



In-Plant Trainings

8 – Session Virtual Platform

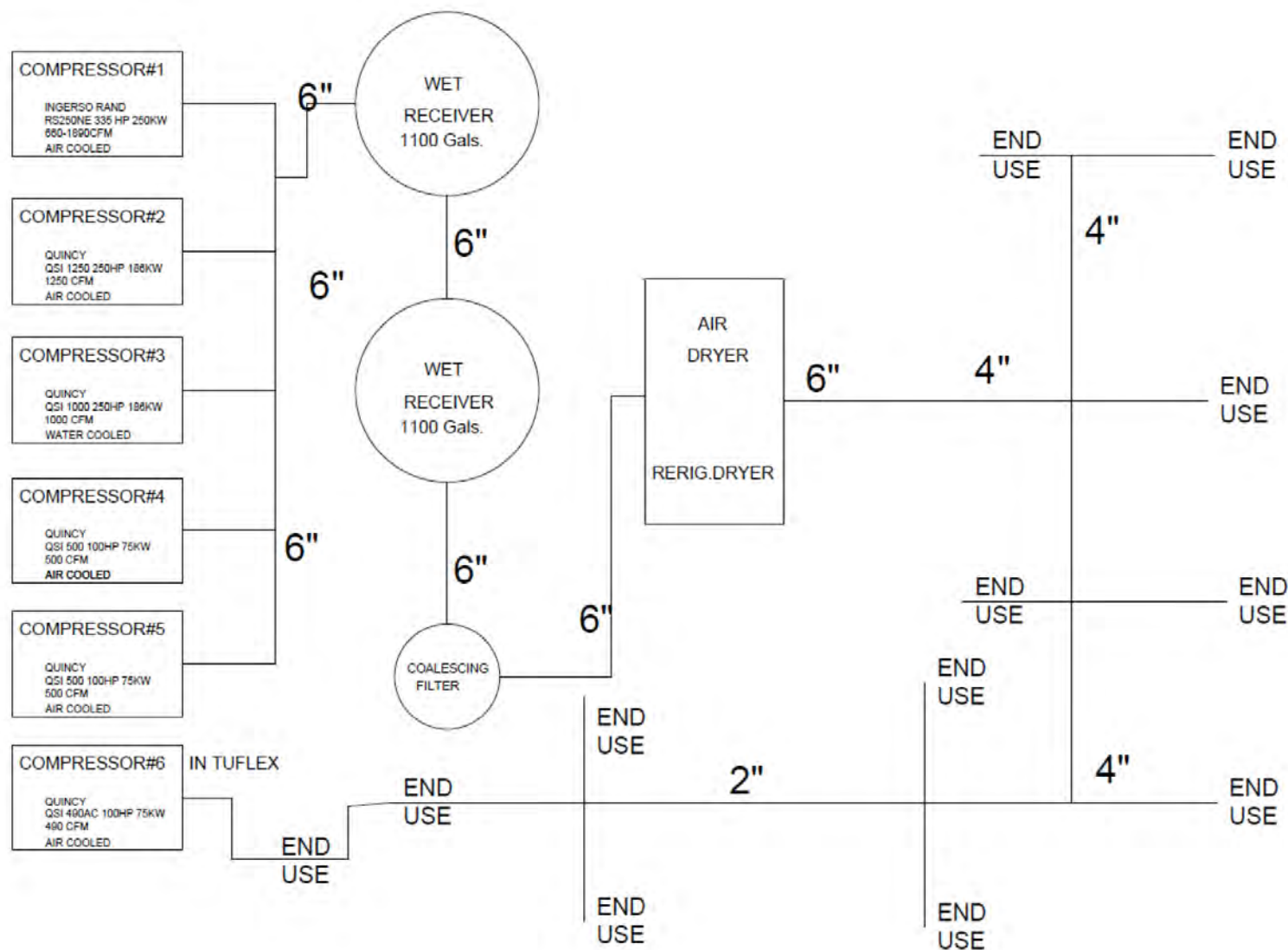


Compressor Types Maintenance Compressor Room Best Practices and Ventilation

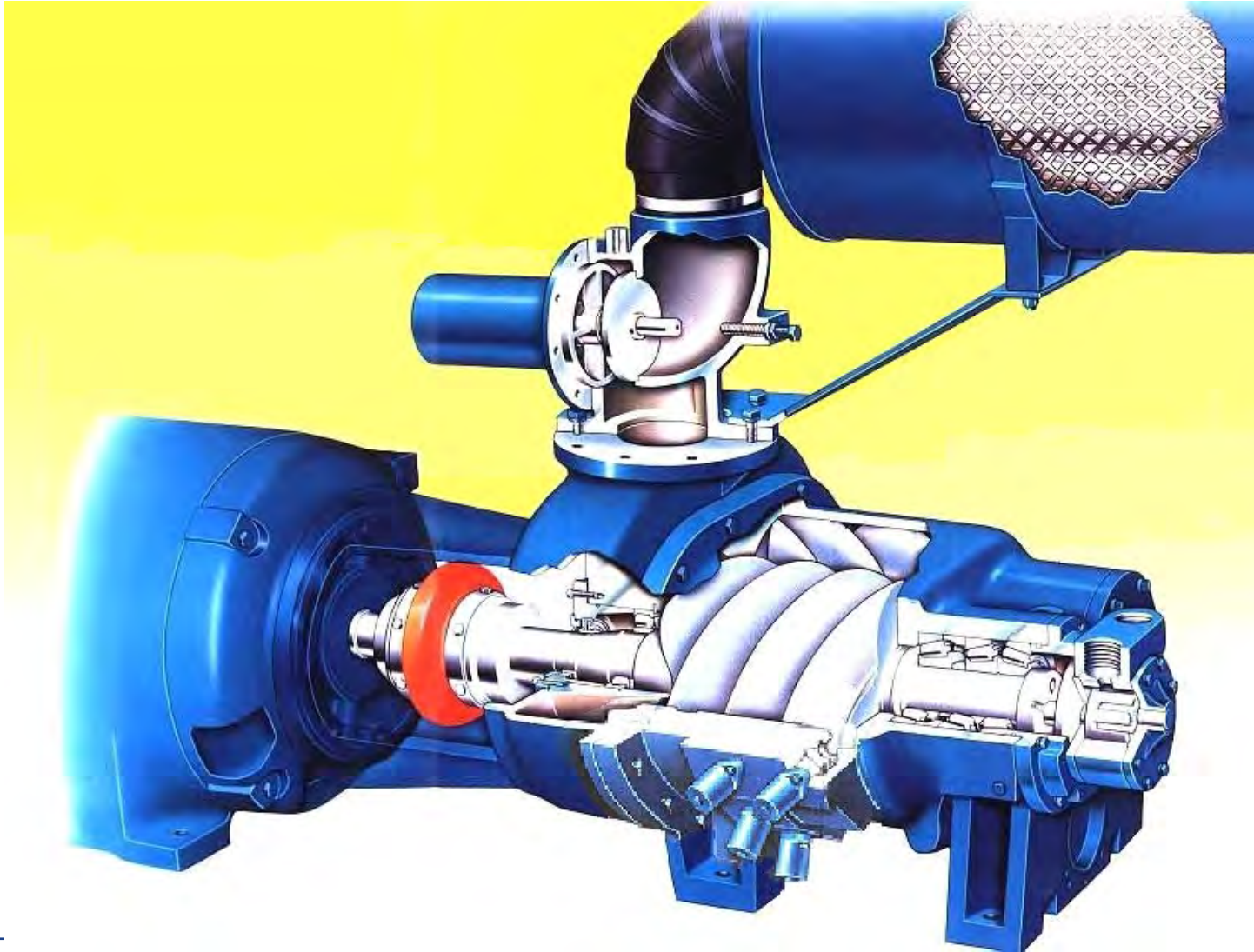
Summary from Week 1

- Measurements need to be taken to understand how a compressed air system is operating
- Measurements can help you adjust and optimize your system
- Data logging can help you better understand and optimize the system, although sometimes substantial improvements can be made without them
- Continuous monitoring is the best way to optimize your system.
- Measurements will help you understand how much you are spending on compressed air on a per unit of production basis.
- Block Diagrams help you understand your system.

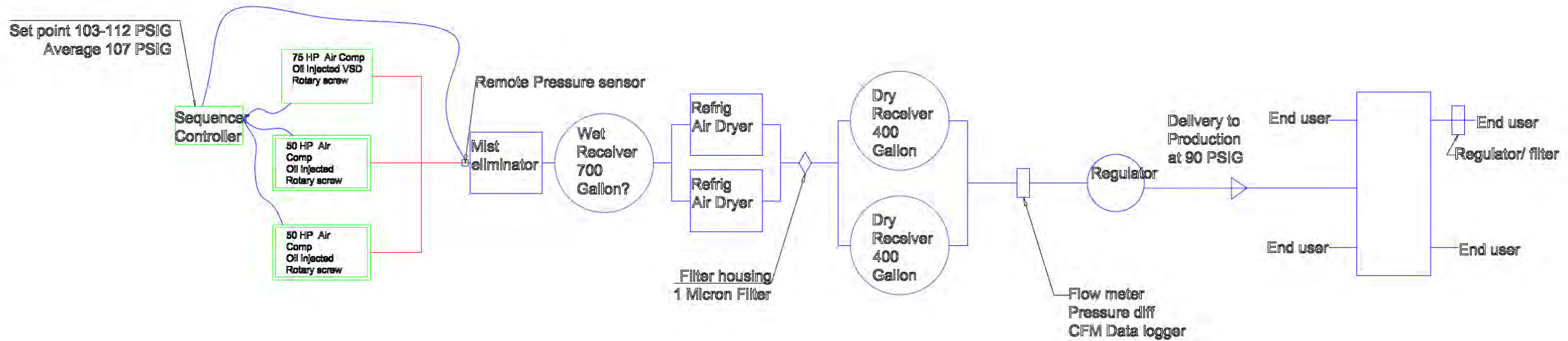
Block Diagrams



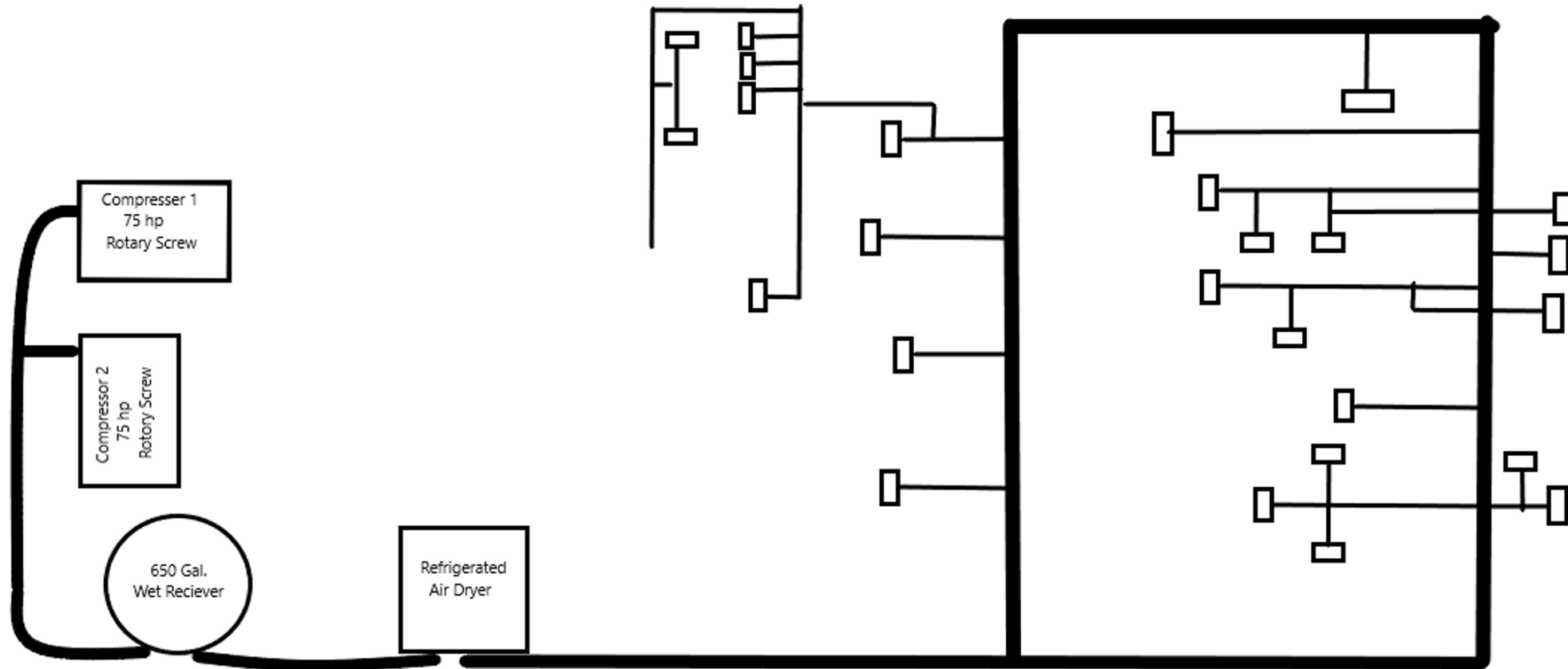
Variable Displacement



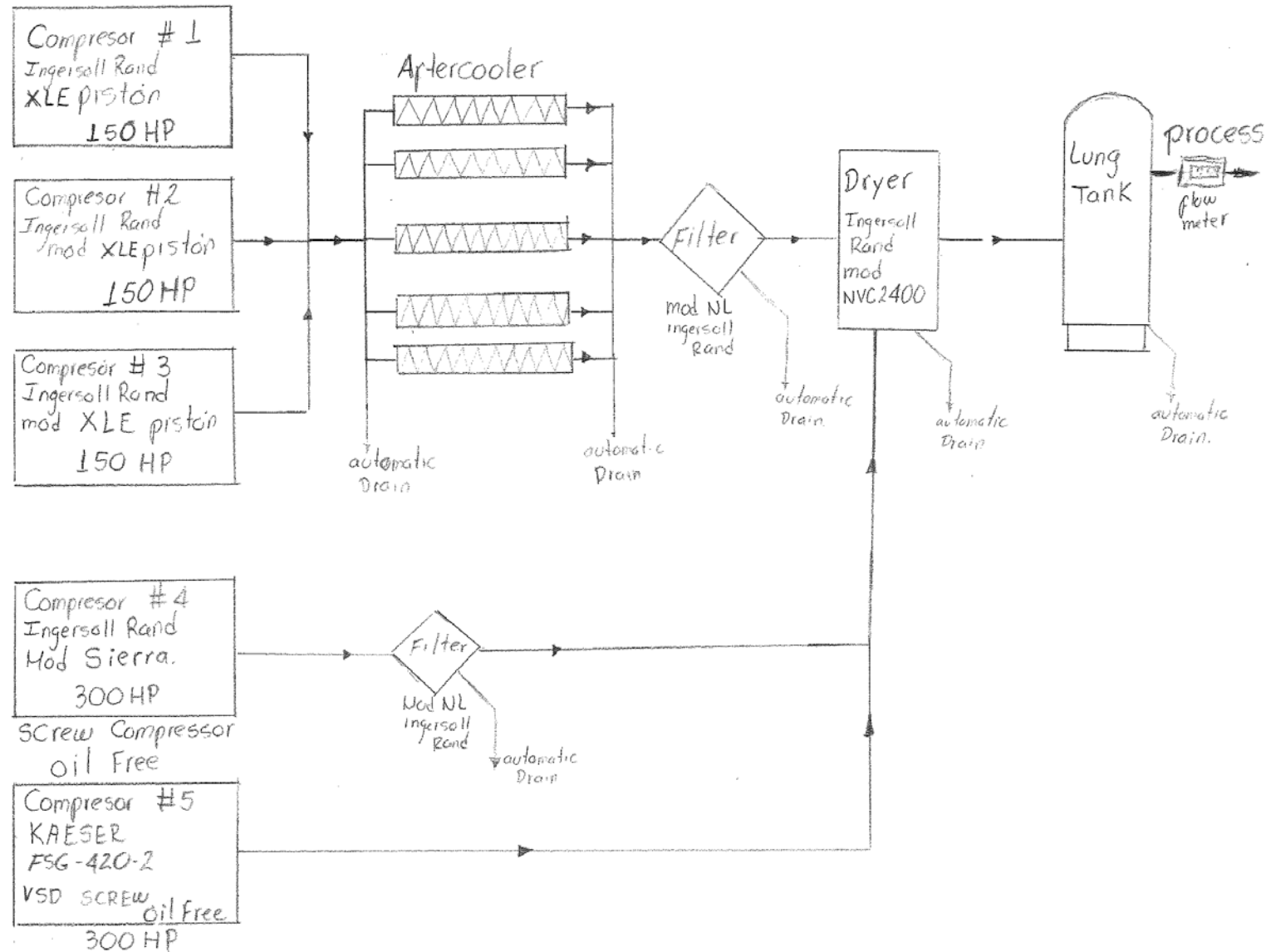
Block Diagrams



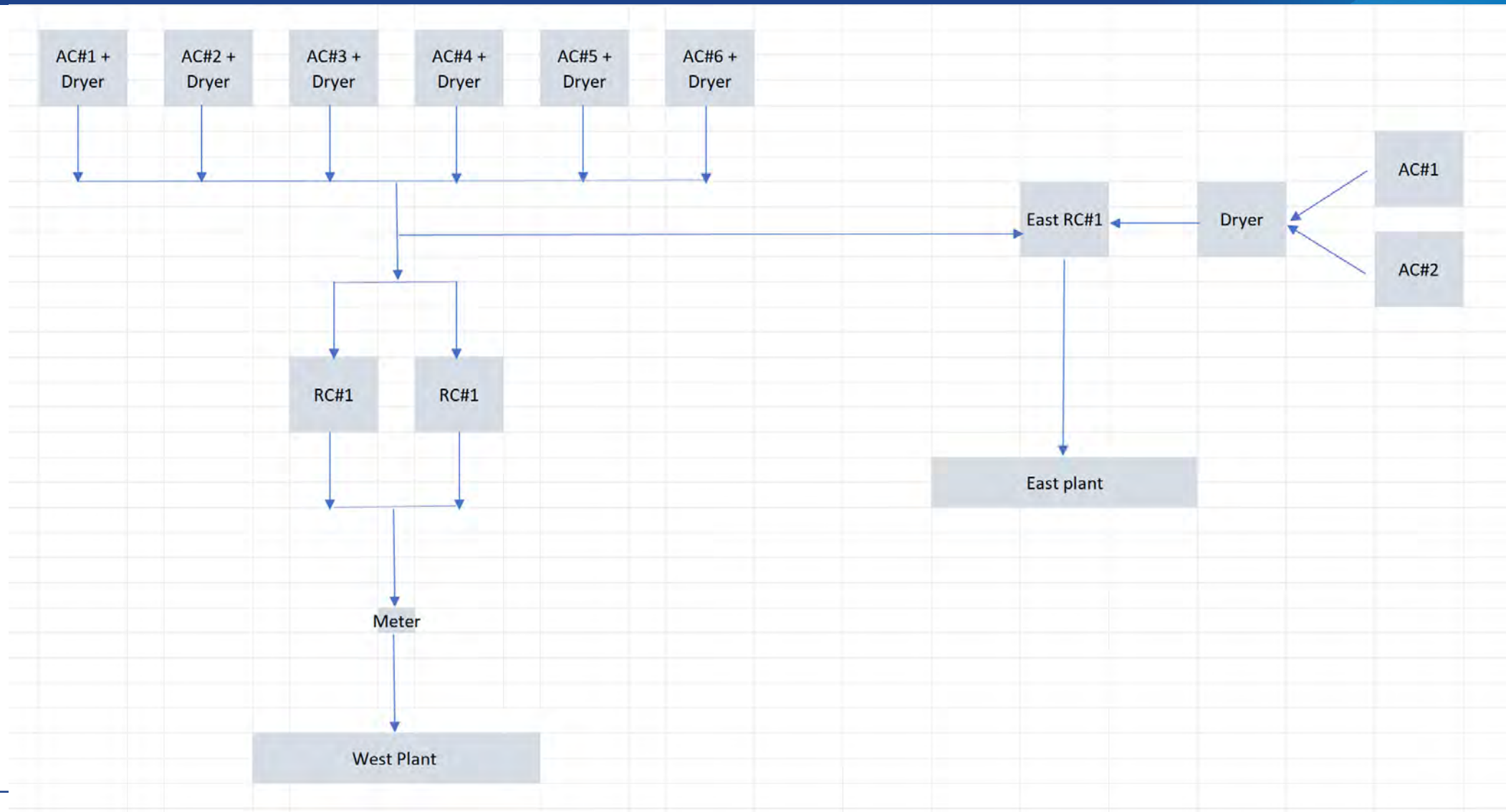
Block Diagrams



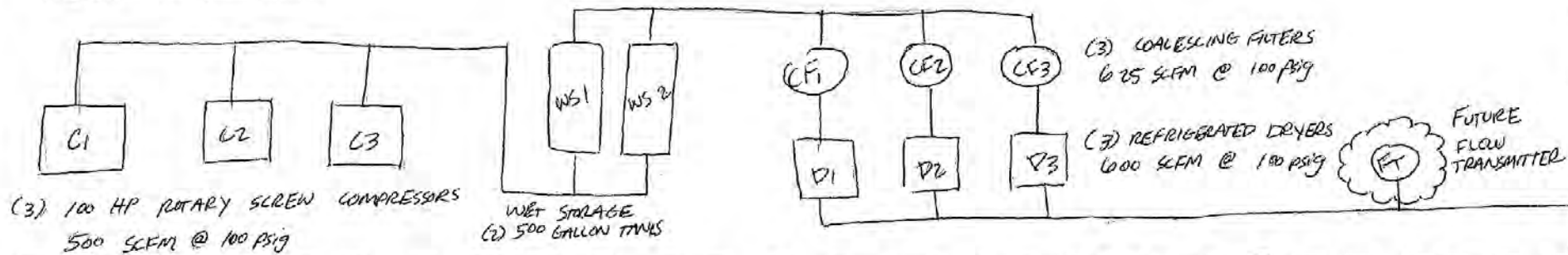
Block Diagrams



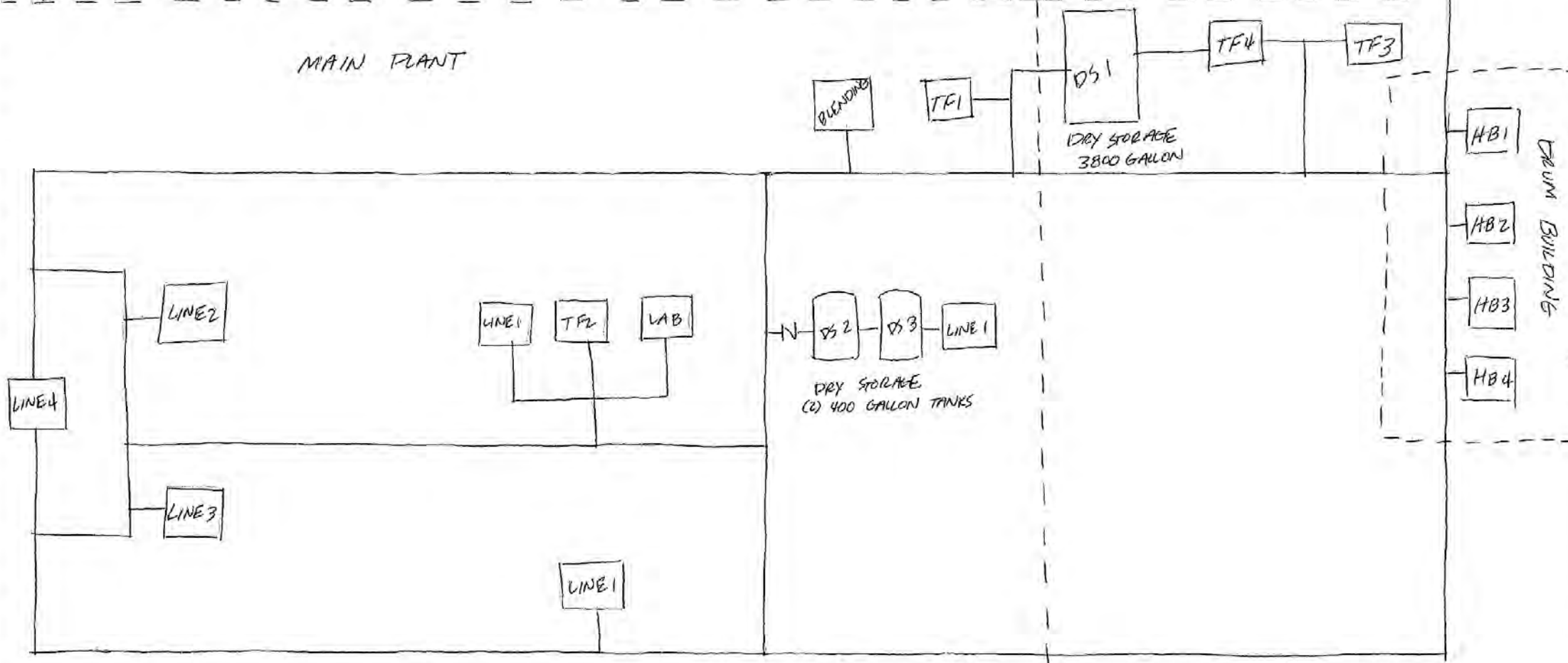
Block Diagrams



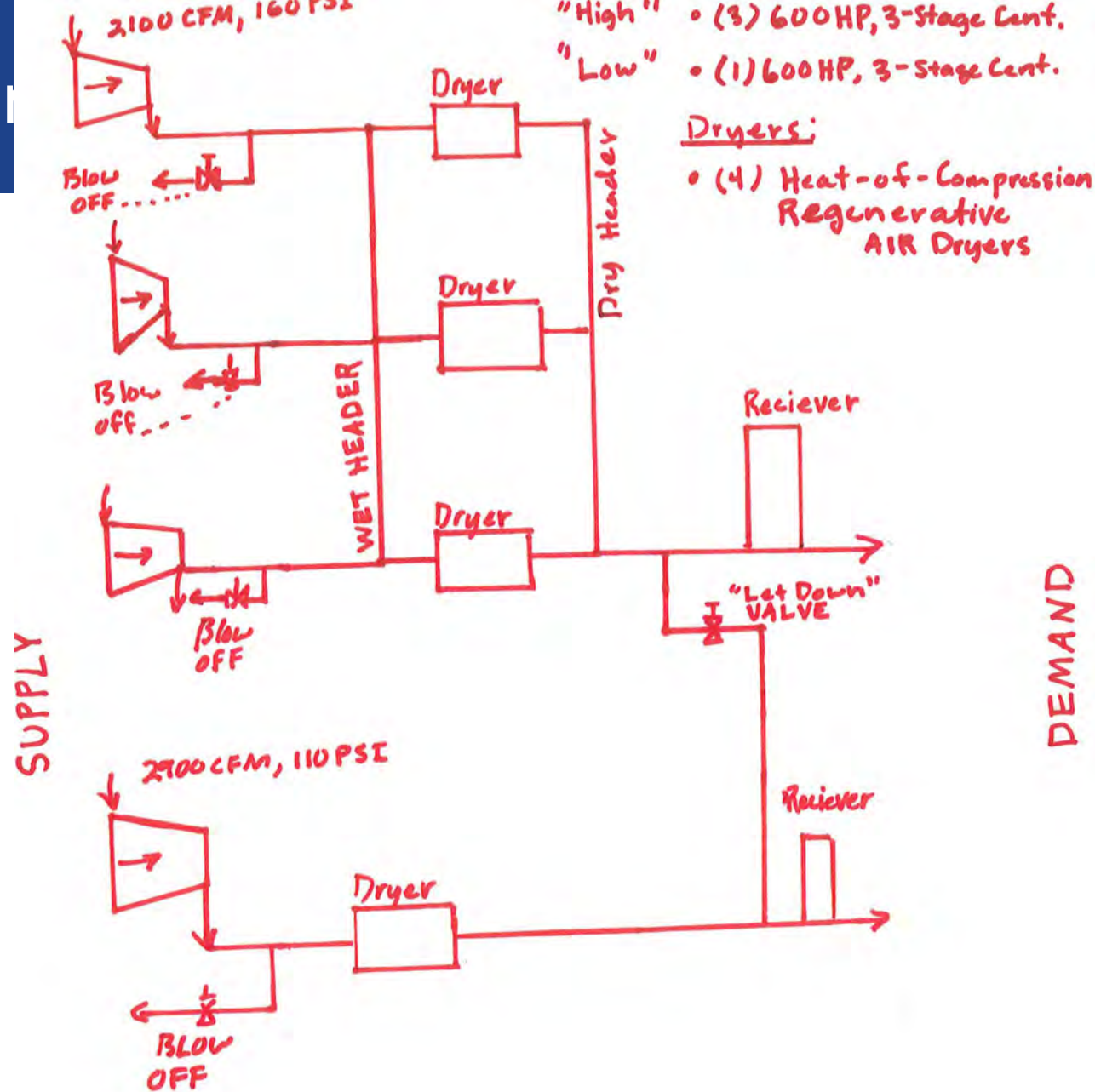
MECHANICAL BUILDING



MAIN PLANT

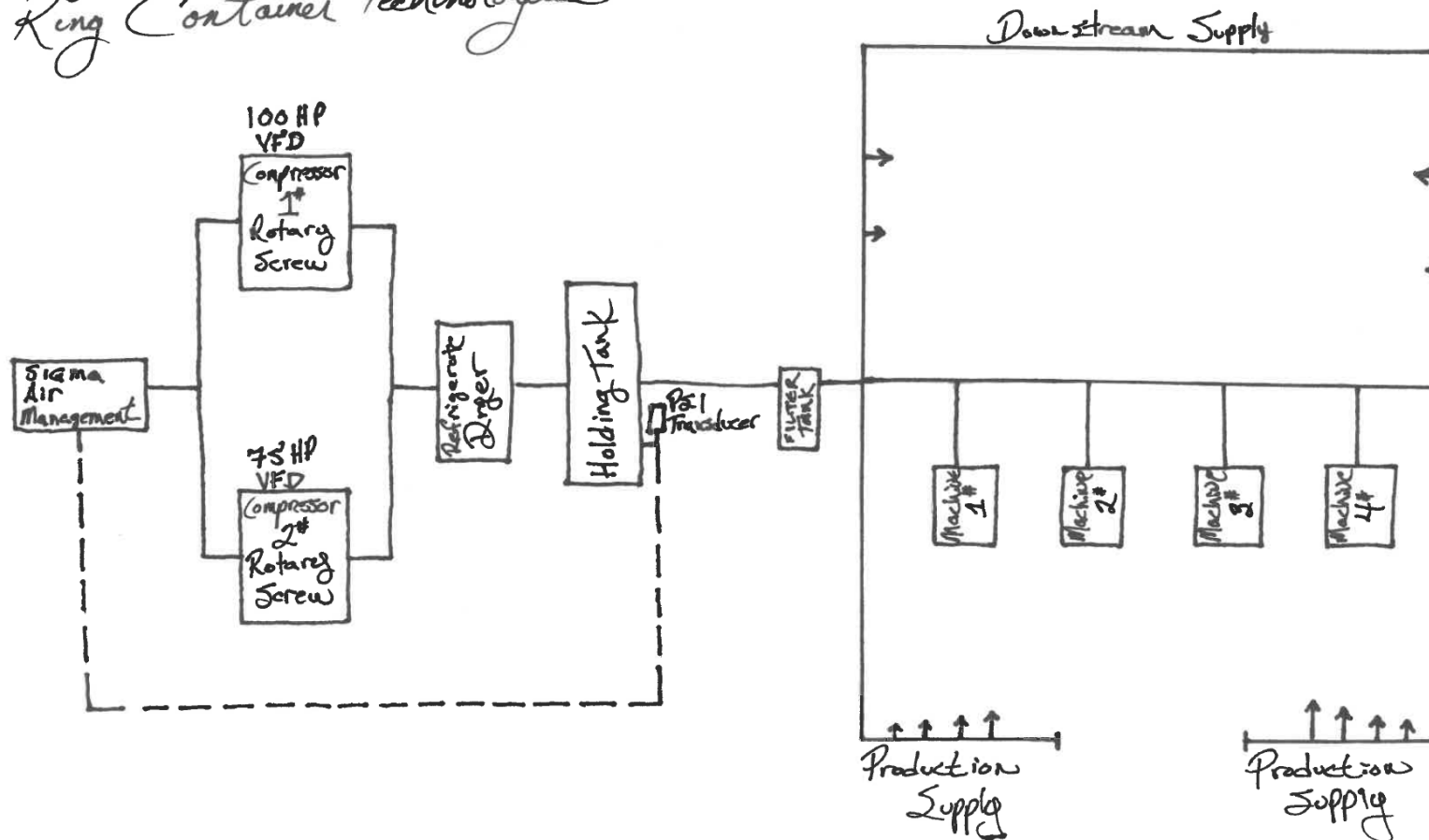


Block Diagram

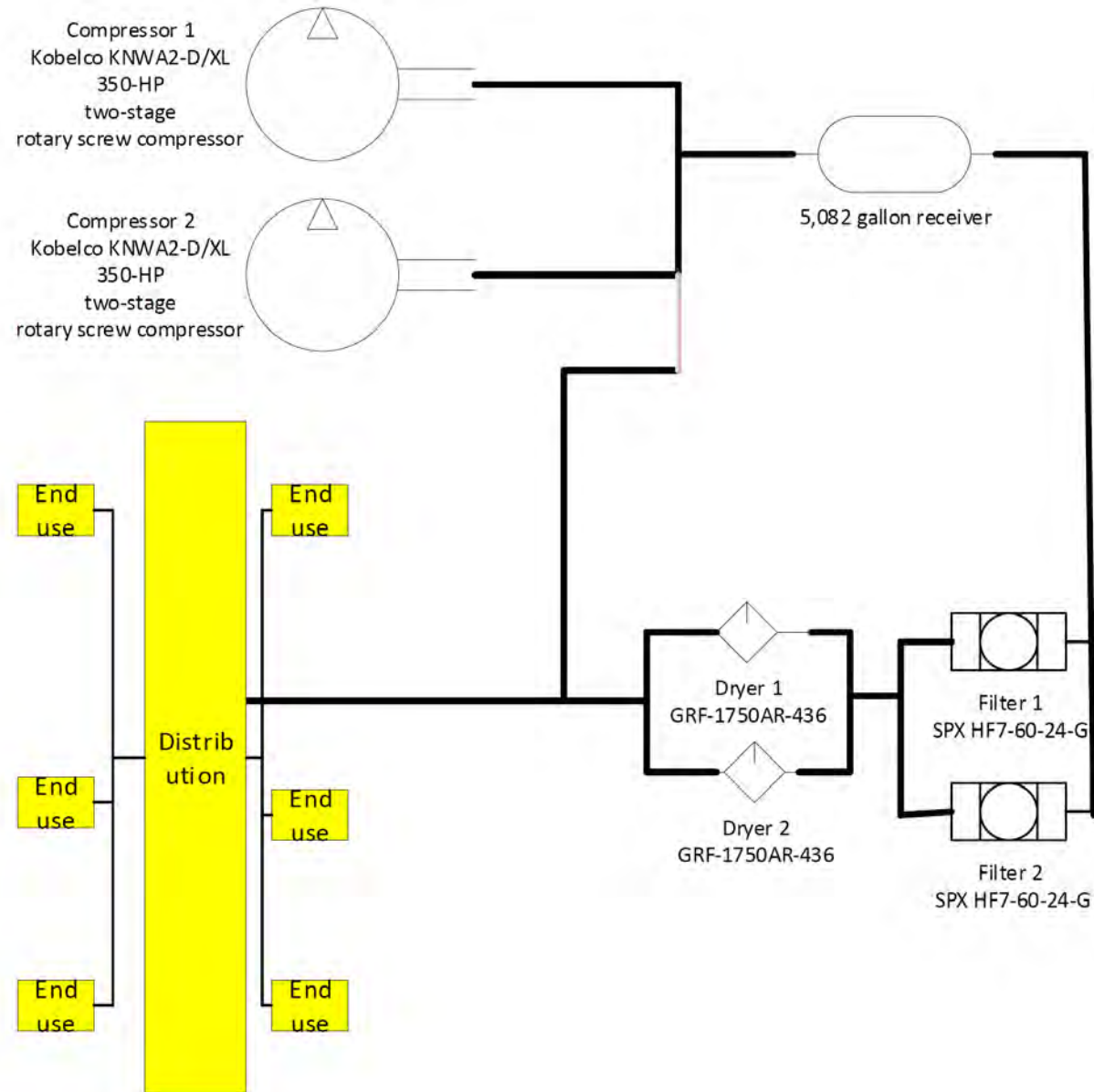


Block Diagrams

Name: Cal & B. Blacklock
Plant: Wagerstown, MD
Ring Container Technologies



Block Diagram



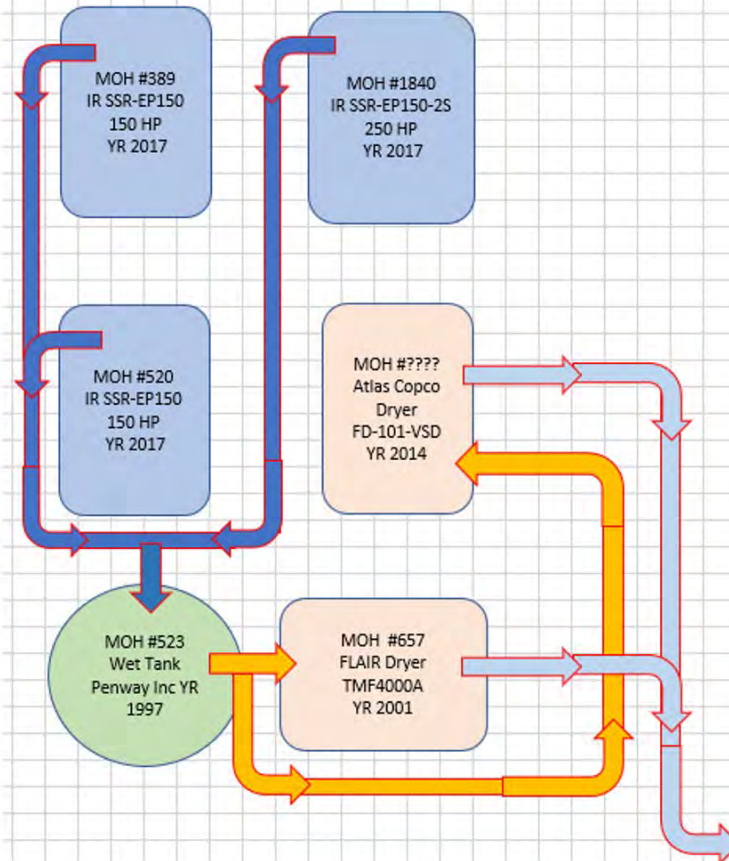
Block Dia

Below is G2 and G4, which have a connecting loop.

Also include all three system as individual layouts in page, 2, 3, 4.

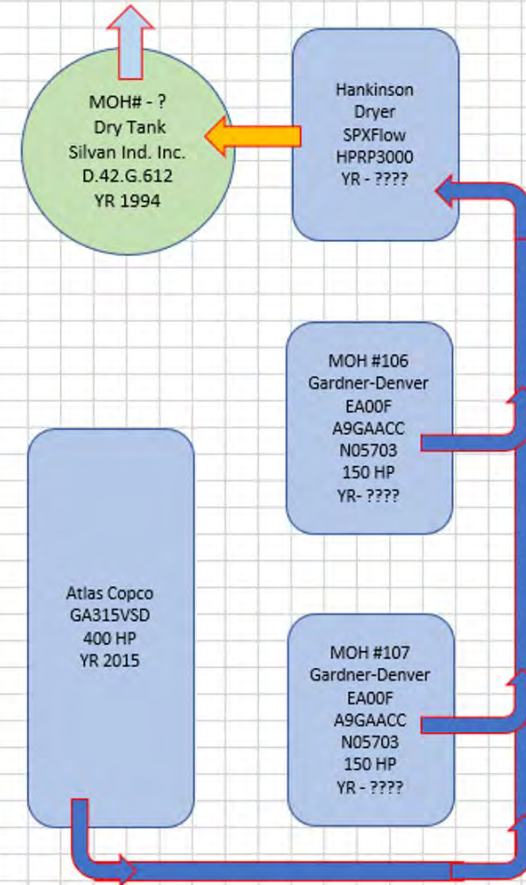
GAMCO - Conneaut, Ohio
G2 -G4 compressors room
not to scale

G4 Compressor Room

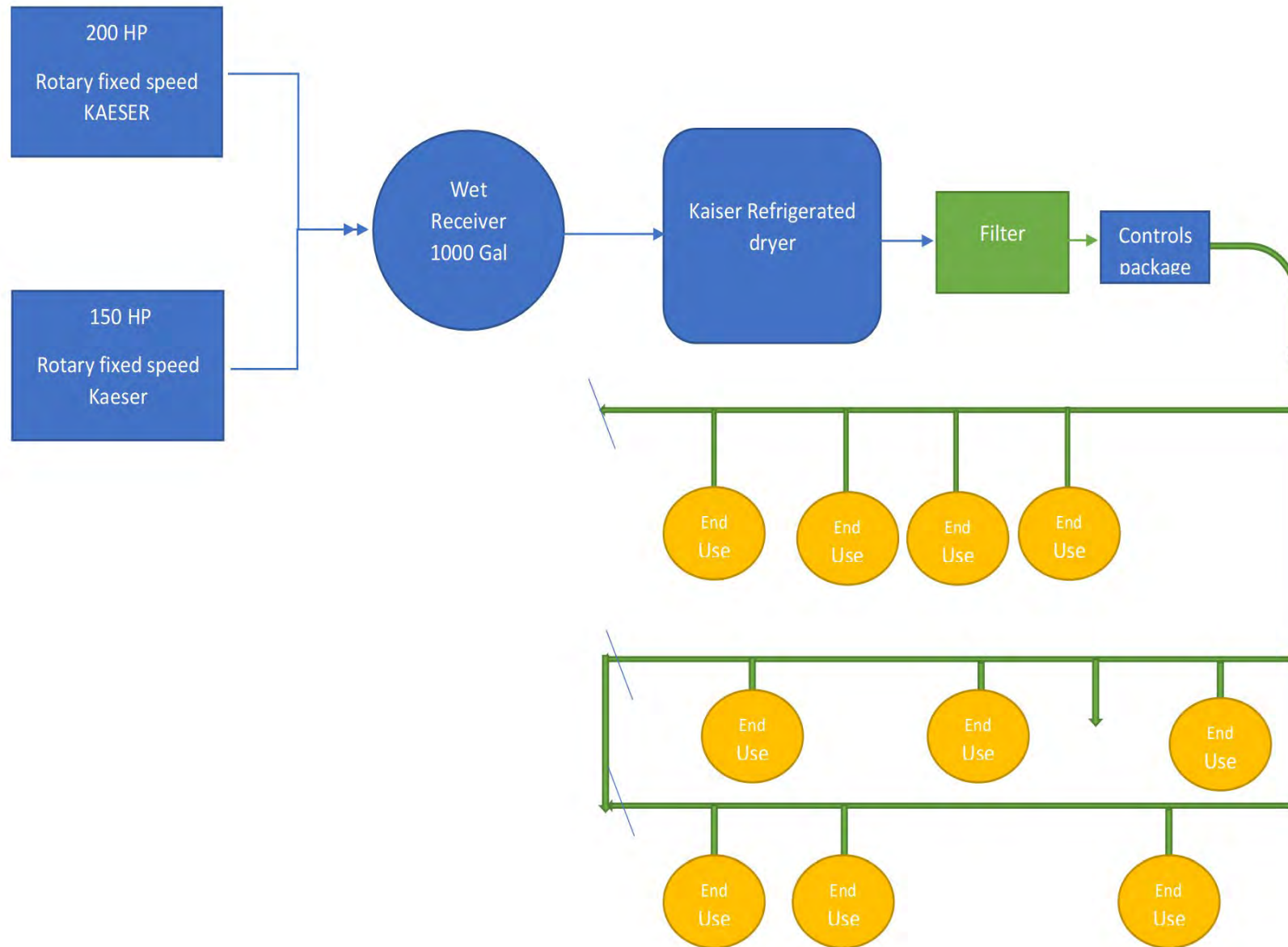


GAMCO - Conneaut, Ohio
G2 -G4 compressors room
not to scale

G2 Compressor Room



Block D



Block Diagram

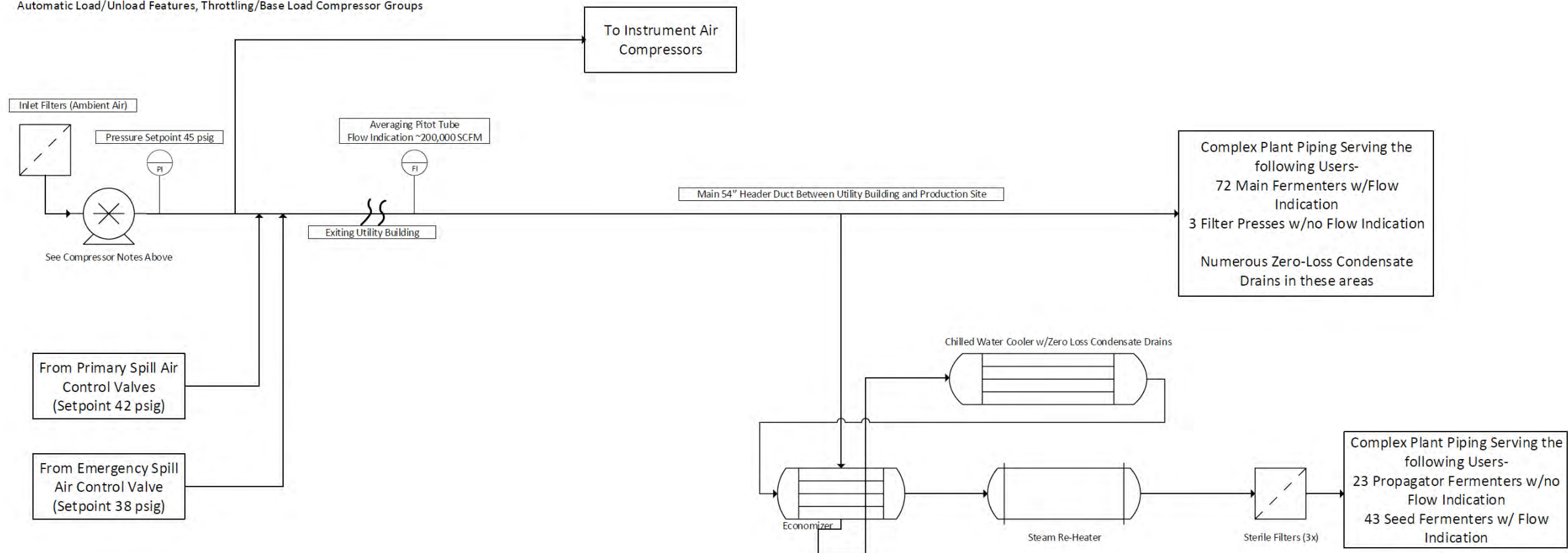
Process Air System Compressor Notes -

20 Process Air Compressors (PACs) –
18 - 4000 HP, Two-Stage Centrifugal with Intercooler/Aftercooler

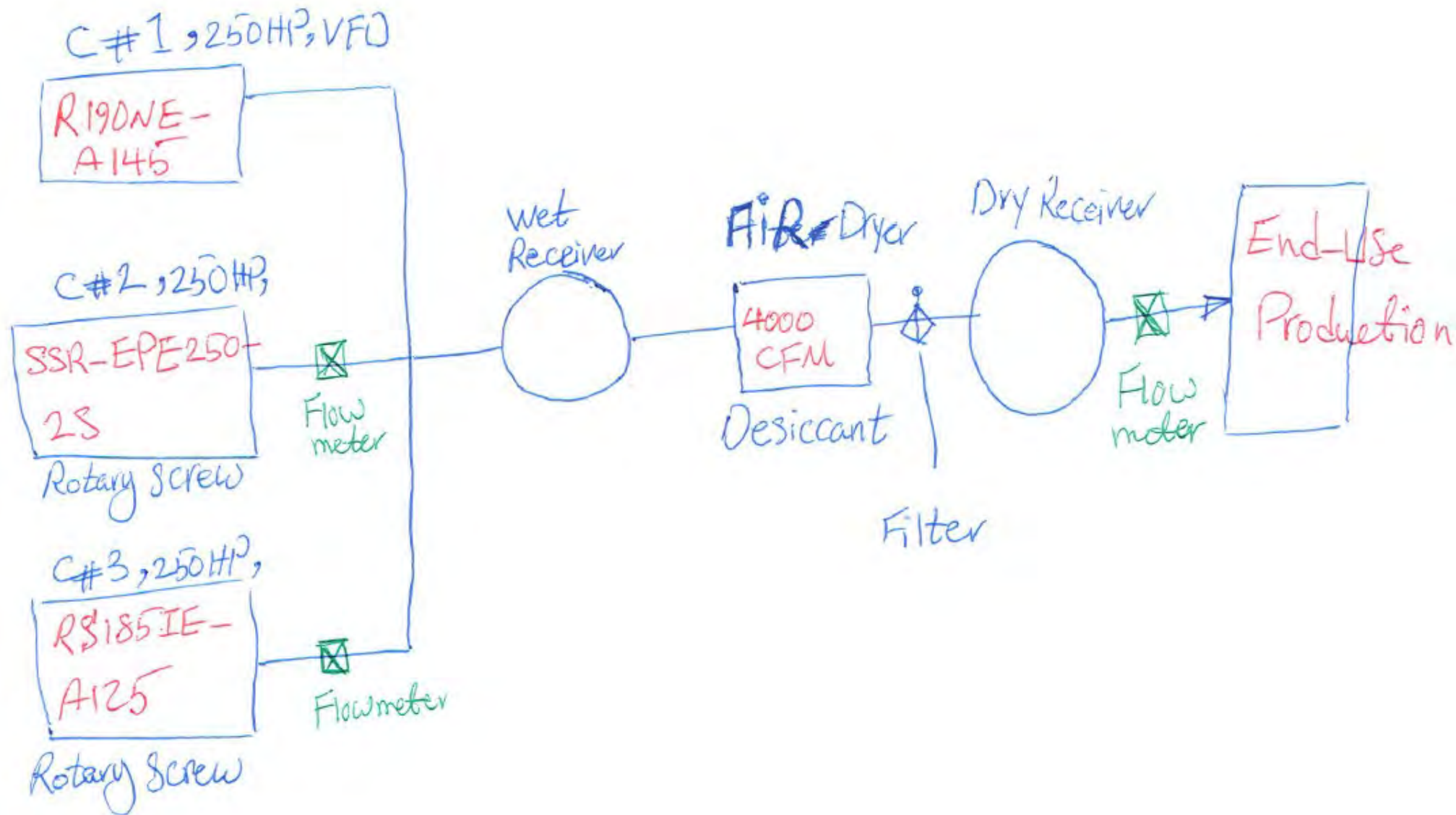
2 – 175#/50# Steam Turbine Driven Units as above

2 PAC Trim – 1600 HP, Two-Stage Centrifugal with Intercooler/Aftercooler

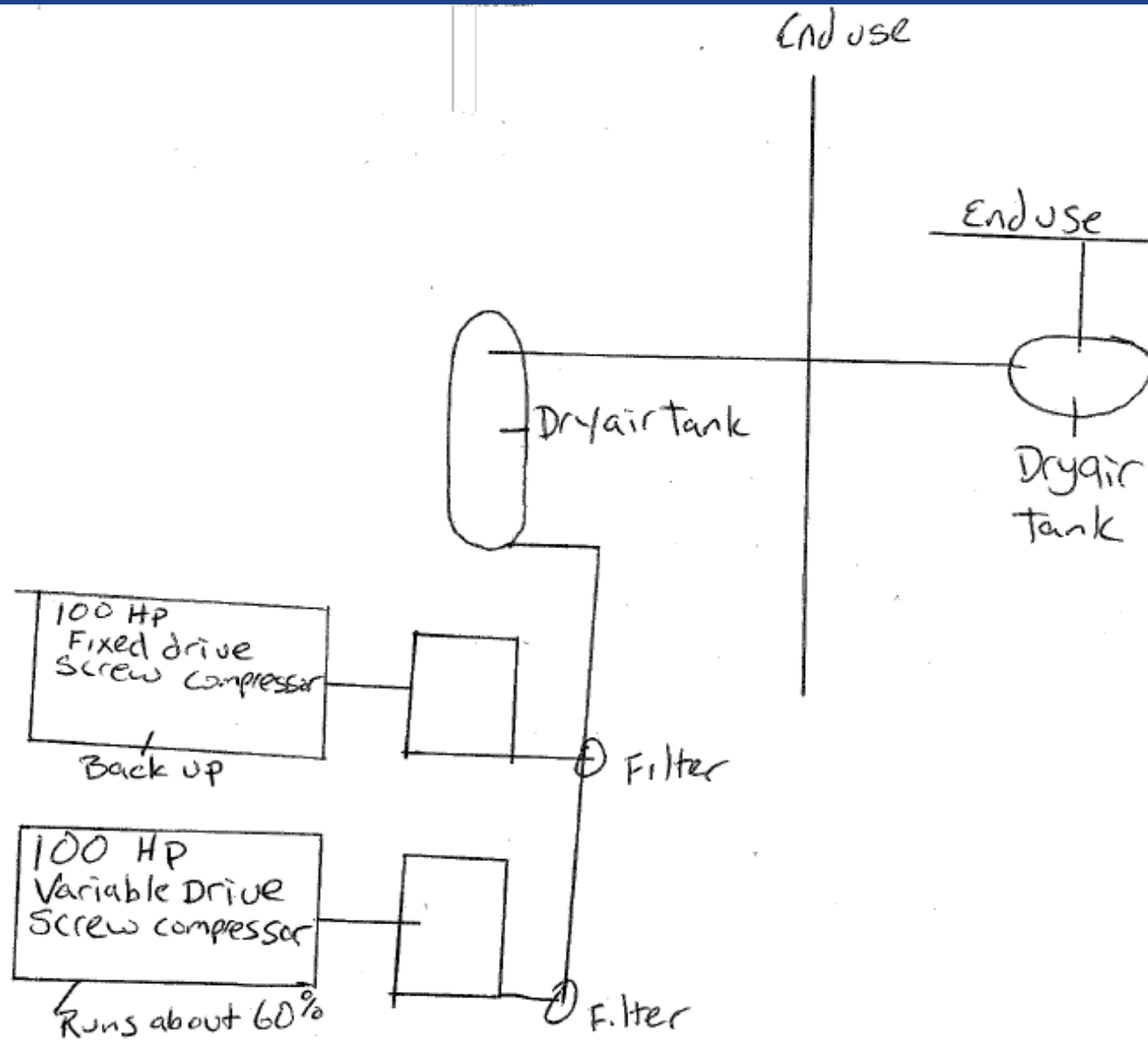
Complex Supervisory PLC Controls -
Automatic Load/Unload Features, Throttling/Base Load Compressor Groups



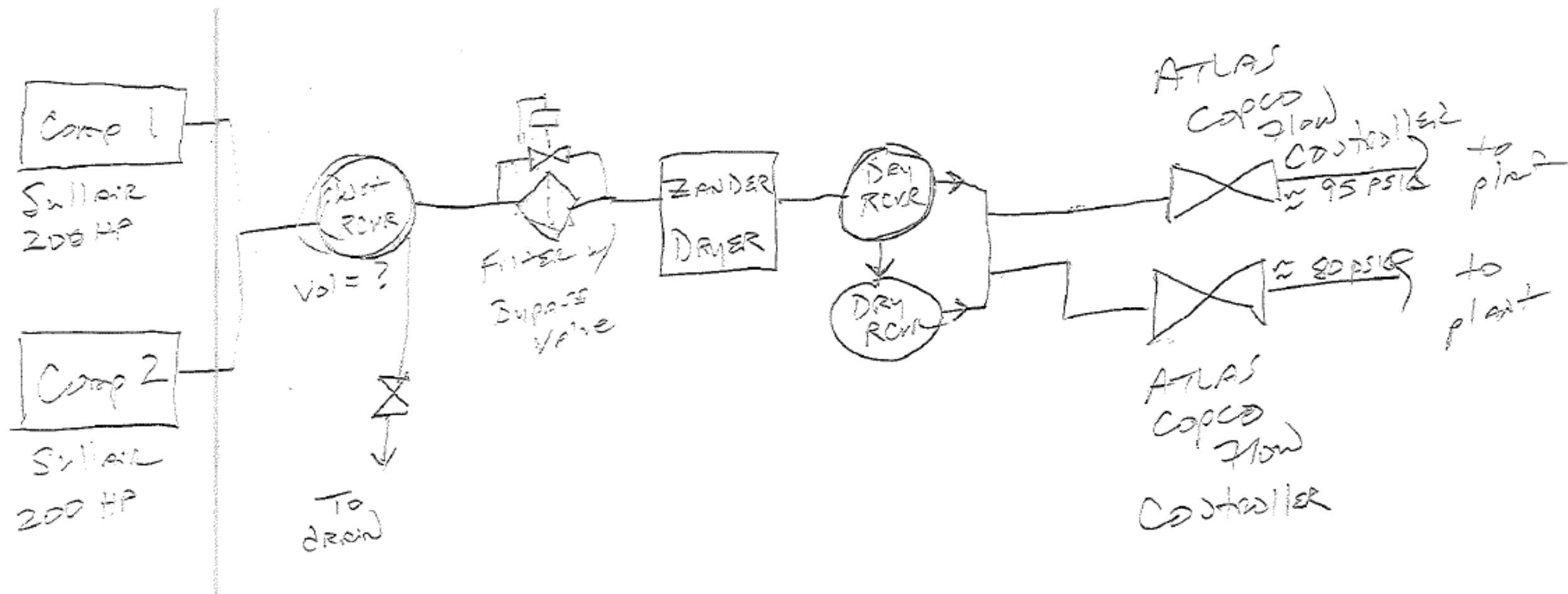
Block Diagrams



Block Diagrams



Block Diagrams



Compressor Types

Two types of compressors:

- Positive Displacement – Typically Rotary Screw
- Dynamic Compressors – Typically Centrifugal

Compressor Types

- Positive displacement compressors can be reciprocating or rotary.

- Reciprocating Compressor



- Rotary Compressor

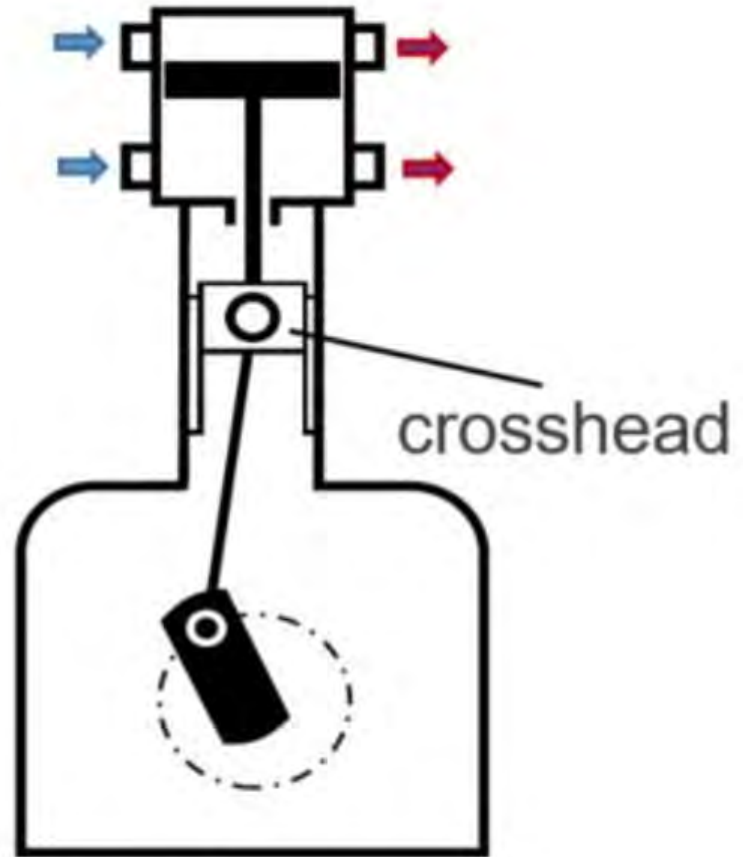


Reciprocation Compressors

- Reciprocating compressors can be either single acting or double acting.



Single
action

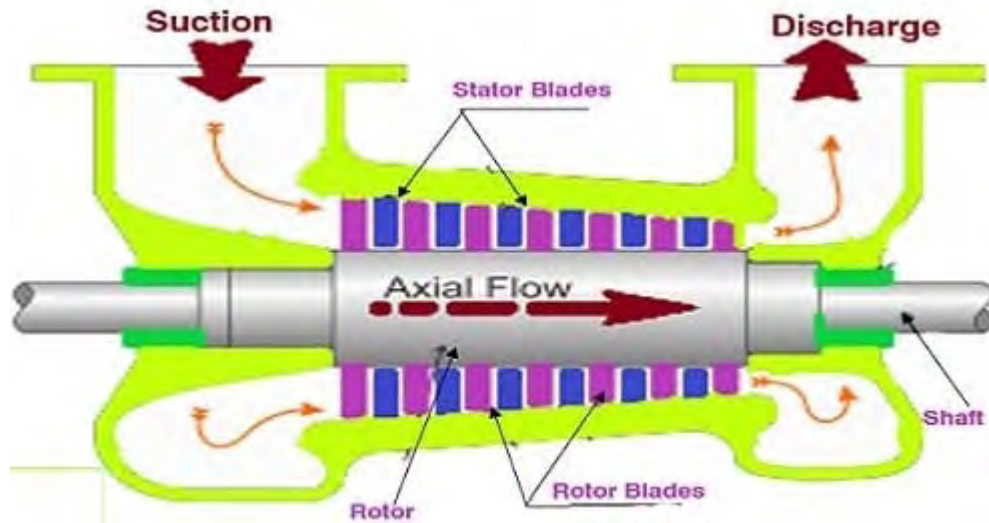


double action

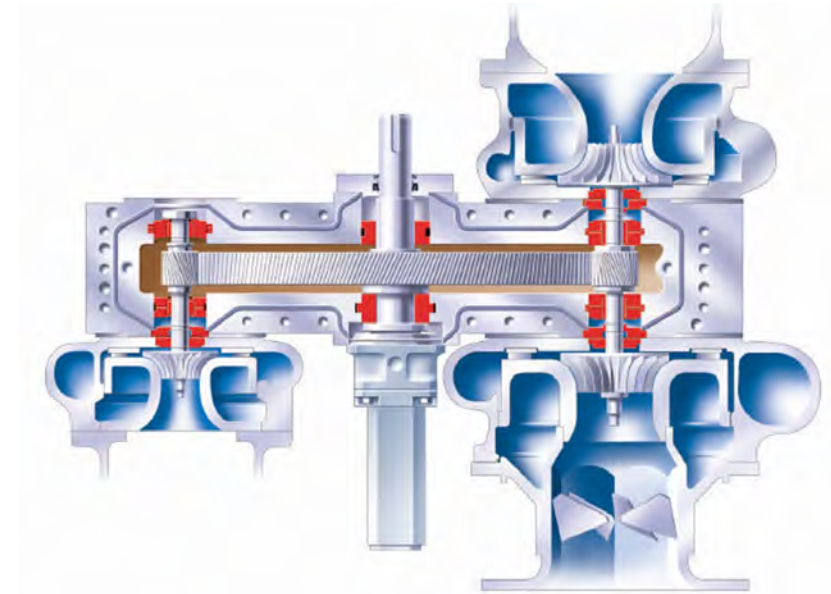
Compressor Types

- Dynamic compressors can be axial or centrifugal.

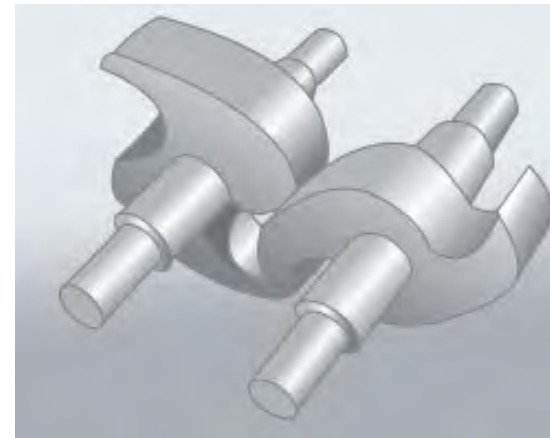
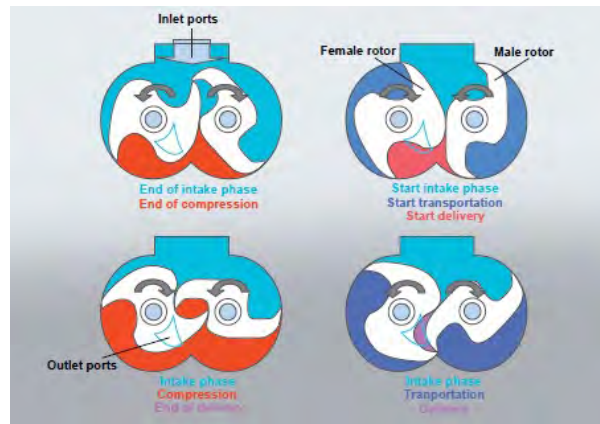
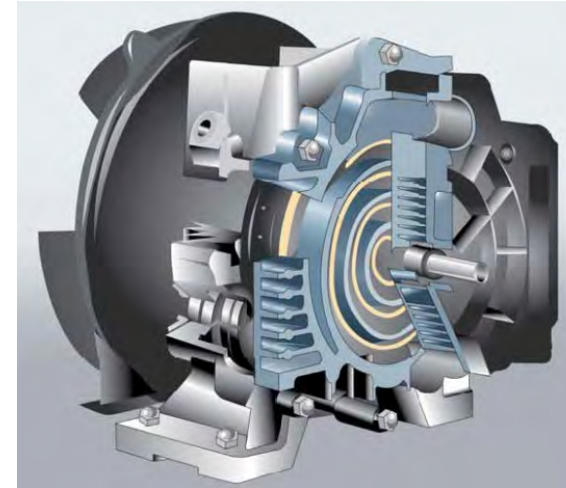
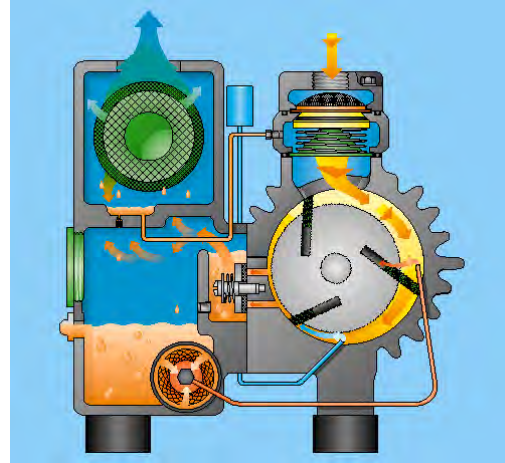
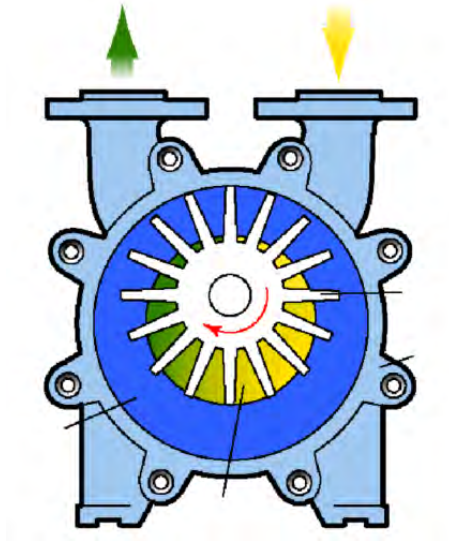
- Axial Compressor



Centrifugal Compressor



Other Types of Compressors



Reciprocation Compressors

- Single-stage compressors compress air once from the inlet pressure to final discharge pressure.
- Multi-stage compressors compress air to one pressure, then compress it to a higher pressure in another stage or stages.



Single-Stage



Two-Stage

+

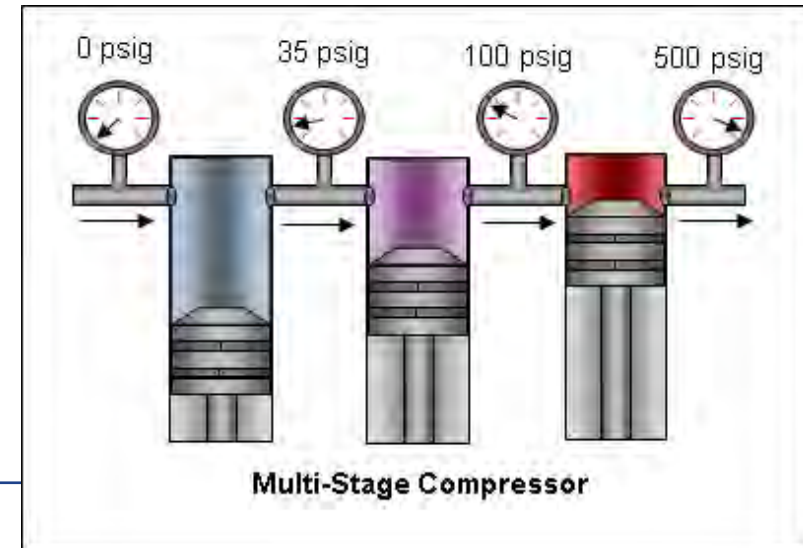
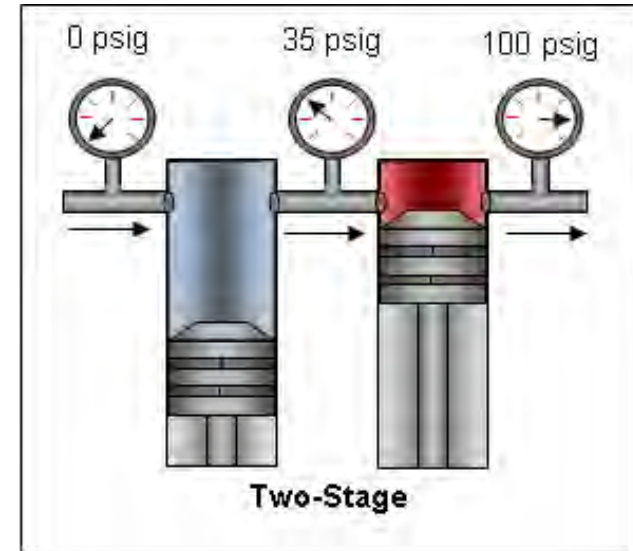
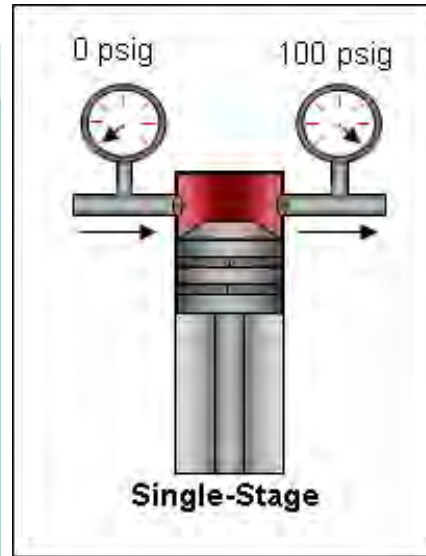
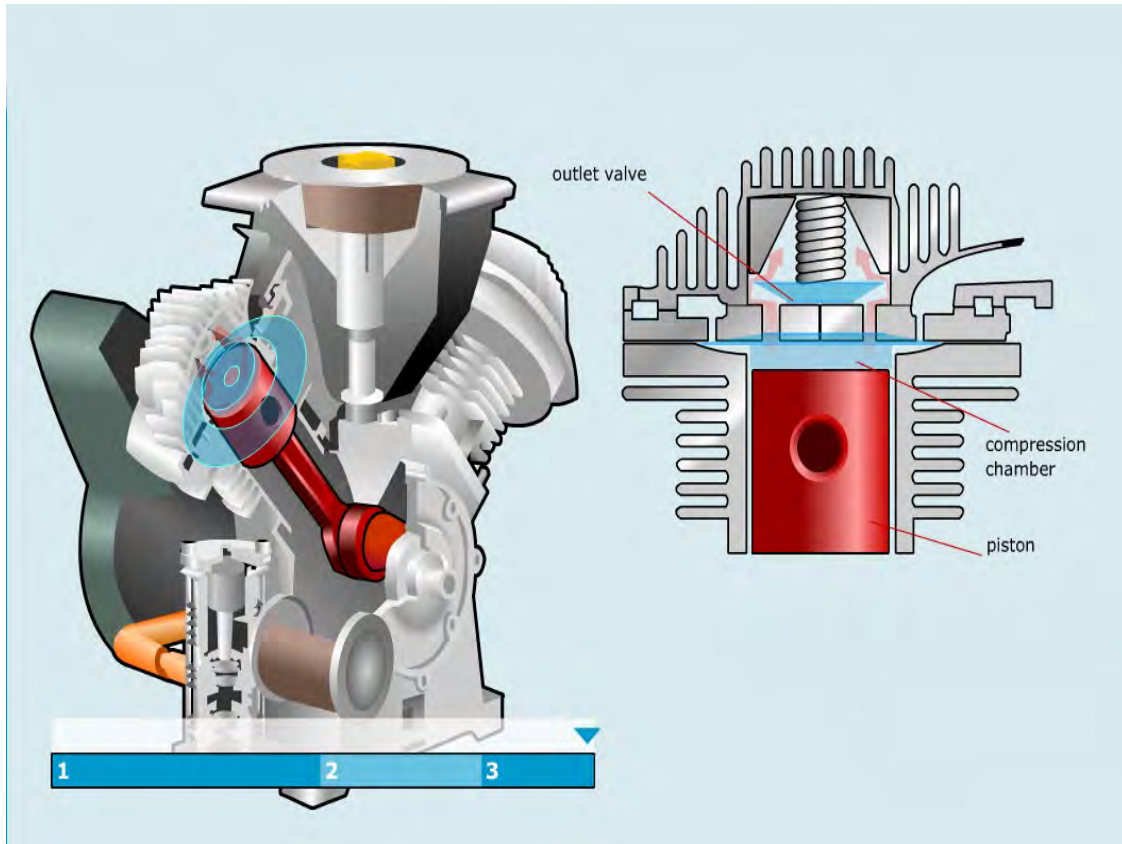
Compression Ratio

- The ratio of inlet pressure to outlet pressure stated in psia.
- Let's suppose we will have an inlet gauge pressure of 100 psig and want a final output gauge pressure of 1000 psig.
- The obvious answer is to divide 1000 by 100 and state the compression ratio as 10.
- Wrong.
- Remember that the numbers quoted were gauge pressures.
- We have to work in absolute pressures.
- That means adding atmospheric pressure (14.7 lbs. at sea level - correct this for your location) to the gauge pressures.
- After correcting for atmospheric pressure and dividing the final pressure by the inlet pressure, we get an overall compression ratio of 8.84.

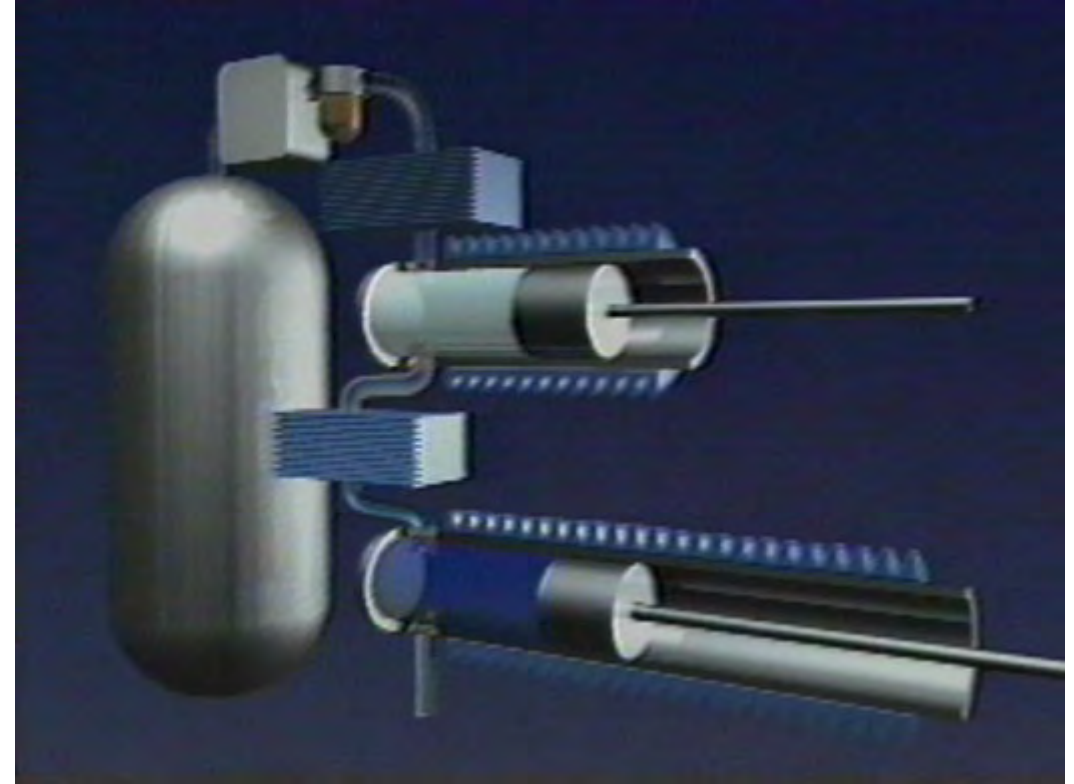
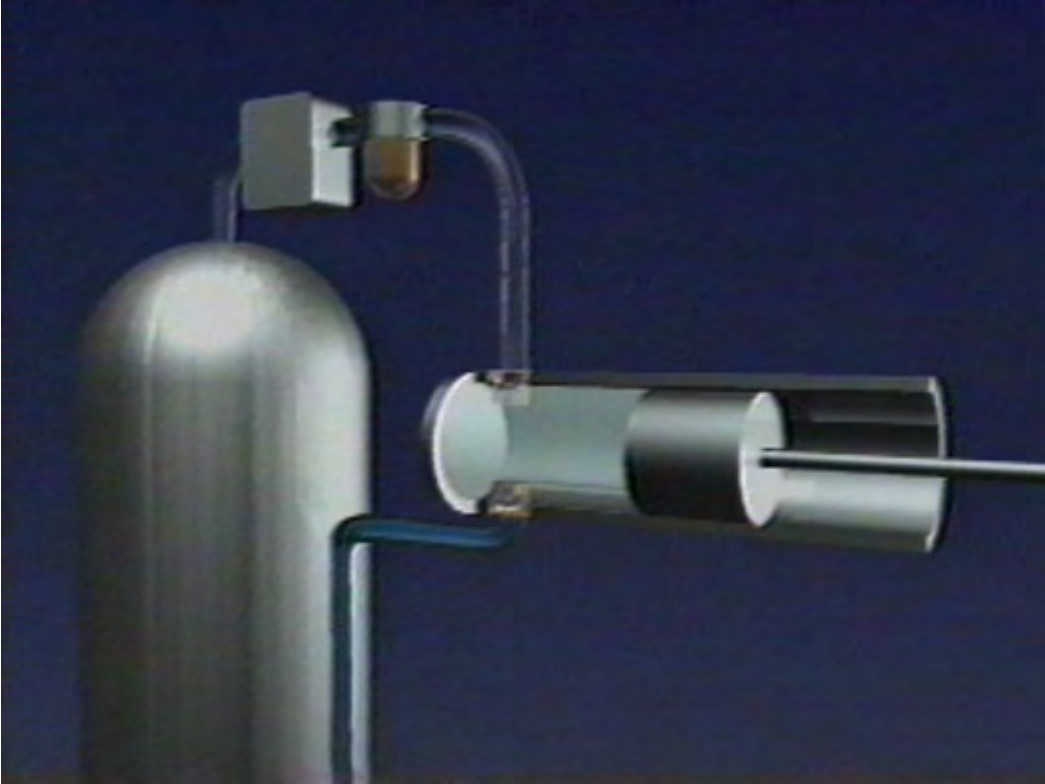
Compression Ratio

- Compressed Air applications will limit compression ratios to between 2.4 and 4.0 per stage.
- As the volume and temperature of the gas we are compressing go up, we will require a multistage unit.
- If we use a two-stage system, we take the square root of the overall compression ratio.
- The square root of 8.84 is 2.97. For a three-stage unit we take the cube root of 8.84, which is 2.06.
- For successive numbers of stages, we take the n^{th} root of the overall compression ratio where n is the number of stages.

Reciprocation Compressors



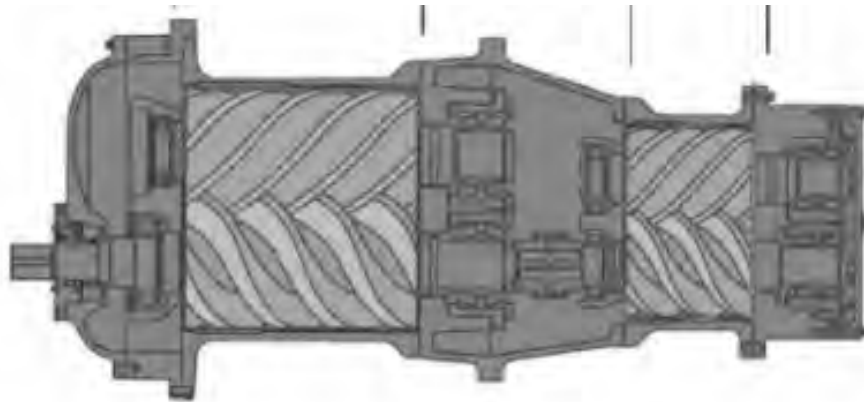
Single Vs Two Stage



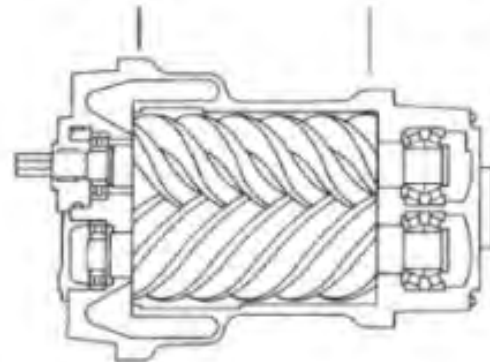
Rotary Screw

- Lubricated rotary screw compressors are available in single stage, operating from 60-200 psig. As well as two stage compressors, which can operate as high as 290 psig.

Two Stage Compressor

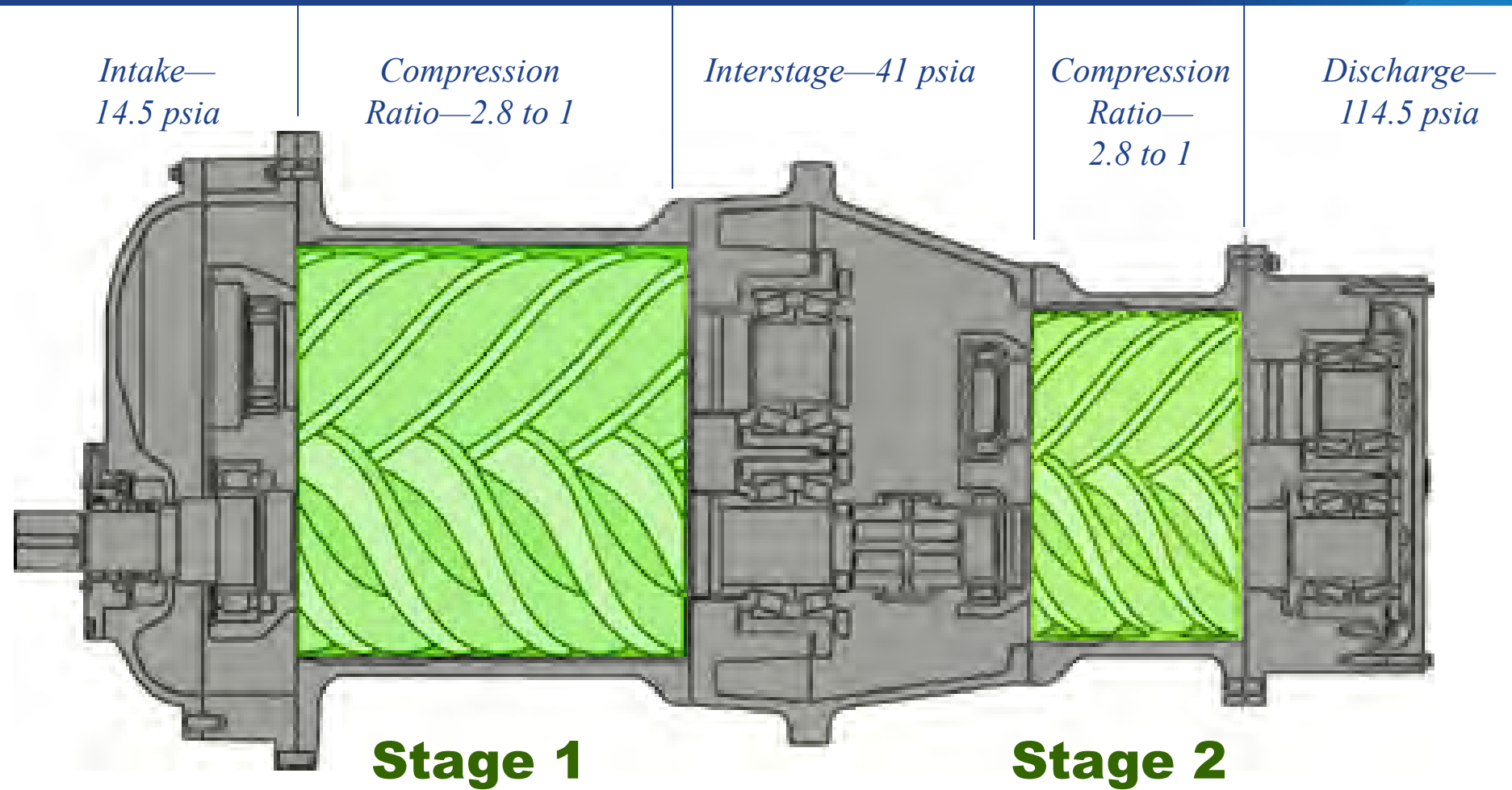


Single Stage Compressor



Two Stage Compressor

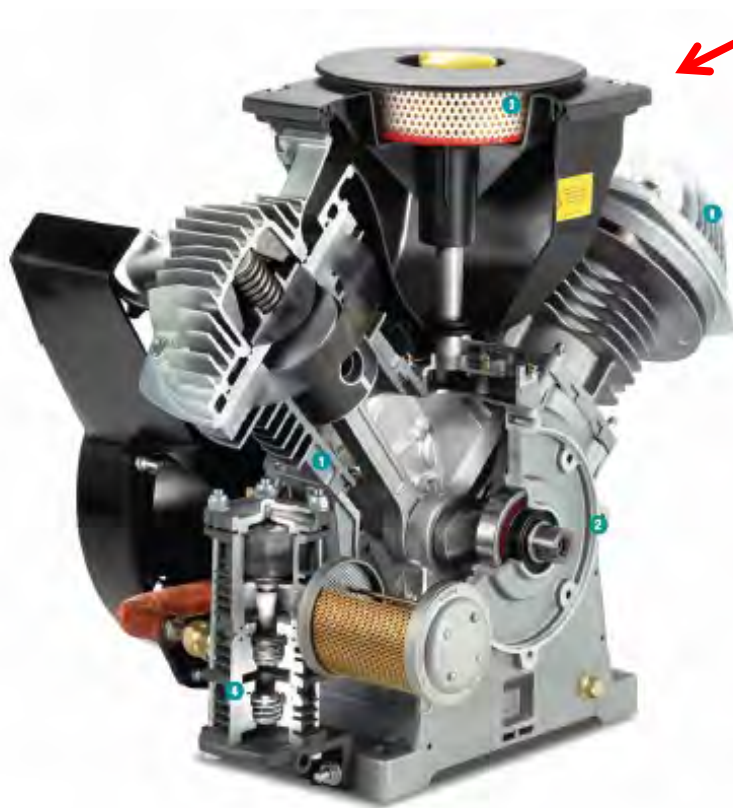
Two Stage



Two-stage Compressor

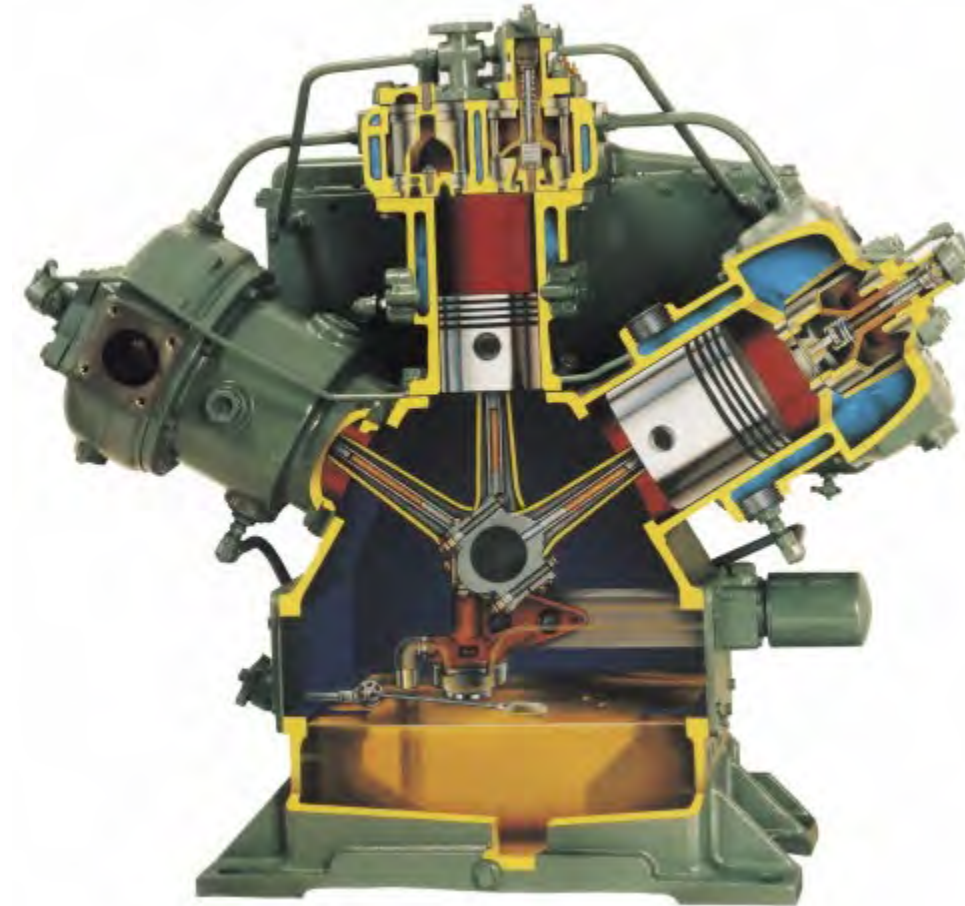
Oil-Less

- Oil-less compressors have no oil in the compression chamber or in the crank case. They can be Reciprocating or Rotary.

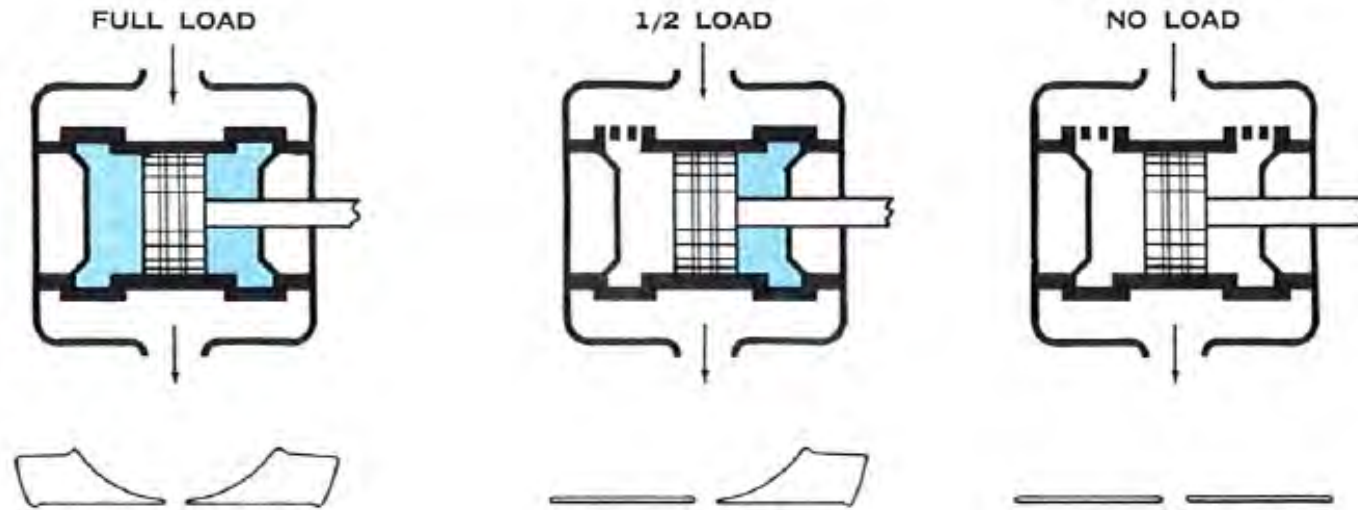


Double Acting

- Cooling water jackets normally are incorporated in the cylinders and cylinder heads to remove some of the heat of compression, maintain thermal stability and improve lubrication, reducing carbonization of valve parts.
- Water cooling jackets around valves and piston rod packing are essential due to localized heating. Valves may be located in the cylinders or in the cylinder heads.

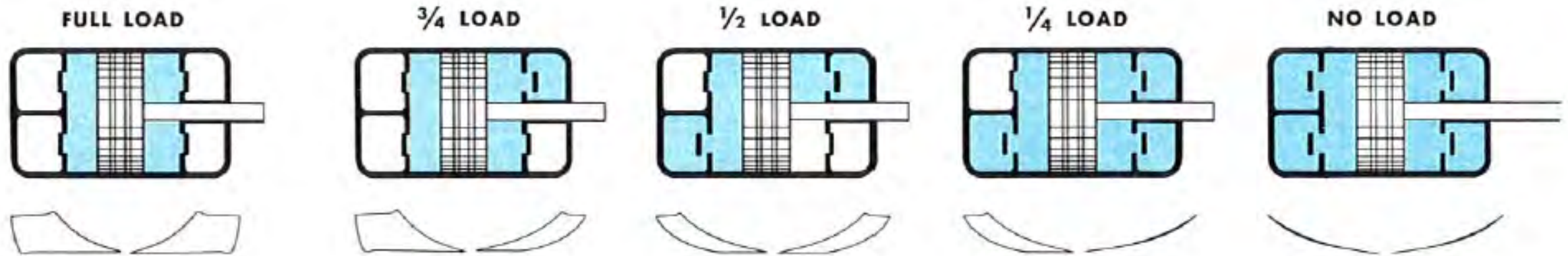


Three Step Unloading



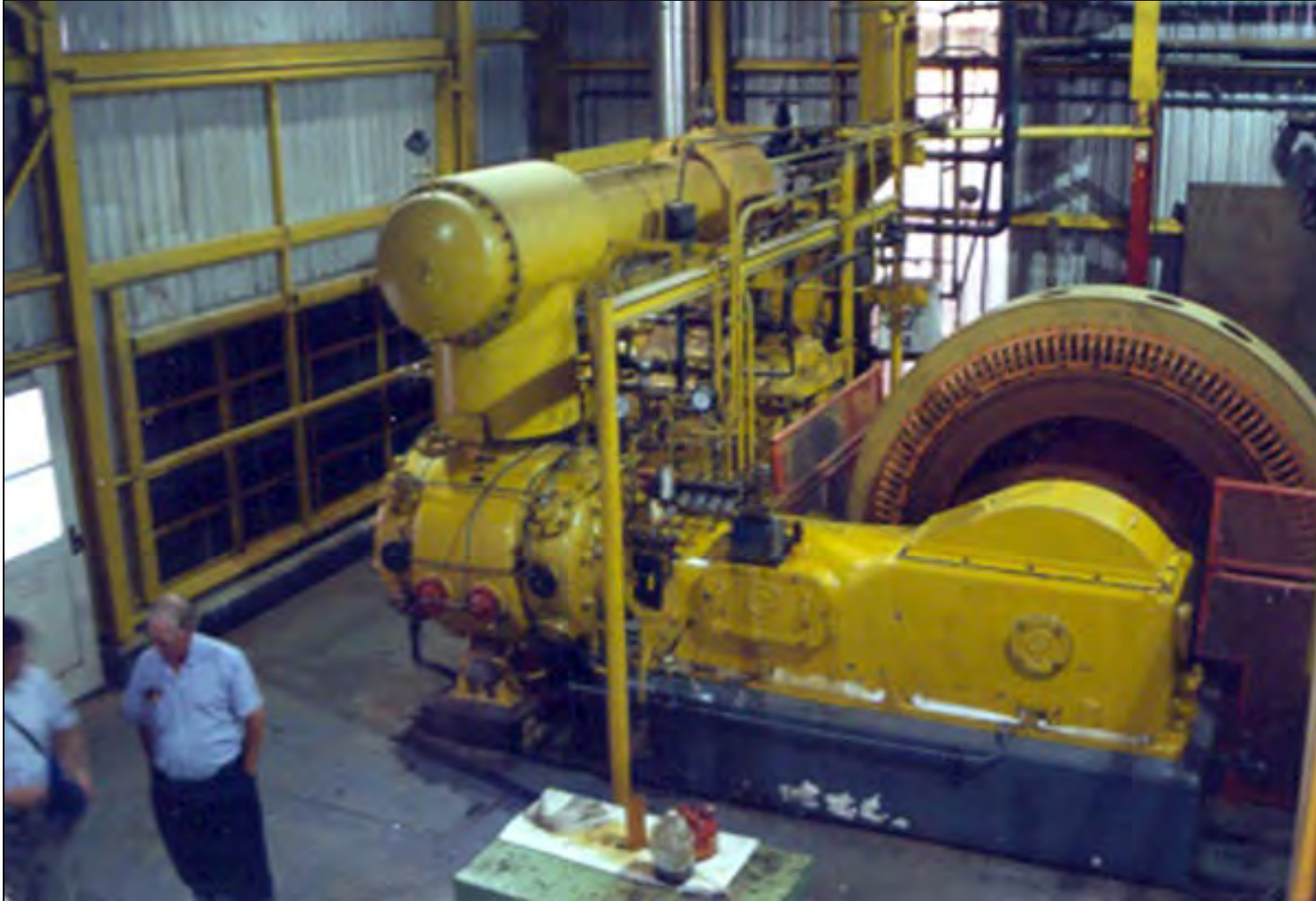
- Unloaders hold the inlet valves open to unload the cylinders, both for reducing the capacity of the compressor and to provide easy starting.
- All inlet valves are equipped with unloaders to provide free and full passage area, thereby reducing unloaded horsepower.
- For one-half load, one end of each cylinder is unloaded; for no load both ends are unloaded.
- The unloaders are air-controlled by the 3-step regulator.

Five Step Using Clearance Control



- The principle of 5-Step Clearance Control Regulation is to increase the cylinder clearance by definite and equal steps as shown by the diagram, thus reducing the cylinder capacity whenever the demand falls off.
- When one clearance valve is open, the volume of that pocket is added to the normal cylinder clearance volume.
- This cuts in half the amount of air taken into that end of the cylinder.
- The sizes of the pockets are proportioned so that when both pockets at one end are opened, no air is taken into that end of the cylinder when operating at rated pressure.

Water-cooled, 900 HP Two Stage, Double Acting, Recip



Two Stage, Double Acting, Recip

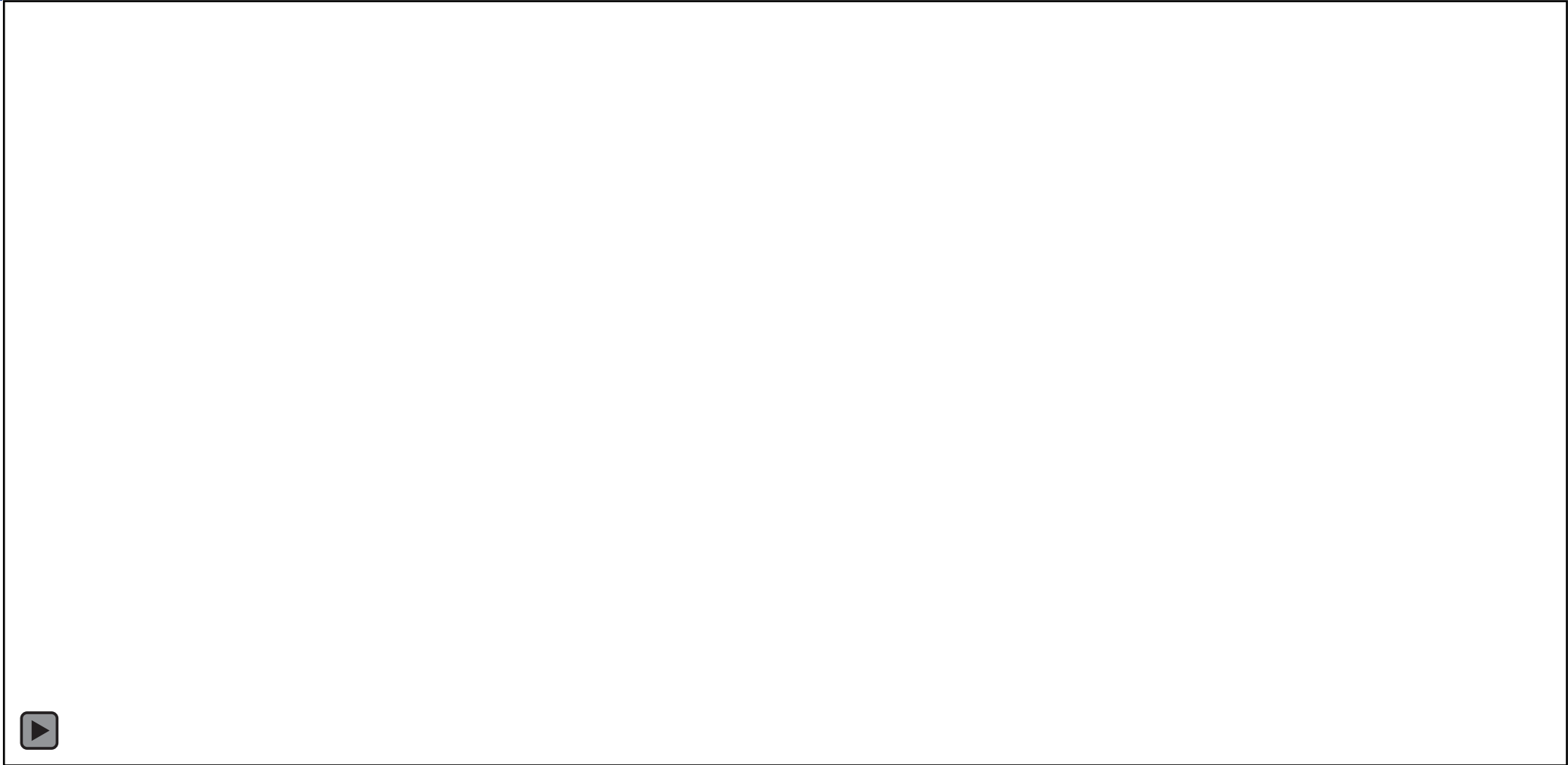


Oil Free Reciprocating

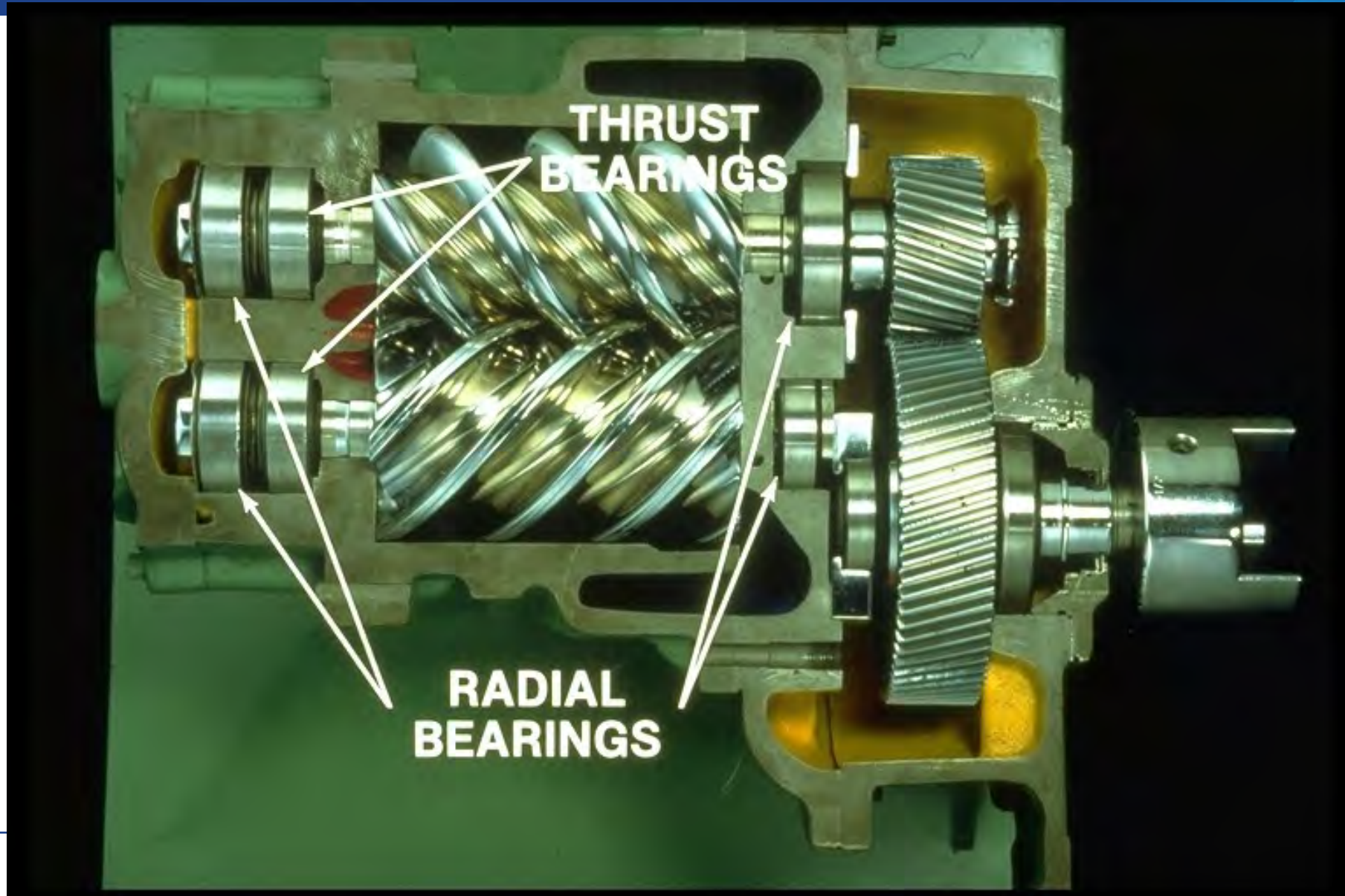
- Oil-free or oil-less reciprocating compressors do not have any lubricant fed to the cylinder or cylinders.
- Piston rings and rod packing usually are of PTFE based materials, carbon, or other synthetic materials, which can operate without added lubrication.



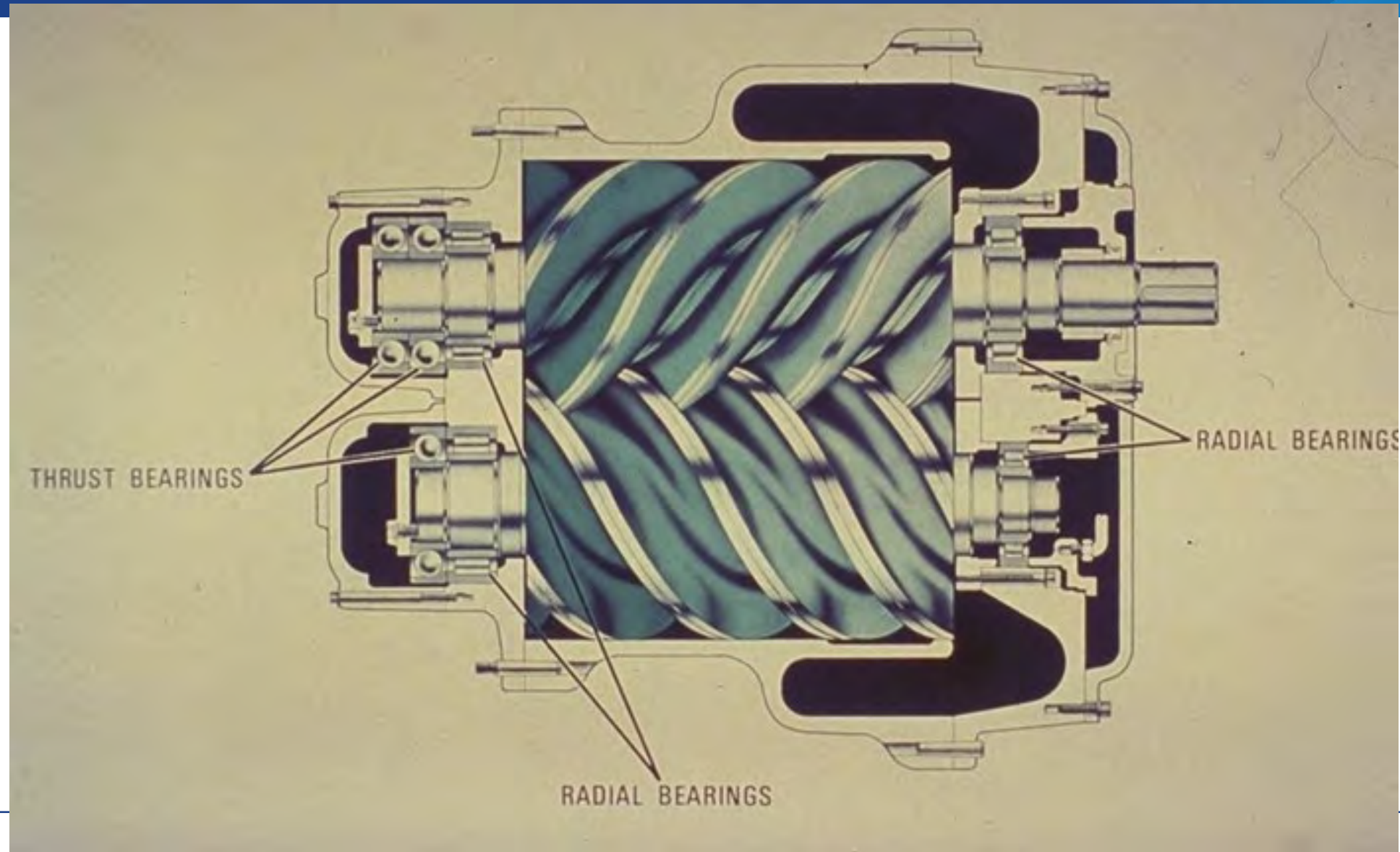
Rotary Screw

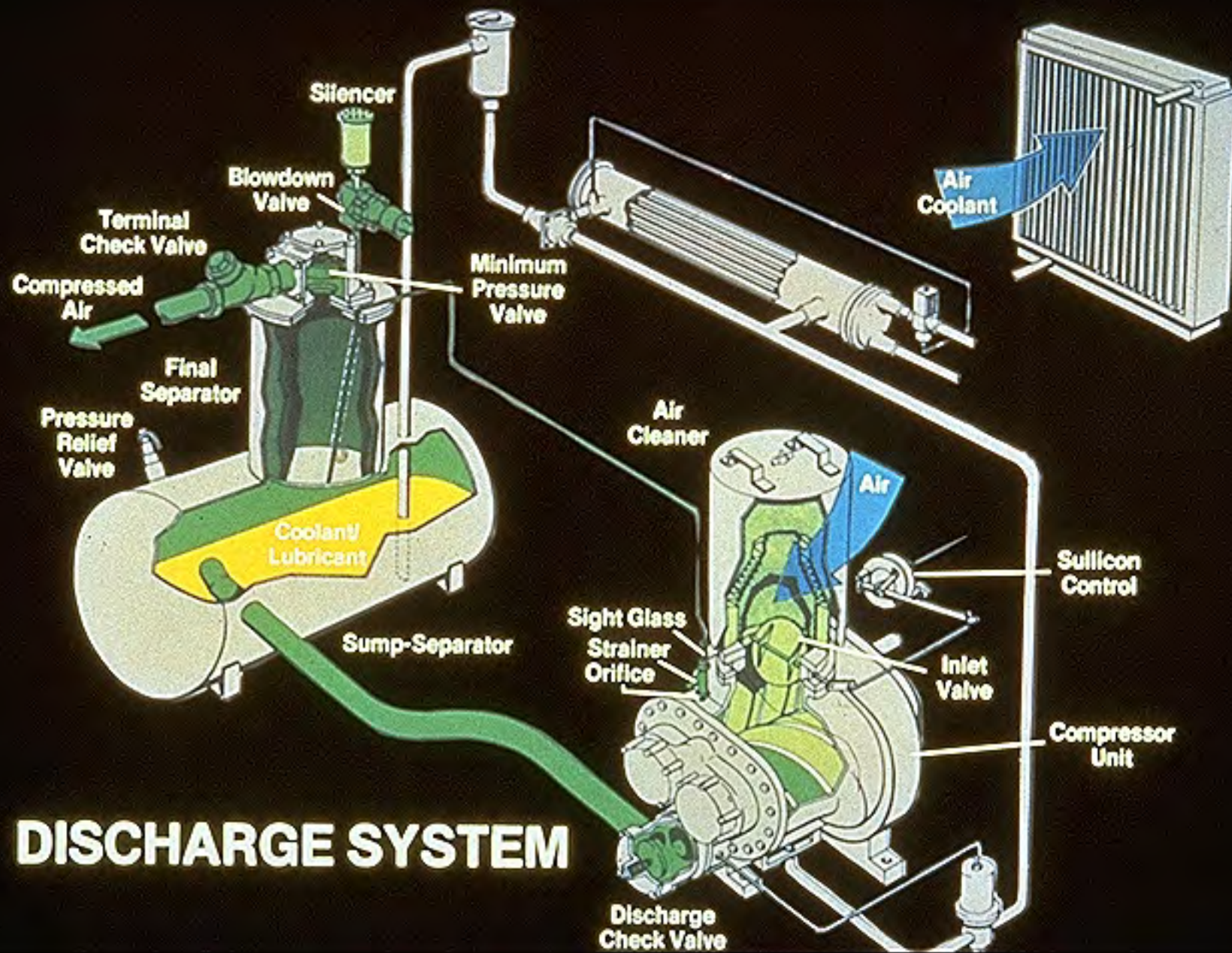


Gear Drive Rotary Screw Air End



Direct Drive Rotary Screw Air End





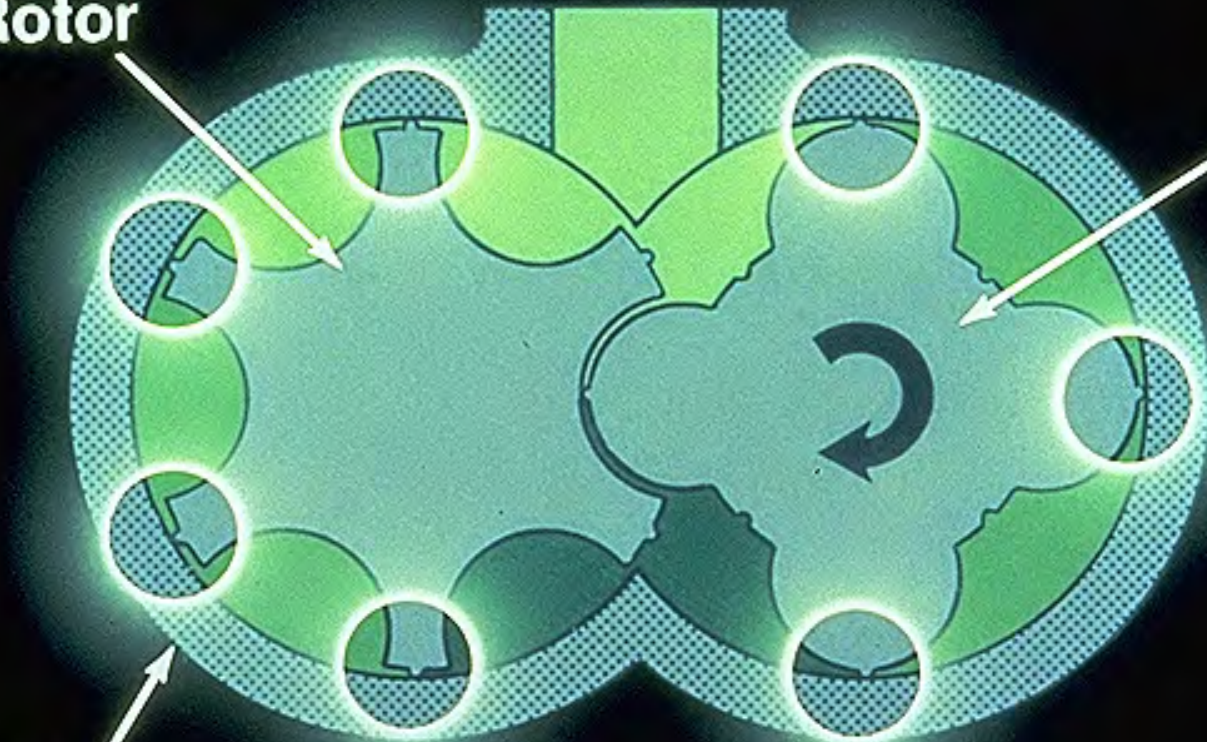
DISCHARGE SYSTEM

AIR LEAKAGE

Female
Rotor

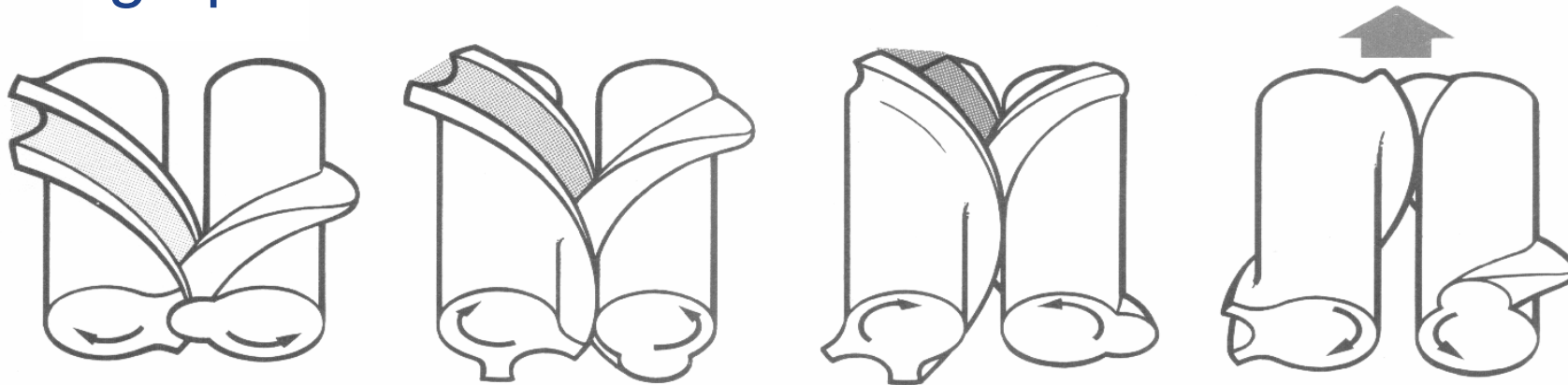
Male
Rotor

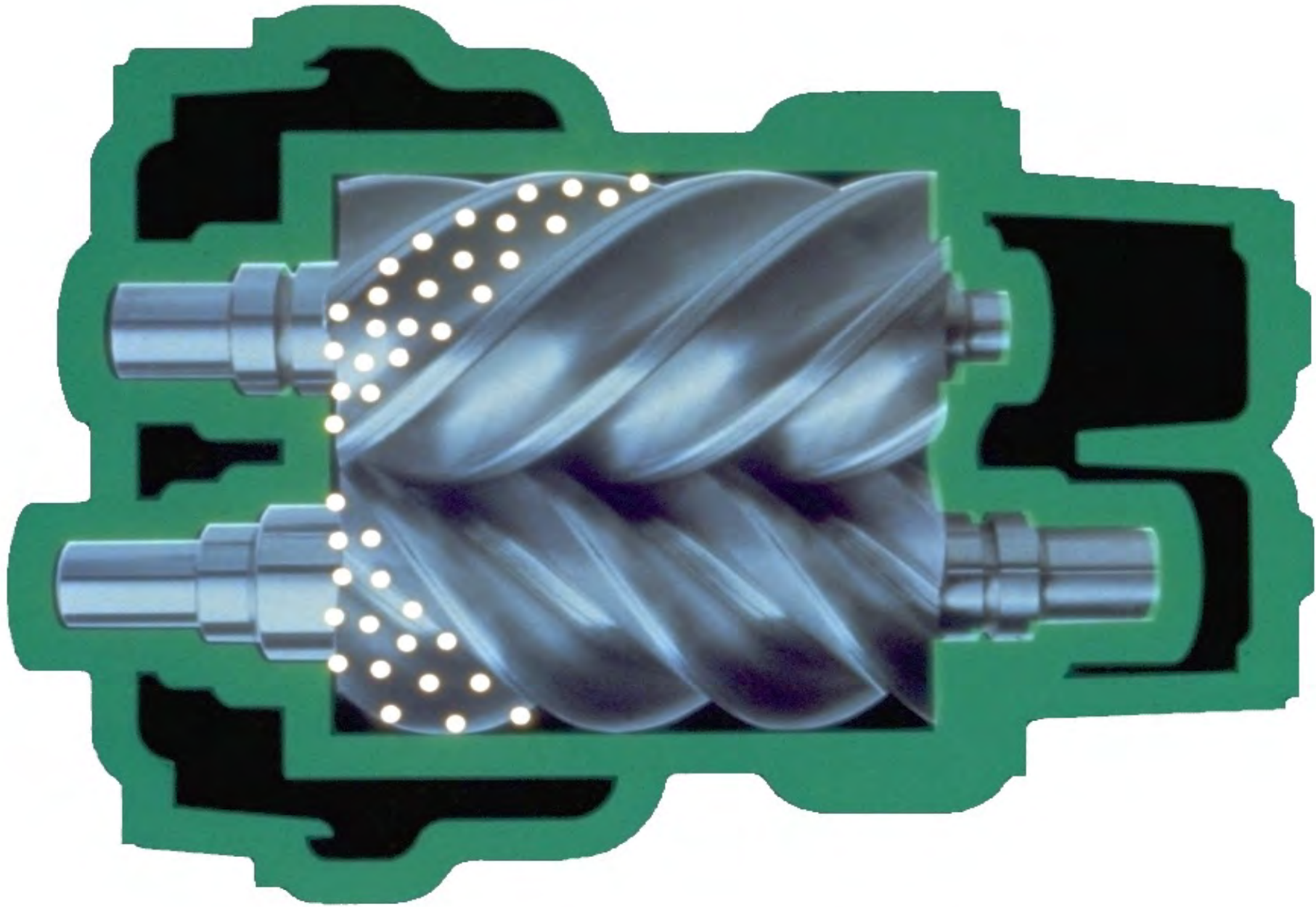
Stator



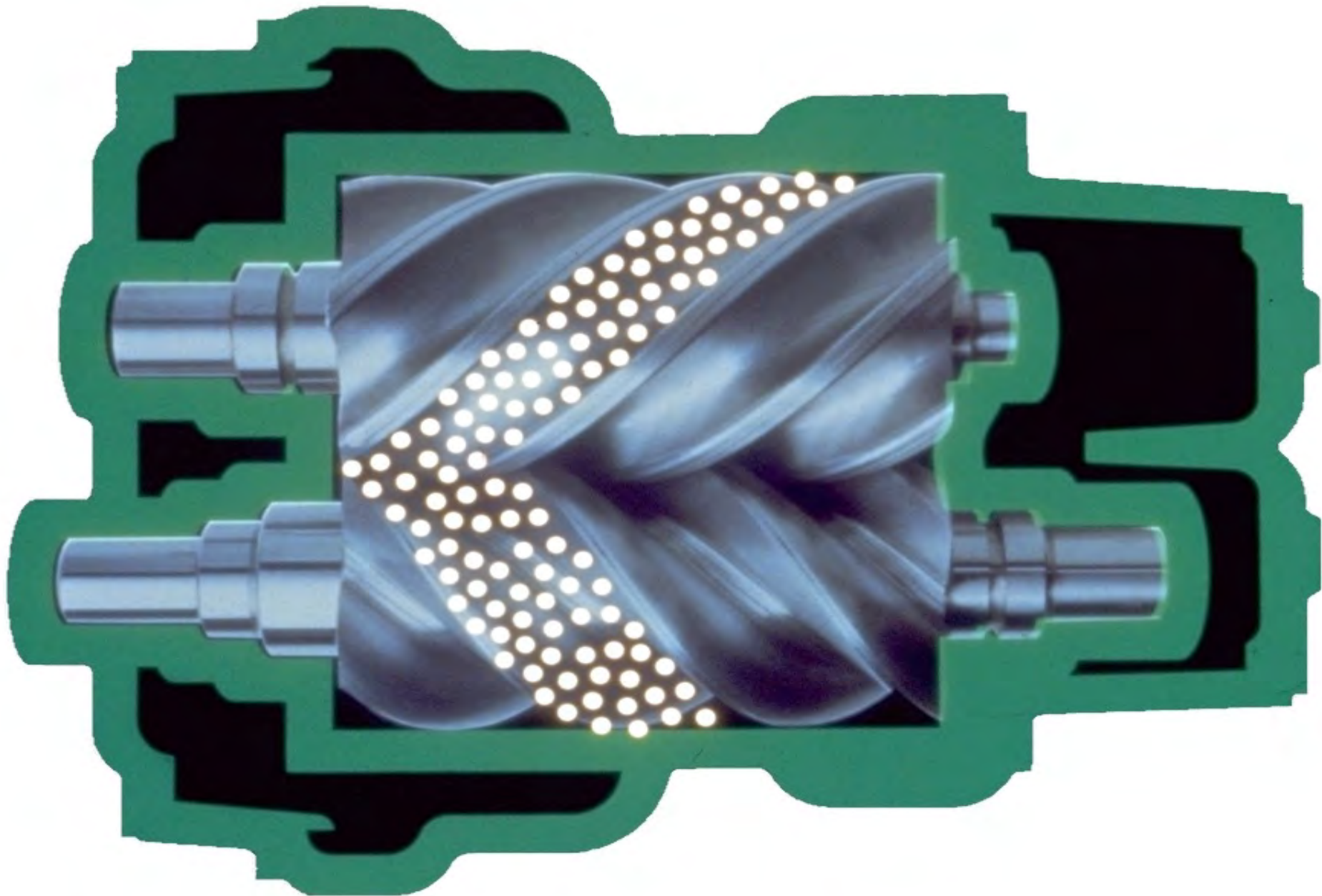
Rotary Screw Compression

- Rotary Screw compression process--traps consecutive quantities of gas between the male lobe and female flute.
- As screw turns, the enclosed volume decreases, thus increasing the pressure.
- Compressed air is then pushed out of the element at the discharge port.

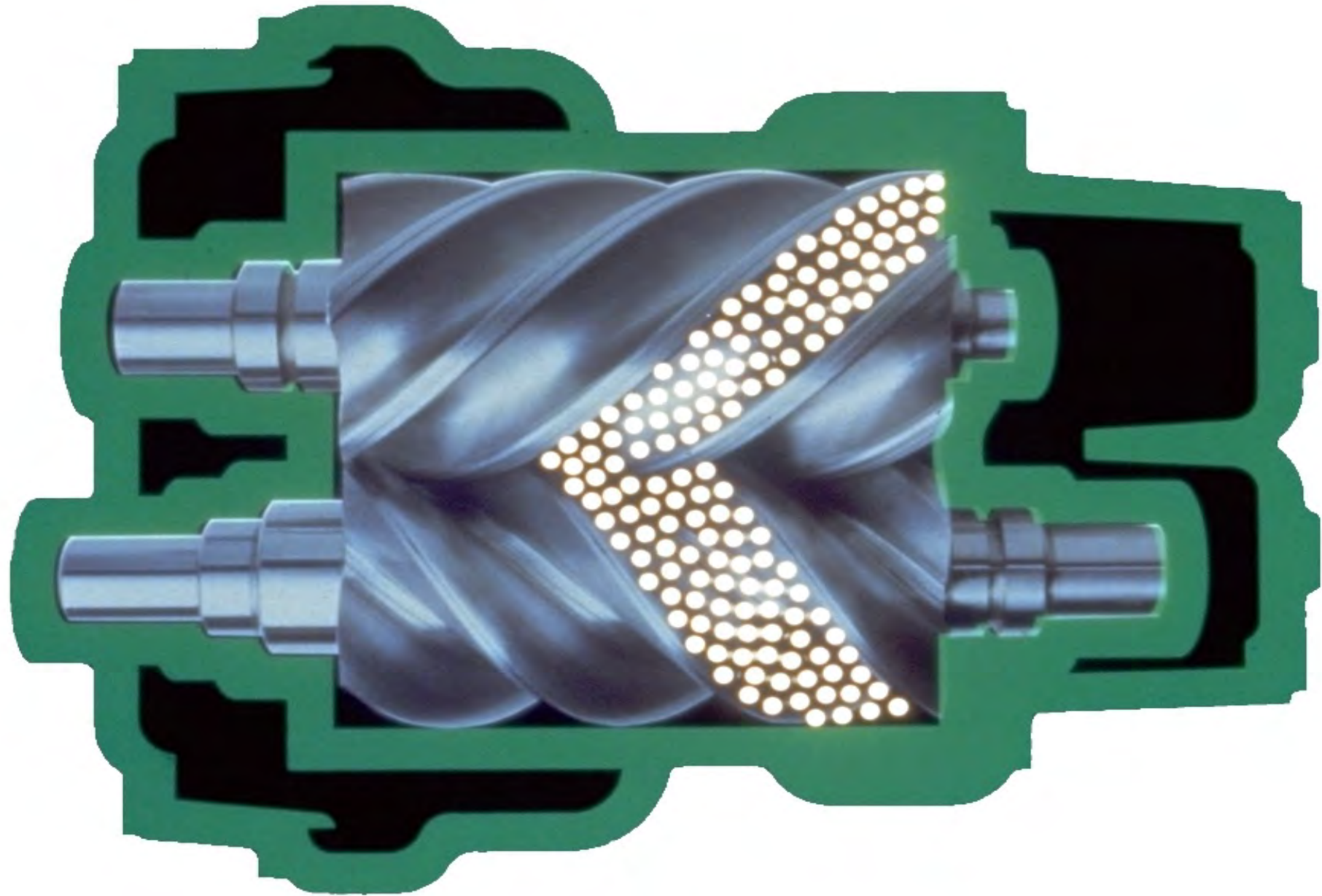




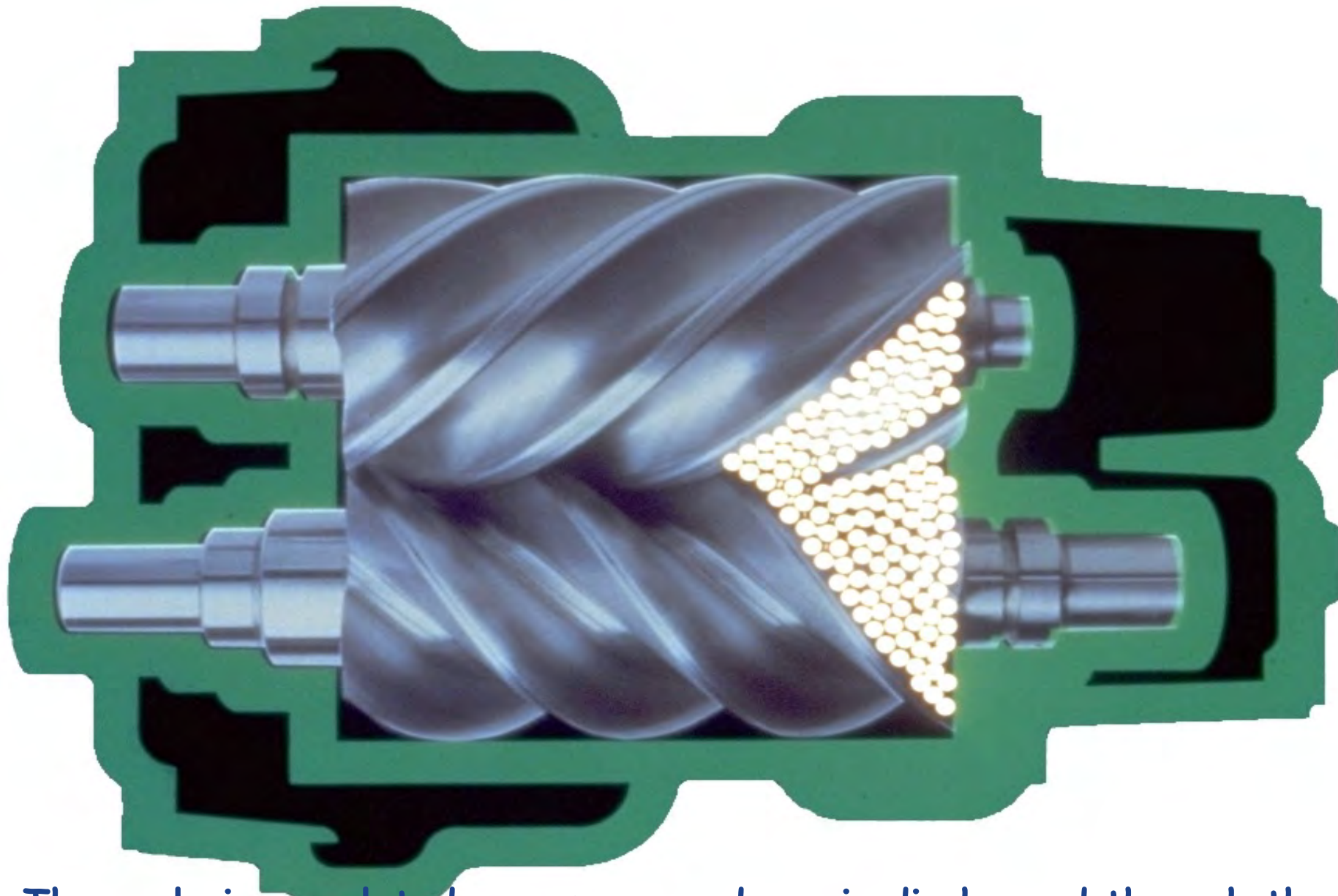
Low pressure gas is drawn axially into the unit as the rotors turn past the intake port in the housing



The rotors have turned past the intake port; gas is trapped in the unit housing and rotor cavities.



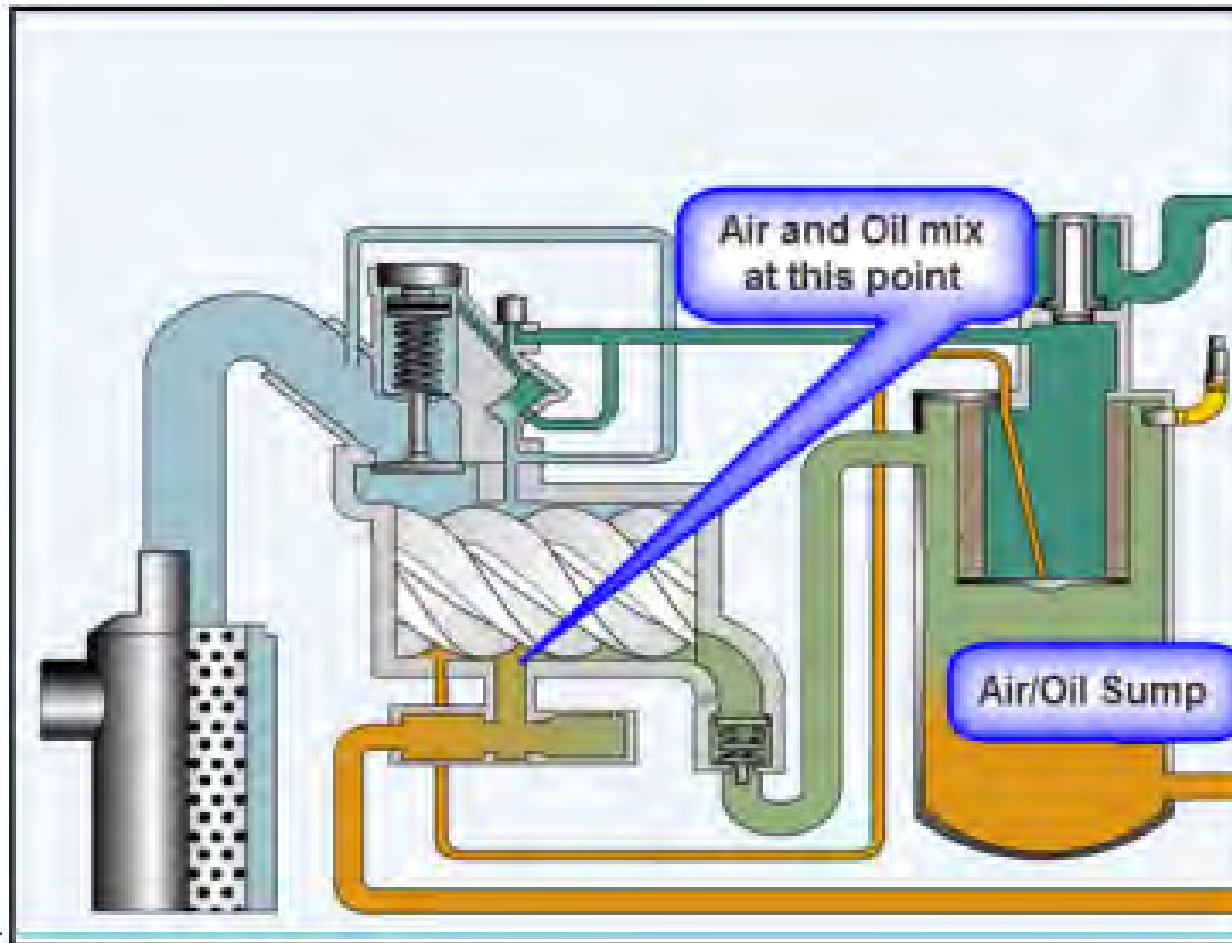
As the rotors continue to turn, lobes reduce the volume in the cavities, raising the pressure of the trapped gas.



The cycle is completed as compressed gas is discharged through the outlet port at the bottom of the housing to atmosphere or to some positive pressure as may be required by the process

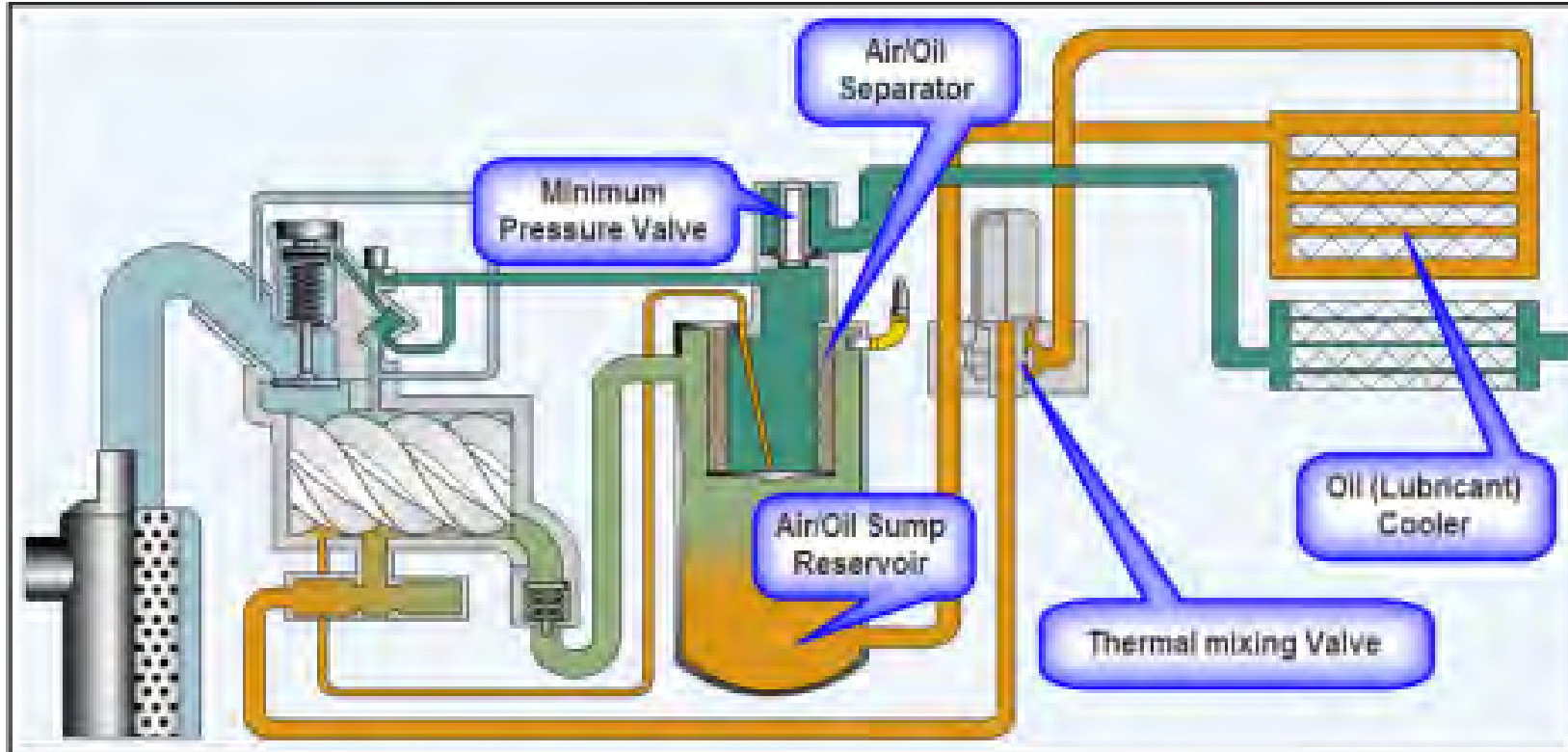
Rotary Screw

- In an oil injected rotary screw compressor, the air and lubricant mix for cooling, sealing and lubrication, the lubricant is separated later, within the full compression cycle.



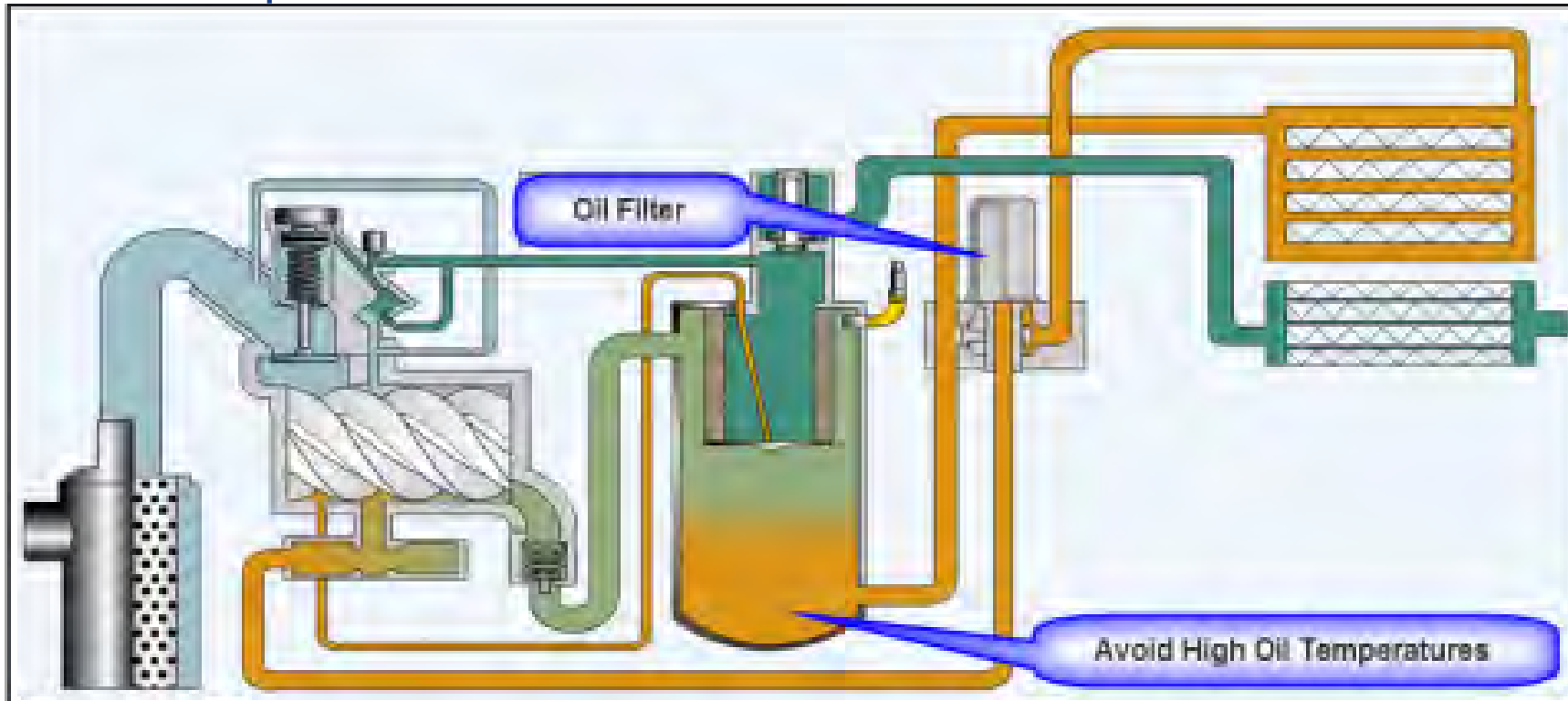
Rotary Screw

- A minimum pressure valve assures proper lubricant circulation and separation. Once separated, it is returned to the air/oil reservoir.
- A lubricant thermal mixing valve is used to maintain a constant and correct injection temperature.

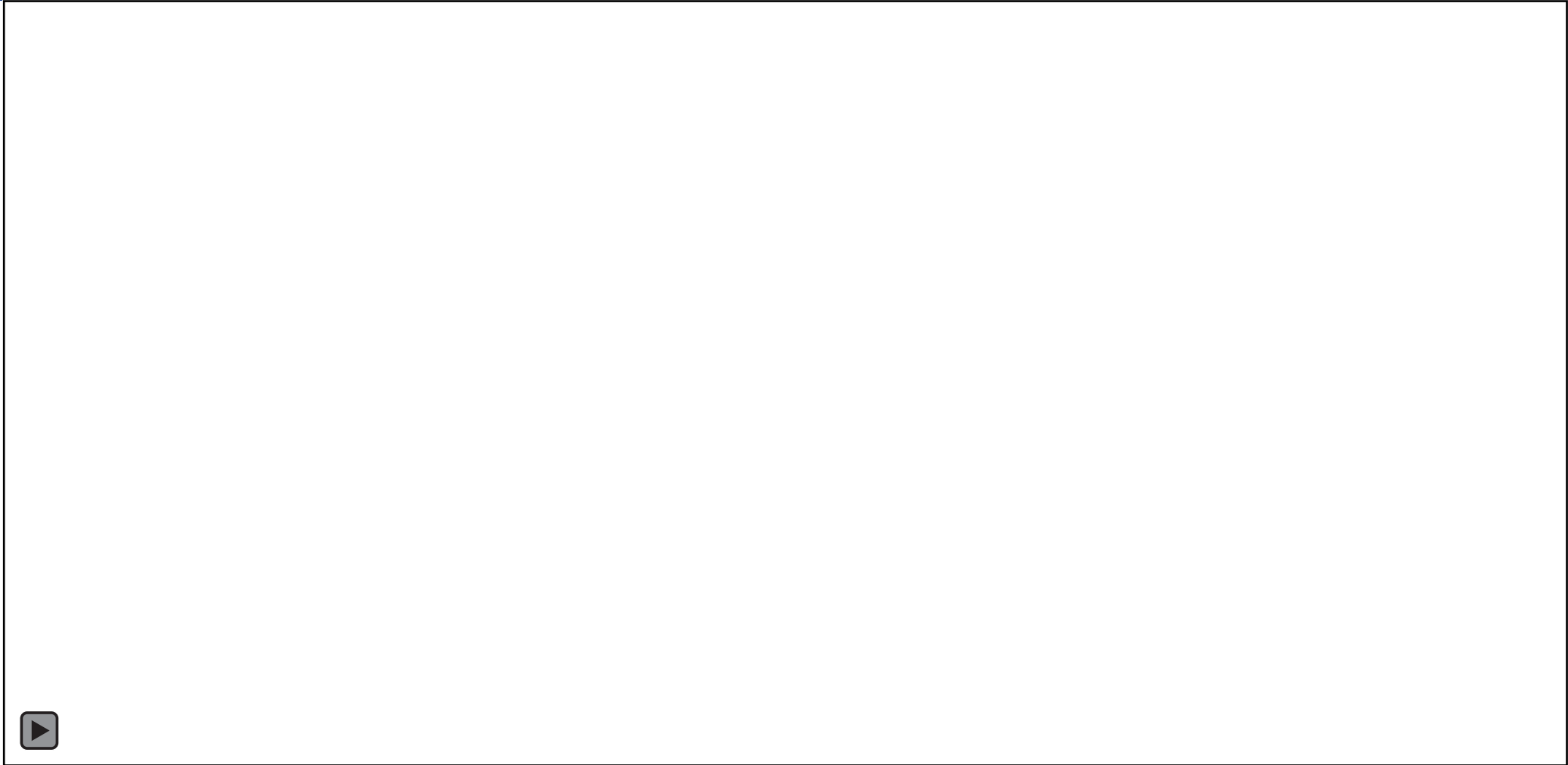


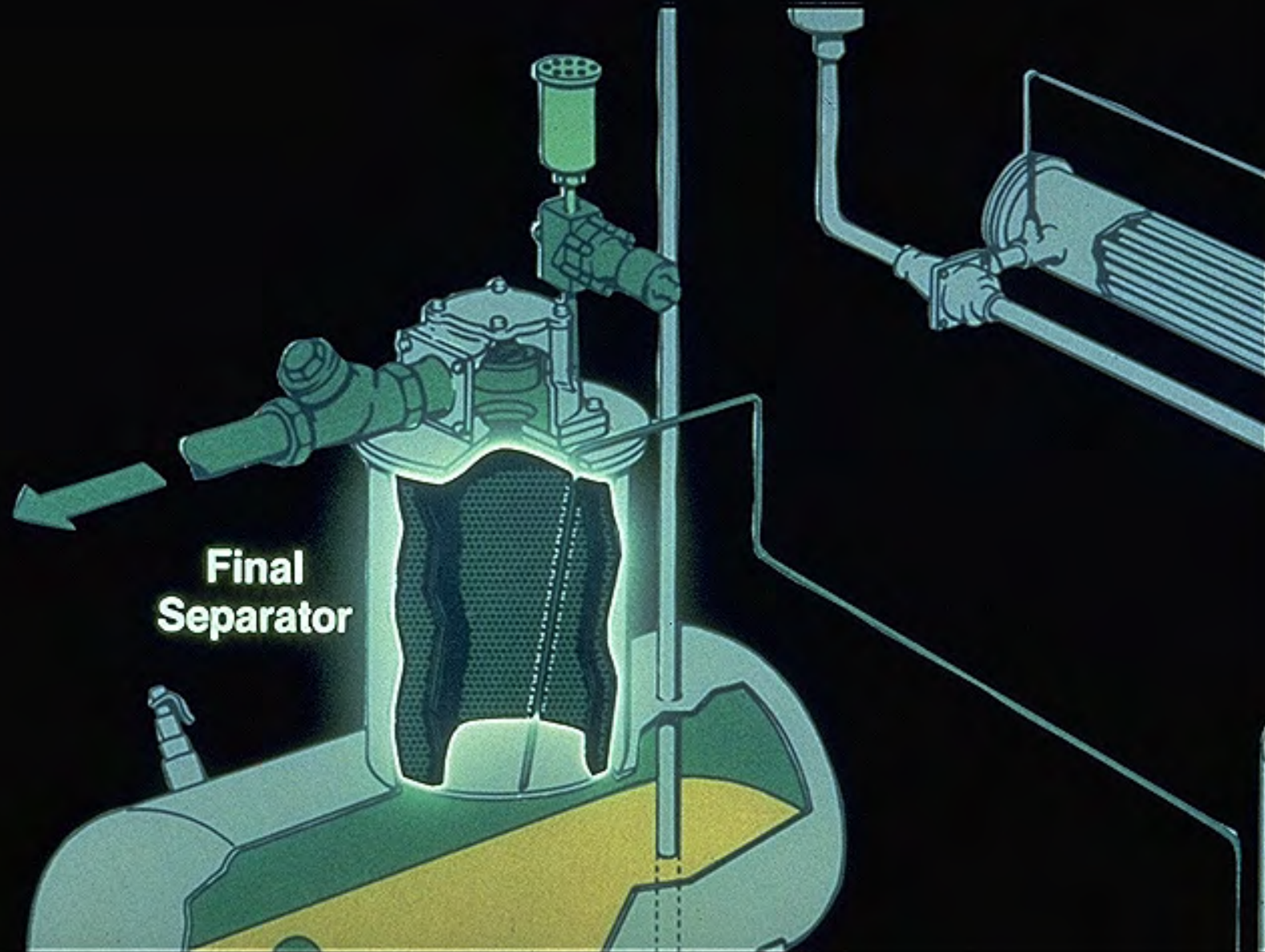
Rotary Screw

- Suitable design temperature and viscosity of the lubricant are required for proper lubrication, sealing and cooling.
- Avoid excessive temperatures to avoid breakdown of lubricant.
- Important to keep lubricant clean.



Rotary Screw





SEPARATOR ELEMENT REPLACEMENT

SECONDARY
ELEMENT

PRIMARY
ELEMENT

RETURN
LINES

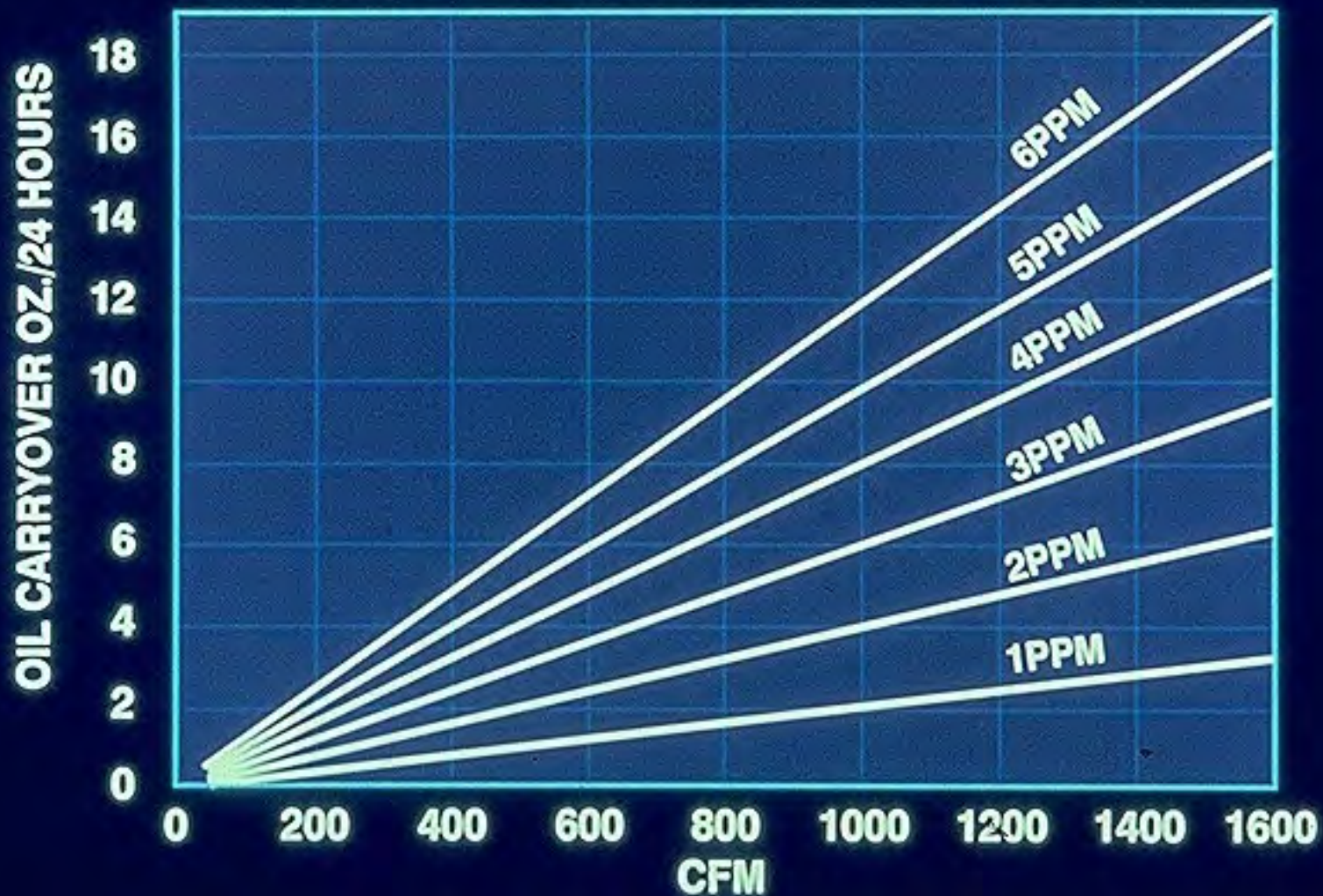
MPV/
CHECK VALVE

CAPSCREW

LOCK
WASHER

THE VALUE OF A SEPARATOR ELEMENT

OIL CARRYOVER OUNCES PER/HOURS CONVERSION

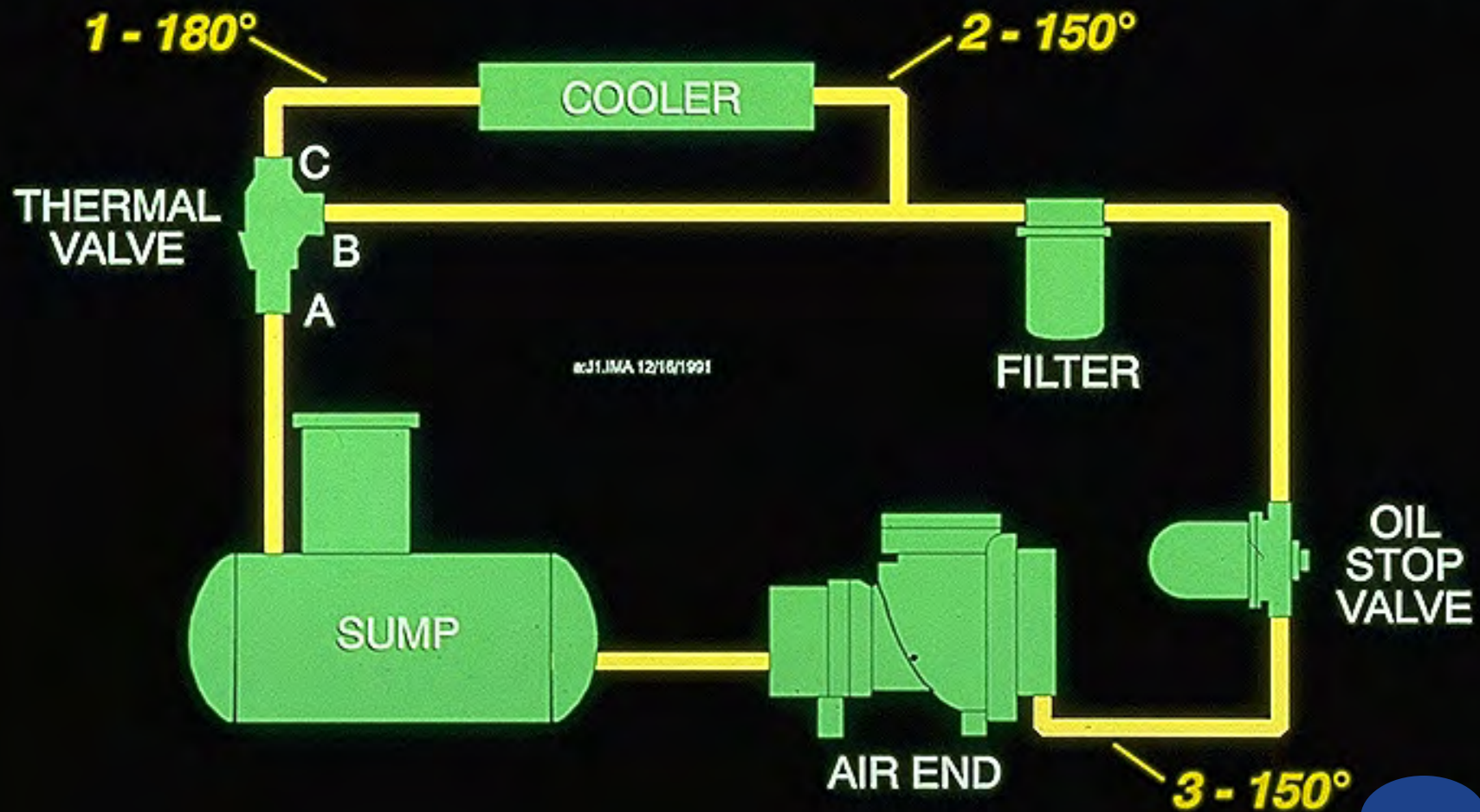


Rotary Screw

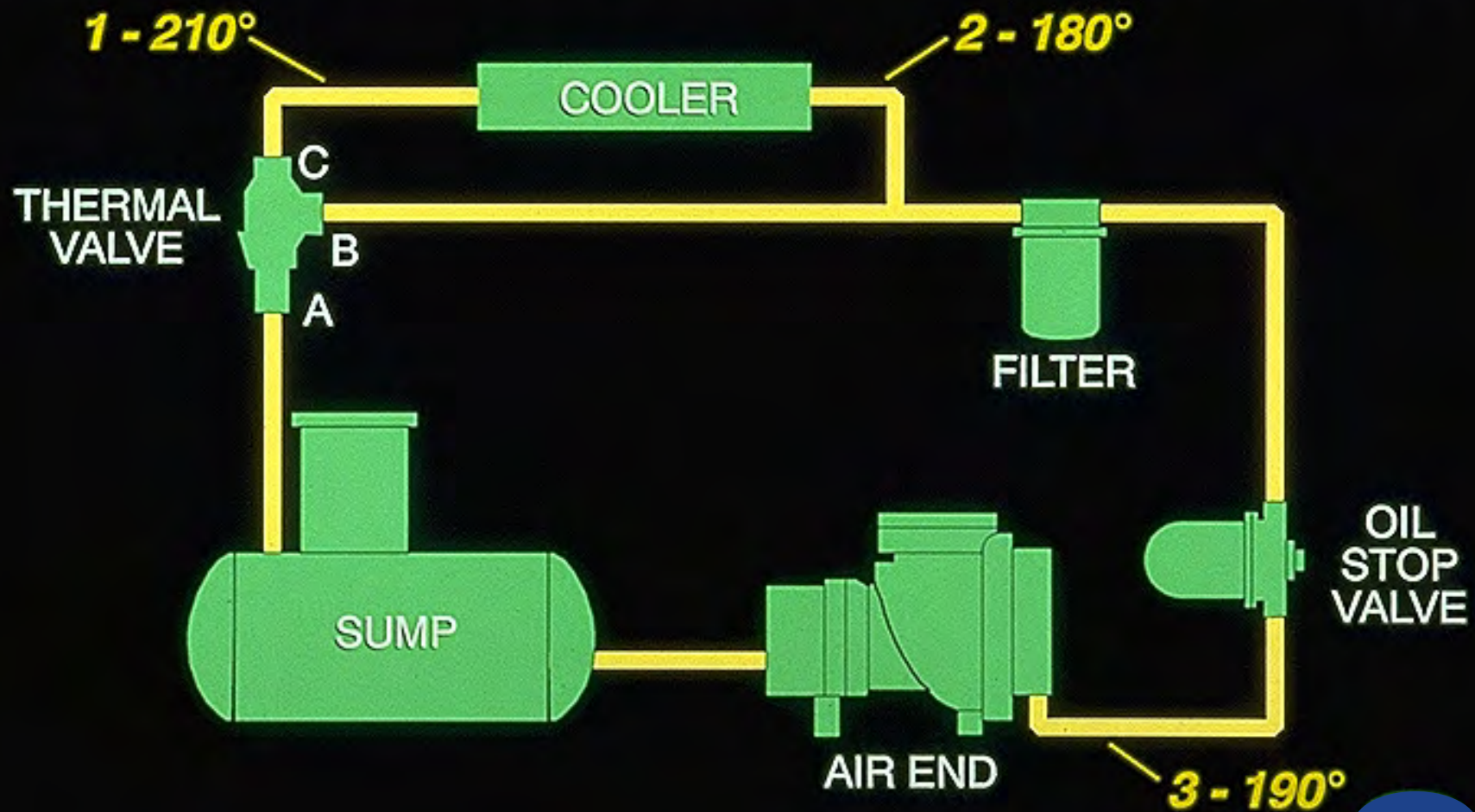
- All air-cooled air compressors need to be operated in well ventilated and clean environments with fairly constant temperatures.



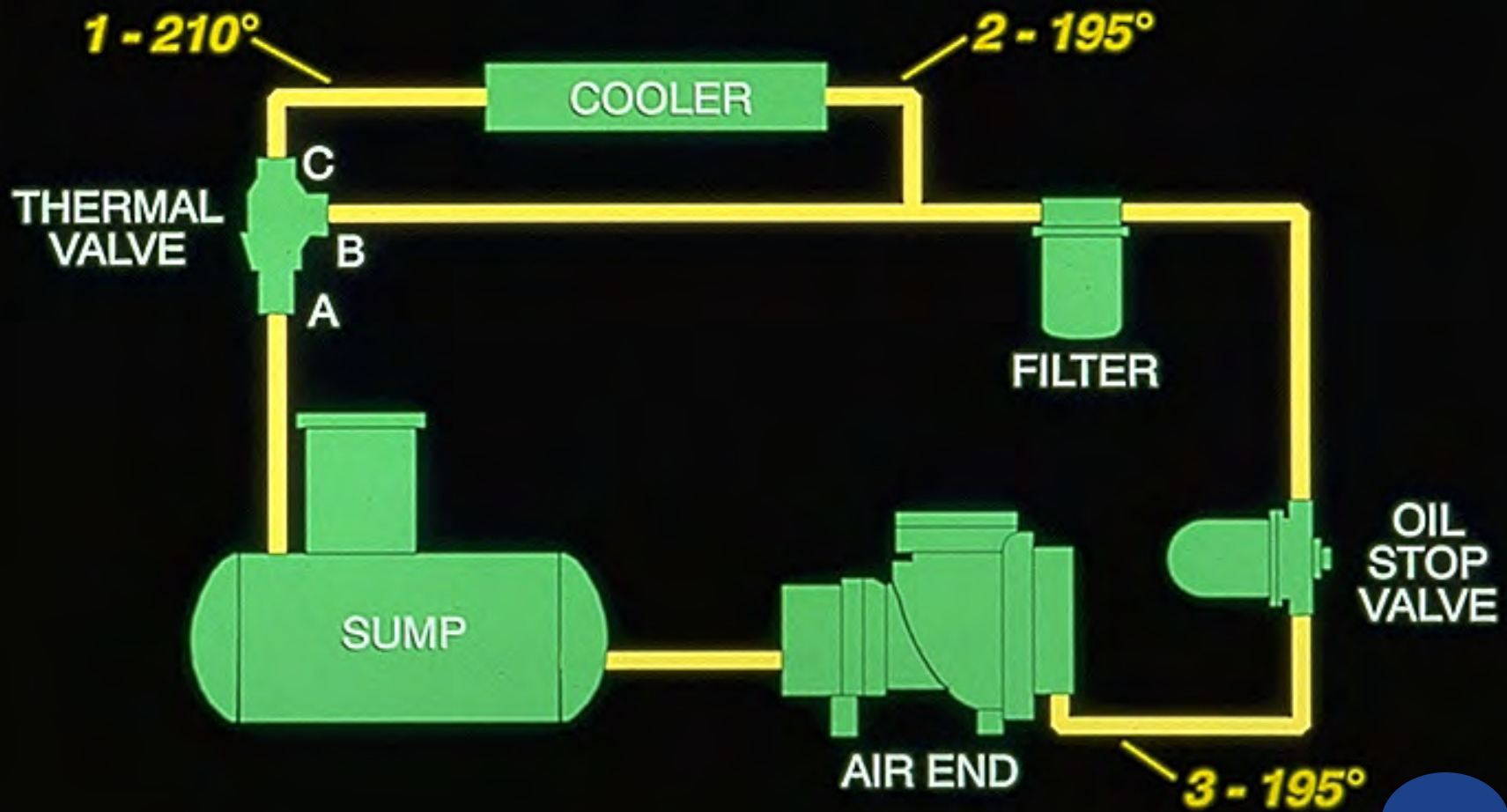
180°F COMPRESSOR DISCHARGE TEMPERATURE



210°F COMPRESSOR DISCHARGE TEMPERATURE



210°F COMPRESSOR DISCHARGE TEMPERATURE



Oil Free Rotary

- Lubricant-free rotary screw air compressors are also a positive displacement type - Two distinct designs are available:

Dry Rotary Screw



Water Injected Screw



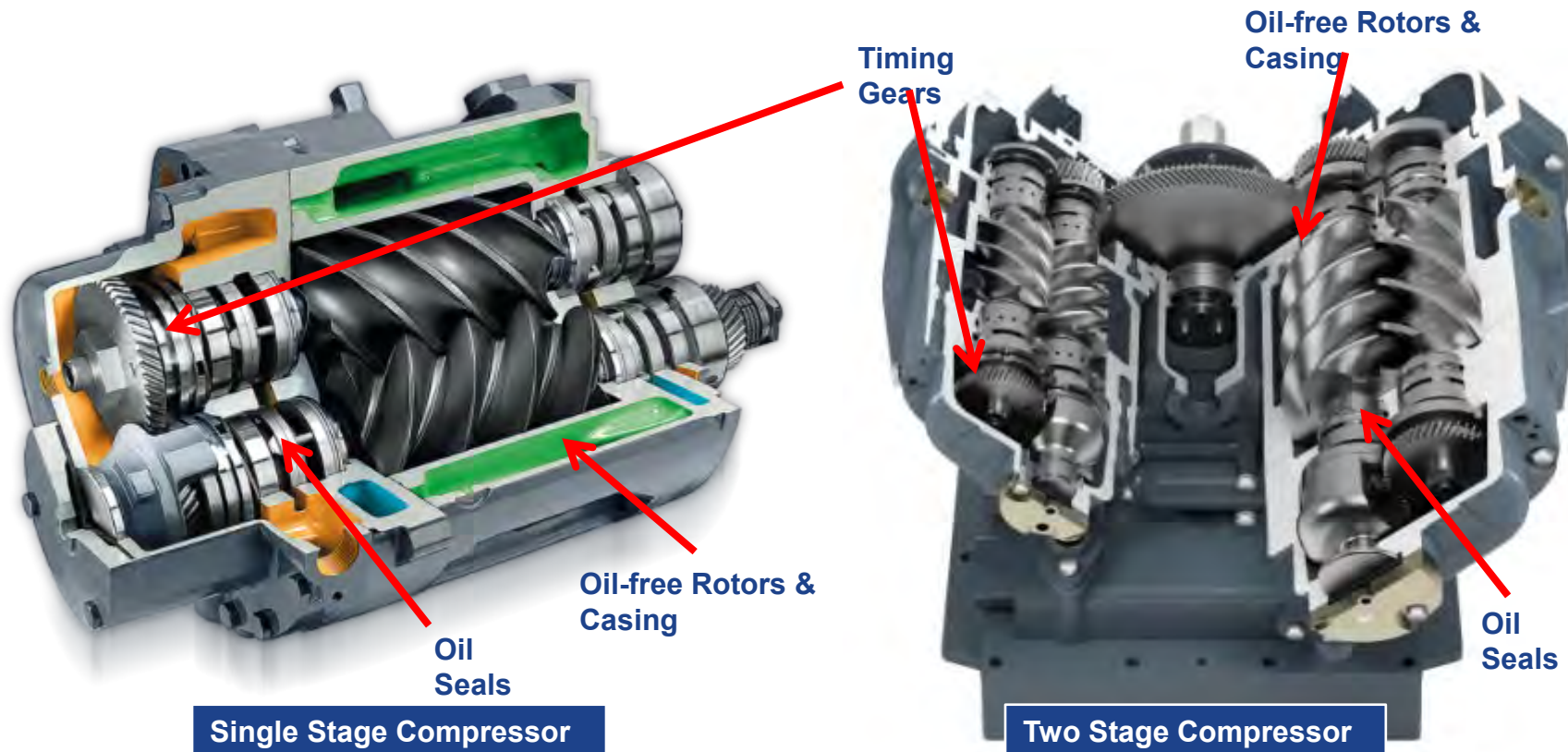
Lubricant-Free Rotary Screw Compressors



- Since there is no injected fluid to remove the heat of compression as done with lubricant injected two stage compressors, most oil free designs use two stages of compression, with an intercooler between the stages and an aftercooler after the second stage.

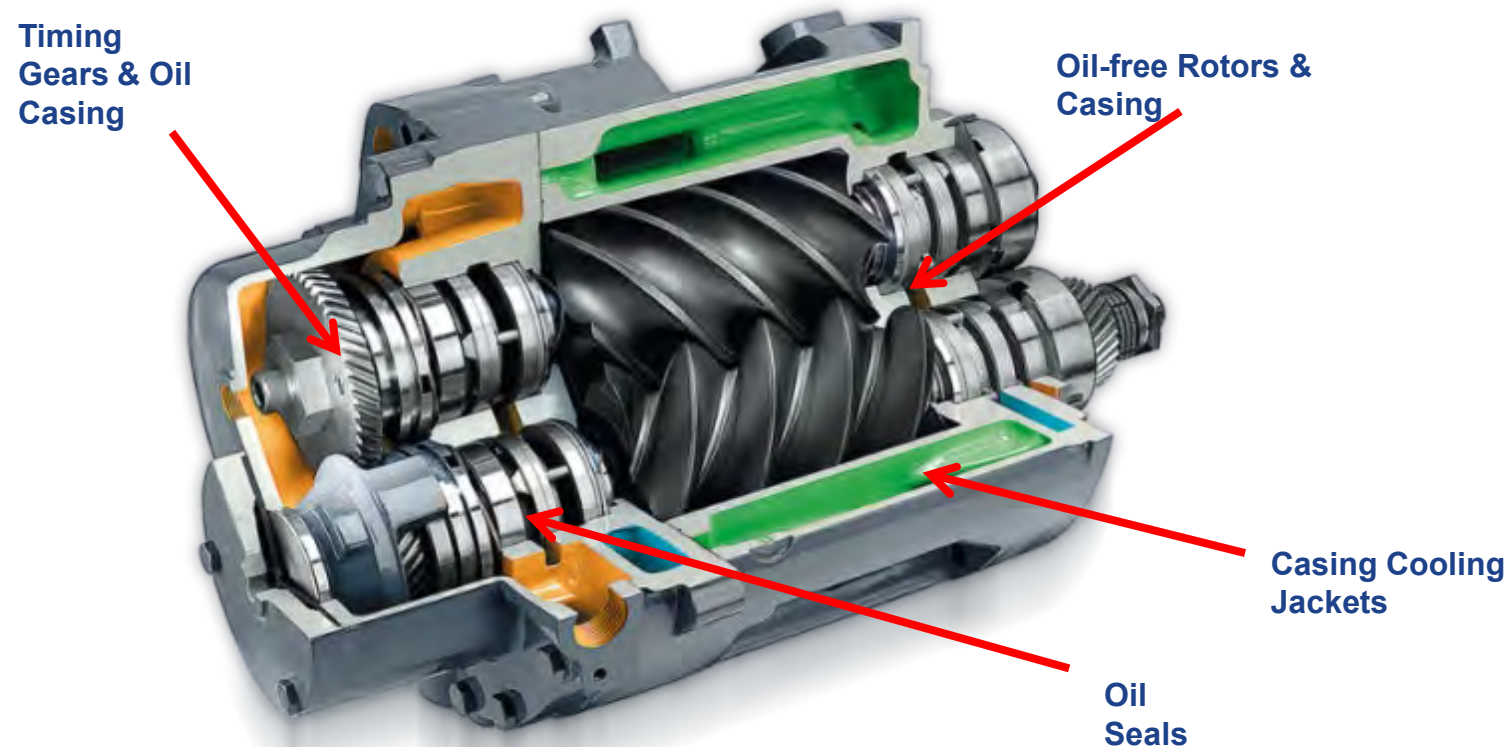
Oil Free Rotary

- Dry-type lubricant-free rotary screw compressors have a range up to 1,200 horsepower and over 5,000 CFM
- Single-stage units can operate up to 50 psig, while two-stage compressors can generally achieve 150 psig.



Oil Free Rotary

- Lubricant-free rotary screw compressors 'do' utilize lubricants but it's main purpose is to lubricate bearings and gears.



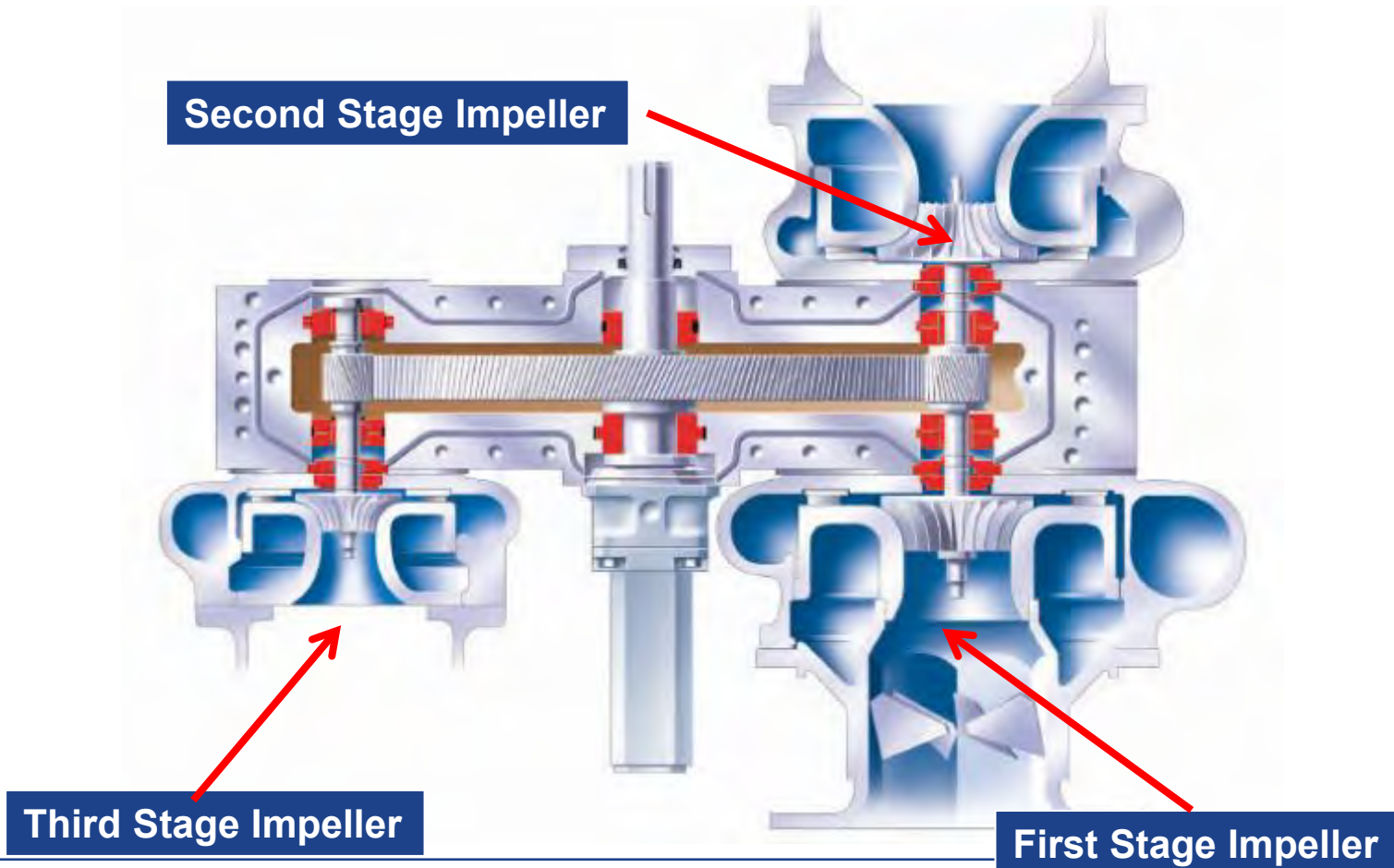
Oil Free Rotary

- With water injected rotary screw compressors – liquid (water) is used for cooling, sealing and lubrication. This coolant in the compression chamber allows these single stage designs to operate at higher pressures (150 to 190 psig)



Dynamic Comrpressors

- Dynamic-type compressors are compressors in which air or gas is compressed by mechanical action of rotating impellers. Centrifugal compressors are Dynamic type.

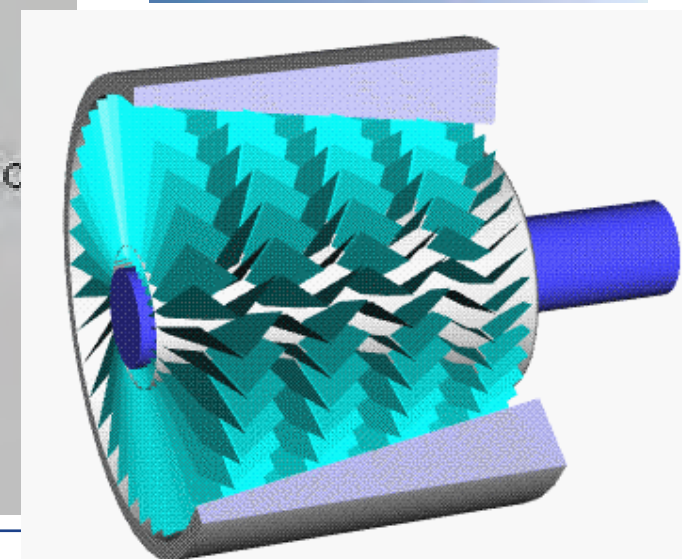
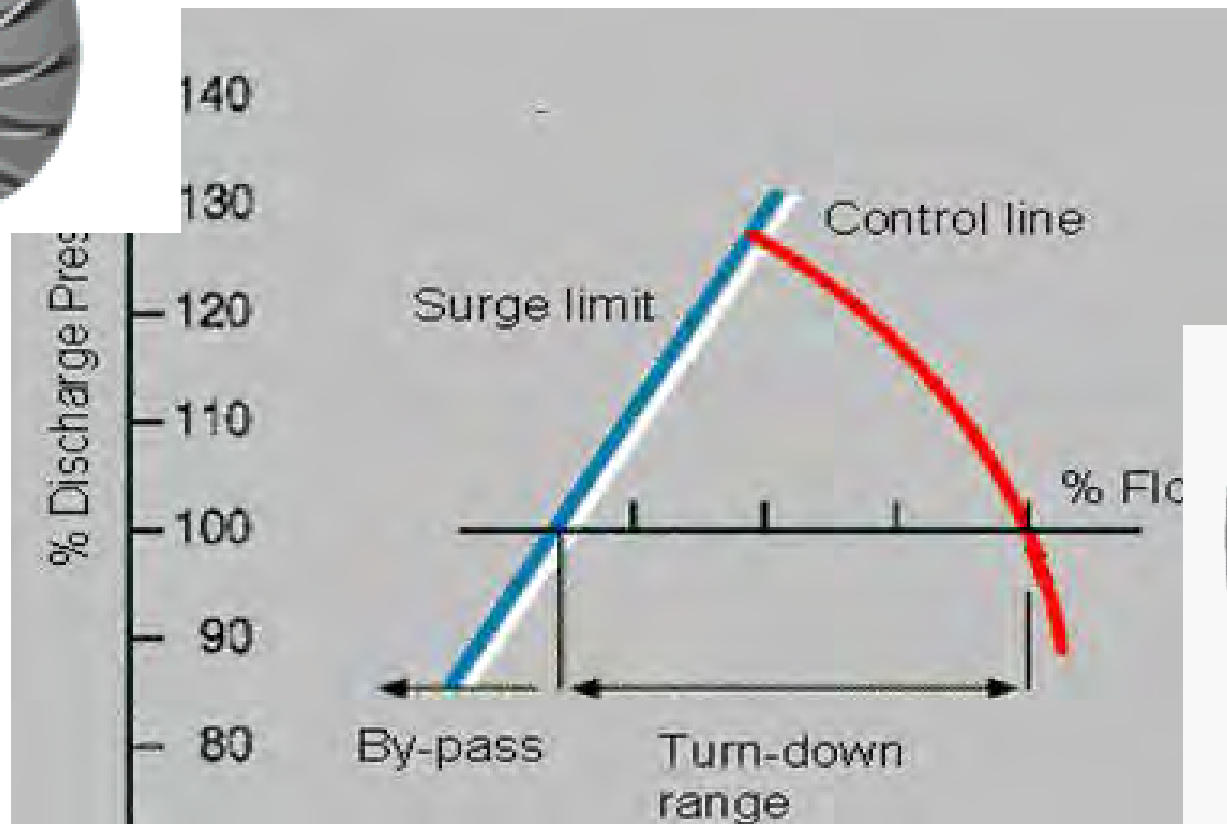
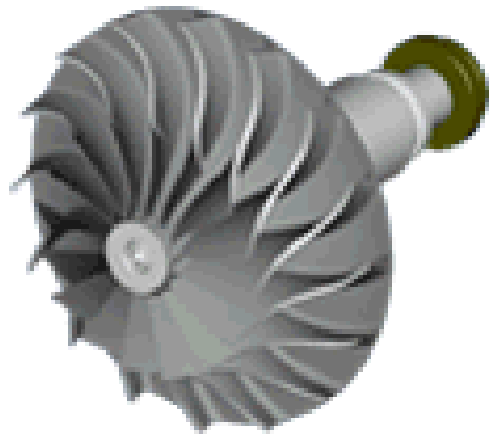


Centrifugal

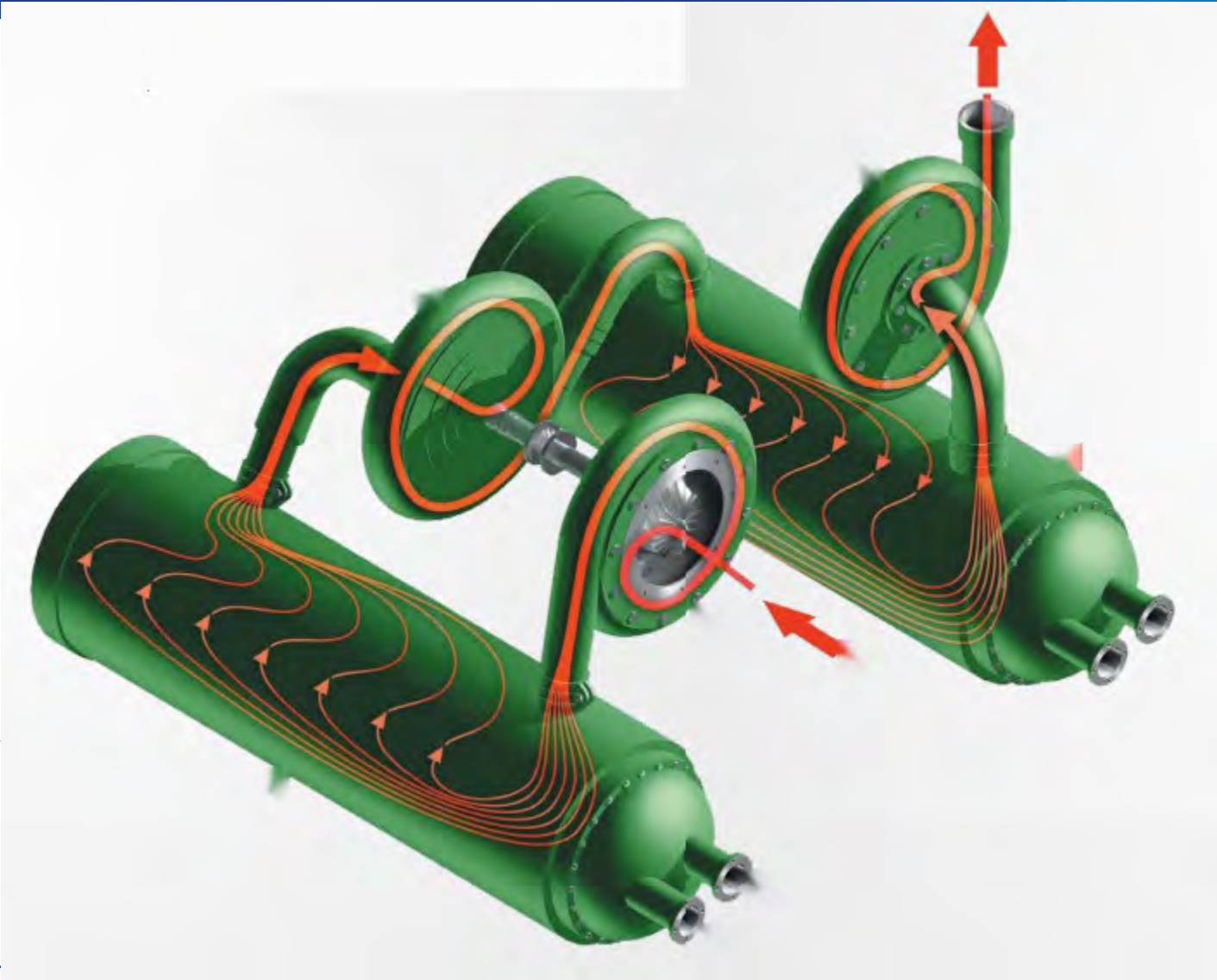
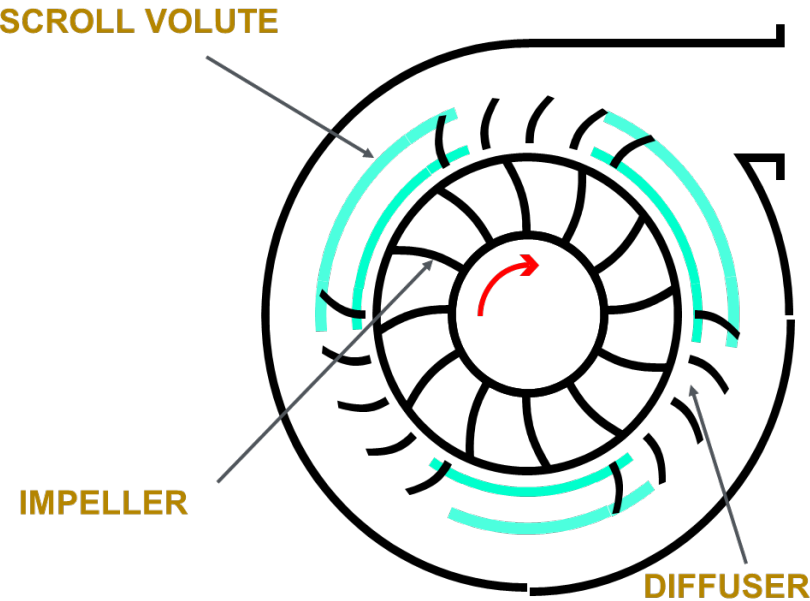
- Centrifugal compressors operate on a very simple principle that converts air velocity into an increase in air pressure.
- In a centrifugal compressor, the velocity of the incoming air is increased by the rotating impeller.
- The velocity is increased by centrifugal force.
- A centrifugal compressor's output capacity and pressure are directly related to the rotational speed of the shaft on which the impeller is mounted.



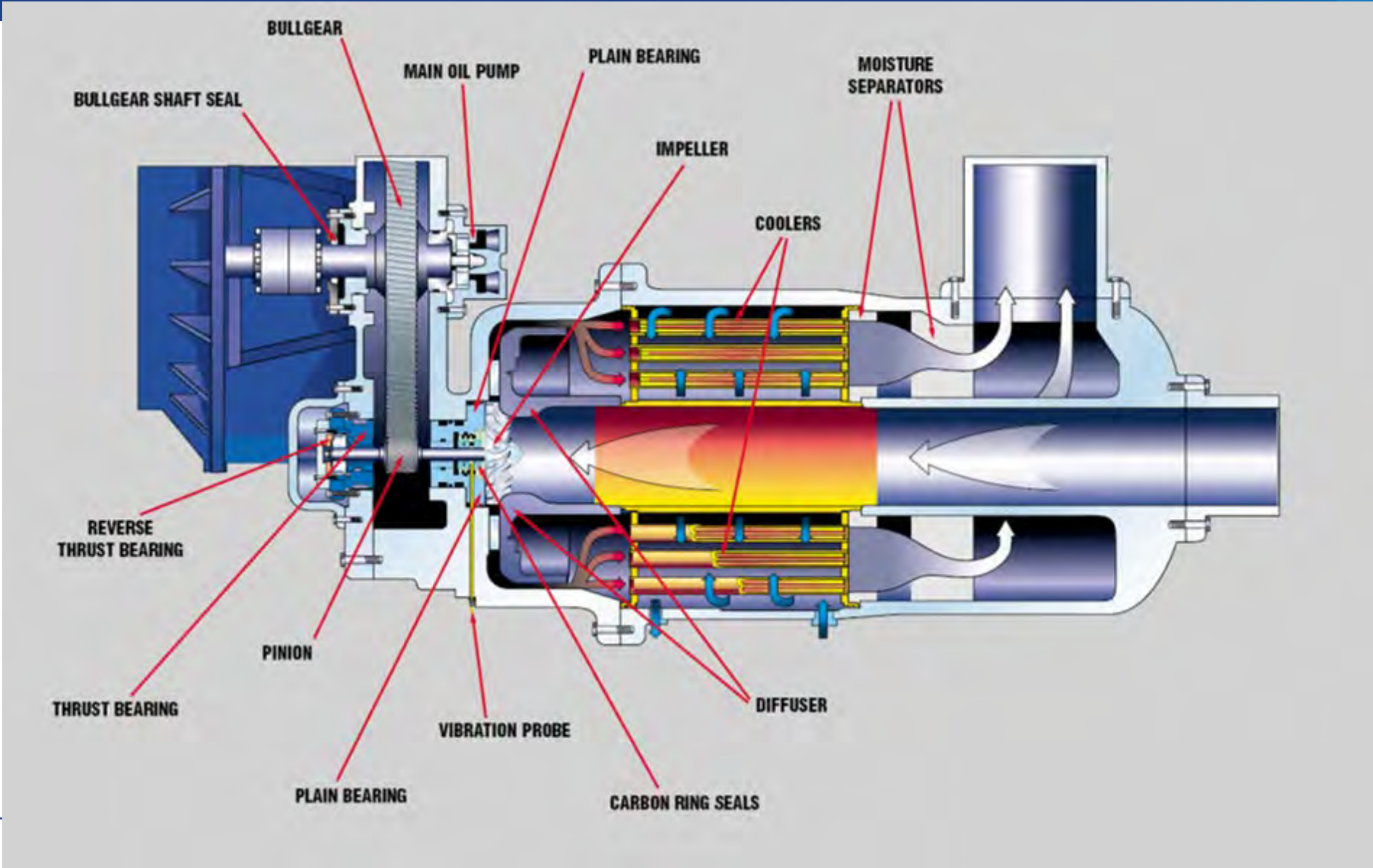
Dynamic Compressors



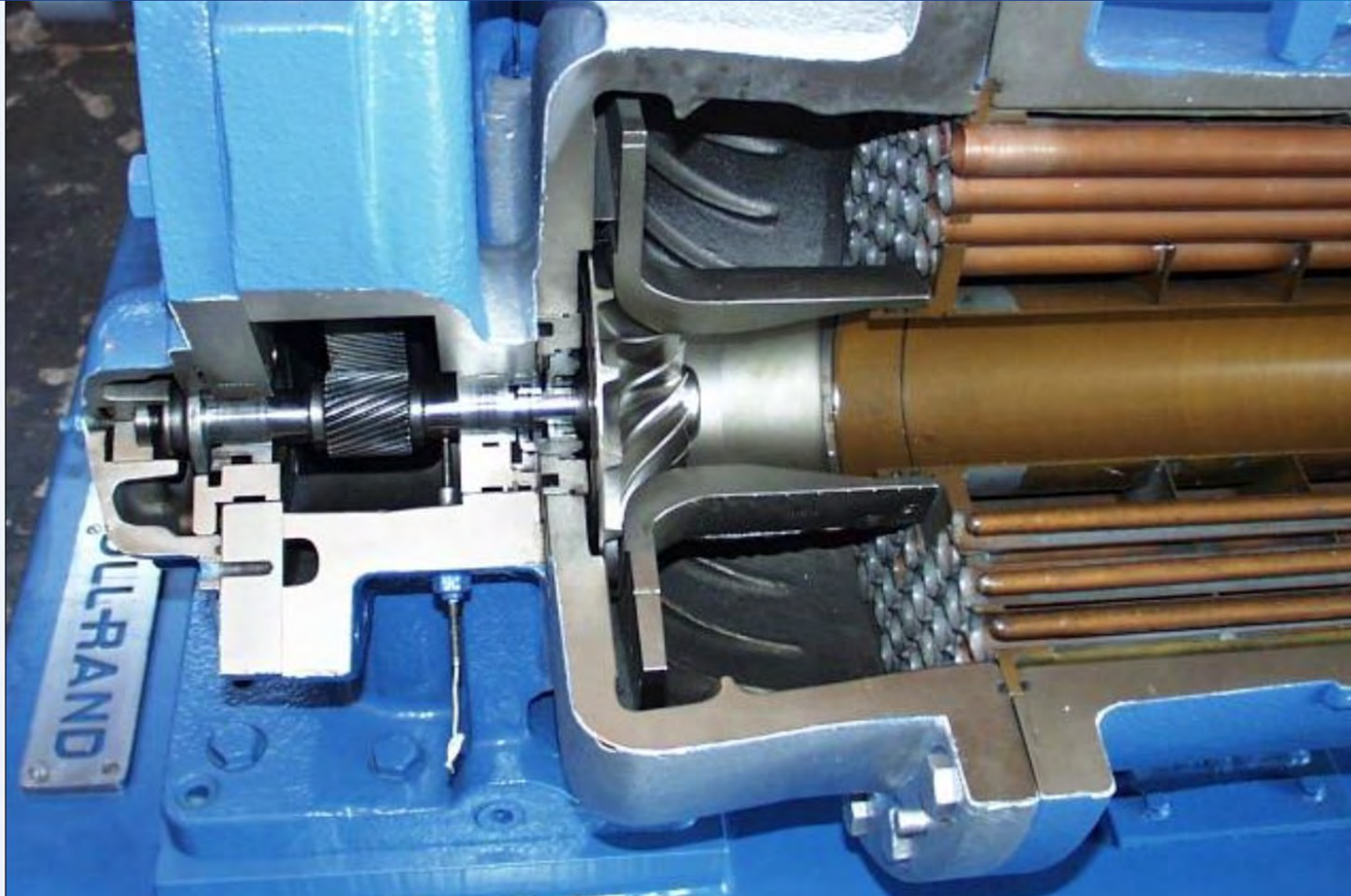
Centrifugal Compressor Terminology



Centrifugal Compressor Terminology



Centrifugal Compressor Terminology



Inlet and Blow Off Valve



Centrifugal Compressor



Centrifugal Compressor Terminology



Compressed Air Maintenance

A Maintenance Case Study

- Compressors tripping from high temperature at full load forced the company to run extra compressors to “share” the load.
- Six compressors part loaded at 60% capacity, 91% power
- Remedy: Clean coolers, address water quality
- Results: Two compressors shut down, savings = \$103,000 annually

Six Common Maintenance Mistakes (System)

1. Not performing leak management
2. Not maintaining filters, end-use filters, and lubricators
3. Ignoring air dryer and condensate trap maintenance
4. Poor ventilation
5. Not taking temperature measurements
6. Not performing lubricant analysis

1. Not Performing Leak Management

- Leaks can make up 20-30% of total system demand
- Proactive leak maintenance programs target 5%
- In addition to wasting energy leaks also:
 - Cause a drop in pressure causing end uses to function less effectively, adversely affecting production
 - Leaks shorten the effective life of all system equipment
 - Leaks can lead to adding unnecessary compressor capacity

2. Filters, End-Use Filters and Lubricators

- Clogged filters cause pressure drop reducing effectiveness at end-use or additional energy at the compressor(s).
- Filter only to the level required for each point of use.
- Use low pressure drop, long-life filters.
- Understand flow characteristics of devices, prevent re-entrainment.
- Replace elements when the cost of their pressure drop exceeds the cost of a replacement element.
- Point of use filters, regulators and lubricators:
 - Provide tools with clean, stable lubricated air supply
 - Can cause tools to wear prematurely if not maintained

3. Dryers and Condensate Traps

- Liquid water is a natural byproduct of the compression process
- Poorly maintained dryers cause quality problems for end uses
- Moisture in compressed air is responsible for costly problems such as:
 - Rusting and scaling in pipelines
 - Clogging of instruments
 - Sticking of control valves
 - Freezing of outdoor lines
 - Product spoilage
- Condensate traps stuck in the closed position can cause quality problems
- Condensate traps stuck in the open position (or bypass valves left open intentionally) waste energy

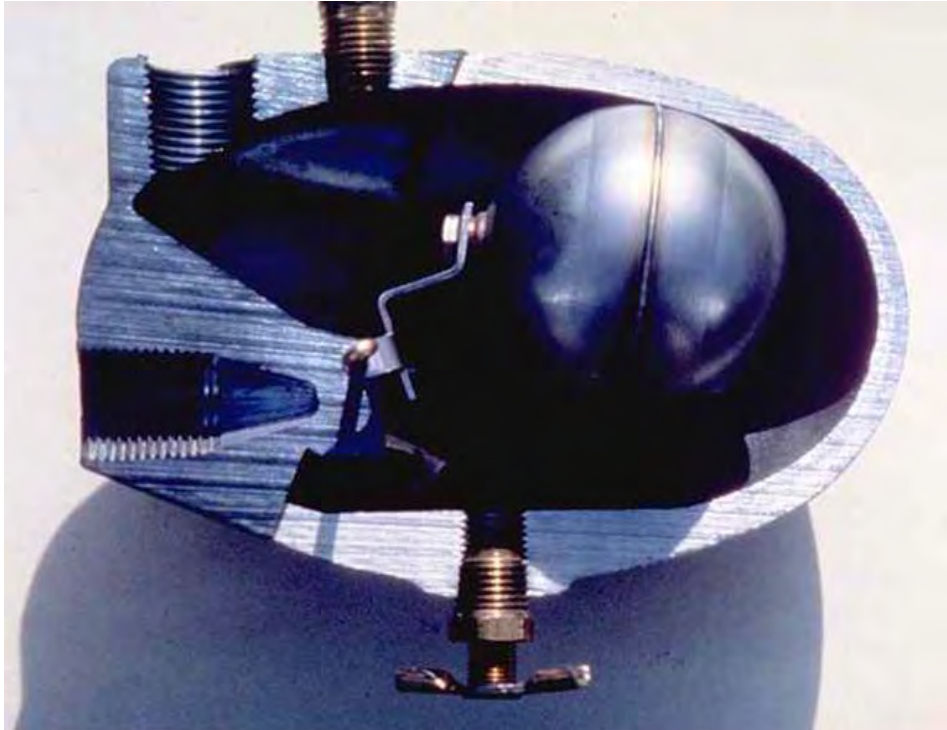
Is the condensate drain even working?



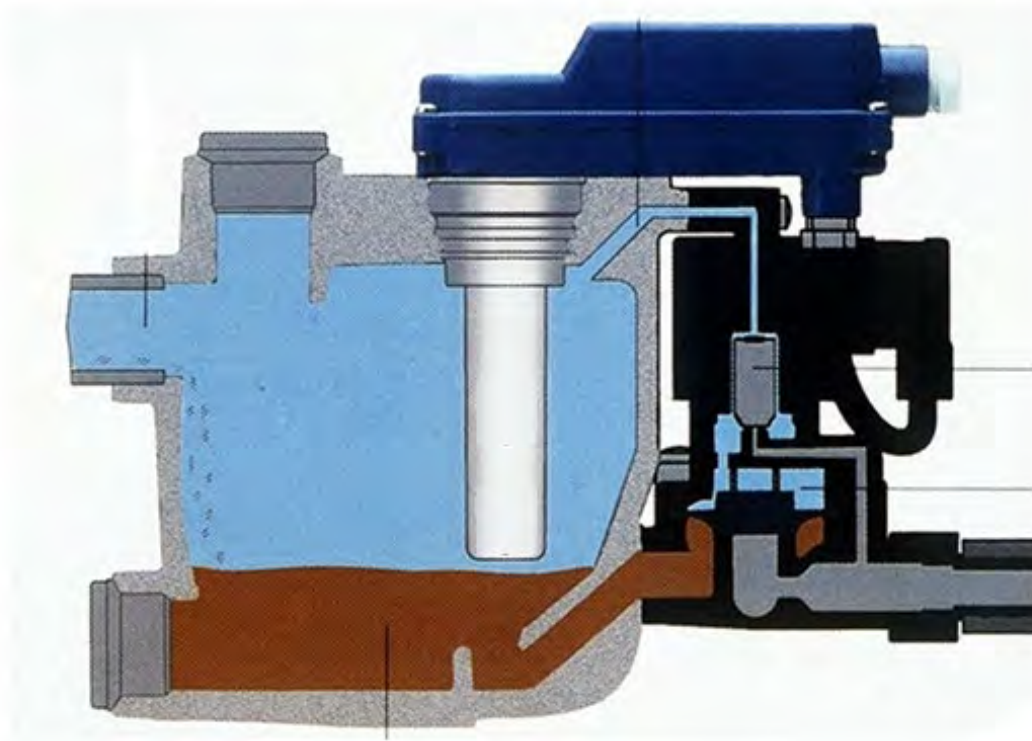
Condensate removal without the loss of compressed air



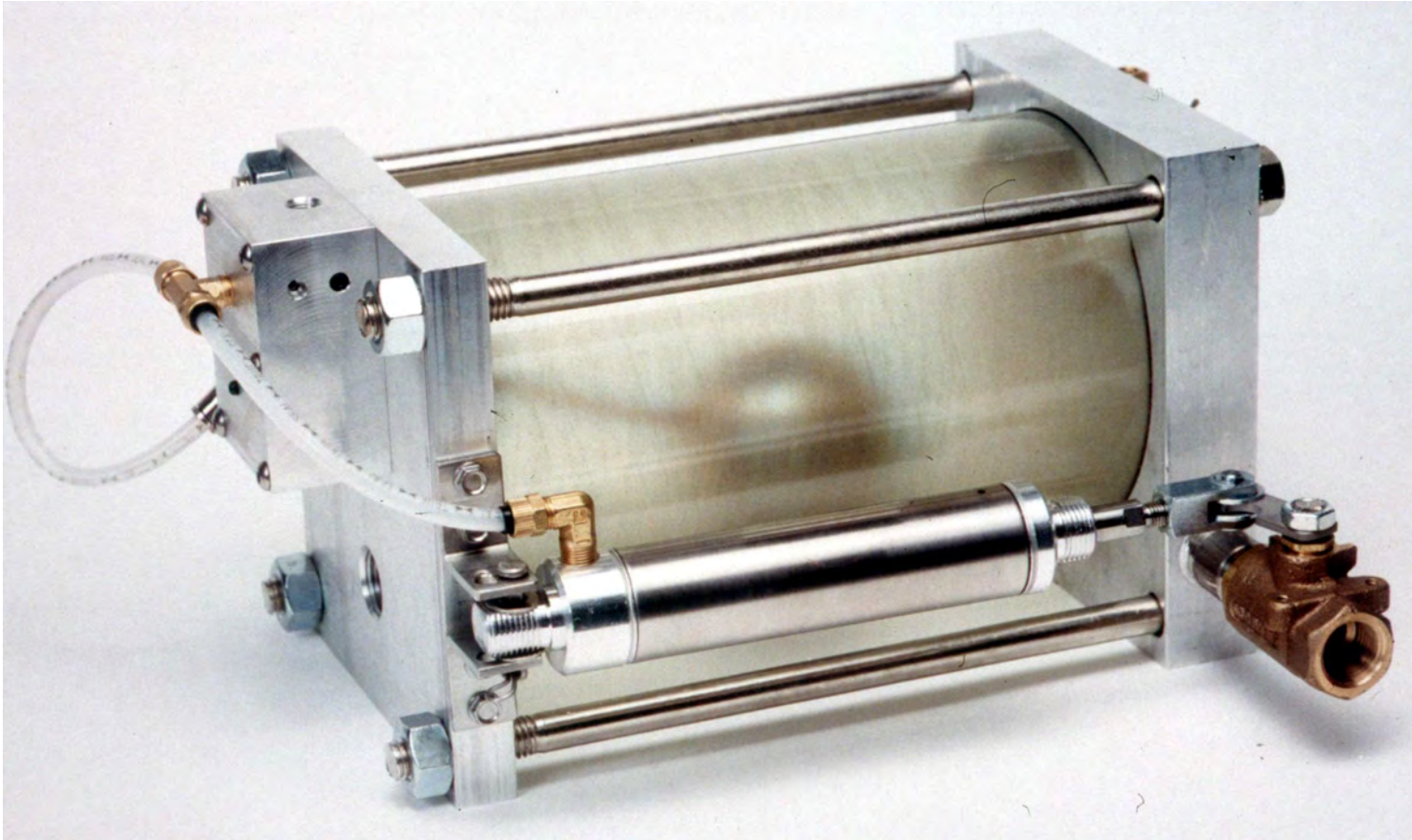
Condensate Drains



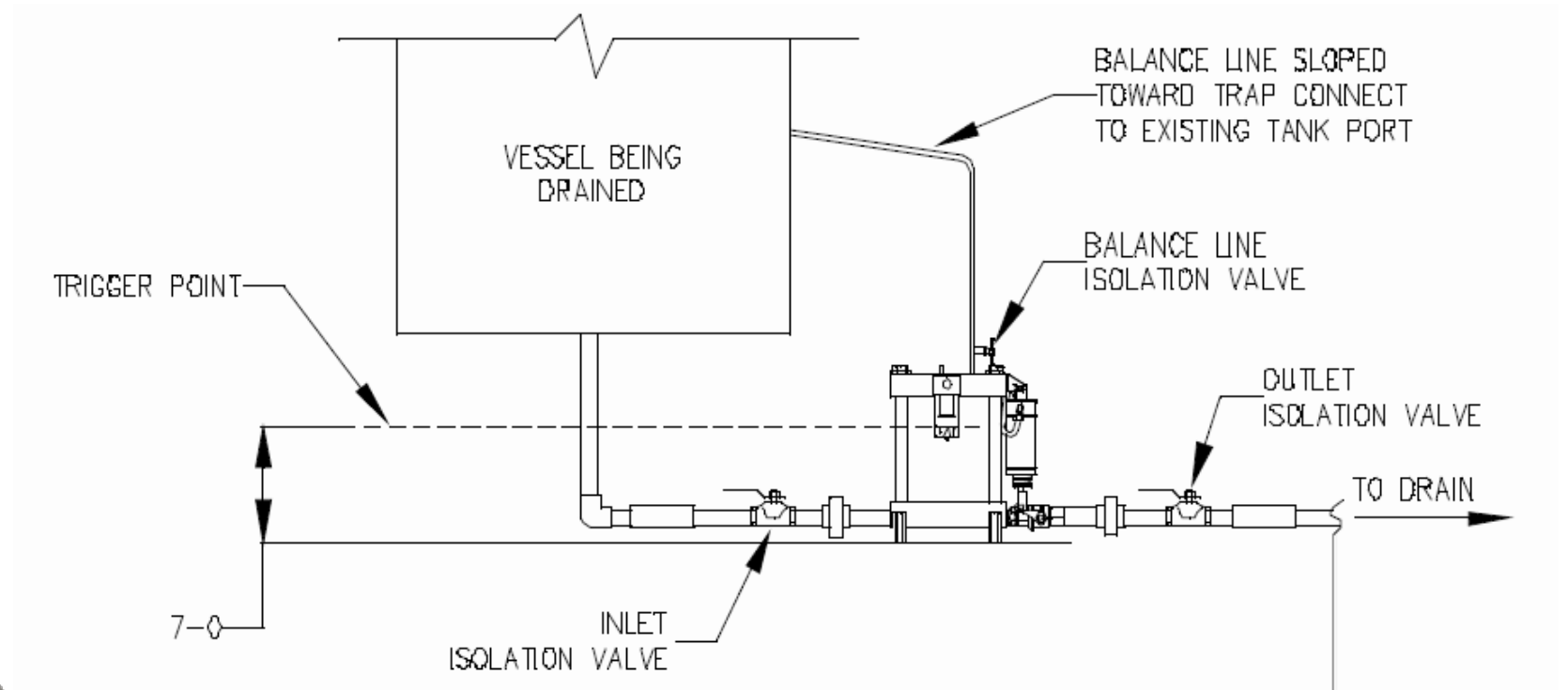
Condensate Drains



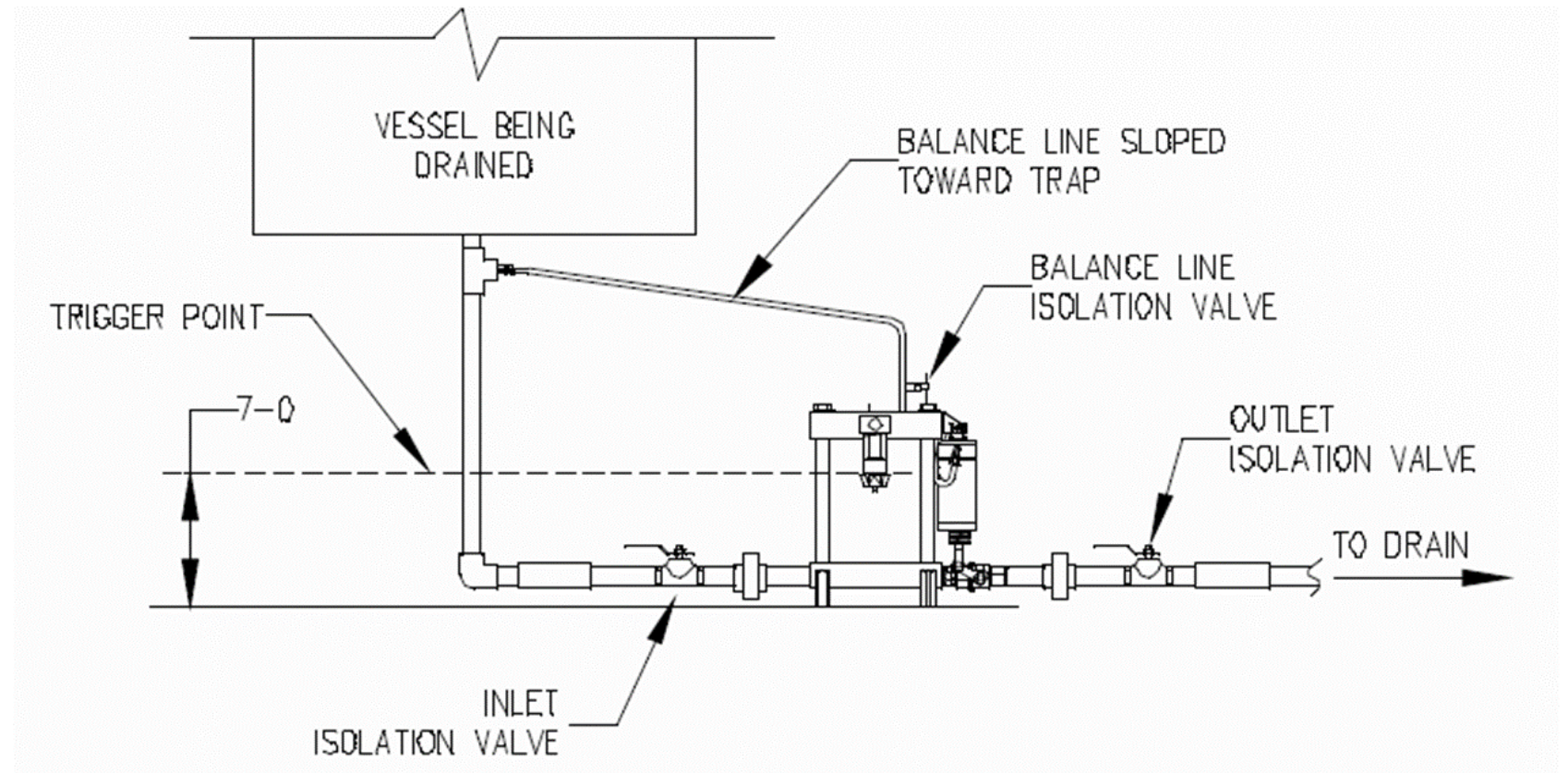
Condensate Drains



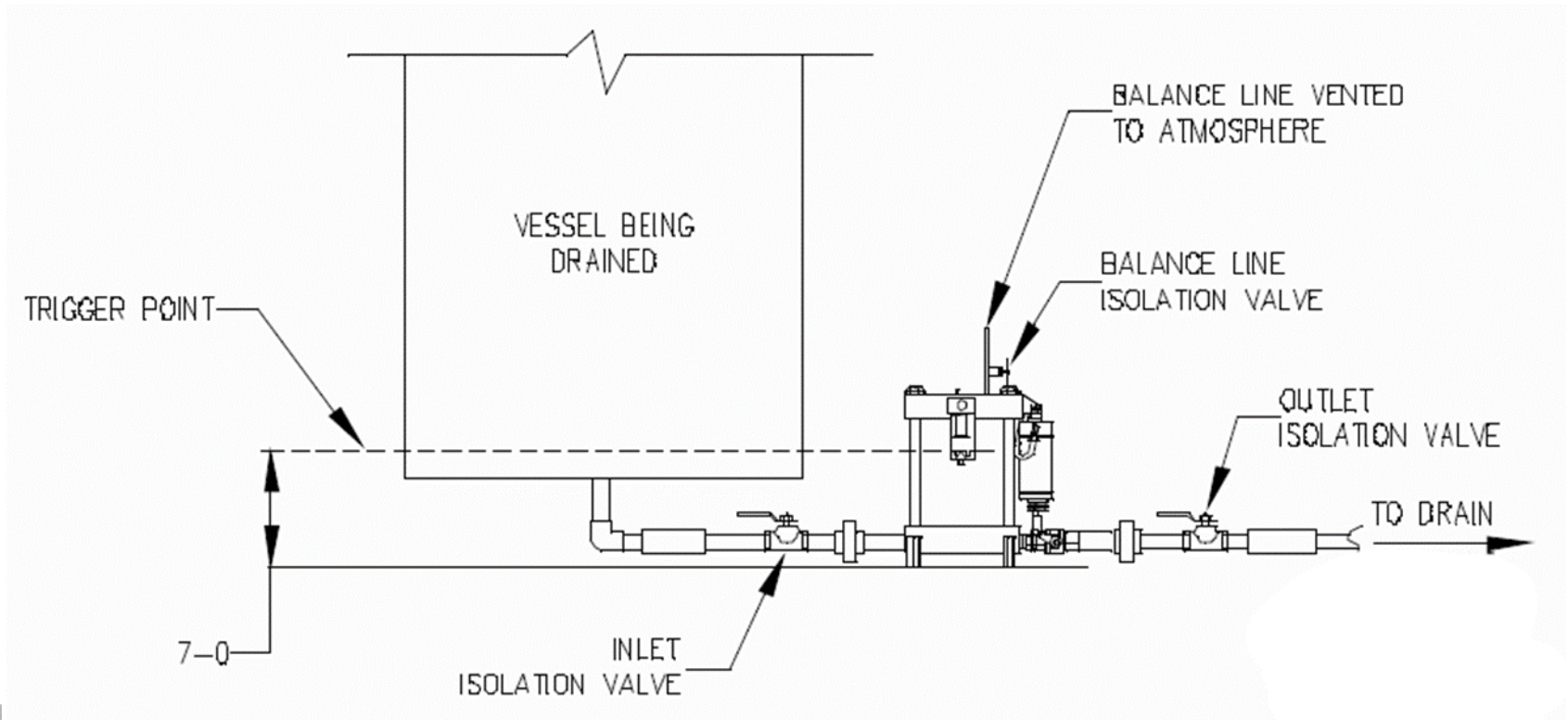
Condensate Drains



Condensate Drains



Condensate Drains



4. Poor Ventilation

- Heat is a common cause of unscheduled shutdowns.
- Compressed air systems require extensive ventilation whether they are air cooled or water cooled.
- Good planning is required to ensure effective ventilation.
 - Avoid recirculating heated ventilation air.
 - Allow for adequate clearance for access to the package.
 - Avoid areas that are extremely humid or where temperatures exceed the capabilities of system components.
- Addressing these issues reduces required maintenance of lubricant, heat exchangers, bearings and hoses.
- Proper ventilation reduces energy costs.

5. Not Taking Temperature Measurements

- Temperature is an indicator of how systems are performing.
- The following measurements are important:
 - Air Intake Temperature
 - Ambient Air Temperature (cooling air)
 - Intercooler Approach Temperature (multi-stage compressors)
 - Lubricant Injected Rotary Screw Oil Temperature
 - Reciprocating Compressor Cylinder Discharge (Valve) Temperature
 - Compressor Discharge Temperature
 - Thermo-mixing Valve Temperature (Oil in, Oil out, and to sump cooler)
 - Aftercooler Outlet Temperature
 - Dryer Inlet Temperature
 - Dryer (Condenser) Ambient Temperature (air-cooled)
 - Dryer (Condenser) Water Inlet and Outlet Temperatures (water-cooled)
 - Motor Temperatures
 - Bearing Temperatures

6. Not Performing Lubricant Analysis

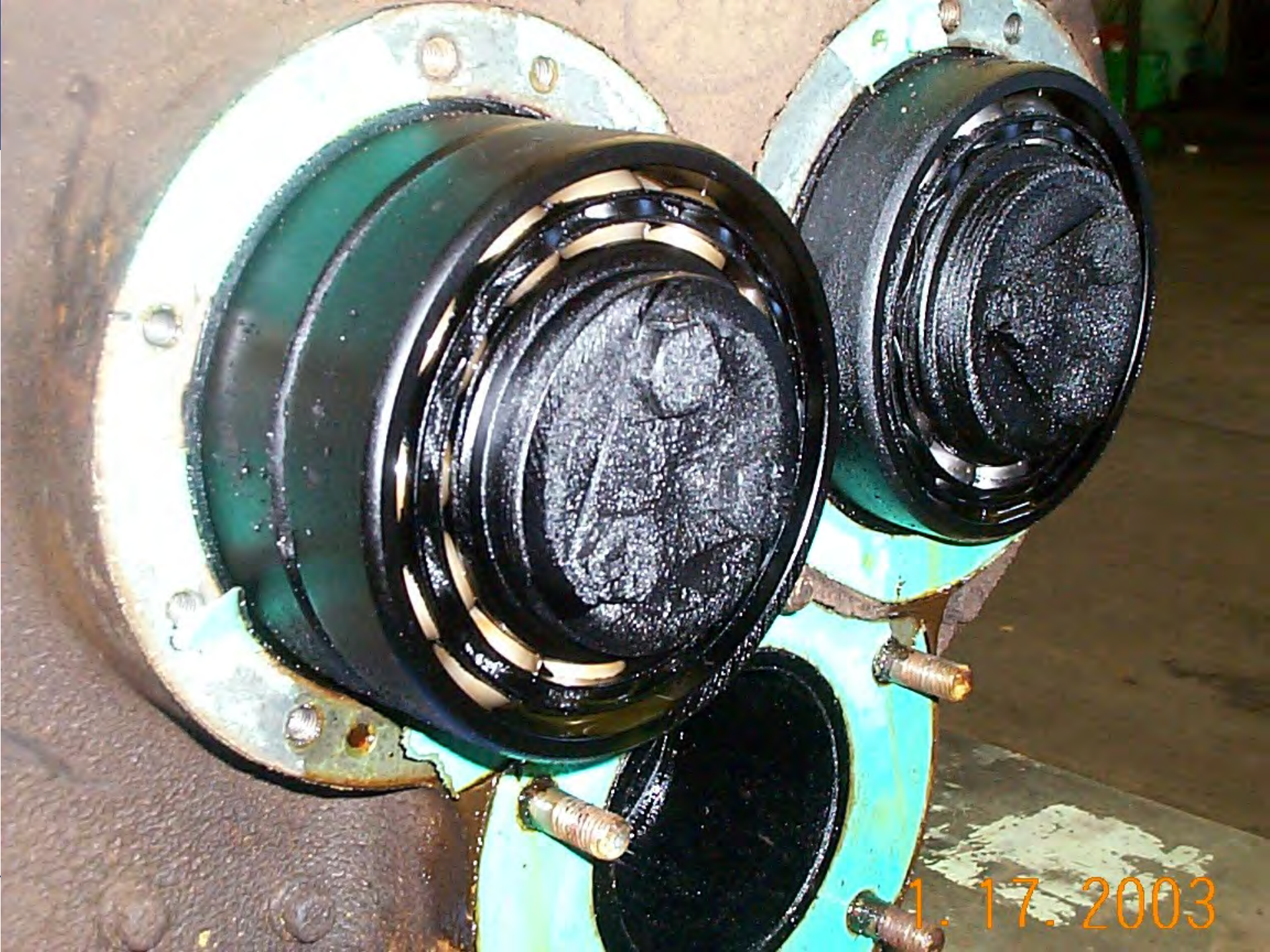
- Lubricant analysis is an indicator of compressor condition
- Key variables to watch in lubricant analysis include:
 - Particle count (ISO code)
 - Total acid number (TAN)
 - Anti-oxidant level
 - Lubricant life remaining
 - Viscosity
 - Contamination ... other lubricants
 - Water ppm



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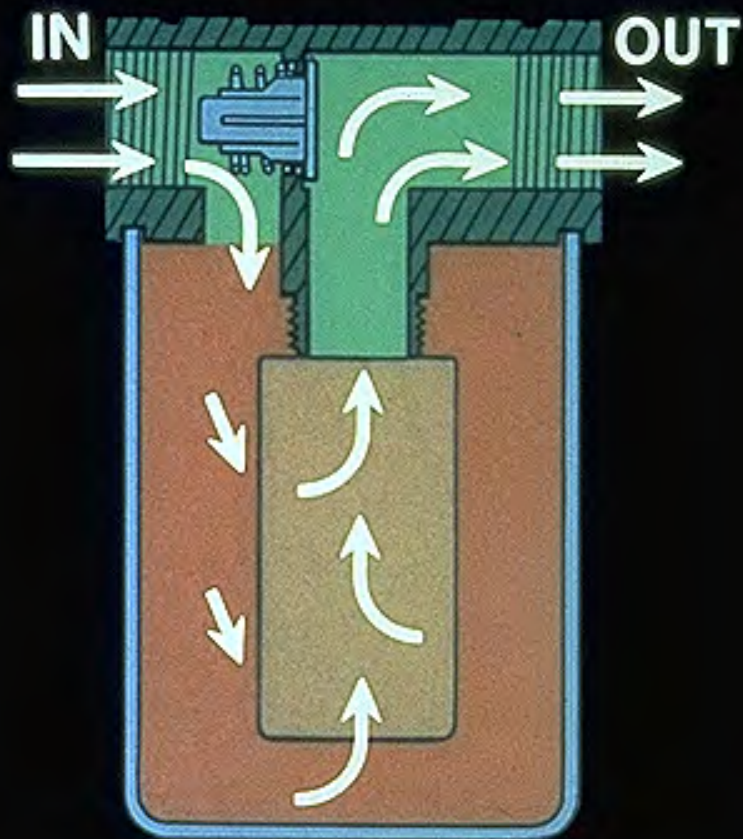
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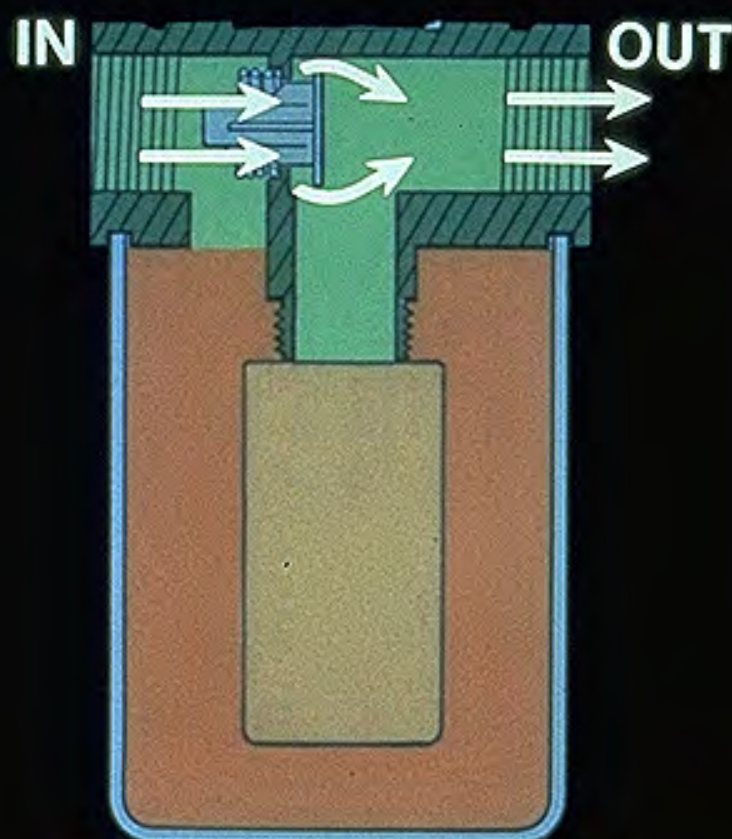
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OIL FILTER BYPASS



**Less Than 20 PSI
Differential**



**Greater Than 20 PSI
Differential**

Other Important Maintenance Issues

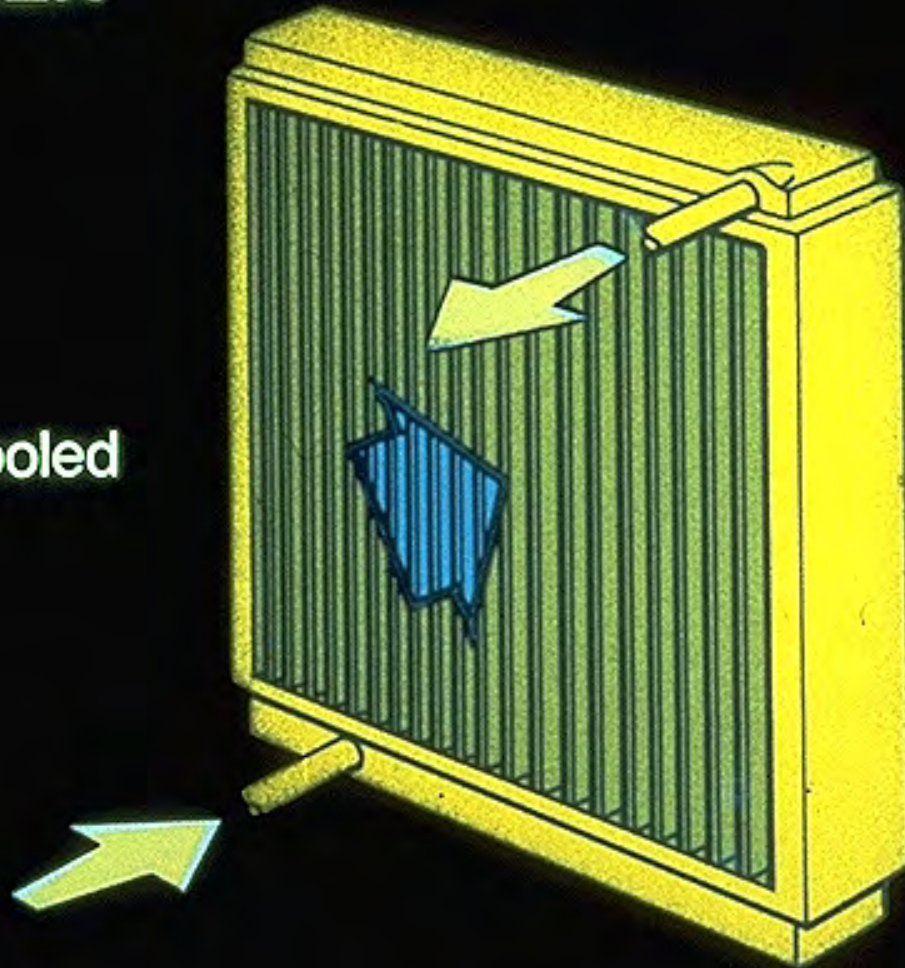
- Condensate Sampling
- Bearing Analysis (Centrifugals)
- Bearing Analysis – Anti-friction (Rotary Screws)
- Motor Rewinding
- Trending
- Cooler cleaning





OIL COOLER

Air Cooled



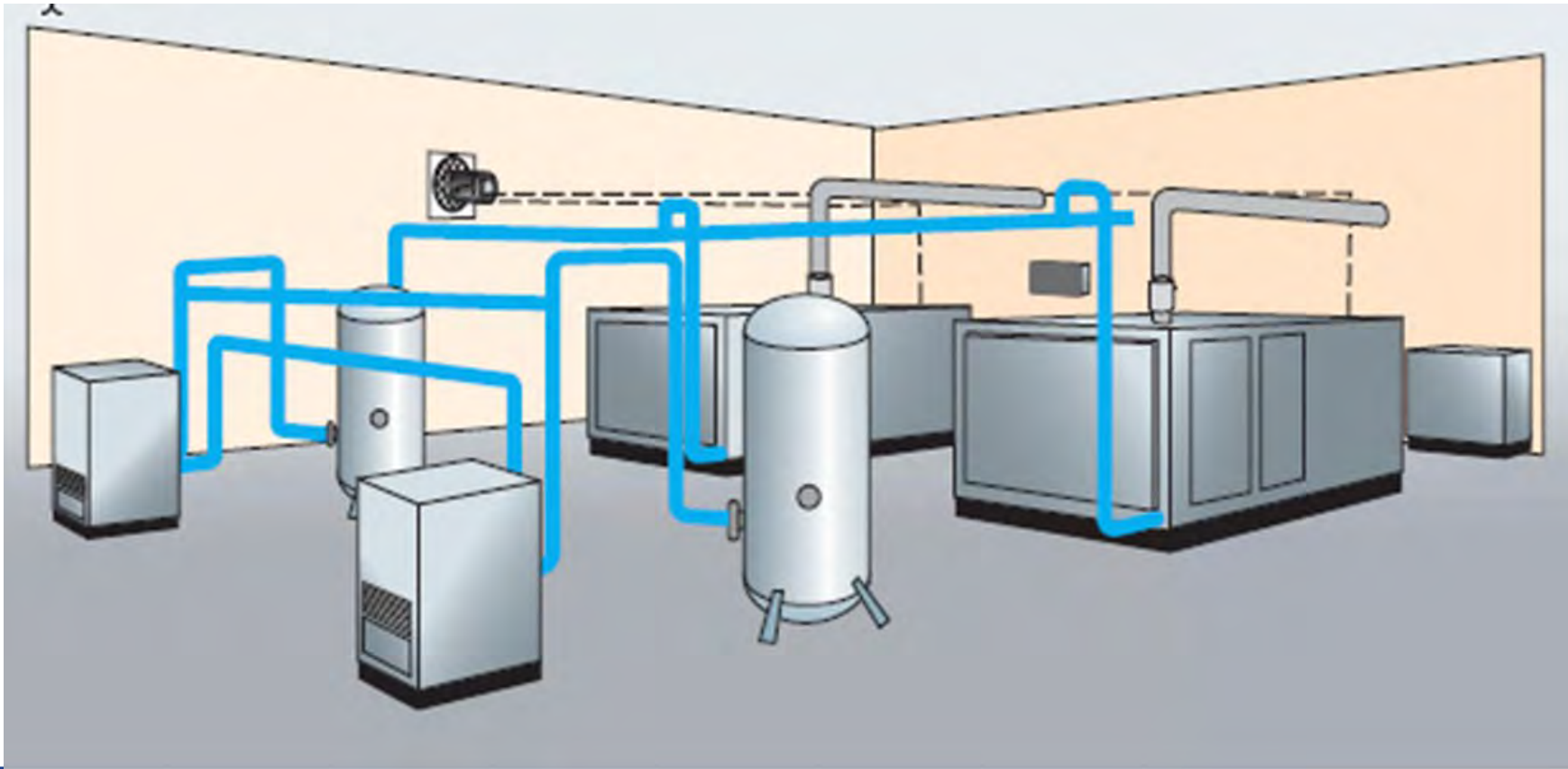




Let's get back to **Compressor Room Ventilation**

Ventilation

- Compressors generate heat; this heat must be removed to make sure the temperature in the compressor room is at an acceptable level. Therefore, proper ventilation is important when designing an efficient compressor room.



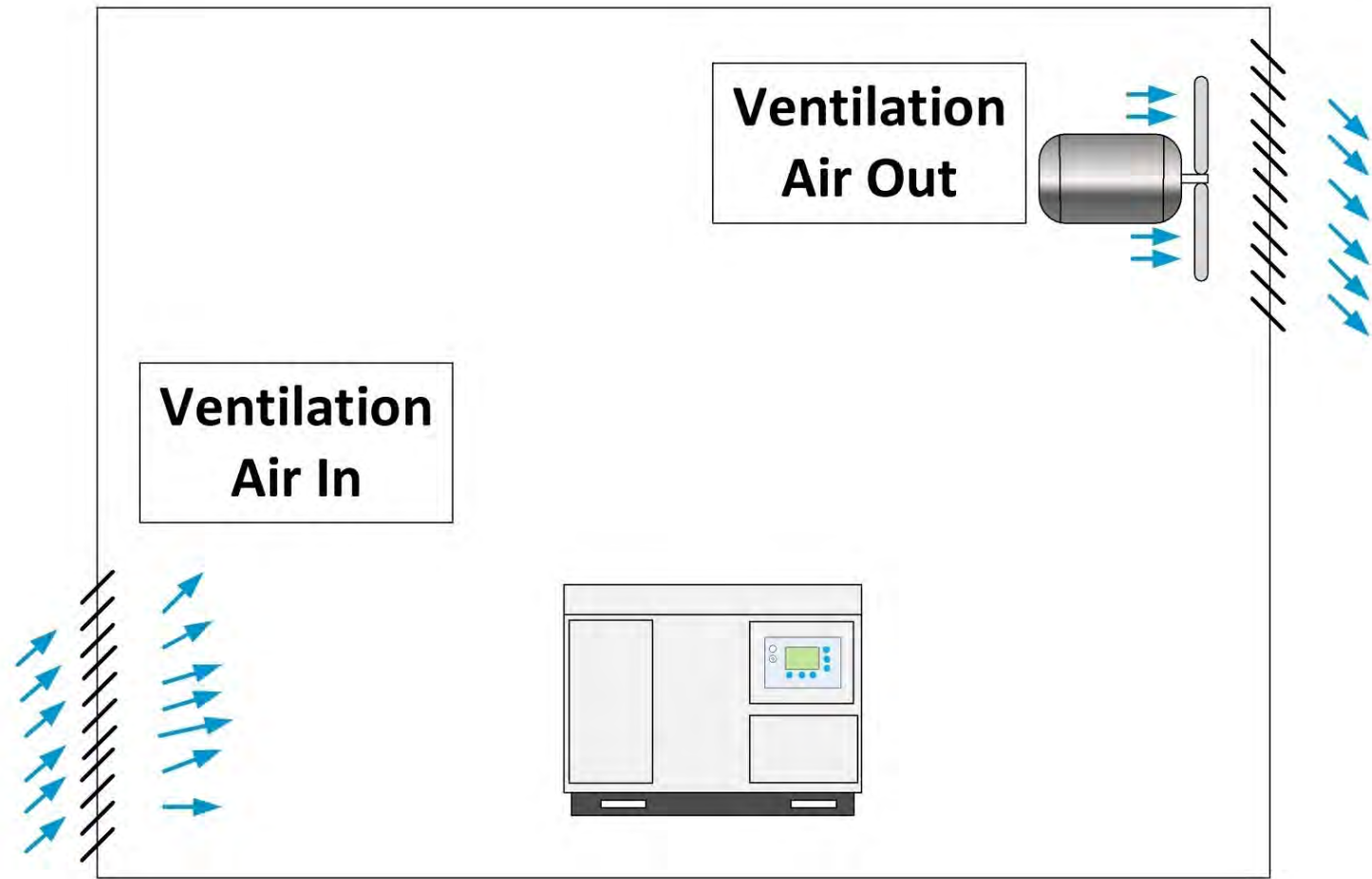
Ventilation

- When choosing a location, it is important to find an area that provides an adequate supply of cool, clean, dry air.
- Consideration must also be given to any harmful gases that may be in the area.
- Some compressors and other critical downstream end uses will experience problems when the compressor is located where there are hydrocarbon, ammonia or chlorine vapors.
- An ambient temperature of 40 – 100°F should be maintained at all times to keep compressors running properly.
- Compressor after coolers are typically designed to cool compressed air to a temperature of “ambient +15° F.”

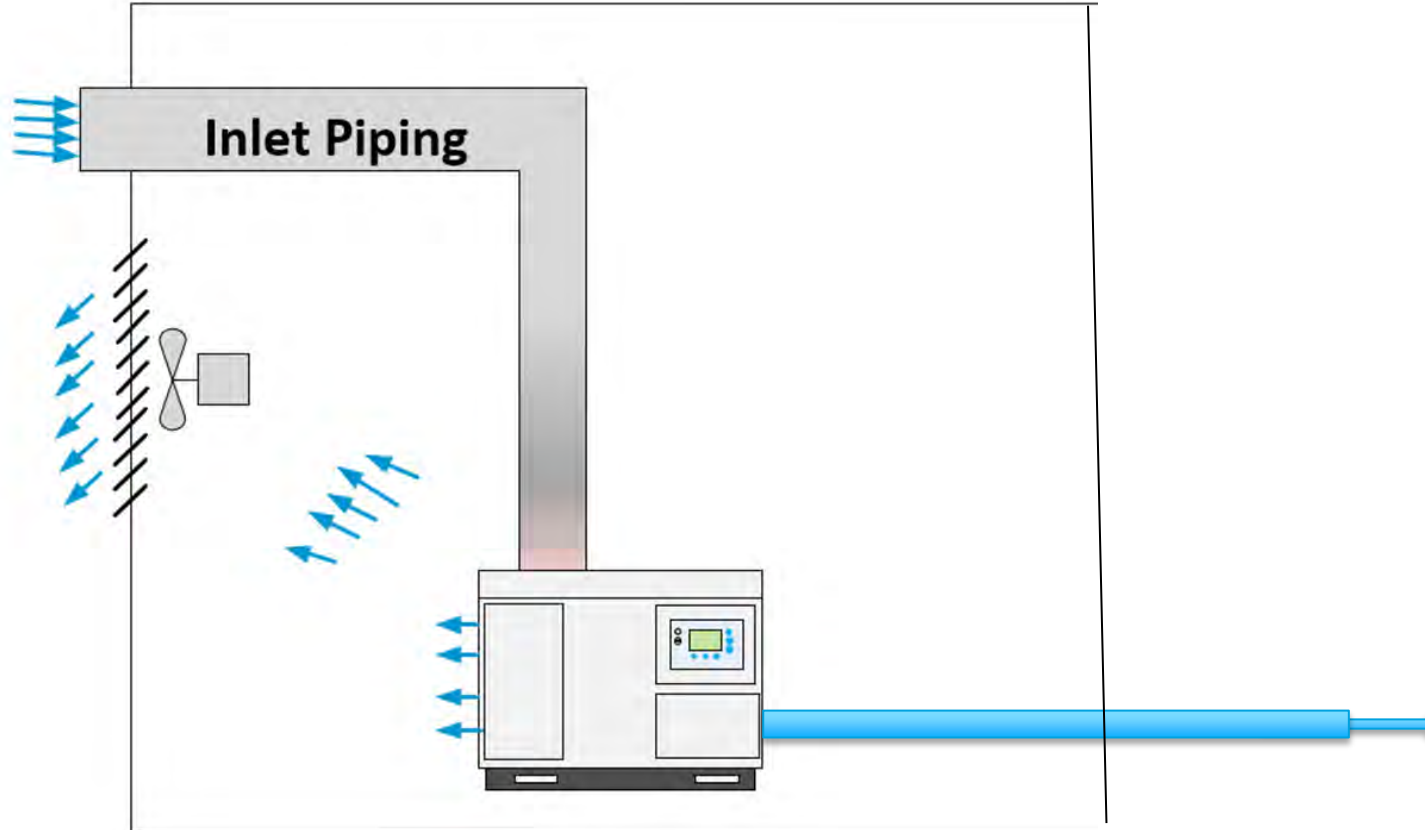
Ventilation

- Conversely, if compressor room temperatures drop below freezing, condensate lines can freeze and cause ice to form in the in the after cooler, discharge line or dryer.
- As ice forms, it will expand and potentially damage any of these components.
- Cold temperatures will also increase coolant viscosity, requiring the motor to use more power to turn the airend.
- In turn, it will drive up energy and maintenance costs due to the malfunctioning of the motor and bearings.

Ventilation



Ventilation



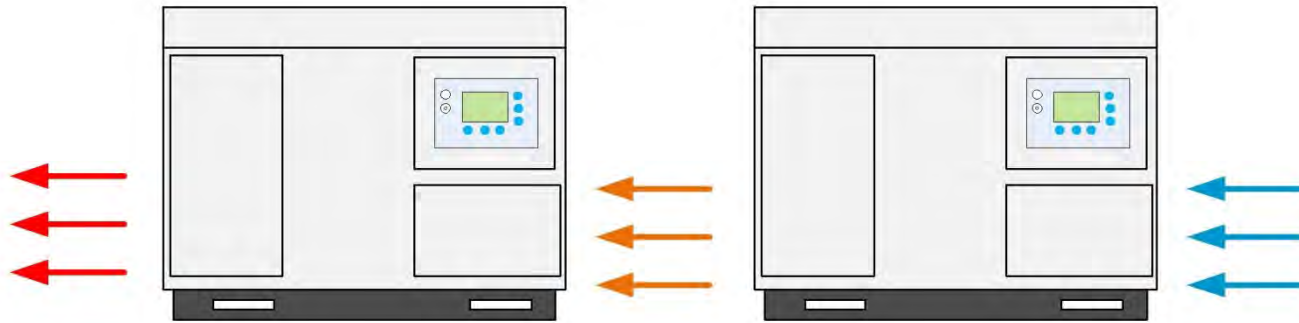
Ducting

- If the design of the compressor room makes it too difficult for cooling air to flow across the compressor, then ducting is the best alternative.
- You have the option of ducting both the inlet and outlet air, or just one, depending on your current setup.
- Make sure to review the manufacturer's specifications on airflow and how to size your ventilation ducting in order to keep backpressure at a minimum.
- Most cooling fans are not designed to work effectively with more than 1/10 psi of backpressure. (about 3 inches water pressure)

Ventilation



Ventilation

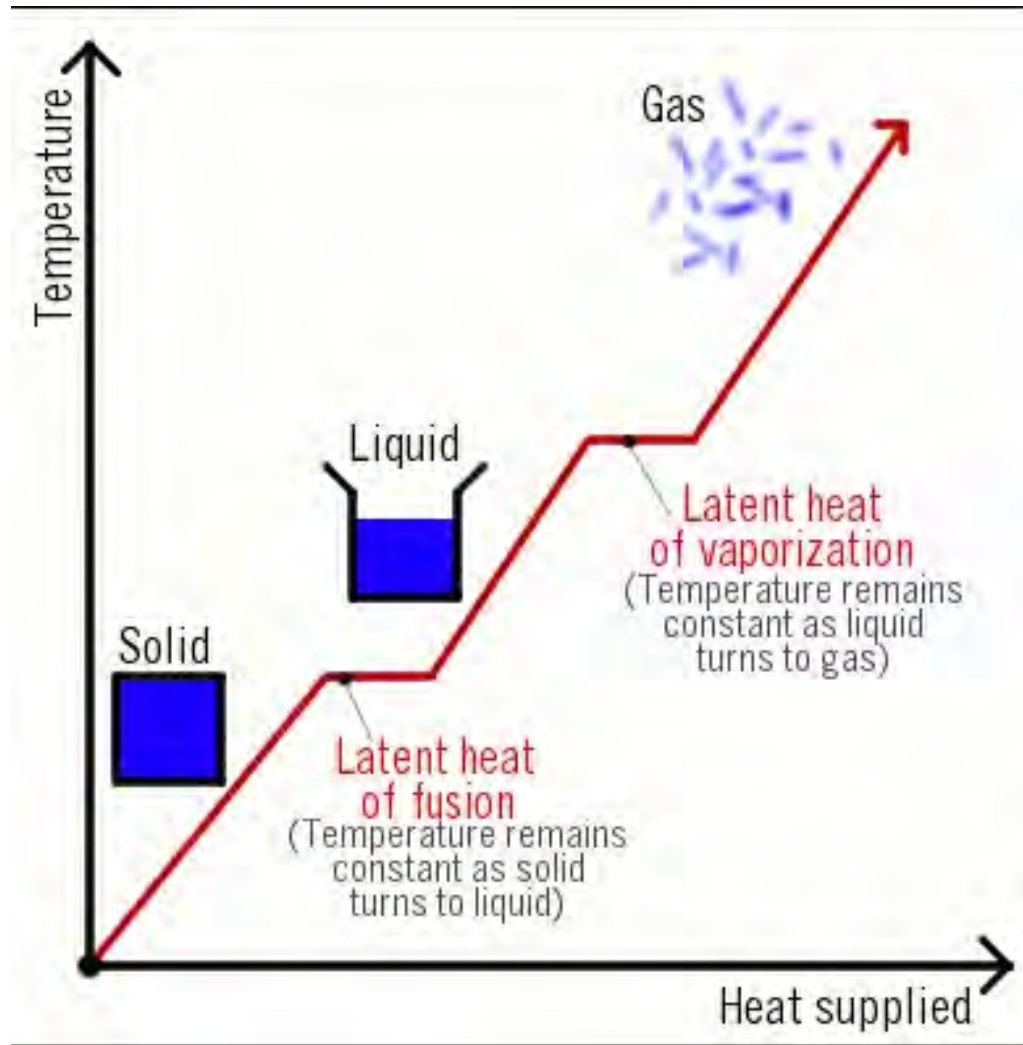


It is important not to block the air flow to the compressor inlet filter. If you have a multiple compressor installation, it is important, especially with air cooled units, that the heat discharge of one compressor does not go directly into the inlet of another compressor. This will cause shutdowns due to high temperature.

Ventilation Equation Derived:

- Exhaust ventilation can be used to remove excess heat and/or humidity if a replacement source of cooler air is available.
- To determine the required general ventilation, one must estimate the acceptable temperature or humidity rise.
- The first step in determining the required volumetric flow is to determine the sensible and latent heat load.
- Next, determine the volumetric flow to dissipate the sensible heat and the volumetric flow to dissipate the latent heat.
- The required general ventilation is the larger of the two volumetric flows.
- Since the sensible heat is always the larger value in a compressor room, we will only work with this equation.

Ventilation Equation Derived:



- **Sensible heat** is literally the heat that can be felt. It is the energy moving from one system to another that changes the temperature rather than changing its phase.

Ventilation Equation Derived:

- The sensible heat rise can be determined by the following:

$$H_s = Q_s \times \rho \times C_p \times \Delta T \times 60_{m/hr}$$

Where:

- H_s = sensible heat gain, BTUs per hour
- Q_s = volumetric flow for sensible heat, CFM
- ρ = density of air, lb/ft³
- C_p = specific heat of the air, BTU/lb-deg F
- ΔT = change in temperature, degrees Fahrenheit
- For air $C_p = 0.24$ BTU/lb-deg F and $\rho = 0.075$ lb/ft³;

It takes 0.24 BTU of heat to change the temperature of one pound of air by one degree F.



Ventilation Equation Derived:

Consequently, the equation becomes:

$$H_s = Q_s \times 0.075_{lb/cf} \times .24_{BTU/lb-deg} \times \Delta T \times 60_{m/hr}$$

Or

$$H_s = Q_s \times 1.08 \times \Delta T$$

$$Q_s = \frac{H_s}{(1.08 \times \Delta T)}$$

- In order to use this equation, it is necessary to first estimate the heat load.
- This will include sunshine, people, lights, and motors as well as other particular sources of heat.
- Of these sunshine light and motors are all completely sensible heat.
- The people heat load is part sensible and part latent and can be ignored in a compressor room situation.
- In using the sensible heat equation, one must decide the amount of temperature rise that will be permitted.
- A 10° rise is very common for a compressor room environment.

Exhaust Size Fan Ventilation Simplified Equation

- The following formula can be used to determine the fan size needed to vent a compressor room given a certain horsepower online and venting into the room:

$$\text{Fan cfm} = \frac{\text{Heatload}(BTU / Hr)}{1.08 \times \text{Temp Rise (deg } F)}$$

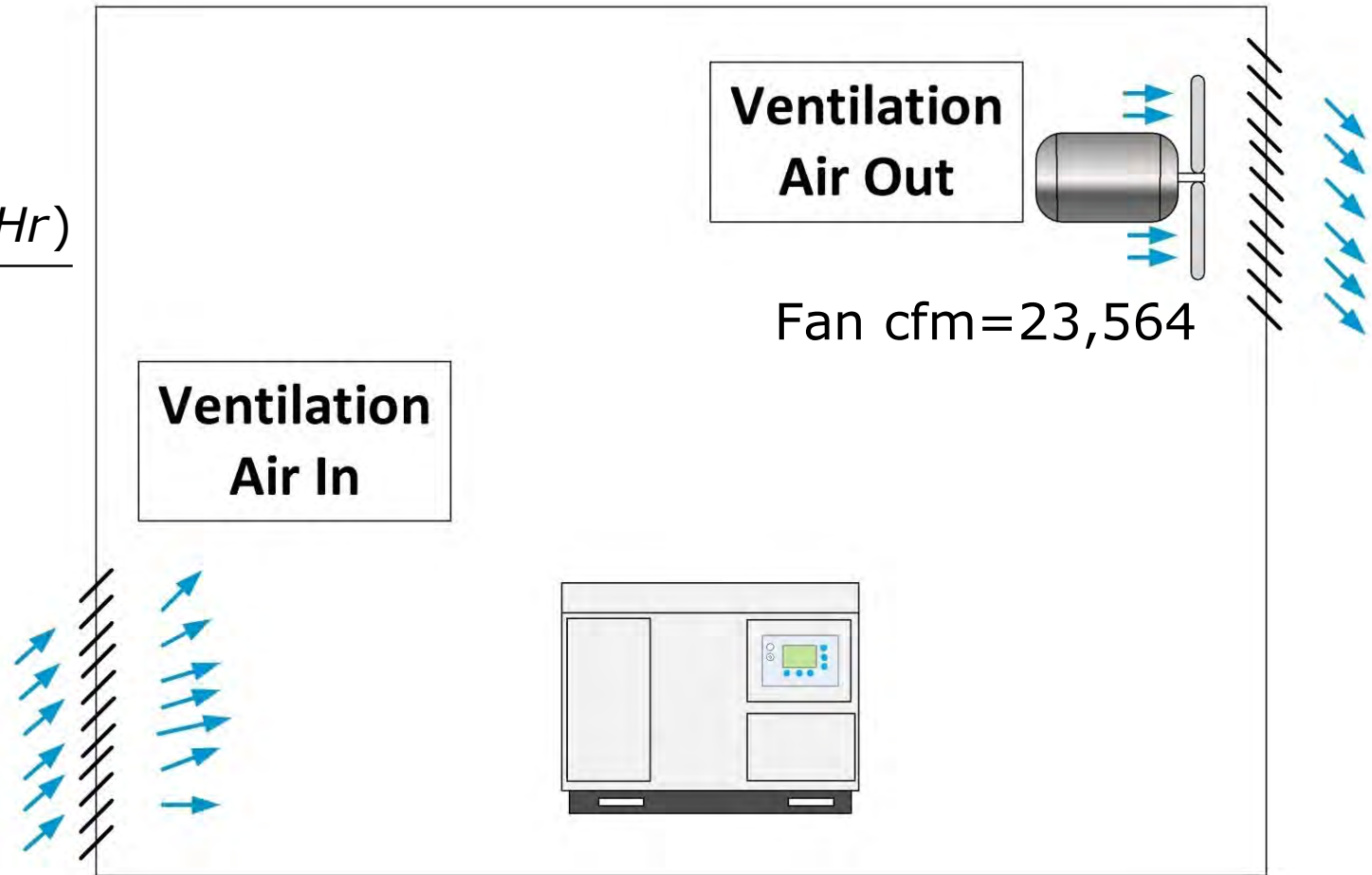
- 1 HP = 2,545 BTU / hr
- The heat load is sensible duty only.
- Temp rise is above make-up air temp.
 - A 10-degree rise is all you really need.

Ventilation Example 100 HP Compressor

$$\text{Fan cfm} = \frac{\text{Heatload}(\text{BTU} / \text{Hr})}{1.08 \times \text{Temp Rise (deg } F)}$$

$$\text{Fan cfm} = \frac{(100 \times 2,545 \text{ BTU} / \text{Hr}) (\text{BTU} / \text{Hr})}{1.08 \times 10}$$

$$\text{Fan cfm} = 23,564$$







Final Notes on Compressor Room Design

Proper Compressor Room Design

- Creating a designated compressor room allows for better control of the compressor's air quality in addition to ensuring the compressors are kept at the proper temperature through the use of HVAC or ventilation.
- Ideally, your compressor room should be located as close to its point of use as possible. Most companies try to locate the compressor room in a centralized location to minimize the distance air must travel to reach all of its processes.
- This also helps minimize the amount of compressed air piping, pressure drop and potential leak points.

Clearance

- Always consult your compressed air manufacturer for proper clearance required in cooling and equipment maintenance.
- For example, compressors with canopies may have doors swinging on hinges or doors needing to be completely removed.
- Each of these options will require a different type of clearance.
- Another example takes into consideration large maintenance issues, requiring the use of larger tools such as hoists or jacking equipment.
- These special circumstances need enough clearance height and floor space for maintenance personnel to access the machines.

Summary

- In an ideal world, we would all have plenty of space, time and money to create the perfect compressed air system.
- Remember to keep the compressors cool, minimize piping pressure drop and to allow sufficient room around the equipment for service.
- Even the best engineered systems will perform poorly unless maintenance is properly performed..
- Poor maintenance practices lead to increased equipment and energy costs, downtime, production problems, poor product quality.

Homework for Week 2 – Inventory of Compressors

- Single Acting Reciprocating
- Double Acting Reciprocating
- Lubricant Injected Rotary Screw
- Lubricant Free Rotary Screw
- Centrifugal
- Scroll
- Vane

Homework for Week 2 – Compressor Info

Nameplate Information

Compressor # _____ (from block diagram)
Manufacturer _____
Model _____
Compressor Type _____
Motor Nameplate Horsepower _____ hp _____ voltage
Rated CFM _____ cfm
Maximum Design Full Load Pressure _____ psig
Age/Comments: _____

How are the pressure setpoints on the compressors' controls configured?

	Load	Unload/Modulate
Pressure setting:	_____ psig	_____ psig
Pressure setting:	_____ psig	_____ psig
Pressure setting:	_____ psig	_____ psig

Operating Schedule Information

Number of Days of Operation Annually _____
Number of Hours per Day _____
Compressor Discharge Pressure _____ psig

Homework for Week 2 – Compression Ratio

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

Next Session 3

Compressor Controls
Intro to Airmaster+
Intro to LogTool
Intro to MEASUR