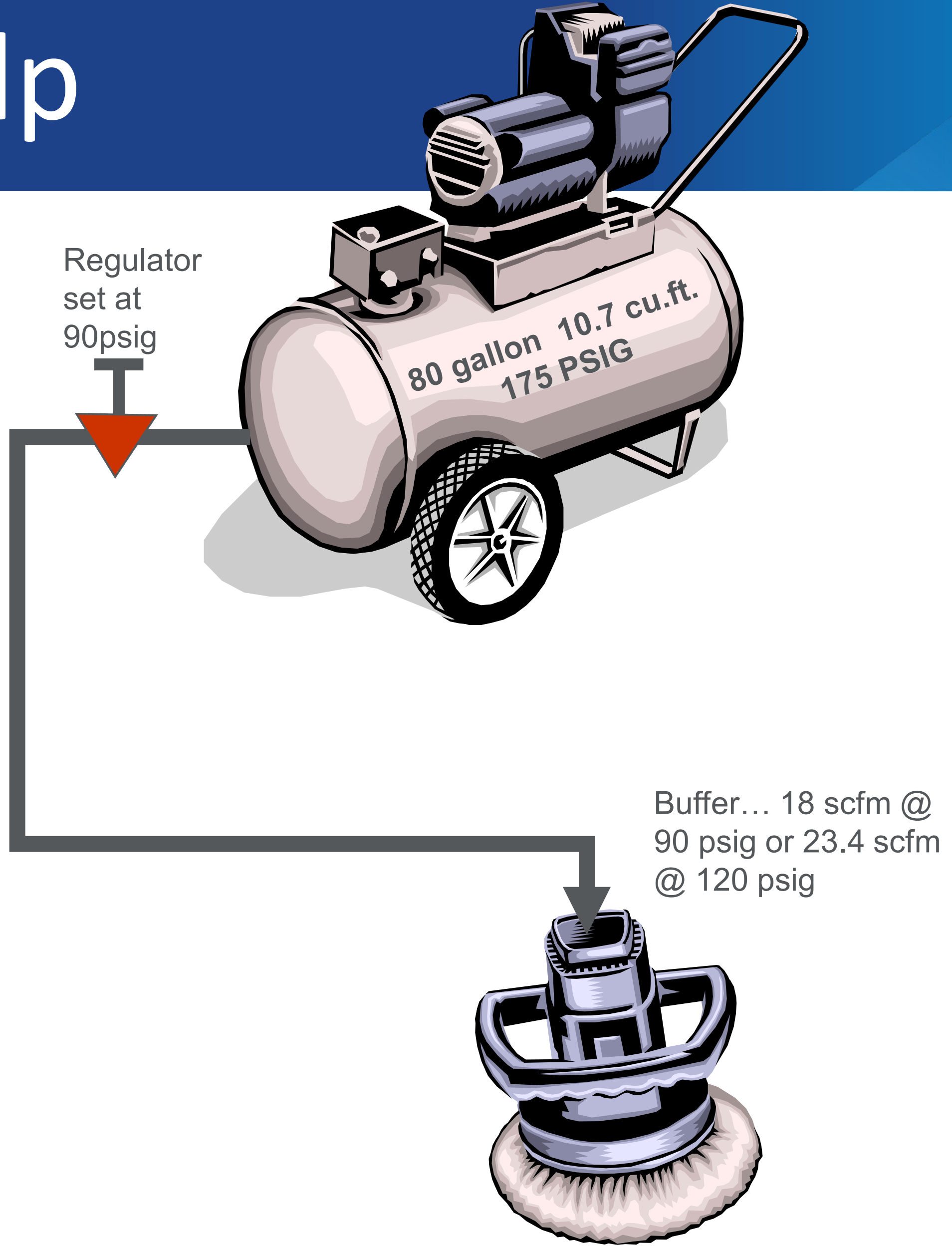

Compressor #1
Baseload - L/NL
125 Hp - 94 kW pkg
500 cfm @ 100 psig
MFFP 110 psig
Compressor #1
Trim - L/NL
125 Hp - 94 kW pkg
500 cfm @ 100 psig
MFFP 110 psig
Compressor #1
Stand-By - L/NL
125 Hp - 94 kW pkg
500 cfm @ 100 psig
MFFP 110 psig
500 gallon
Receiver
(wet)
Refrigerated
Dryer
Pressure
/ Flow
Control
Supply
Header
1,000 gallon
Receiver
(dry)

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

Primary Storage

How does Volume Help

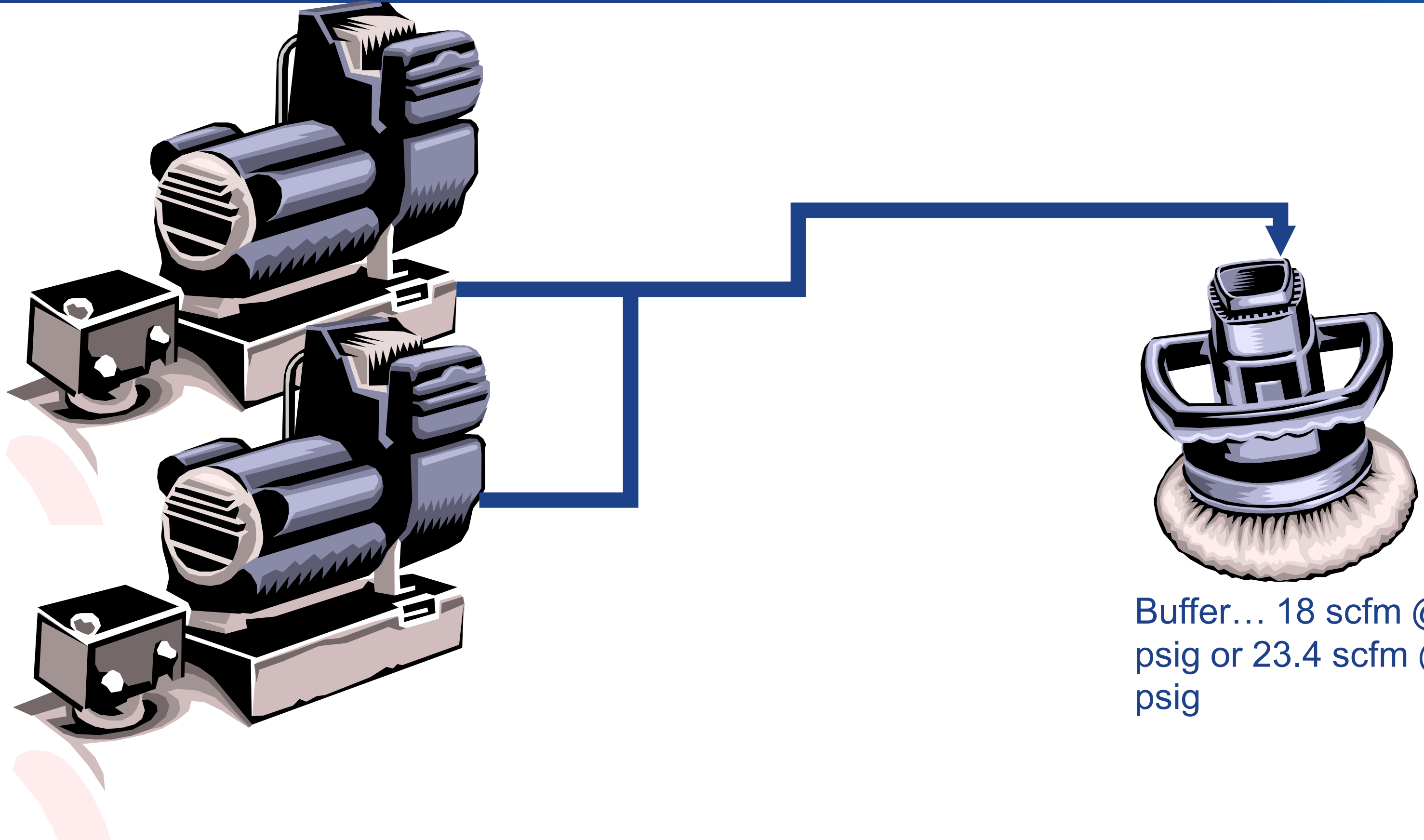
- A paint area in a body shop has a 5 HP compressor mounted on an 80-gallon air receiver. This receiver is pumped up to 175 psig. The air flow to the buffer which uses 18 SCFM at 90 PSIG, is regulated to 90 PSIG outflow from the regulator.
- The compressor delivers 12-13 SCFM at 90 psig but yet it runs the 18 SCFM sander just fine.
- How can this work???
- The buffer uses more volume(scfm) than the compressor can deliver !!
- If there were no regulation and receiver, you can be sure that the compressor would not be able to run the tool



Regulator set at 90psig

Buffer… 18 scfm @ 90 psig or 23.4 scfm @ 120 psig

How does Volume Help



Buffer… 18 scfm @ 90 psig or 23.4 scfm @ 120 psig

With no receiver, the painter must install a second 5 hp compressor and therefore use twice the energy as before

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

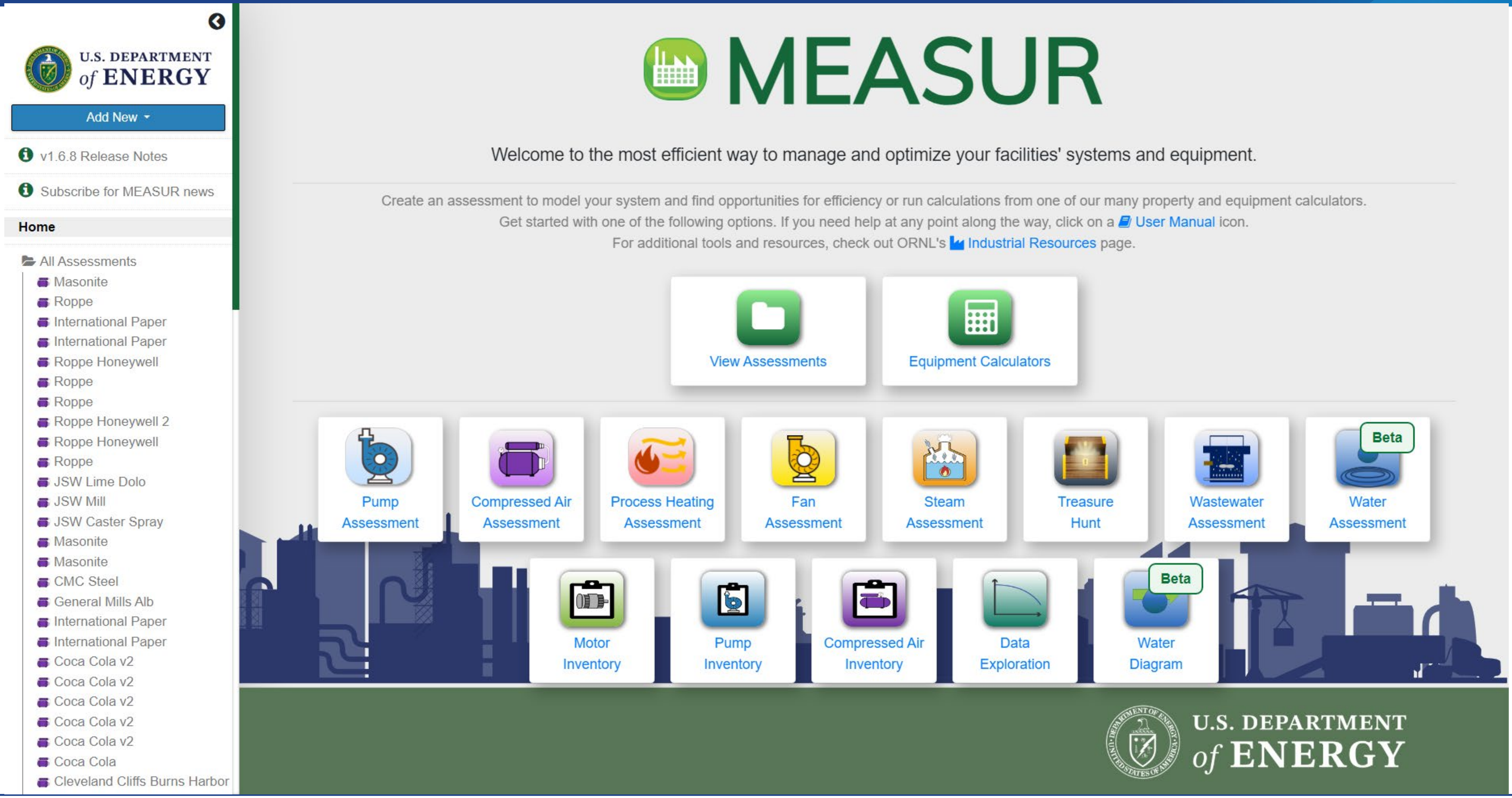
Session 3

Logtool, and the MEASUR Tool

Why MEASUR?

- ~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 systems approach to assessing compressed air systems, analyzing collected data, and reporting results

MEASUR Main Menu



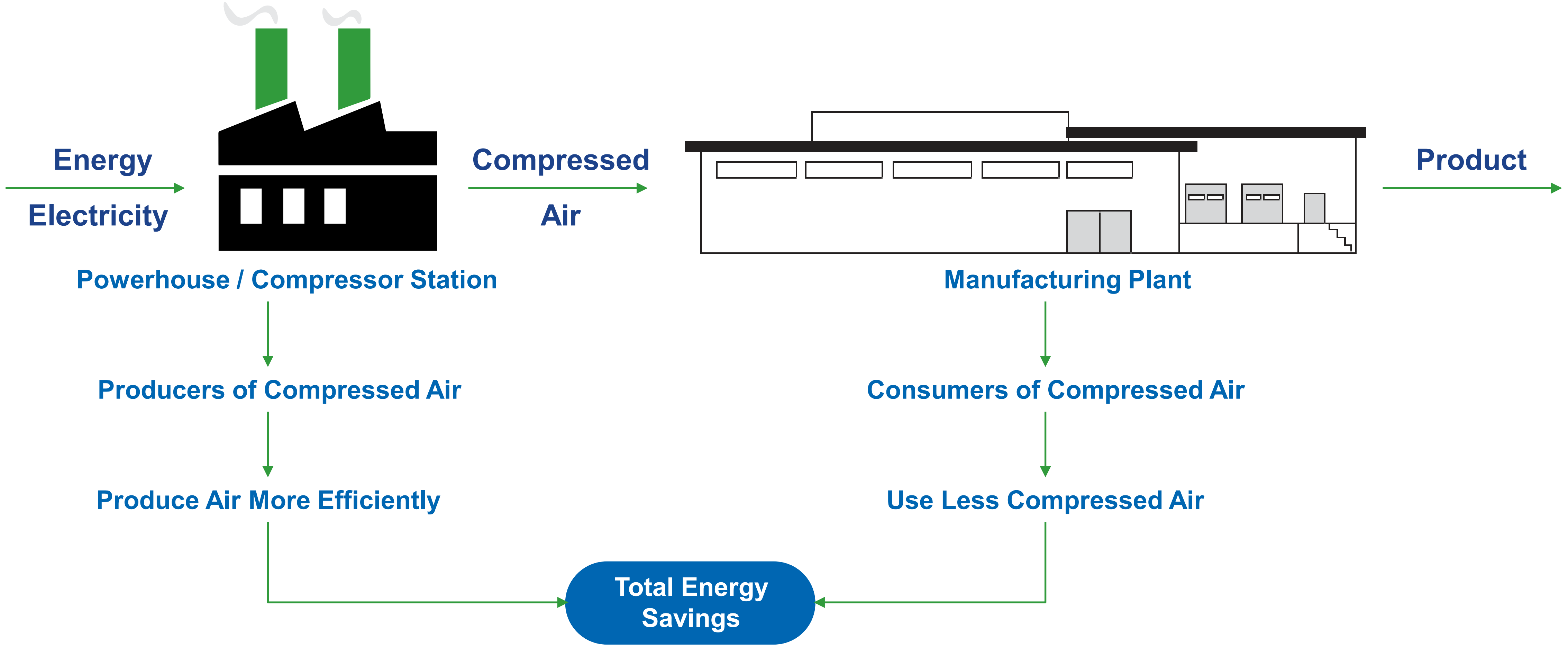
Welcome to the most efficient way to manage and optimize your facilities' systems and equipment.

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.
For additional tools and resources, check out ORNL's Industrial Resources page.

U.S. DEPARTMENT of ENERGY
Add New
v1.6.8 Release Notes
Subscribe for MEASUR news
Home
All Assessments
Masonite
Roppe
International Paper
International Paper
Roppe Honeywell
Roppe
Roppe
Roppe Honeywell 2
Roppe Honeywell
Roppe
JSW Lime Dolo
JSW Mill
JSW Caster Spray
Masonite
Masonite
CMC Steel
General Mills Alb
International Paper
International Paper
Coca Cola v2
Coca Cola v2
Coca Cola v2
Coca Cola v2
Coca Cola v2
Coca Cola
Cleveland Cliffs Burns Harbor
MEASUR
View Assessments
Equipment Calculators
Pump Assessment
Compressed Air Assessment
Process Heating Assessment
Fan Assessment
Steam Assessment
Treasure Hunt
Wastewater Assessment
Beta
Water Assessment
Motor Inventory
Pump Inventory
Compressed Air Inventory
Data Exploration
Beta
Water Diagram
U.S. DEPARTMENT of ENERGY

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.



Energy Electricity

Compressed Air

Product

Powerhouse / Compressor Station

Producers of Compressed Air

Produce Air More Efficiently

Manufacturing Plant

Consumers of Compressed Air

Use Less Compressed Air

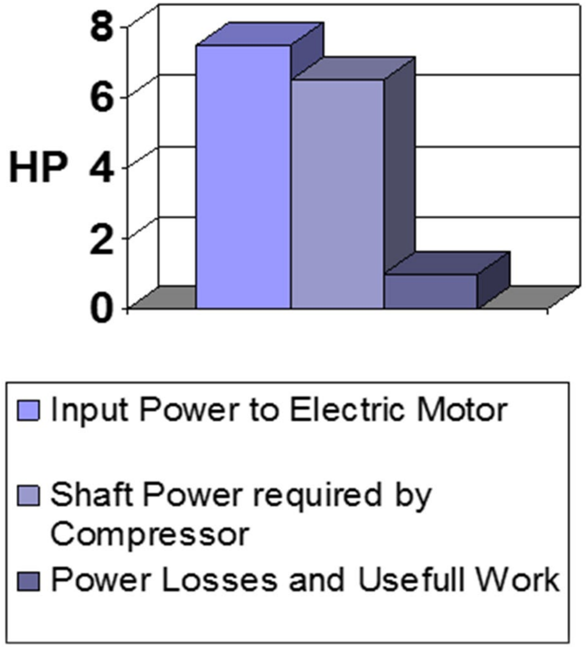
Total Energy Savings

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



TONSON
TONSON

MEASUR Features

- 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

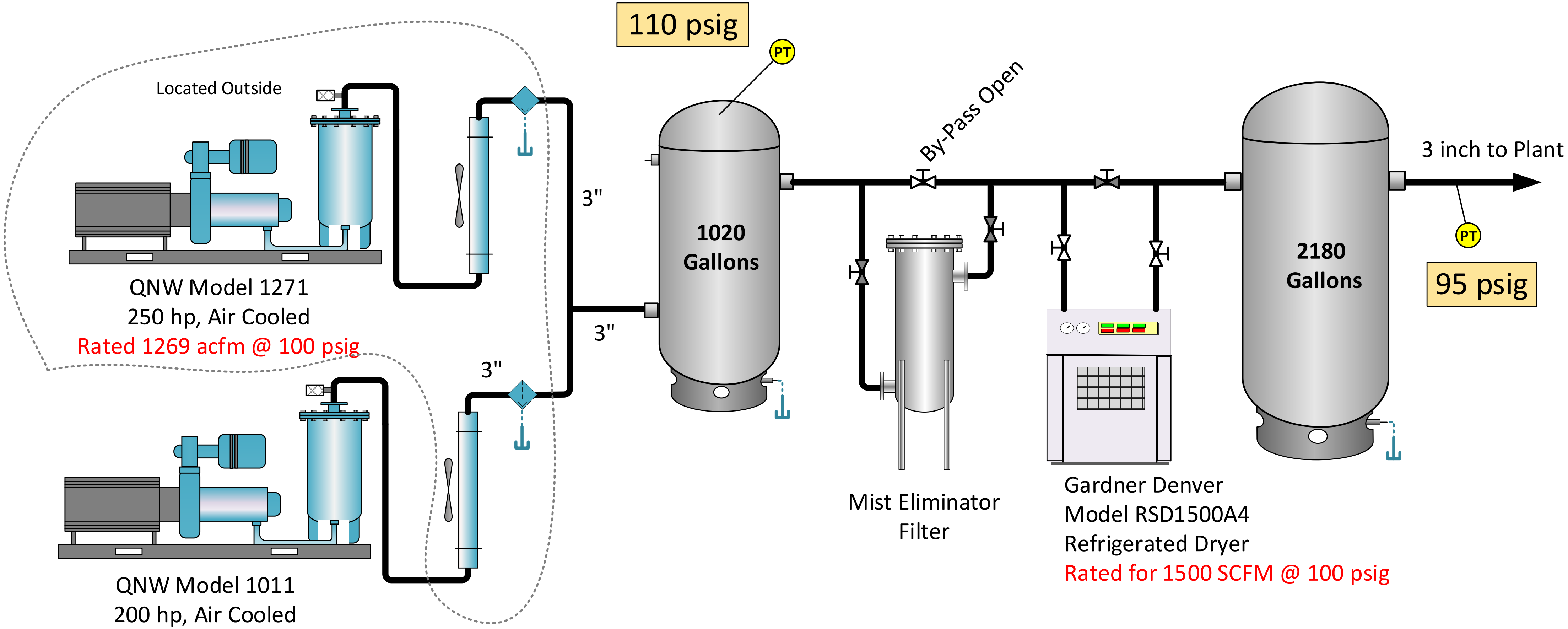
Why LogTool?

- 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 is a tool 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

Box Plant Company Example


110 psig
PT
Located Outside
By-Pass Open
3"
3"
3"
1020 Gallons
2180 Gallons
3 inch to Plant
PT
95 psig

QNW Model 1271
250 hp, Air Cooled
Rated 1269 acfm @ 100 psig

QNW Model 1011
200 hp, Air Cooled
Rated 1014 acfm @ 100 psig

Mist Eliminator Filter

Gardner Denver
Model RSD1500A4
Refrigerated Dryer
Rated for 1500 SCFM @ 100 psig

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.

CHAPTER 4

Compressed Air Distribution (Systems)

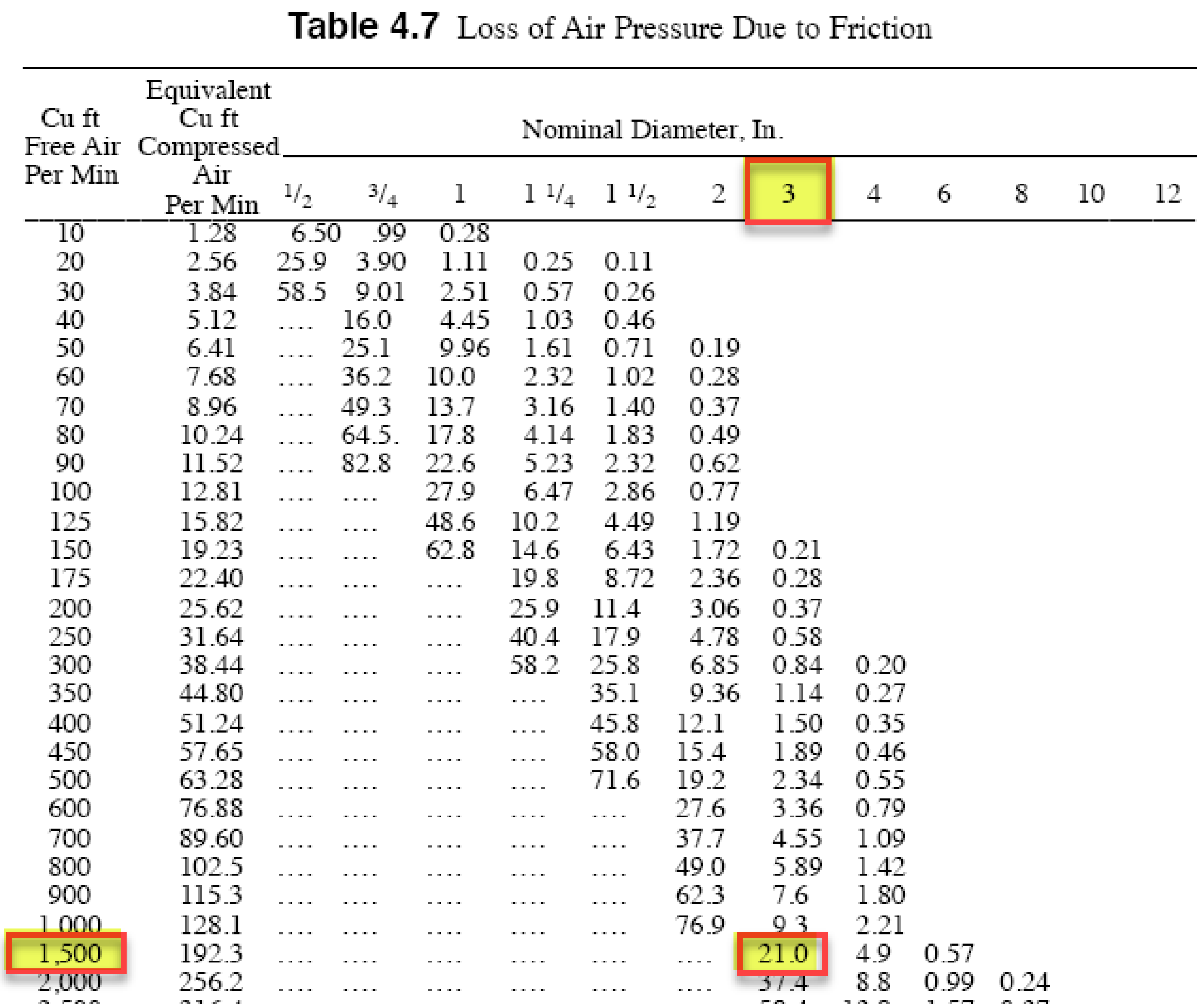
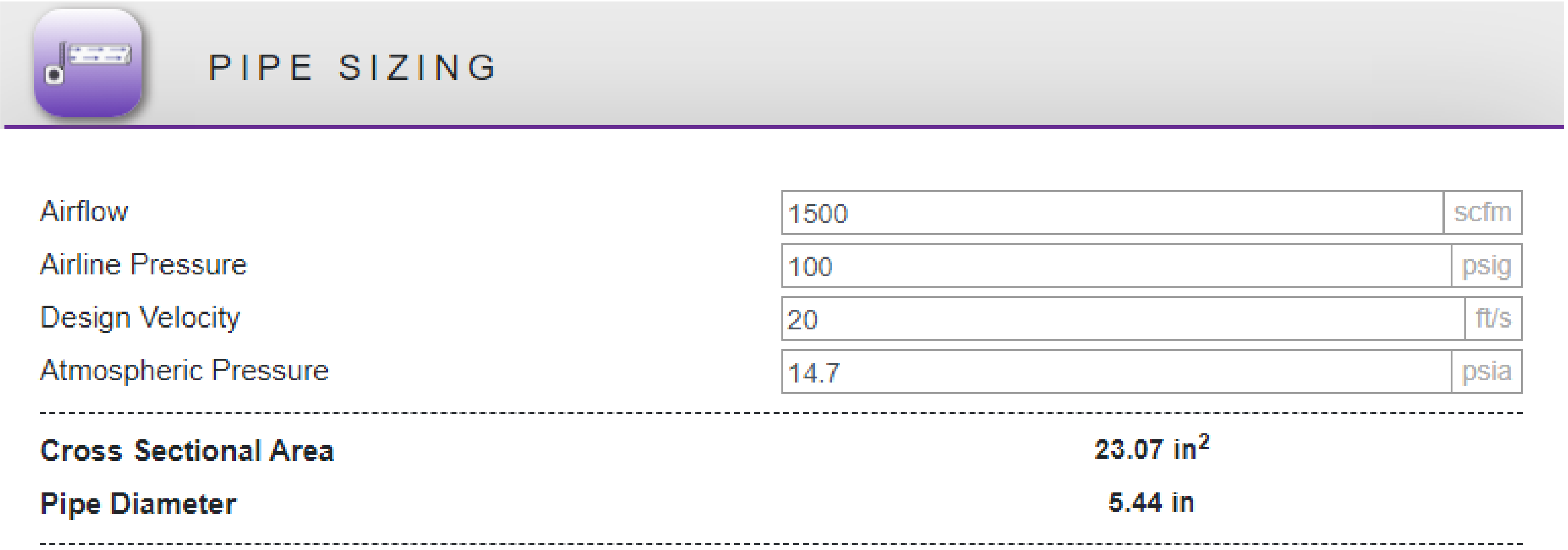


Table 4.7 Loss of Air Pressure Due to Friction

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		

Pipe Velocity

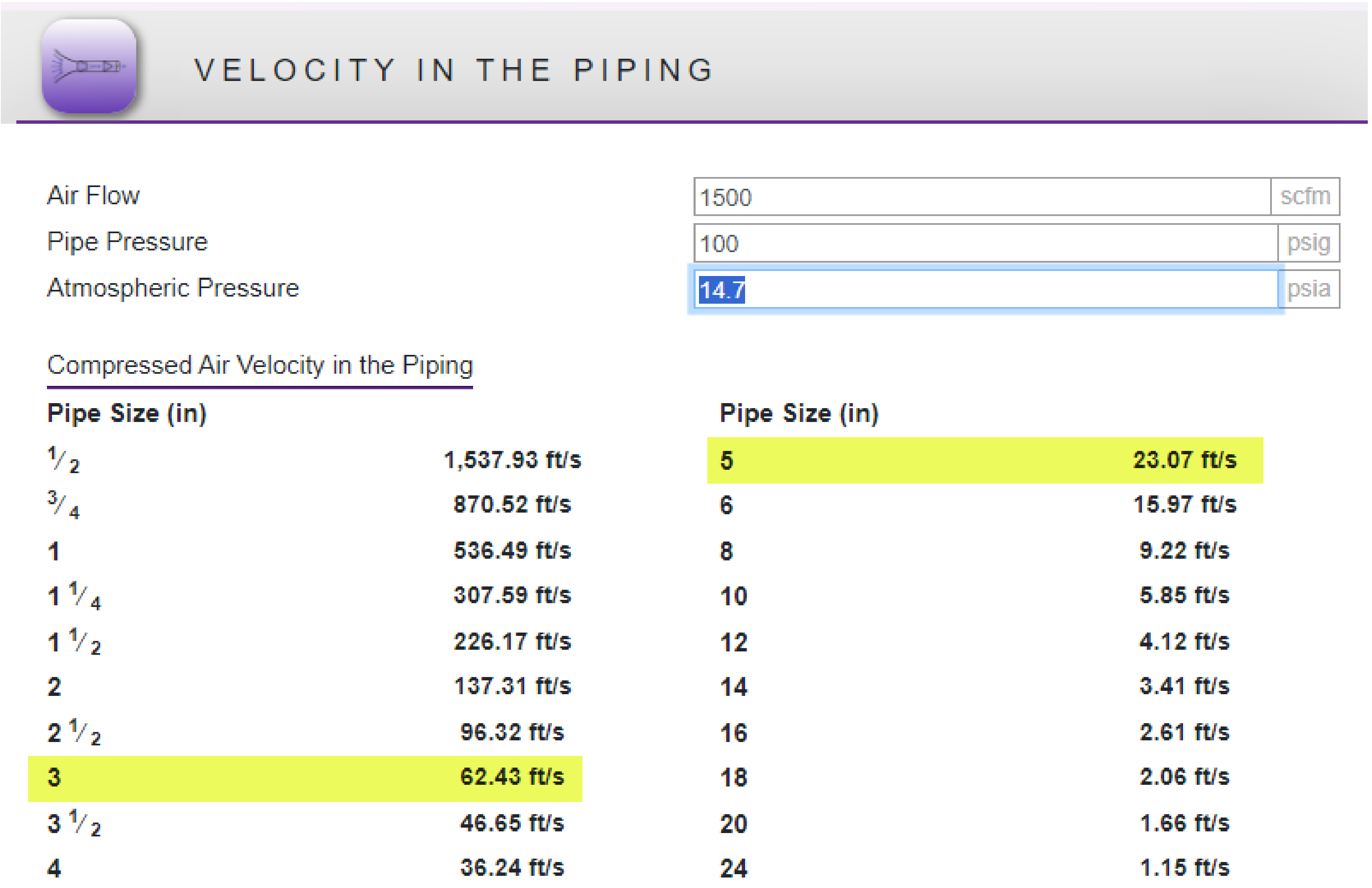


PIPE SIZING

Airflow	1500	scfm
Airline Pressure	100	psig
Design Velocity	20	ft/s
Atmospheric Pressure	14.7	psia

Cross Sectional Area	**23.07 in^2**
Pipe Diameter	**5.44 in**

Pipe Velocity



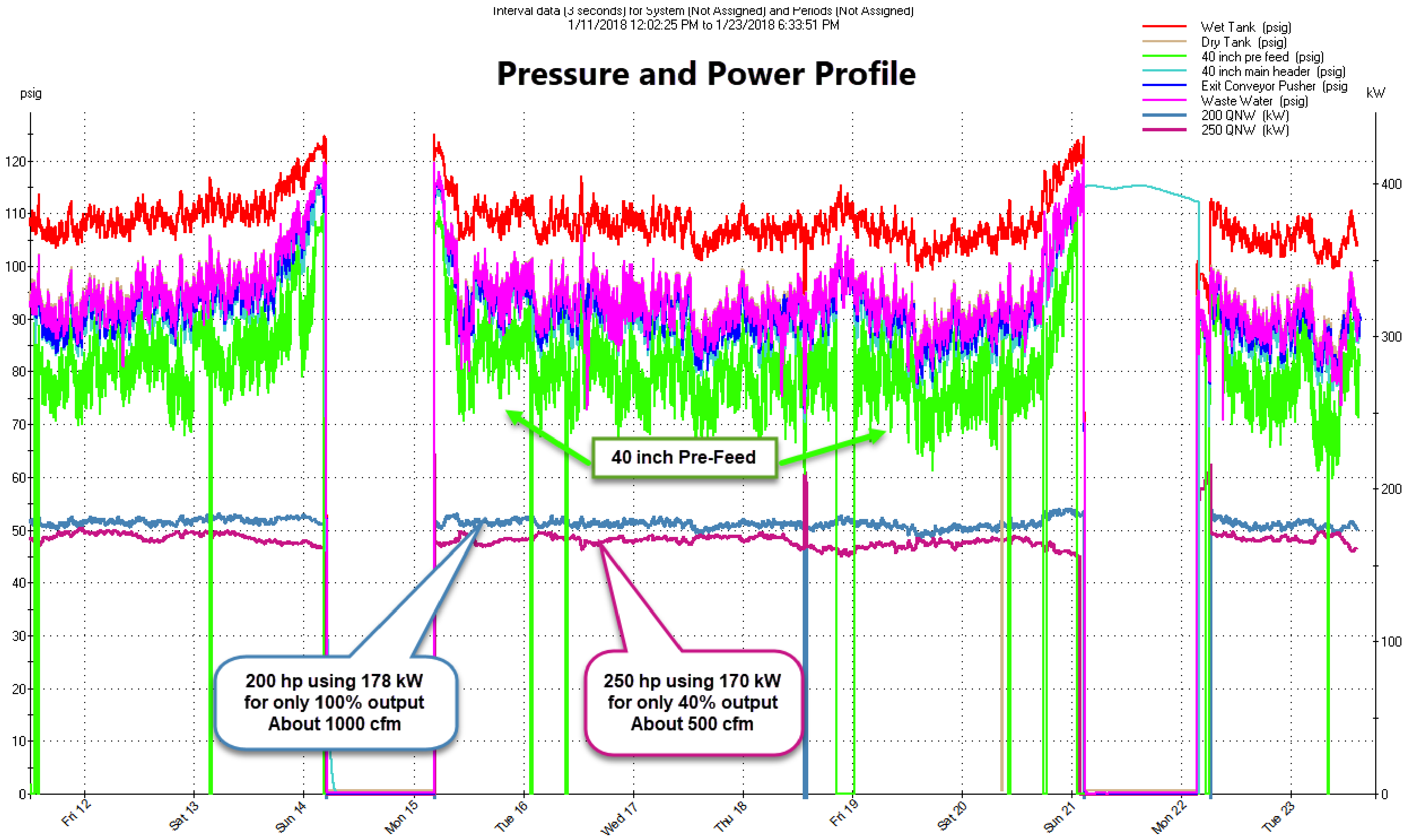
VELOCITY IN THE PIPING

Air Flow	1500	scfm
Pipe Pressure	100	psig
Atmospheric Pressure	14.7	psia

Compressed Air Velocity in the Piping

Pipe Size (in)		Pipe Size (in)	
1/2	1,537.93 ft/s	5	23.07 ft/s
3/4	870.52 ft/s	6	15.97 ft/s
1	536.49 ft/s	8	9.22 ft/s
1 1/4	307.59 ft/s	10	5.85 ft/s
1 1/2	226.17 ft/s	12	4.12 ft/s
2	137.31 ft/s	14	3.41 ft/s
2 1/2	96.32 ft/s	16	2.61 ft/s
3	62.43 ft/s	18	2.06 ft/s
3 1/2	46.65 ft/s	20	1.66 ft/s
4	36.24 ft/s	24	1.15 ft/s

LogTool Trend Plot

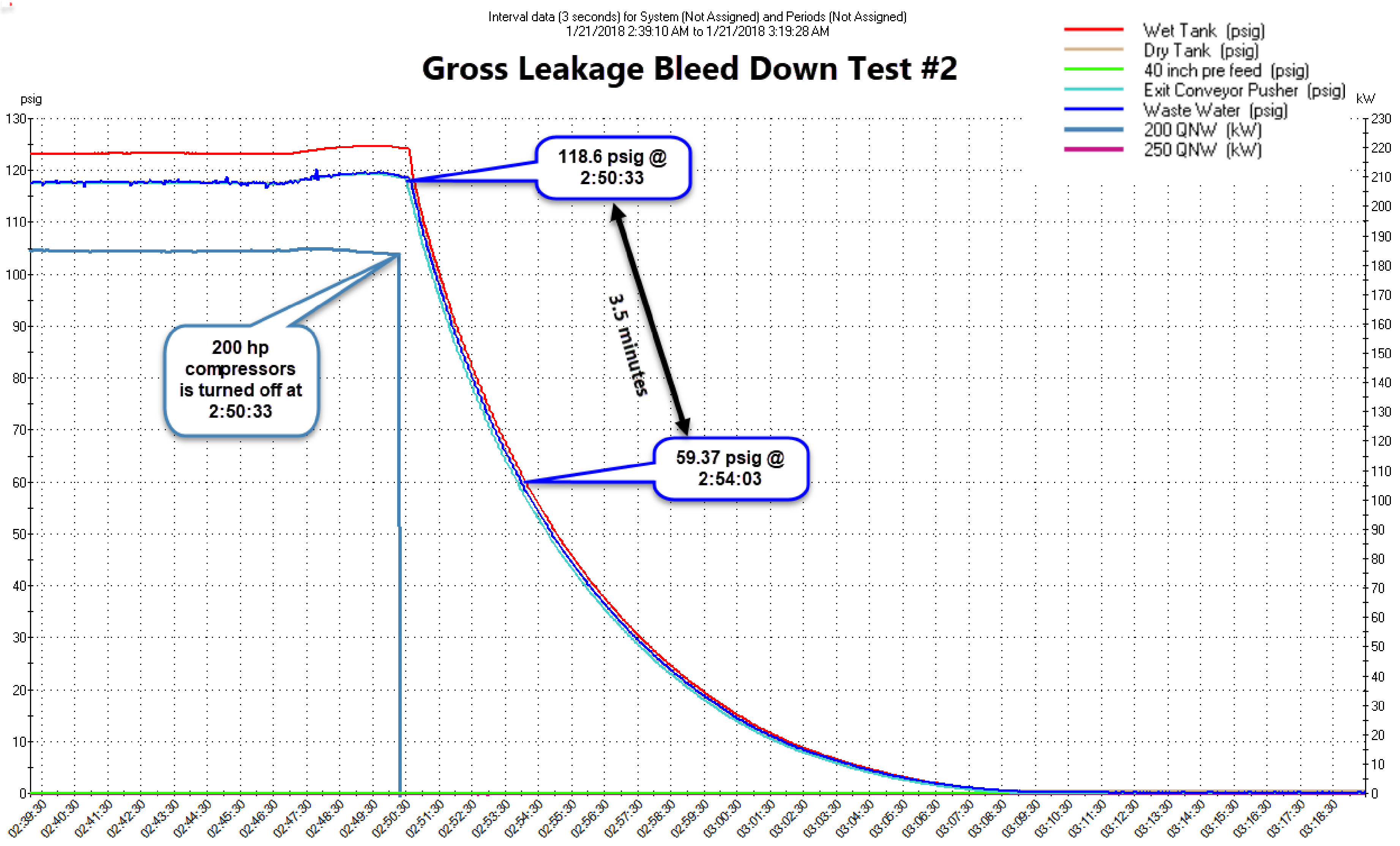


40 inch Pre-Feed

200 hp using 178 kW
for only 100% output
About 1000 cfm

250 hp using 170 kW
for only 40% output
About 500 cfm

LogTool Trend Plot



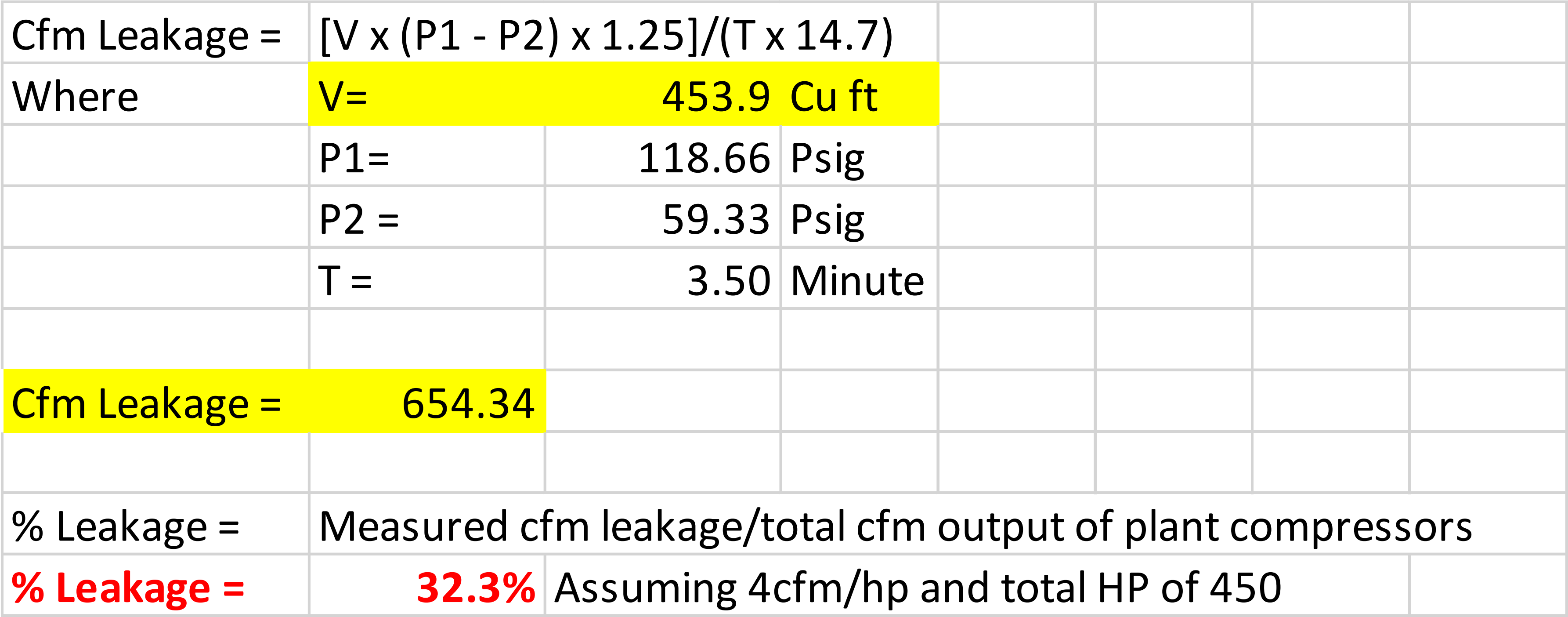
118.6 psig @ 2:50:33

3.5 minutes

59.37 psig @ 2:54:03

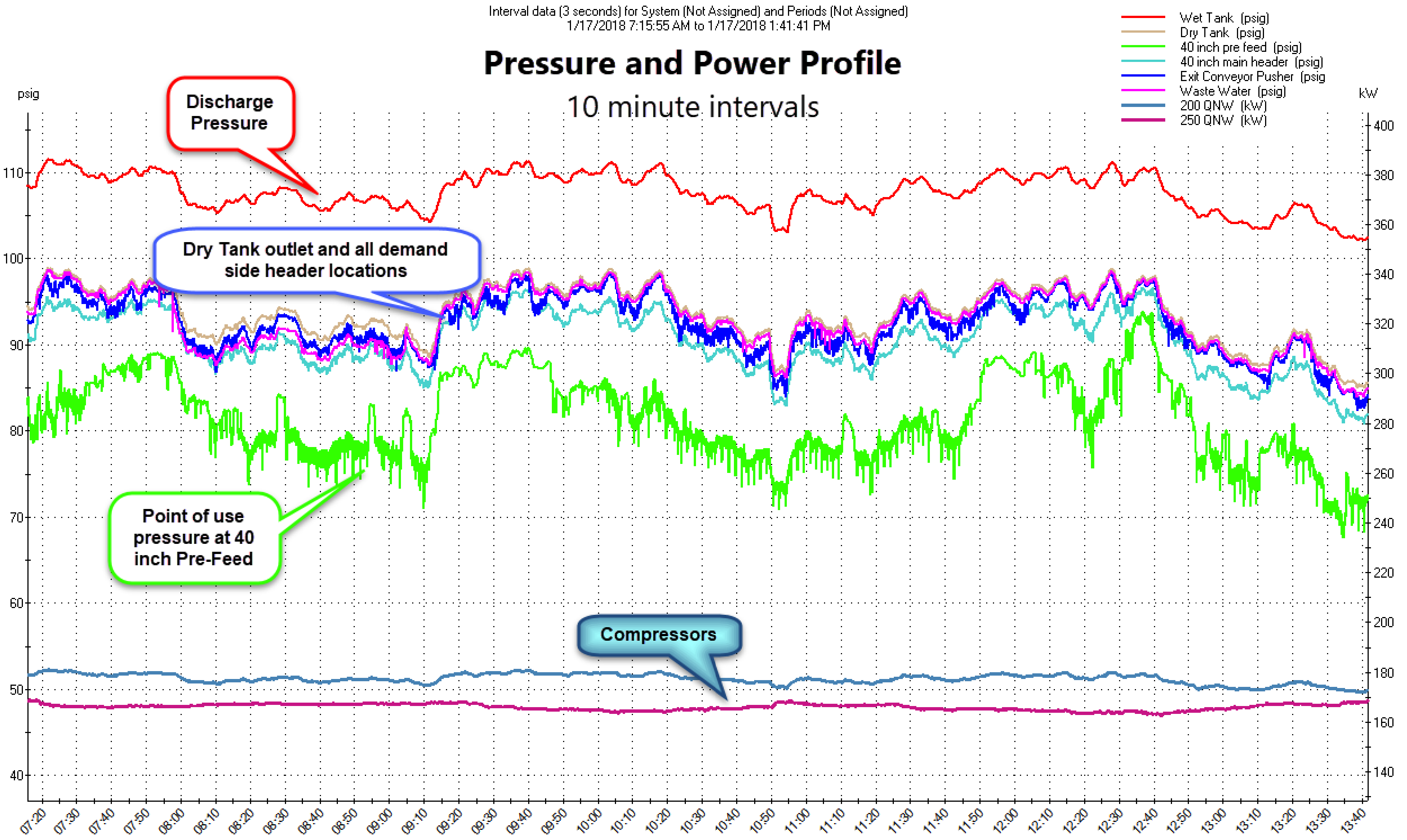
200 hp compressors is turned off at 2:50:33

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	

LogTool Trend Plot



Interval data (3 seconds) for System (Not Assigned) and Periods (Not Assigned)
1/17/2018 7:15:55 AM to 1/17/2018 1:41:41 PM

Pressure and Power Profile

10 minute intervals

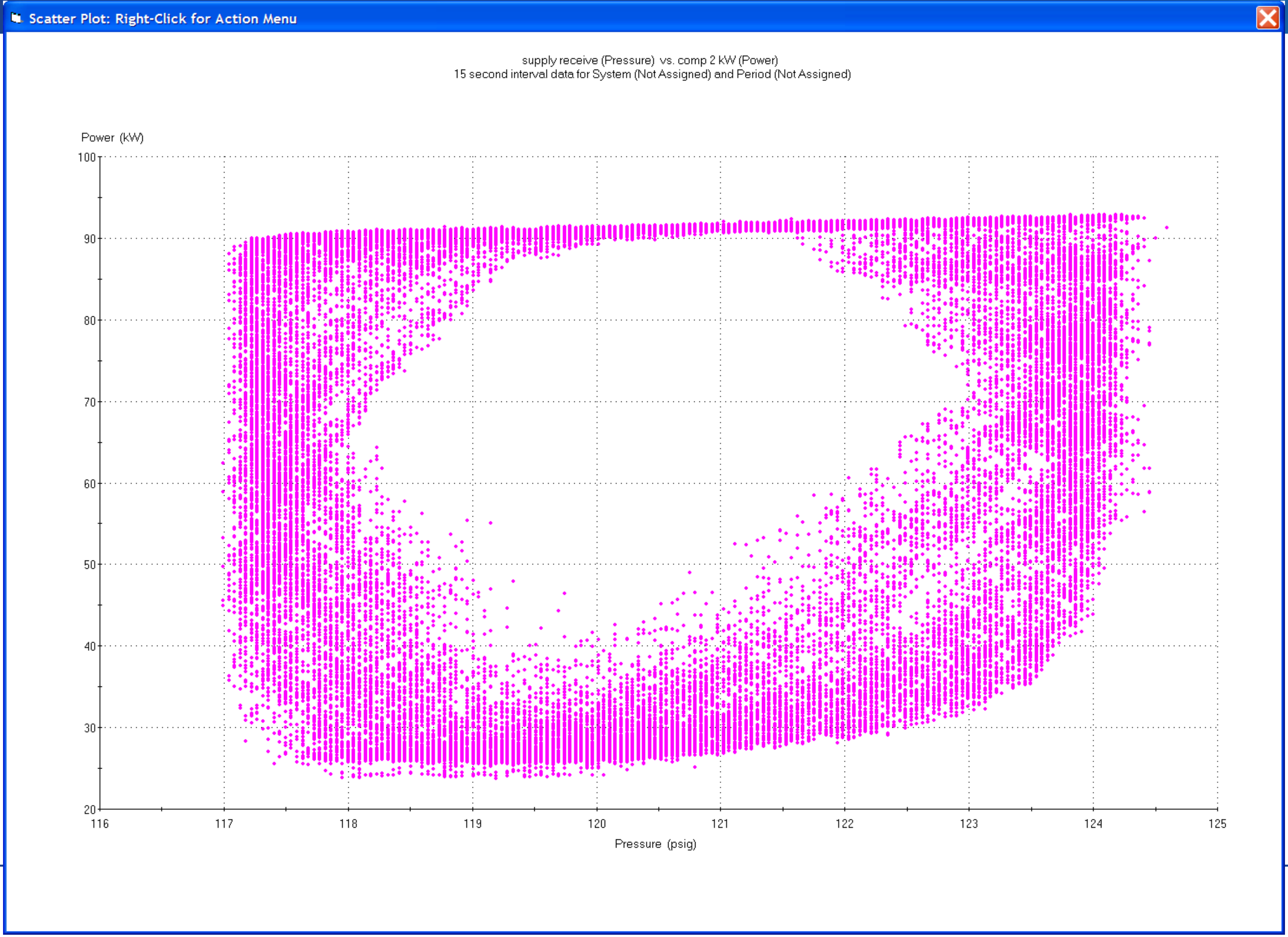
Discharge Pressure

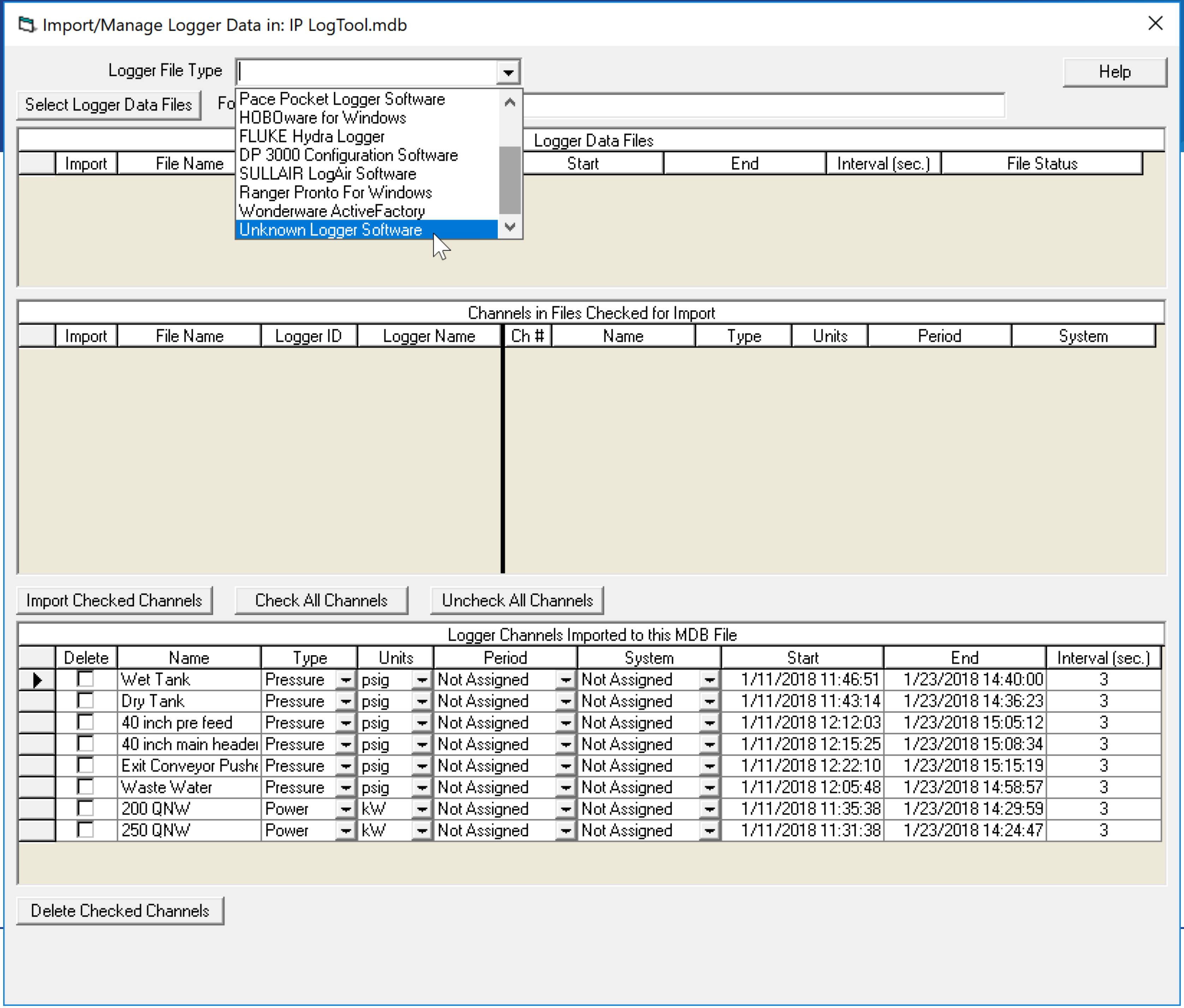
Dry Tank outlet and all demand side header locations

Point of use pressure at 40 inch Pre-Feed

Compressors

LogTool Scatter Plot

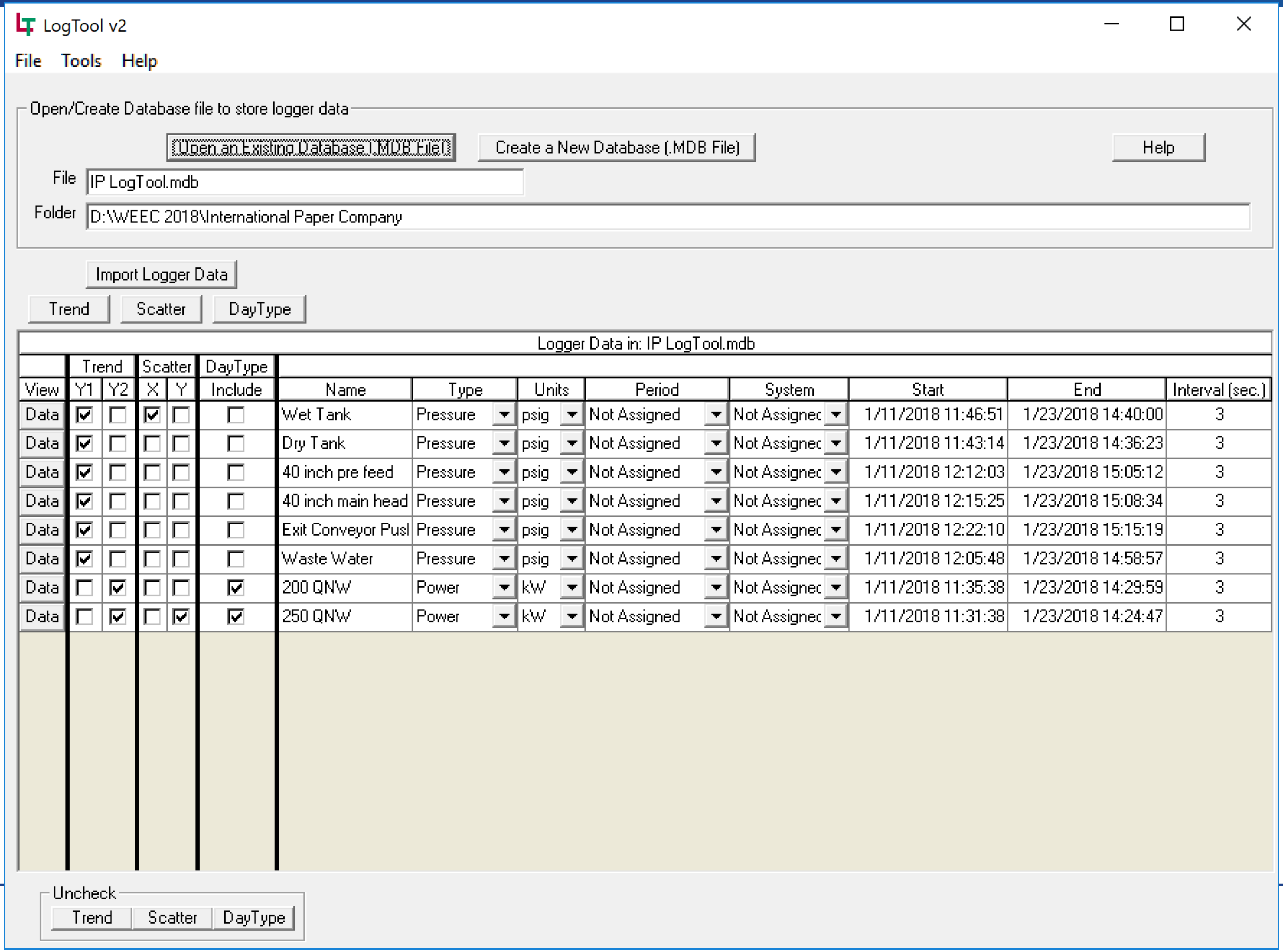

Scatter Plot: Right-Click for Action Menu
supply receive (Pressure) vs. comp 2 kW (Power)
15 second interval data for System (Not Assigned) and Period (Not Assigned)
Power (kW)
100
90
80
70
60
50
40
30
20
116
117
118
119
120
121
122
123
124
125
Pressure (psig)


Import/Manage Logger Data in: IP LogTool.mdb
Logger File Type
Help
Select Logger Data Files
Fo
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
Delete Checked 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 heade	Pressure	psig	Not Assigned	Not Assigned	1/11/2018 12:15:25	1/23/2018 15:08:34	3
☐	Exit Conveyor Pushe	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

LogTool Main Menu


LogTool v2
File
Tools
Help
Open/Create Database file to store logger data
Open an Existing Database (.MDB File)
Create a New Database (.MDB File)
Help
Import Logger Data
Trend
Scatter
DayType
Uncheck
Trend
Scatter
DayType

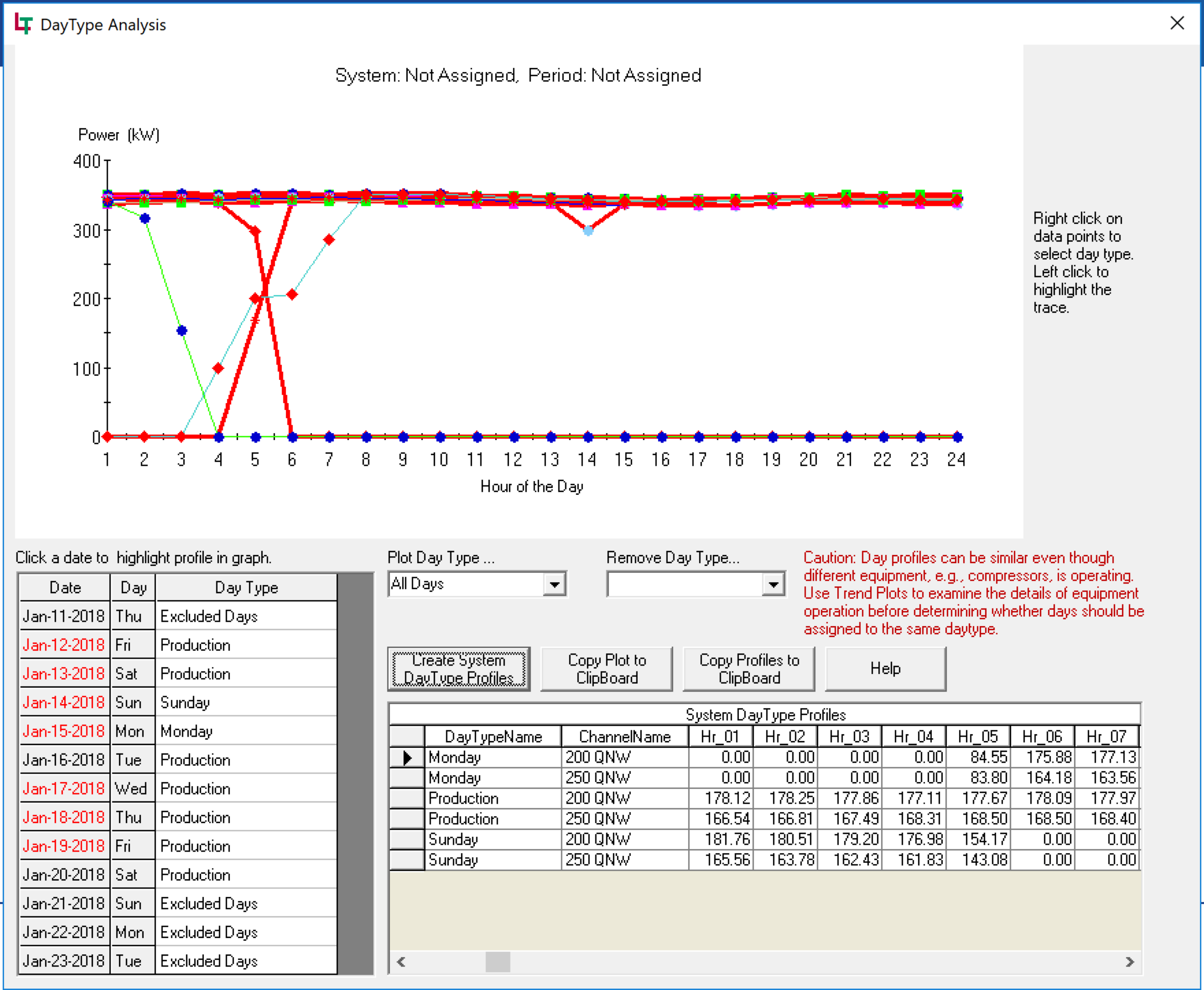
File: IP LogTool.mdb

Folder: D:\WEEC 2018\International Paper Company

Logger Data in: IP LogTool.mdb

	Trend		Scatter		DayType								
View	Y1	Y2	X	Y	Include	Name	Type	Units	Period	System	Start	End	Interval (sec.)
Data	☑	☐	☑	☐	☐	Wet Tank	Pressure	psig	Not Assigned	Not Assignec	1/11/2018 11:46:51	1/23/2018 14:40:00	3
Data	☑	☐	☐	☐	☐	Dry Tank	Pressure	psig	Not Assigned	Not Assignec	1/11/2018 11:43:14	1/23/2018 14:36:23	3
Data	☑	☐	☐	☐	☐	40 inch pre feed	Pressure	psig	Not Assigned	Not Assignec	1/11/2018 12:12:03	1/23/2018 15:05:12	3
Data	☑	☐	☐	☐	☐	40 inch main head	Pressure	psig	Not Assigned	Not Assignec	1/11/2018 12:15:25	1/23/2018 15:08:34	3
Data	☑	☐	☐	☐	☐	Exit Conveyor Pusl	Pressure	psig	Not Assigned	Not Assignec	1/11/2018 12:22:10	1/23/2018 15:15:19	3
Data	☑	☐	☐	☐	☐	Waste Water	Pressure	psig	Not Assigned	Not Assignec	1/11/2018 12:05:48	1/23/2018 14:58:57	3
Data	☐	☑	☐	☐	☑	200 QNW	Power	kW	Not Assigned	Not Assignec	1/11/2018 11:35:38	1/23/2018 14:29:59	3
Data	☐	☑	☐	☑	☑	250 QNW	Power	kW	Not Assigned	Not Assignec	1/11/2018 11:31:38	1/23/2018 14:24:47	3

Enter LogTool Data Into AIRMaster


DayType Analysis
System: Not Assigned, Period: Not Assigned
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
Create System DayType Profiles
Copy Plot to ClipBoard
Copy Profiles to ClipBoard
Help

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

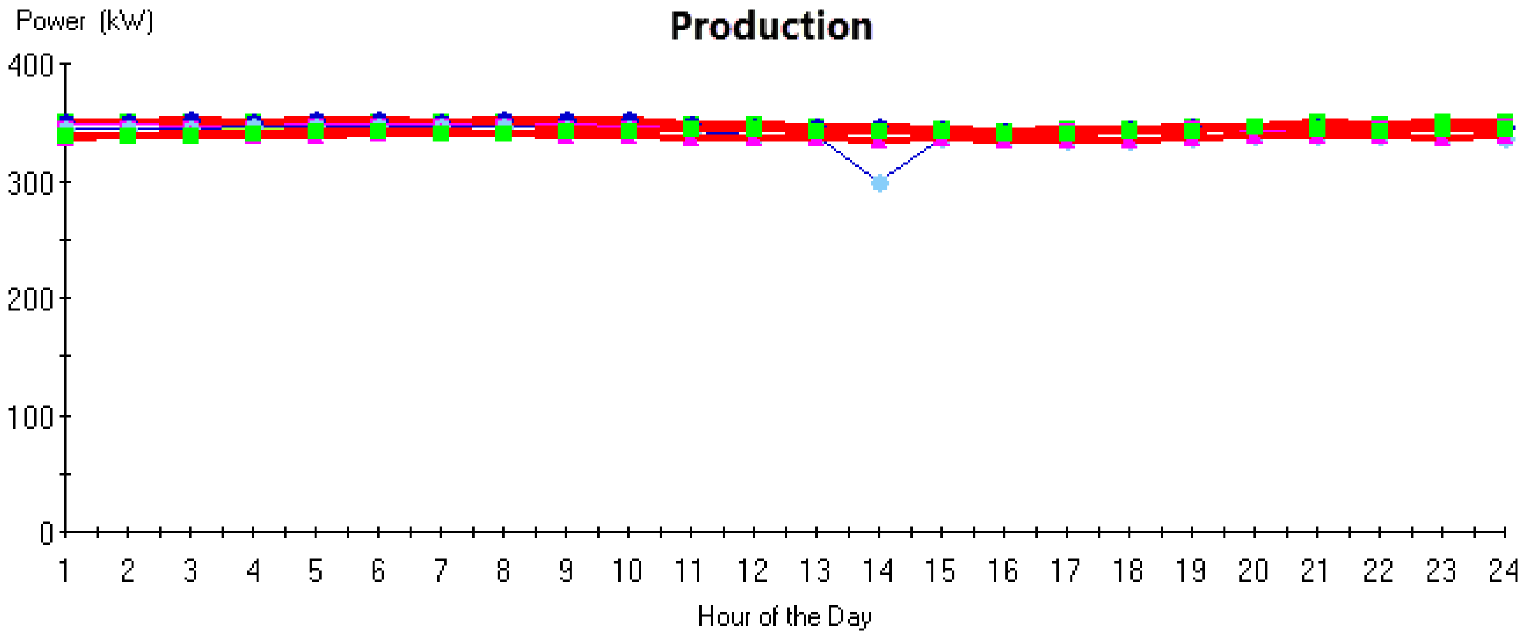
Remove Day Type...

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.

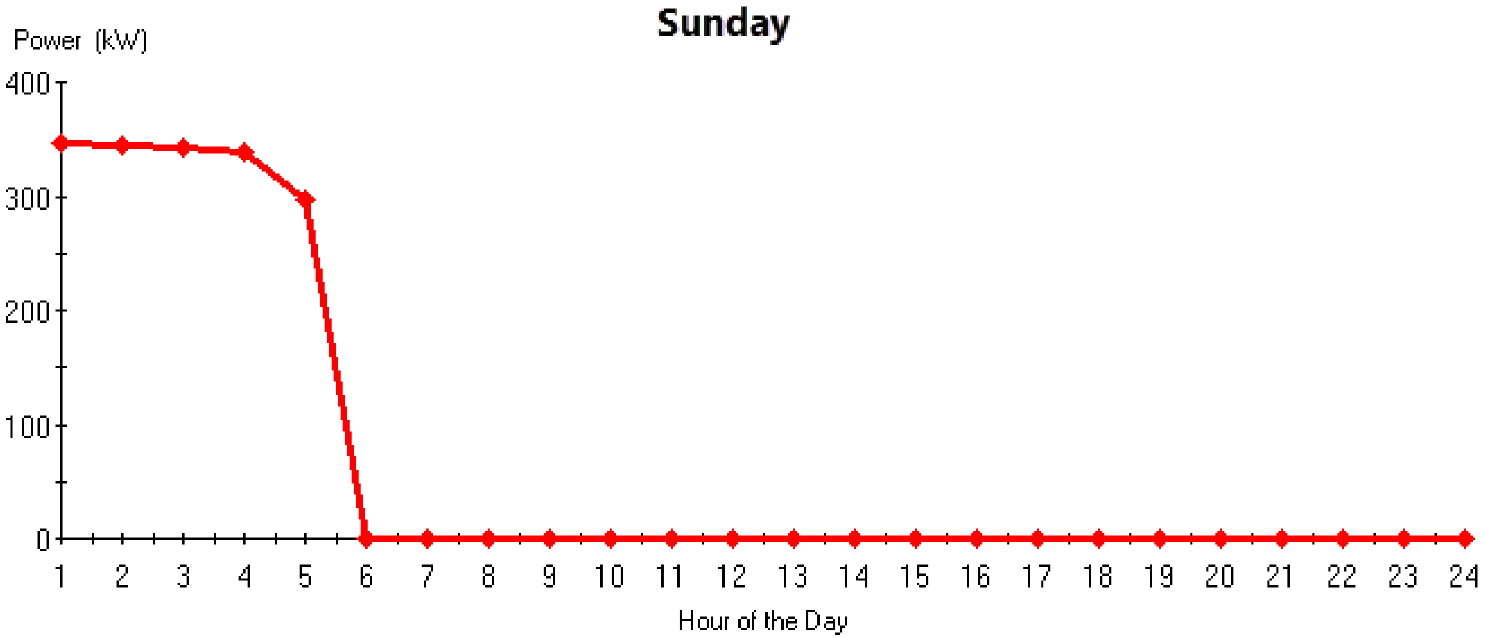
System DayType Profiles

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

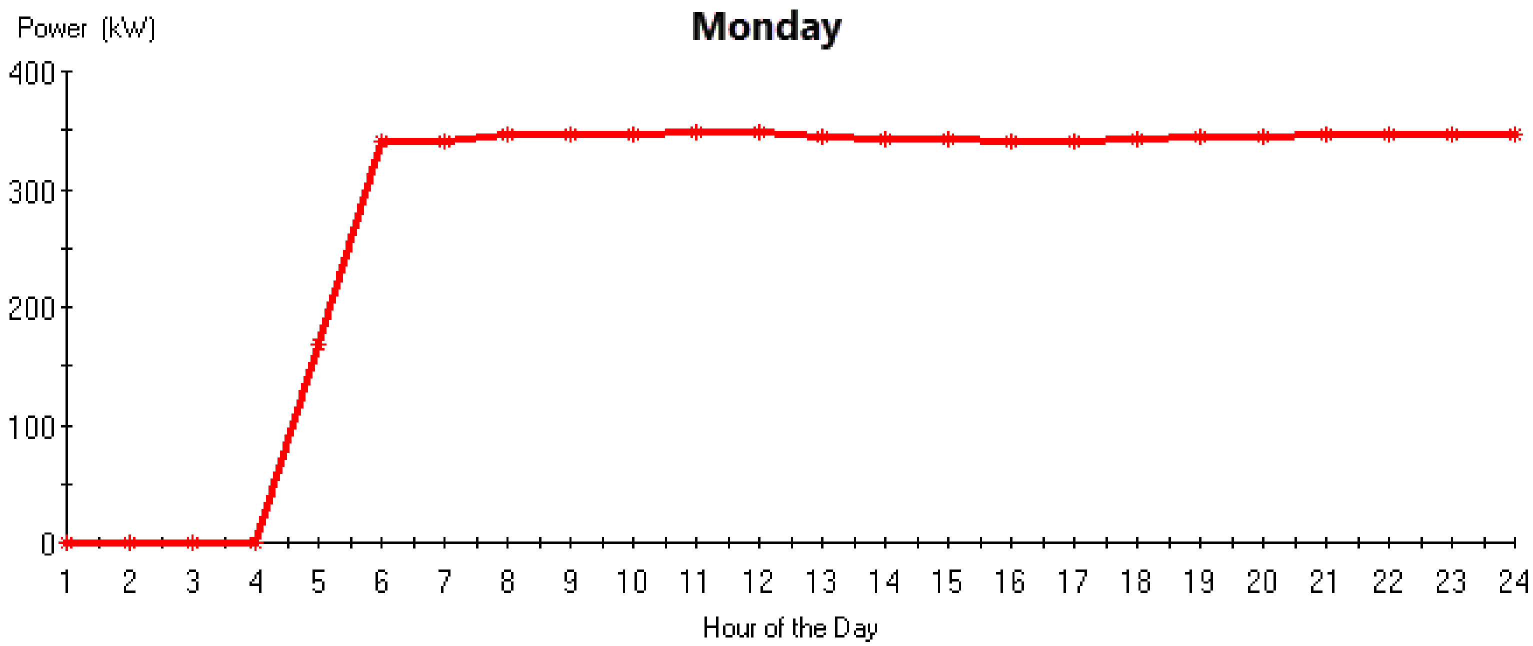
DayType Profiles



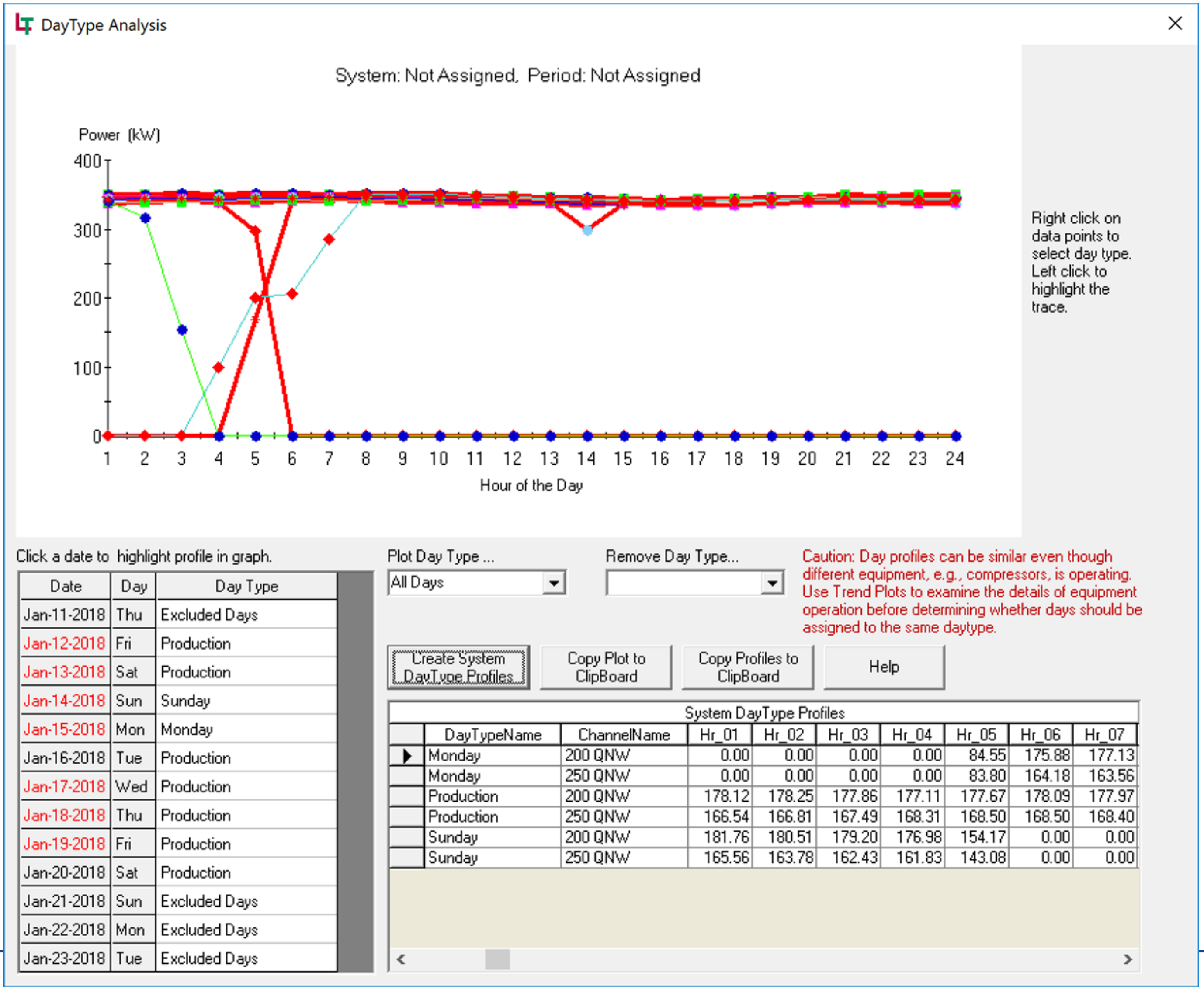
DayType Profiles



DayType Profiles



Create the baseline from the Data


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

System: Not Assigned, Period: Not Assigned

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

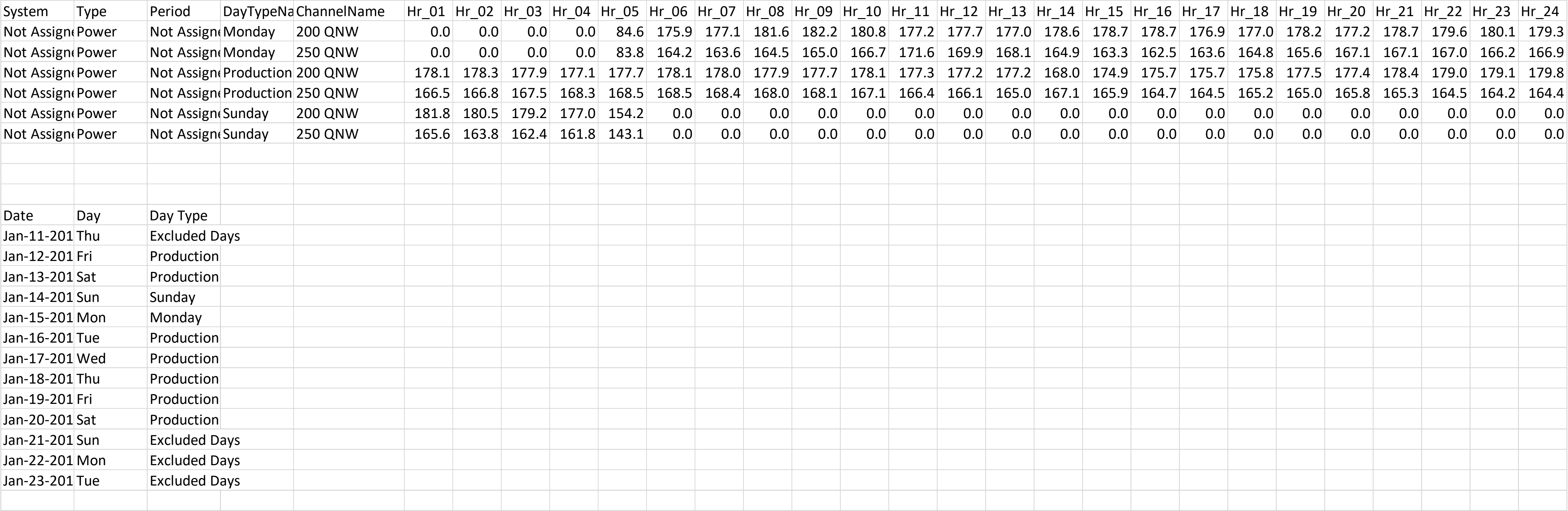
Remove Day Type...

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.

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

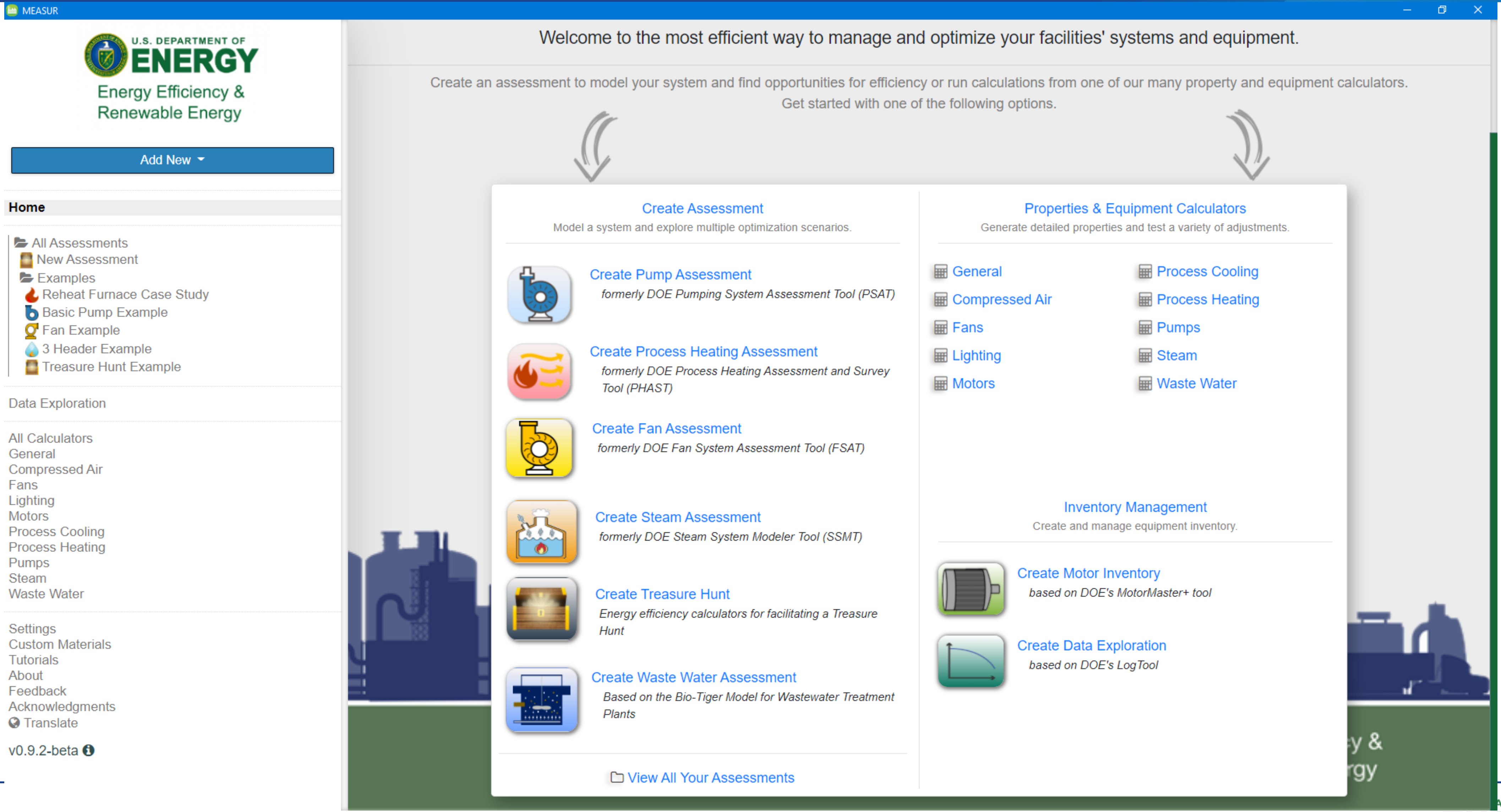
LogTool Data



System	Type	Period	DayTypeNa	ChannelName	Hr_01	Hr_02	Hr_03	Hr_04	Hr_05	Hr_06	Hr_07	Hr_08	Hr_09	Hr_10	Hr_11	Hr_12	Hr_13	Hr_14	Hr_15	Hr_16	Hr_17	Hr_18	Hr_19	Hr_20	Hr_21	Hr_22	Hr_23	Hr_24
Not Assign	Power	Not Assign	Monday	200 QNW	0.0	0.0	0.0	0.0	84.6	175.9	177.1	181.6	182.2	180.8	177.2	177.7	177.0	178.6	178.7	178.7	176.9	177.0	178.2	177.2	178.7	179.6	180.1	179.3
Not Assign	Power	Not Assign	Monday	250 QNW	0.0	0.0	0.0	0.0	83.8	164.2	163.6	164.5	165.0	166.7	171.6	169.9	168.1	164.9	163.3	162.5	163.6	164.8	165.6	167.1	167.1	167.0	166.2	166.9
Not Assign	Power	Not Assign	Production	200 QNW	178.1	178.3	177.9	177.1	177.7	178.1	178.0	177.9	177.7	178.1	177.3	177.2	177.2	168.0	174.9	175.7	175.7	175.8	177.5	177.4	178.4	179.0	179.1	179.8
Not Assign	Power	Not Assign	Production	250 QNW	166.5	166.8	167.5	168.3	168.5	168.5	168.4	168.0	168.1	167.1	166.4	166.1	165.0	167.1	165.9	164.7	164.5	165.2	165.0	165.8	165.3	164.5	164.2	164.4
Not Assign	Power	Not Assign	Sunday	200 QNW	181.8	180.5	179.2	177.0	154.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Not Assign	Power	Not Assign	Sunday	250 QNW	165.6	163.8	162.4	161.8	143.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Date	Day	Day Type
Jan-11-201	Thu	Excluded Days
Jan-12-201	Fri	Production
Jan-13-201	Sat	Production
Jan-14-201	Sun	Sunday
Jan-15-201	Mon	Monday
Jan-16-201	Tue	Production
Jan-17-201	Wed	Production
Jan-18-201	Thu	Production
Jan-19-201	Fri	Production
Jan-20-201	Sat	Production
Jan-21-201	Sun	Excluded Days
Jan-22-201	Mon	Excluded Days
Jan-23-201	Tue	Excluded Days

MEASUR Tool



MEASUR
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
Add New
Home
All Assessments
New Assessment
Examples
Reheat Furnace Case Study
Basic Pump Example
Fan Example
3 Header Example
Treasure Hunt Example
Data Exploration
All Calculators
General
Compressed Air
Fans
Lighting
Motors
Process Cooling
Process Heating
Pumps
Steam
Waste Water
Settings
Custom Materials
Tutorials
About
Feedback
Acknowledgments
Translate
v0.9.2-beta

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.

Create Assessment

Model a system and explore multiple optimization scenarios.

- Create Pump Assessment — *formerly DOE Pumping System Assessment Tool (PSAT)*
- Create Process Heating Assessment — *formerly DOE Process Heating Assessment and Survey Tool (PHAST)*
- Create Fan Assessment — *formerly DOE Fan System Assessment Tool (FSAT)*
- Create Steam Assessment — *formerly DOE Steam System Modeler Tool (SSMT)*
- Create Treasure Hunt — *Energy efficiency calculators for facilitating a Treasure Hunt*
- Create Waste Water Assessment — *Based on the Bio-Tiger Model for Wastewater Treatment Plants*

View All Your Assessments

Properties & Equipment Calculators

Generate detailed properties and test a variety of adjustments.

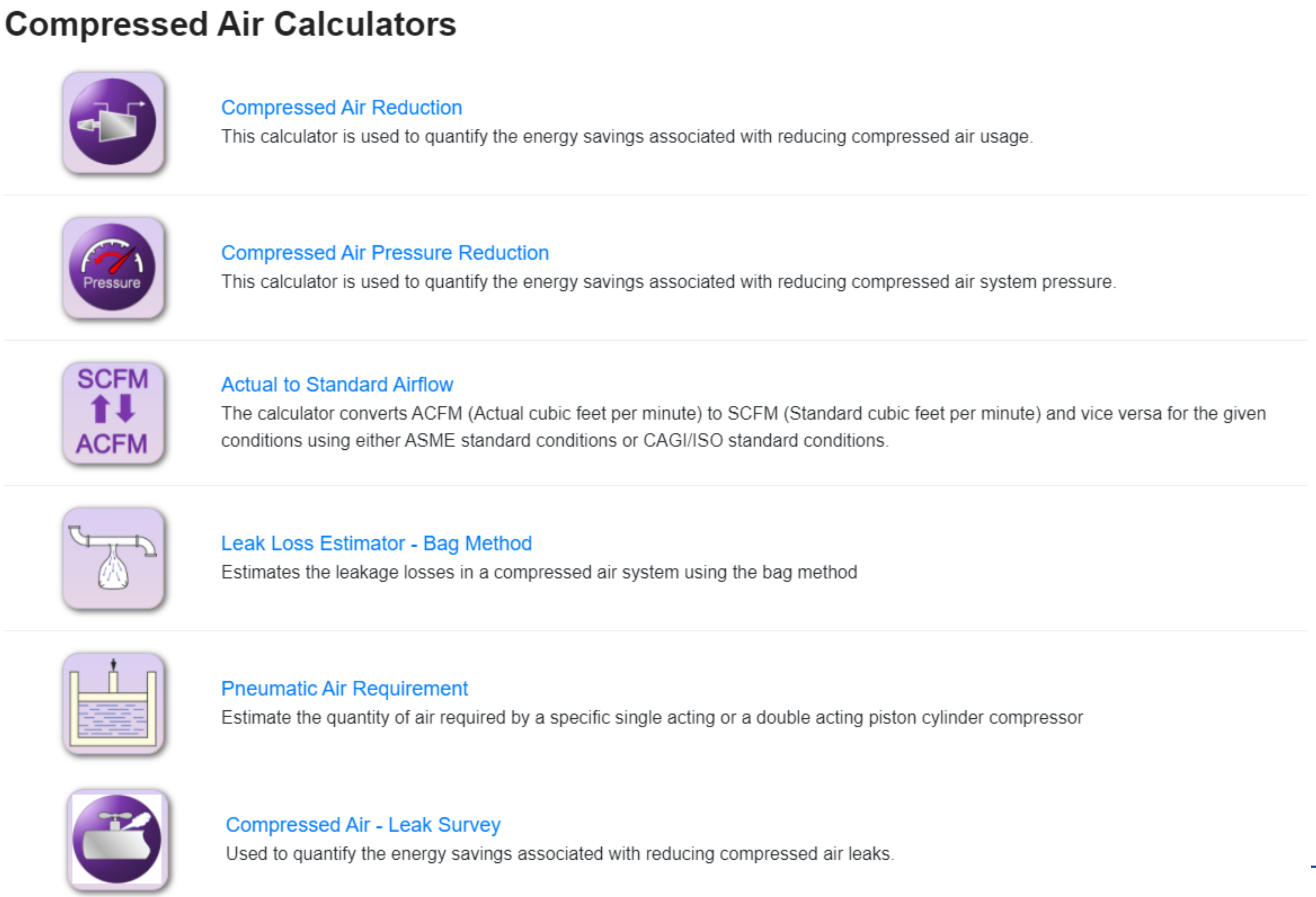
- General
- Compressed Air
- Fans
- Lighting
- Motors
- Process Cooling
- Process Heating
- Pumps
- Steam
- Waste Water

Inventory Management

Create and manage equipment inventory.

- Create Motor Inventory — *based on DOE's MotorMaster+ tool*
- Create Data Exploration — *based on DOE's LogTool*

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.

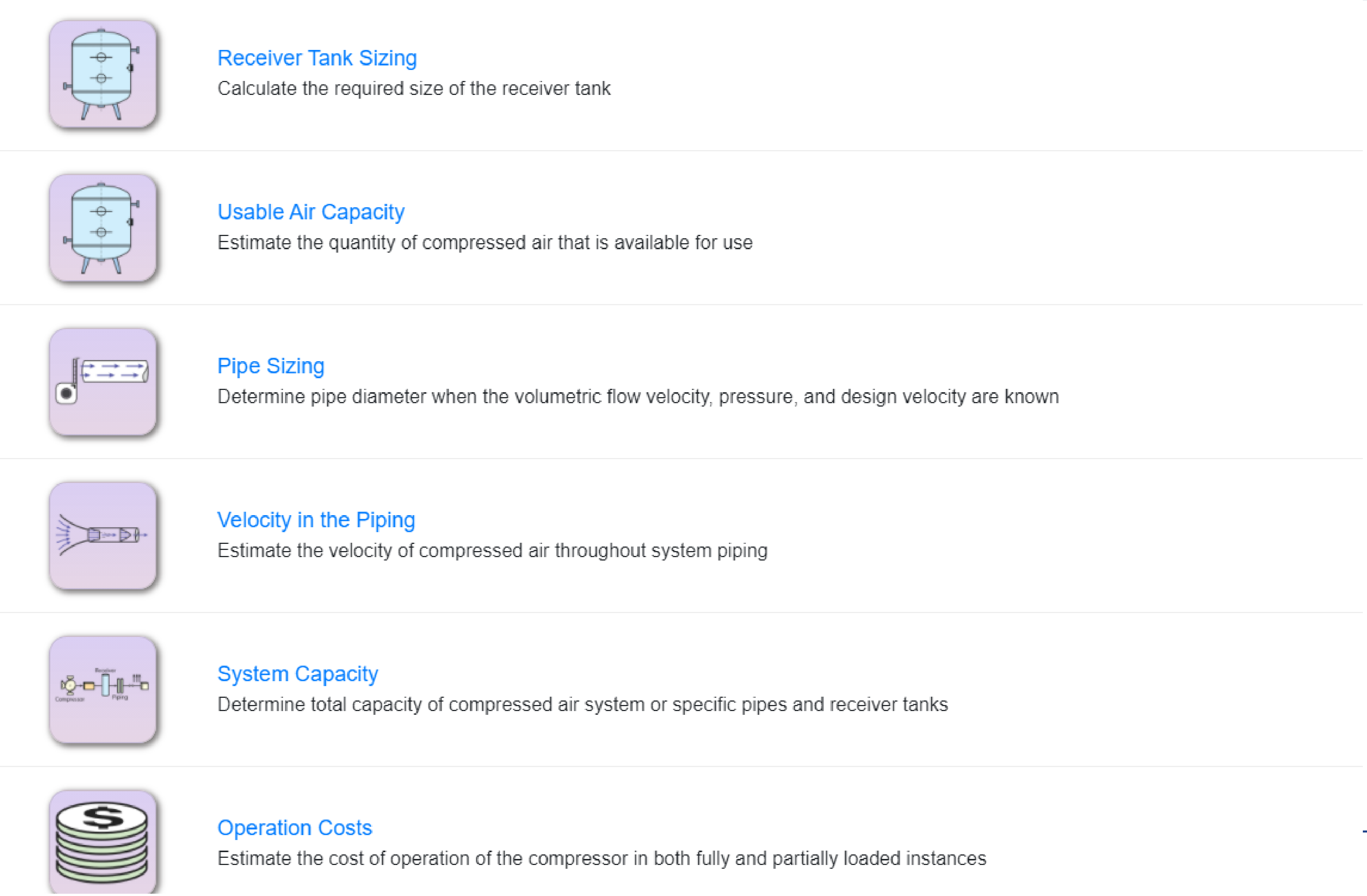
Actual to Standard Airflow
The calculator converts ACFM (Actual cubic feet per minute) to SCFM (Standard cubic feet per minute) and vice versa for the given conditions using either ASME standard conditions or CAGI/ISO standard conditions.

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

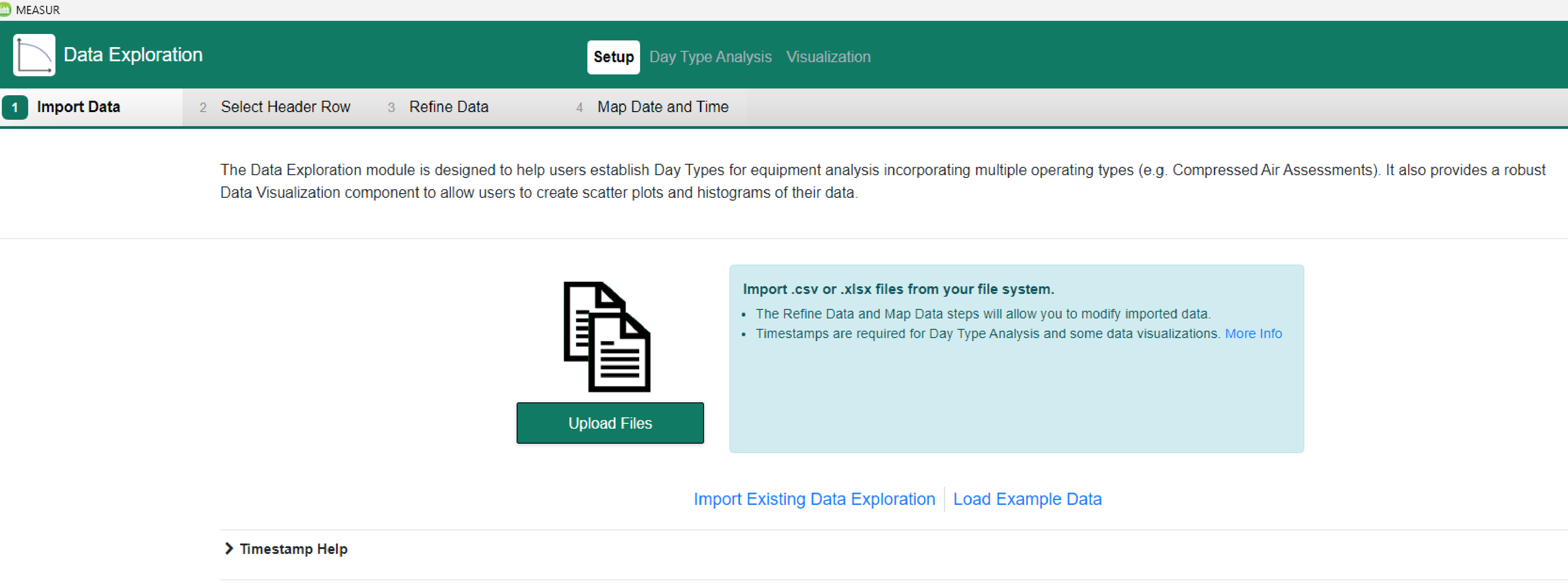
Pipe Sizing
Determine pipe diameter when the volumetric flow velocity, pressure, and design velocity are known

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

MEASUR Tool



MEASUR
Data Exploration
Setup
Day Type Analysis
Visualization
1 Import Data
2 Select Header Row
3 Refine Data
4 Map Date and Time

The Data Exploration module is designed to help users establish Day Types for equipment analysis incorporating multiple operating types (e.g. Compressed Air Assessments). It also provides a robust Data Visualization component to allow users to create scatter plots and histograms of their data.

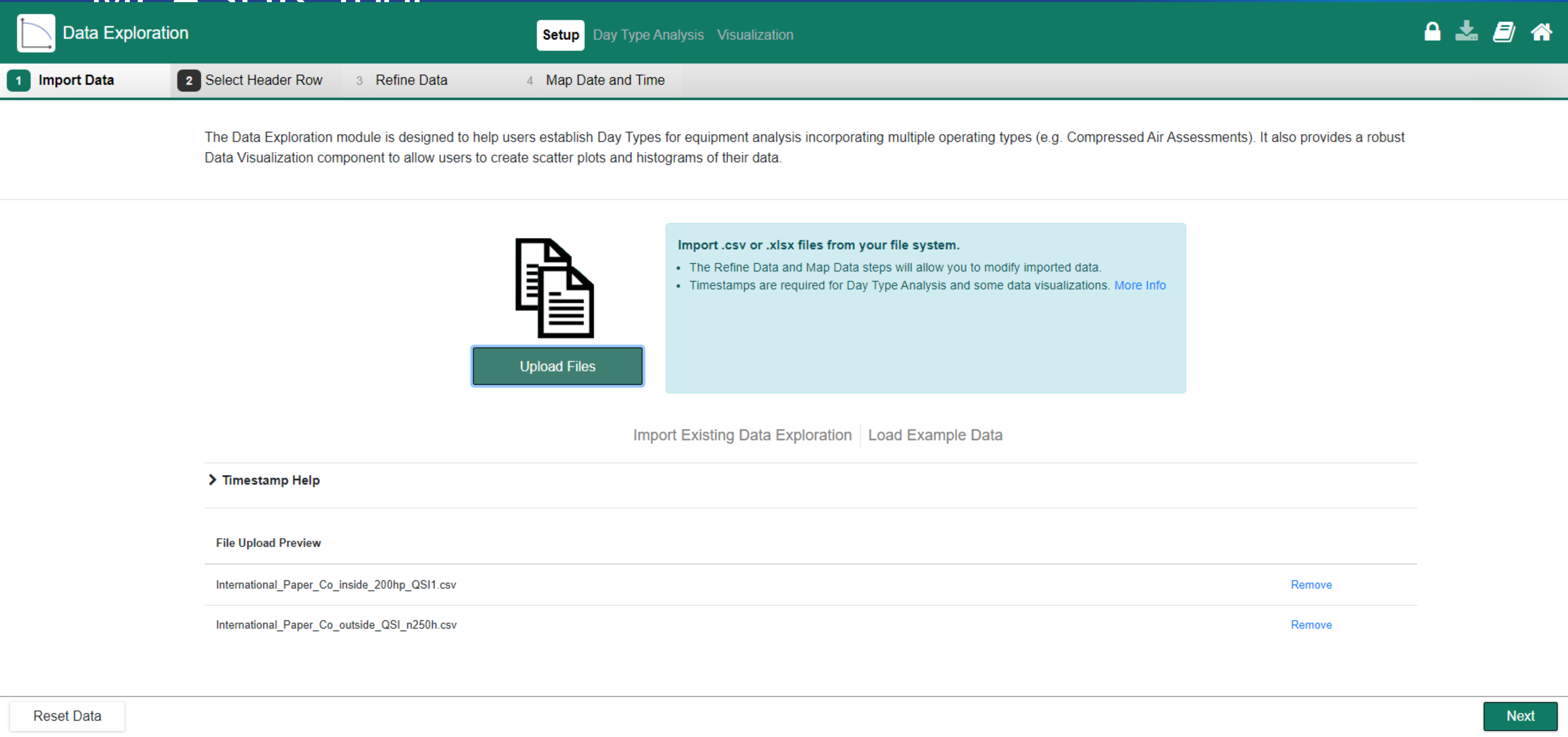
Upload Files

Import .csv or .xlsx files from your file system.

- The Refine Data and Map Data steps will allow you to modify imported data.
- Timestamps are required for Day Type Analysis and some data visualizations. More Info

Import Existing Data Exploration
Load Example Data
Timestamp Help

MEASUR Tool


Data Exploration
Setup
Day Type Analysis
Visualization
1 Import Data
2 Select Header Row
3 Refine Data
4 Map Date and Time
Upload Files
Import Existing Data Exploration
Load Example Data
Timestamp Help
Remove
Remove
Reset Data
Next

The Data Exploration module is designed to help users establish Day Types for equipment analysis incorporating multiple operating types (e.g. Compressed Air Assessments). It also provides a robust Data Visualization component to allow users to create scatter plots and histograms of their data.

Import .csv or .xlsx files from your file system.

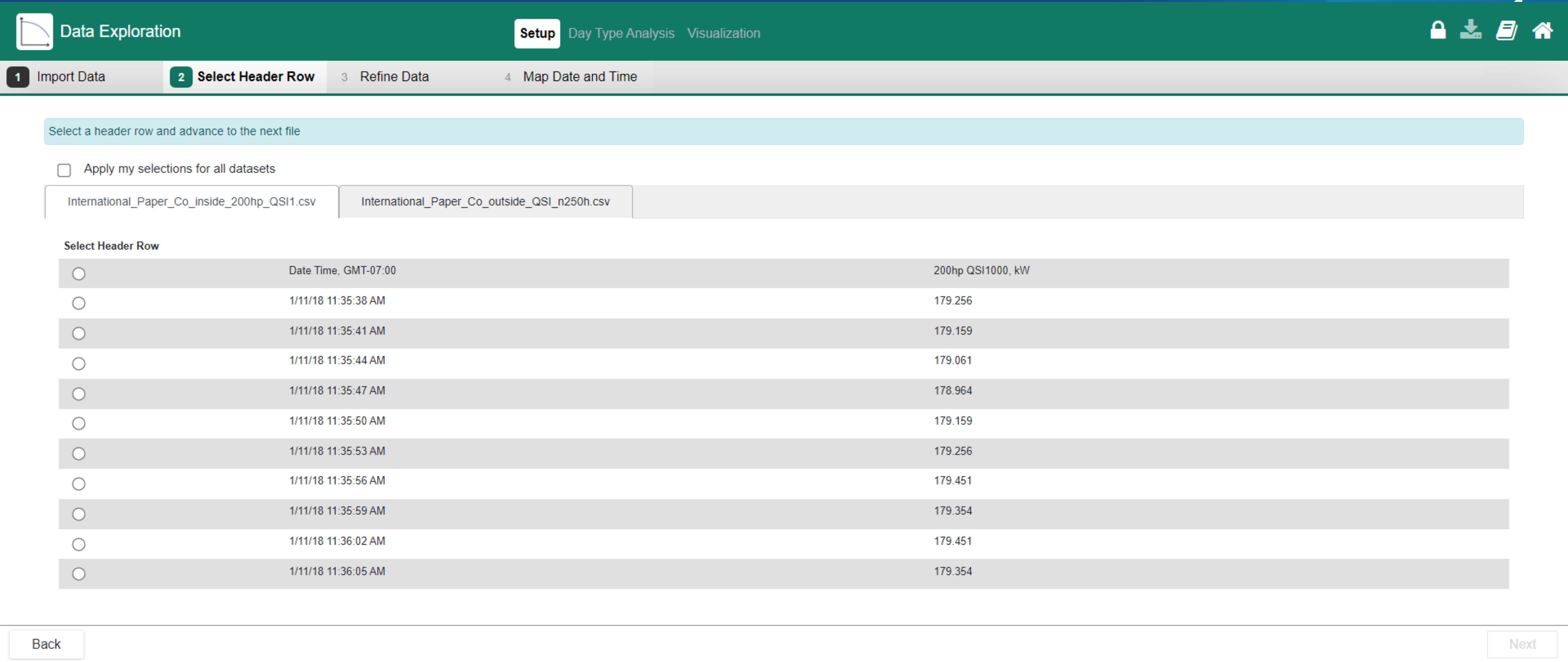
- The Refine Data and Map Data steps will allow you to modify imported data.
- Timestamps are required for Day Type Analysis and some data visualizations. More Info

File Upload Preview

International_Paper_Co_inside_200hp_QSI1.csv

International_Paper_Co_outside_QSI_n250h.csv

MEASUR Tool


Data Exploration
Setup
Day Type Analysis
Visualization
1 Import Data
2 Select Header Row
3 Refine Data
4 Map Date and Time
International_Paper_Co_inside_200hp_QSI1.csv
International_Paper_Co_outside_QSI_n250h.csv
Back
Next

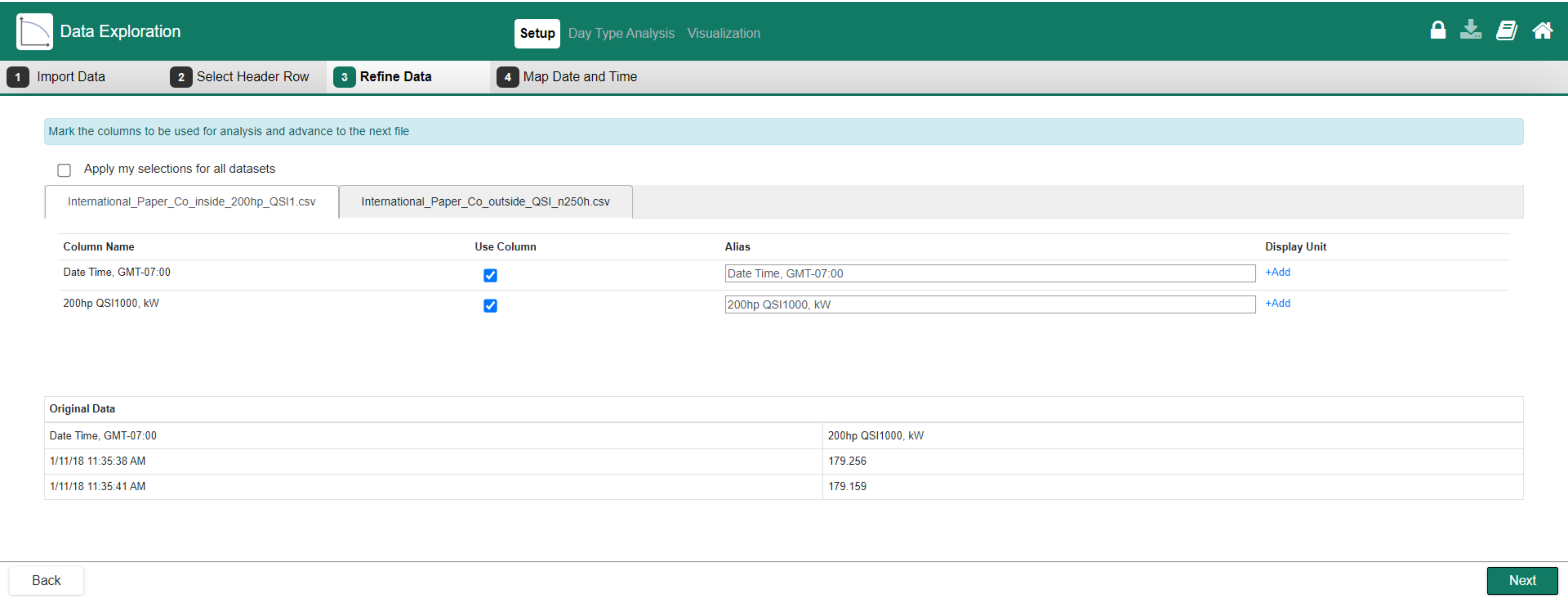
Select a header row and advance to the next file

☐ Apply my selections for all datasets

Select Header Row

○	Date Time, GMT-07:00	200hp QSI1000, kW
○	1/11/18 11:35:38 AM	179.256
○	1/11/18 11:35:41 AM	179.159
○	1/11/18 11:35:44 AM	179.061
○	1/11/18 11:35:47 AM	178.964
○	1/11/18 11:35:50 AM	179.159
○	1/11/18 11:35:53 AM	179.256
○	1/11/18 11:35:56 AM	179.451
○	1/11/18 11:35:59 AM	179.354
○	1/11/18 11:36:02 AM	179.451
○	1/11/18 11:36:05 AM	179.354

MEASUR Tool


Data Exploration
Setup
Day Type Analysis
Visualization
1 Import Data
2 Select Header Row
3 Refine Data
4 Map Date and Time
+Add
Back
Next

Mark the columns to be used for analysis and advance to the next file

☐ Apply my selections for all datasets

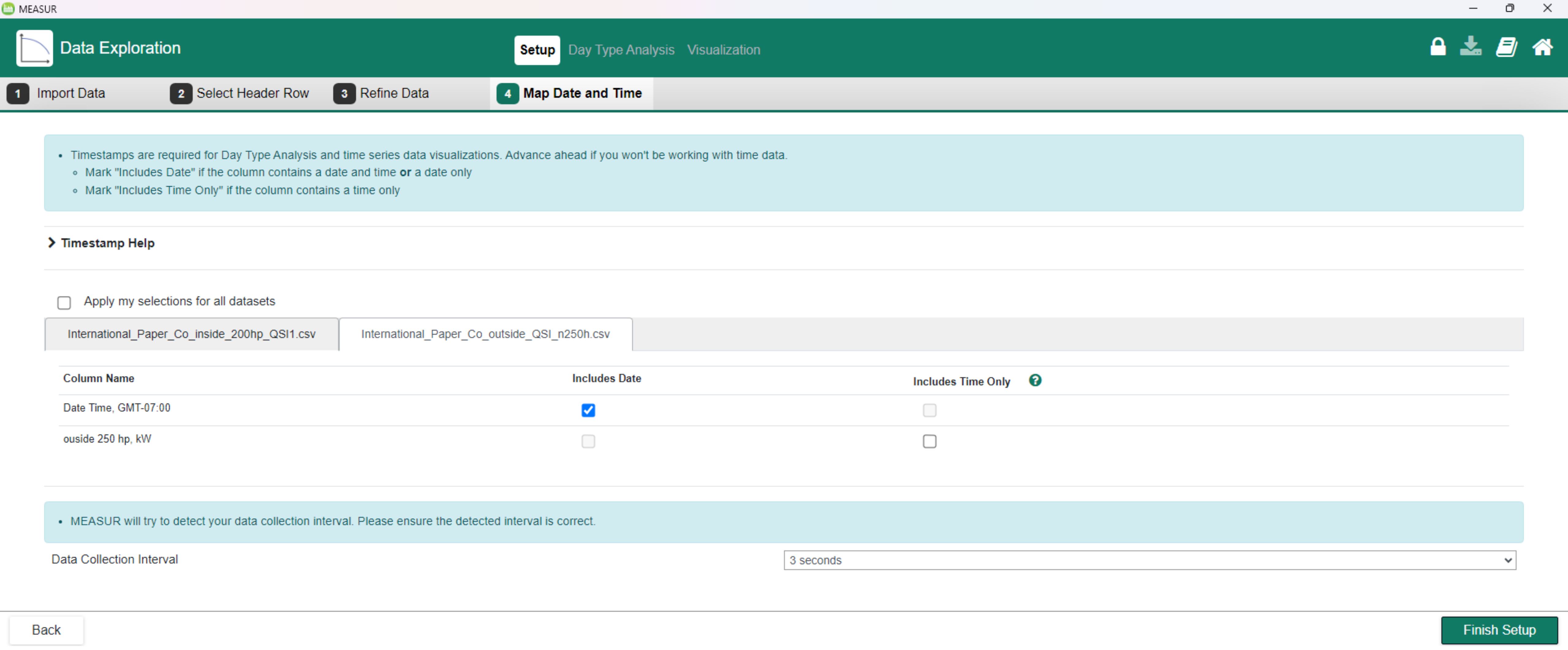
International_Paper_Co_inside_200hp_QSI1.csv | International_Paper_Co_outside_QSI_n250h.csv

Column Name	Use Column	Alias	Display Unit
Date Time, GMT-07:00	☑	Date Time, GMT-07:00	+Add
200hp QSI1000, kW	☑	200hp QSI1000, kW	+Add

Original Data

Date Time, GMT-07:00	200hp QSI1000, kW
1/11/18 11:35:38 AM	179.256
1/11/18 11:35:41 AM	179.159

MEASUR Tool



MEASUR
Data Exploration
Setup
Day Type Analysis
Visualization
1 Import Data
2 Select Header Row
3 Refine Data
4 Map Date and Time

- Timestamps are required for Day Type Analysis and time series data visualizations. Advance ahead if you won't be working with time data.
  - Mark "Includes Date" if the column contains a date and time **or** a date only
  - Mark "Includes Time Only" if the column contains a time only

Timestamp Help

☐ Apply my selections for all datasets

International_Paper_Co_inside_200hp_QSI1.csv
International_Paper_Co_outside_QSI_n250h.csv

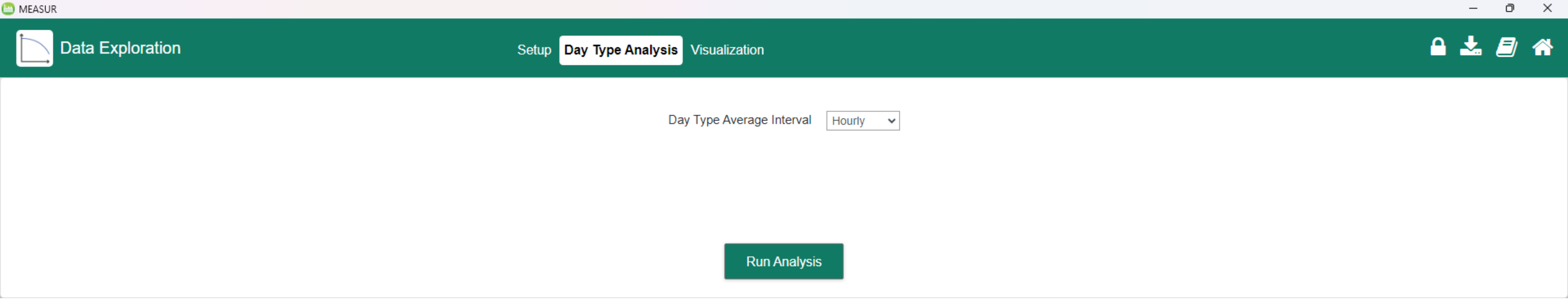
Column Name	Includes Date	Includes Time Only
Date Time, GMT-07:00	☑	☐
ouside 250 hp, kW	☐	☐

- MEASUR will try to detect your data collection interval. Please ensure the detected interval is correct.

Data Collection Interval: 3 seconds

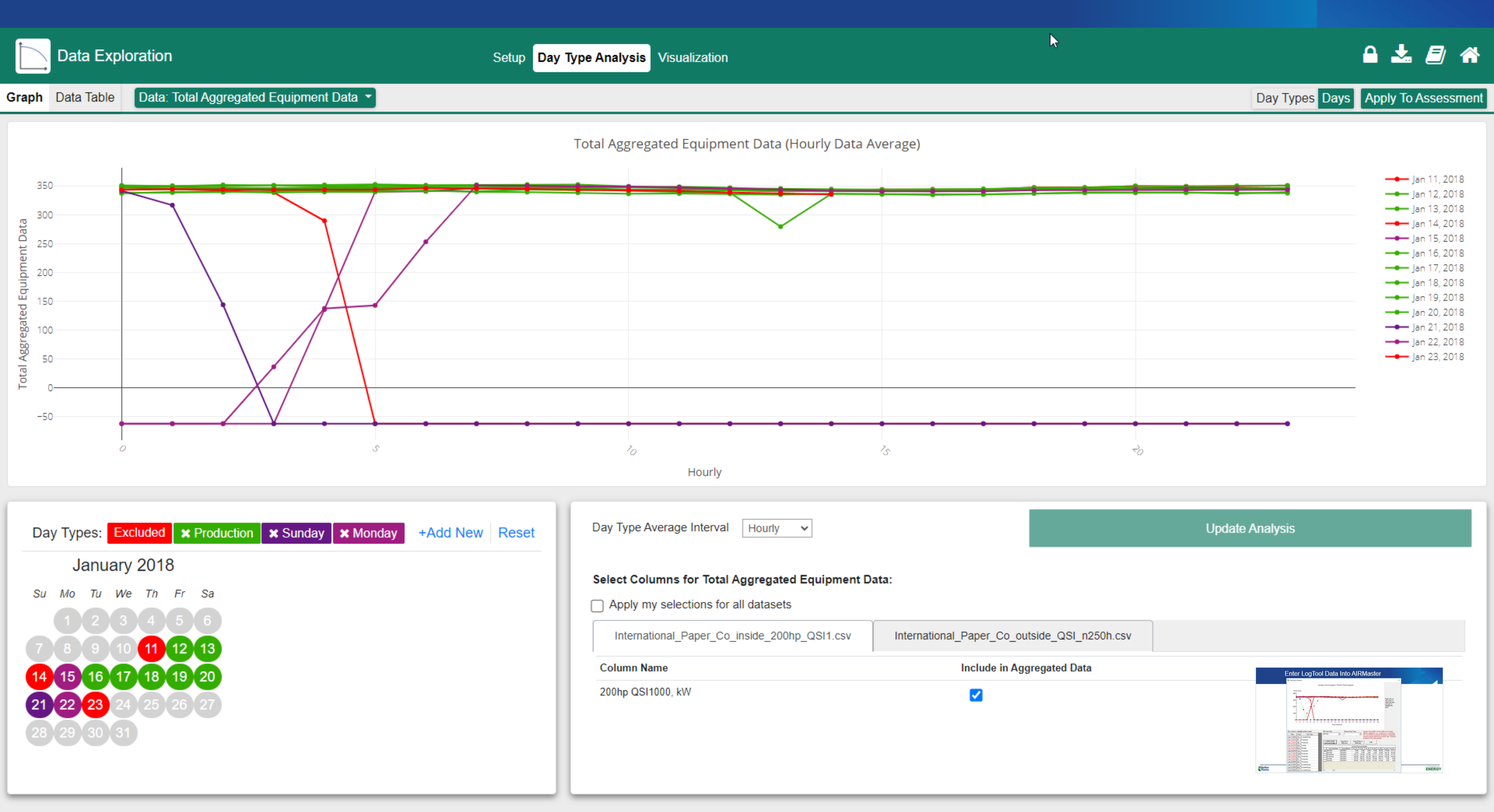
Back
Finish Setup

MEASUR Tool



MEASUR
Data Exploration
Setup
Day Type Analysis
Visualization
Run Analysis

Day Type Average Interval: Hourly



Data Exploration
Setup
Day Type Analysis
Visualization
Graph
Data Table
Data: Total Aggregated Equipment Data
Day Types
Days
Apply To Assessment
Total Aggregated Equipment Data (Hourly Data Average)
Total Aggregated Equipment Data
350
300
250
200
150
100
50
0
−50
0
5
10
15
20
Hourly
Jan 11, 2018
Jan 12, 2018
Jan 13, 2018
Jan 14, 2018
Jan 15, 2018
Jan 16, 2018
Jan 17, 2018
Jan 18, 2018
Jan 19, 2018
Jan 20, 2018
Jan 21, 2018
Jan 22, 2018
Jan 23, 2018
Day Types:
Excluded
✖ Production
✖ Sunday
✖ Monday
+Add New
Reset
January 2018
Su
Mo
Tu
We
Th
Fr
Sa
1
2
3
4
5
6
7
8
9
10
11
12
13
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24
25
26
27
28
29
30
31
Update Analysis
Enter LogTool Data Into AIRMaster

Day Type Average Interval: Hourly

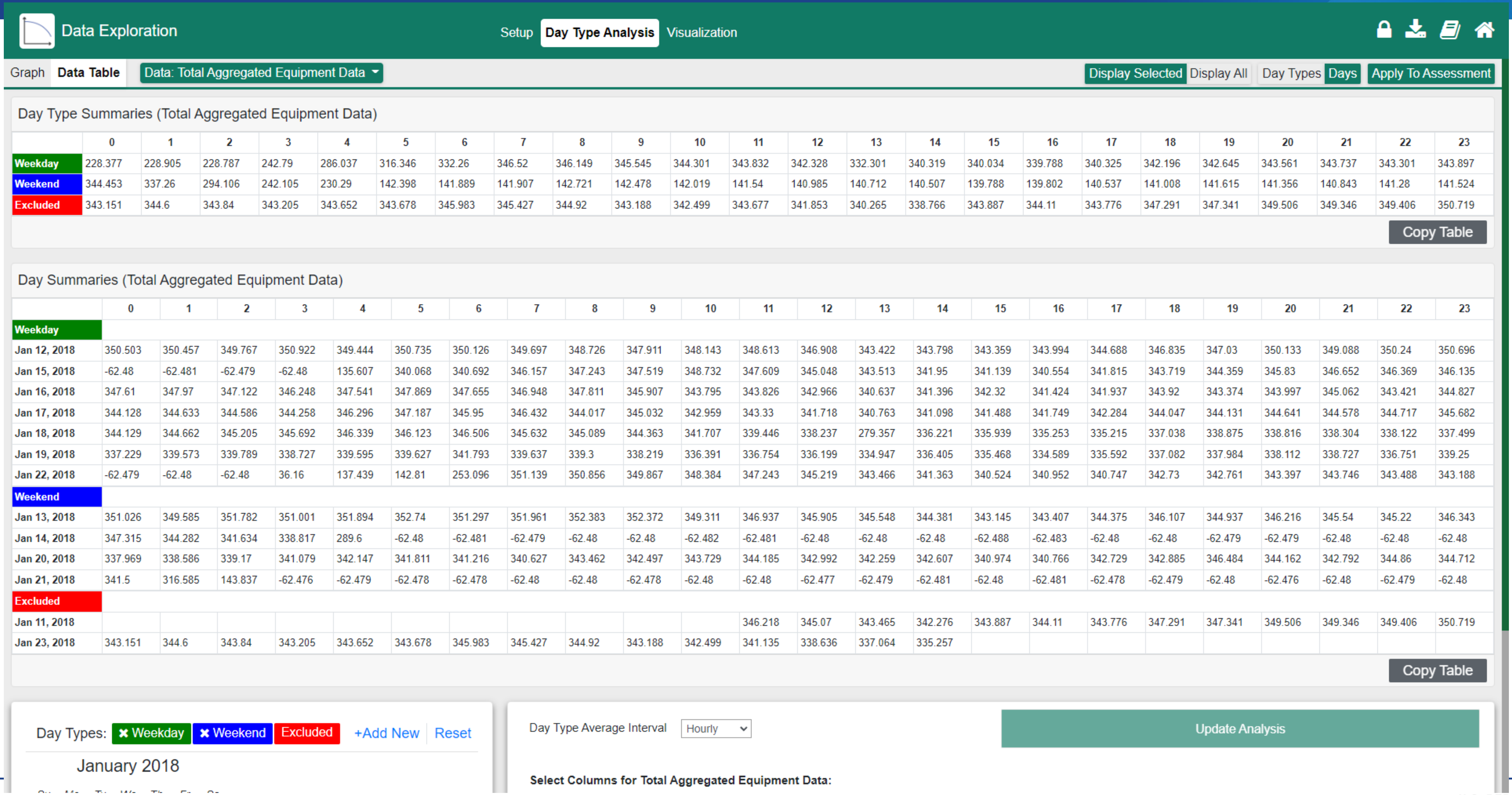
Select Columns for Total Aggregated Equipment Data:

☐ Apply my selections for all datasets

International_Paper_Co_inside_200hp_QSI1.csv | International_Paper_Co_outside_QSI_n250h.csv

Column Name	Include in Aggregated Data
200hp QSI1000, kW	☑

Let's compare to old Log Tool



Day Type Summaries (Total Aggregated Equipment Data)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
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	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	344.453	337.26	294.106	242.105	230.29	142.398	141.889	141.907	142.721	142.478	142.019	141.54	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	343.151	344.6	343.84	343.205	343.652	343.678	345.983	345.427	344.92	343.188	342.499	343.677	341.853	340.265	338.766	343.887	344.11	343.776	347.291	347.341	349.506	349.346	349.406	350.719

Day Summaries (Total Aggregated Equipment Data)

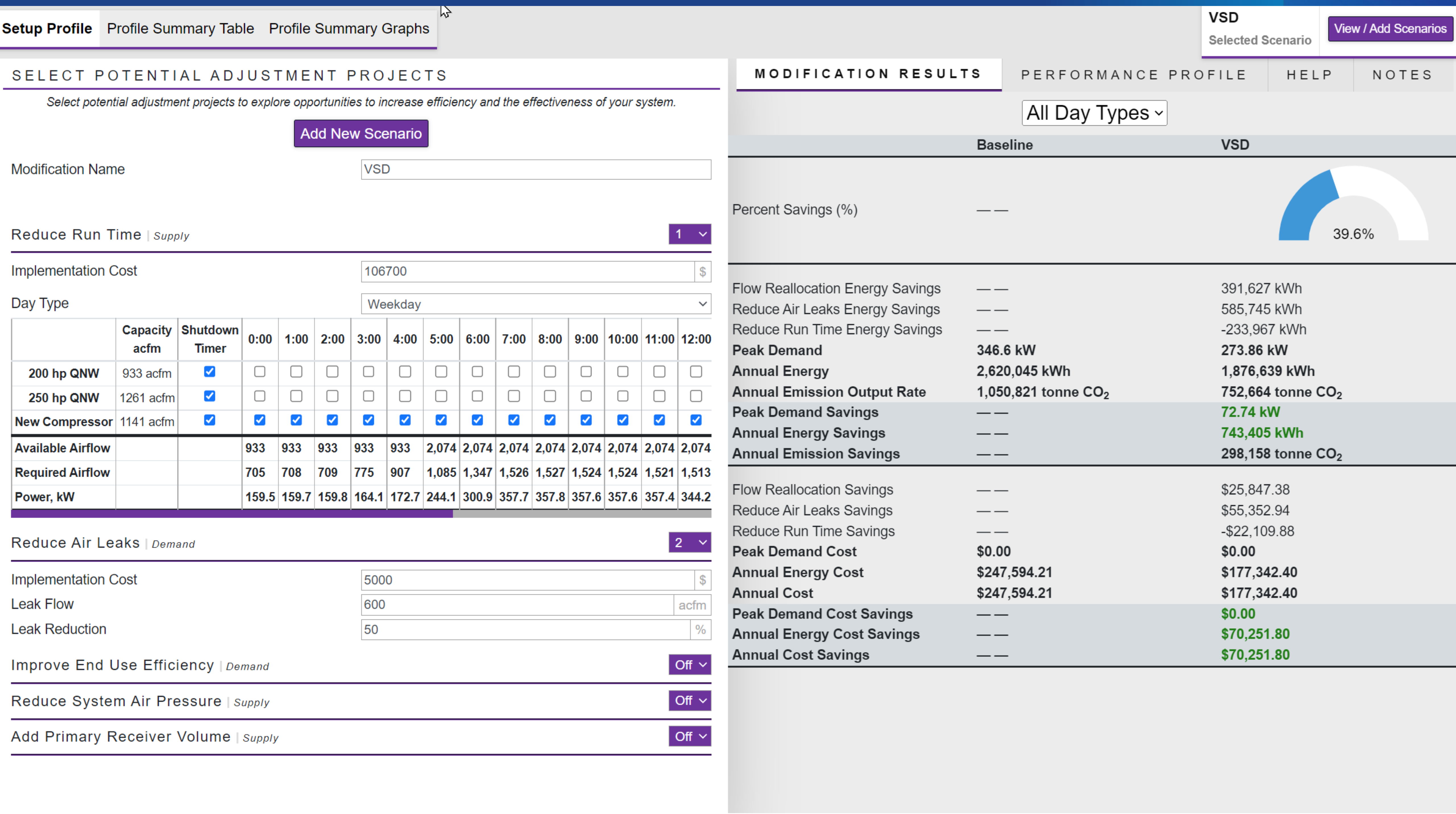
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Weekday																								
Jan 12, 2018	350.503	350.457	349.767	350.922	349.444	350.735	350.126	349.697	348.726	347.911	348.143	348.613	346.908	343.422	343.798	343.359	343.994	344.688	346.835	347.03	350.133	349.088	350.24	350.696
Jan 15, 2018	-62.48	-62.481	-62.479	-62.48	135.607	340.068	340.692	346.157	347.243	347.519	348.732	347.609	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	347.61	347.97	347.122	346.248	347.541	347.869	347.655	346.948	347.811	345.907	343.795	343.826	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	344.128	344.633	344.586	344.258	346.296	347.187	345.95	346.432	344.017	345.032	342.959	343.33	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	344.129	344.662	345.205	345.692	346.339	346.123	346.506	345.632	345.089	344.363	341.707	339.446	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	337.229	339.573	339.789	338.727	339.595	339.627	341.793	339.637	339.3	338.219	336.391	336.754	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	-62.479	-62.48	-62.48	36.16	137.439	142.81	253.096	351.139	350.856	349.867	348.384	347.243	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	351.026	349.585	351.782	351.001	351.894	352.74	351.297	351.961	352.383	352.372	349.311	346.937	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	347.315	344.282	341.634	338.817	289.6	-62.48	-62.481	-62.479	-62.48	-62.48	-62.482	-62.481	-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	337.969	338.586	339.17	341.079	342.147	341.811	341.216	340.627	343.462	342.497	343.729	344.185	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	341.5	316.585	143.837	-62.476	-62.479	-62.478	-62.478	-62.48	-62.48	-62.478	-62.48	-62.48	-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												346.218	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	343.151	344.6	343.84	343.205	343.652	343.678	345.983	345.427	344.92	343.188	342.499	341.135	338.636	337.064	335.257									

Day Types: ✖ Weekday ✖ Weekend Excluded

January 2018

Day Type Average Interval: Hourly

Select Columns for Total Aggregated Equipment Data:


Setup Profile
Profile Summary Table
Profile Summary Graphs
VSD
Selected Scenario
View / Add Scenarios
Add New Scenario
MODIFICATION RESULTS
PERFORMANCE PROFILE
HELP
NOTES

SELECT POTENTIAL ADJUSTMENT PROJECTS

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

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 %

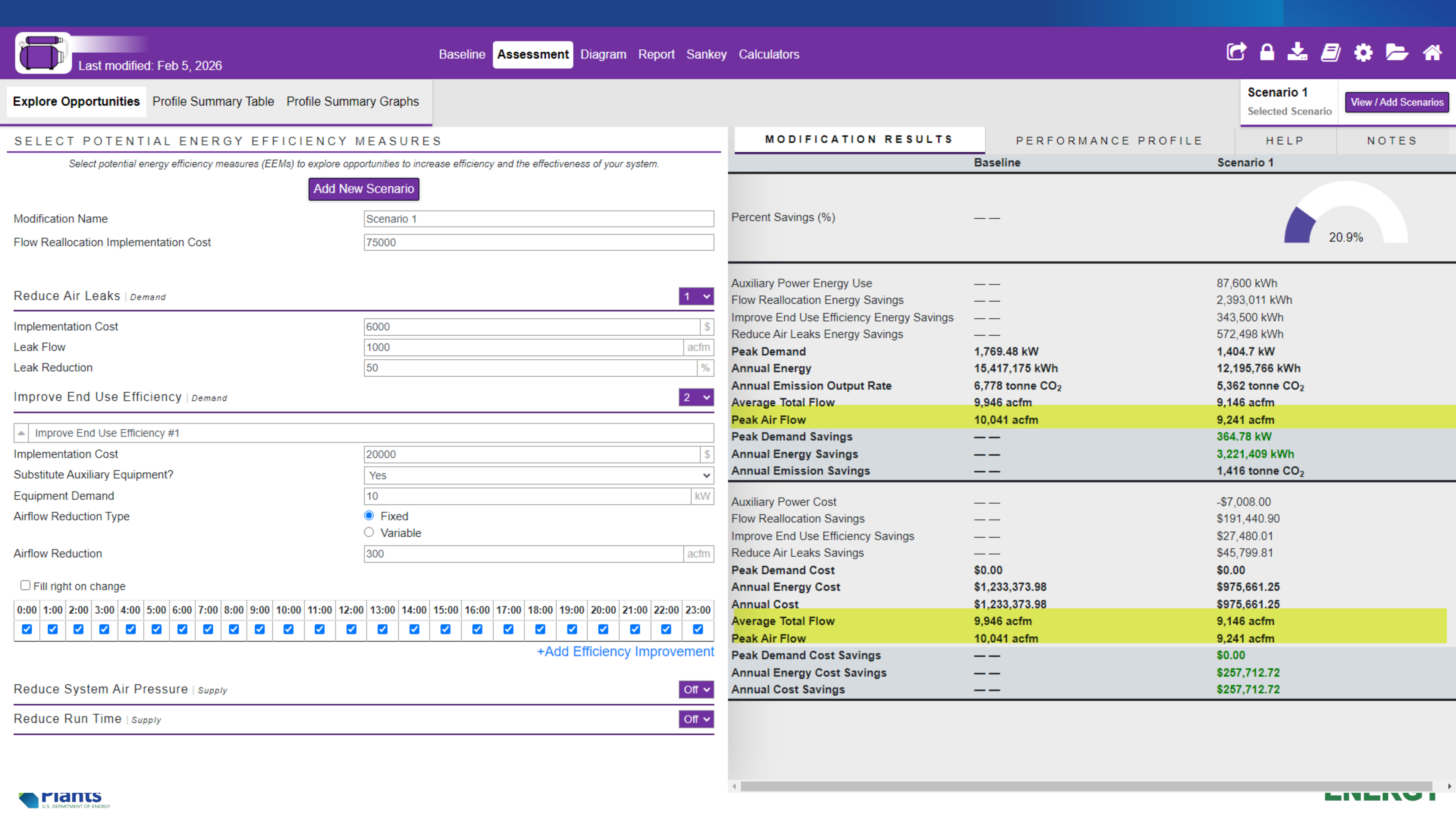
Improve End Use Efficiency | *Demand*: Off

Reduce System Air Pressure | *Supply*: Off

Add Primary Receiver Volume | *Supply*: Off

All Day Types

	Baseline	VSD
Percent Savings (%)	— —	39.6%
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**


Baseline
Assessment
Diagram
Report
Sankey
Calculators
Explore Opportunities
Profile Summary Table
Profile Summary Graphs
Scenario 1
Selected Scenario
View / Add Scenarios
MODIFICATION RESULTS
PERFORMANCE PROFILE
HELP
NOTES
Add New Scenario
+Add Efficiency Improvement

Last modified: Feb 5, 2026

SELECT POTENTIAL ENERGY EFFICIENCY MEASURES

Select potential energy efficiency measures (EEMs) to explore opportunities to increase efficiency and the effectiveness of your system.

Modification Name	Scenario 1
Flow Reallocation Implementation Cost	75000

Reduce Air Leaks | *Demand* — 1

Implementation Cost	6000 $
Leak Flow	1000 acfm
Leak Reduction	50 %

Improve End Use Efficiency | *Demand* — 2

Improve End Use Efficiency #1

Implementation Cost	20000 $
Substitute Auxiliary Equipment?	Yes
Equipment Demand	10 kW
Airflow Reduction Type	● Fixed ○ Variable
Airflow Reduction	300 acfm

☐ Fill right on change

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	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

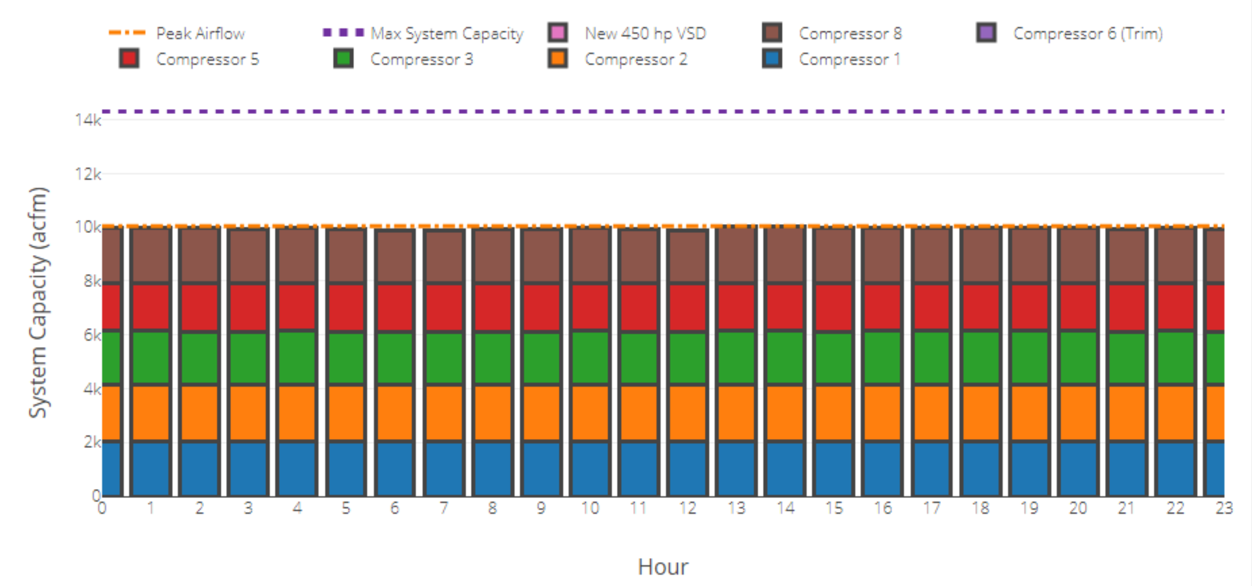
Reduce System Air Pressure | *Supply* — Off

Reduce Run Time | *Supply* — Off

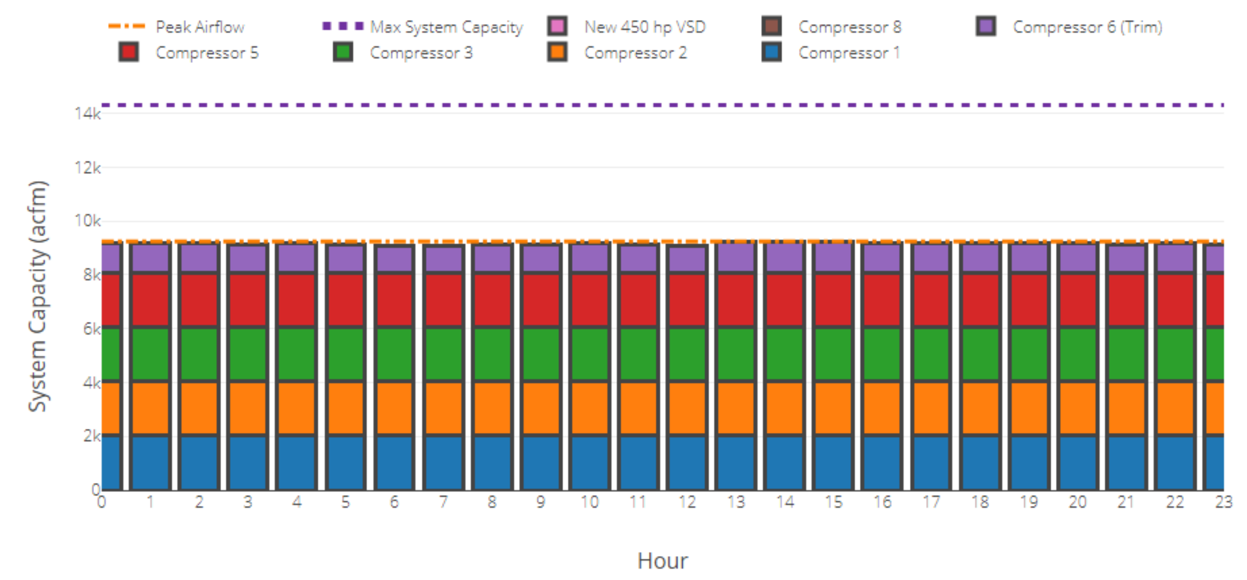
MODIFICATION RESULTS

	Baseline	Scenario 1
Percent Savings (%)	— —	20.9%
Auxiliary Power Energy Use	— —	87,600 kWh
Flow Reallocation Energy Savings	— —	2,393,011 kWh
Improve End Use Efficiency Energy Savings	— —	343,500 kWh
Reduce Air Leaks Energy Savings	— —	572,498 kWh
Peak Demand	**1,769.48 kW**	**1,404.7 kW**
Annual Energy	**15,417,175 kWh**	**12,195,766 kWh**
Annual Emission Output Rate	**6,778 tonne CO_2**	**5,362 tonne CO_2**
Average Total Flow	**9,946 acfm**	**9,146 acfm**
Peak Air Flow	**10,041 acfm**	**9,241 acfm**
Peak Demand Savings	**— —**	**364.78 kW**
Annual Energy Savings	**— —**	**3,221,409 kWh**
Annual Emission Savings	**— —**	**1,416 tonne CO_2**
Auxiliary Power Cost	— —	-$7,008.00
Flow Reallocation Savings	— —	$191,440.90
Improve End Use Efficiency Savings	— —	$27,480.01
Reduce Air Leaks Savings	— —	$45,799.81
Peak Demand Cost	**$0.00**	**$0.00**
Annual Energy Cost	**$1,233,373.98**	**$975,661.25**
Annual Cost	**$1,233,373.98**	**$975,661.25**
Average Total Flow	**9,946 acfm**	**9,146 acfm**
Peak Air Flow	**10,041 acfm**	**9,241 acfm**
Peak Demand Cost Savings	**— —**	**$0.00**
Annual Energy Cost Savings	**— —**	**$257,712.72**
Annual Cost Savings	**— —**	**$257,712.72**

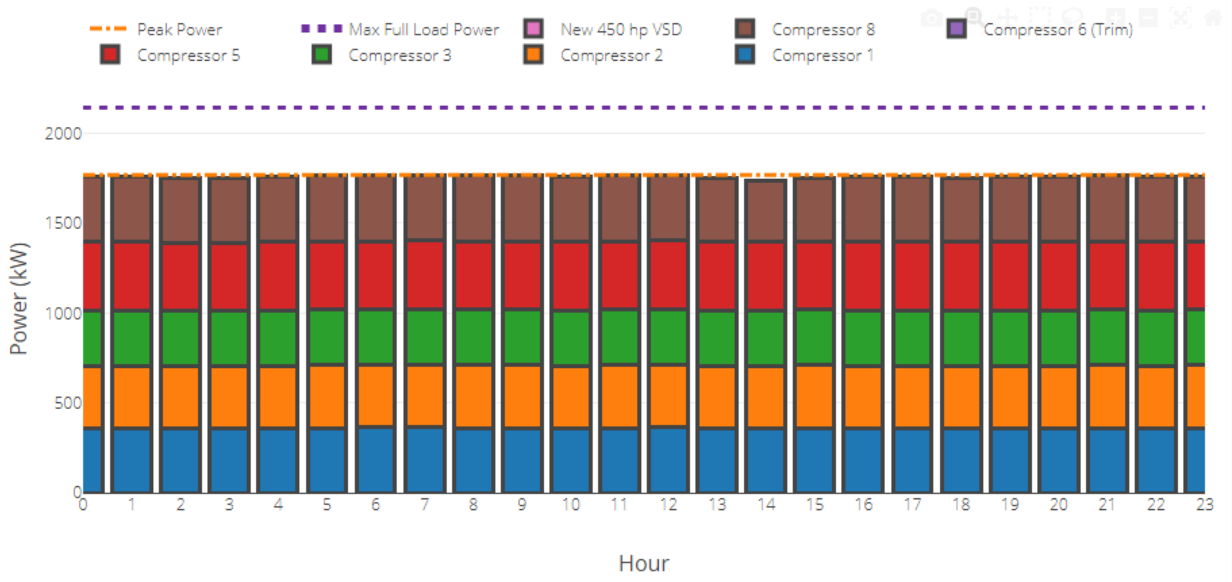
Baseline System Capacity



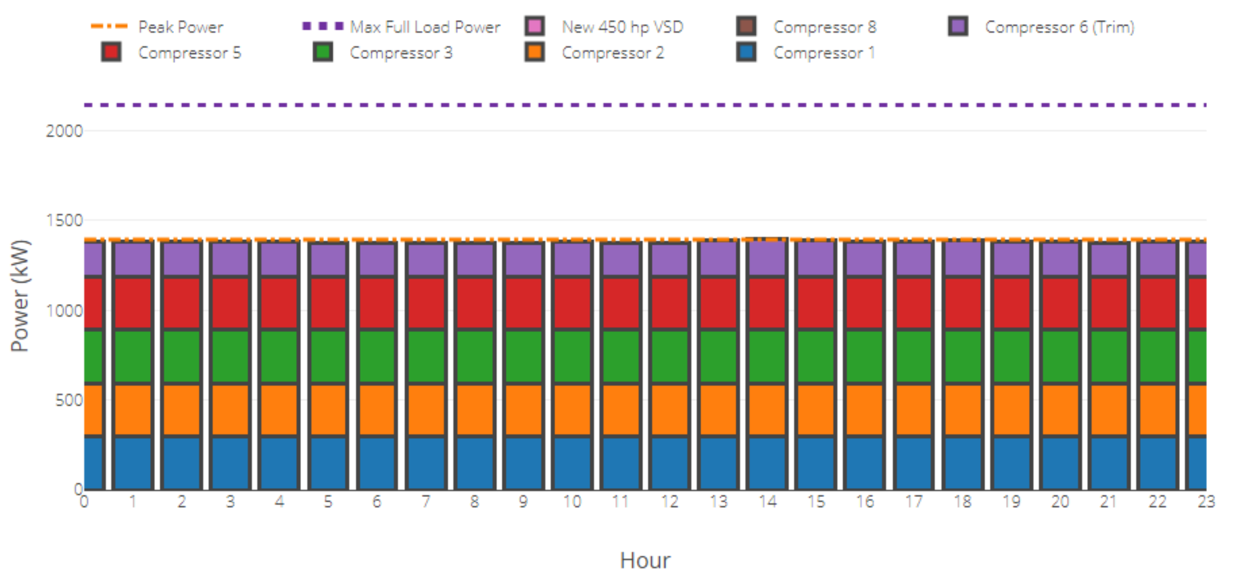
Scenario 1 System Capacity



Baseline System Power



Scenario 1 System Power



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?

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ENERGY