Better Plants
U.S. DEPARTMENT OF ENERGY

In-Plant Trainings

Session 6 – System Volume vs Storage

Homework from Last Session

Name: ___________________Amos Hunter__________________________

Company: ________________3M__________________________

In many cases, misapplication of compressed air at the end-use causes systems to perform poorly. Please fill out the information below:

1. What is the pressure going Into the main header?
   a. Pressure: ____100 nominal, 110 more frequently seen_________psig

2. What Is the end-use pressure required for typical applications In the plant?
   a. Pressure: ______100_____psig

3. List any applications that require higher than typical pressure:

Application	Approximate End-Use Pressure Required
________________________________	__________psig
________________________________	__________psig
________________________________	__________psig
________________________________	__________psig

4. List any applications that require lower than typical pressure:

Application	Approximate End-Use Pressure Required
_________air knives_____________	high volume flow______psig
___________air wands / guns_________	used for cleaning, blowing psig
________________________________	__________psig
________________________________	__________psig

5. List any applications where users complain about low pressure:

Application	Approximate End-Use Pressure Required
____________robotics (actuators, pick and place)	____psig
________________________________	__________psig
________________________________	__________psig
________________________________	__________psig

6. Have compressor setpoints been raised to try and compensate for low pressure at end-use applications? _____X_____Yes_______________No

   Comments:_______leaks are a known Issue, also the use of air knives may not be the best application

Name: _Sean Hammons

Company: Shaw Industries__

In many cases, misapplication of compressed air at the end-use causes systems to perform poorly.

Please fill out the information below based on your own compressed air system.

1. What is the pressure going into the main header?
   a. Pressure: __170__psig

2. What Is the end-use pressure required for typical applications in the plant?
   a. Pressure: _120 psig

3. List any applications that require higher than typical pressure:

Application	Approximate End-Use Pressure Required
__Air entanglement jet tac __________	___120_ _psig
_ _________	___ _____psig
______________________________	__________psig
______________________________	__________psig

4. List any applications that require lower than typical pressure:

Application	Approximate End-Use Pressure Required
______________________________	__________psig
______________________________	__________psig
______________________________	__________psig
______________________________	__________psig

Application	Approximate End-Use Pressure Required
______Air tac ______________	___120 ___psig
______________________________	__________psig
______________________________	__________psig
______________________________	__________psig

6. Have compressor setpoints been raised to try and compensate for low pressure at end-use applications? ___X___Yes_______________No

   Comments:_____Upon reviewing the process requirements, I think an investigation on the losses in the machine may be contributing to the need for the higher pressures.___________________________

Name: _____Igor Ryabov___________________________________

Company: ___P&G_______________________________________

In many cases, misapplication of compressed air at the end-use causes systems to perform poorly.

Please fill out the information below based on your own compressed air system.

1. What is the pressure going into the main header?
   a. Pressure: _____90______psig

2. What Is the end-use pressure required for typical applications in the plant?
   a. Pressure: _____80______psig

3. List any applications that require higher than typical pressure:

Application	Approximate End-Use Pressure Required
__Reject station__________________	____87____psig
__Crimp roll load pressure__________	____87_____psig
______________________________	__________psig
______________________________	__________psig

4. List any applications that require lower than typical pressure:

Application	Approximate End-Use Pressure Required
_____Online printing roll pressure __	___22___psig
_____Pneumatic cylinder pressure___	____54___psig
_____Control system pressure______	____62___ psig
_______Glue application___________	_____65___psig

5. List any applications where users complain about low pressure:

Application	Approximate End-Use Pressure Required
___Reject station__________________	___90_____psig
______________________________	__________psig
______________________________	__________psig
______________________________	__________psig

6. Have compressor setpoints been raised to try and compensate for low pressure at end-use applications?   No

   Comments: ____No complaints currently.

   ____

Name: Rob Barrier

Company: 9/7/2022

In many cases, misapplication of compressed air at the end-use causes systems to perform poorly.

Please fill out the information below based on your own compressed air system.

1. What is the pressure going into the main header?
   a. Pressure: 106 psig

2. What Is the end-use pressure required for typical applications in the plant?
   a. Pressure: 80-90 psig

3. List any applications that require higher than typical pressure:

Application	Approximate End-Use Pressure Required
NONE	______ psig
	______ psig
	______ psig
	______ psig

4. List any applications that require lower than typical pressure:

Application	Approximate End-Use Pressure Required
Flexflow Conveyors	40-45 psig
Bump-Turn Conveyors	40-45 psig
Rotary Bottle Filler	65 psig
Glue Pots	30 psig

5. List any applications where users complain about low pressure:

Application	Approximate End-Use Pressure Required
Robotic Palletizer	80 psig
	______ psig
	______ psig
	______ psig

6. Have compressor setpoints been raised to try and compensate for low pressure at end-use applications? X Yes ______ No

   Comments: Recently, a downstream receiver/buffer tank has been installed accommodate late of air pressure In one critical production zone of the factory.

Compressed Air Systems VINPLT Homework

Session 5

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BETTER PLANTS

Name: Gary Baker

Company: Mitsubishi Electric

In many cases, misapplication of compressed air at the end-use causes systems to perform poorly.

Please fill out the information below based on your own compressed air system.

1. What is the pressure going into the main header?
   a. Pressure: 96/101 psig

2. What is the end-use pressure required for typical applications in the plant?
   a. Pressure: 85ish psig

3. List any applications that require higher than typical pressure:

Application	Approximate End-Use Pressure Required
Wastewater	120 psig own compressor
	psig
	psig
	psig

4. List any applications that require lower than typical pressure:

Application	Approximate End-Use Pressure Required
Stapler	65 psig
Starter1 Main	82 psig
Starter Assy	83 psig
Starter2 Main	79 psig

5. List any applications where users complain about low pressure:

Application	Approximate End-Use Pressure Required
	psig
	psig
	psig
	psig

6. Have compressor setpoints been raised to try and compensate for low pressure at end-use applications? ✓ Yes ____ No

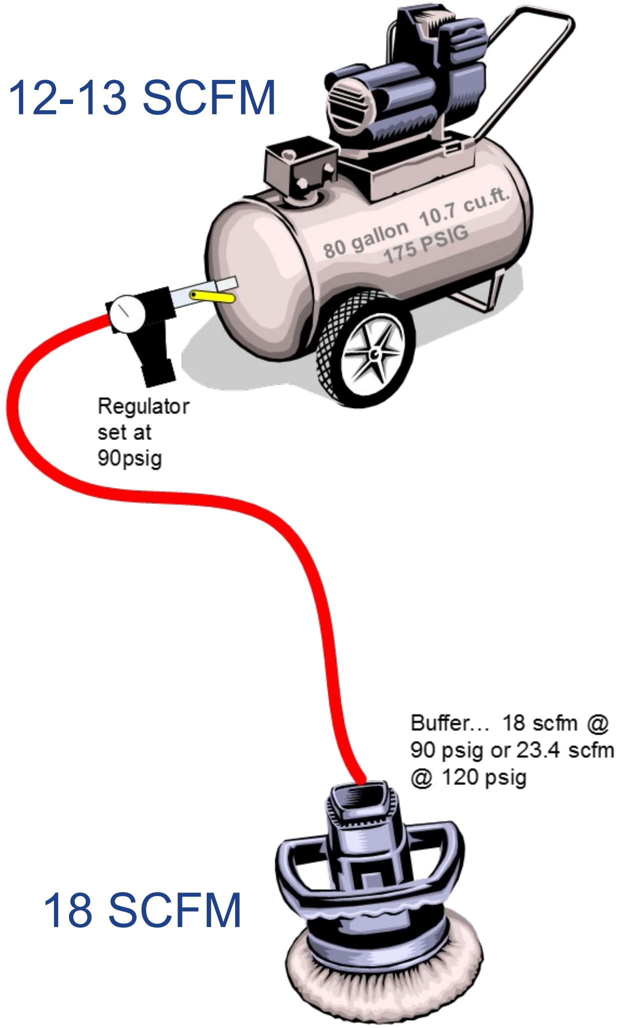
Comments: Japanese want a buffer + some loss from leaks. Working to fix leaks.

Session 6

System Volume vs Storage

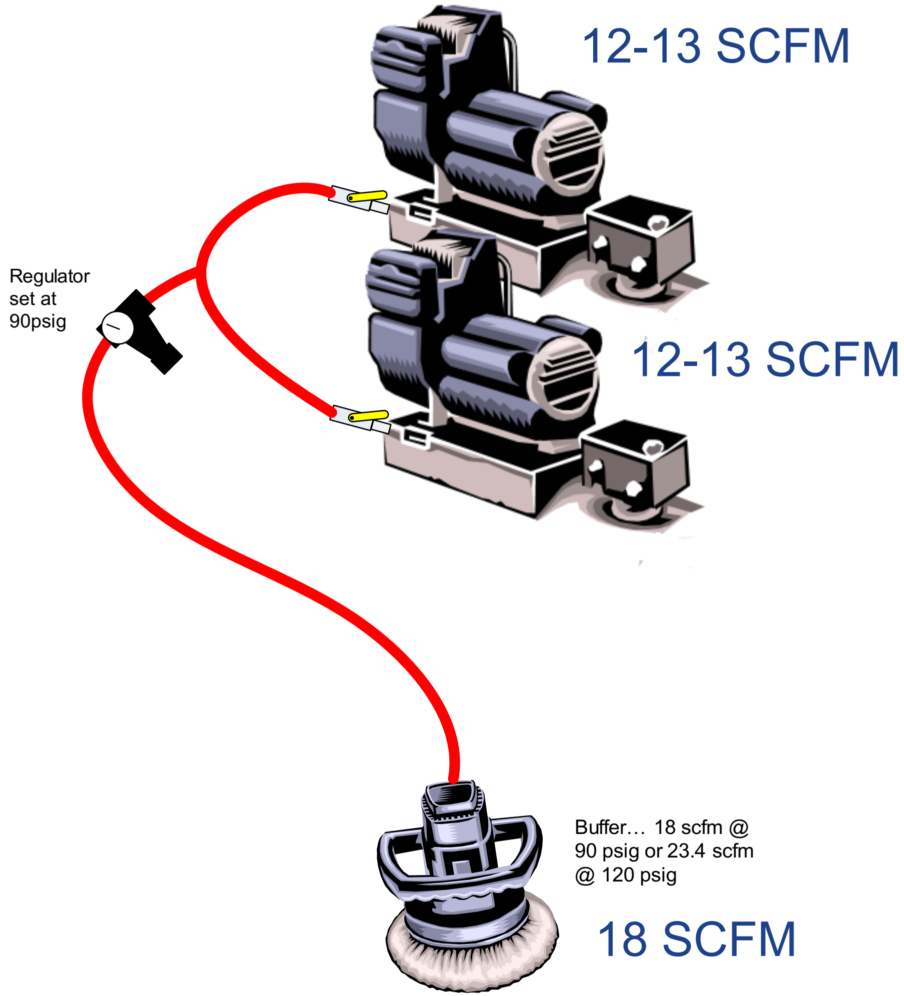
A Simple Example

- 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

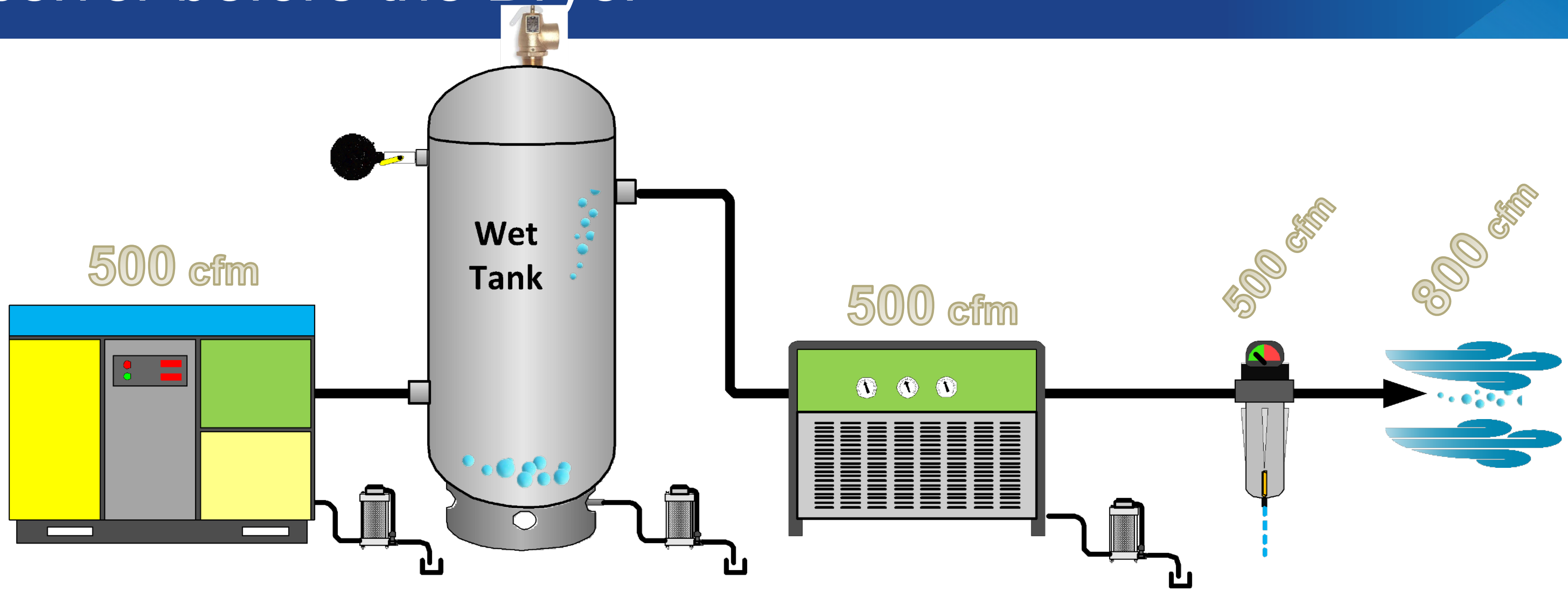
- With no receiver, the painter must install a second 5 hp compressor and therefore use twice the energy as before



Where Does it 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

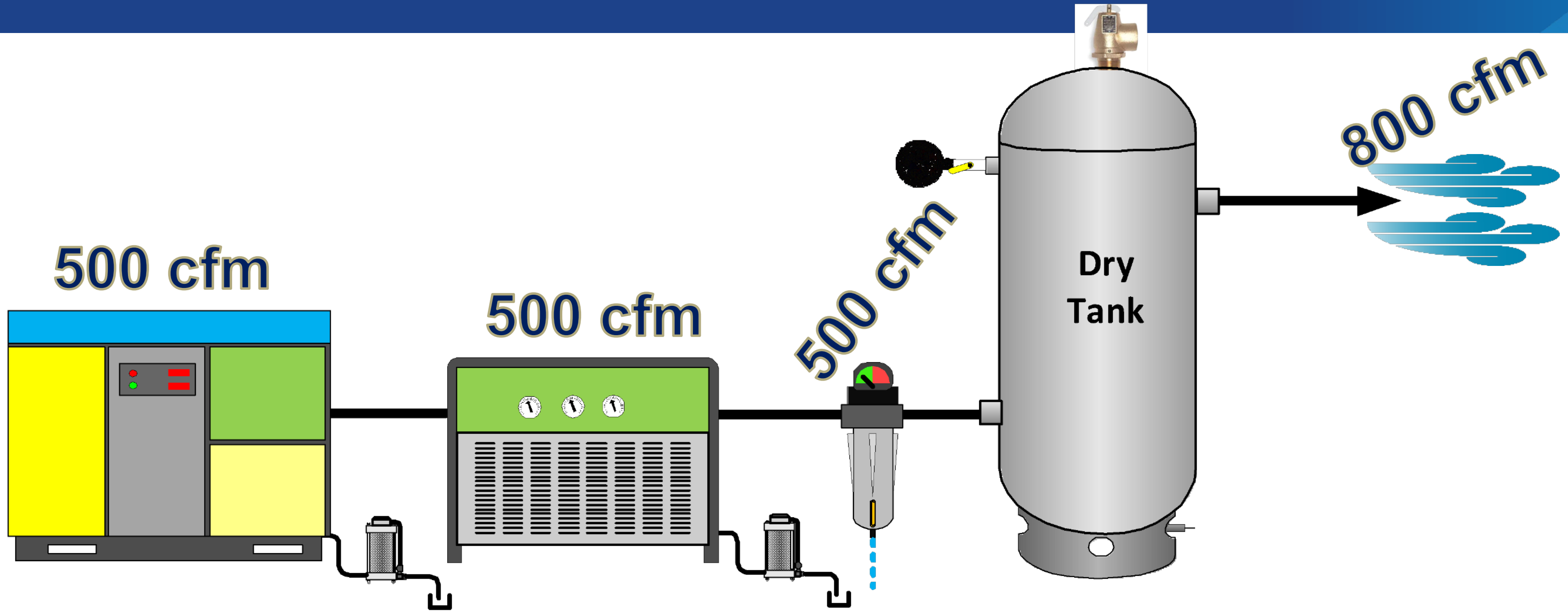


- A Wet Receiver creates radiant cooling and drops out some of the condensate and entrained oil, thus benefiting the dryer.
- However, the receiver will be filled with saturated air, and if there is a sudden demand that exceeds the capacity rating of the compressor and matching dryer, the dryer can be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

Where Does it Go?

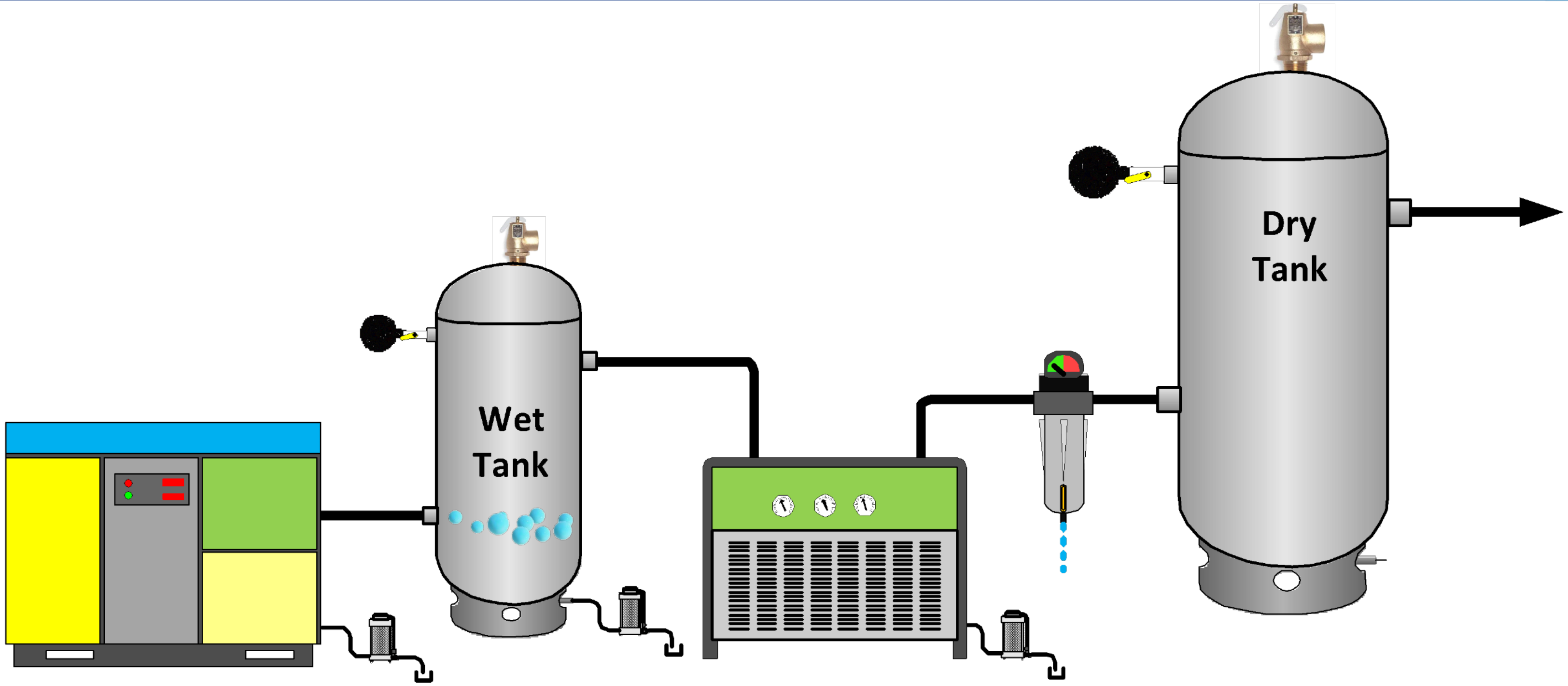
- Dry Receivers: Dry receivers are located immediately downstream of dryers and filters.
- When sudden large air demands occur, dry air receivers should have adequate capacity to minimize a drop in system air pressure.

Dry Receiver after the Dryer



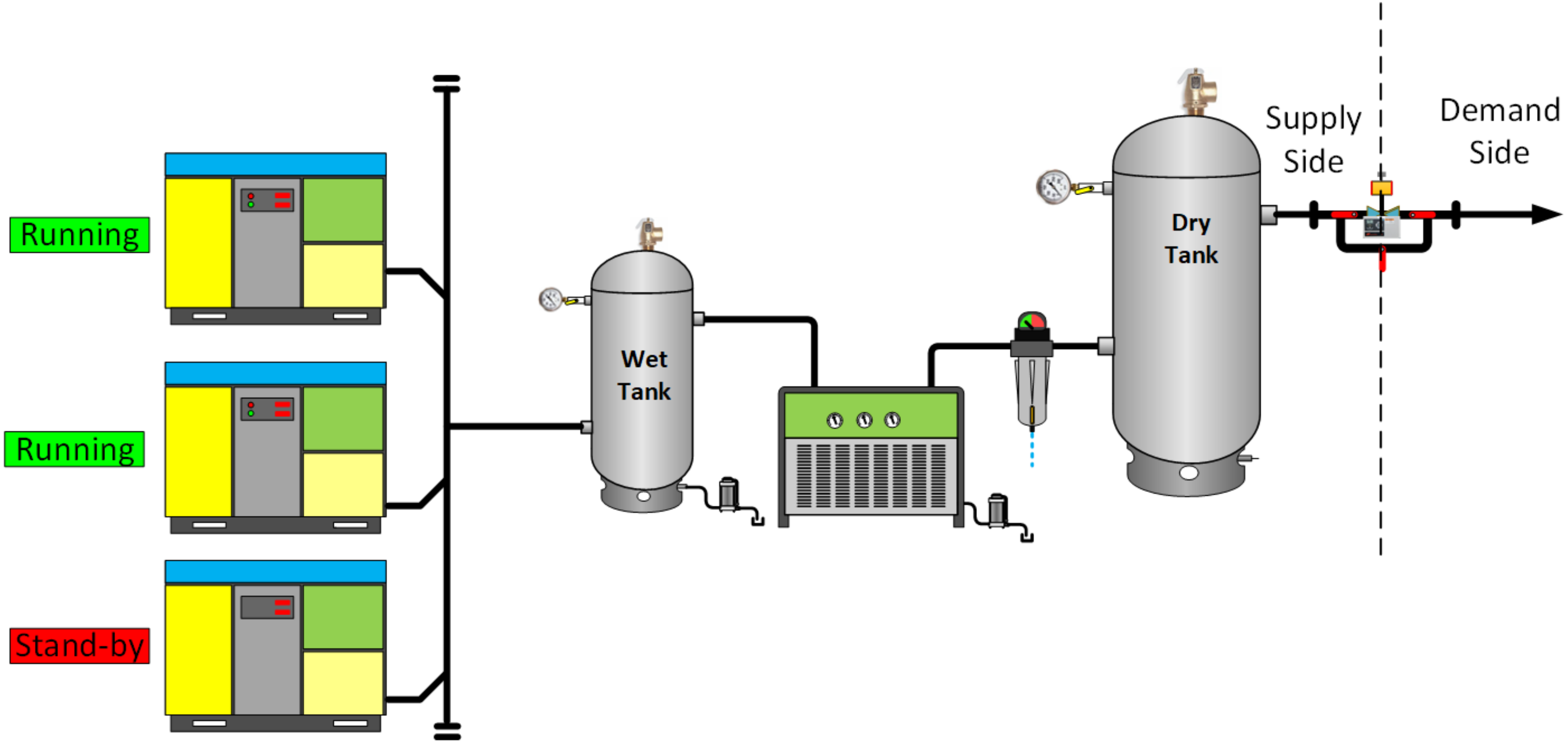
- The receiver is filled with compressed air which has been cleaned and dried.
- A sudden demand in excess of the compressor and dryer capacity rating will be met with dried air.

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.

Best Practice with Pressure Flow Controller



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

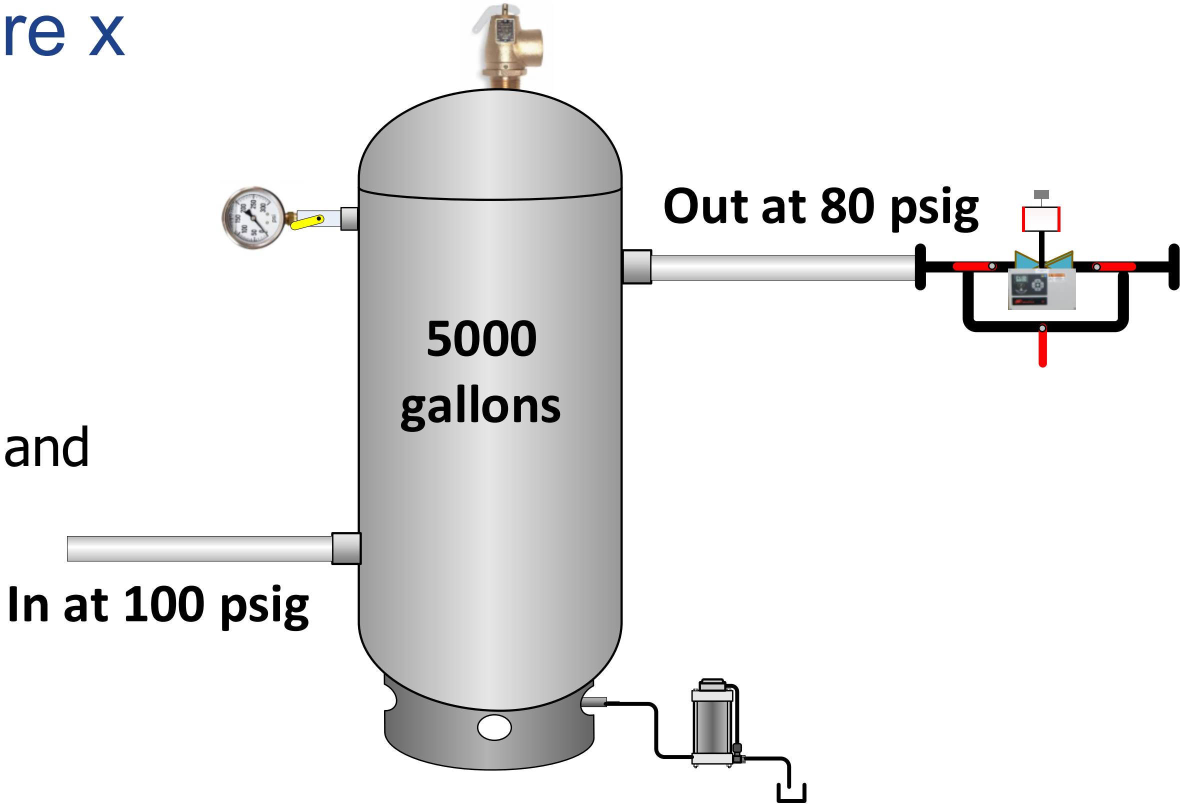
What is the usable (useful) storage?

5000 gallons / 7.48 gal/cuft =668.5 cubic feet

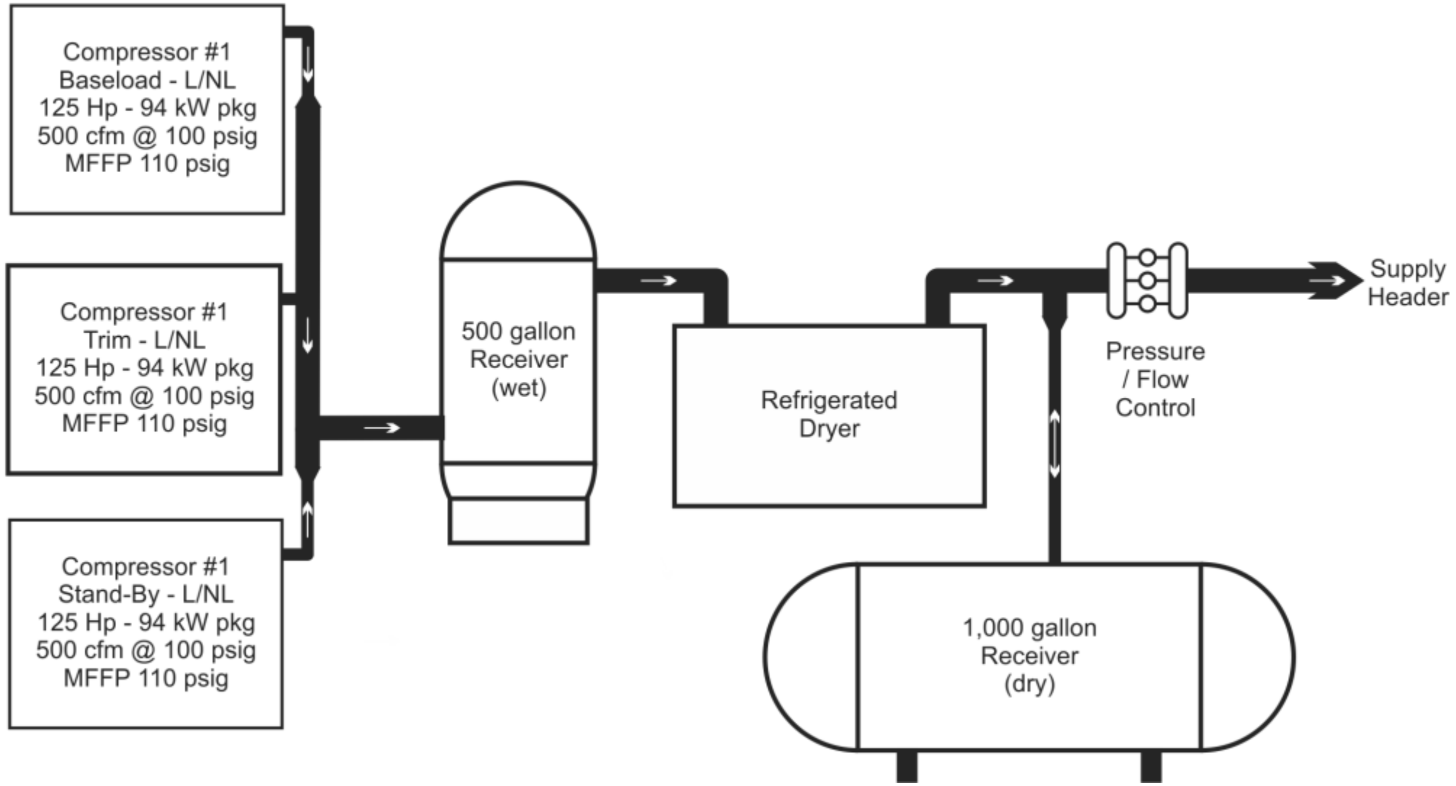
668.5 cuft / 14.5 psia = **46.1 cuft /psia**

46.1 cuft /psia x 20 psia =

= 922 cuft of usable storage

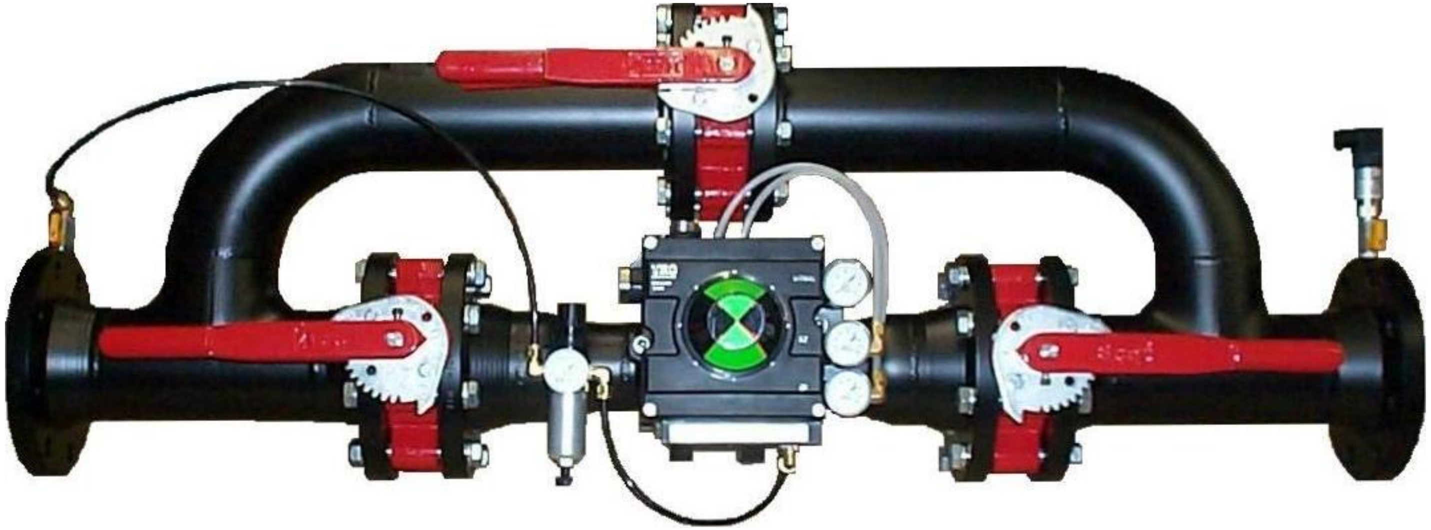


Pressure/Flow Controllers



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

Pressure/Flow Controllers



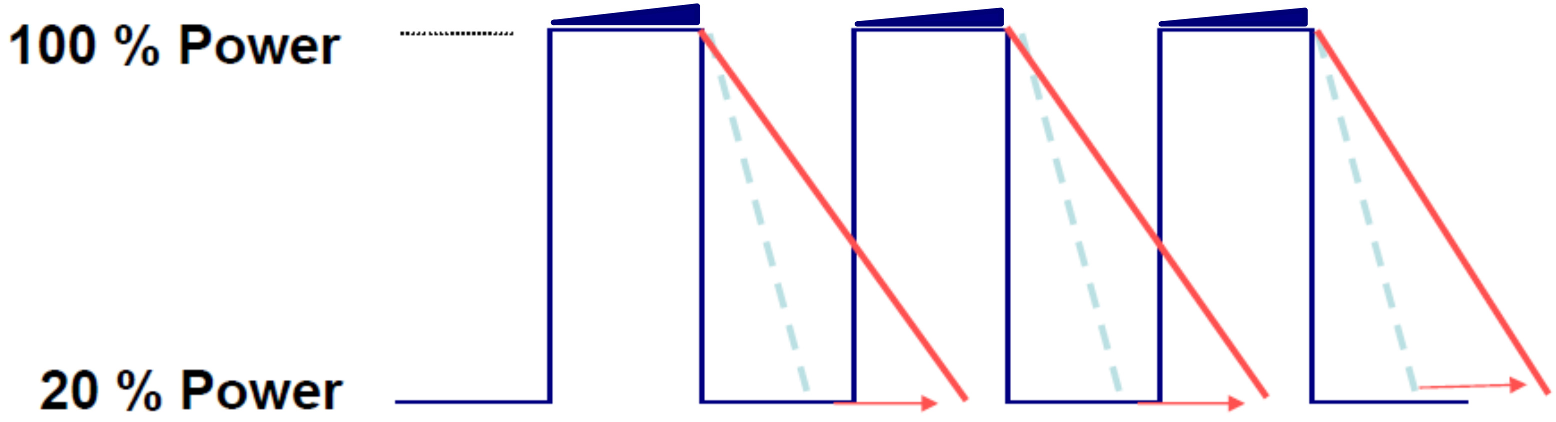
What Size?

- 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.

What Size?

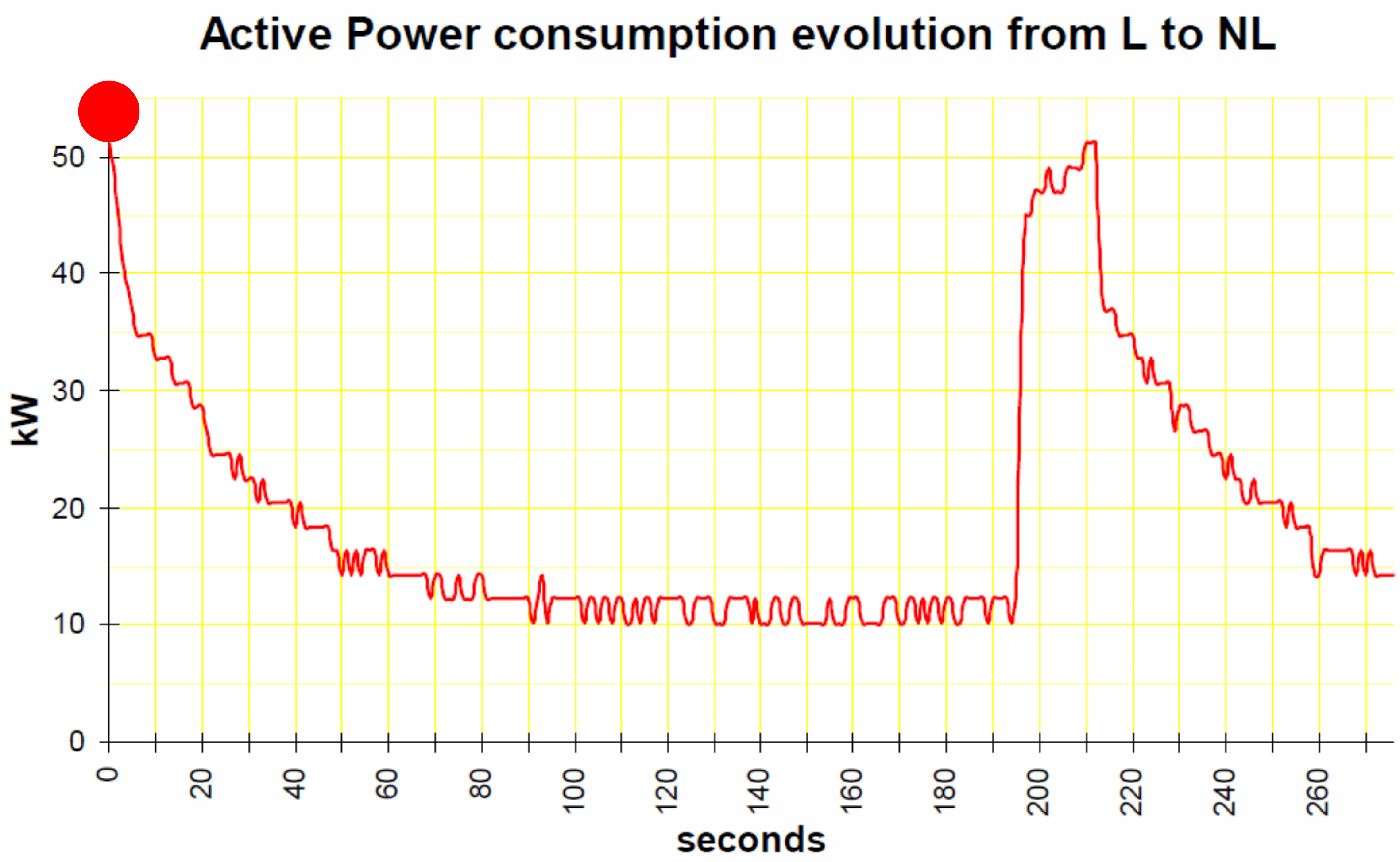
- Some oil injected rotary screw compressors are sold with load/unload capacity control, which is claimed to be the most efficient.
- This also can be misleading, since an adequate receiver volume is essential to obtain any real savings in energy.
- Some rules of thumb established many years ago for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

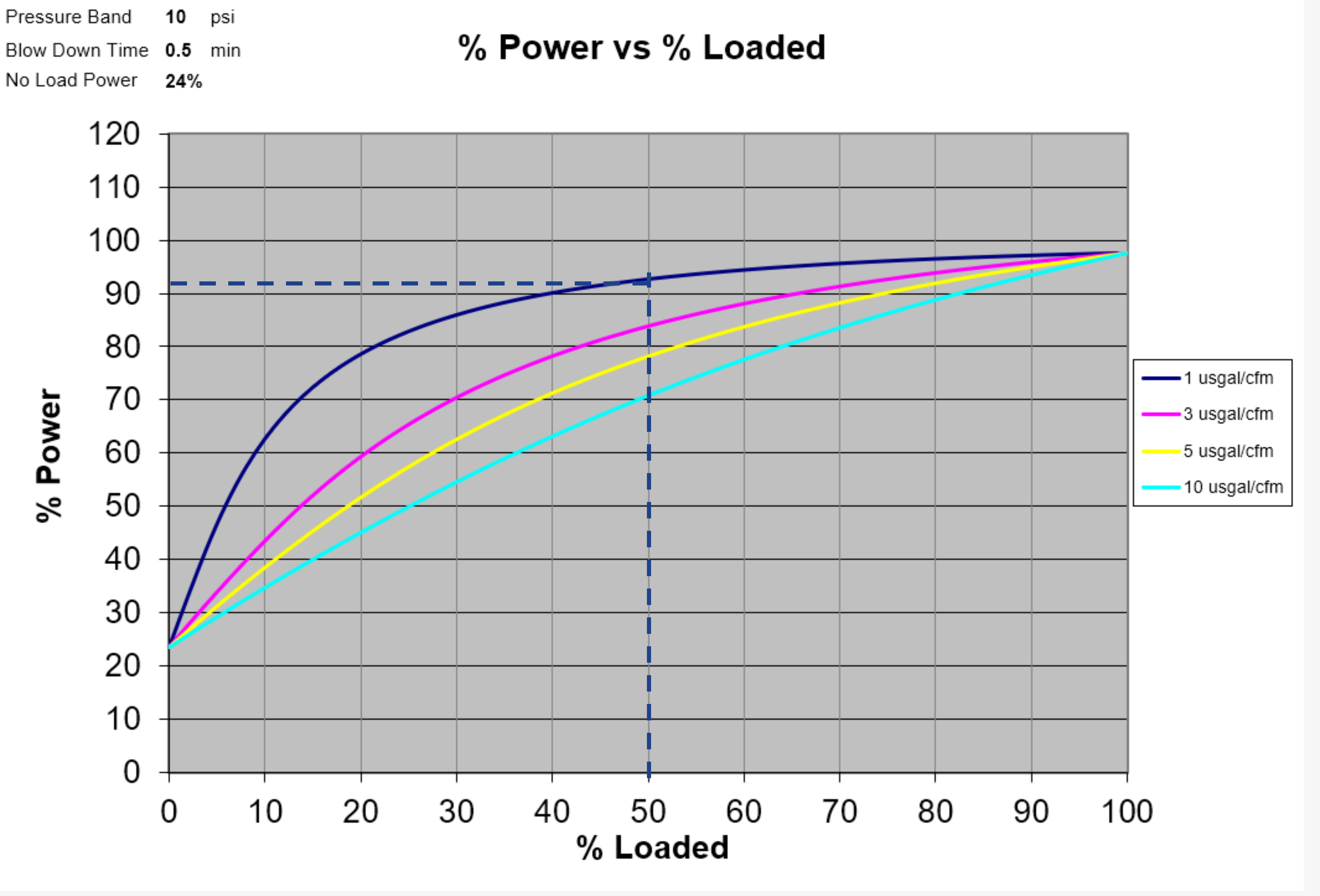
Capacity Control by Load/No-Load



- 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

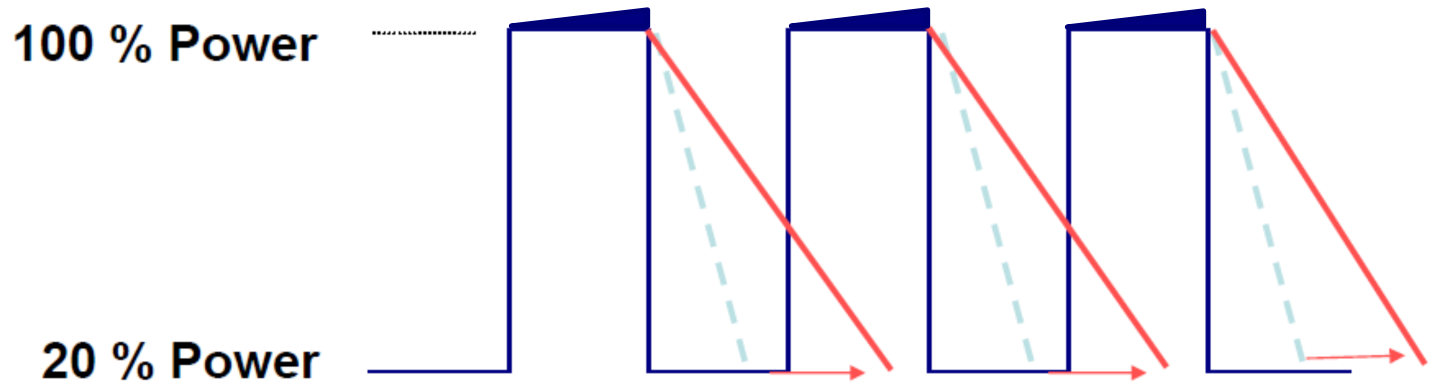



Pressure Band 10 psi
Blow Down Time 0.5 min
No Load Power 24%
% Power vs % Loaded
% Power
% Loaded
0
10
20
30
40
50
60
70
80
90
100
110
120
1 usgal/cfm
3 usgal/cfm
5 usgal/cfm
10 usgal/cfm

What Size For Variable Speed Compressors?

- For variable speed compressors the receiver size can be smaller.
- 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.

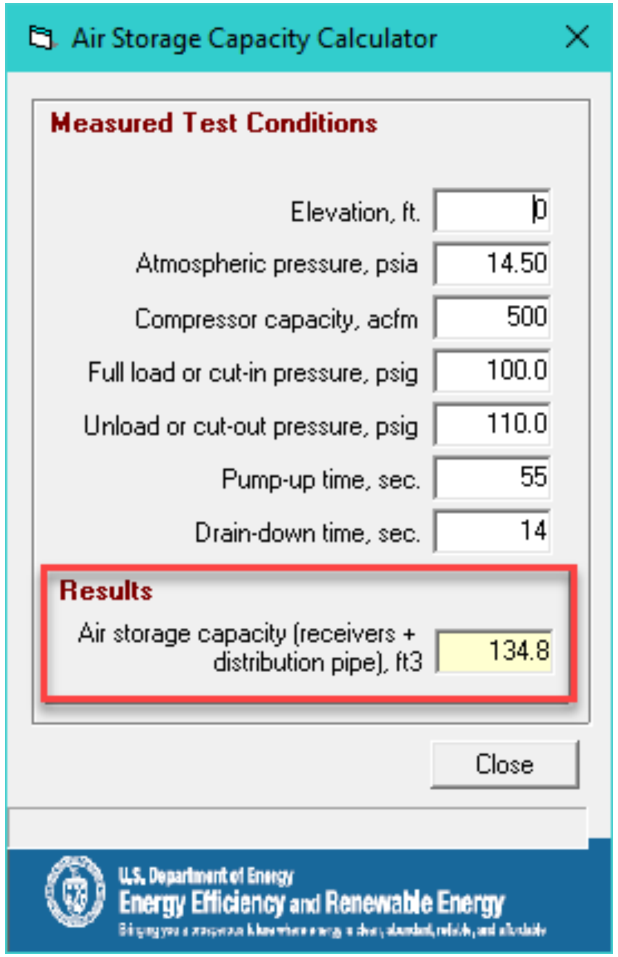
What Size For Oil Free Compressors?



- 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.

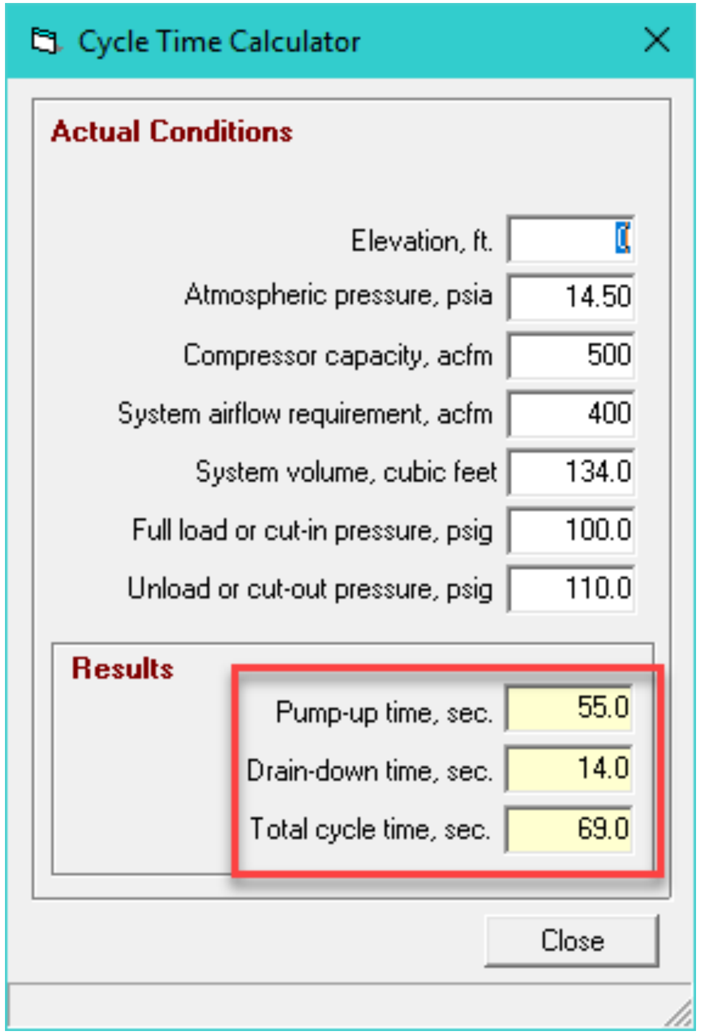
How do you determine "Effective" Volume?

- Using one of the calculators from Airmaster+ software :
- During a period of constant air demand, the cycle time can be used to determine the effective volume
- A 100 hp 500 acfm compressor operating at 80% load with a 55 second load time and 14 second unload time equates to an effective volume of 134.8 cubic feet
- 134 cuft = 1000 gal



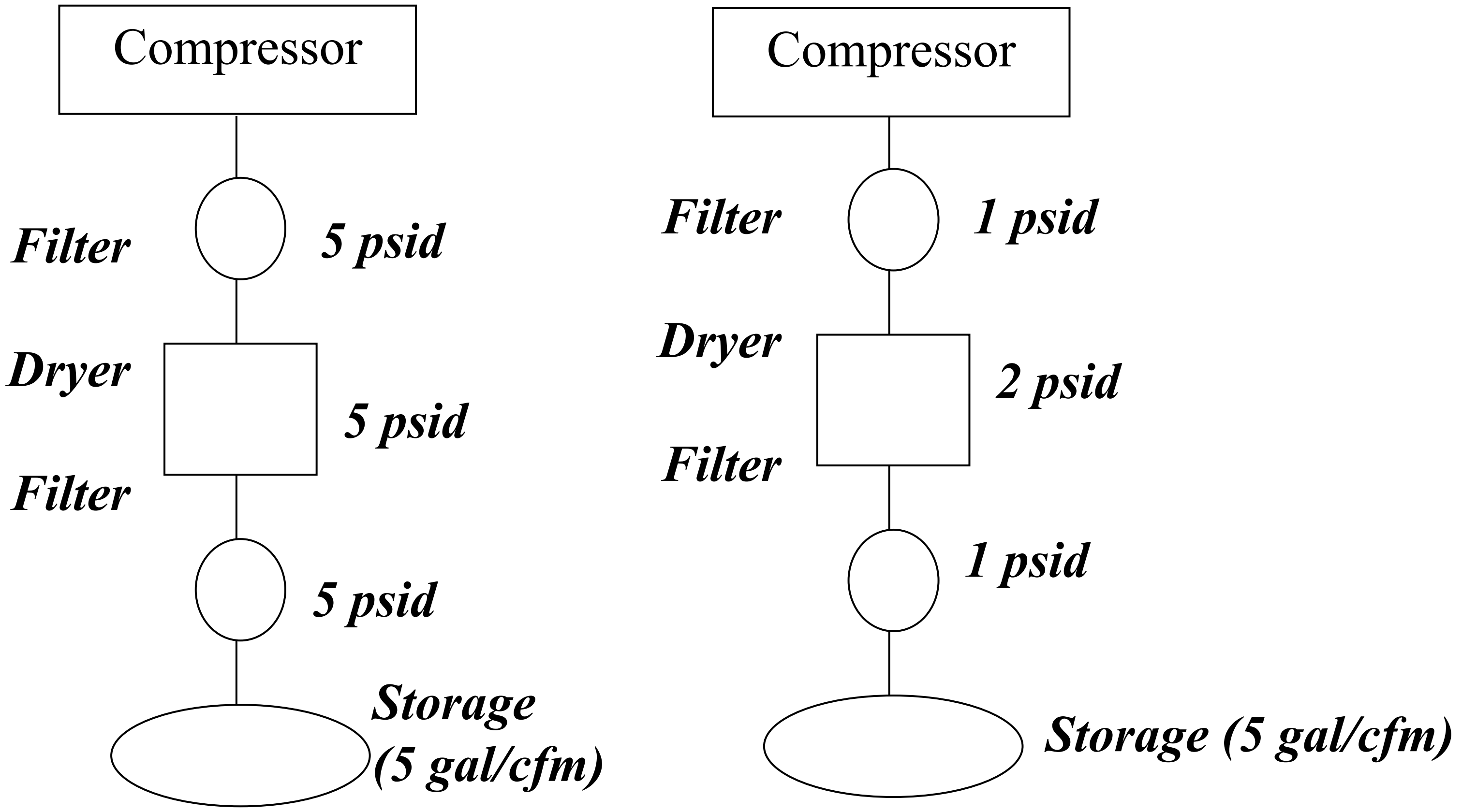
How do you determine cycle time?

- Using one of the calculators from Airmaster+ software :
- A 100 hp 500 acfm compressor operating at 80% load (400/500) with volume at 2 gal per cfm will have a 69 second cycle time
- 134 cuft = 1000 gal



Effectiveness of Storage

Compressor has a 10 psig Control Band

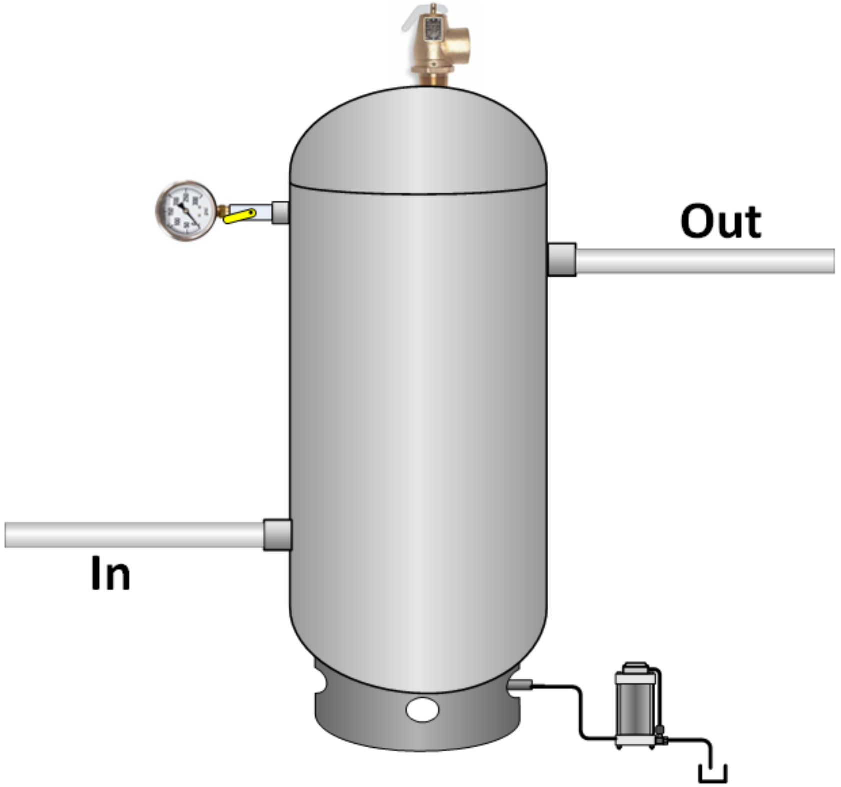


Some Best Practice Recommendations:

- 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

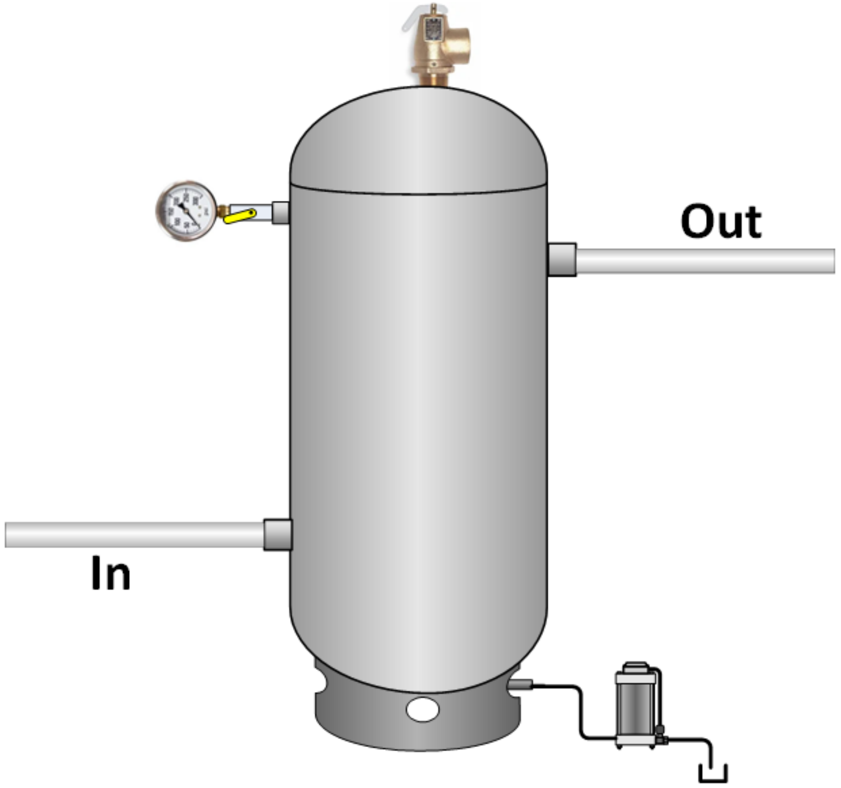
Some Best Practice Recommendations:

- 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

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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

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

- 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 P2 back to P1
- Pa = Absolute atmospheric pressure (psia)
- P1 = Initial receiver pressure
- P2 = 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.

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

176.4 x 7.48 gal/cu.ft. = 1319.5 gallons

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

1548 gallons ÷ 7.48 gal/cu.ft. =207 cu.ft.

Example Using MEASUR

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**

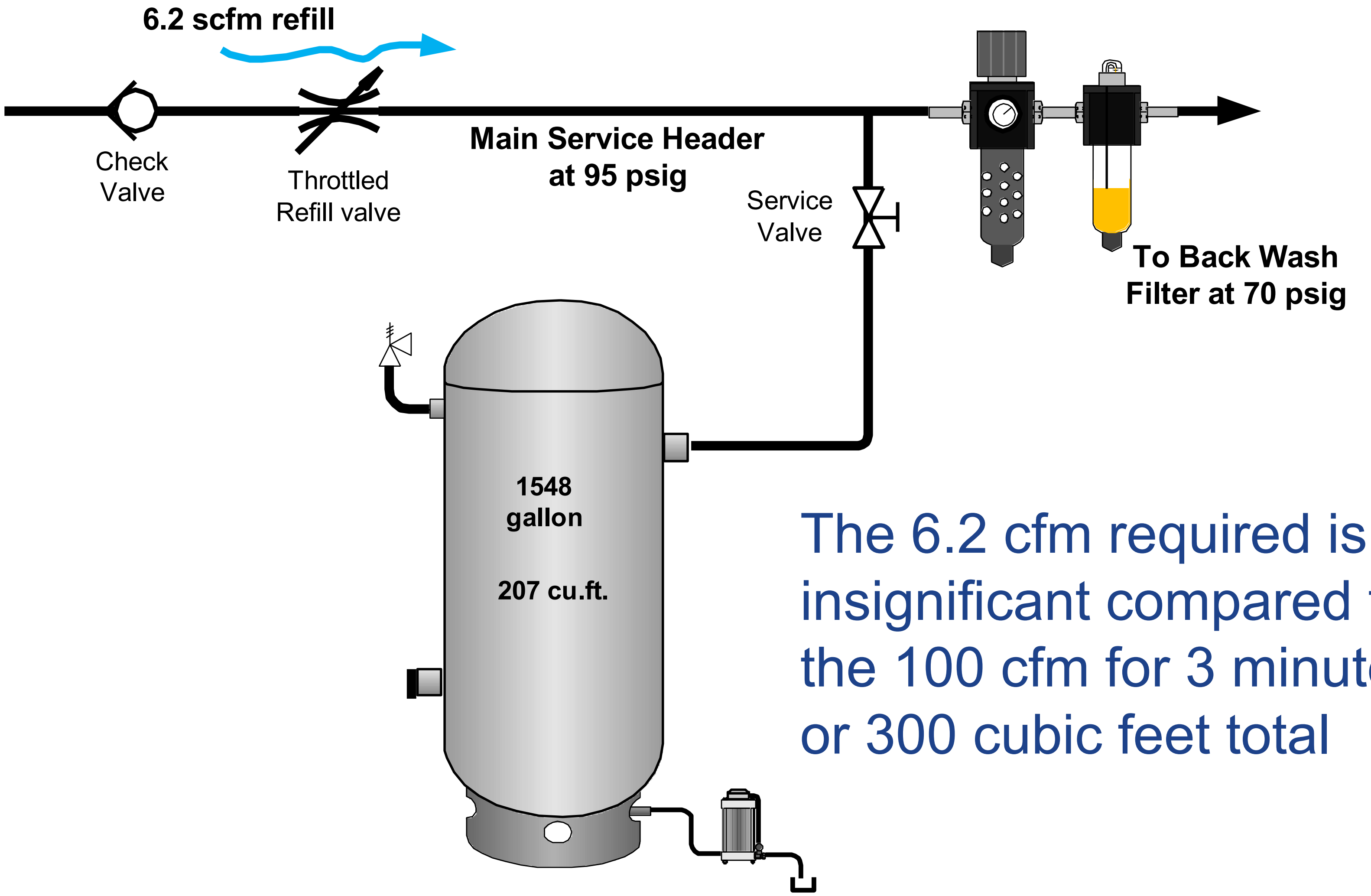
Generate Example | Reset Data

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.

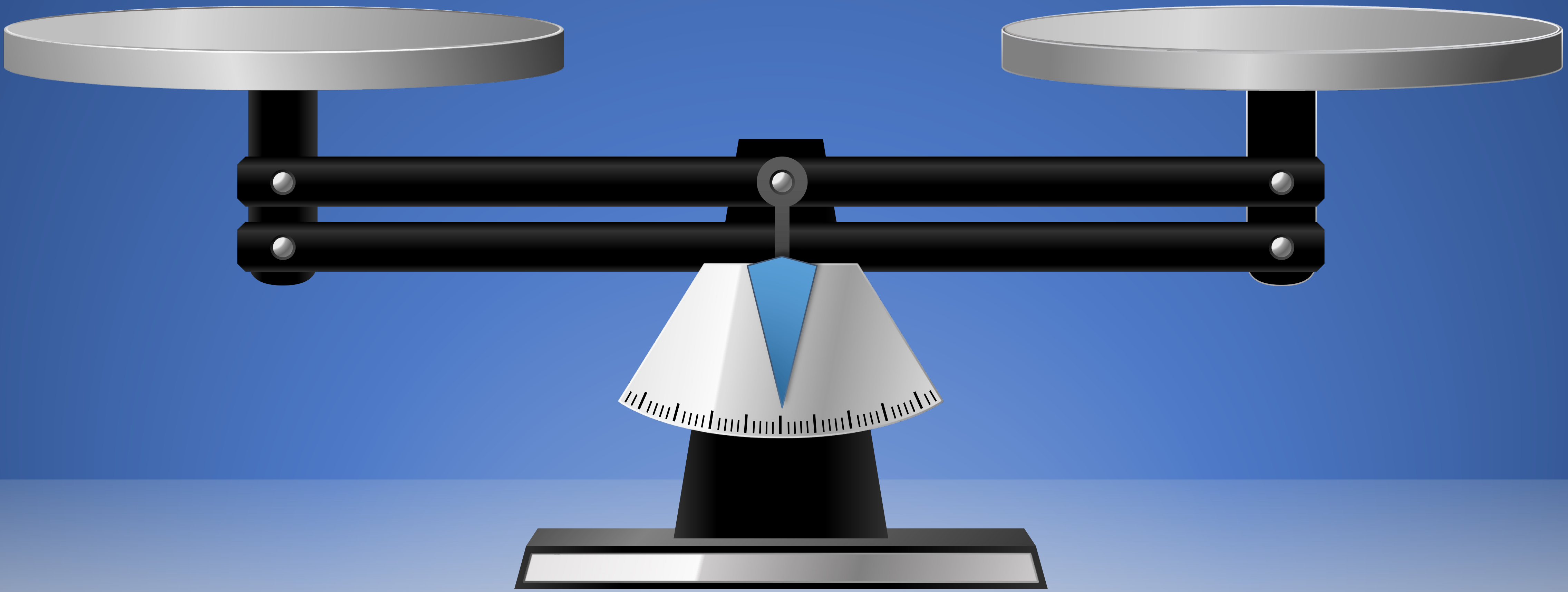
$$Solving\ For\ S = \frac{Vx(P_1 - P_2)}{T \times 14.7} \qquad S = \frac{207 \times (25)}{57 \times 14.7} = 6.2\ CFM$$

Example

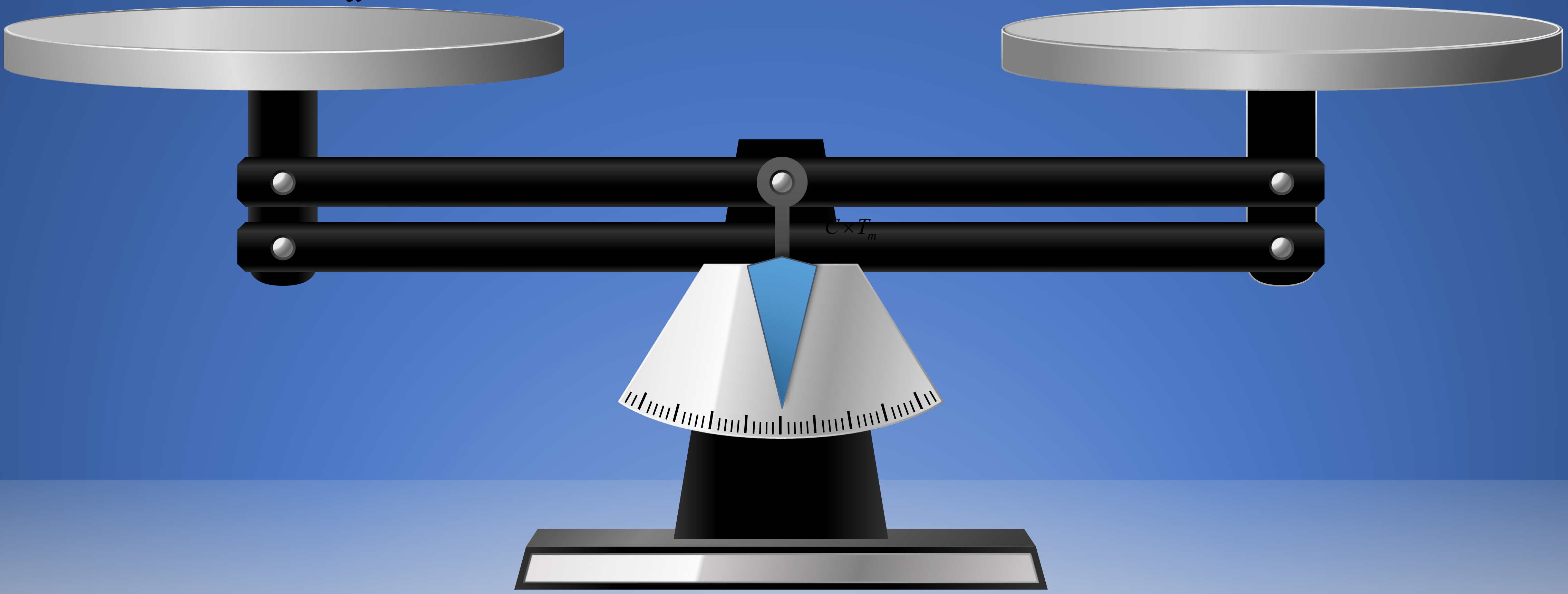


The 6.2 cfm required is insignificant compared to the 100 cfm for 3 minutes or 300 cubic feet total

Another way of looking at this Back Wash Filter Problem

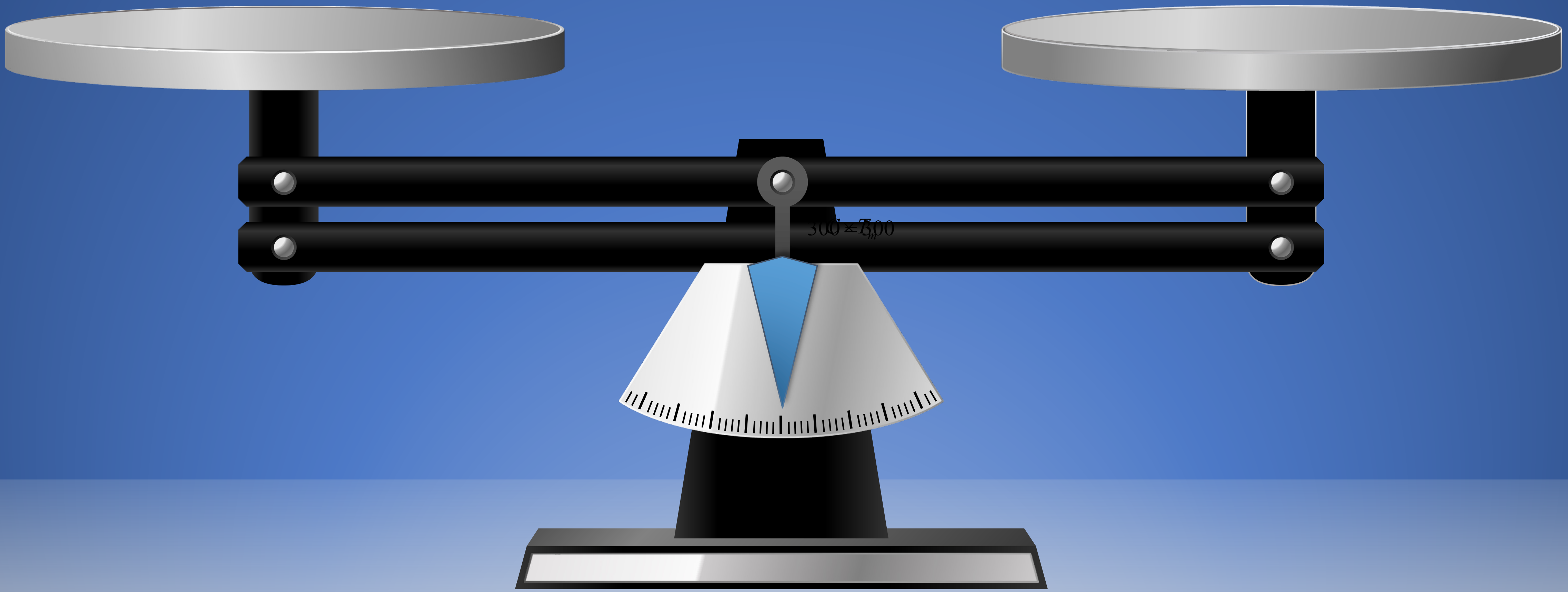


$$V_{cf} \times \frac{\Delta P}{P_a} = C \times T_m$$



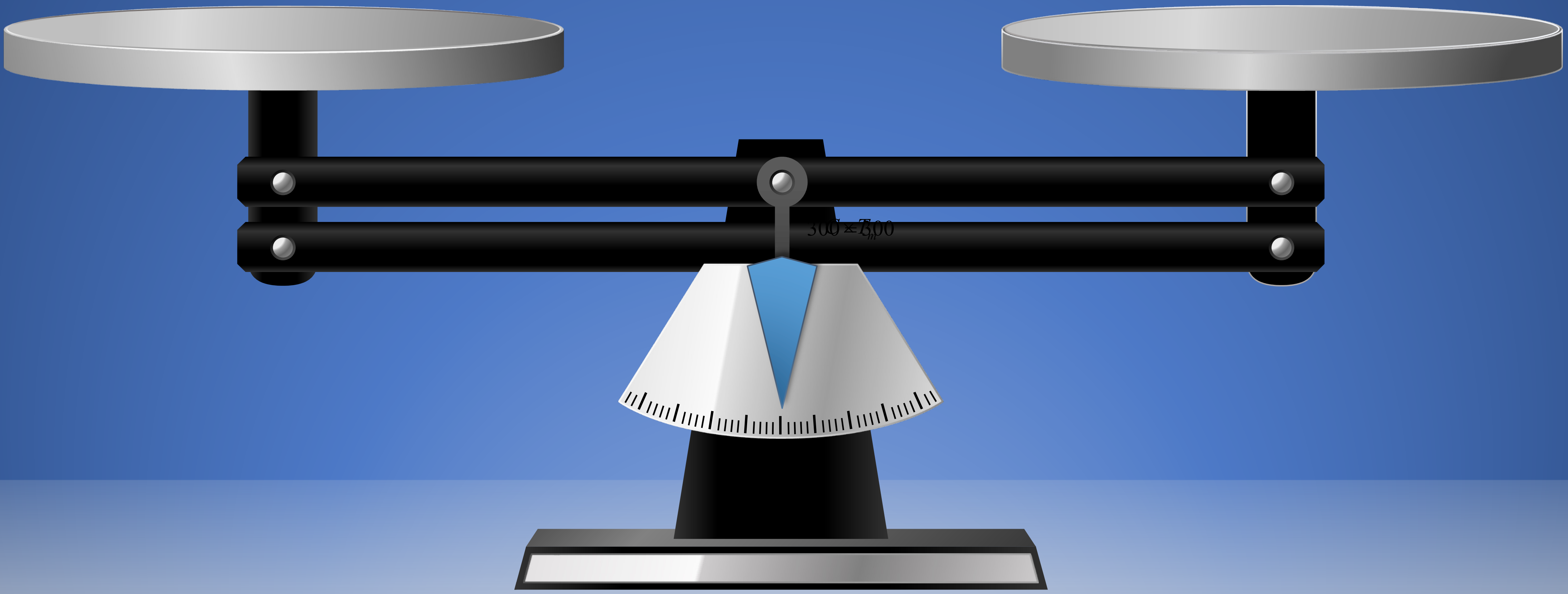
Supply = Demand

$$V_{cf} \times \frac{25}{14.7} = 100 \times 3$$



Supply = Demand

300 = 300



Supply = Demand

Example of Local Storage for Critical End Use Pressure

Example of Local Storage

Pneumatic Capacitance

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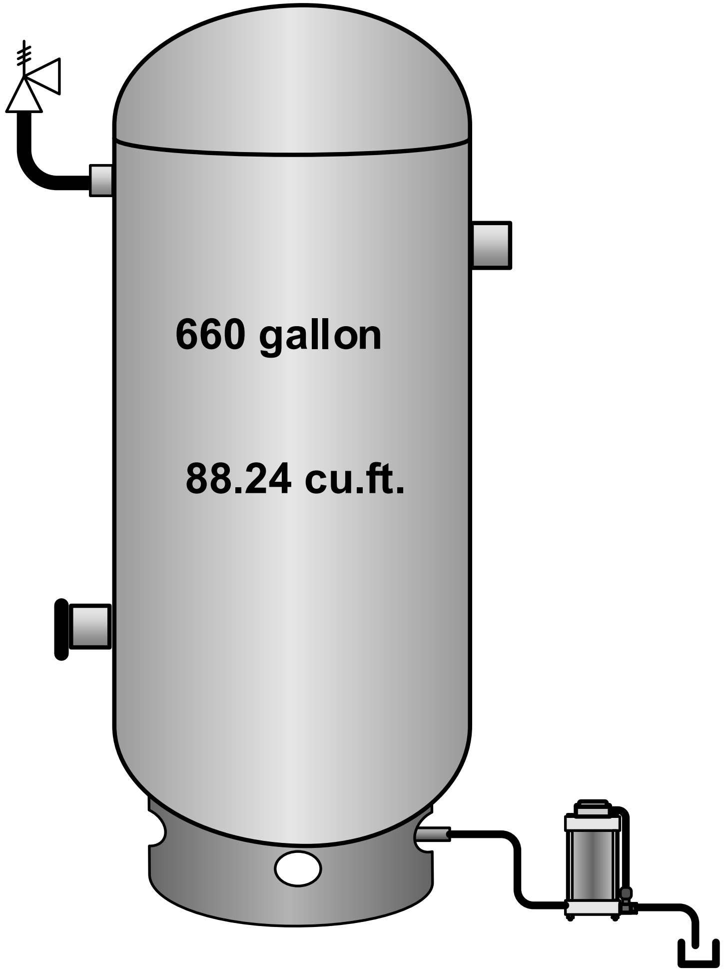
Storage or Volume

- 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.

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

System Drawdown

Three different methods could be used to calculate:

#1 Capacitance:

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

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

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 cu ft/se**c and capacitance = 200/14.7 = **13.6 cuft /psi**

5 cuft/sec ÷ 13.6 cu ft/psi = .367 psi/sec x 25 sec = **9 psig drawdown**

System Drawdown

Three different methods could be used to calculate:

#2 Receiver calc:

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

Draw down rate = solve for ΔP

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

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?

200 cu ft = ((25/60) x (300 cfm) x 14.7)) ÷ ΔP

ΔP = (.416min x 300 x 14.7) ÷ 200 cuft = **9 psig**

System Drawdown

Three different methods could be used to calculate:

#3 Supply = Demand:

Draw down rate = solve for ΔP

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

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?

200 cu ft X (Δp/14.7) = 300cfm x 25/60

ΔP = 9 psig

System Drawdown

- A demand event results in a 200 scfm airflow rate being supplied from the system's air storage volume which is 1,000 gallons. What is the pressure drawdown rate in psi/sec that will result?

System Drawdown

- Answer

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

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

$$DrawDownRate = .37\, psi / \sec$$

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

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

Receiver Sizing

- 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

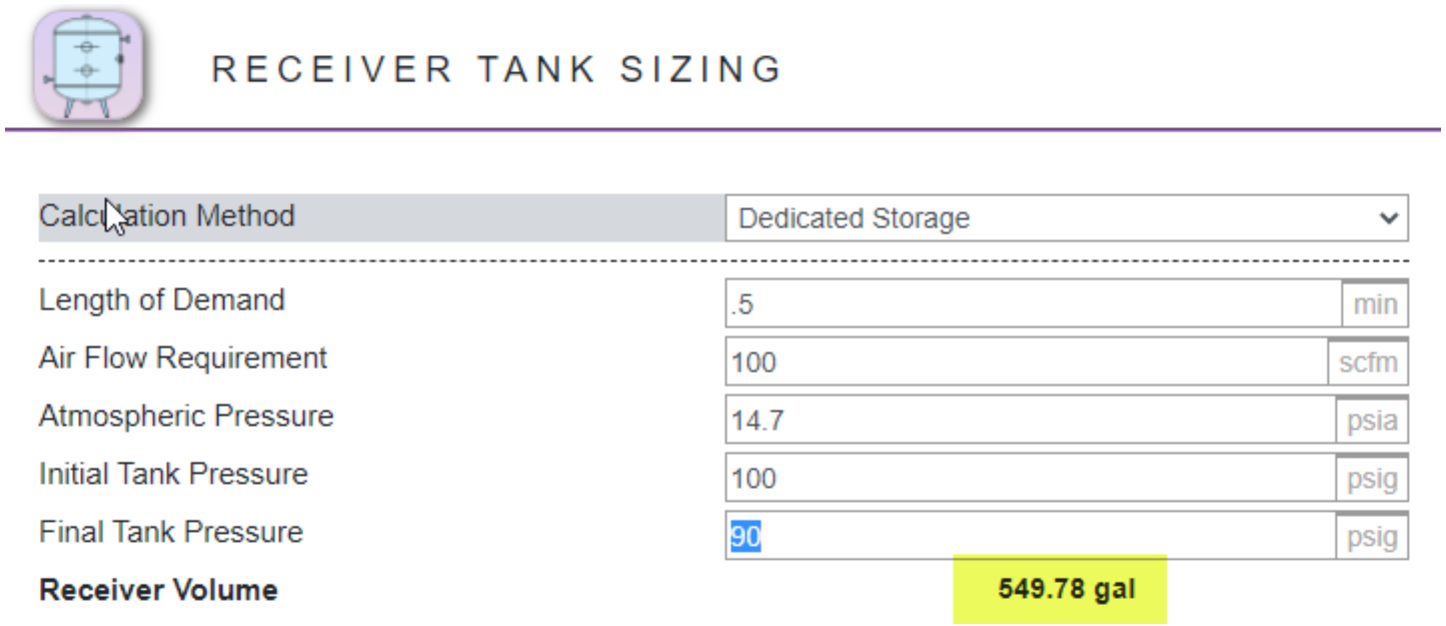
- Answer

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

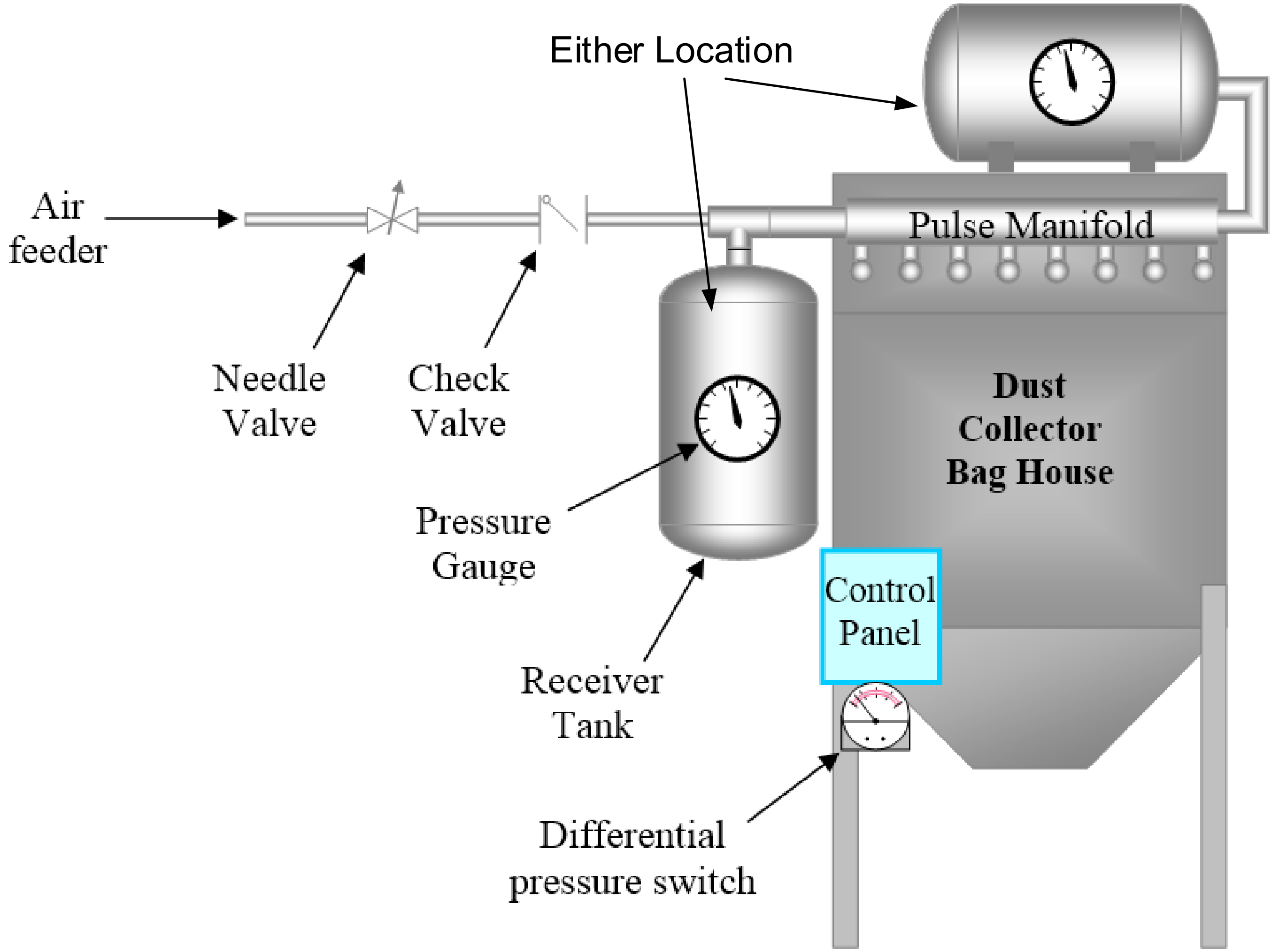
$$V_{cf} = \frac{.5 \times (100) \times 14.7}{10}$$

$$V_{cf} = 73.5$$

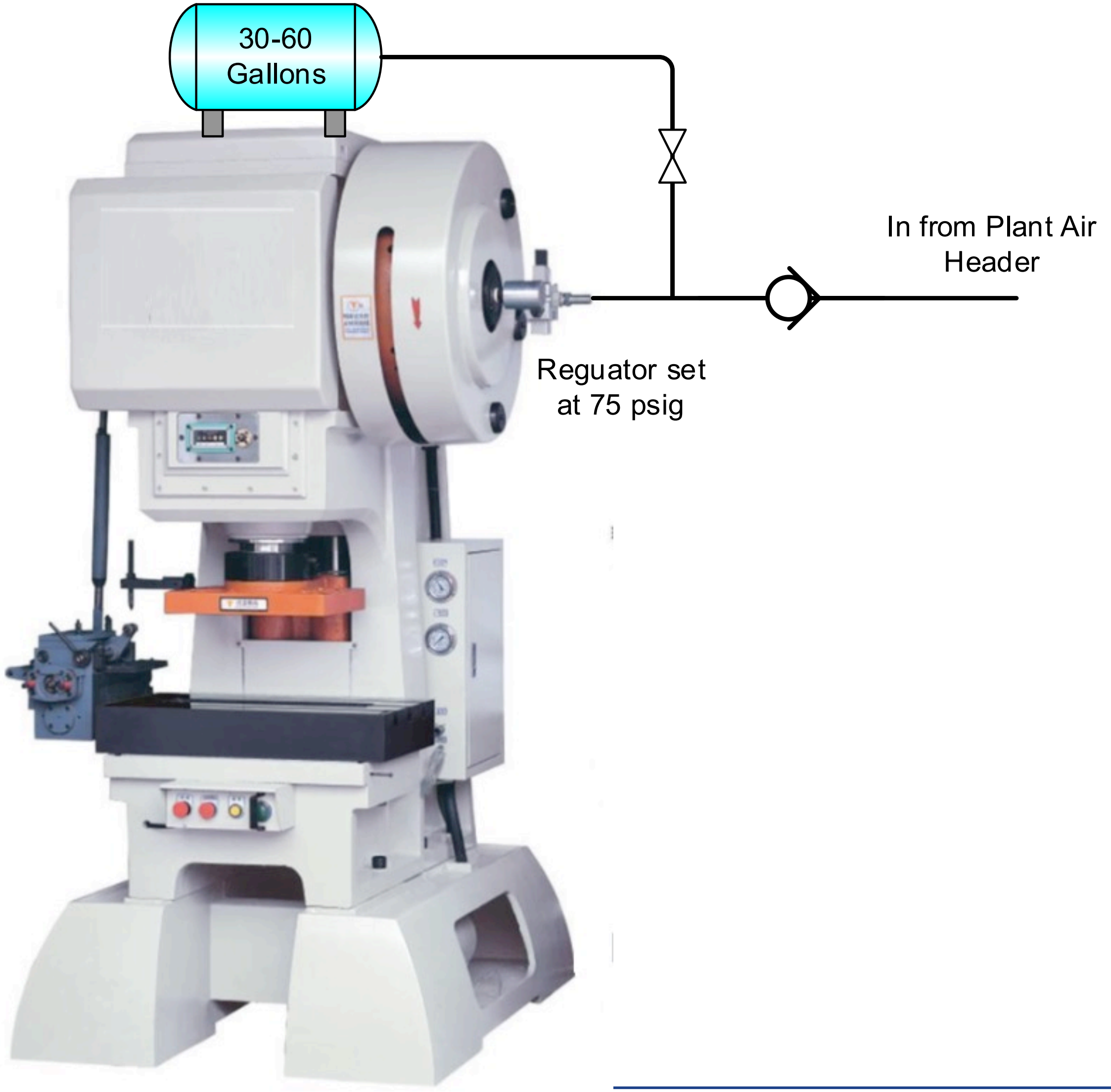
$$V_{gal} = 73.5_{cf} \times 7.48_{galcf} = 549.78_{gal}$$



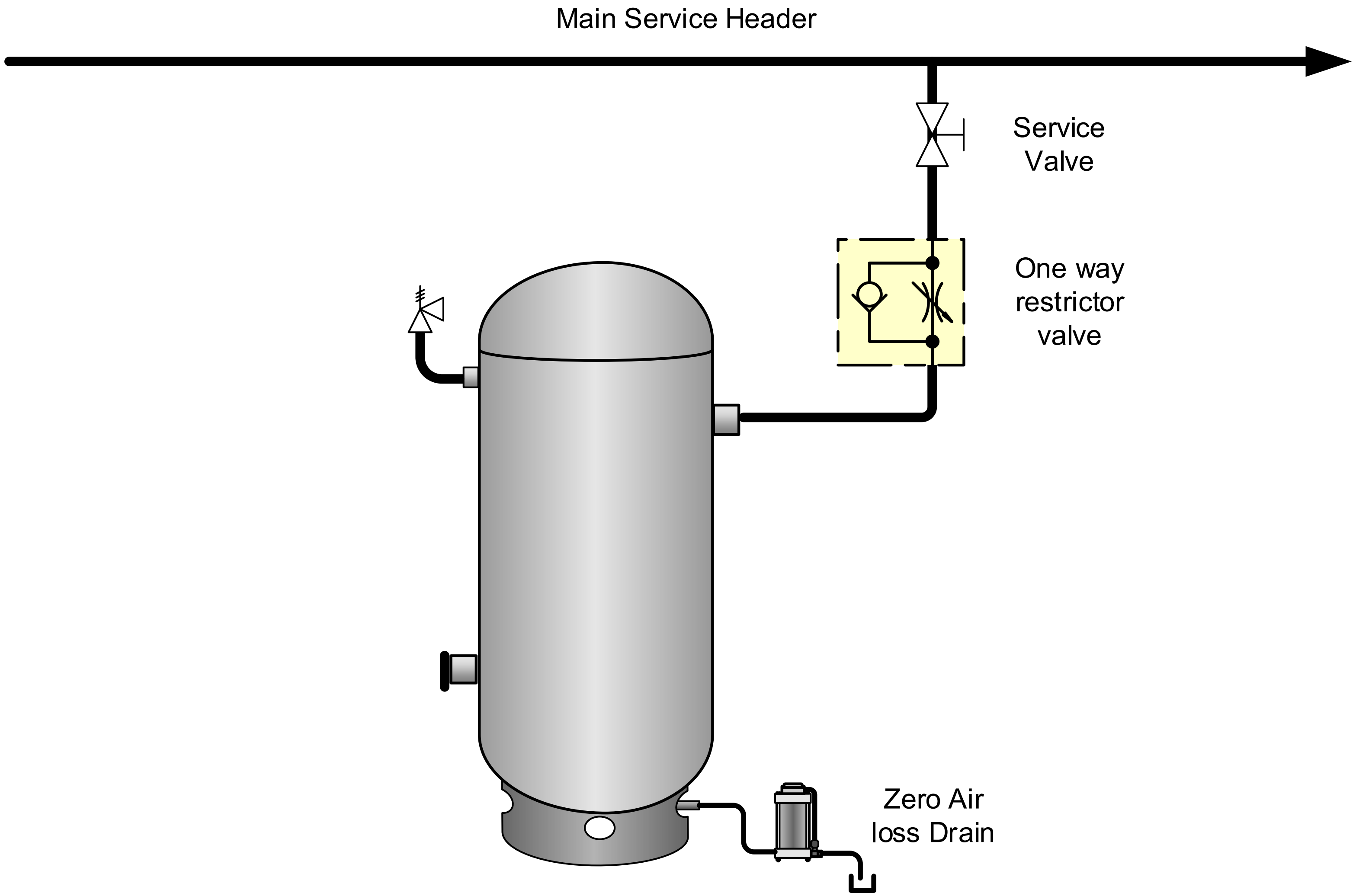
Dedicated Storage to Shield the system from a high flow end use application



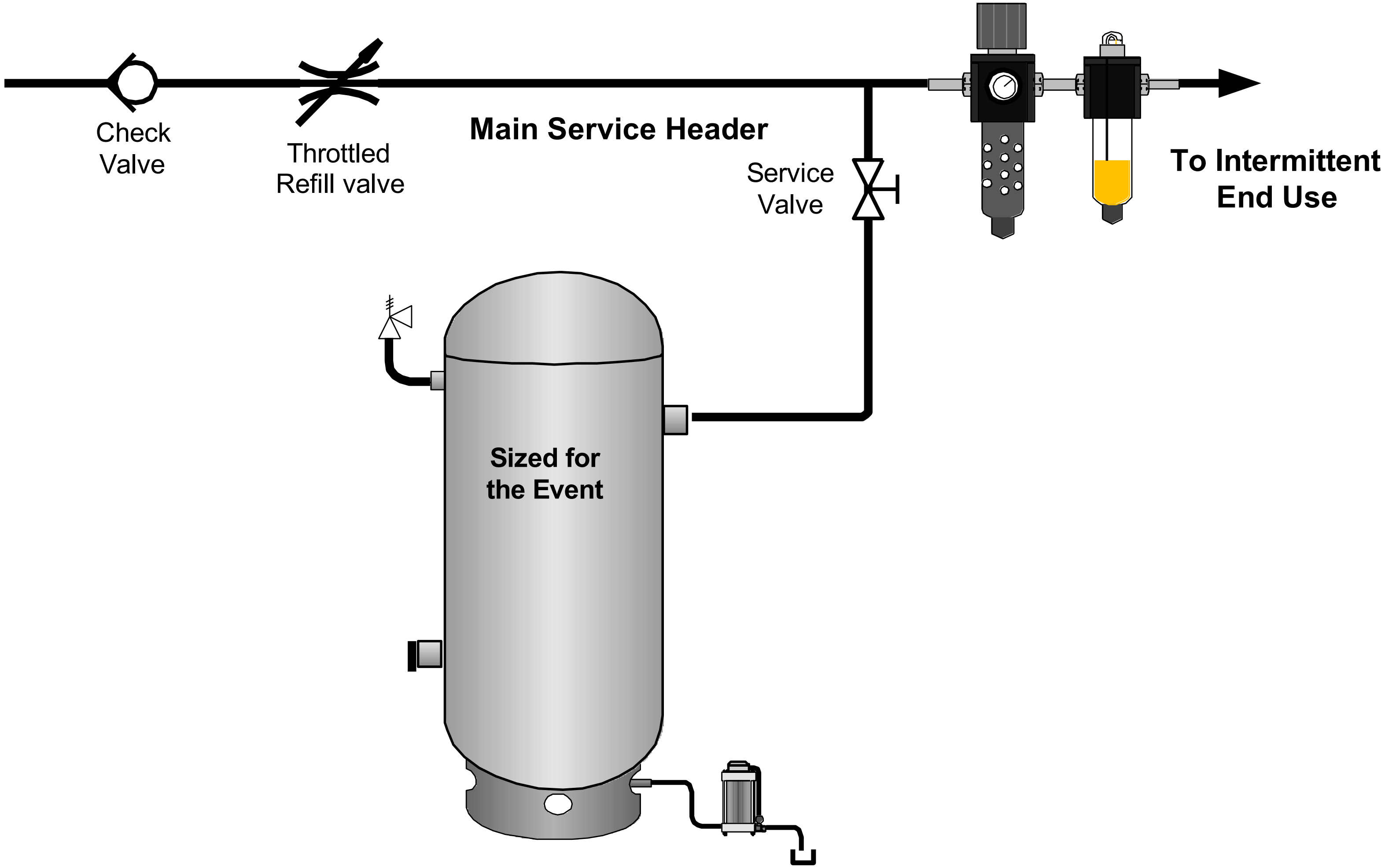
Critical Pressure End Use



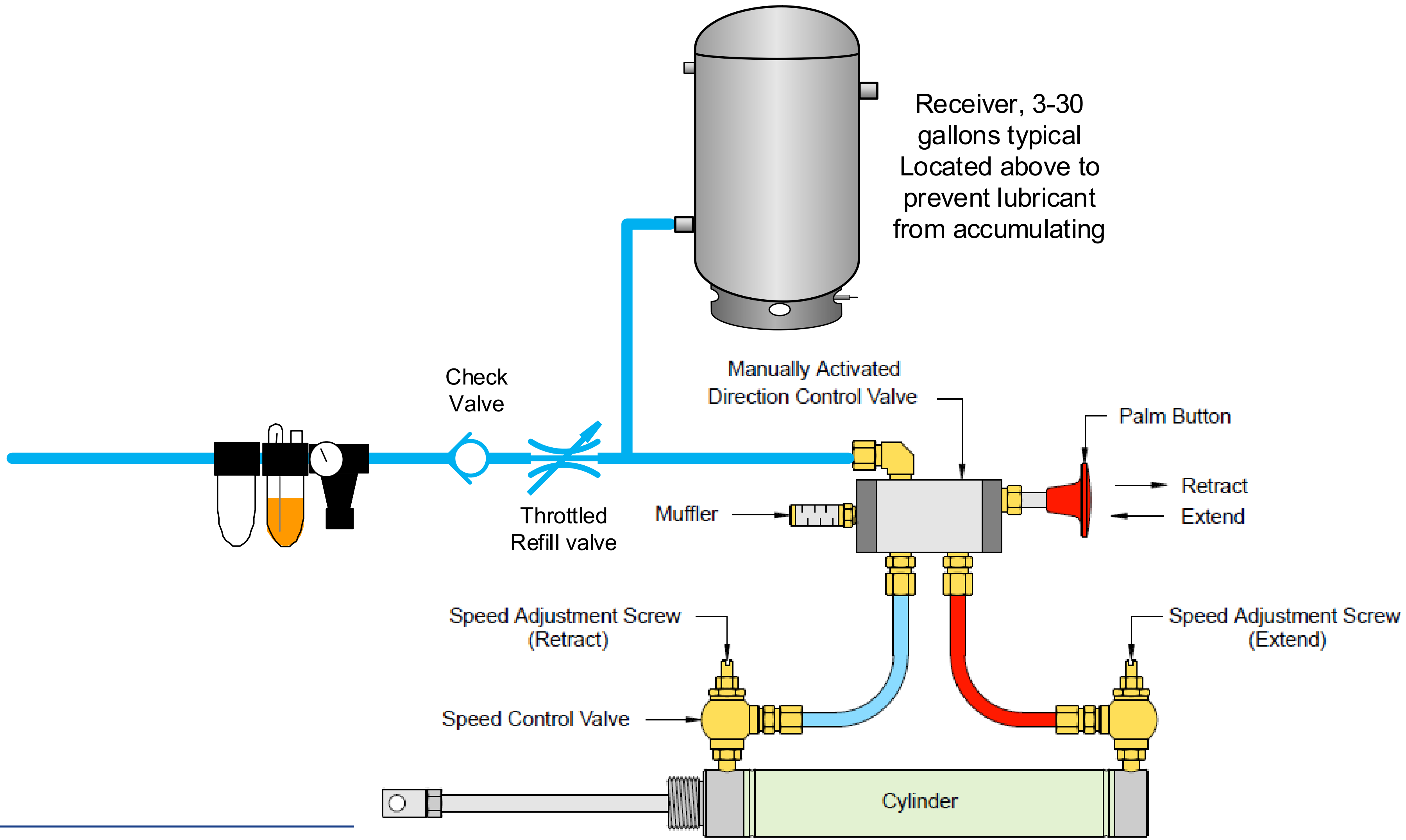
General Storage



Dedicated Storage with Metered Recovery

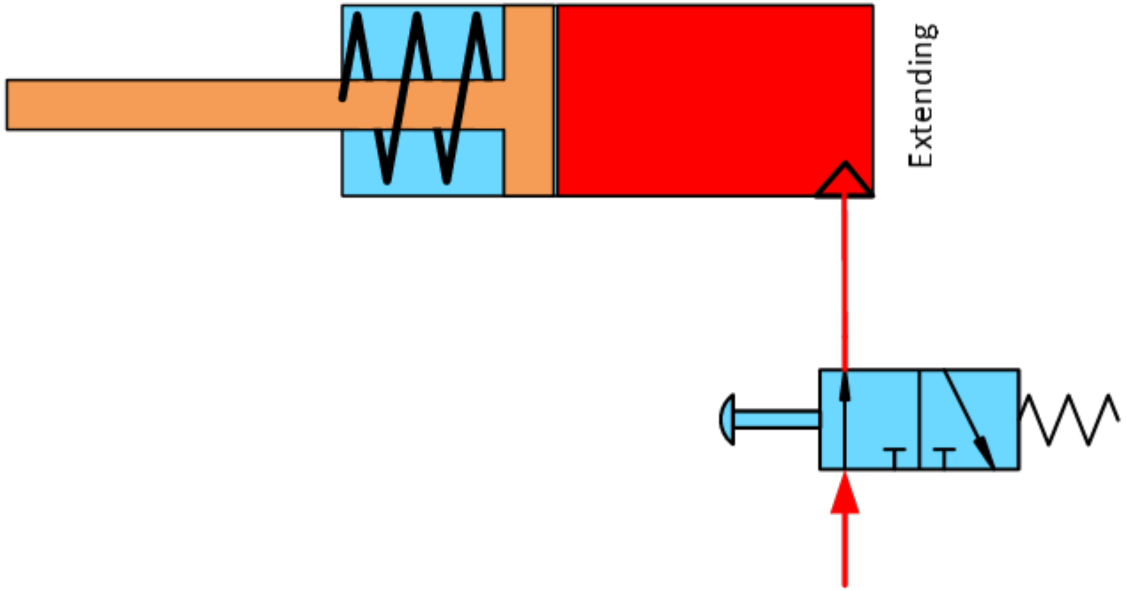


Dedicated Storage with Metered Recovery



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?

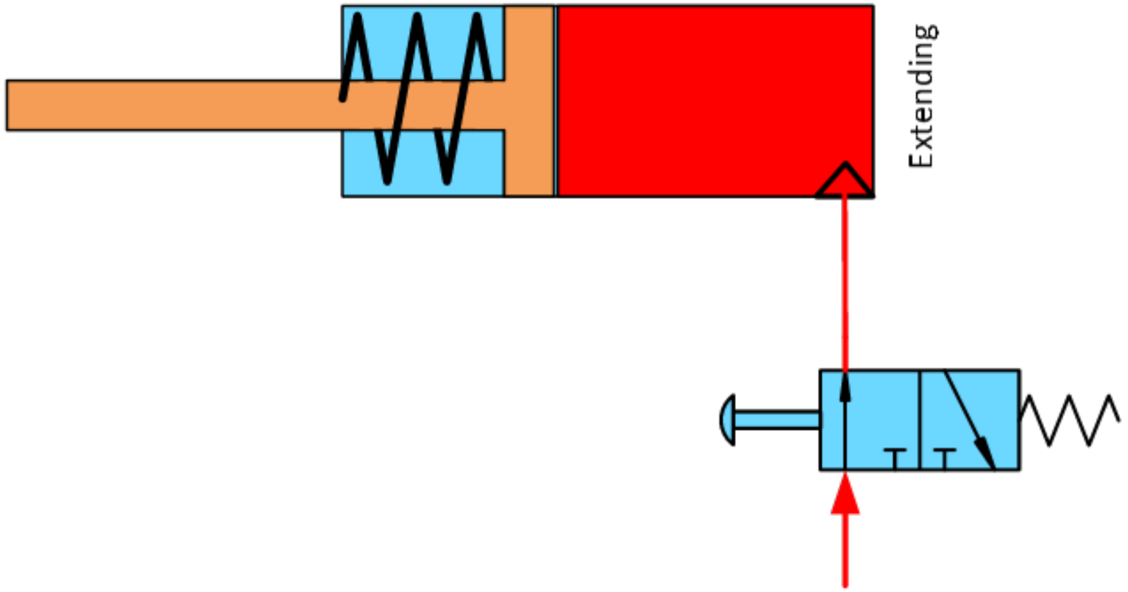


Peak Flow vs Average Flow

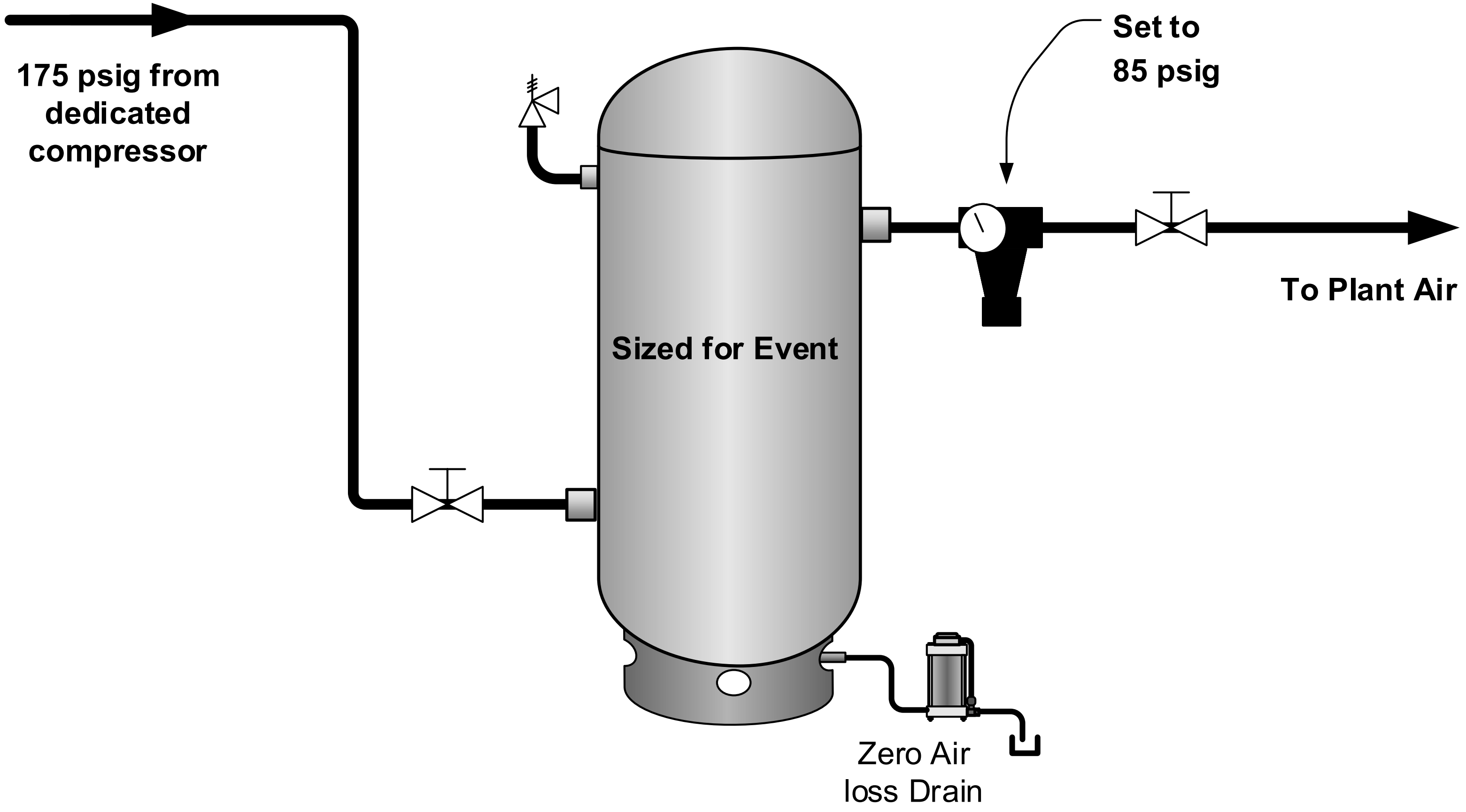
- Answers:
  - Average flow = 2 cfm
  - Peak flow – 20 cfm

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

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



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.

Next Week Session 7 - The Demand Side

- 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.