



In-Plant Trainings

Session 7 – System Volume vs Storage





Homework Review

From Session 6

Homework from last session 6

- Open blowing **We have air knives to blow water from cups lids before printing codes @ low pressure**
- Vacuum Generation **We have multiple machines and do pick and place operation using vacuum generators**
- Cabinet cooling **A few air operated cabinet coolers most have been phased out to electronic units**
- Diaphragm pumps **Multiple pumps for chemicals, a lot of the pumps have been converted to electric diaphragm pumps**
- Timer drains/open drains **Multiple timed Air blows for draining condensate from air separators**
- Air Motors **One air motor that runs a conveyor speed adjusted for different products**

Homework from last session 6

- Open blowing - clean off stations are equipped with blow off nozzles to clean micro holes in parts.
- Sparging (agitating, stirring, mixing) - Used for slurry room agitation of a additive, If not agitated material turns to a cement like substance.
- Aspirating
- Atomizing
- Padding
- Dilute phase transport
- Dense phase transport
- Vacuum generation
- Personnel cooling
- Open handheld blowguns or lances - Used regularly for cleaning off and dry product/parts after parts go through cleaning cycles, prior to inspection stations.
- Cabinet cooling
- Vacuum venturis
- Diaphragm pumps - used to transfer wastewater/liquids into bulk waste tanks.
- Timer drains/open drains - condensate drains on compressor system.
- Air Motors



Homework from last session 6

- Open blowing

We have MULTIPLE instances of open blowing. All of them are to direct/control/clean our cotton candy like product that tends to float away or go in the wrong direction if it's not aggressively told where to go. While these applications are required for process control, something that we do not have in place are automated solenoid valves to control the flow. Right now all of these open blowing applications are open unless someone closes the manual valve. Meaning even if the equipment isn't running, it's likely the open blowing is still occurring. An improvement to this would be to install solenoid valves that would close automatically if the equipment is not operational, rather than relying on an operator to do so.

The majority of our open air blow bars are $\frac{1}{4}$ " slits that are 4-8' long and are constantly blowing.

- Dense phase transport

We are a glass manufacturing facility. We make glass by melting our specialty mix of sand. This sand is blended and then is dense phase transported approximately 60 feet horizontally and 20 feet vertically via compressed air. It is not a diagonal pipe run but a zig zag where the material traverses horizontally, then vertically, and horizontally again into a large holding tank. The material is then fed out of the tank via an auger. This is not a constant process but happens 5-10 times a day for a few minutes and it consumes a large amount of compressed air.



Homework from last session 6

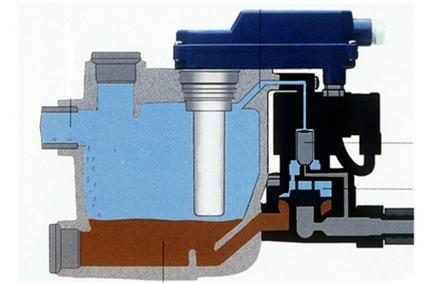
- Open handheld blowguns or lances

We use handheld air wands/blowguns constantly in the plant. Our product is very similar to cotton candy and sticks to everything and gets everywhere. Cleaning with air is the preferred method to get it to unstick and corral the material for clean up. We are currently trialing out the handheld blowers to see if they have the strength to clean up the material.



- Timer drains/open drains

We currently utilize solenoid timer drains on our compressors and downstream compressor house equipment (receiver, dryer, ect.) I'm currently doing the calculations on the ROI for installing zero-loss air drains instead.



Homework from last session 6

- **Atomizing:**
Compressed air is used in the paint booth to atomize paint into fine droplets so that it can be evenly sprayed onto products.
- **Open handheld blowguns or lances:**
Compressed air blowguns are used in the shop floor to remove dust, debris, or metal chips from machines and workpieces.
- **Air motors:**
It is useful in the workshop. It powers tools like tools that are used for drilling and fastening things together. It can also be used for assembly tasks.
- **Vacuum venturis:**
Compressed air can be used in the packaging machine to generate vacuum through venturi devices for gripping or moving products during packaging.
- **Cabinet cooling:**
Compressed air is useful for cooling down control cabinets or panels. This helps to prevent the components inside from overheating.
- **General shop air:**
Compressed air is distributed through the system to supply multiple shop floor operations such as cleaning, tool operation, and equipment support.

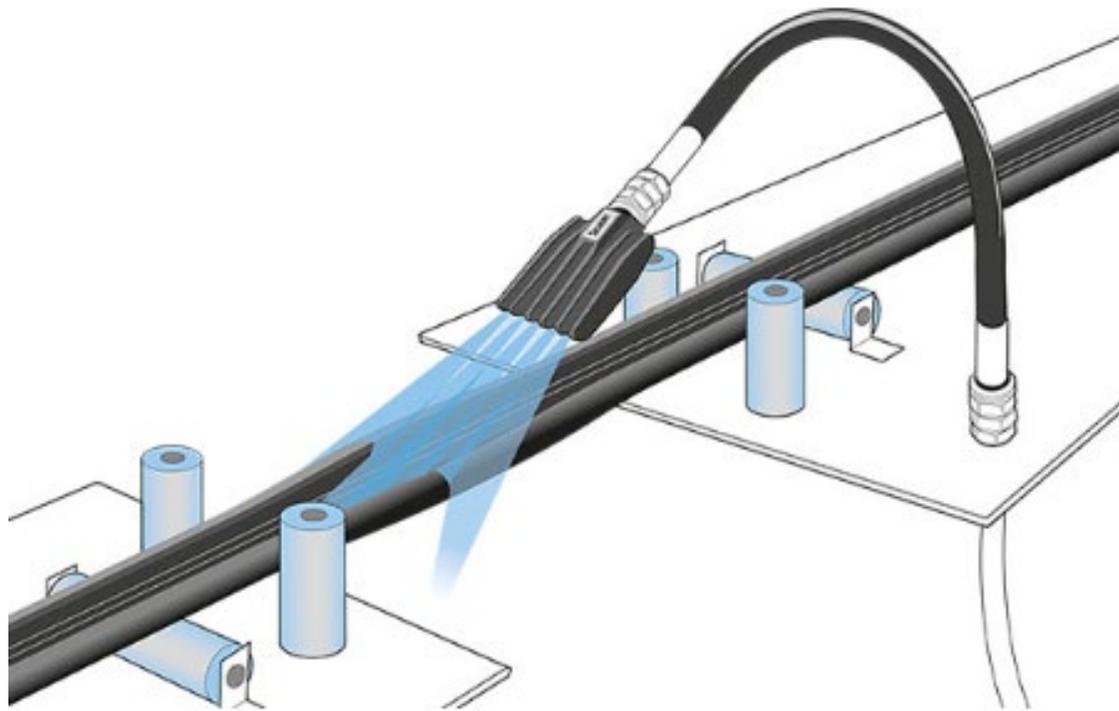
Homework from last session 6

- **Open blowing**- General cleaning, product separation from conveyors, equipment cooling
- **Atomizing**- Oil mist, product marking (ink)
- **Vacuum generation**- 55-gallon barrel vacuum, not used very often (usually use high vac system)
- **Personnel cooling**- Air horns used for personnel cooling in very hot environments
- **Open handheld blowguns or lances**- Equipment and general cleanup
- **Cabinet cooling**- Generally try to use fans, but have used compressed air in the past
- **Diaphragm pumps**- Water transfer, chemical transfer
- **Timer drains/open drains**- Drain alls
- **Air Motors**- Various process applications

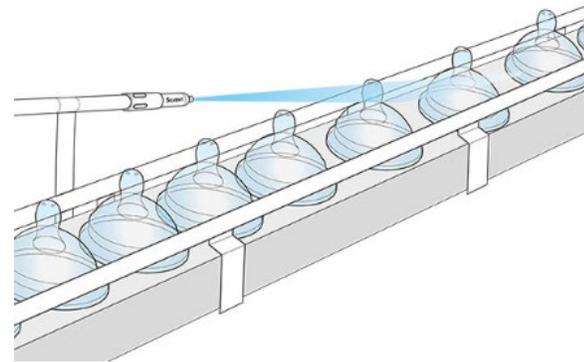
Blower Options



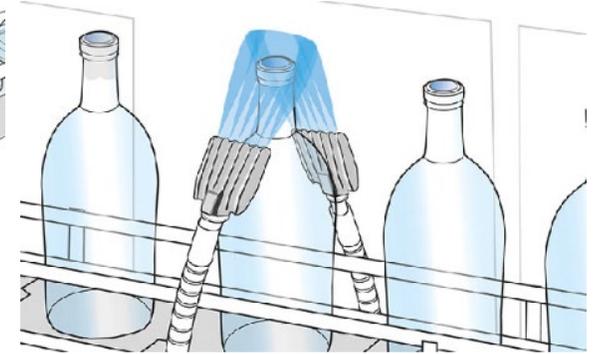
How is Compressed Air Used?



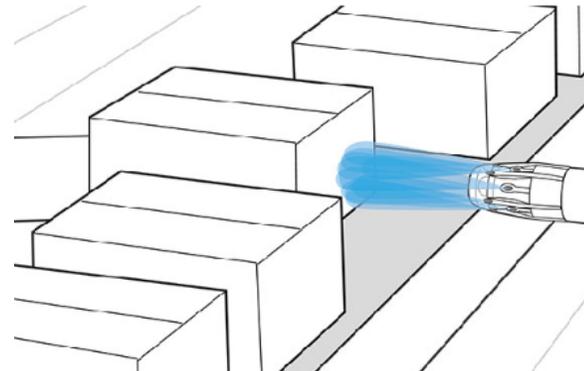
Cleaning



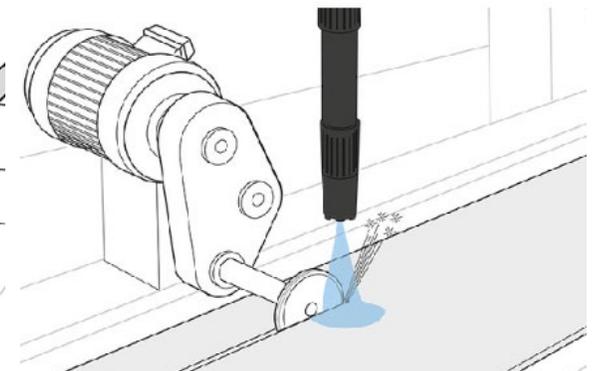
Transporting



Drying



Sorting



Cooling

Choose Nozzles wisely

Technical data

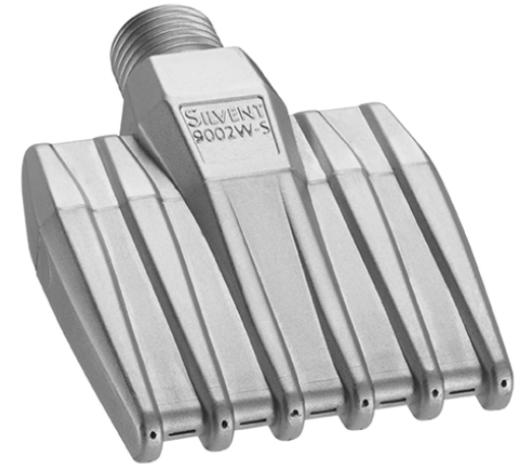
Replace open pipe Ø (inch)	1/4
Blowing force	1.7 lbs
Air consumption (scfm)	22.1
Sound level (dB(A))	83
Nozzle technology	Slot

Benefits when replacing an open pipe

Replace open pipe Ø (inch)	1/4	
Noise reduction	19 [dB(A)]	73%
Energy savings	17.1 [scfm]	43%

Blowing properties at different pressures

Pressure (psi)	40	60	80	100	120
Blowing force (oz)	13.7	20.6	27.5	34.4	41.2
Air consumption (scfm)	11.1	16.7	22.3	27.8	33.4
Sound level (dB(A))	75.0	79.0	82.0	84.0	85.0



Inappropriate uses?



Inappropriate uses?



Simple Electric Agitator



Electric "In Barrel" Agitator System

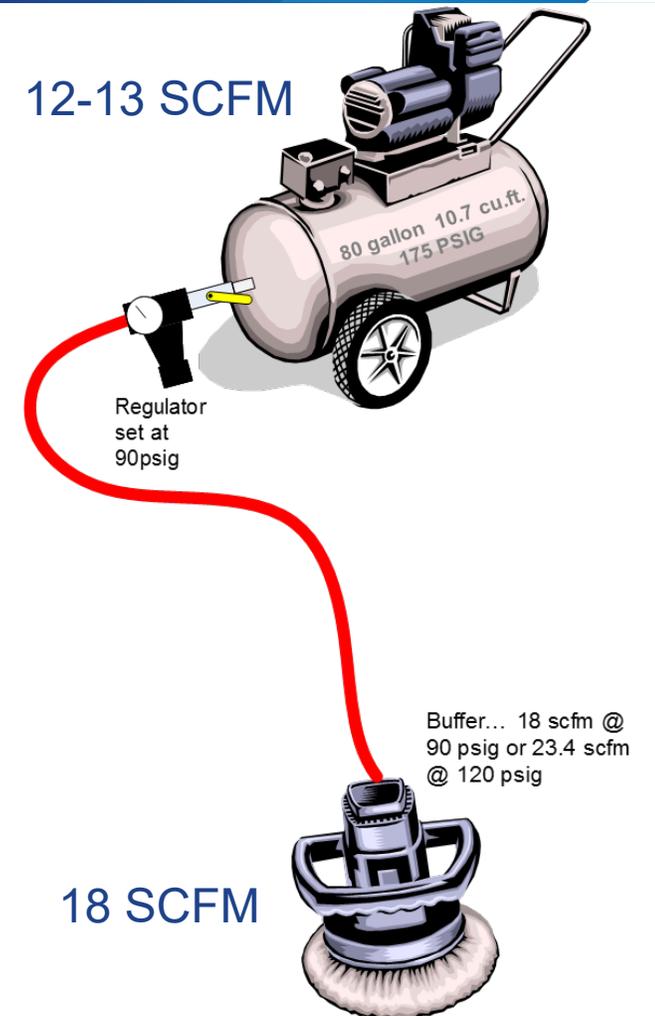


System Volume vs Storage

Session 7

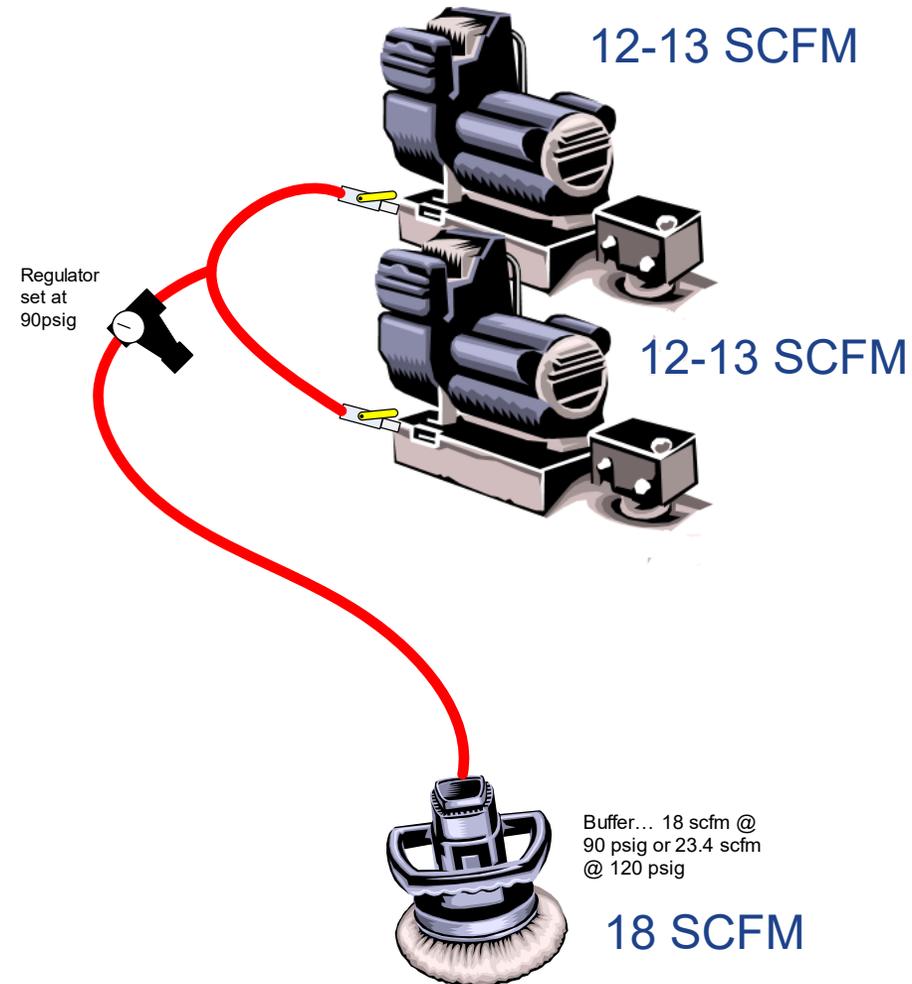
A Simple Example

- 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 OK.
- How can this work???
- The buffer uses more volume(scfm) than the compressor can deliver !!



A Simple Example

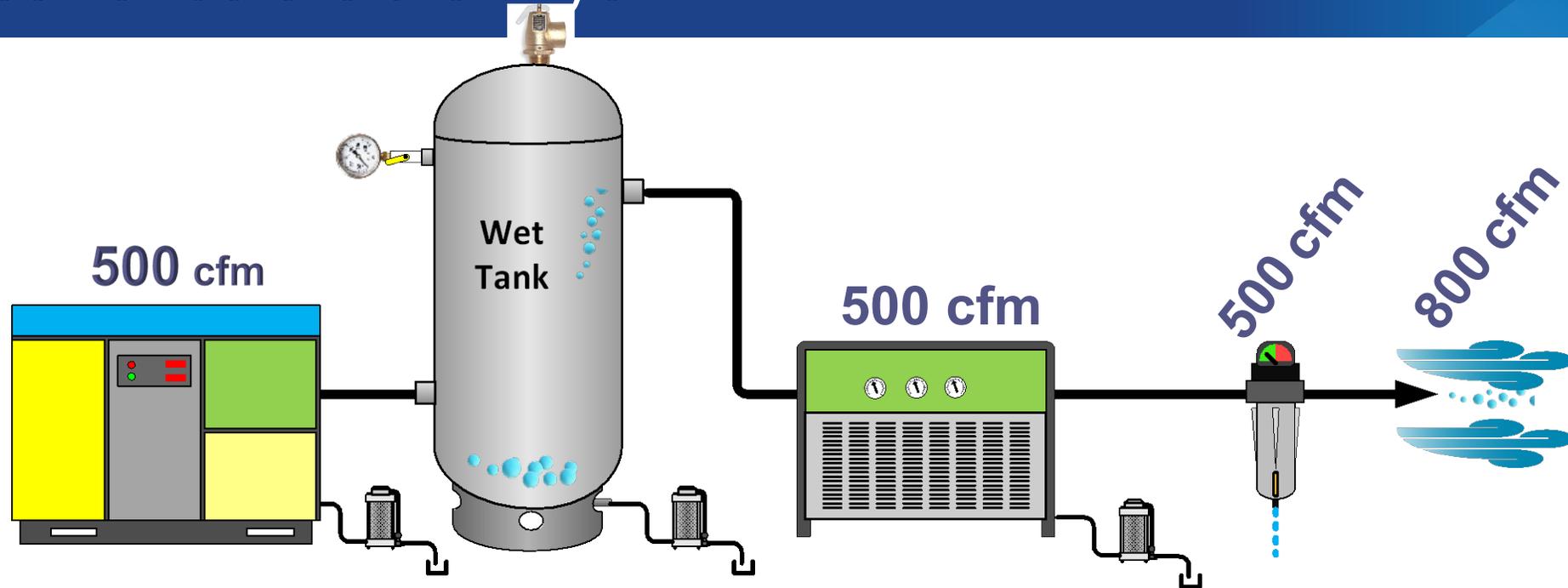
- With no receiver, the painter must install a second 5 hp compressor and therefore use twice the energy as before



Where Does the Receiver Go?

- There are wet air receivers and dry air receivers
- Wet Receivers: Wet receivers are located at the discharge of the compressors and provide additional storage capacity and reduce moisture.
- The large surface area of the air receiver acts as a free cooler, which is what removes the moisture.
- Because the moisture is being reduced at this point in the system, the load on filters and dryers will be reduced.
- Wet receivers also act as “Control Storage” which can maximize the effective operation of the compressor control.

Wet Receiver before the Dryer

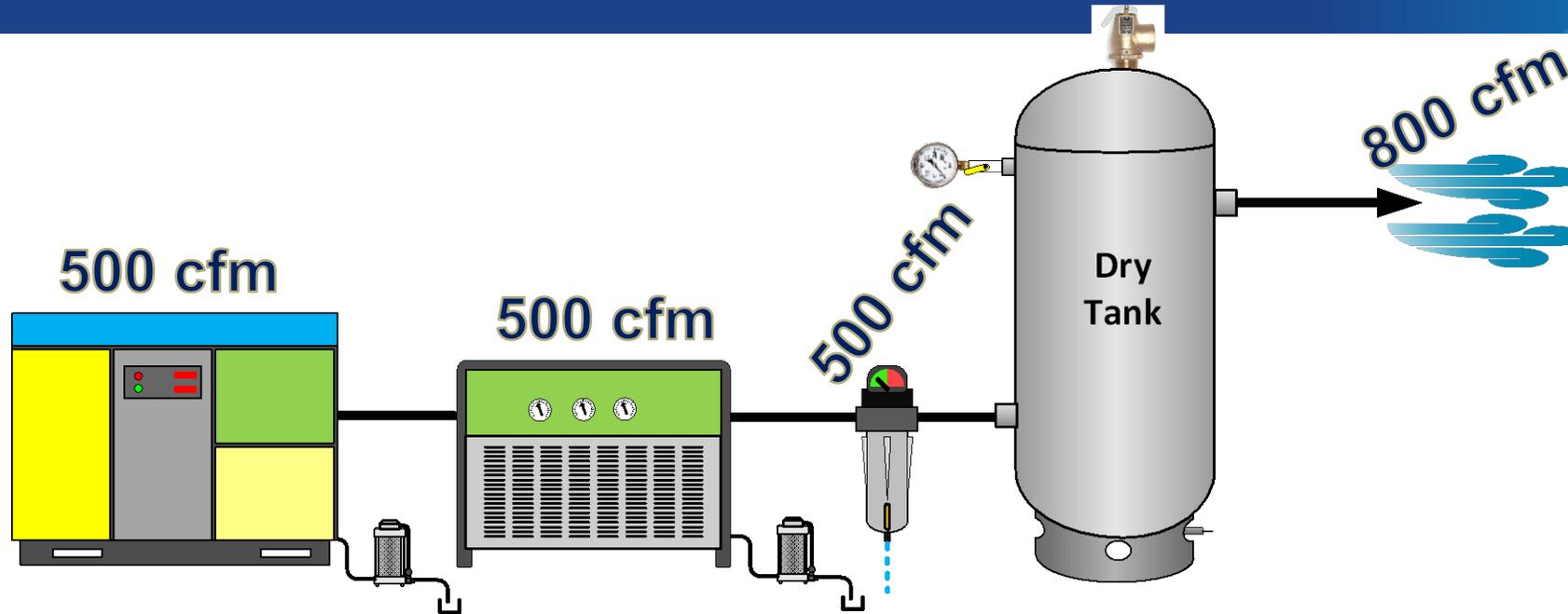


- A Wet Receiver creates radiant cooling and drops out some of the condensate and entrained oil, thus benefiting the dryer.
- However, the receiver will be filled with saturated air, and if there is a sudden demand that exceeds the capacity rating of the compressor and matching dryer, the dryer can be overloaded, resulting in a higher pressure dew point.

Where Does it Go?

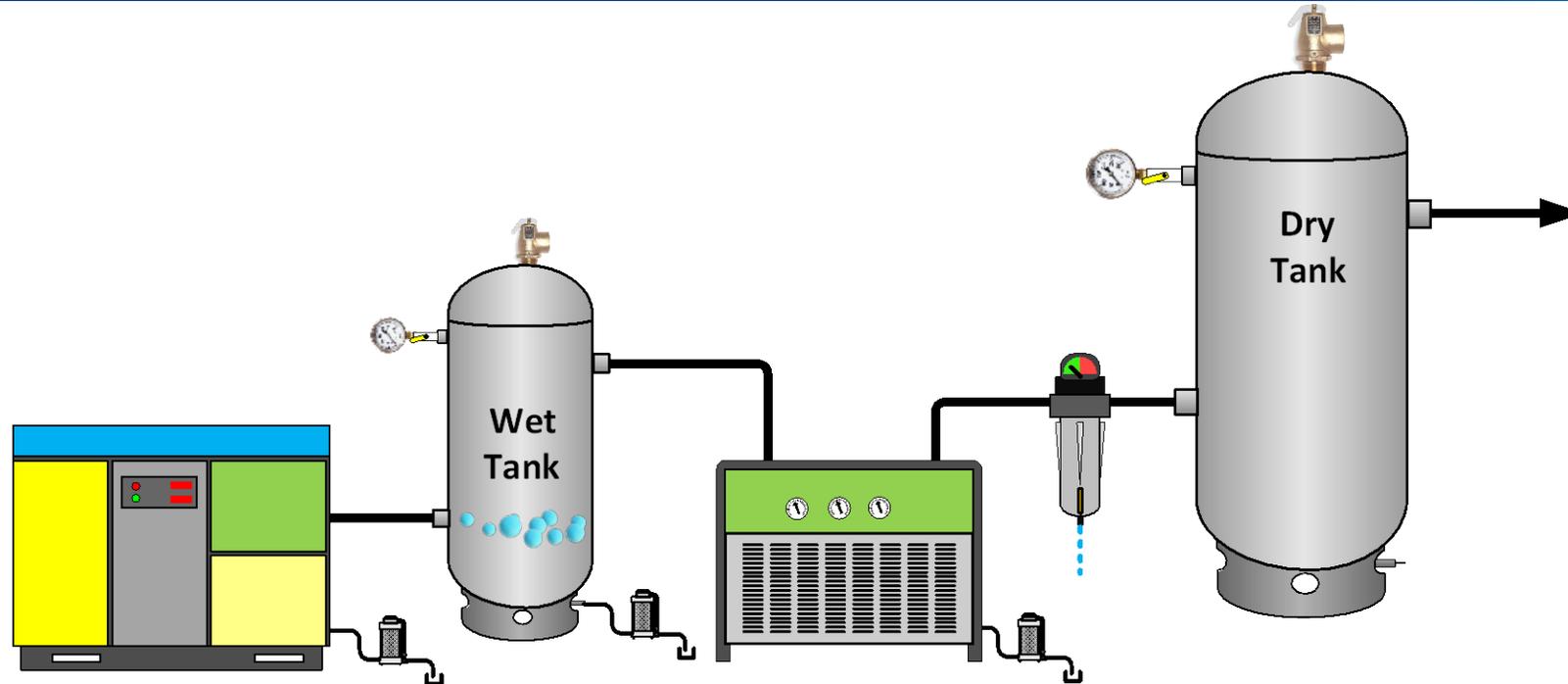
- **Dry Receivers:** Dry receivers are located immediately downstream of dryers and filters.
- When sudden large air demands occur, dry air receivers should have adequate capacity to minimize a drop in system air pressure.

Dry Receiver after the Dryer



- The receiver is filled with compressed air which has been cleaned and dried.
- A sudden demand in excess of the compressor and dryer capacity rating will be met with dried air.

Best Practice



- A best practice is often to have two receivers at the supply side.
- One “wet” air receiver before the dryer to provide control storage and condensate drop out.
- And a second “dry” air receiver to meet sudden demands.
- Typical size ratio is 25% -30% wet and 70% - 75% dry.



PLANT COMPRESSED AIR

PROCESS COMPRESSED AIR

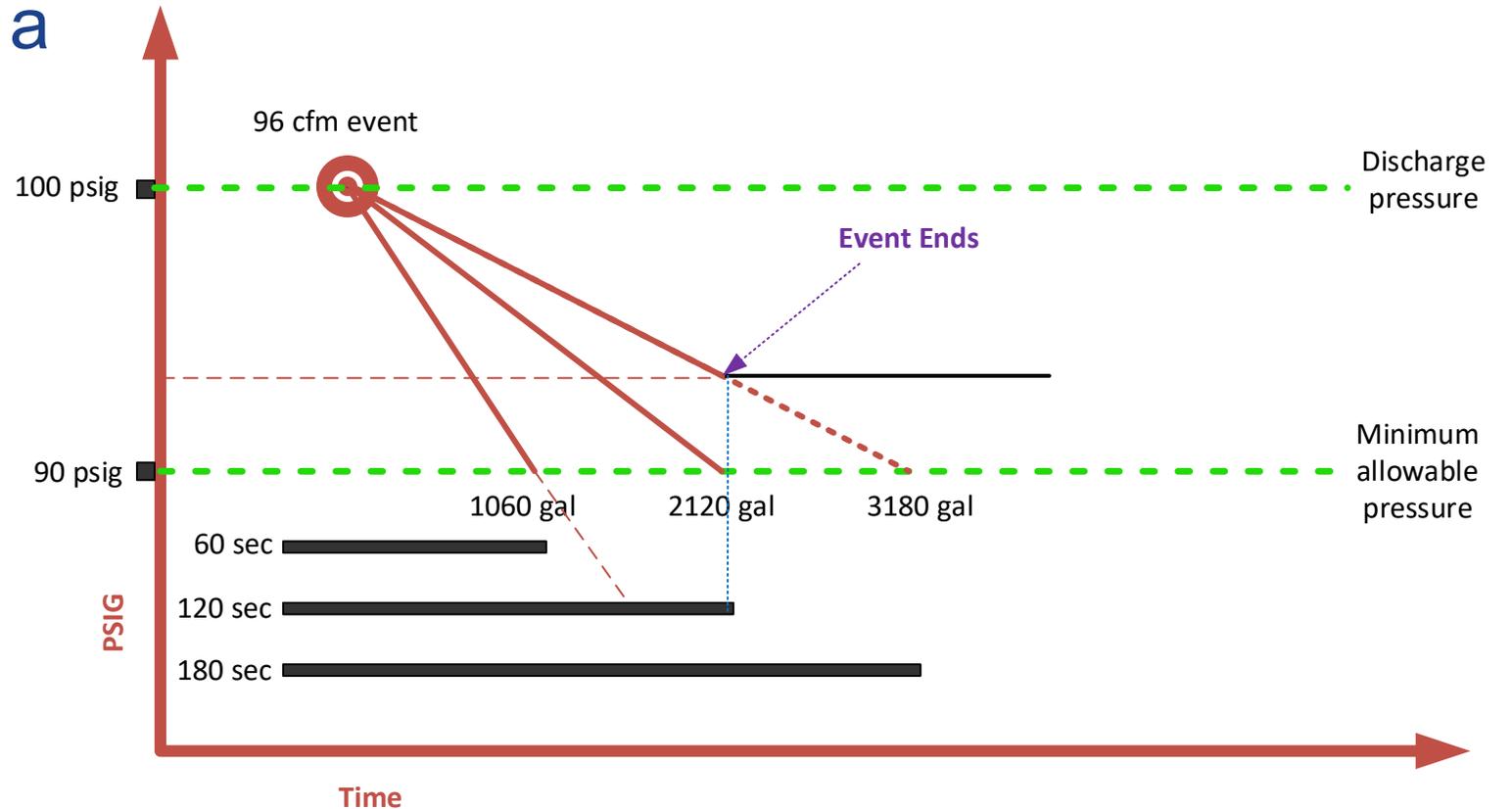
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Effect of Storage on Rate of Change

- Control storage has a tremendous influence upon rate of change
- Larger control storage means slower rate of change.
- Slower rate of change allows the system to handle more demand events without adding on-line HP.
- Consider the following example:

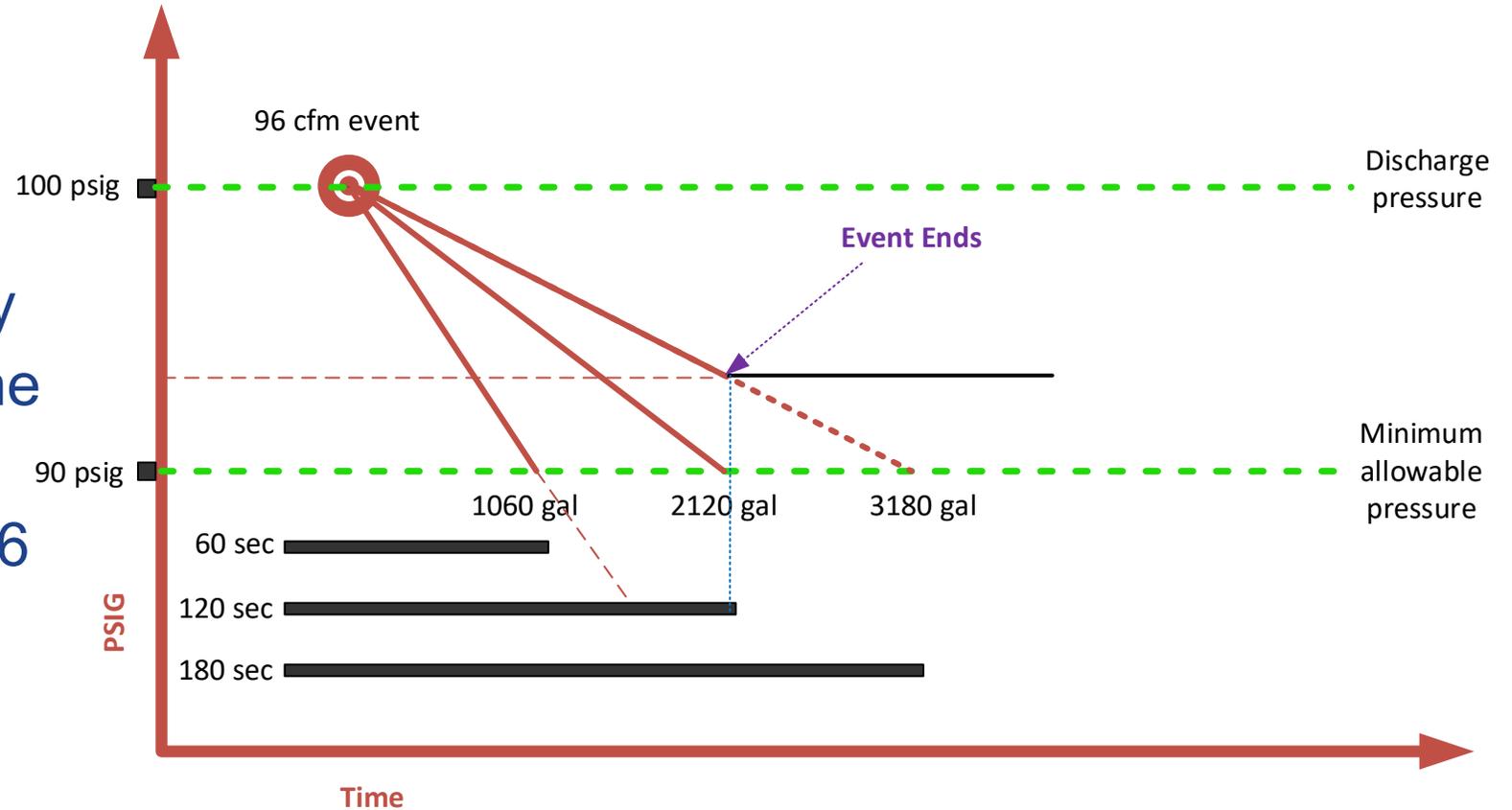
Effect of Storage on Rate of Change

- The minimum allowable, critical pressure, for a system is 90 psig.
- The one operating compressor in the system is fully loaded and maintaining the system at a discharge pressure of 100 psig.



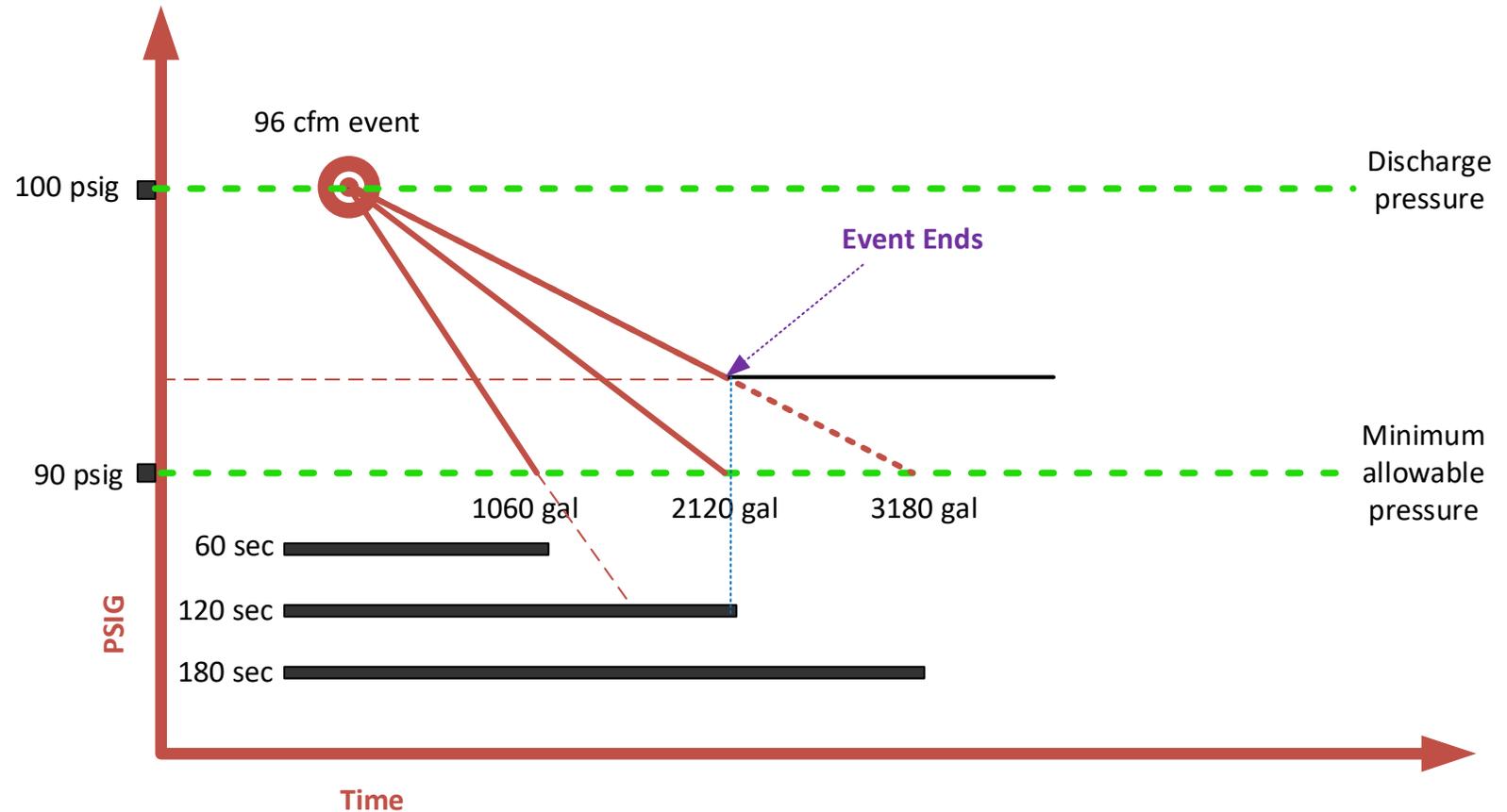
Effect of Storage on Rate of Change

- Someone operates a tool in the plant that consumes an additional 96 cfm.
- Since the compressor is fully loaded and cannot deliver the additional 96 cfm, there is a negative rate of change of 96 cfm and system pressure falls because demand is greater than supply.



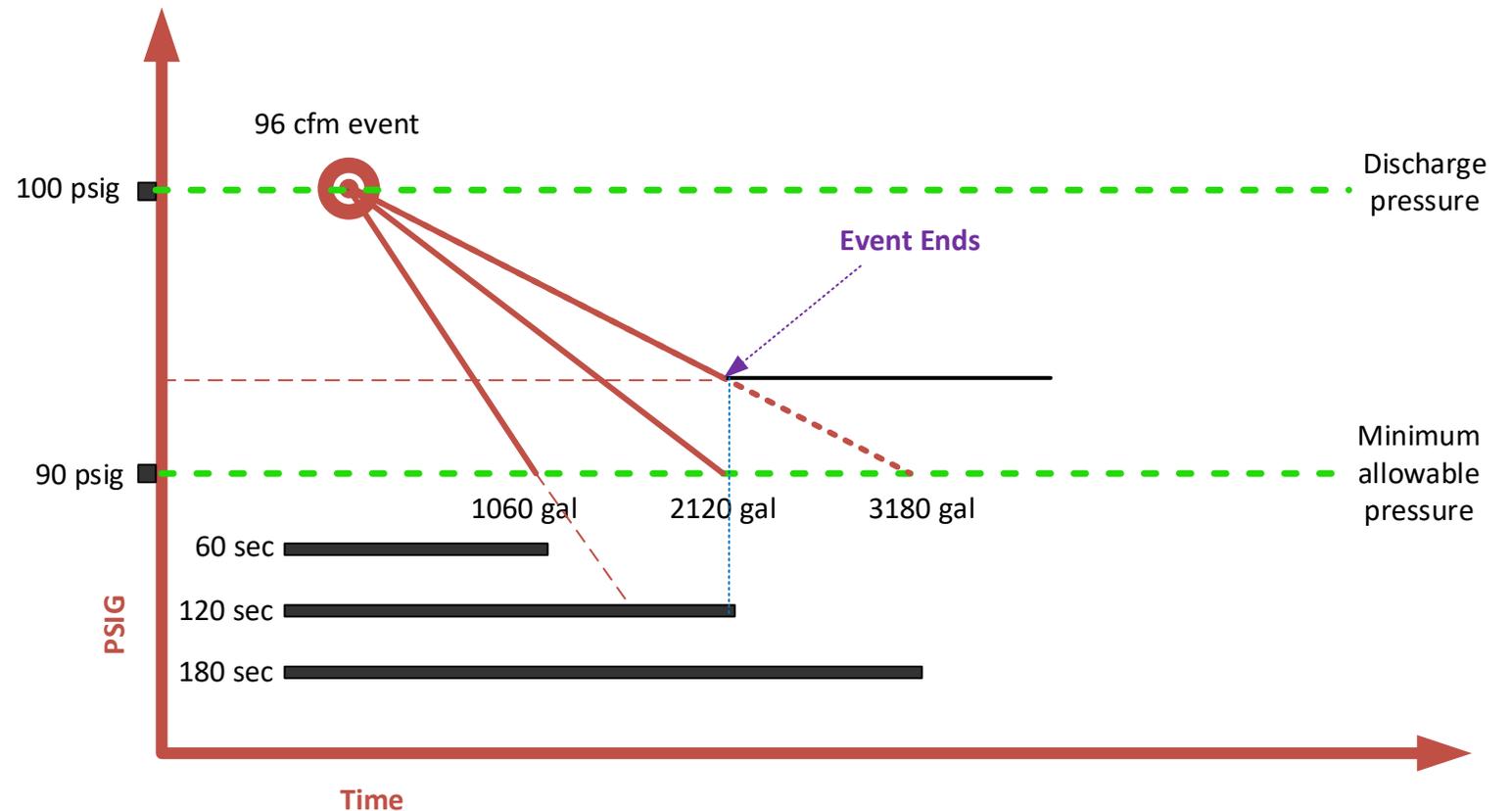
Effect of Storage on Rate of Change

- If the control storage is 1060 gallons, it will take 60 seconds, one minute, for the plant pressure to fall from 100 psig to 90 psig.
- If the control storage is doubled to 2120 gallons, it will take double the time, 2 minutes, for the plant pressure to fall from 100 psig to 90 psig.
- If the control storage is tripled to 3180 gallons, it will take triple the time, 3 minutes, for the plant pressure to fall from 100 psig to 90 psig.



Effect of Storage on Rate of Change

- As this example shows, the time to reach the critical pressure during any event is directly proportional to the total amount of control storage in the system.
- By slowing the rate of change, control storage allows time for the system dynamics to change to the point that the demand becomes less than supply and pressure recovers without having to start an additional compressor.



System Drawdown

Capacitance:

Volume in cuft ÷ 14.7 = capacitance in cu. ft./psi

$$DrawDownRate = \frac{debitflow_{cuftsec}}{capacit_{cuftpsi}} \times Time_{sec}$$

Example: If the control storage is 1060 gallons, how long will it take the plant pressure to fall from 100 psig to 90 psig.

96 acfm = **1.6 cu ft/sec** and capacitance = 1060gal÷7.48gal/cuft = 147.711 cuft

147.711/14.7 = **9.64cuft /psi**

1.6 cuft/sec ÷ 9.64 cu ft/psi = .166 psi/sec

.166 psi/sec x 60 sec = 9.96 psi

System Drawdown

Using Receiver Calculation:

$$\Delta P = \frac{T_{\min} \times (\text{DebitFlow}) \times P_a}{V_{cf}}$$

Solve for ΔP

$$V_{cf} = \frac{T_{\min} \times (C - R) \times P_a}{P_1 - P_2}$$

$$\Delta P = \frac{(1_{\min}) \times (96_{cfm}) \times 14.7}{147.711_{cf}} = 9.9 \text{ psig}$$

Local Storage to Stabilize Pressure Fluctuations

System Volume

- System volume is very important to compressor control.
- Think of the real-world comparison of a bicycle tire to a heavy truck tire.
- Both run at the same 100psi, but when you tap the valve stem of the bicycle tire, it goes flat, the bike is un-rideable. Tap the valve stem of the heavy truck tire and it doesn't care. It's probably still at 100psi.
- This is the difference that system volume makes in a compressed air system. Larger volume makes the system more stable, making controls more effective.



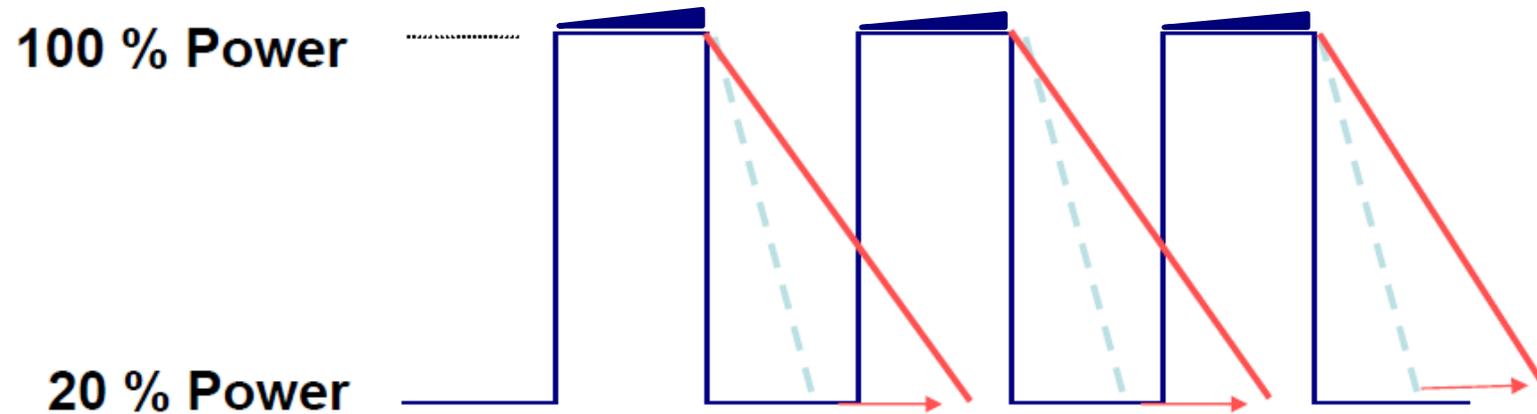
What Size for Control Storage?

- In the past, mainly with reciprocating compressors, rules of thumb for sizing a primary air receiver, have been from 1 gallon per cfm to 3 gallons per cfm of compressor capacity.
- This is no longer regarded as good practice and the recommended primary receiver size will vary with the type of compressor capacity control used.
- You should be at 5 gal/cfm of the trim compressor.
- Rule of thumb is 3-5 but a system analysis will show you the proper control storage to be using.

What Size for Control Storage?

- Some oil injected rotary screw compressors are sold with load/unload capacity control, which is claimed to be the most efficient.
- This also can be misleading, since an adequate receiver volume is essential to obtain any real savings in energy.
- Some rules of thumb established many years ago for reciprocating air compressors, are not adequate for an oil injected rotary screw compressor.

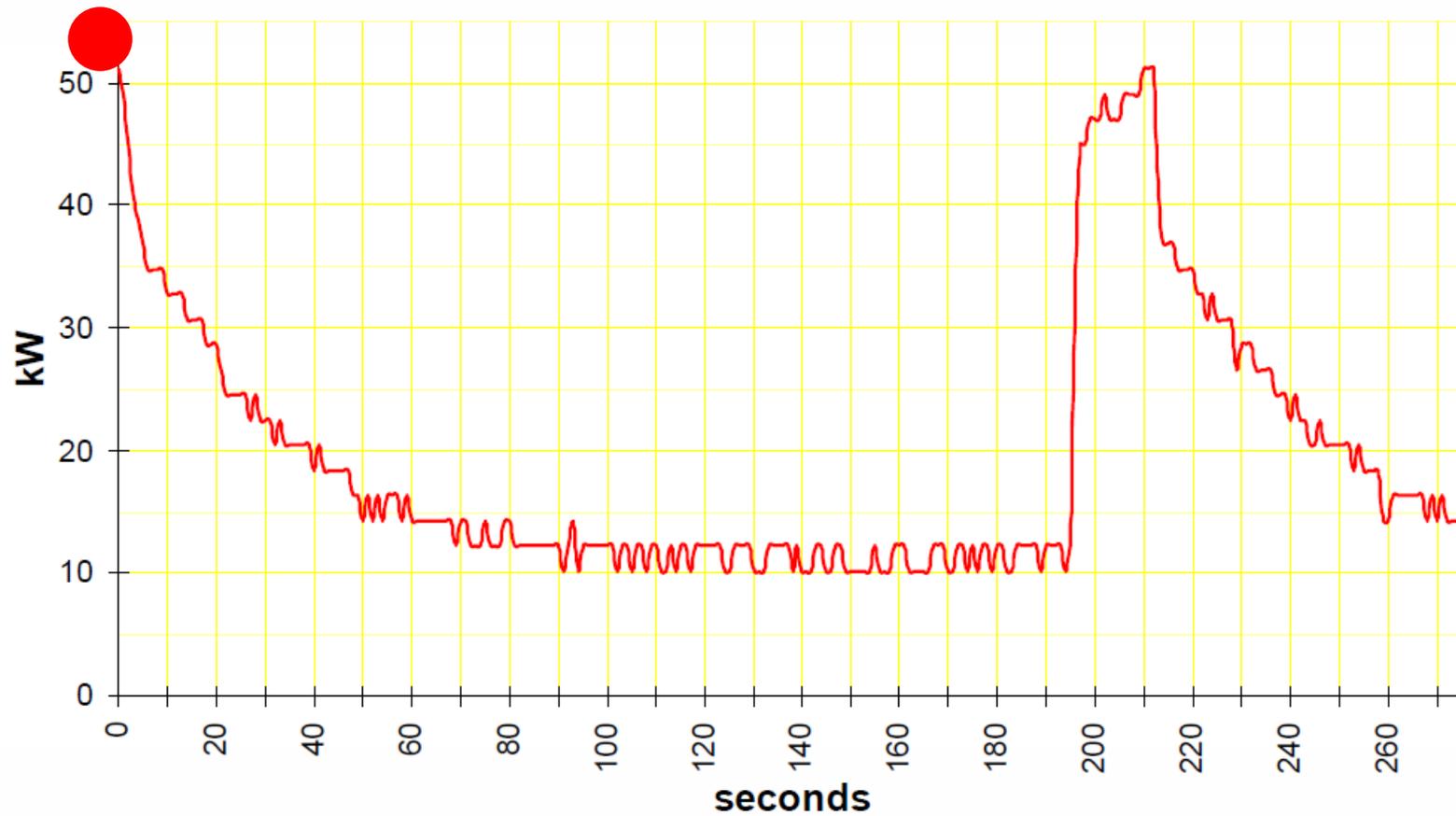
Capacity Control by Load/No-Load



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

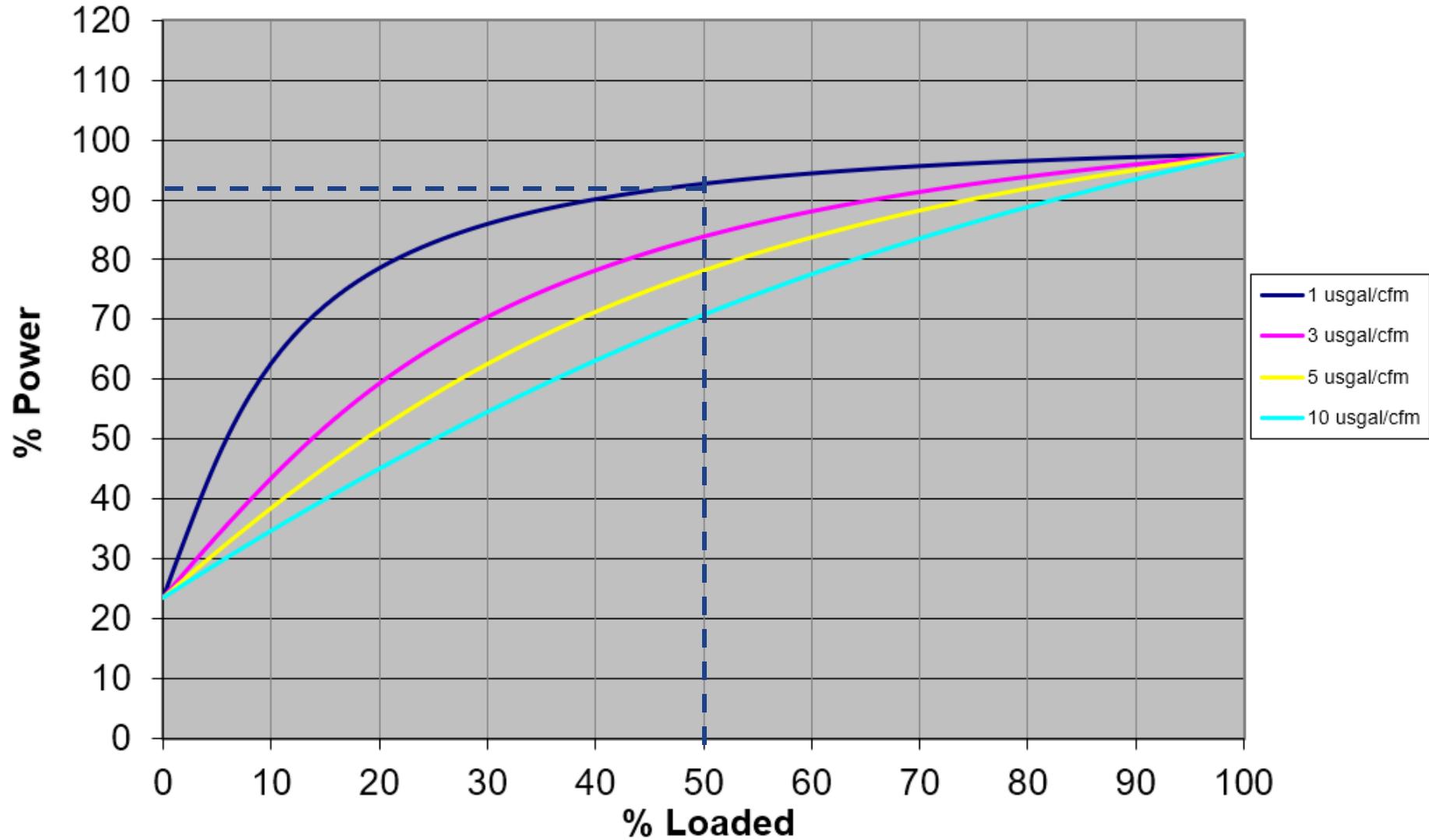
Capacity Control by Load/No-Load

Active Power consumption evolution from L to NL



Pressure Band 10 psi
Blow Down Time 0.5 min
No Load Power 24%

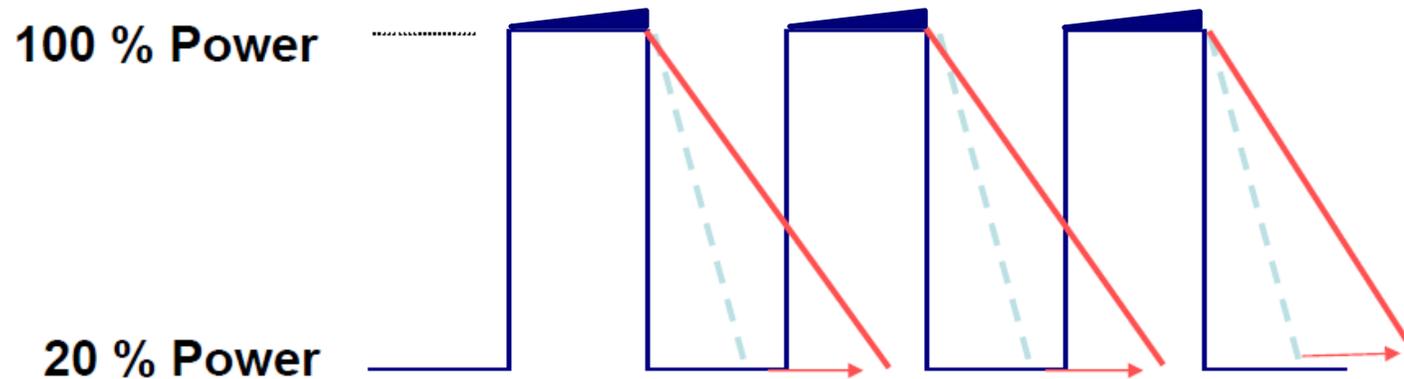
% Power vs % Loaded



What Size For Variable Speed Compressors?

- For variable speed compressors the receiver size should still be 3-5 gallons/cfm
- Variable speed compressors don't tend to run unloaded so don't have this period of wasted energy
- They can also vary their speed to meet demand, so the receiver doesn't need to be so big.
- However, variable speed compressors do still need air receivers to smooth out downstream demand so they can adjust their speed efficiently.

What Size For Oil Free Compressors?



- Since there is no sump blowdown to ride out, the concern would be cycle time.
- Consult with the manufacturer
- Most do not want less than one cycle per 30 seconds. Desirable to have one cycle per minute.

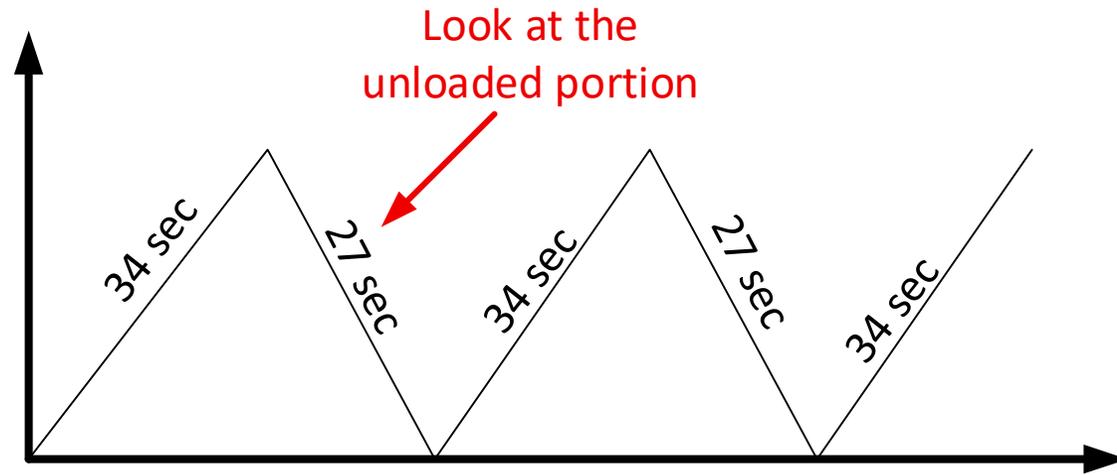
System Volume

- The **mechanical** volume of a system is simply the sum of the individual volumes of each air receiver, pipeline, or other vessel within the compressed air system.
- The **effective** volume of the system is the system's mechanical volume adjusted for the actual pressure increase and decrease that occurs.

Effective Volume

- A compressed air system in a plant at sea level (14.5 psia) has a trim compressor rated for 430 acfm which operates 34 seconds loaded and 27 seconds unloaded.
- The control pressure range is 100 psig load / 110 psig unload.
- The system has a 1,000-gallon receiver, 30 ft of 6" schedule 40 pipe (6.065 inch ID), 100 ft. of 4" schedule 40 pipe (4.026 inch ID), and 335 ft. of 2" schedule 40 pipe (2.067 inch ID).
- How can I find the effective volume?

Effective Volume



$$V_{cf} = \frac{T_m \times C \times P_a}{P_1 - P_2} \quad V_{cf} = \frac{\left(\frac{27}{60}\right) \times 239.7 \times 14.5}{10}$$

$$V_{cf} = 156.4$$

$$Flow_{\%} = \left(\frac{T}{T+t}\right) \times 100$$

$$Flow_{\%} = \left(\frac{34}{34+27}\right) \times 100$$

$$Flow_{\%} = .5573$$

$$Flow = 430 \times .5573$$

$$Flow = 239.7$$

System Capacity



SYSTEM CAPACITY

Pipes

Pipe Size (in)	Pipe Length (ft)
<input type="text" value="6"/>	<input type="text" value="30"/>
<input type="text" value="4"/>	<input type="text" value="100"/>
<input type="text" value="2"/>	<input type="text" value="335"/>

[Add Pipe](#)

Receiver Tanks

Receiver 1	<input type="text" value="1000"/>	gal
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[Add Receiver Tank](#)

Leak Rate Calculator

Normal Operating Pressure	<input type="text" value="110"/>	psi
Test Pressure	<input type="text" value="100"/>	psi
Time	<input type="text" value=".45"/>	min
Atmospheric Pressure	<input type="text" value="14.7"/>	psia

Total Pipe Volume	170 gal (23 ft ³)
Total Receiver Volume	1,000 gal (134 ft ³)
Total Capacity of Compressed Air System	1,170 gal (156 ft ³)
Leak Rate	295.43 acfm

Receiver Sizing for Demand Events

- A system operates with 100 scfm demand deficit for 30 seconds of time. If the system pressure must be no lower than 90 psig and at the beginning of the event the pressure is 100 psig, what size receiver is necessary?
 - Use the MEASUR Tool for “Receiver Tank Sizing”

Receiver Sizing for Demand Events

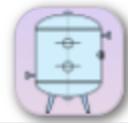
■ Answer

$$V_{cf} = \frac{T_{\min} \times (C - R) \times P_a}{P_1 - P_2}$$

$$V_{cf} = \frac{.5 \times (100) \times 14.7}{10}$$

$$V_{cf} = 73.5$$

$$V_{gal} = 73.5_{cf} \times 7.48_{gal/cf} = 549.78_{gal}$$

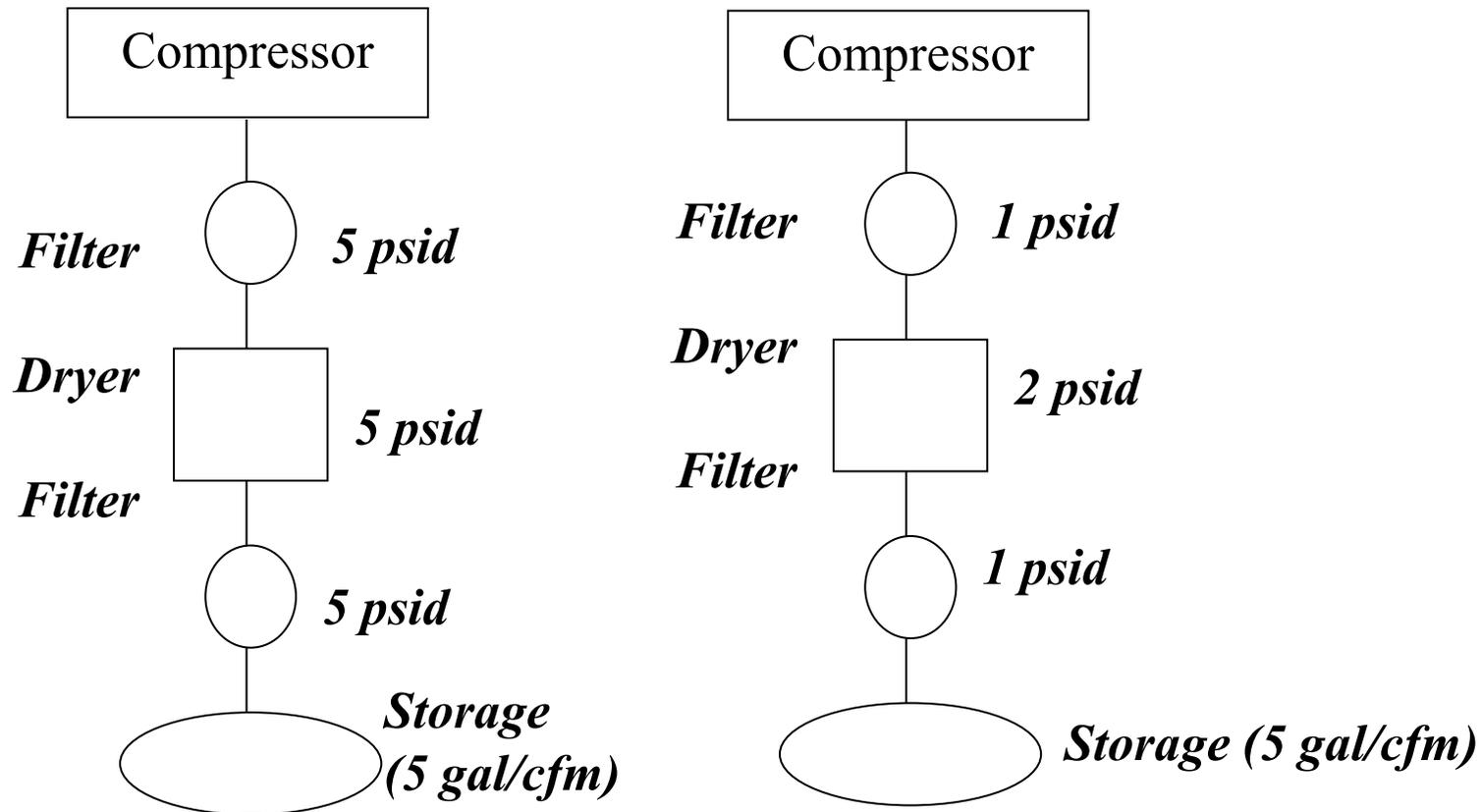


RECEIVER TANK SIZING

Calculation Method	Dedicated Storage
Length of Demand	.5 min
Air Flow Requirement	100 scfm
Atmospheric Pressure	14.7 psia
Initial Tank Pressure	100 psig
Final Tank Pressure	90 psig
Receiver Volume	549.78 gal

Effectiveness of Storage

Compressor has a 10 psig Control Band

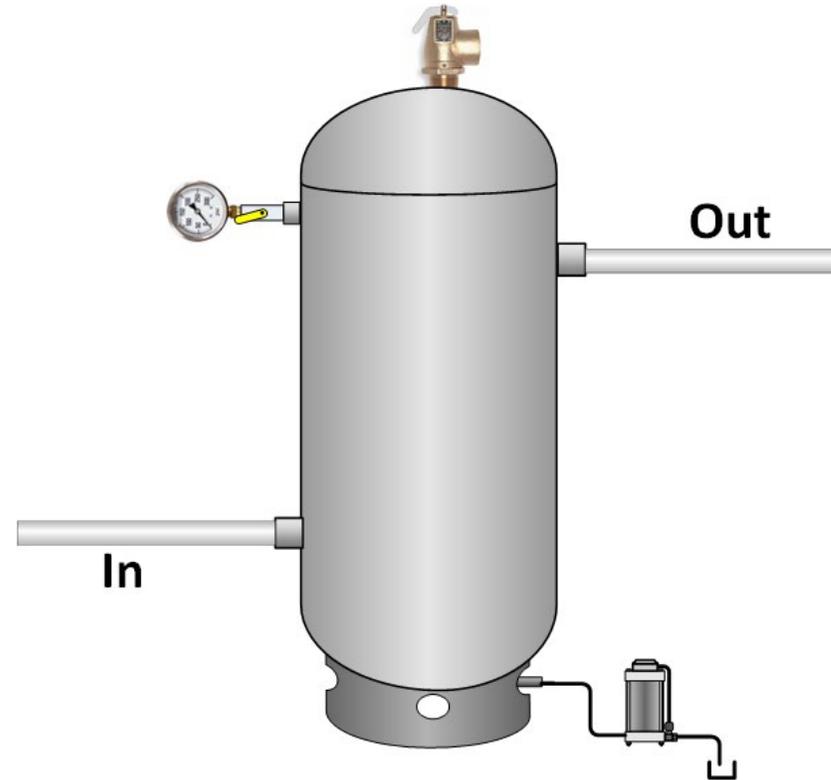


Some Best Practice Recommendations:

- Locate the receiver as close to the compressors as practical in the coolest location with the fewest possible elbows.
- When manifolding compressor connections, ensure that the pipe to the receiver is at least equal in cross sectional area to the sum of the areas of the compressor discharge connections
- Do not connect a reciprocating compressor into the same manifold as a rotary or centrifugal compressor

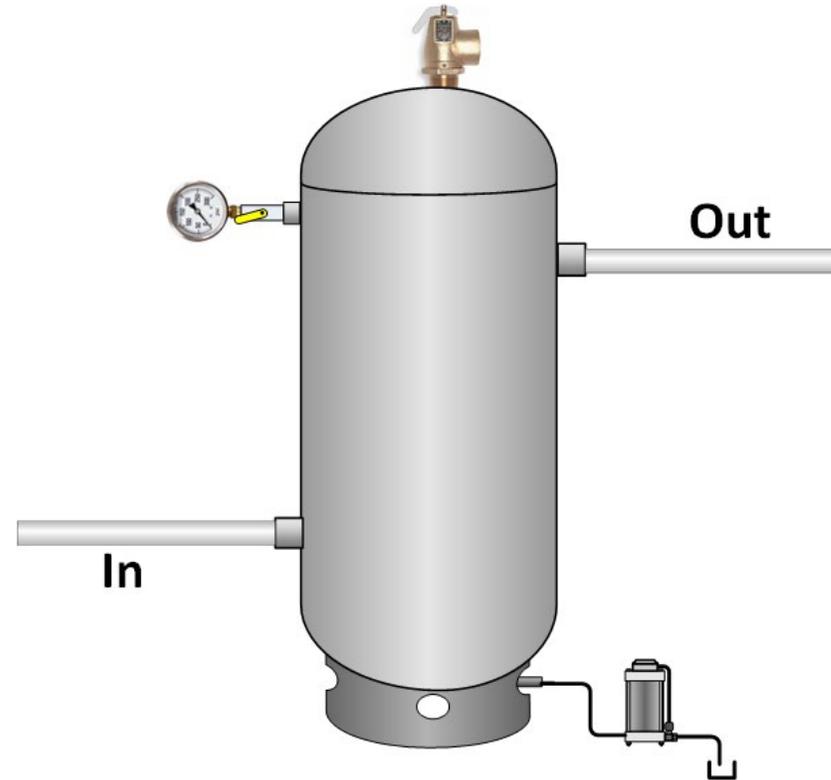
Some Best Practice Recommendations:

- Air should enter the air receiver at the largest port in the lower section, and discharge from the largest appropriate port in the upper section.
- Adequate automatic zero air loss drain traps should be installed for removal of accumulated condensate in lieu of timer or manual drains.
- Each air receiver should be equipped with a PRV valve and a pressure gauge with a valve to facilitate replacement when necessary.



Some Best Practice Recommendations:

- When used with lubricant free compressors, it is advisable to specify an air receiver having a galvanized interior or special epoxy coating to prevent corrosion.
- Safety valve capacity shall be sized to prevent receiver pressure from exceeding 110 percent or 3 psi (which ever is greater) of the maximum allowable working pressure.





Secondary Storage

Secondary Storage

- Secondary Storage Receivers can be used to:
 - Supplement the primary receivers to stabilize system pressure and thus keep unneeded compressors from operating
 - Supply adequate compressed air for a single intermittent event of a known duration.

Calculating the size of the Receiver

$$V = \frac{T(C - S)P_a}{P_1 - P_2}$$

- V = Volume of the receiver in cubic feet
- T = Time interval in minutes during which the receiver can supply air to the specific event
- C = Total air required by the event in cubic feet per minute
- S = Spare air for restoring the pressure from P_2 back to P_1
- P_a = Absolute atmospheric pressure (psia)
- P_1 = Initial receiver pressure
- P_2 = Final receiver pressure required to support the event

Example

Assume a back wash filter requires **100 cfm every hour** for a duration of **3 minutes** at 70 psig. Normal system pressure is maintained at a nominal 95 psig. For this calculation assume S to be zero.

$$V = \frac{T(C - S)Pa}{P_1 - P_2} \quad V = \frac{3(100 - 0)14.7}{95 - 70} = 176.4 \text{ Cubic Feet}$$

$$176.4 \times 7.48 \text{ gal/cu.ft.} = 1319.5 \text{ gallons}$$

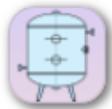
Select the next largest standard air receiver size which would be 1548 gallons

$$1548 \text{ gallons} \div 7.48 \text{ gal/cu.ft.} = 207 \text{ cu.ft.}$$

Example Using MEASUR



Manufacturing Energy Assessment Software for Utility Reduction



RECEIVER TANK SIZING

Calculation Method	Dedicated Storage	▼
Length of Demand	3	min
Air Flow Requirement	100	scfm
Atmospheric Pressure	14.7	psia
Initial Tank Pressure	95	psig
Final Tank Pressure	70	psig
Receiver Volume	1,319.47 gal	

Generate Example

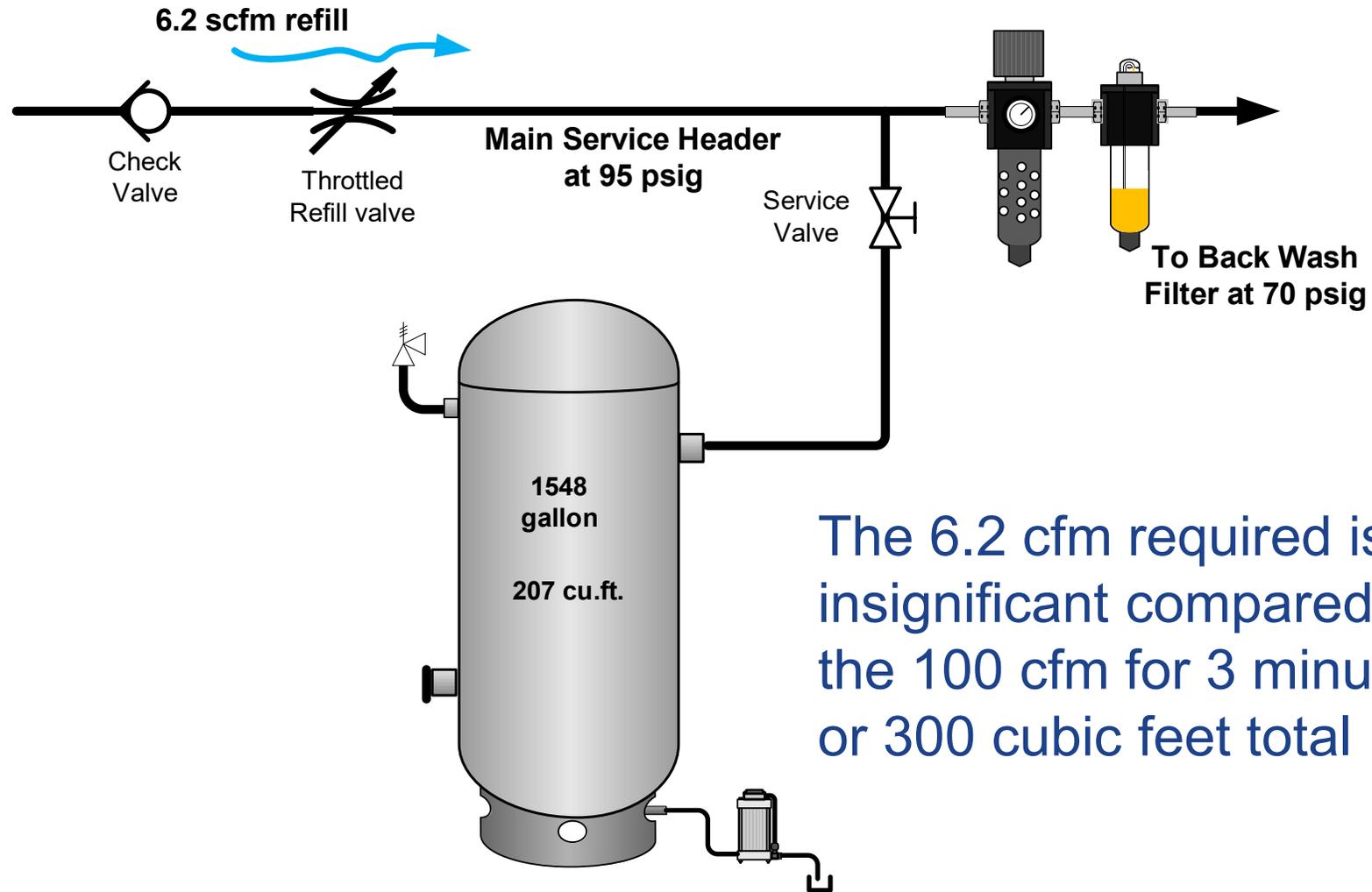
Reset Data

Example

The next part of the calculation is to calculate the metered refill rate. Restating the formula, “S” required to restore the pressure to 95 psig within the 57 minutes until the next backwash.

$$\text{Solving For } S = \frac{Vx(P_1 - P_2)}{T \times 14.7} \quad S = \frac{207 \times (25)}{57 \times 14.7} = 6.2 \text{ CFM}$$

Example

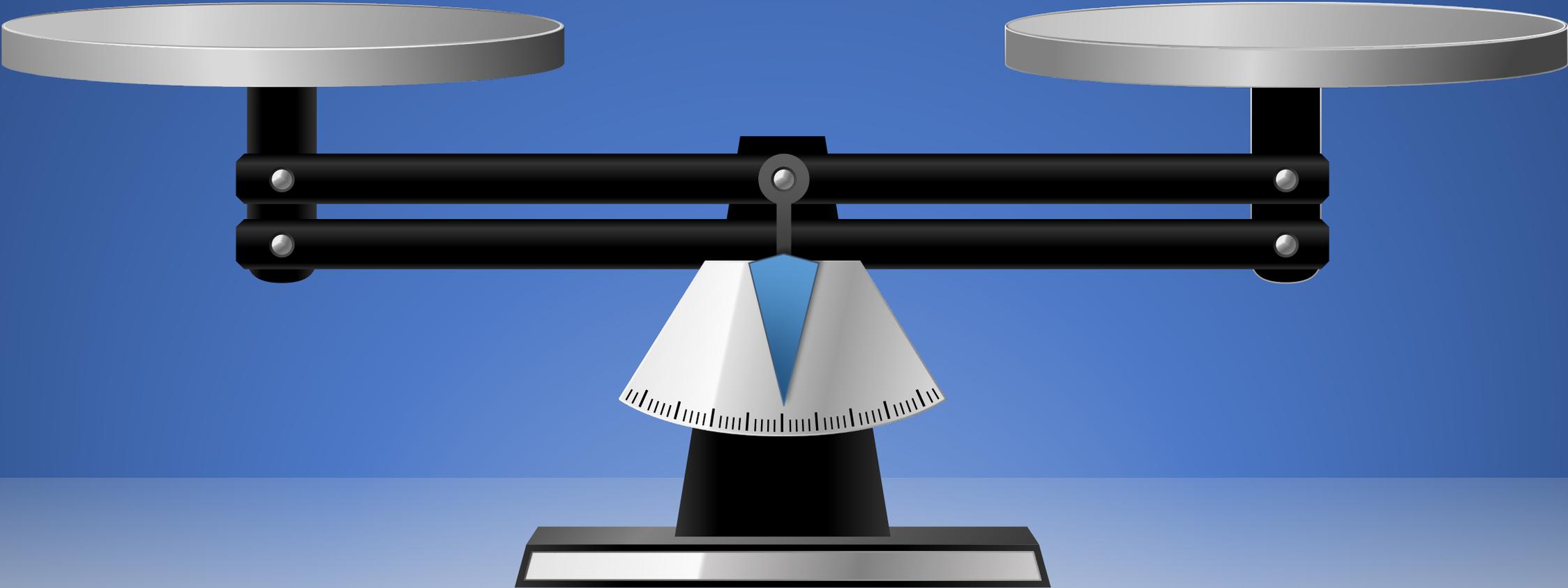


The 6.2 cfm required is insignificant compared to the 100 cfm for 3 minutes or 300 cubic feet total

Another way of looking at this Back Wash Filter Problem

Supply

Demand

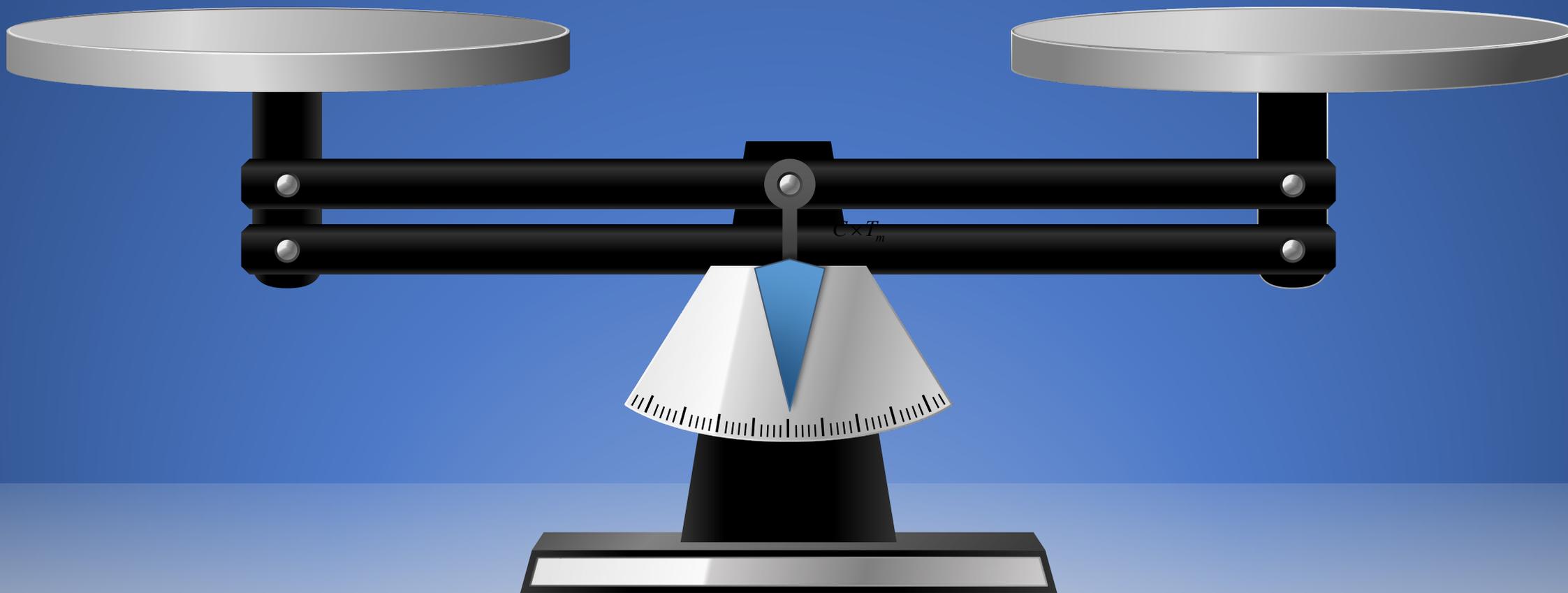


Alignment

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

=

$$C \times T_m$$

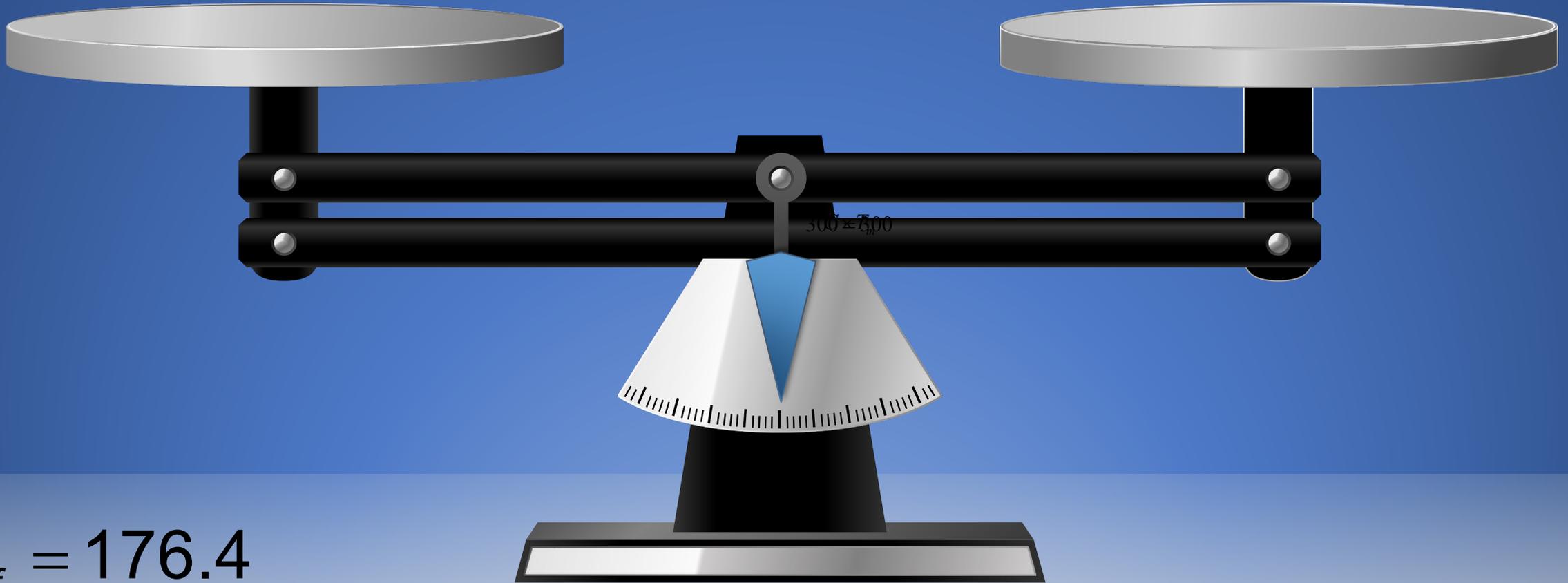


Supply = Demand

$$V_{cf} \times \frac{25}{14.7}$$

=

$$100 \times 3$$



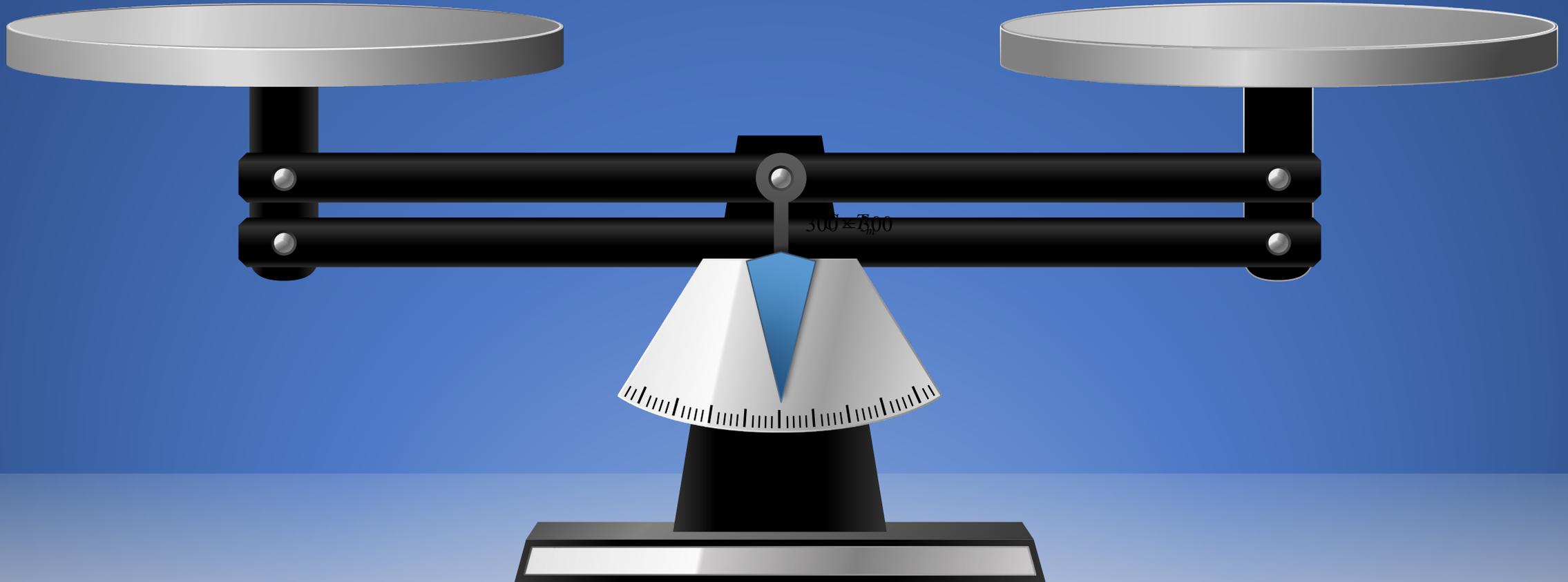
$$V_{cf} = 176.4$$

Supply = Demand

300

=

300



300 = 300

Supply = Demand

Example of Local Storage for Critical End Use Pressure



Example of Local Storage





Pneumatic Capacitance

Storage or Volume

- Pneumatic capacitance is the stored air within a compressed air system –
- Capacitance is expressed as the ratio of stored air volume (scf) to the storage pressure differential
- In order for there to be any stored energy, there has to be a pressure differential across the storage device.



Microsoft Excel
Worksheet

$$V_{cf} = \frac{T_{\min} \times (C - S) \times P_a}{P_1 - P_2}$$

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

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

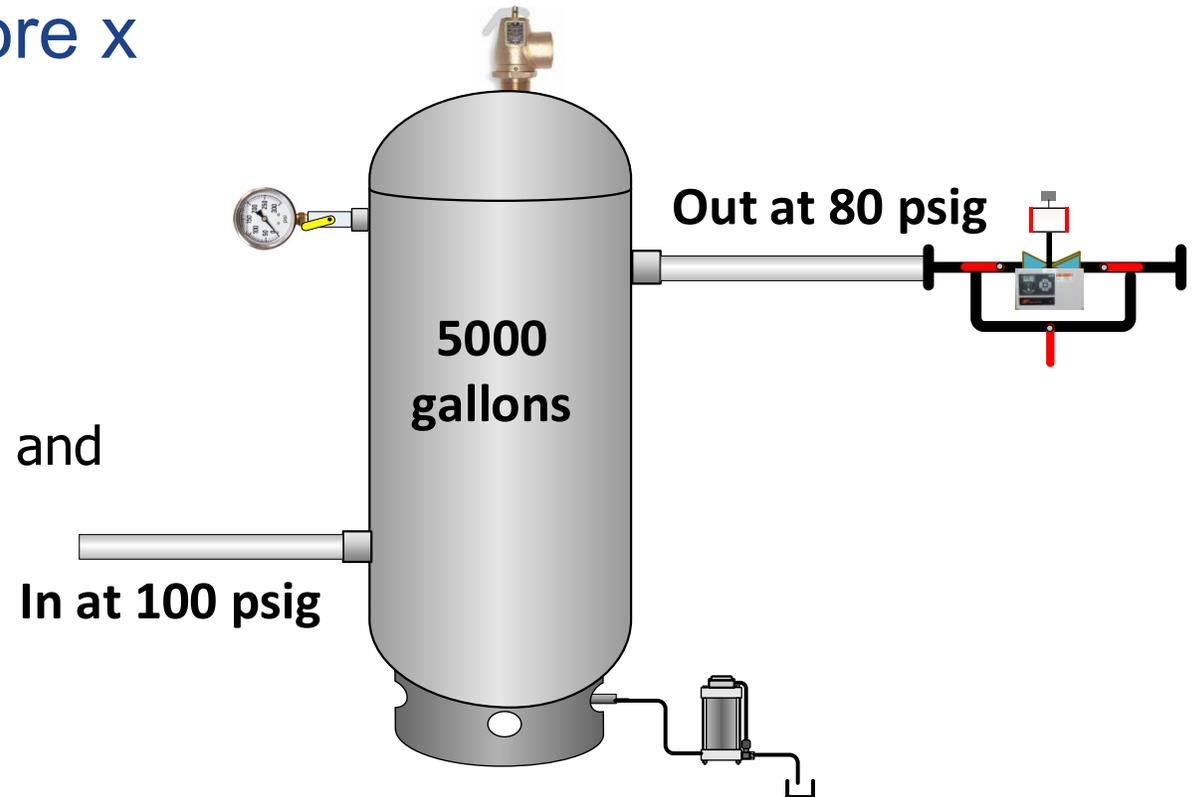
What is the usable (useful) storage?

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



Pneumatic capacitance and Boyle's Law

- Boyle's Law explains the fundamental pressure-volume relationship of gases, while pneumatic capacitance describes the storage capacity within a pneumatic system.
 - Boyle's Law is a fundamental gas law that describes the inverse relationship between the pressure and volume of a gas when the temperature and amount of gas remain constant. $P_1V_1=P_2V_2$
- Pneumatic capacitance, on the other hand, refers to the ability of a pneumatic system to store compressed air.
 - It is analogous to electrical capacitance, where a capacitor stores electrical energy. In a pneumatic system, the receiver tank acts as the capacitor, storing compressed air under pressure.



Microsoft Excel
Worksheet

Useful Storage

- 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

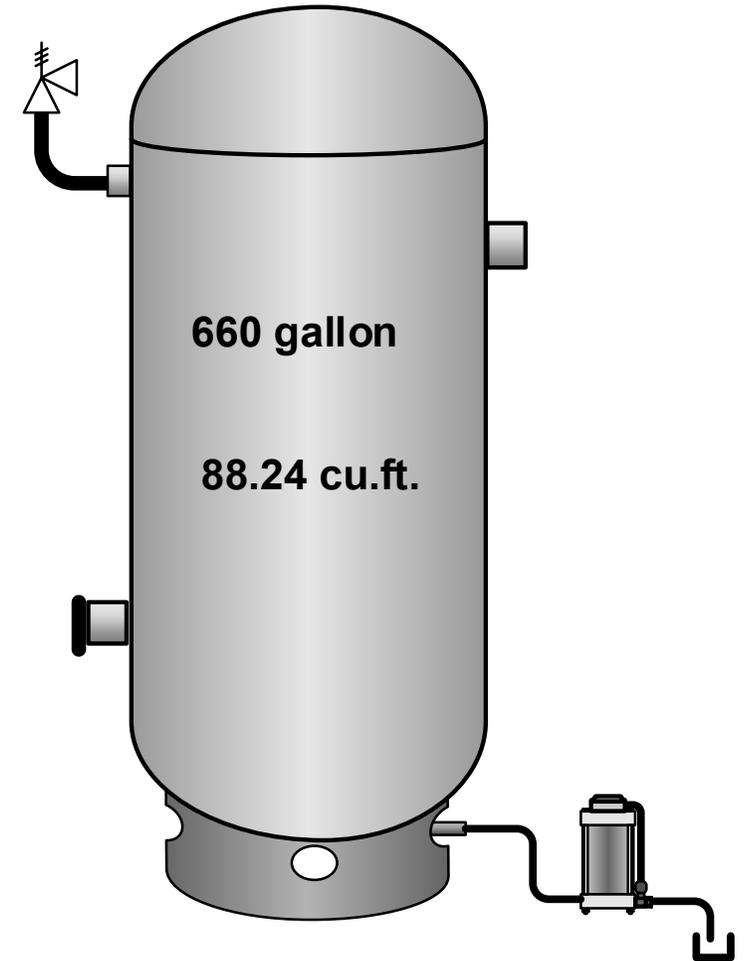
What is the usable (useful) storage?

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**



Microsoft Excel
Worksheet

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

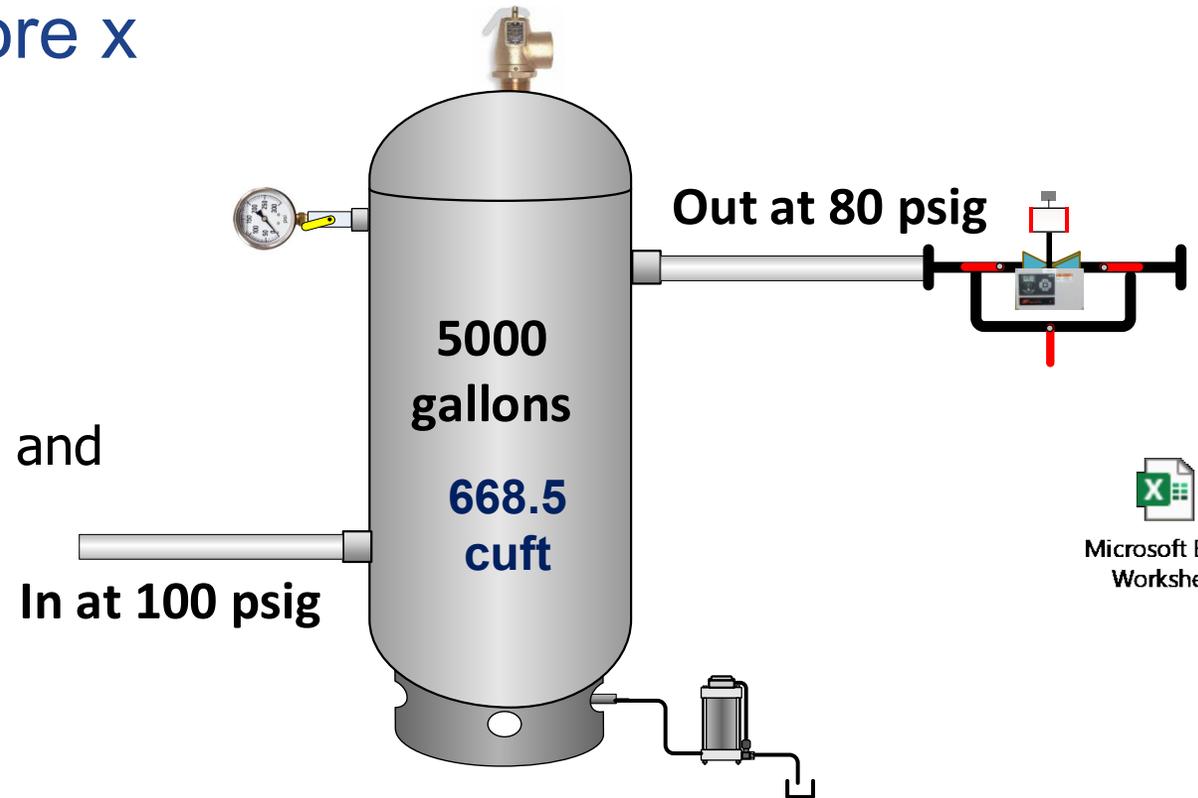
What is the usable (useful) storage?

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



Microsoft Excel Worksheet

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

Useful Storage

- Useful Storage = Capacity to Store x Allowable Pressure Drop

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

Given a 200 gallon tank with pressure in at 116 and pressure out at 3

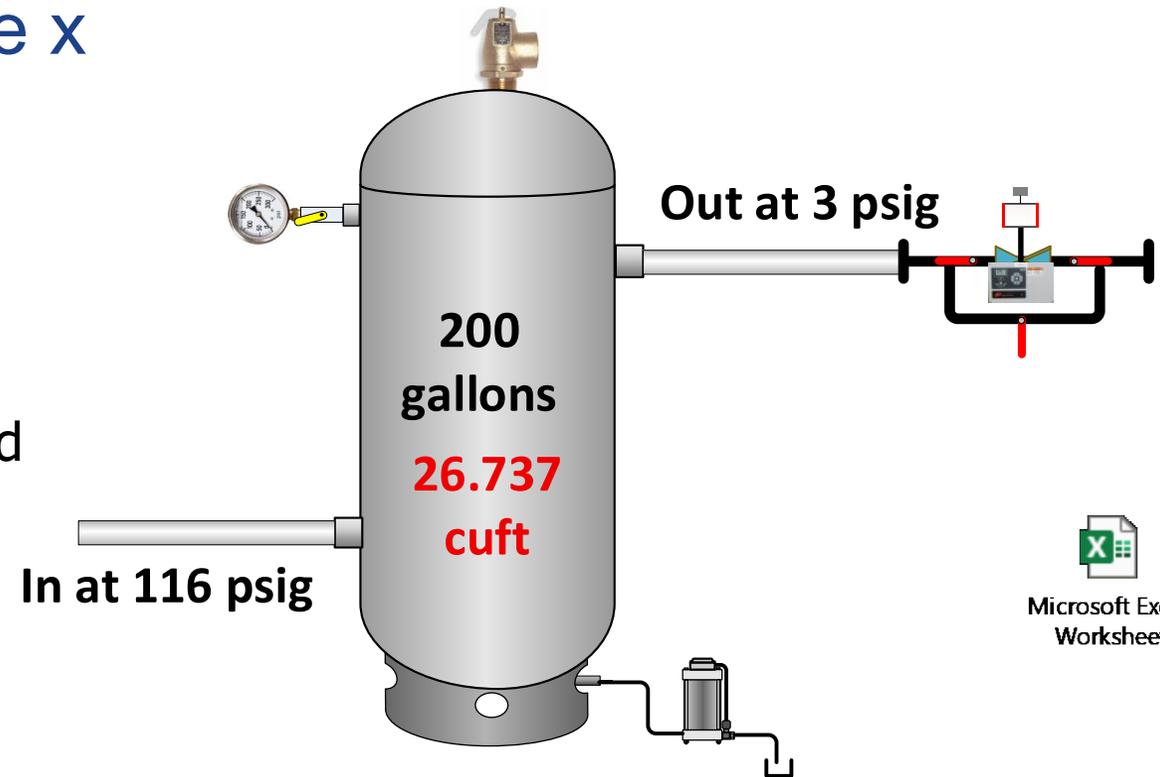
What is the usable (useful) storage?

200 gallons / 7.48 gal/cuft = 26.737 cubic feet

26.737 / 14.5 psia = **1.843 cuft / psia**

1.843 cuft / psia x 113 psia =

= 208.26 cuft of usable storage



Microsoft Excel
Worksheet

$$\text{Solving For } S_{\text{refill}} = \frac{V_{cf} \times (P_1 - P_2)}{T_m \times 14.7} \quad \text{Solving For } S_{\text{refill}} = \frac{26.737_{cf} \times (113)}{T_m \times 14.7}$$

Boyles Law

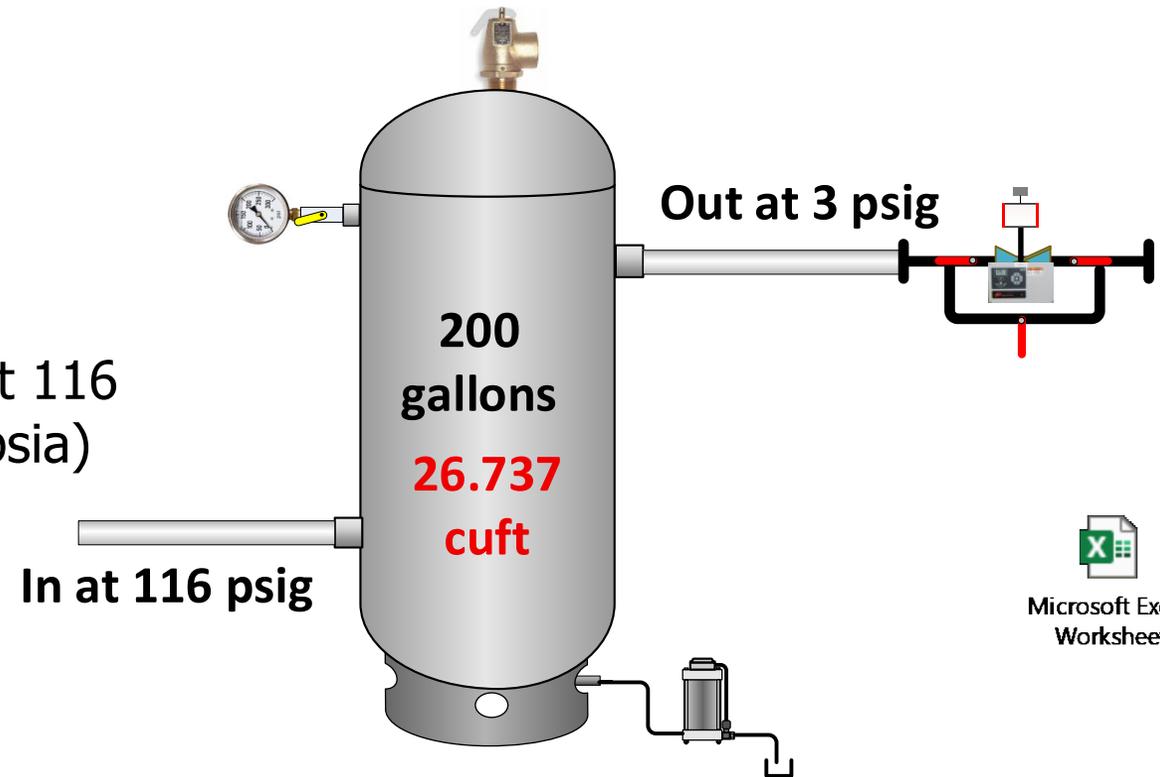
- $P_1V_1=P_2V_2$

$$V_2 = \frac{P_1V_1}{P_2}$$

Given a 200-gallon (26.7 cf) tank with pressure in at 116 psig (130.5 psia) and pressure out at 3 psig (17.5 psia)
What is the expanded volume available?

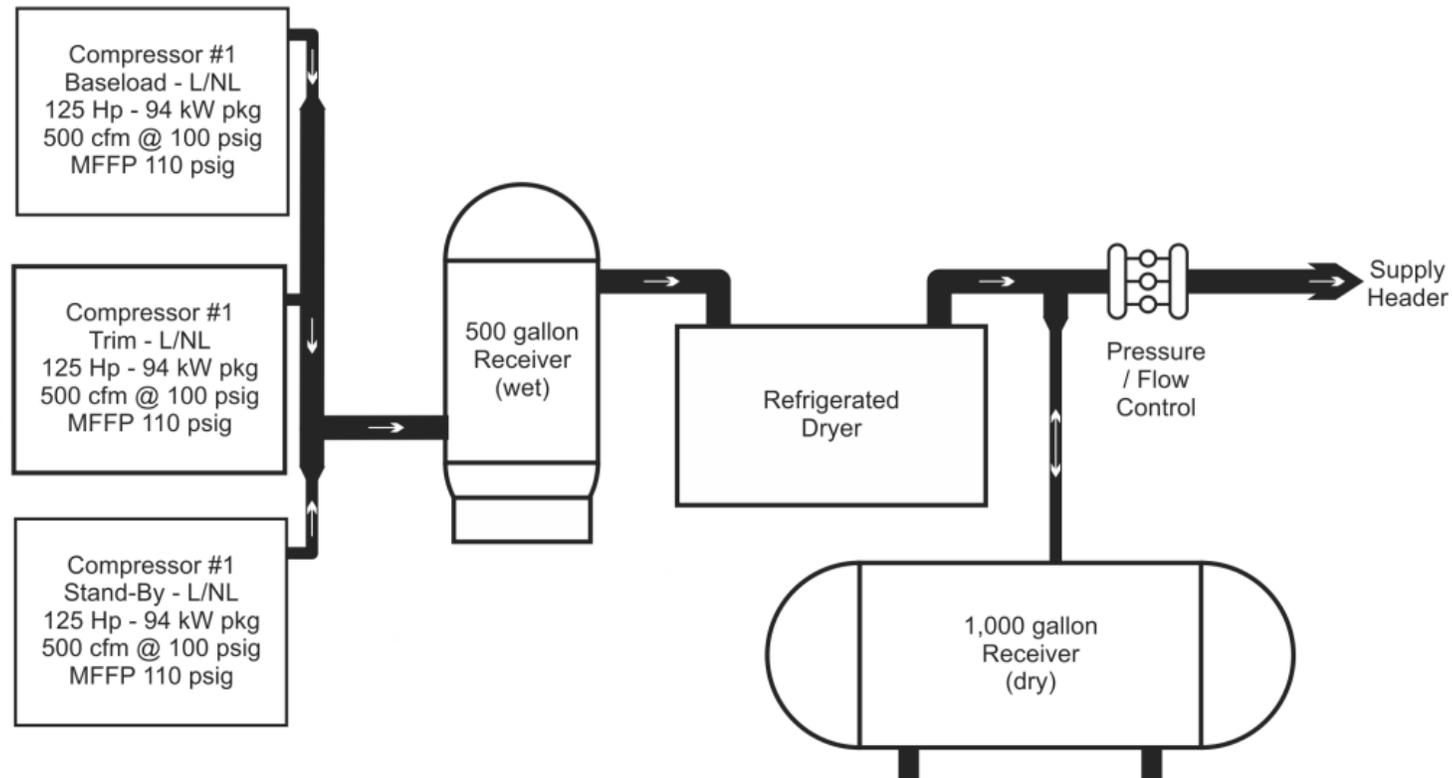
$$V_2 = \frac{130.5_{psia} \times 26.7_{cft}}{17.5} \quad V_2 = 199cft$$

= 199 cft of usable storage



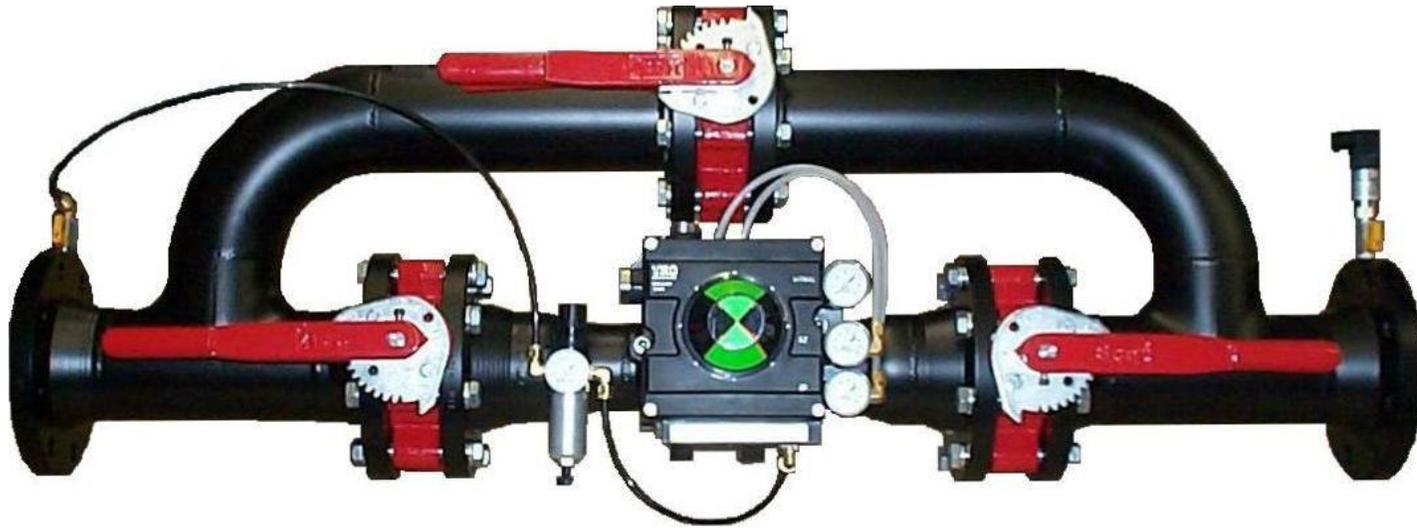
Microsoft Excel
Worksheet

Pressure/Flow Controllers – Do I Need One?



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

Pressure/Flow Controllers

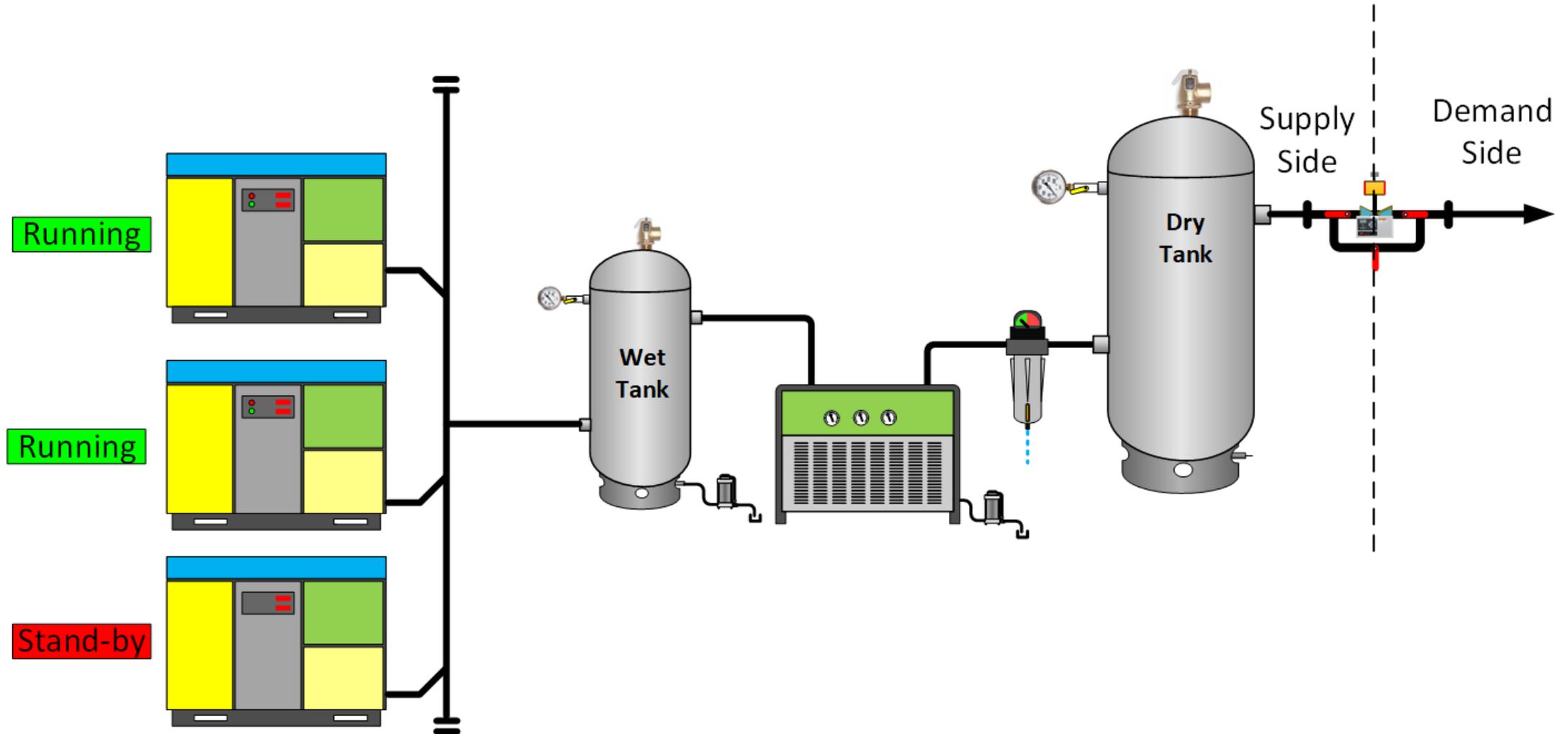


Pressure/Flow Controllers

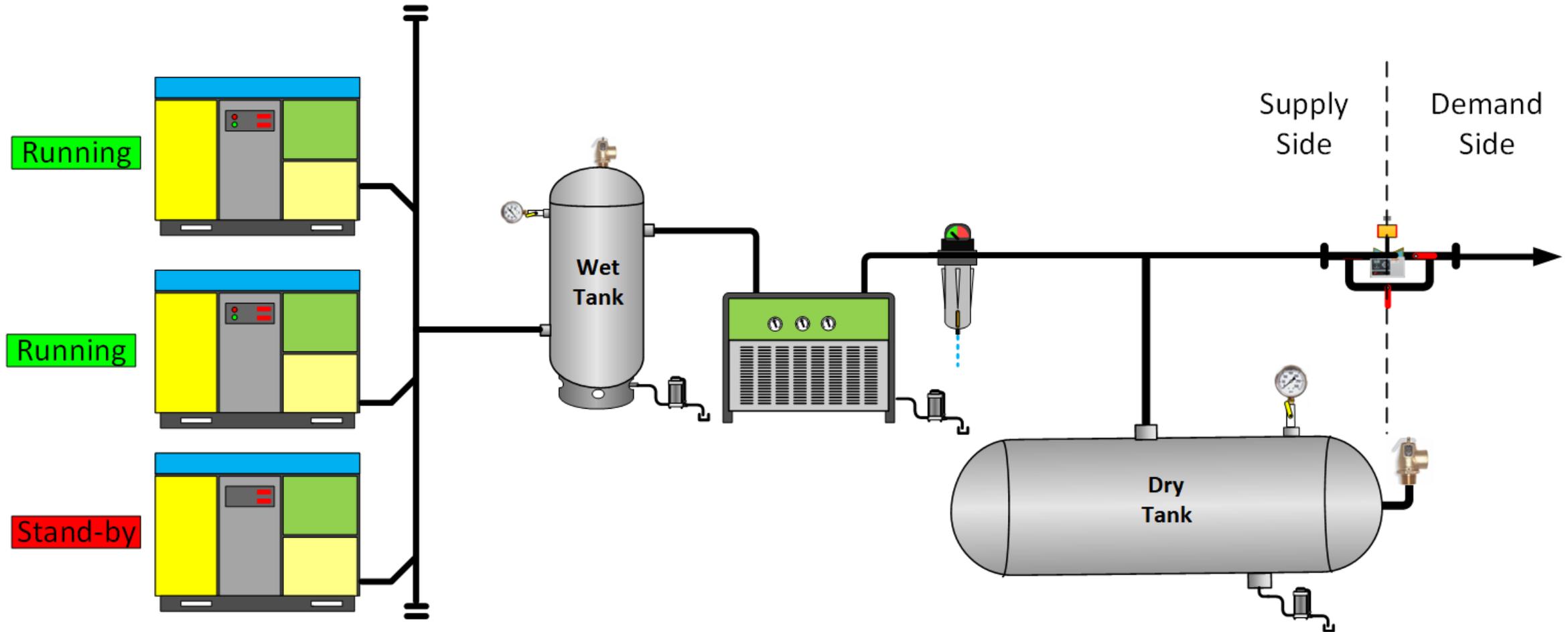
- Make sure regulators are made for full flow with superior response time



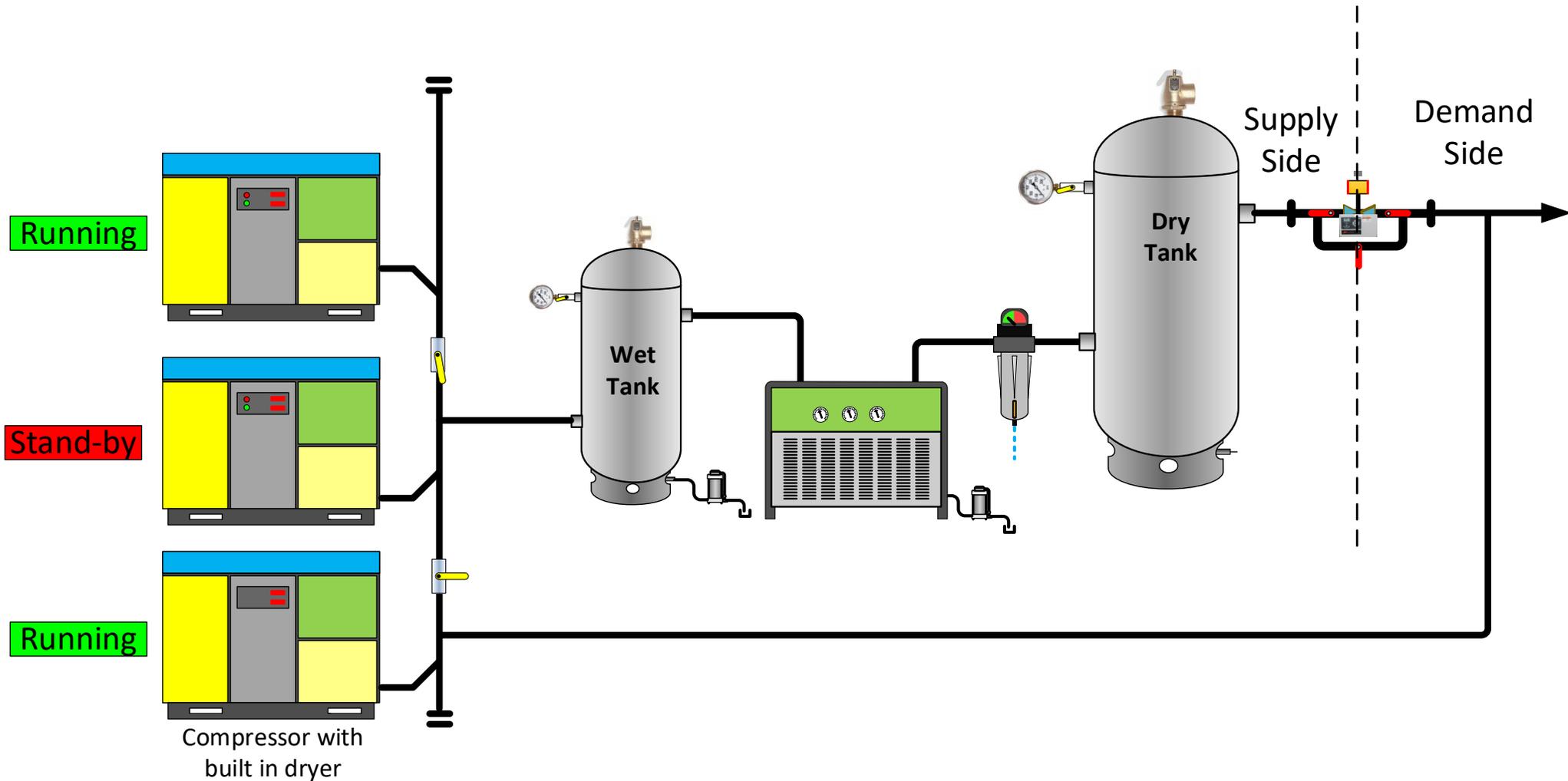
Best Practice with Pressure Flow Controller



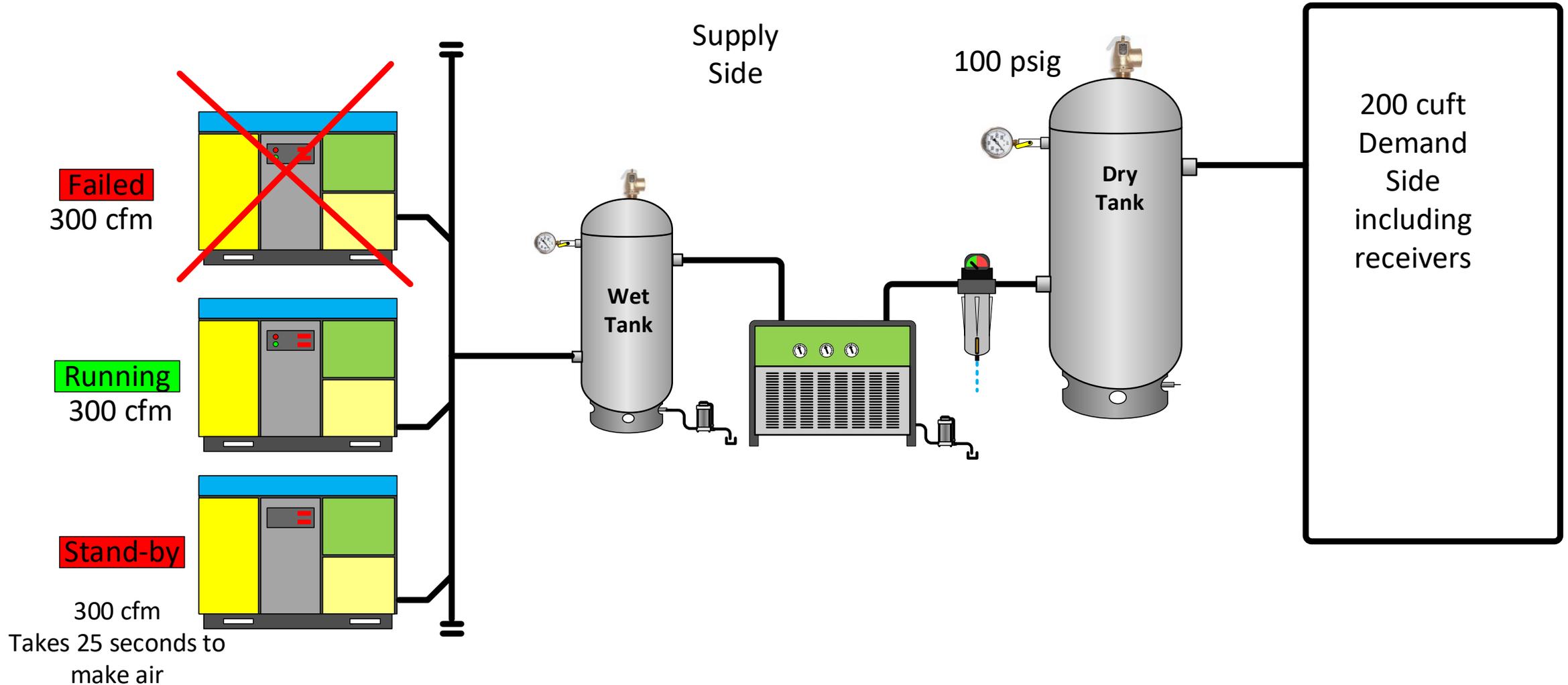
Best Practice with Pressure Flow Controller



Best Practice with Pressure Flow Controller



System Drawdown Without a Pressure Flow Control Valve



System Drawdown

Three different methods could be used to calculate:

#1 Capacitance:

Volume in cuft ÷ 14.7 = capacitance in cu. ft./psi

$$\text{DrawDownRate} = \frac{\text{DebitFlow}_{\text{cuft sec}}}{\text{Capacit}_{\text{cuftpsi}}} \times \text{Time}_{\text{sec}}$$

Example: a 200-cu ft system is operating at 100 psig with a total demand of 600 acfm using two 300 acfm compressors online. If one compressor fails, what will the drawdown of pressure be in 25 seconds?

300 acfm = **5 cfs**

Capacitance = $200_{\text{cuft}} / 14.7_{\text{psia}} = \mathbf{13.6 \text{ cuft /psi}}$

$$\text{DrawDownRate} = \frac{5_{\text{cuft sec}}}{13.6_{\text{cuftpsi}}} \times 25_{\text{sec}}$$

$$\text{DrawDownRate} = .367_{\text{psi/sec}} \times 25_{\text{sec}} = 9 \text{ psig}$$

System Drawdown

Three different methods could be used to calculate:

#2 Receiver calc:

$$\Delta P = \frac{T_{\min} \times (\text{DebitFlow}) \times P_a}{V_{cf}}$$

$$V_{cf} = \frac{T_{\min} \times (C - R) \times P_a}{P_1 - P_2}$$

Solve for ΔP

Example: a 200-cuft system is operating at 100 psig with a total demand of 600 acfm using two 300 acfm compressors online. If one compressor fails, what will the drawdown of pressure be in 25 seconds?

$$\Delta P = \frac{\left(\frac{25}{60}\right) \times (300_{cfm}) \times 14.7}{200_{cf}} = 9 \text{ psig}$$

System Drawdown

Three different methods could be used to calculate:

#3 Supply = Demand:

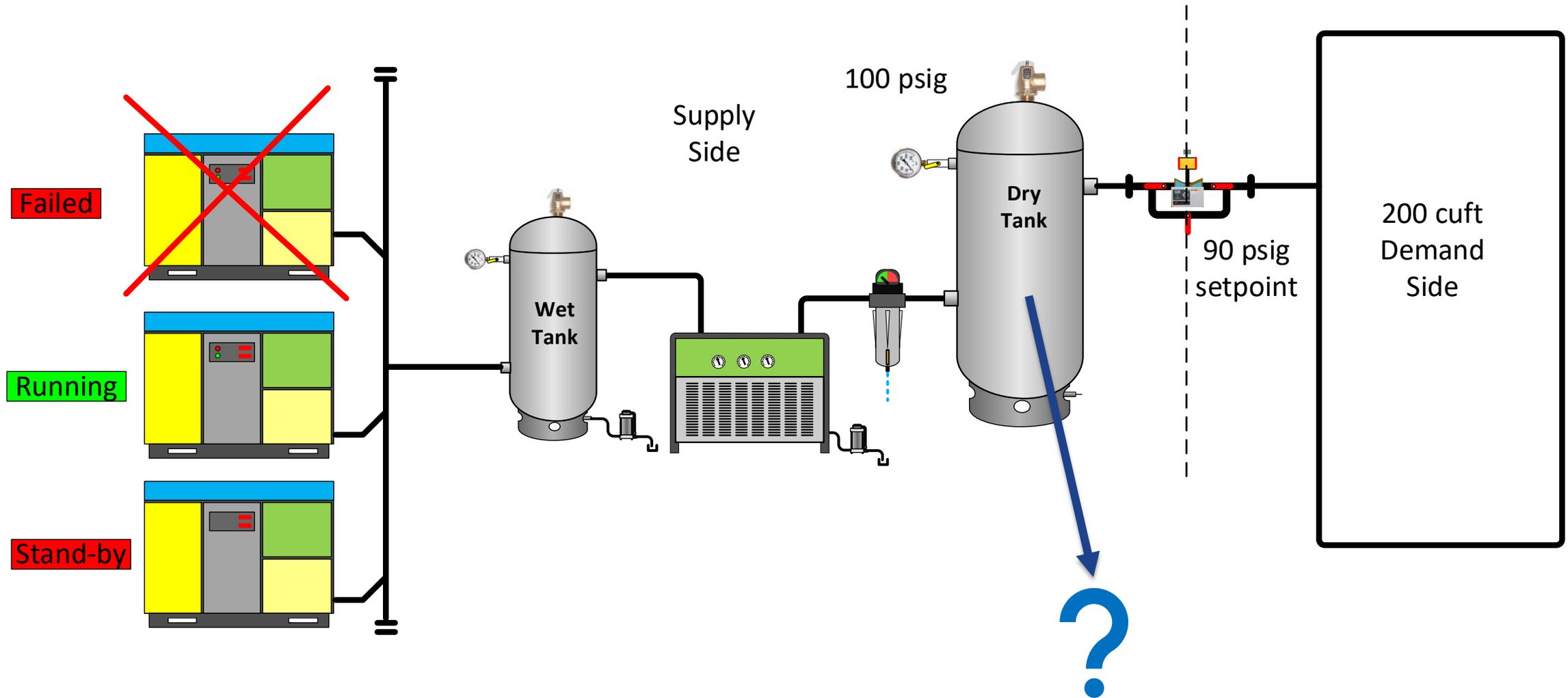
$$V_{cf} \times \frac{\Delta P}{P_a} = DebitFlow \times T_{min} \qquad 200_{cf} \times \frac{\Delta P}{14.7} = 300 \times \left(\frac{25}{60} \right)$$

Example: a 200 cu ft system is operating at 100 psig with a total demand of 600 acfm using two 300 acfm compressors online. If one compressor fails, what will the drawdown of pressure be in 25 seconds?

$$\Delta P \times 13.6 = 125$$

$$\Delta P = 9$$

System Drawdown With Pressure Flow Control Valve



System Drawdown

Sizing a receiver for storage using PFC valve

$$V_{cf} = \frac{\left(\frac{25}{60}\right) \times (300) \times 14.7}{10}$$

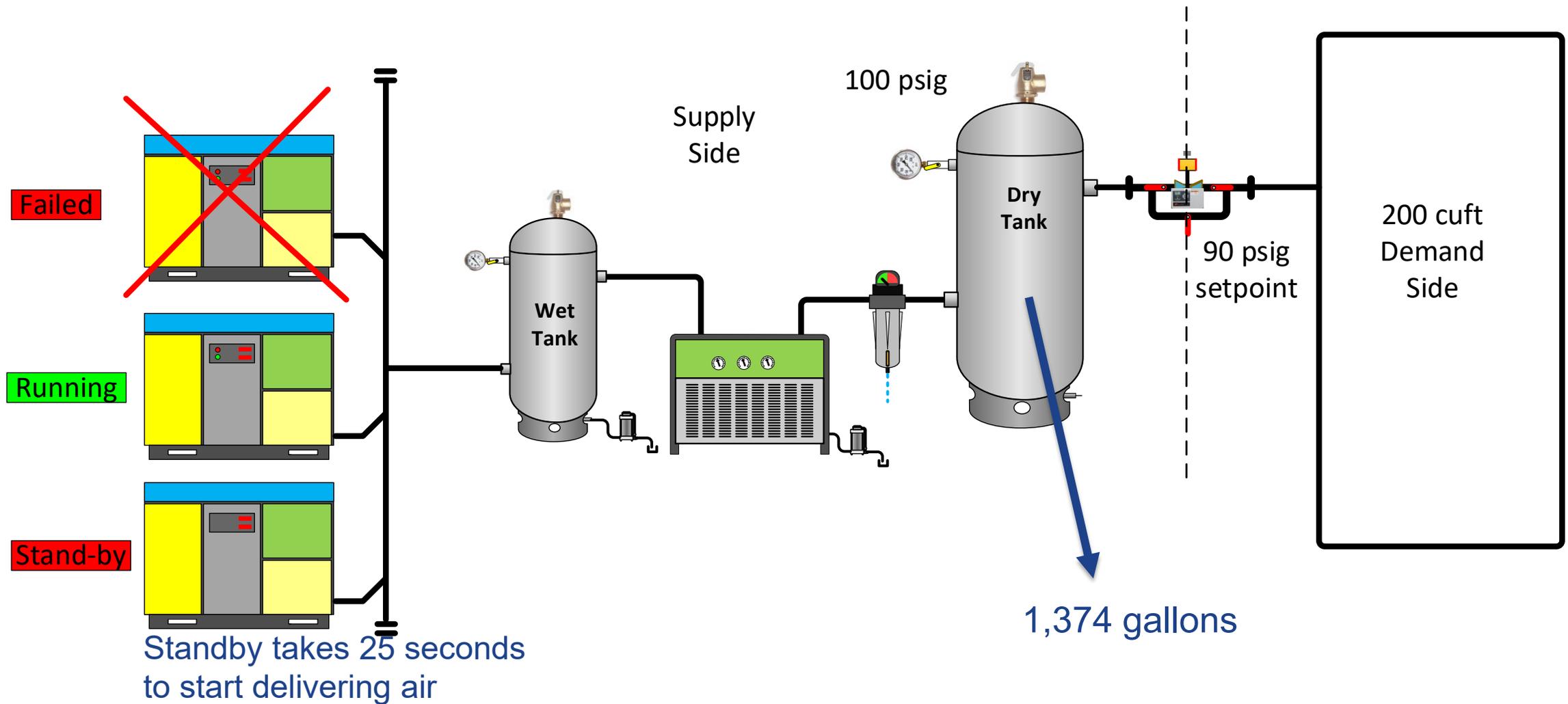
Receiver calc: $V_{cf} = \frac{T_{\min} \times (C - R) \times P_a}{P_1 - P_2}$

Example: a 200-cu ft system is operating at 100 psig with a total demand of 600 acfm using two 300 acfm compressors online. If one compressor fails, what size receiver will prevent pressure drawdown while waiting 25 seconds for the backup compressor to make air? System pressure cannot fall below 90 psig

$$V_{cf} = 183.75 \quad V_{gal} = 183.75 \times 7.48_{galcuft} = 1,374$$

A 1374-gallon receiver will deliver 200 cubic feet of air for 25 seconds. The pressure in the vessel will start at 100 psig and end up at 90 psig

System Drawdown With Pressure Flow Control Valve



Example: System Drawdown

- A demand event results in a 200 scfm airflow rate being supplied from the system's air storage volume which is 133.7 cf ft (1,000 gallons). What is the pressure drawdown rate in psi/sec that will result?
 - This drawdown can take place in a storage tank behind a pressure flow control valve or will take place in the distribution volume.
 - Your choice

System Drawdown

- Answer

$$\text{DrawDownRate} = \frac{\text{DebitFlow}_{\text{cuftsec}}}{\text{Capacit}_{\text{cuftpsi}}} \times \text{Time}_{\text{sec}}$$

$$\text{DrawDownRate} = \frac{3.333_{\text{cfs}}}{9.09_{\text{cfpsi}}} \times 1_{\text{sec}}$$

$$\text{DrawDownRate} = .37 \text{ psi / sec}$$

$$\frac{1000_{\text{gal}}}{7.48_{\text{gal / cf}}} = 133.7_{\text{cf}}$$

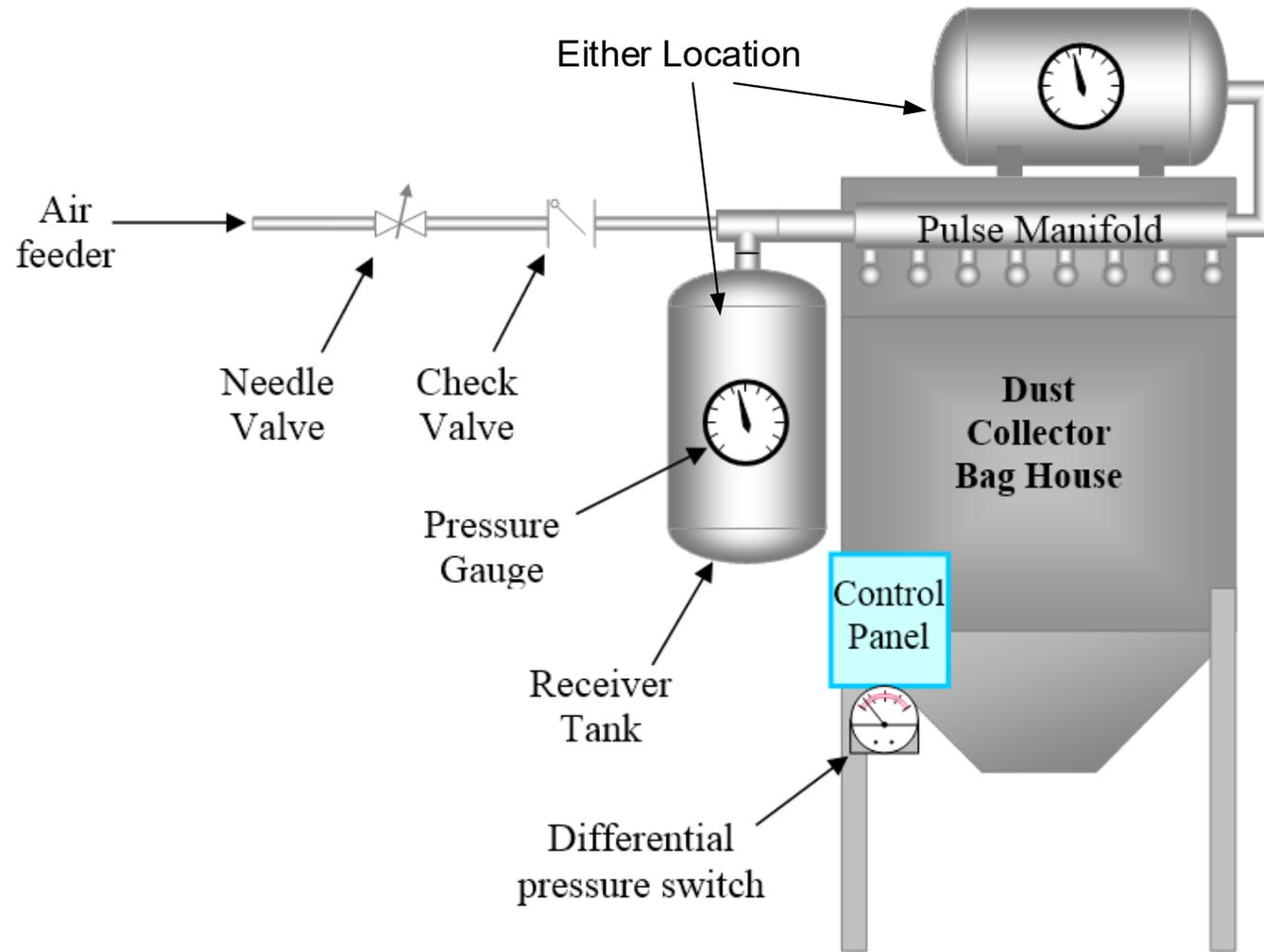
$$\text{Capacitance} = \frac{133.7_{\text{cf}}}{14.7_{\text{psia}}} = 9.09_{\text{cfpsi}}$$

$$\frac{200_{\text{cfm}}}{60} = 3.333_{\text{cfs}}$$

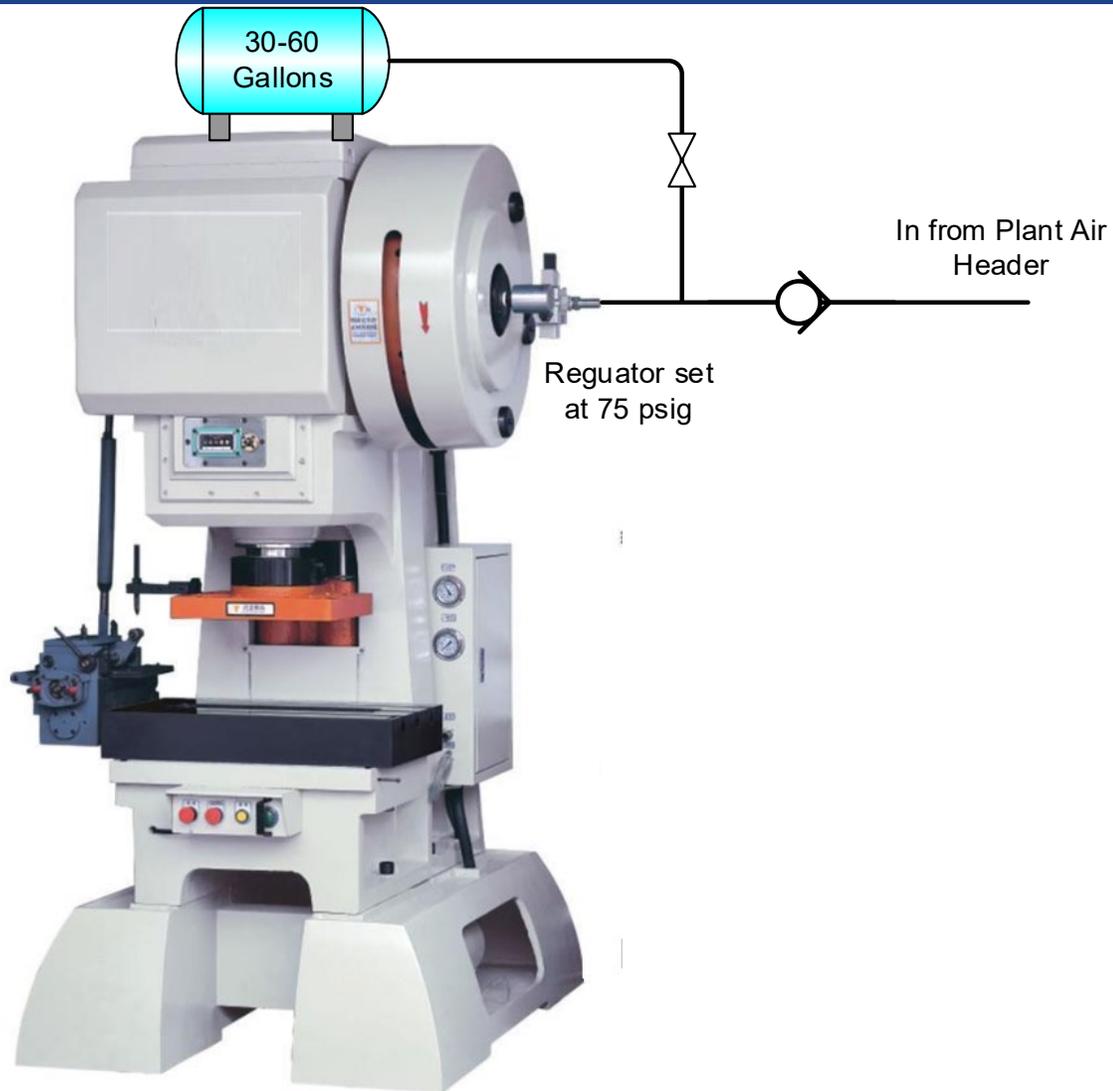
Storage Examples

High-volume intermittent events create the appearance of inadequate supply because they can cause the pressure to fall in the system before the compressors can react.

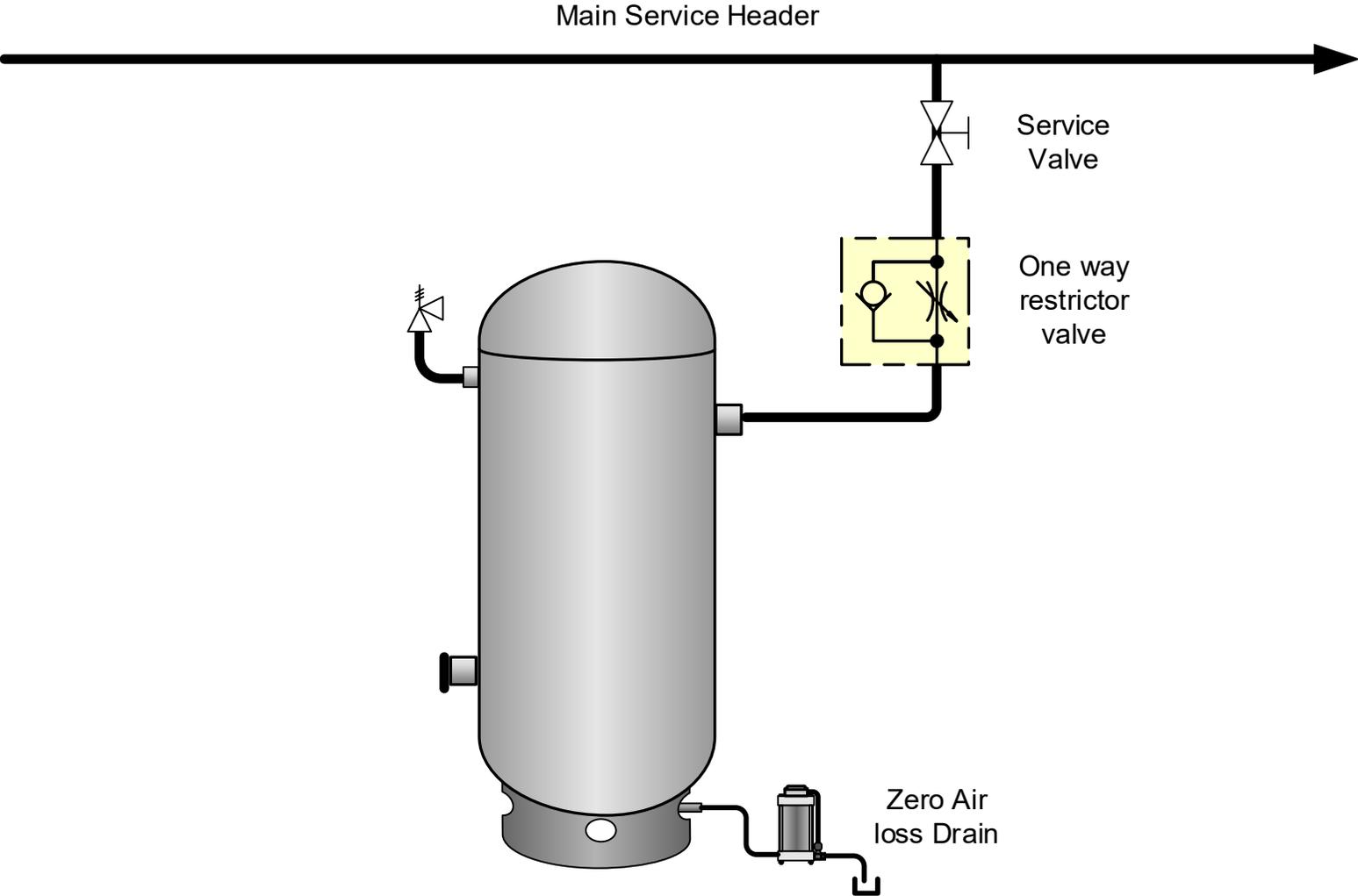
Dedicated Storage to Shield the system from a high flow end use application



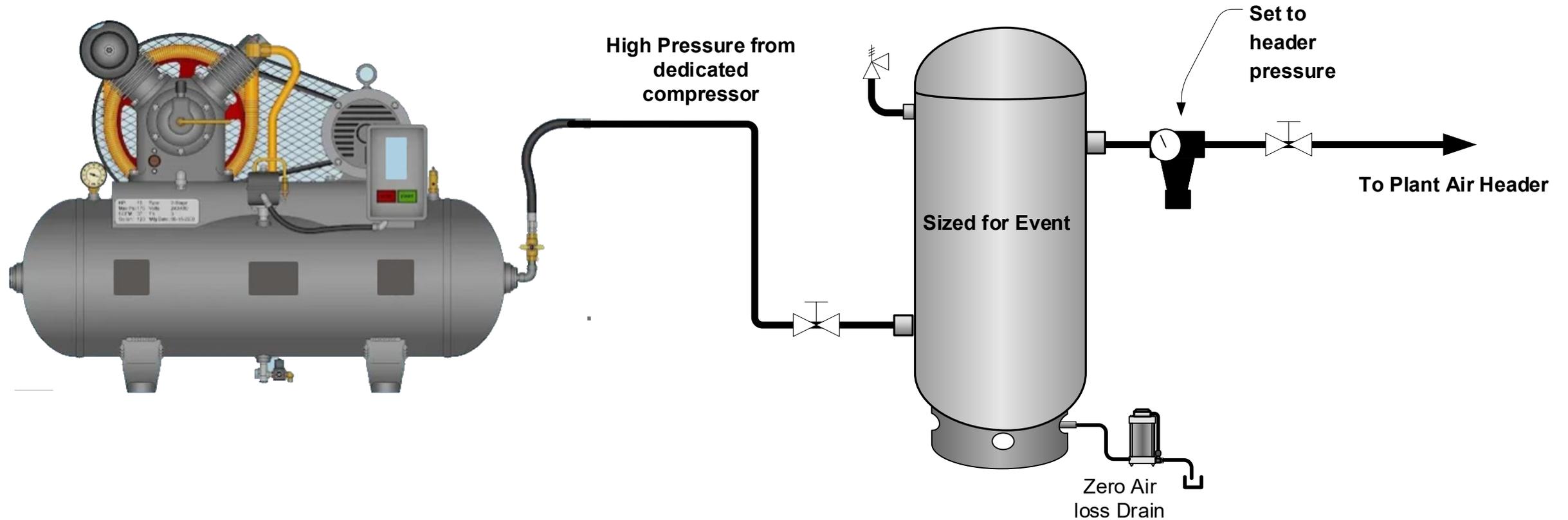
Critical Pressure End Use



General Storage



High Pressure Offline Storage



Example High Pressure Offline Storage

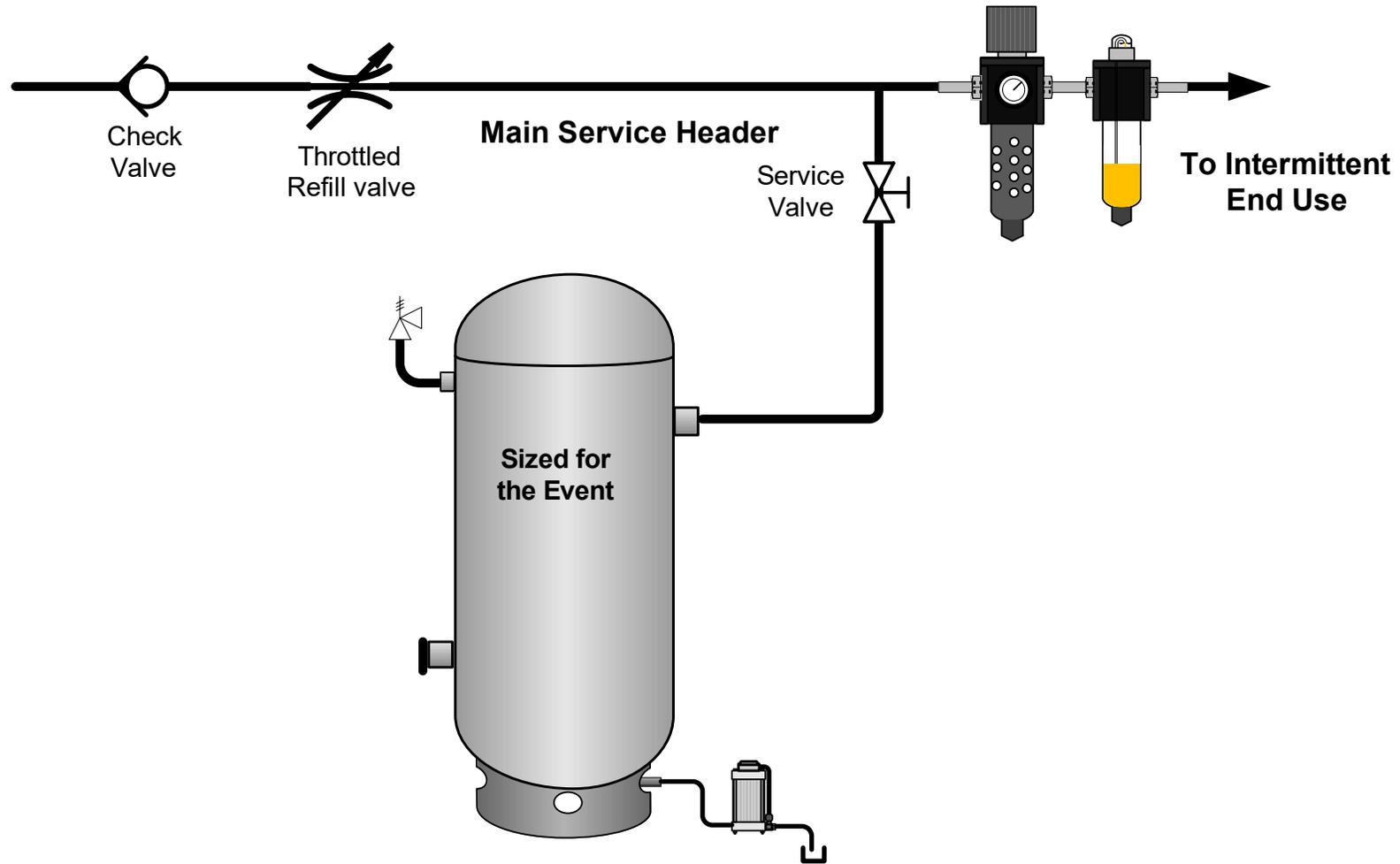
Assume a back wash filter requires **100 cfm every hour** for a duration of **3 minutes** at 70 psig. A high-pressure compressor is available for 200 psig operation. For this calculation assume S to be zero.

$$V = \frac{T(C - S)Pa}{P_1 - P_2} \quad V = \frac{3(100 - 0)14.7}{200 - 70} = 33.92 \text{ Cubic Feet}$$

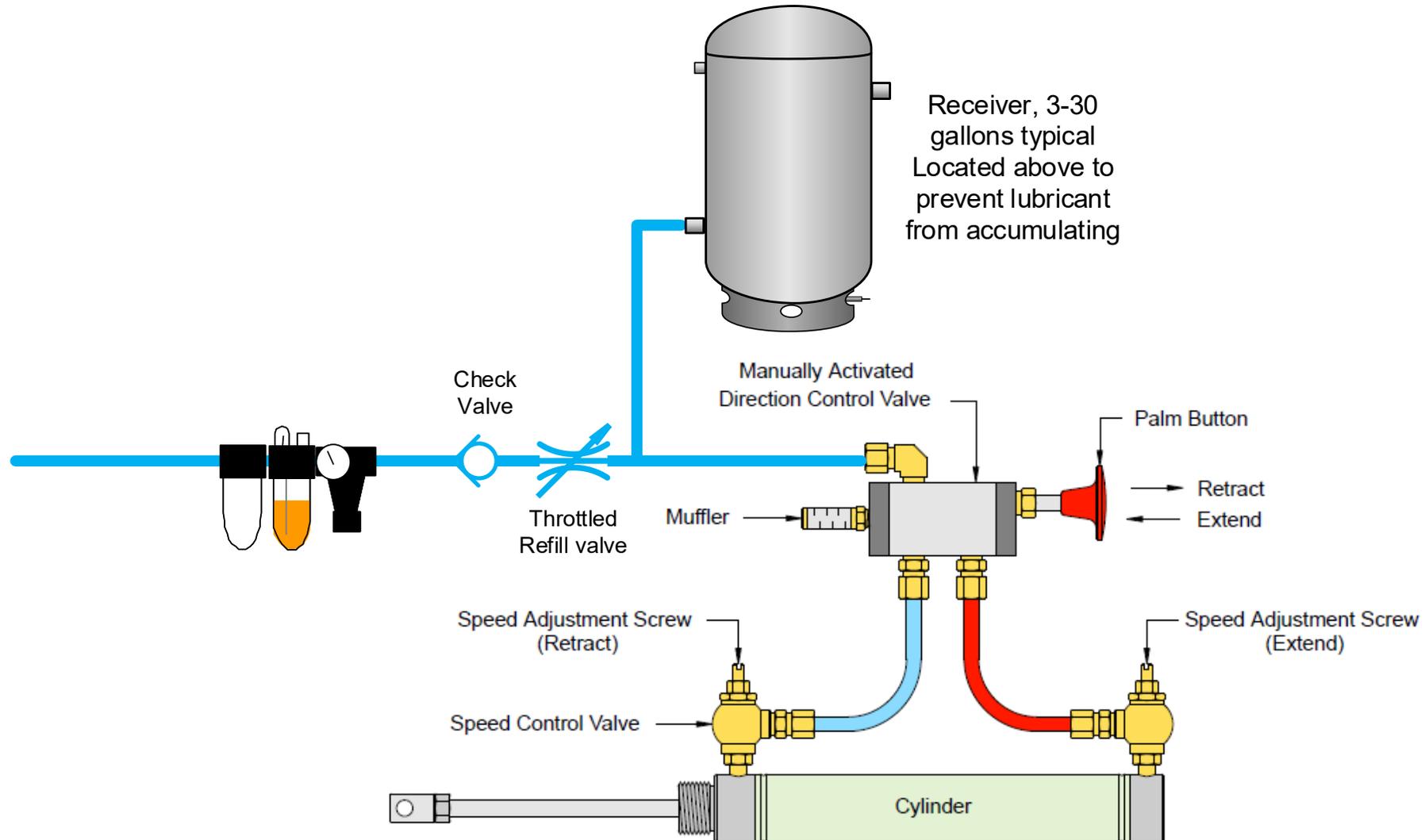
$$33.92 \times 7.48 \text{ gal/cu.ft.} = 253.7 \text{ gallons}$$

That's a lot smaller receiver than the 1319 gallons using the 95-70 differential.

Dedicated Storage with Metered Recovery

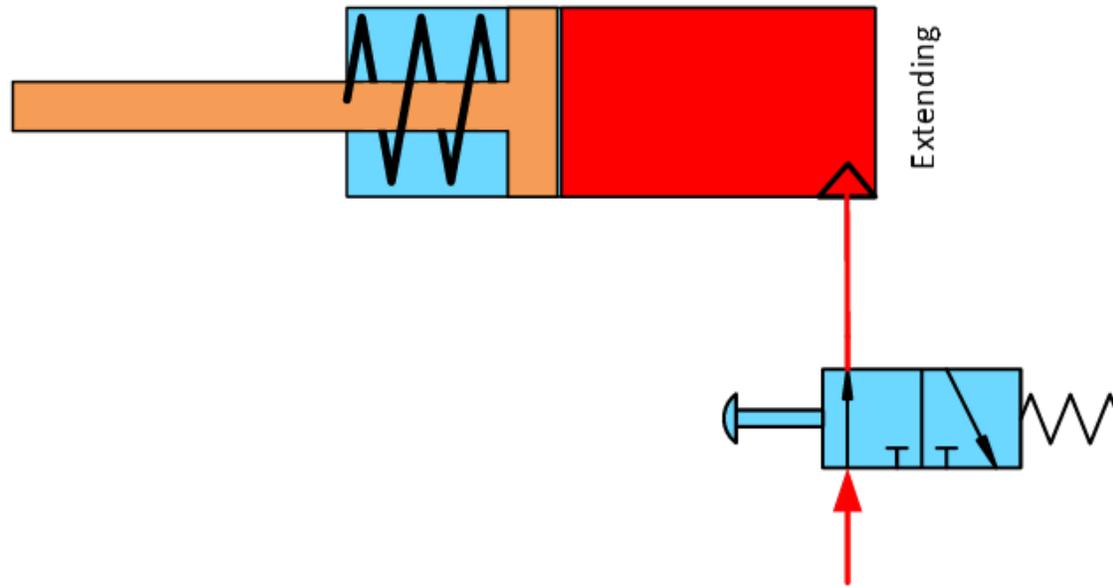


Dedicated Storage with Metered Recovery



Peak Flow vs Average Flow

- The single acting spring return air cylinder picture below requires 1 cubic foot of compressed air and actuates to full stroke in 3 seconds. If the cylinder actuates 2 x per minute, what is the peak and average flow?

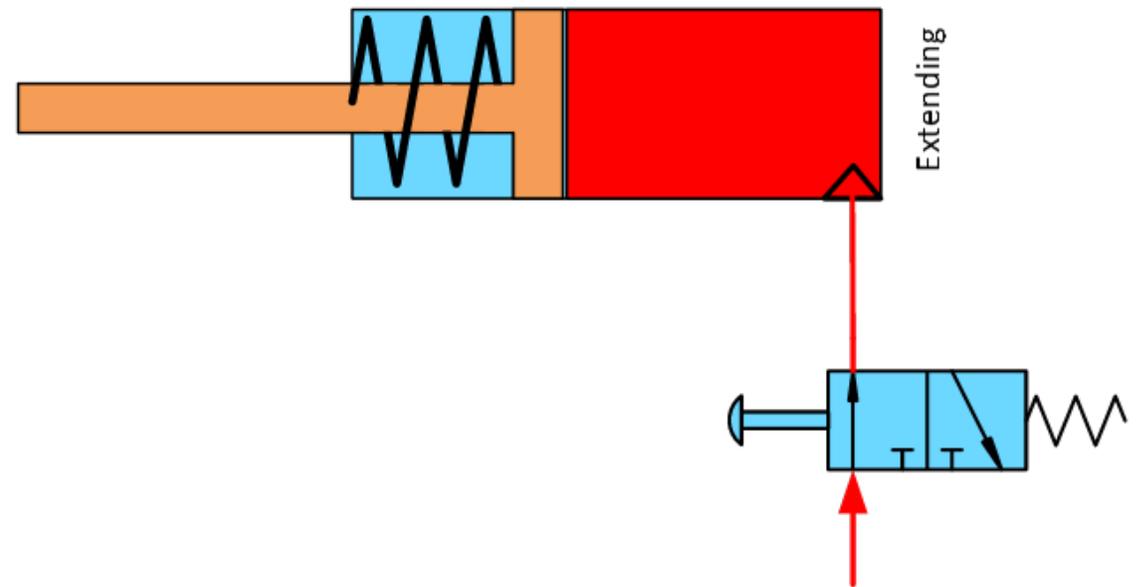


Peak Flow vs Average Flow

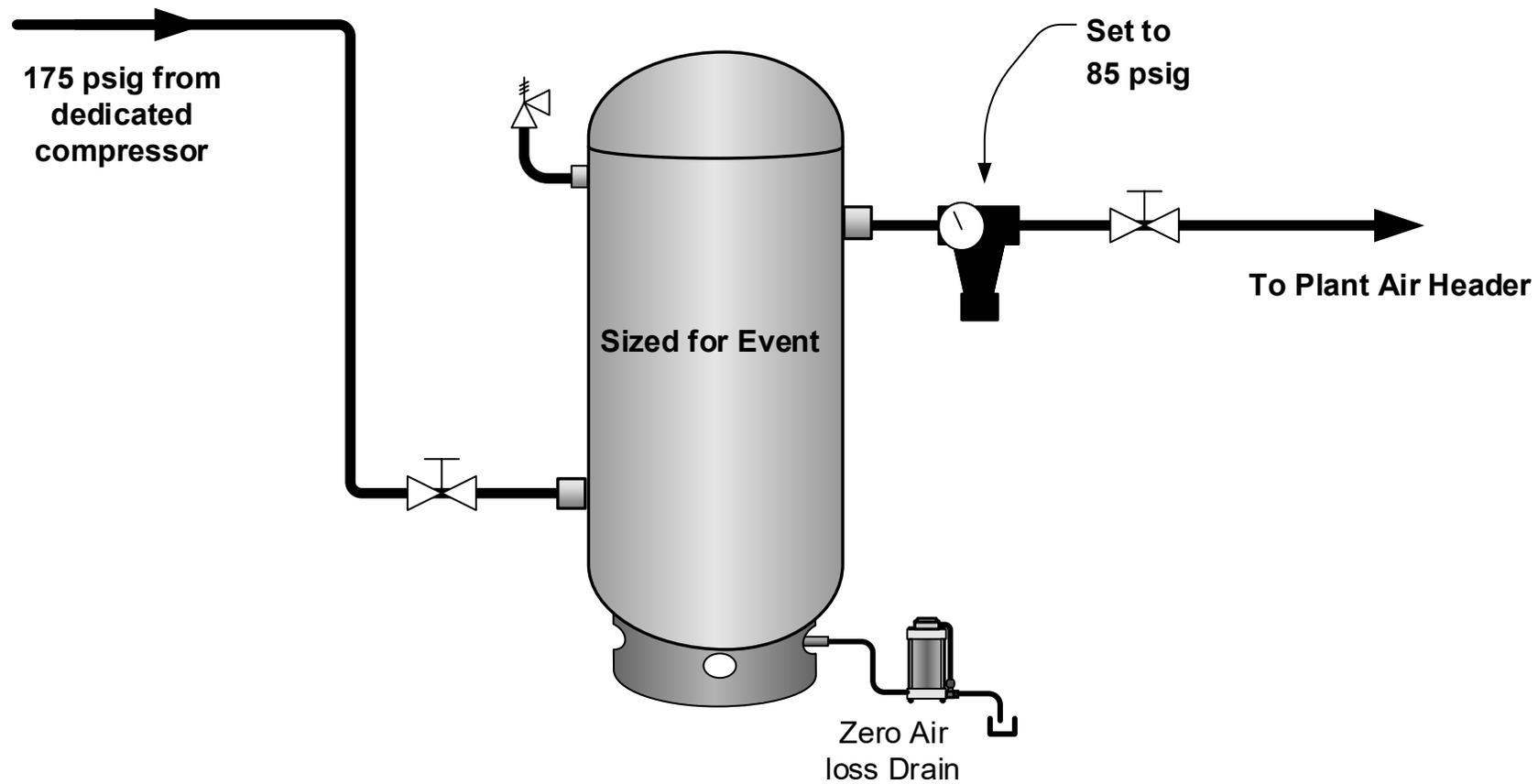
- Answers:
 - Average flow = 2 cfm
 - Peak flow – 20 cfm

$$\frac{1cf}{3\text{sec}} \times \frac{60\text{sec}}{1\text{min}} = 20cfm$$

$$\frac{60}{3} = 20cfm$$



Offline High Pressure Storage



Conclusion

- By applying the basic storage principles involved in a compressed air system, you can immediately improve the performance of production equipment in terms of productivity and quality and make major reductions in the operating costs of your compressed air system.
- The alternative to applying these basic storage principles in the system is to operate too much pressure and power all of the time to compensate for the lack of storage.
- The next time someone complains about insufficient air pressure, remember there are alternatives to raising the pressure and buying or operating another compressor.

MEASUR Review

- Figures
- International Paper
- Hon
- Fujifilm
- Fuji
- Corning Inc
- Corning Inc
- SRP
- Examples
 - Compressed Air Example
 - Waste Water Example
 - Treasure Hunt Example
 - Steam Example
 - Fan Example
 - Pump Example
 - Process Heating - Fuel E...
 - Toy Factory

Data Exploration

All Calculators

General

Compressed Air

Fans

Lighting

Motors

Process Cooling

Process Heating

Pumps

Steam

Wastewater

Settings

Custom Materials

User Manuals

About

Feedback

Privacy Notice

Acknowledgments

v1.4.0 ⓘ

MEASUR

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

Create an assessment to model your system and find opportunities for efficiency or run calculations from one of our many property and equipment calculators.

Get started with one of the following options.

If you need help at any point along the way, click on a [User Manual](#) icon.



[View Assessments](#)



[Equipment Calculators](#)



[Pump Assessment](#)



[Compressed Air Assessment](#)



[Process Heating Assessment](#)



[Fan Assessment](#)



[Steam Assessment](#)



[Treasure Hunt](#)



[Wastewater Assessment](#)



[Motor Inventory](#)



[Pump Inventory](#)



[Data Exploration](#)

U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

MEASUR Tool – upload your data

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](#)



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Import Existing Data Exploration | Load Example Data

> Timestamp Help

File Upload Preview

International_Paper_Co_inside_200hp_QSI1.csv

[Remove](#)

International_Paper_Co_outside_QSI_n250h.csv

[Remove](#)

Reset Data

Next

MEASUR Tool



Data Exploration

Setup

Day Type Analysis Visualization



1 Import Data

2 Select Header Row

3 Refine Data

4 Map Date and Time

Select a header row and advance to the next file

Apply my selections for all datasets

International_Paper_Co_inside_200hp_QSI1.csv

International_Paper_Co_outside_QSI_n250h.csv

Select Header Row

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

Back

Next

MEASUR Tool



Data Exploration

Setup

Day Type Analysis Visualization



1 Import Data

2 Select Header Row

3 Refine Data

4 Map Date and Time

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	<input checked="" type="checkbox"/>	<input type="text" value="Date Time, GMT-07:00"/>	+Add
200hp QSI1000, kW	<input checked="" type="checkbox"/>	<input type="text" value="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

Back

Next

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	<input checked="" type="checkbox"/>	<input type="checkbox"/>
outside 250 hp, kW	<input type="checkbox"/>	<input type="checkbox"/>

- 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 – Run Analysis

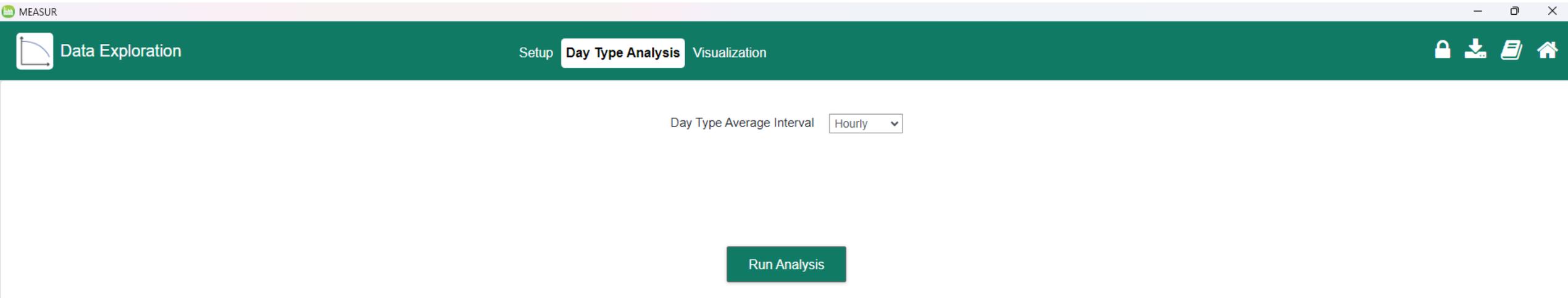
MEASUR

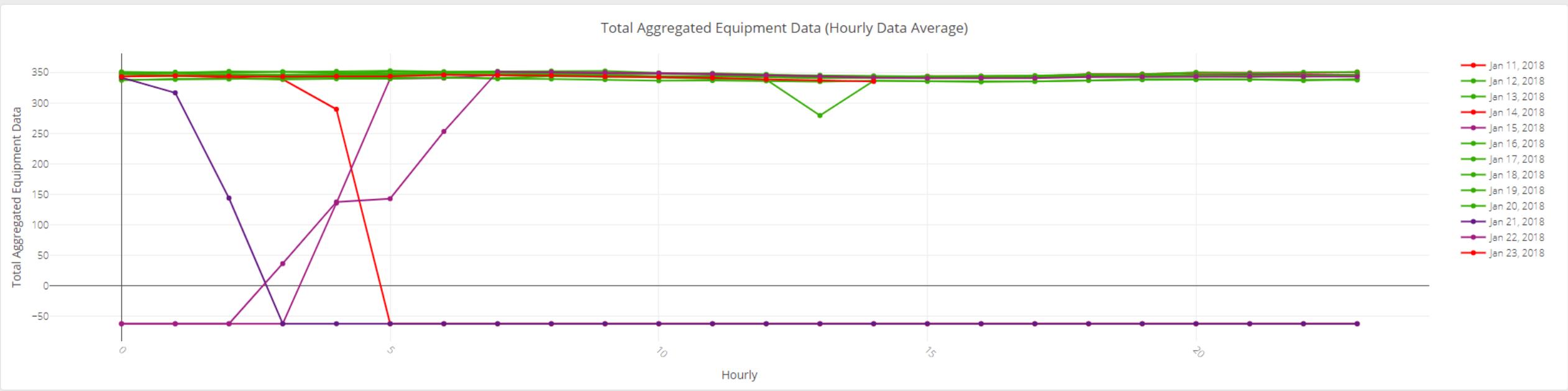
Data Exploration

Setup **Day Type Analysis** Visualization

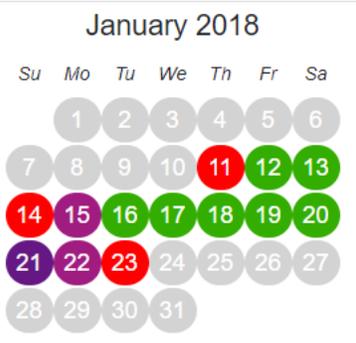
Day Type Average Interval

Run Analysis





Day Types: **Excluded** **Production** **Sunday** **Monday** +Add New Reset



Day Type Average Interval: Hourly

Update Analysis

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	<input checked="" type="checkbox"/>

Create Your Compressor Inventory

COMPRESSOR INVENTORY

Compressor Name:

Description:

[Set Data From Existing Compressor](#)

NAMEPLATE DATA

Compressor Type:

Motor Power: hp

Full Load Operating Pressure: psig

Rated Capacity at Full Load Pressure: acfm

Full Load Amps: amps

Total Package Input Power: kW

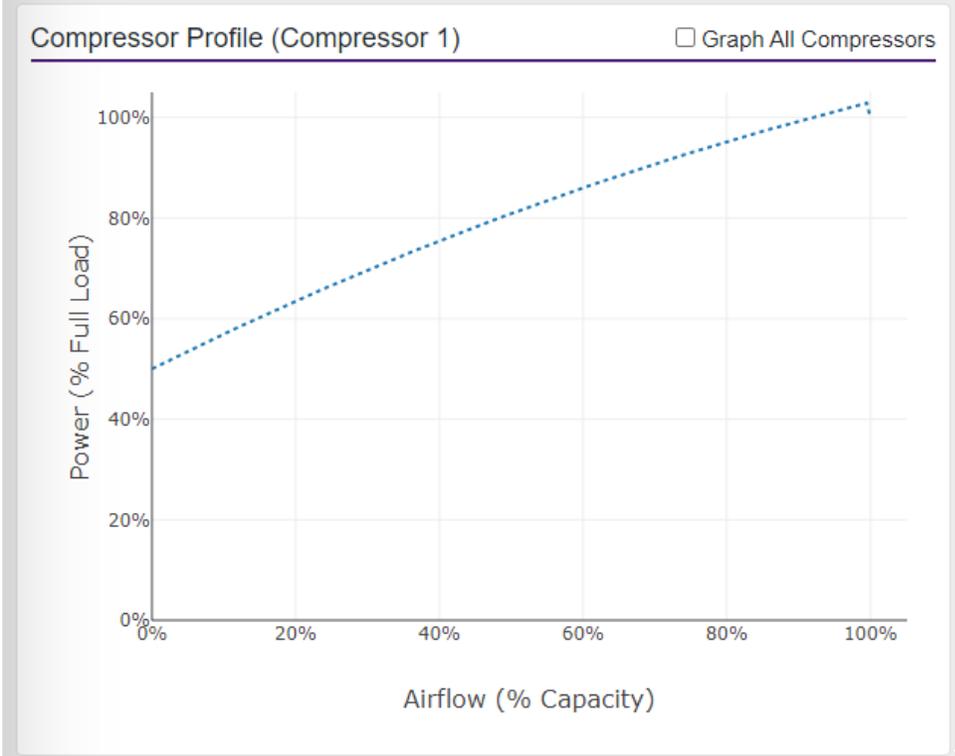
[▶ CONTROLS](#)
[▶ INLET CONDITIONS](#)
[▶ DESIGN DETAILS](#)
[▼ PERFORMANCE POINTS](#)

	Discharge Pressure	Airflow	Power
Full Load (cut-in)	<input type="text" value="100"/> psig	<input type="text" value="18"/> acfm	<input type="text" value="4.6"/> kW
Max Full Flow (cut-out)	<input type="text" value="110"/> psig	<input type="text" value="18"/> acfm	<input type="text" value="4.9"/> kW
No Load (unloaded)	<input type="text" value="15"/> psig	<input type="text" value="0"/> acfm	<input type="text" value="2.3"/> kW

CURRENT INVENTORY [HELP](#)

Name	Compressor Type	Control Type	Pressure Range		
▶ Compressor 1	Single stage lubricant-injected rotary screw	Load/unload	100 - 110 psig	<input type="text" value=""/>	<input type="text" value=""/>
Compressor 2	Single stage lubricant-injected rotary screw	Start/Stop	100 - 110 psig	<input type="text" value=""/>	<input type="text" value=""/>

[+Add New Compressor](#)



Enter Your Operation Profile

1 Assessment Basics
 2 System Information
 3 Inventory
 4 Day Types
 5 **System Profile**

Setup Profile
 Profile Summary
 Graphs
 Annual Summary

Select Day Type:
 Data Interval:

Profile Data Type:
 Pressure Control Range: 100 - 110 psig

Compressor Ordering (No Sequencer)

Fill right on change
 [Turn All Off](#)
[Turn All On](#)

	FLP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Compressor 1	100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Compressor 2	100	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Profile Data

Fill right on change

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Compressor 1	% Capacity	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Compressor 2	% Capacity	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

Find Energy Savings!

Setup Profile | Profile Summary Table | Profile Summary Graphs

Scenario 1 | [View / Add Scenarios](#)

SELECT POTENTIAL ADJUSTMENT PROJECTS

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

[Add New Scenario](#)

Modification Name:

Reduce Air Leaks 1 ▾

Implementation Cost: \$

Leak Flow: acfm

Leak Reduction: %

Improve End Use Efficiency Off ▾

Reduce System Air Pressure Off ▾

Adjust Cascading Set Points Off ▾

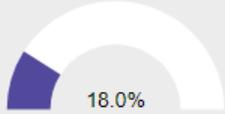
Use Automatic Sequencer Off ▾

Reduce Run Time Off ▾

Add Primary Receiver Volume Off ▾

MODIFICATION RESULTS | COMPRESSOR PROFILE | HELP | NOTES

All Day Types ▾

	Baseline	Scenario 1
Percent Savings (%)	— —	 18.0%
Flow Reallocation Savings	— —	\$201.99
Reduce Air Leaks Savings	— —	\$150.57
Peak Demand	3.87 kW	3.17 kW
Peak Demand Savings	— —	0.7 kW
Peak Demand Cost	\$232.19	\$190.38
Peak Demand Cost Savings	— —	\$41.81
Annual Energy (kWh)	29,662	24,321
Annual Energy Savings (kWh)	—	5,342
Annual Cost	\$1,957.72	\$1,605.16
Annual Savings	—	\$352.56

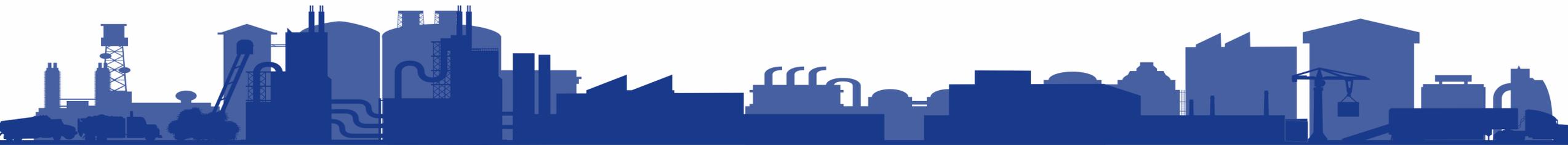
Example Presentation



Compressed Air Systems VINPLT: Close out Presentation



Company Name:
Facility Name:
Participant Name(s):



Block Diagram of the Compressed Air System

Savings Opportunities in Compressor Controls

Savings Opportunities in Pressure Setpoints

Savings Opportunities in Compressed Air Distribution Systems

Savings Opportunities in Compressed Air Users

Tips Learned from this Training

Next Steps or Action Items after the Compressed Air VINPLT

- What are your next steps to implement opportunities?
- What are you planning to do after the VINPLT?
- Lessons learned?

Questions and Answers



Next Week Session 8 – Final Report Out

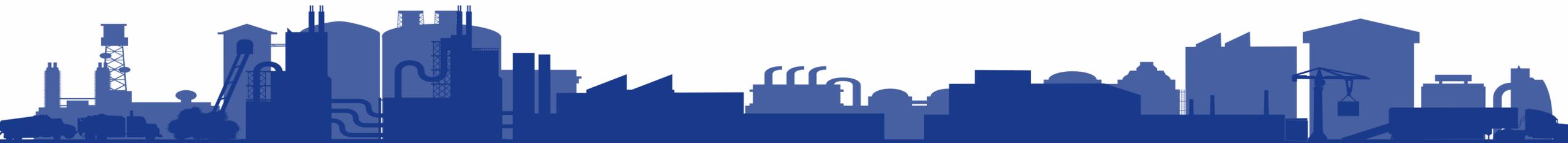
- The goal of this session:
 - To understand how to maintain an efficient compressed air system by managing wastes.
 - To take advantage of the heat emitted from a compressed air system.



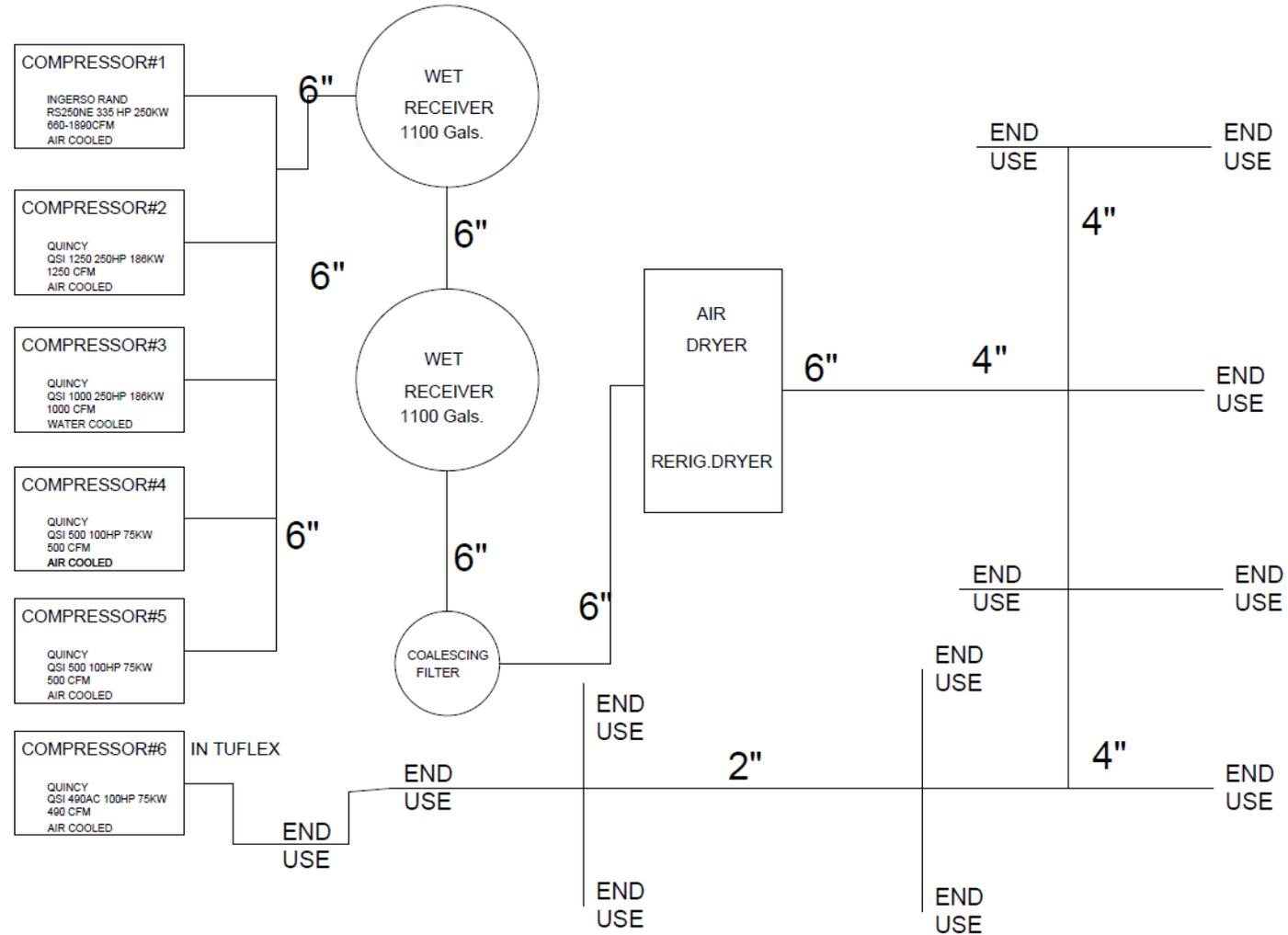
**Compressed Air Systems VINPLT:
Close out Presentation Example for
Last Online Training**



Company Name: FLEXCO FLOORS
Facility Name: FLEXCO MAIN PLANT
**Participant Name(s): Marcus Hyde, Steve
Opheim**



Block Diagram of the Compressed Air System



Savings Opportunities in Compressor Controls

Present Control system and problems

Our Air Compressor Control System was suppose to cycle on and off compressors as demand required. The system was purchased from Ingersoll Rand and their guy could never figure out how to tie in all the other compressors that were Quincy's.

System never worked correctly so Boiler Operator is in charge of manually turning on and off the compressor with demand requirements.

This works good for turning compressors on as required because he gets an alarm signal for low pressure. We use time of day experience to turn off the compressor that are not required for demand.

Savings Opportunities in Compressor Controls

We need to install an Automatic demand control system.

We need a system that can be setup and adjusted by our in-house technicians.

System that I believe would work best is to have the newest Ingersoll Variable Frequency Drive be the lead compressor. Once it reaches 100% Load for a given time and can not hold 90 psi. Other compressors need to be added. Turning on one of our 3 Quincy 100HP (4) valve stage compressor one at a time as compacity requires. The other Compressors in our system are only required for maintenance and emergency use.

Savings Opportunities in Pressure Setpoints

We currently run the compressors at what we have determined presently to be our lowest PSI possible for the majority of the Plant Operations. 90 PSI.

We do have (2) Machines that require higher pressure one for cutting hard rubber with a Air guillotine and one that lifts heavy rolls with a pneumatic manipulator. (Both of these operations have a small air amplifier that increases PSI. They are low usage and CFM requirement machines .)

Savings Opportunities in Compressed Air Distribution Systems

Our current Compressed Air Distribution system is Bad.
70 year old plant with lots of new systems without much
distribution system up-grading.

Larger Main Distribution Line should be installed
New Main Line should be something other than Carbon Steel
and be looped (feed from both ends) as possible.

Additional Dryer capacity would help for large demand times
and for maintenance of current Dryer.

Savings Opportunities in Compressed Air Users

- Minimize all compressed air usage.
- Use Cordless Leaf Blowers for areas that currently use compressed air for cleaning.
- Convert air Knife/nozzles systems to LP Air Blowers
- Convert some of our high cycling guillotine cutoff systems to servo motor electric driven units.

Tips Learned from this Training

- Use of Aluminum Pipe for compressed air. (had not thought of this as an option.)
- The importance of going large with main distribution header.
- How bad air motors are in efficiency vs. Electric Motors
- Leaks detection program importance.

Next Steps or Action Items after the Compressed Air VINPLT

- What are your next steps to implement opportunities?
 - Incorporate alternative methods other than compressed air in all projects.
- What are you planning to do after the VINPLT?
 - Update systems as funding is available.
 - Track and communicate compressed air usage/cost with the tools provided.
- Lessons learned?
 - Having all employees involved in compressed air conservation.
 - Proper system flow to accommodate the most efficient usage at reduced cost.