Better Plants
U.S. DEPARTMENT OF ENERGY

In-Plant Trainings

Virtual Platform

Session Two
Compressor Types

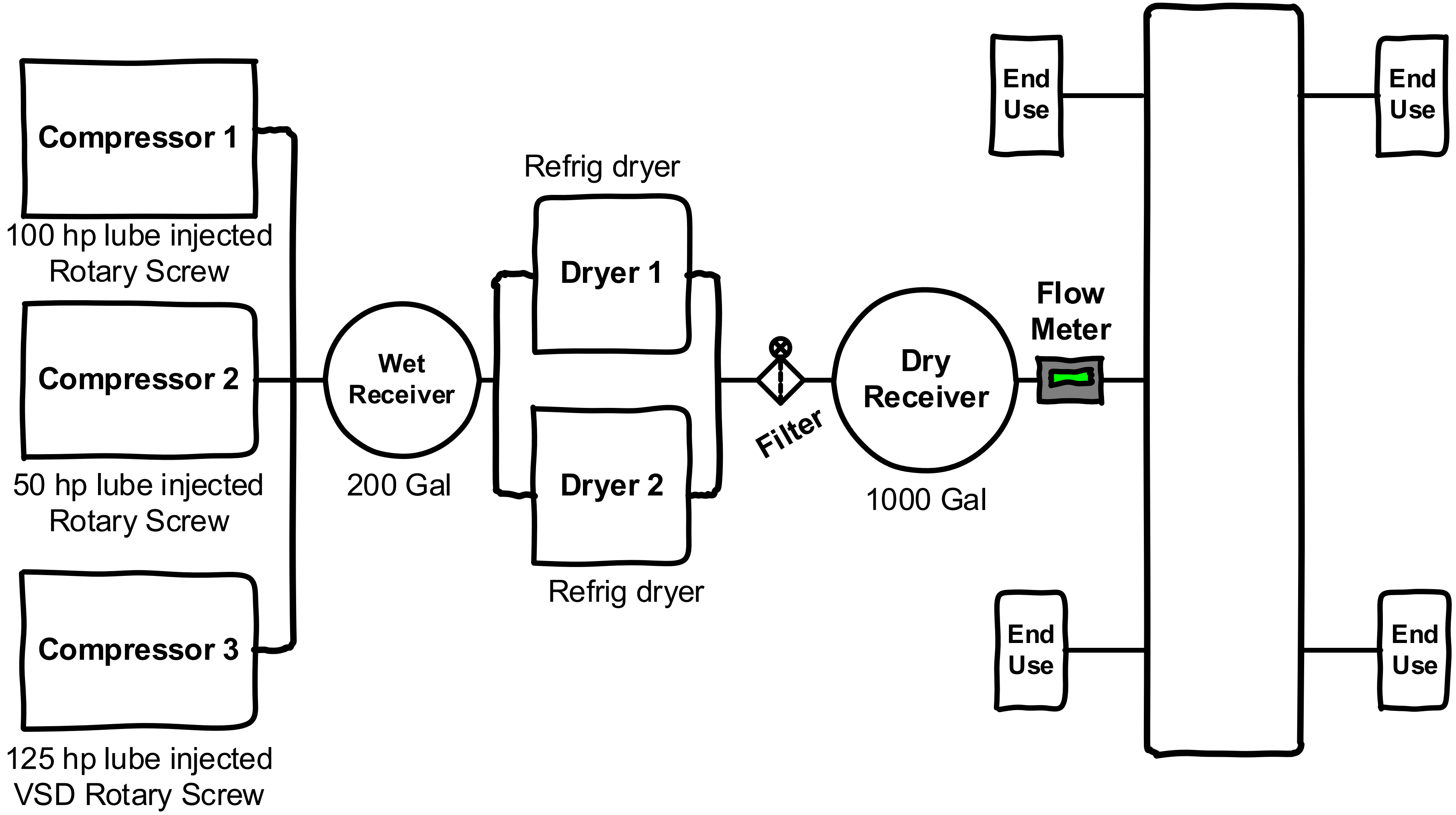
Week 2

Homework from Session 1

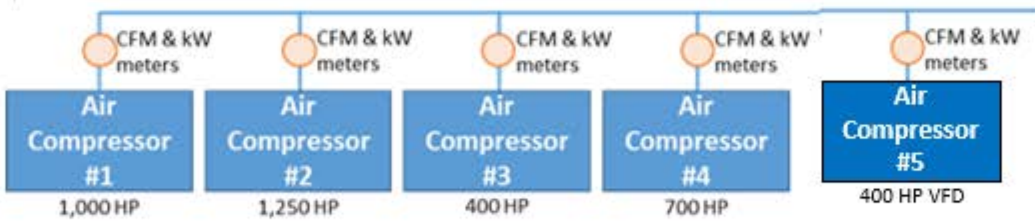
Homework for Week 1 – Block Diagram

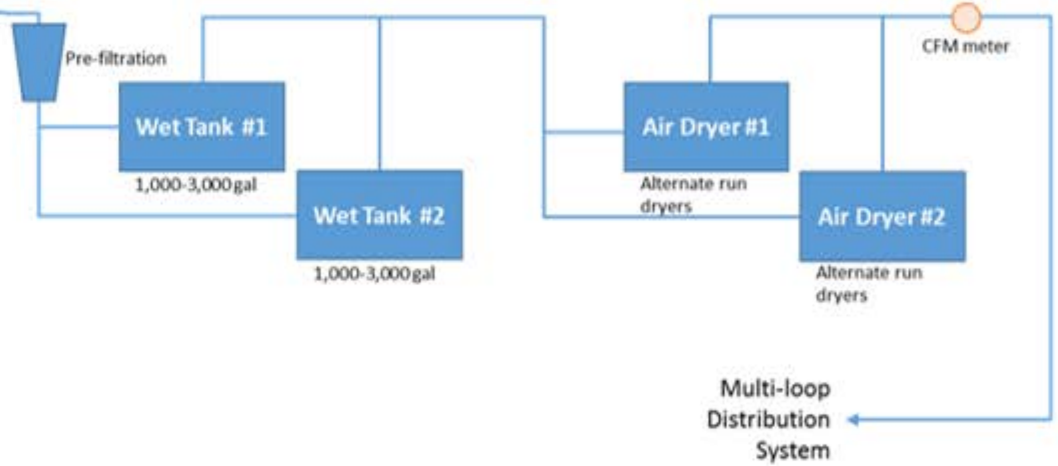
- Draw a block diagram of your compressed air system.
  - No P&ID drawings please.
- Include supply side and demand side if possible.
- Indicate compressor type and horsepower.
- Show dryer type and any filters.

Homework for Week 1 – Example Diagram



Homework for Week 1 – From Dwayne





Compressor List — Updated 12/28/20

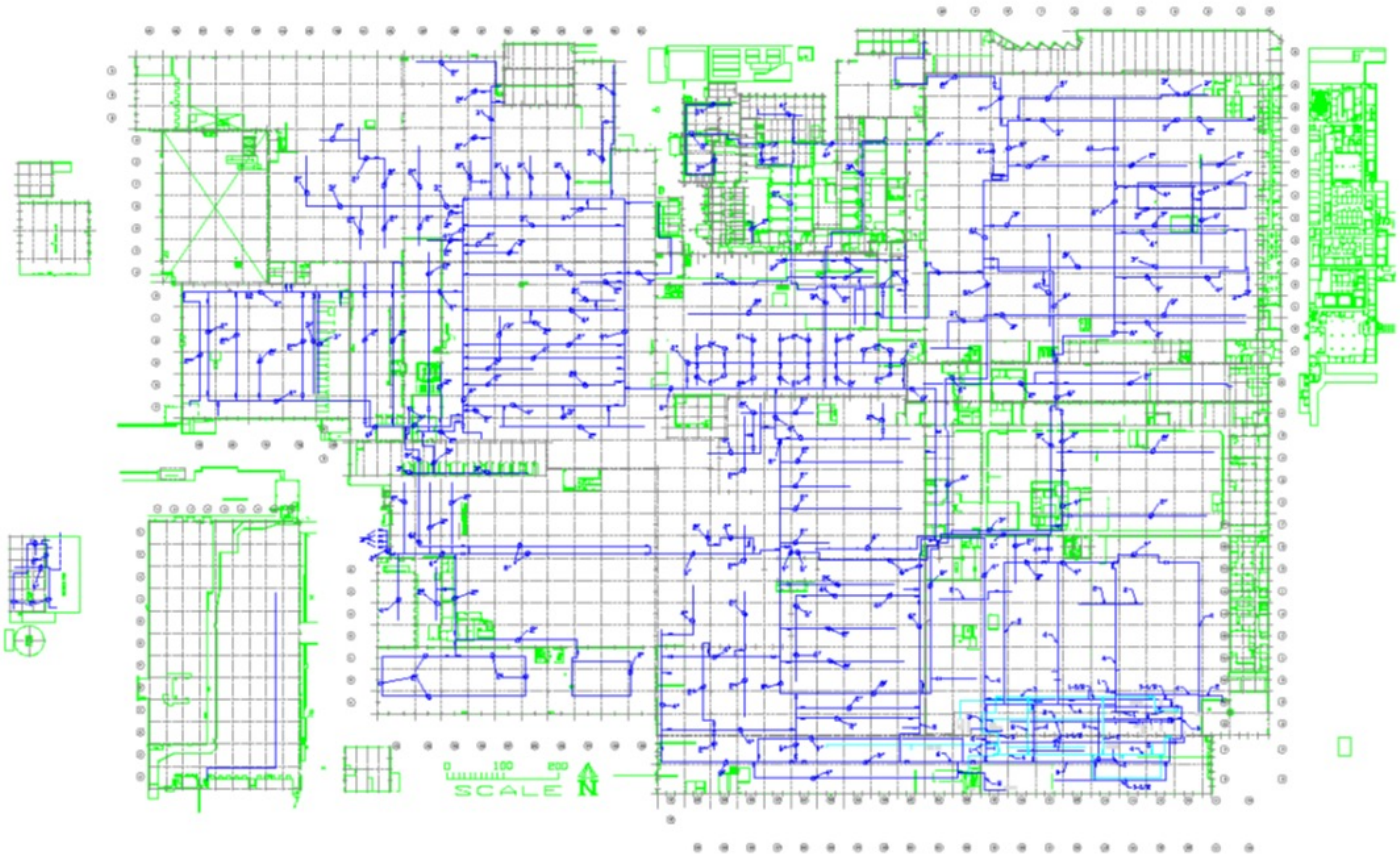
Compressor # 1	Compressor # 2	Compressor # 3	Compressor # 4	Compressor # 5
4875 CFM 1100 H.P. DE-56336	5860 CFM 1250 H.P. DE-36959	2000 CFM 400 H.P. DE-28336	3165 CFM 700 H.P. DE-56335	1785 CFM 400 H.P. DE-56818
Manufacturer: Ingersoll Rand	**Manufacturer:** Ingersoll Rand	**Manufacturer:** Ingersoll Rand	**Manufacturer:** Ingersoll Rand	**Manufacturer:** Ingersoll Rand
Type: Centrifugal	**Type:** Centrifugal	**Type:** Reciprocating	**Type:** Centrifugal	**Type:** Screw
Model #: C80045M3	**Model #:** Centac 70	**Model #:** Type XLE	**Model #:** C700-31M3	**Model #:** E315ne
Serial #: C13667	**Serial #:** M73-0373	**Serial #:** JH35253	**Serial #:** C13479	**Serial #:** MOX1003079
Year Purchased: 2015	**Year Purchased:** 1973	**Year Purchased:** 1965	**Year Purchased:** 2013	**Year Purchased:** 2020
Rebuilt: -	**Rebuilt:** 1998	**Rebuilt:** 2012	**Rebuilt:** -	**Rebuilt:** -

Normal mode of operation for the facility is to run one centrifugal compressor (#1 or #2) for base loading with one trim compressor (compressor #3, #4, or #5) for load or partial load operation.

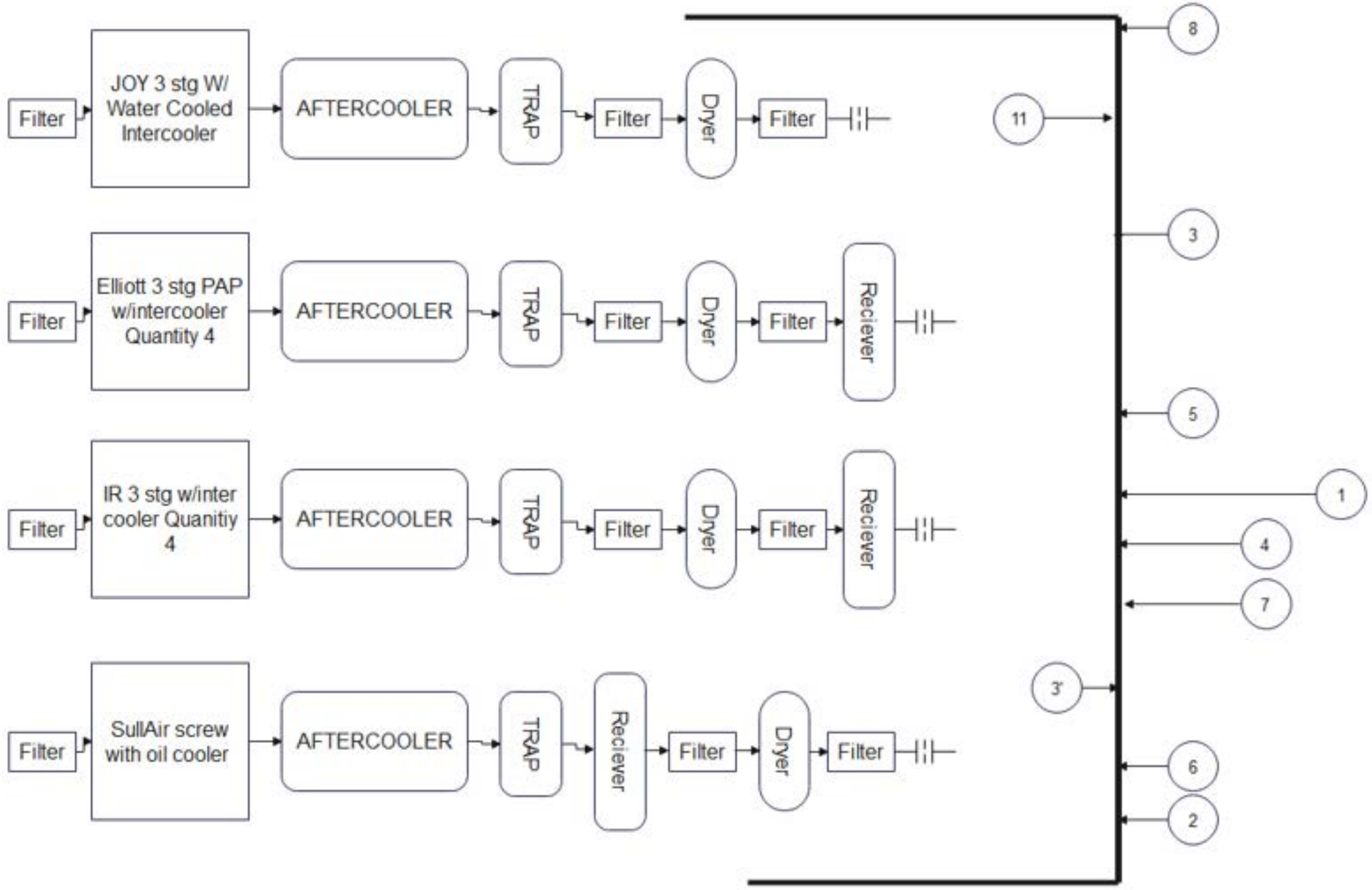
This ensures that all processes will have adequate pressure balance for production purposes. Compressed air has partial support for our fire suppression system in certain areas.

Typically, there is 8000 CFM available at any one time. This is from only 2 compressors being run. This allows DDC to maintain the redundancy that is required for the facility.

Homework for Week 1 – From Dwayne

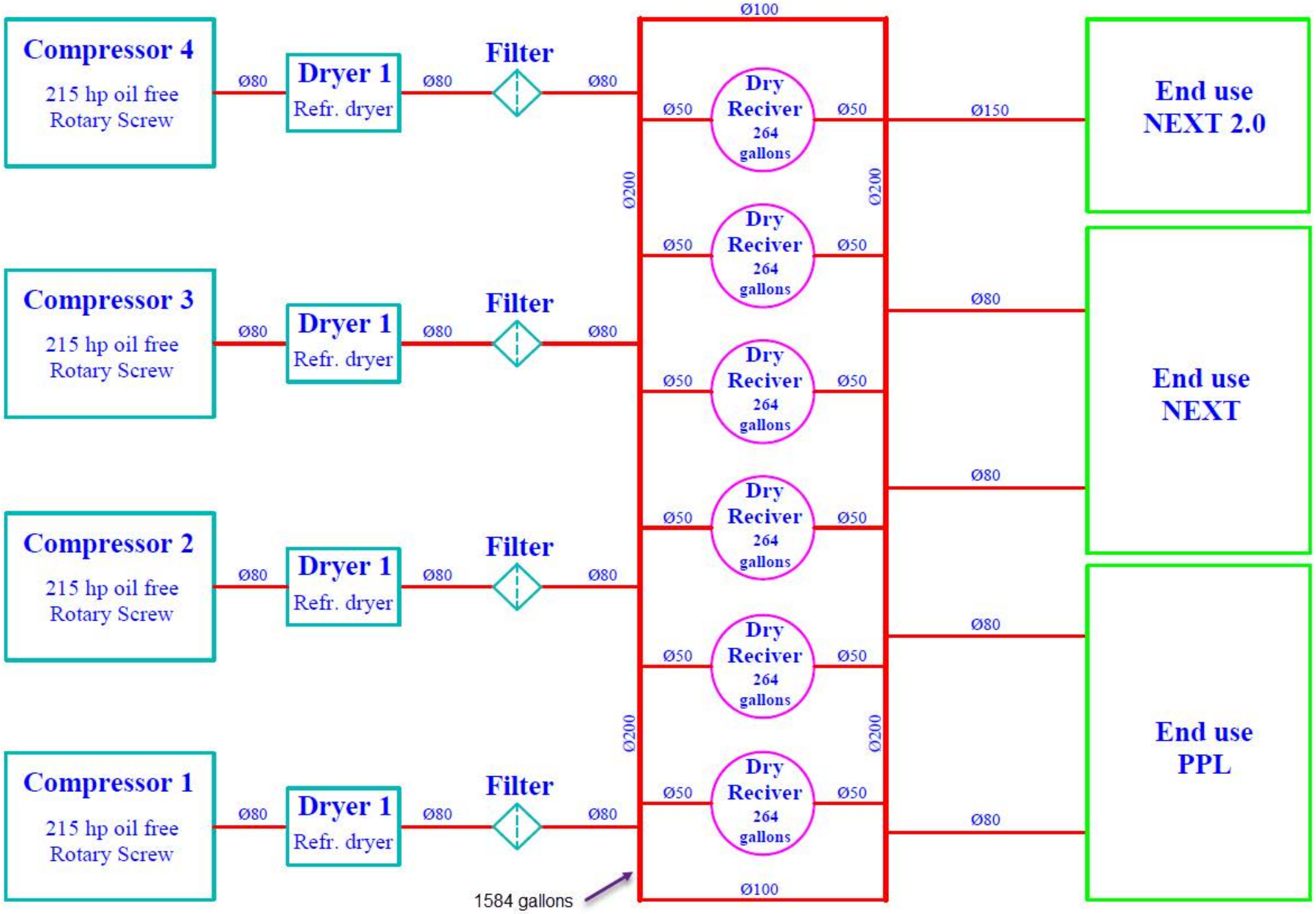


Homework for Week 1 – From George Gunter

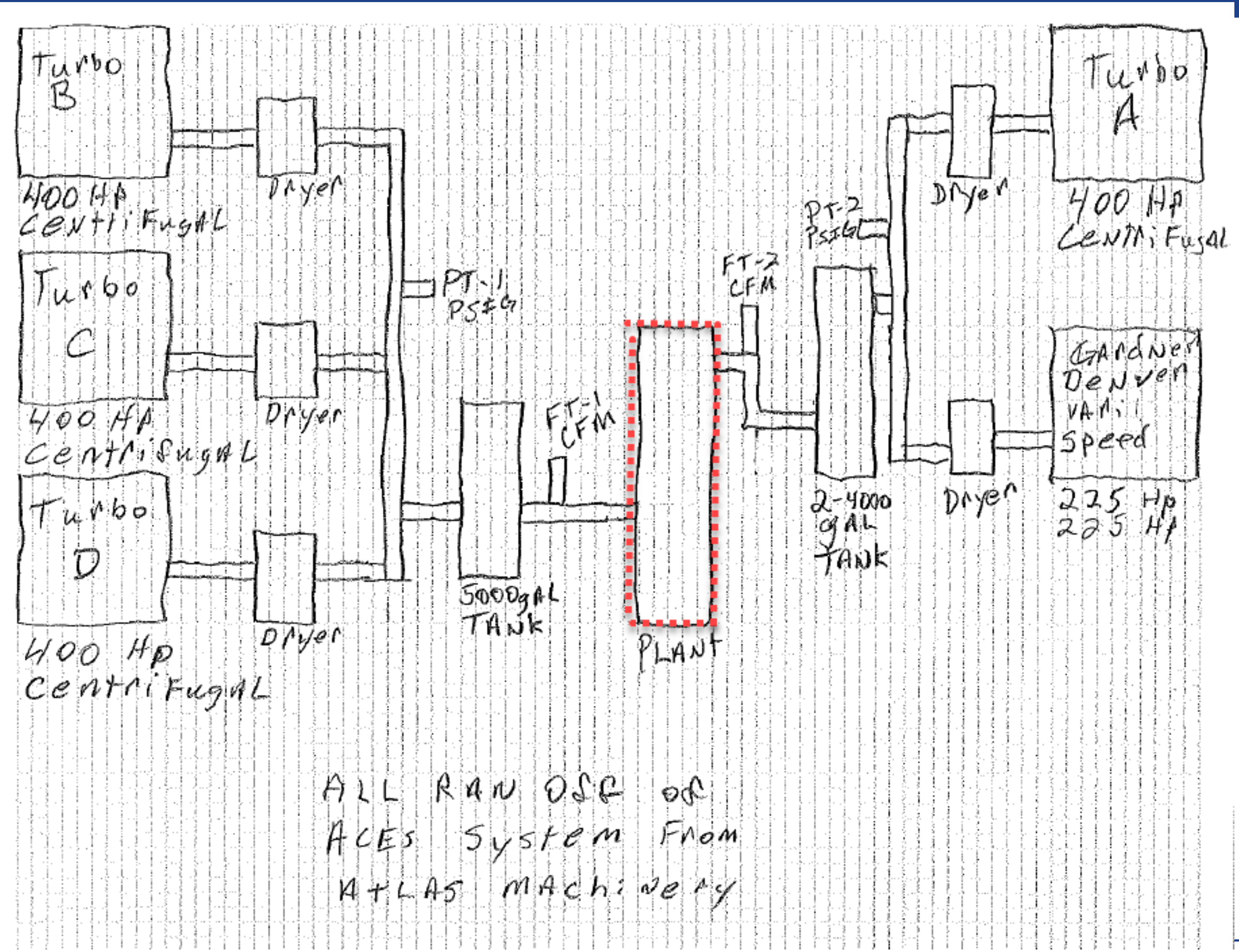


- 10 compressors @ 600 hp,, not all running at the same time.
- They all have an orifice plate for flow measurement, size is unknown at the moment.

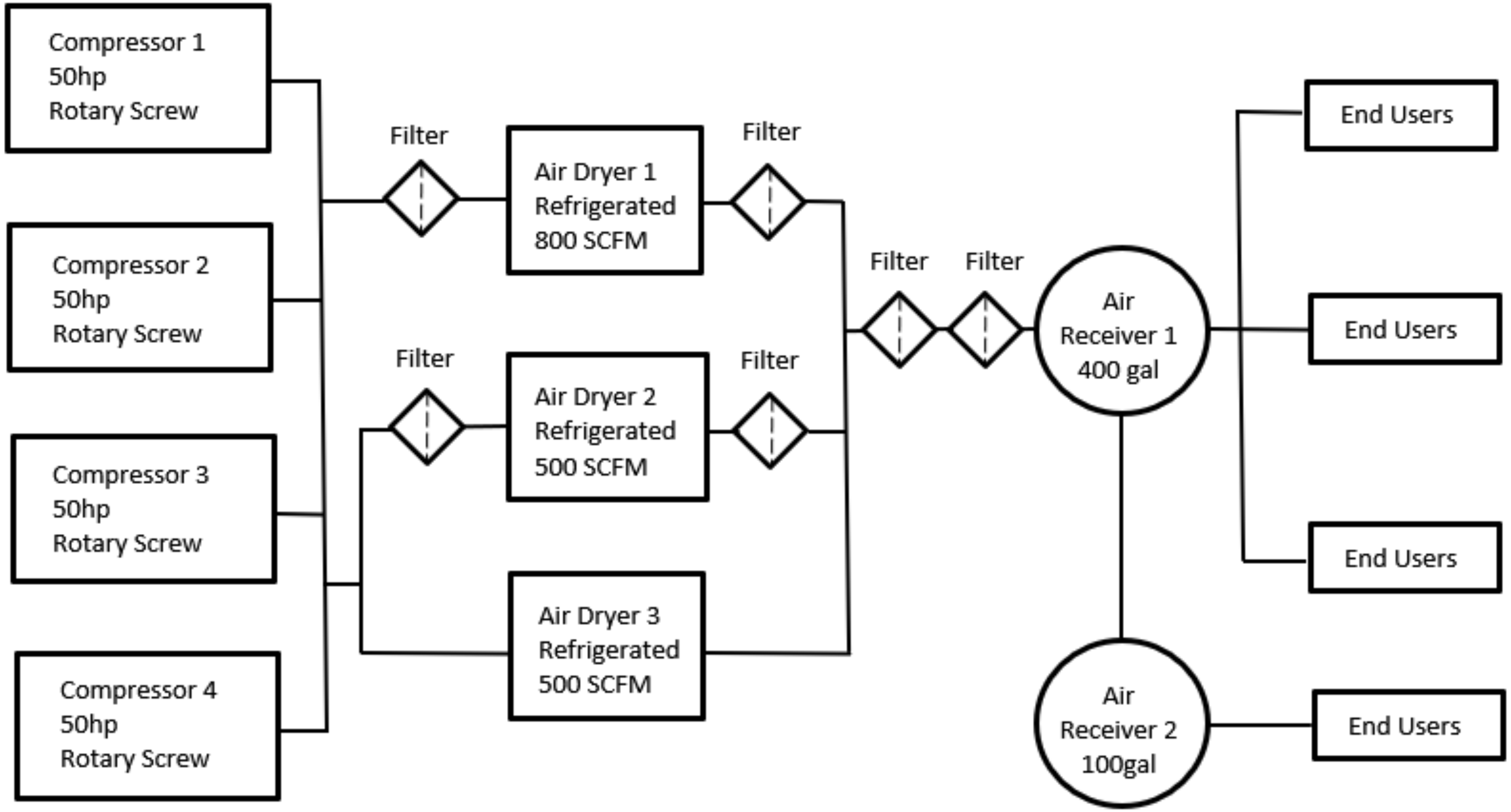
Homework for Week 1 – From Igor



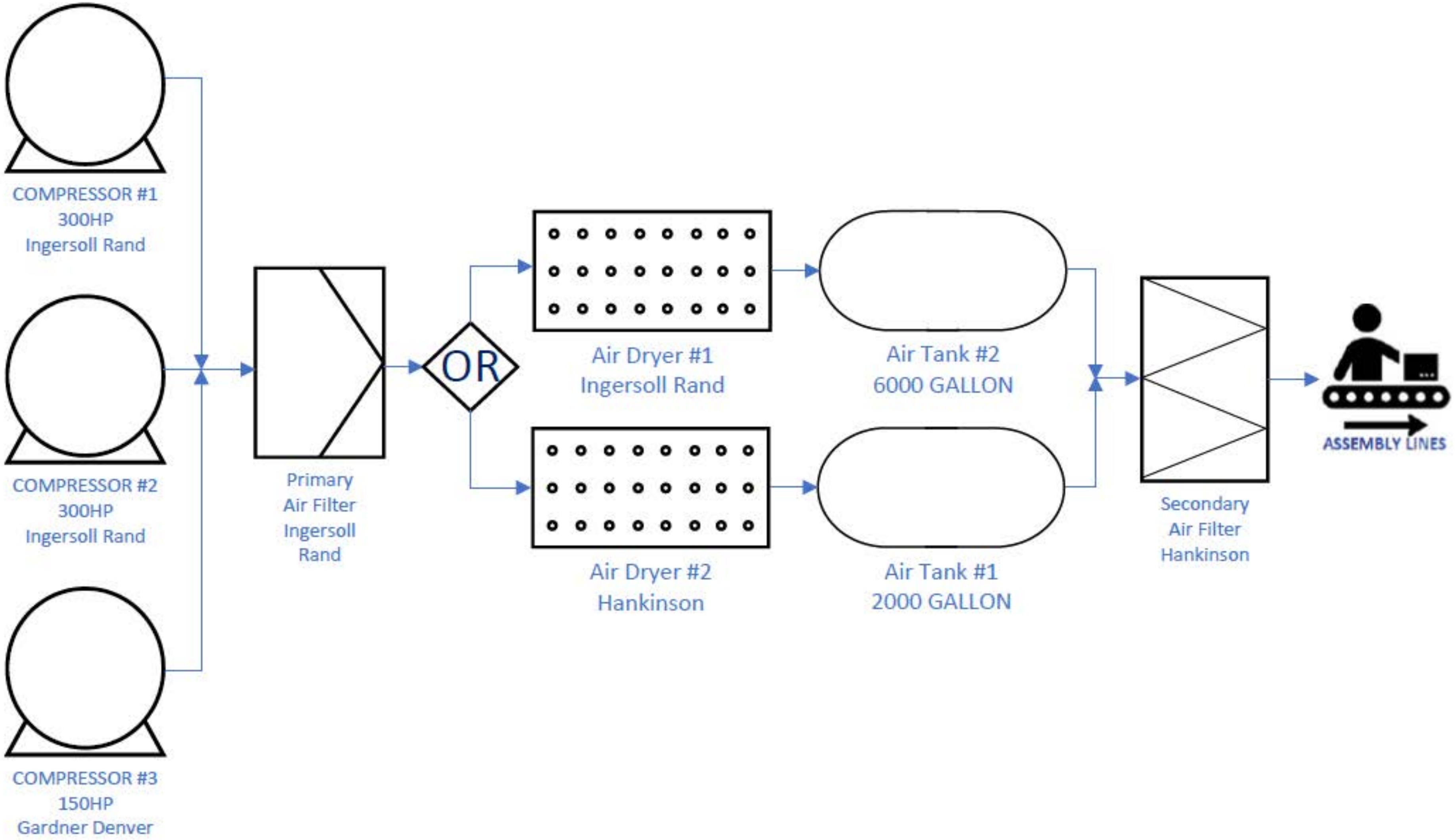
Homework for Week 1 – From Gary Baker



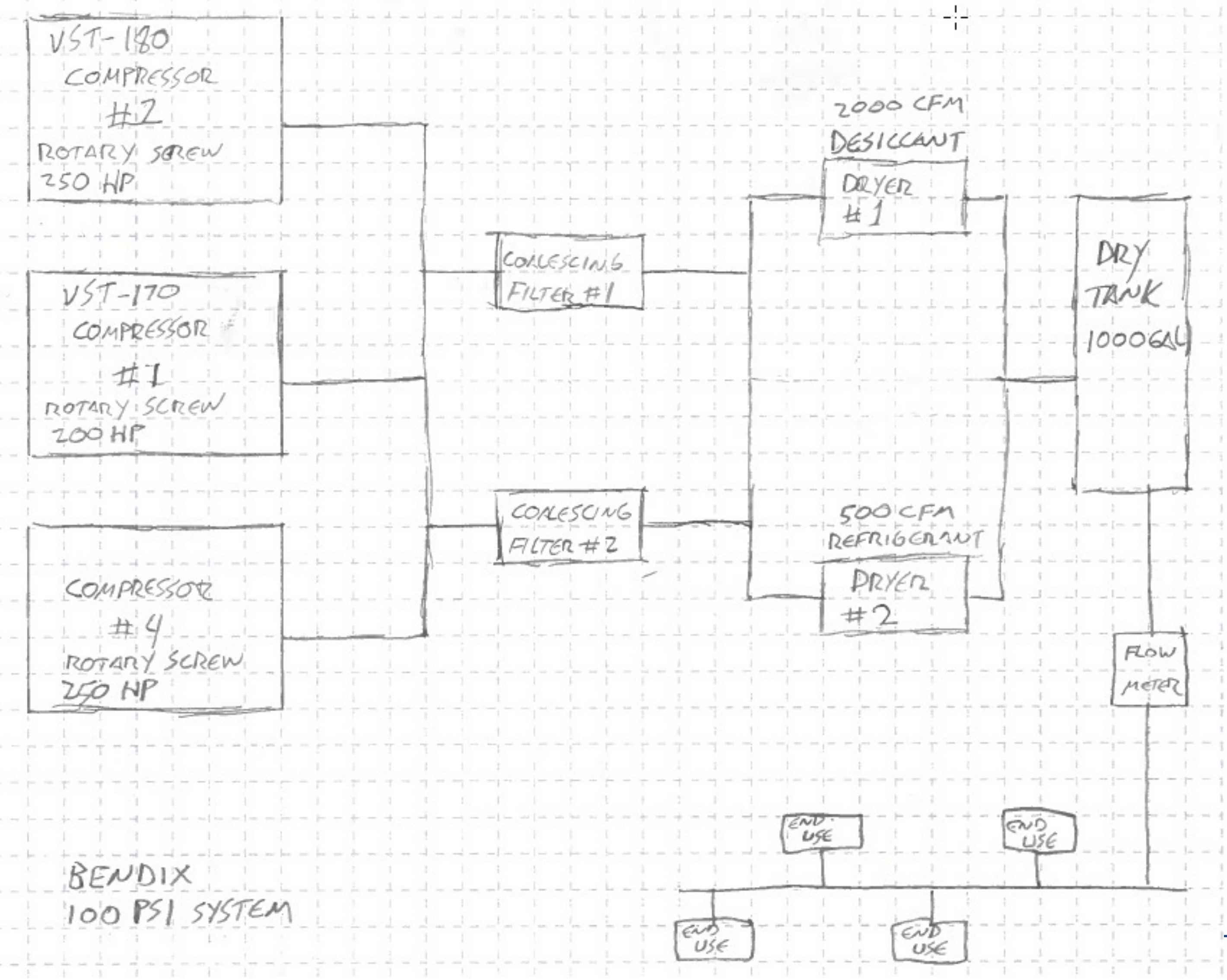
Homework for Week 1 – From Robert Barrier



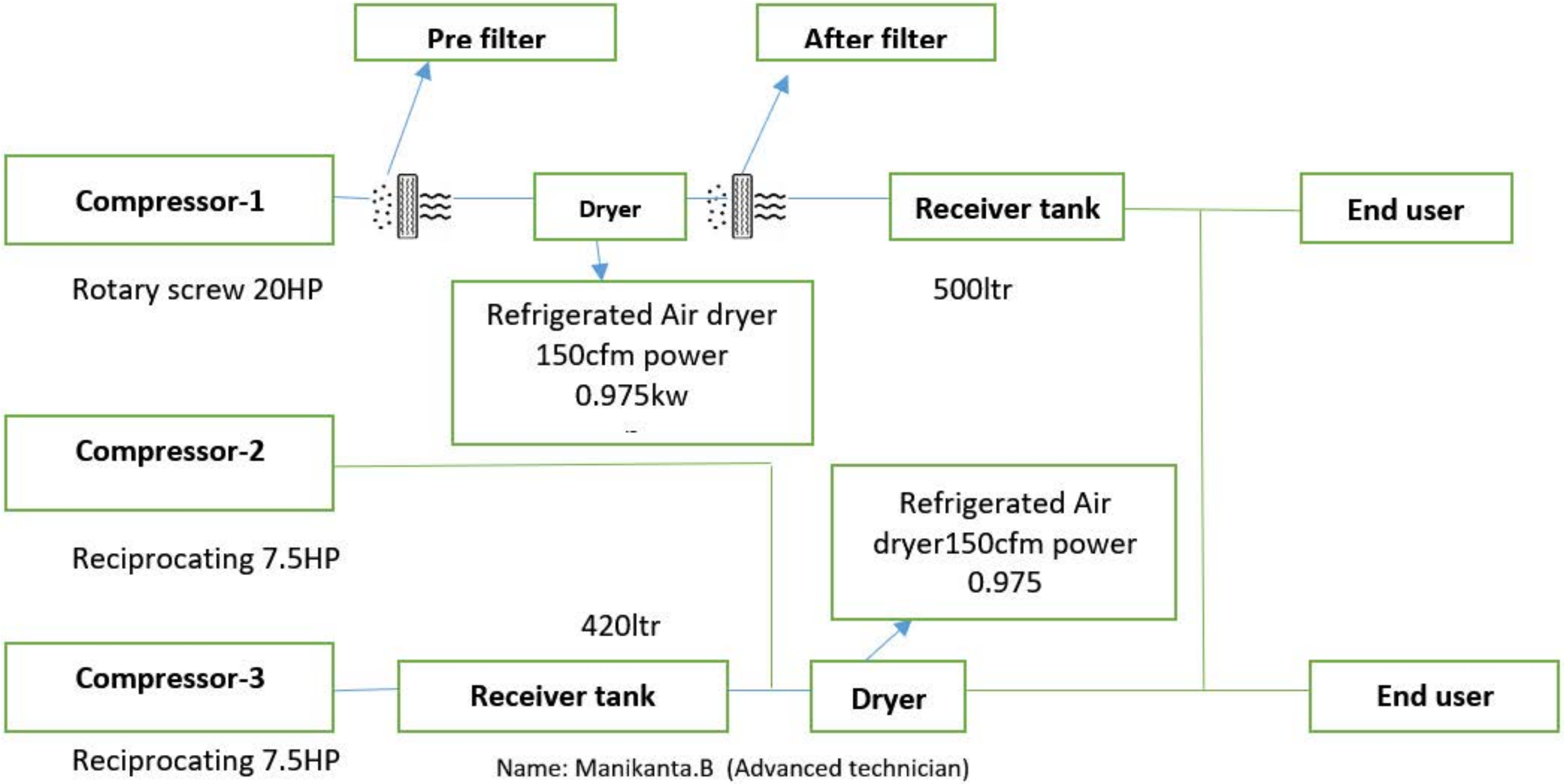
Homework for Week 1 – From Musa Maner



Homework for Week 1 – From Matt



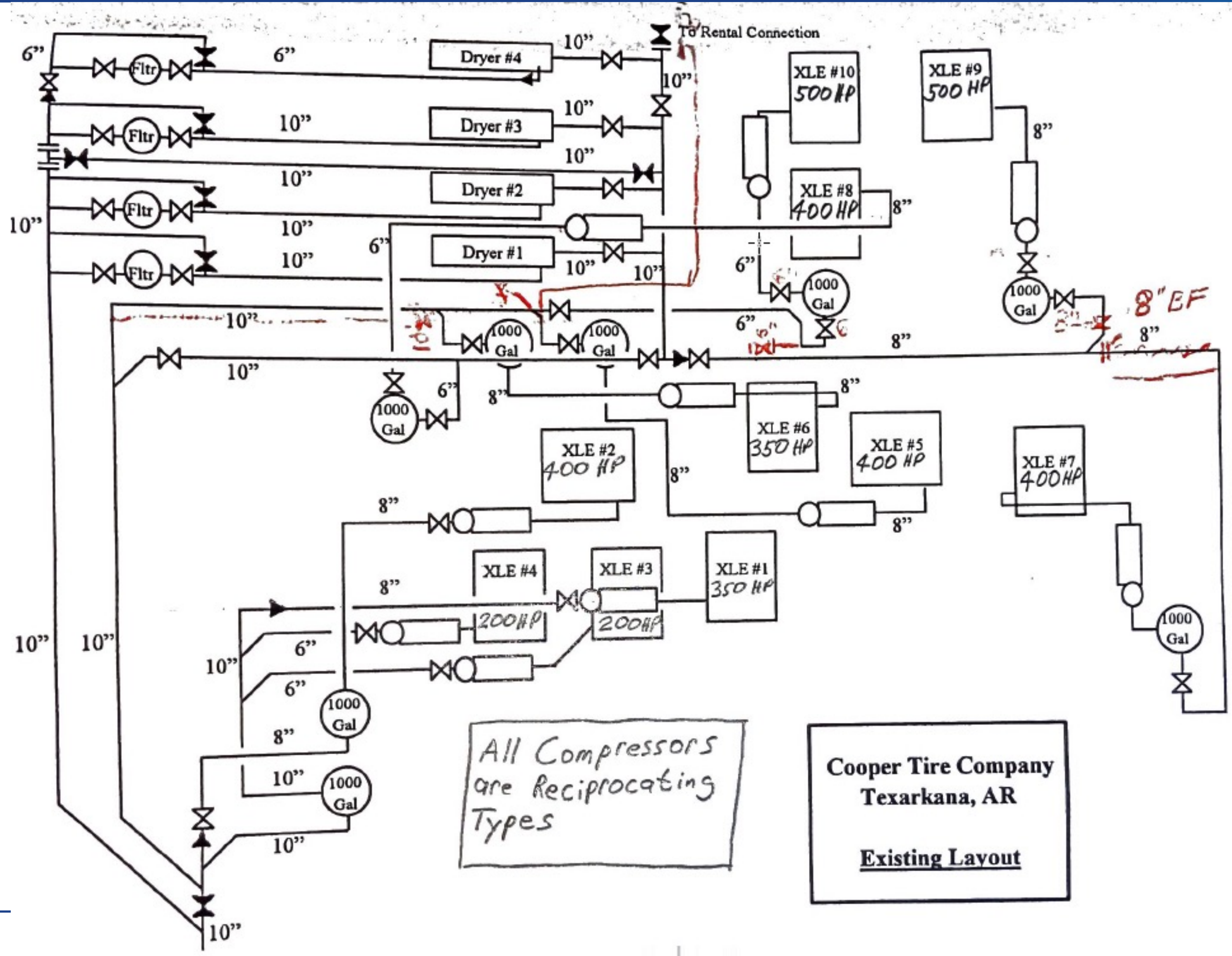
Homework for Week 1 – From Manikanta, Chethan, Pramod



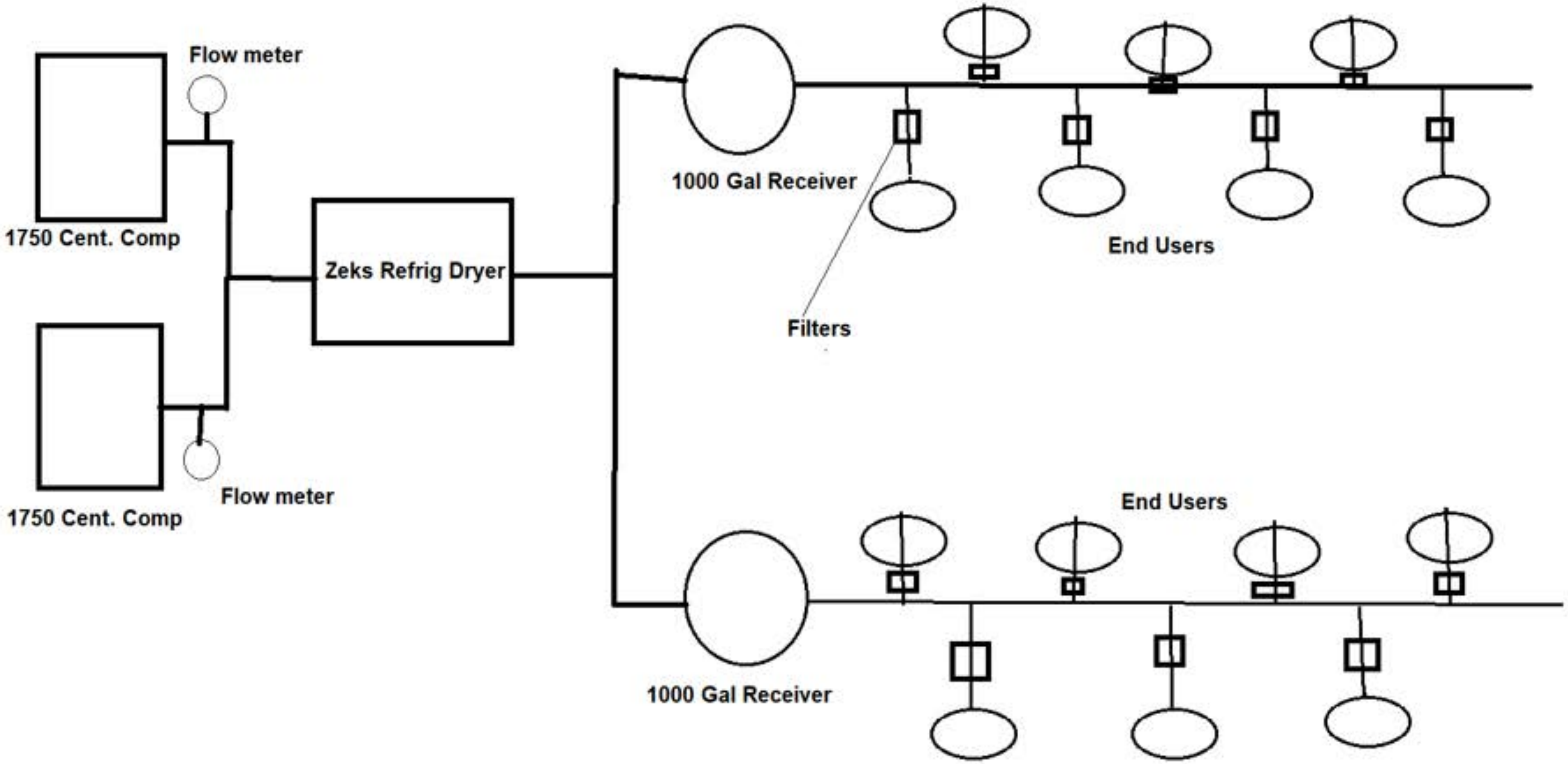
Name: Manikanta.B (Advanced technician)

Company: H&V Advanced Materials India Private limited

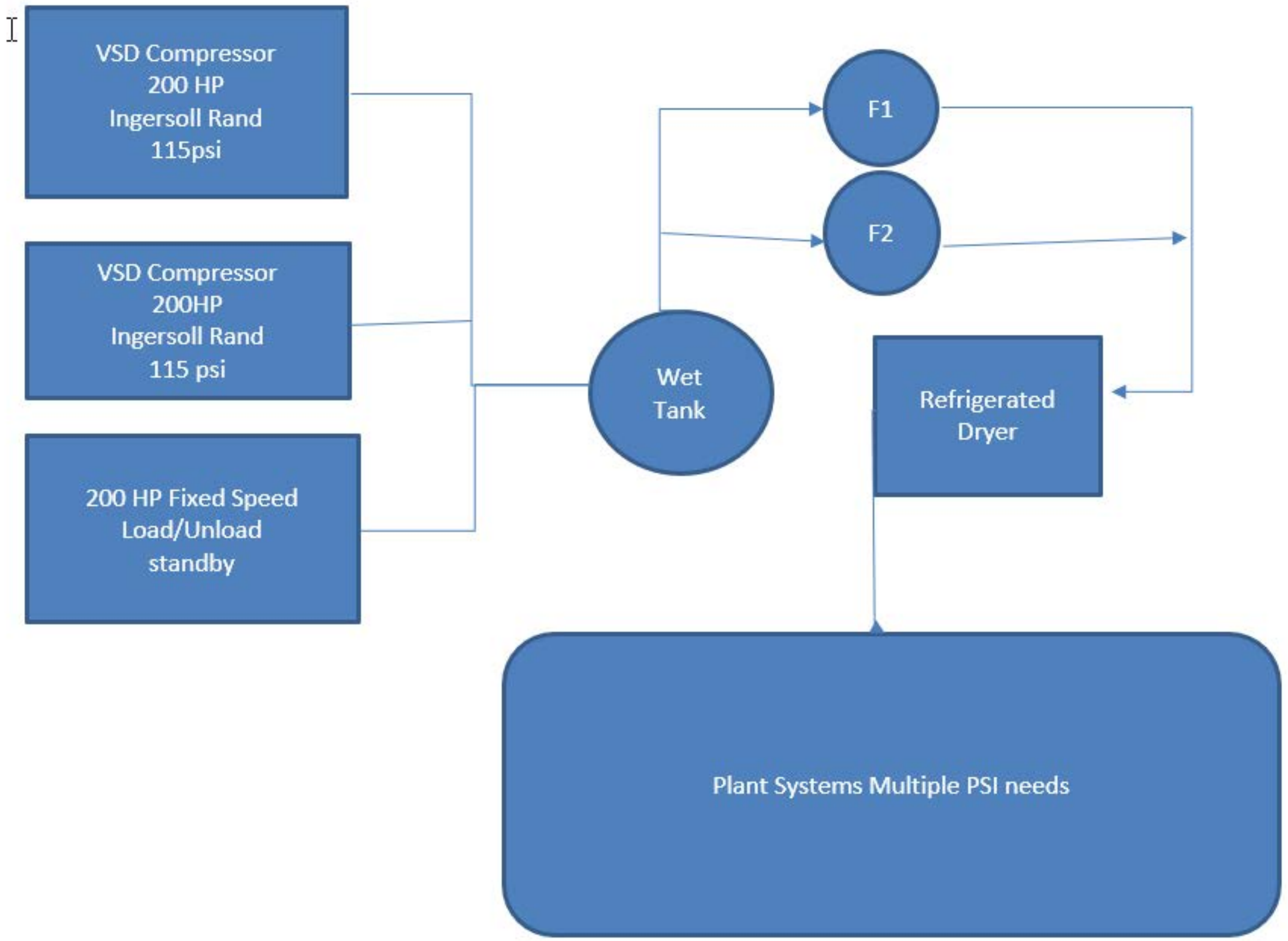
Homework for Week 1 – From John



Homework for Week 1 – From Sean

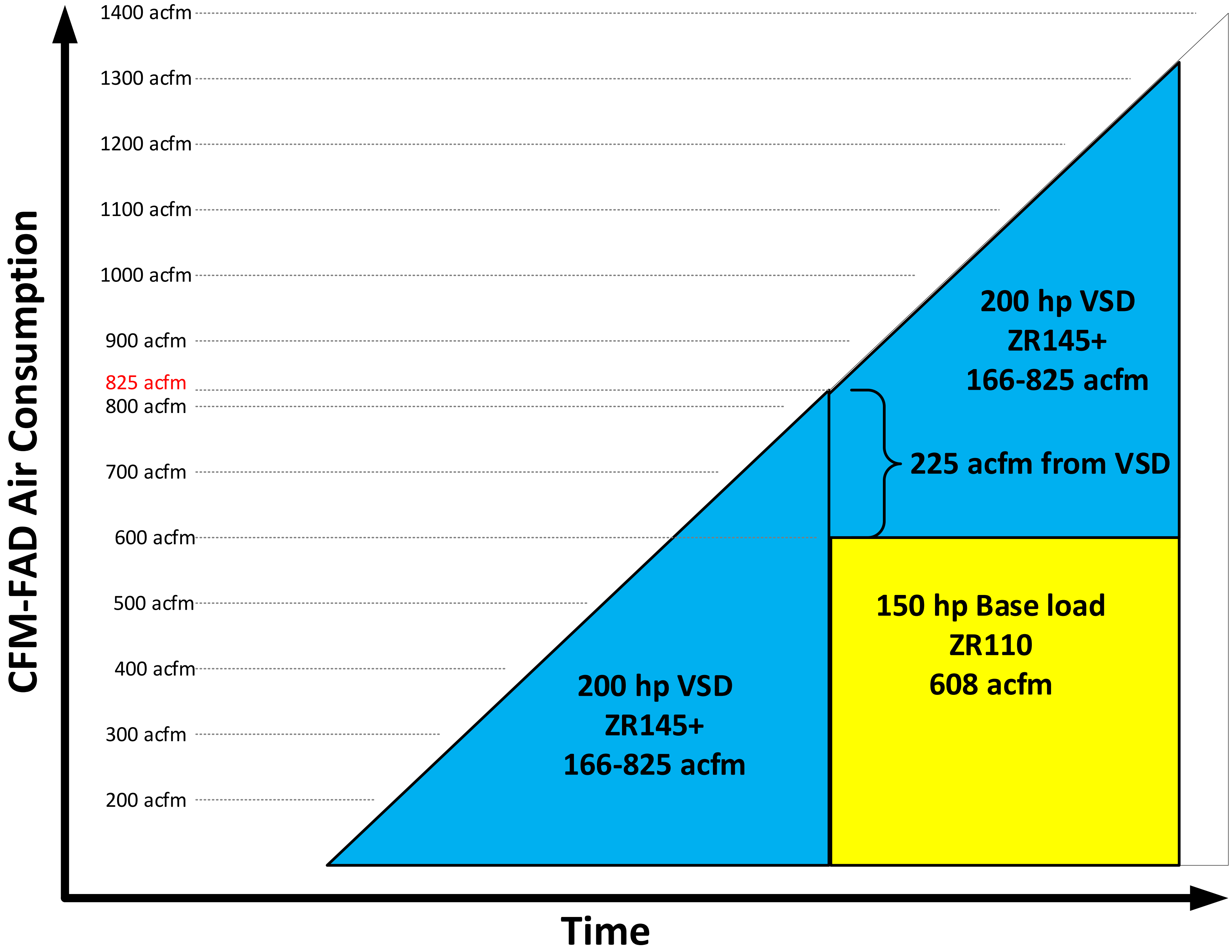


Homework for Week 1 – From Rick Cunningham



- System is not designed correctly

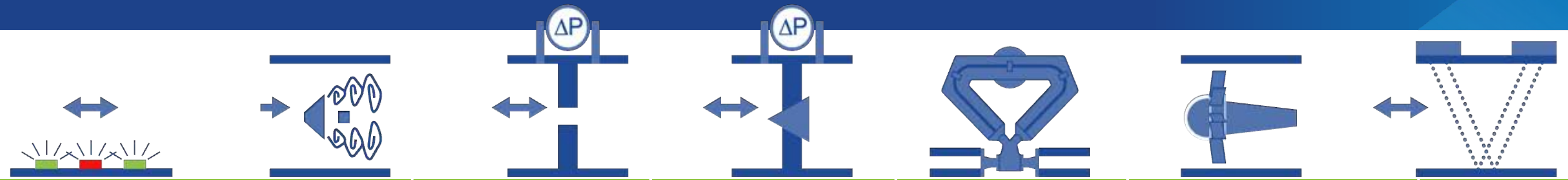
1. Insufficient storage
2. Running higher than needed pressures for most applications to make up for line design and leaks
3. Undoubtedly fouled piping as factory is over 100 years old
4. Running VFD units instead of base loading with fixed speed and trimming with VFD
5. No flow control for downstream
6. Lack of pressure and flow measurements
7. Lack of history on units and equipment
8. Improper use of air for things that should use other methods



CFM-FAD Air Consumption
1400 acfm
1300 acfm
1200 acfm
1100 acfm
1000 acfm
900 acfm
825 acfm
800 acfm
700 acfm
600 acfm
500 acfm
400 acfm
300 acfm
200 acfm
200 hp VSD
ZR145+
166-825 acfm
225 acfm from VSD
150 hp Base load
ZR110
608 acfm
200 hp VSD
ZR145+
166-825 acfm
Time

Quick Review on Flowmeters

Types of Meters - Comparisons



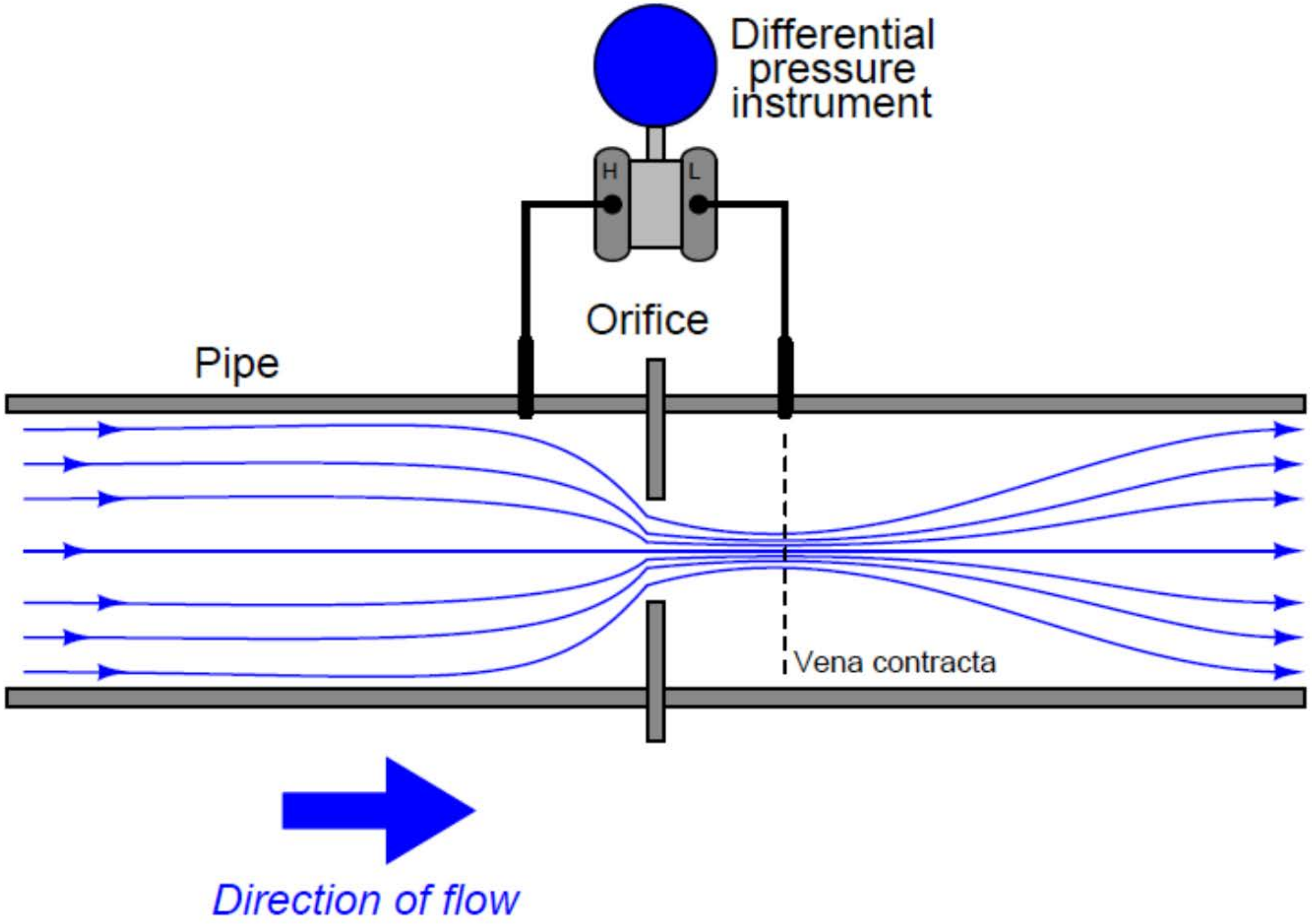
	Thermal	Vortex	DP – Orifice plate	DP – Insertion	Coriolis	Turbine/ rotary displacement	Clamp on ultrasonic
Mass flow	Yes	Optional	Optional	Optional	Yes	Optional	Optional
Meter run	20D	15D	15D	20D	0D	10D	20D
Pressure loss	Low	Medium/high	high	Low	Low	Low	Low
Dirty air	Fouling	OK	Clogging	Fouling/Clog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

Orifice Plate Flow Meters

These meters are another carry over from fluid engineering.

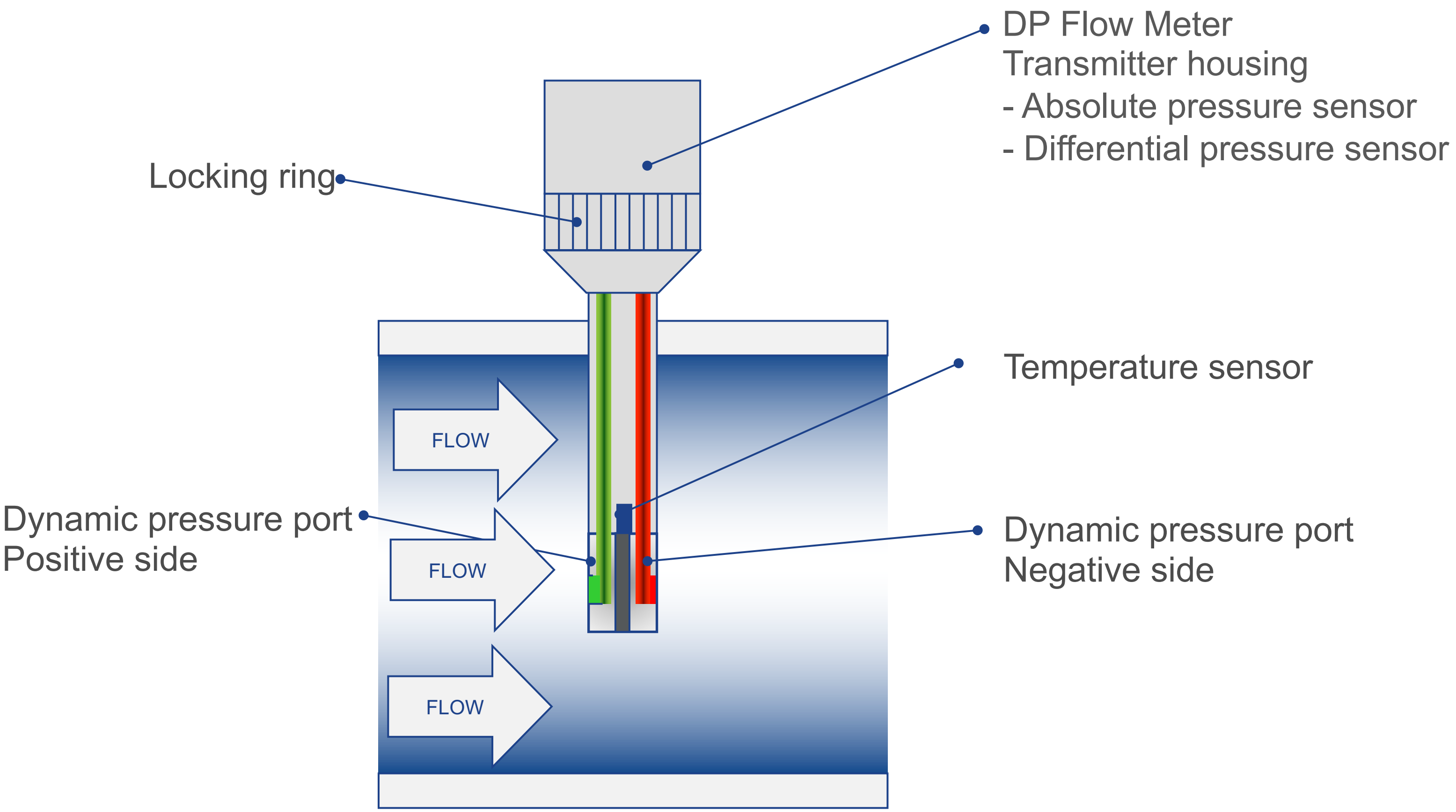
They operate on the physics of a pressure drop being created as a medium flows through an orifice.

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



Differential Pressure Technology

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



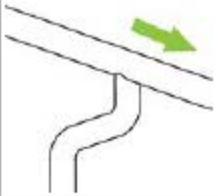
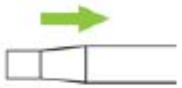
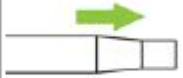
Min and Max Flow per Pipe Size

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

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

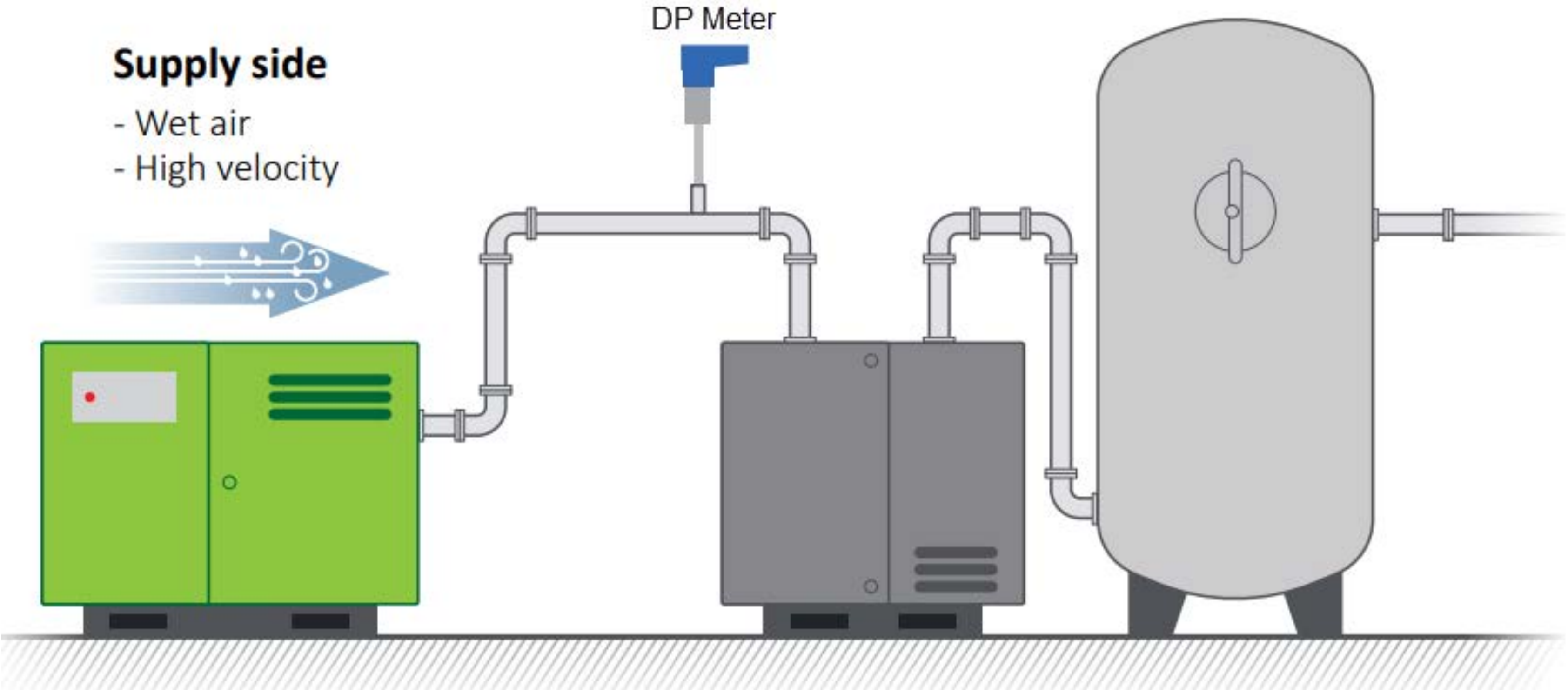
Schedule 10 Standard Seamless Carbon Steel Pipe					
ID (inch)	*ID (mm)*	*Min flow (scfm)*	*Max flow (scfm)*	*Min flow (m^3_n/hr)*	*Max flow (m^3_n/hr)*
2,2	54,8	100	999	**170**	**1697**
3,3	82,8	228	2282	**388**	**3877**
4,3	108,2	390	3897	**662**	**6621**
6,4	161,5	868	8678	**1474**	**14743**
8,3	211,6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

Flow Meter Location

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

DP Insertion Flow Meters

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



Compressor Types

Compressor Types

Two types of compressors:

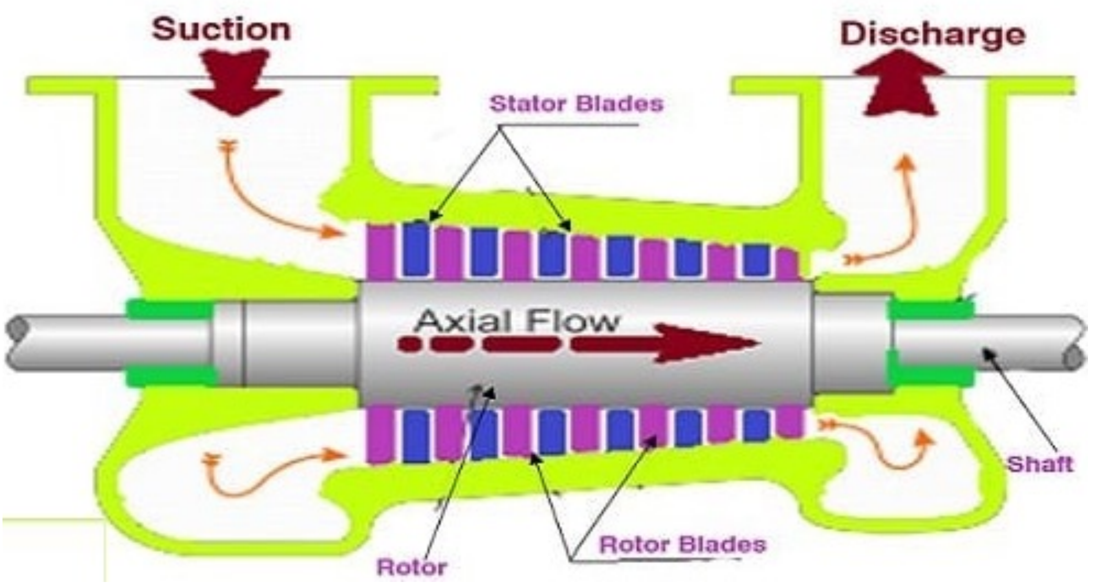
- Positive Displacement – Typically Rotary Screw
- Dynamic Compressors – Typically Centrifugal

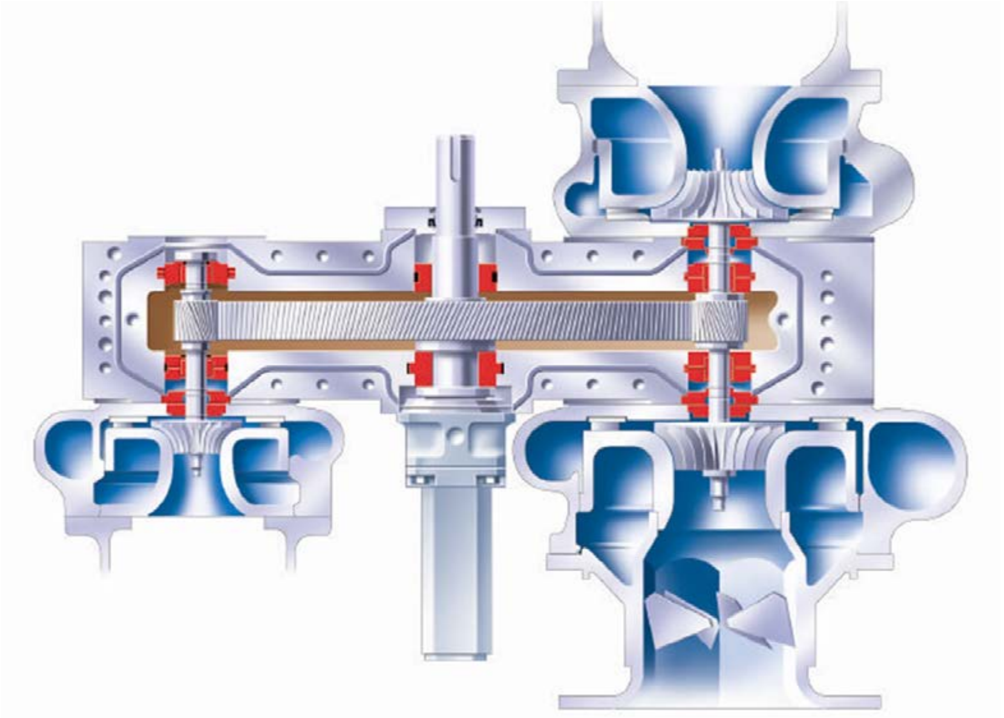
Compressor Types

- Positive displacement compressors can be reciprocating or rotary.
- Reciprocating Compressor — Rotary Compressor

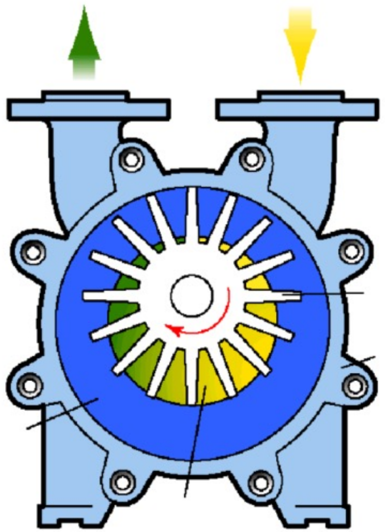
Compressor Types

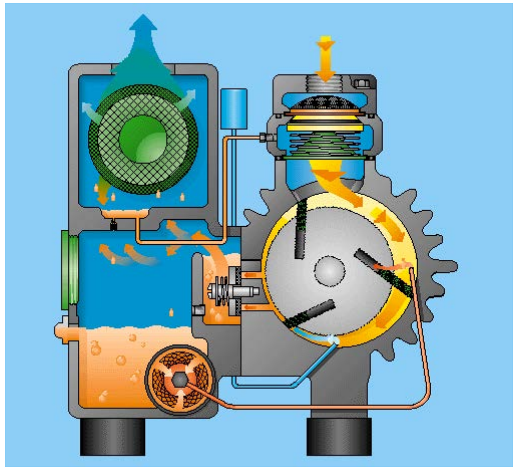
- Dynamic compressors can be axial or centrifugal.
- Axial Compressor — Centrifugal Compressor

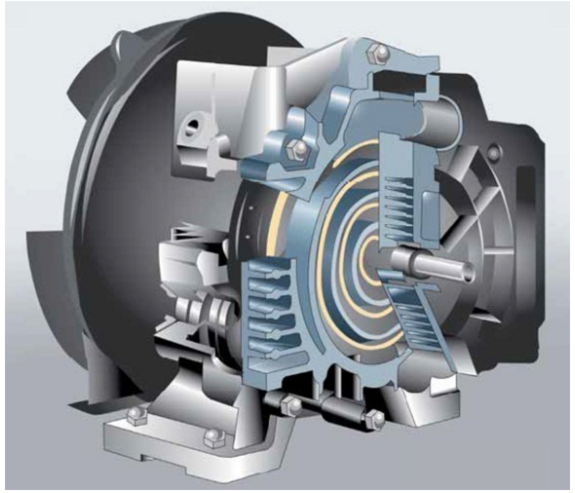


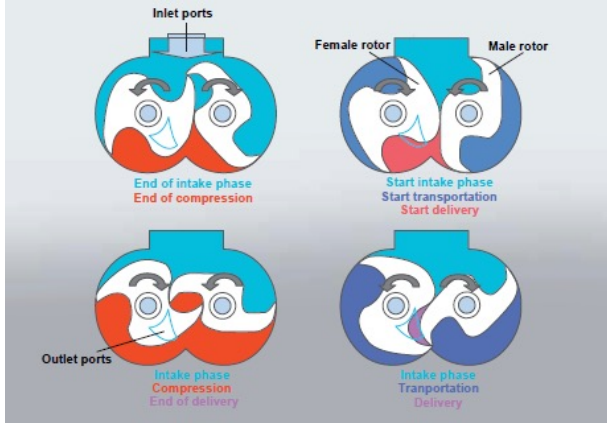


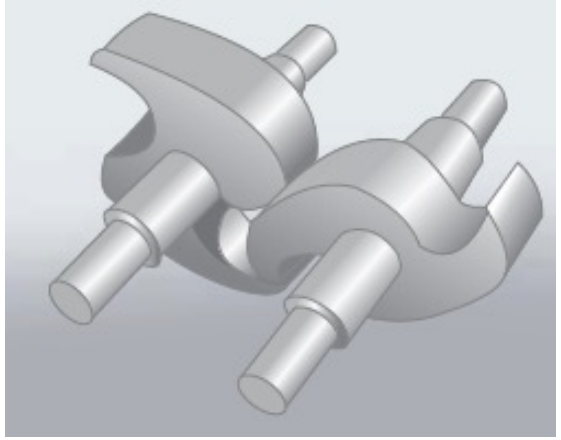
Other Types of Compressors





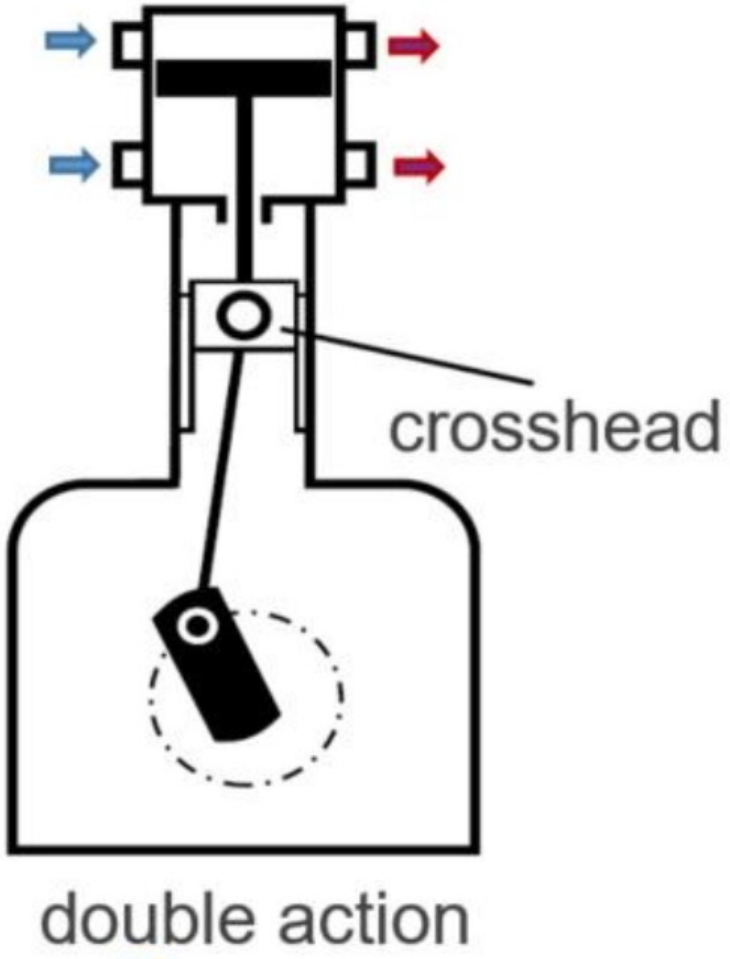






Reciprocation Compressors

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



Reciprocation Compressors

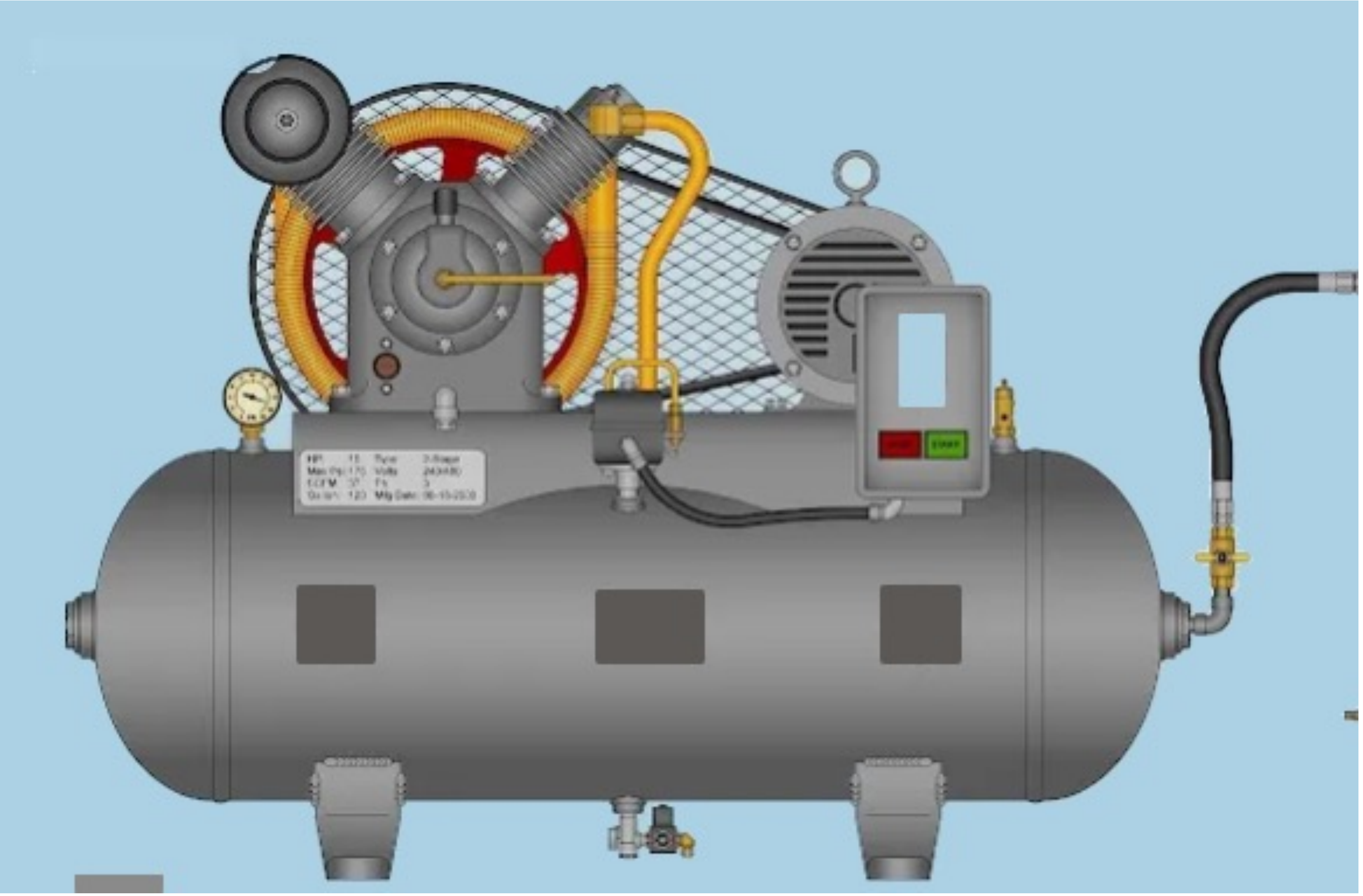
- Single-stage compressors compress air once from the inlet pressure to final discharge pressure.
- Multi-stage compressors compress air to one pressure, then compress it to a higher pressure in another stage or stages.

Single-Stage

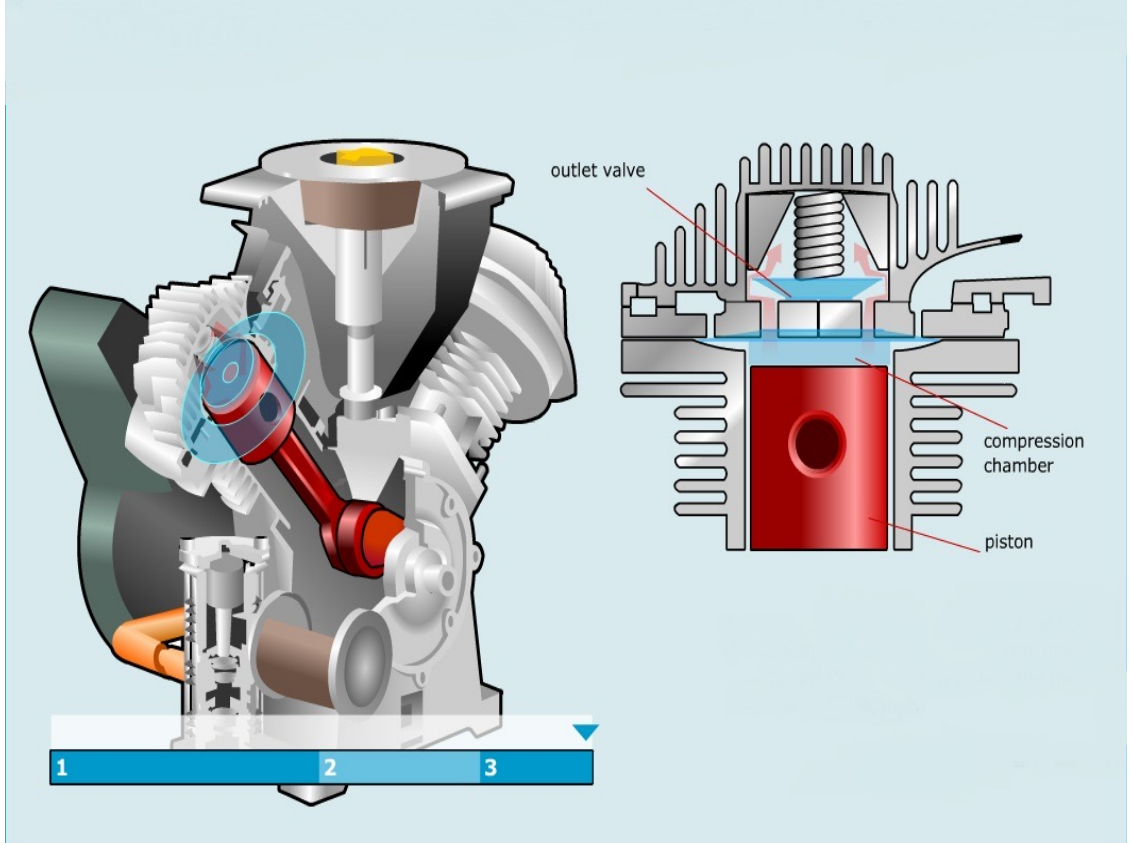
Two-Stage

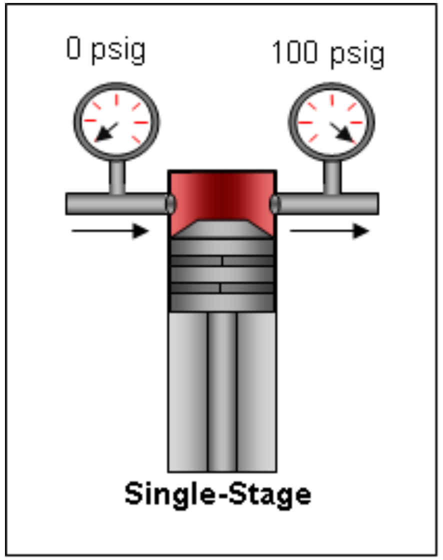
Reciprocation Compressors

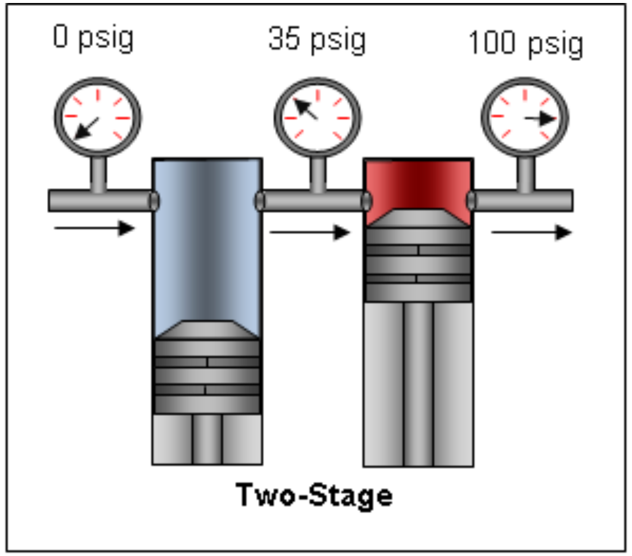
- Compressors can be single-stage or multistage units.

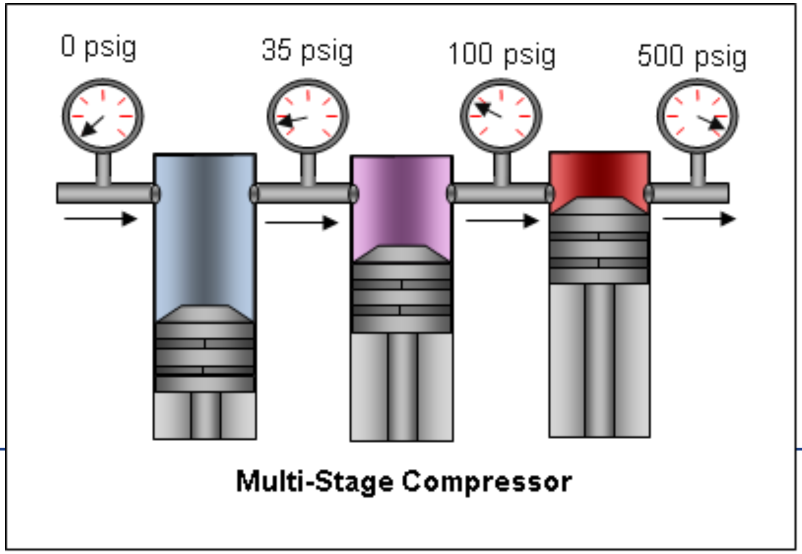


Reciprocation Compressors

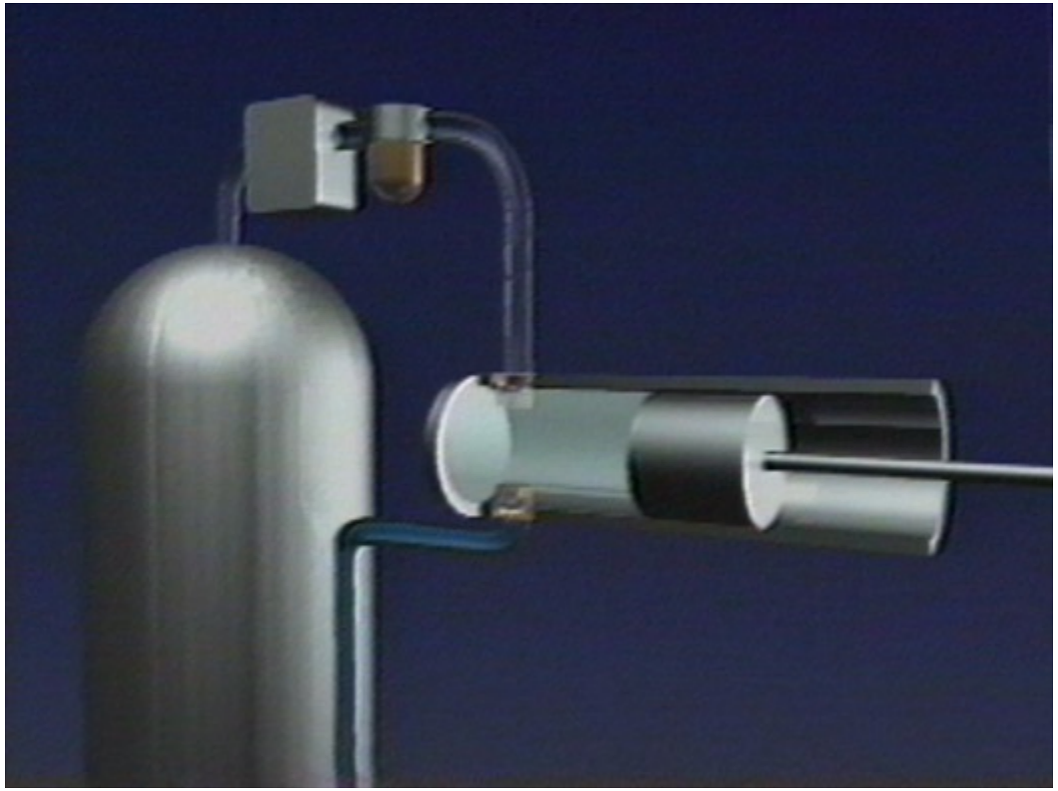


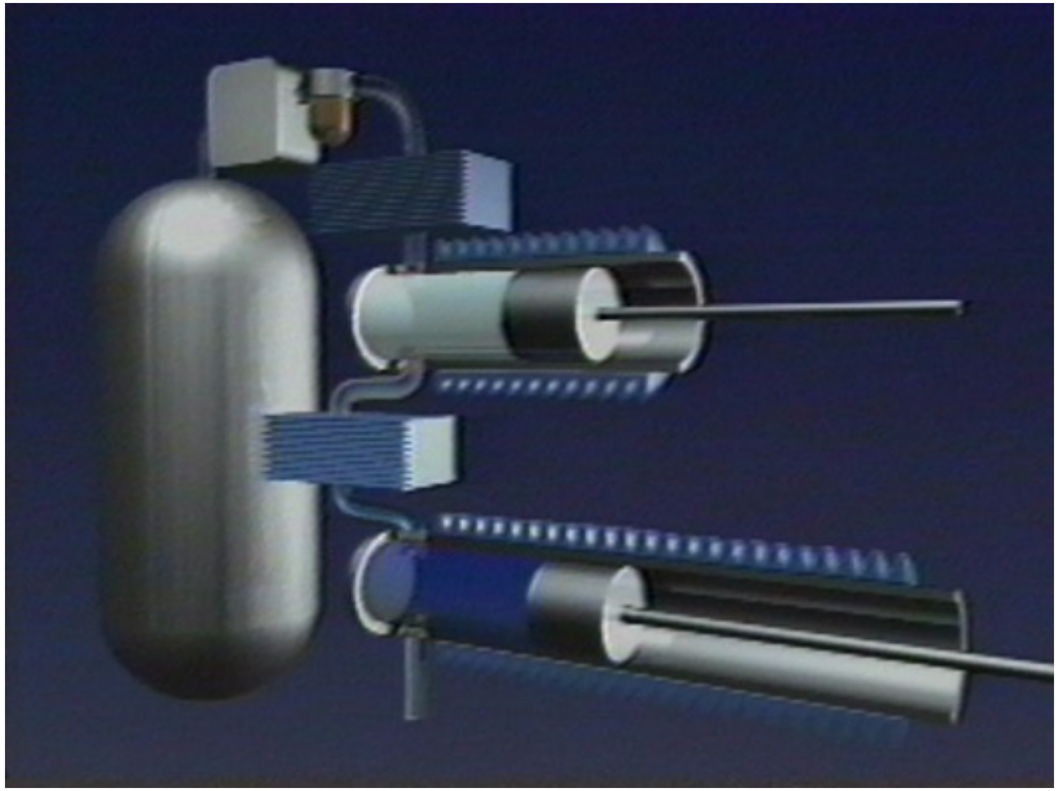






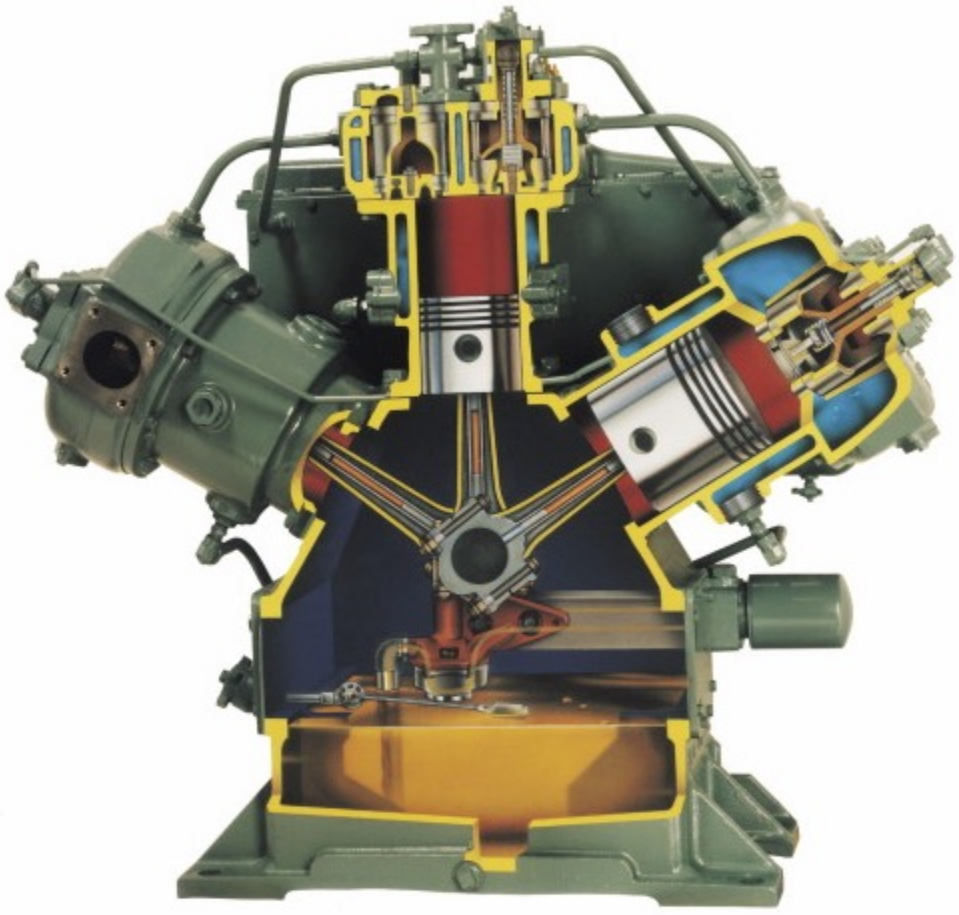
Single Vs Two Stage





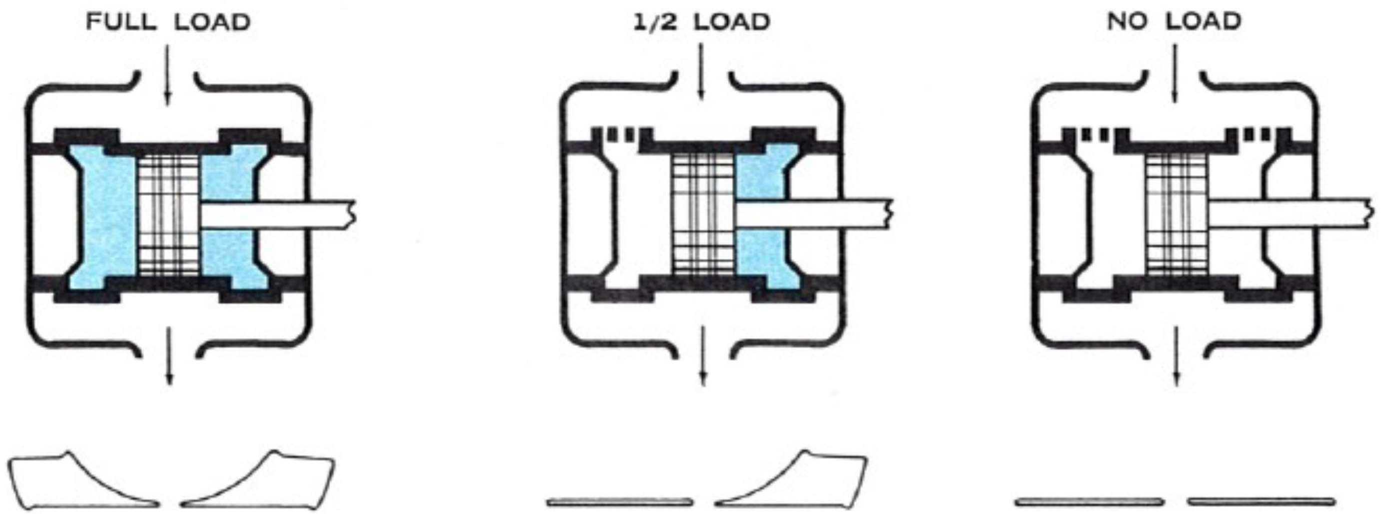
Double Acting

- 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.



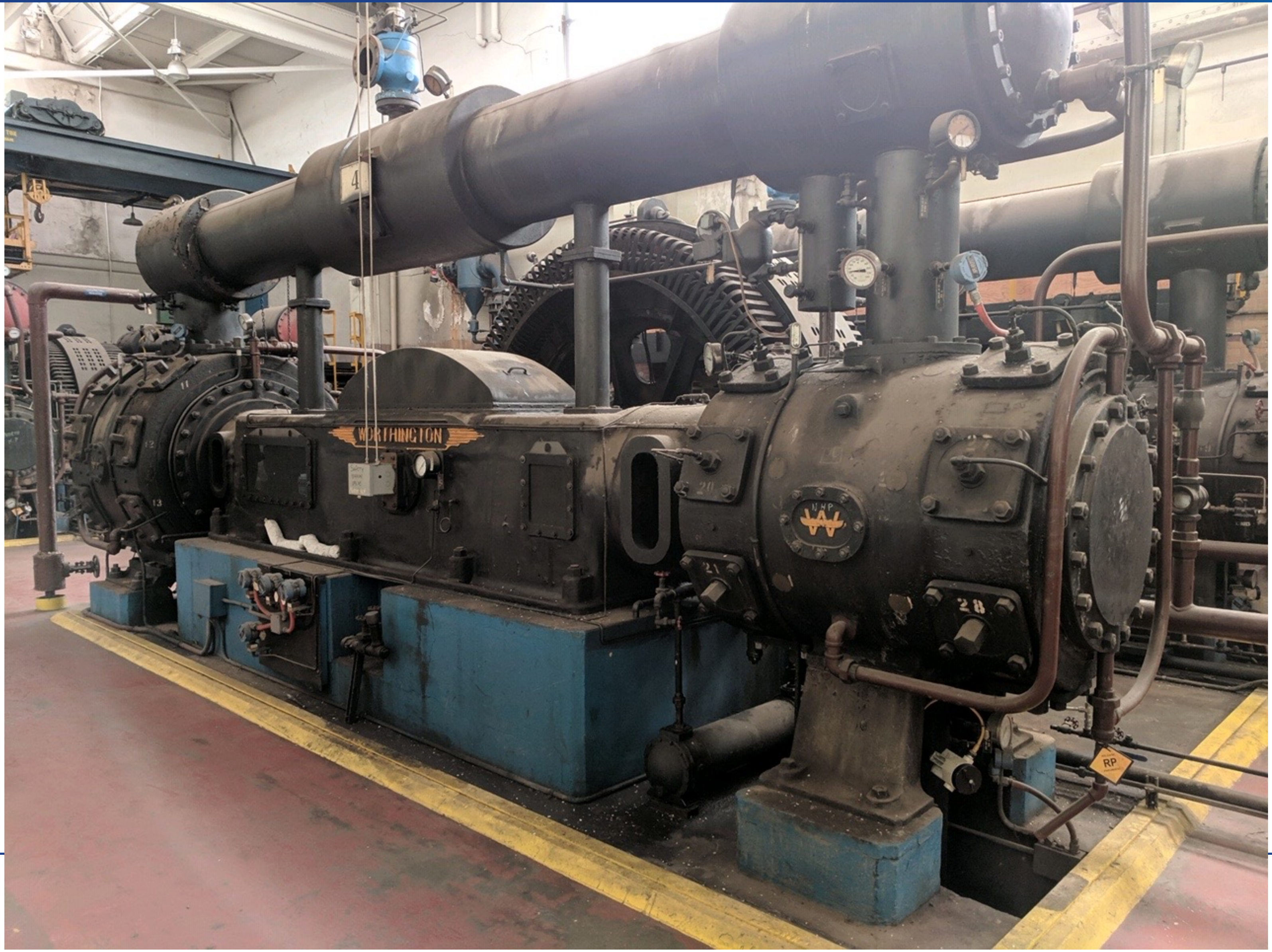
Three Step

Three-step free-air unloading



On 7″ stroke sizes, Free-Air 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.

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



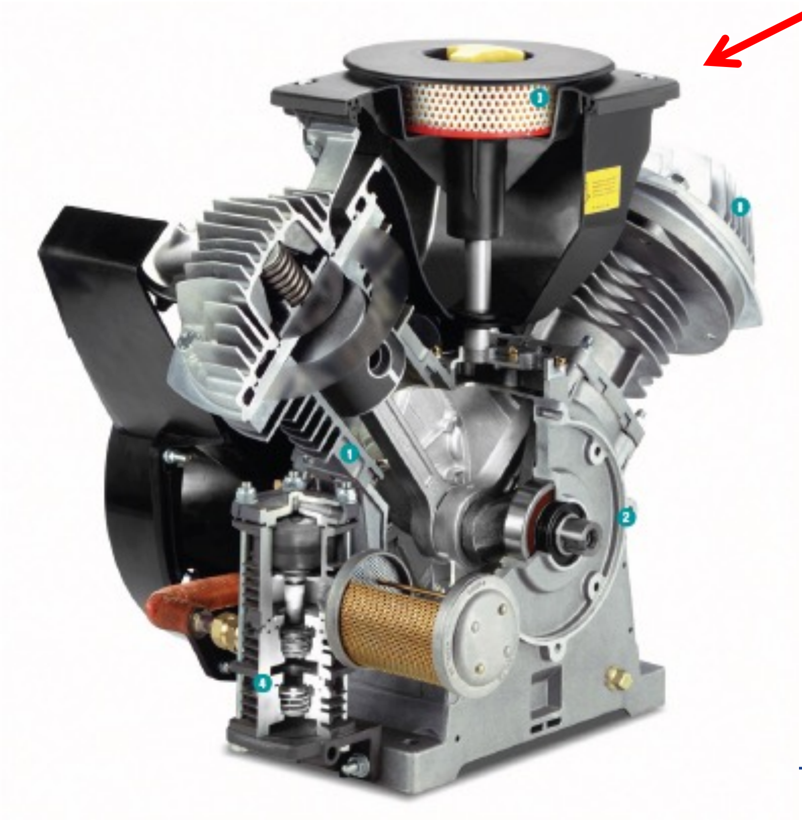
Two Stage, Double Acting, Recip

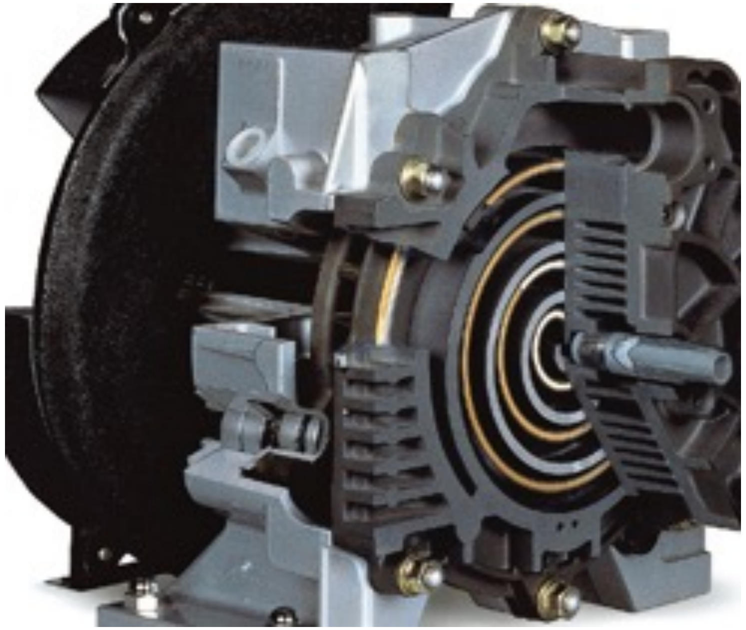
Oil Free Reciprocating

- 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.

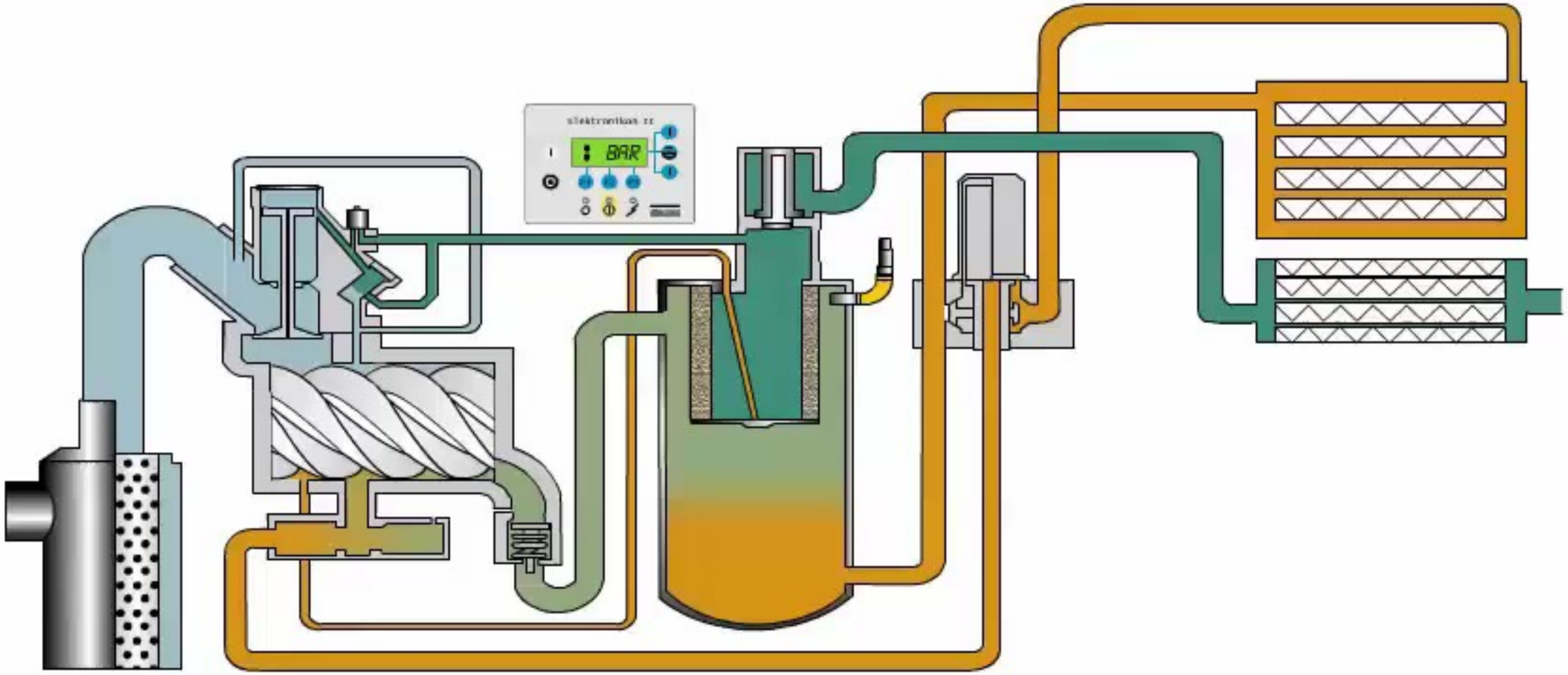
Oil-Less

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

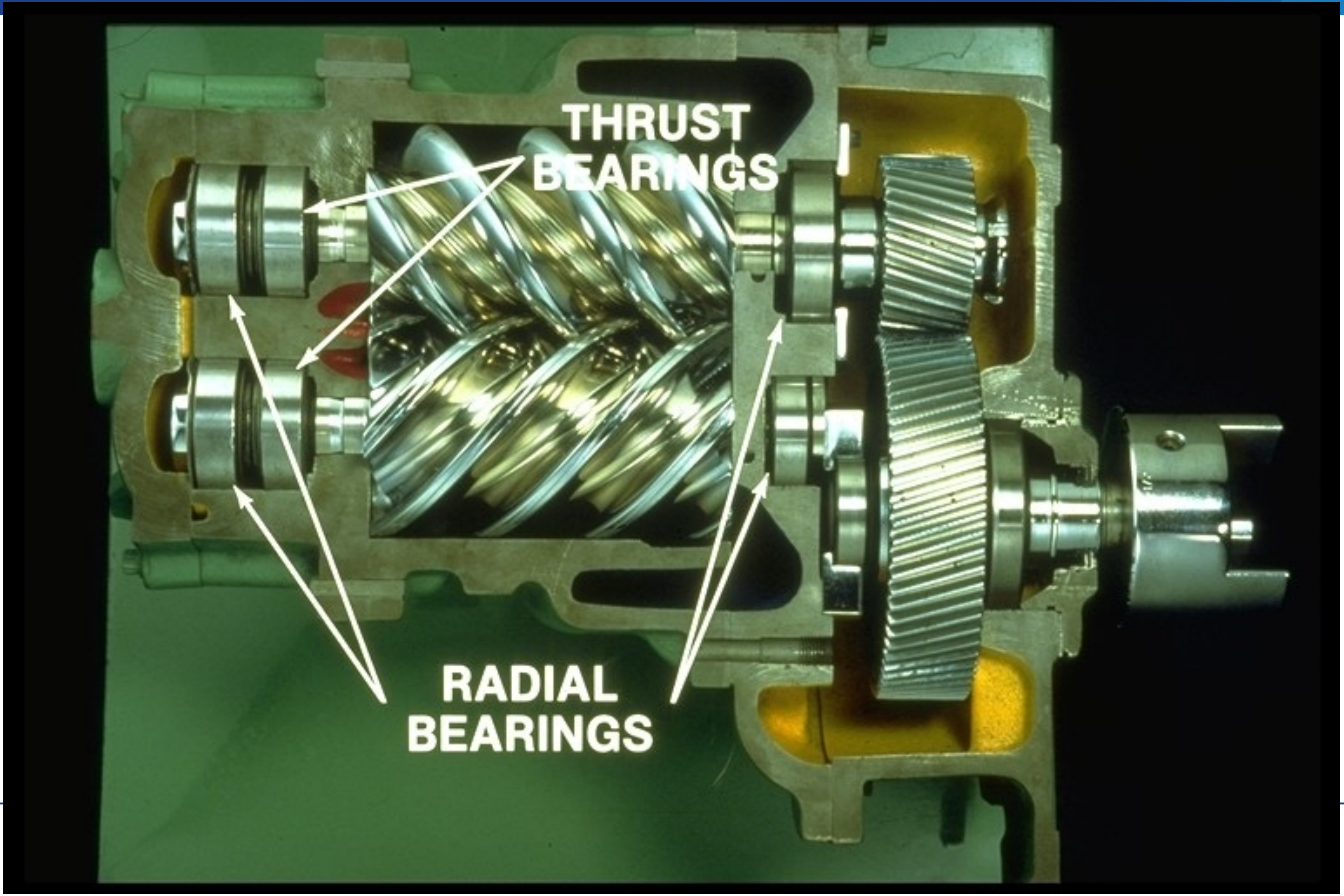




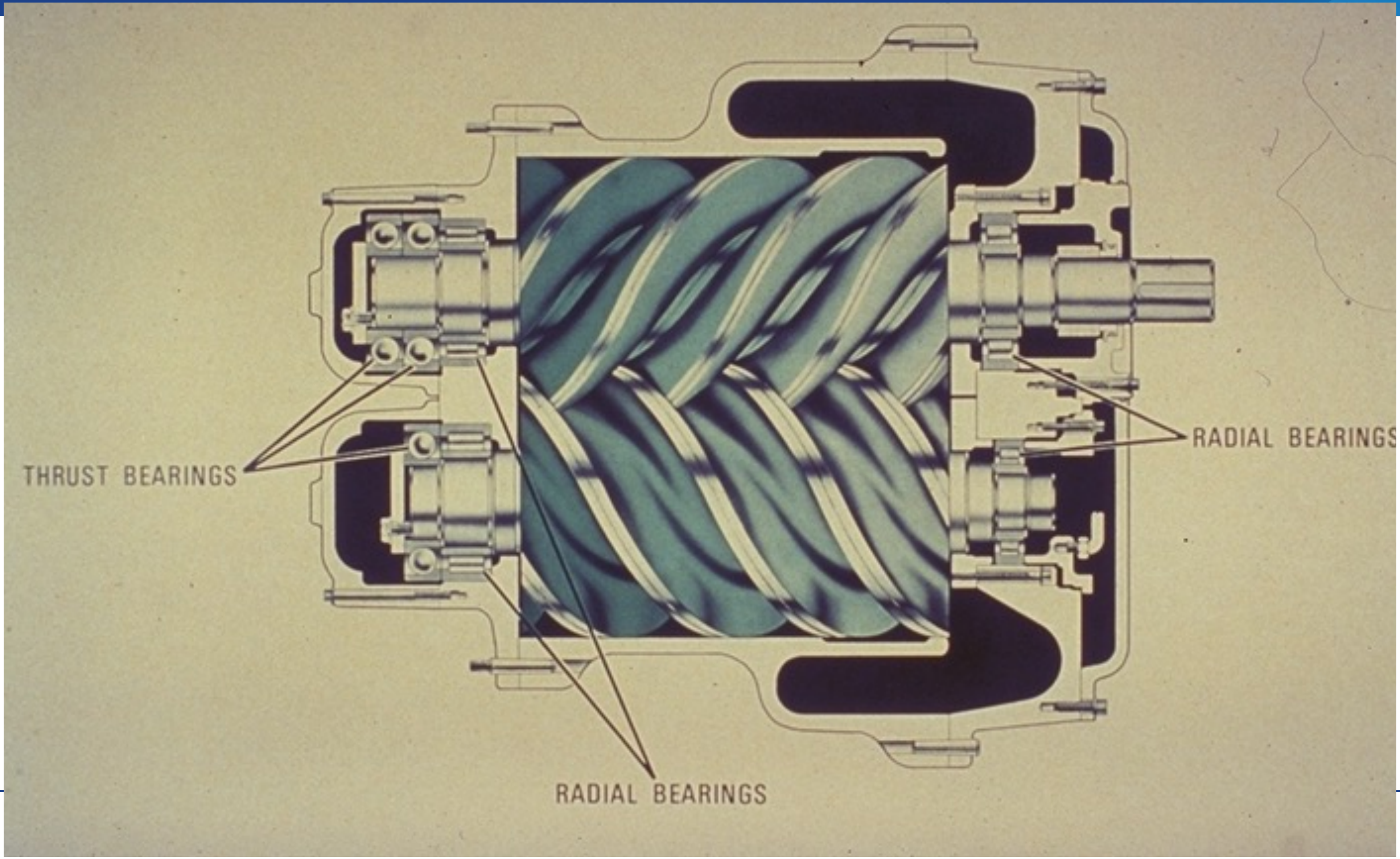
Rotary Screw



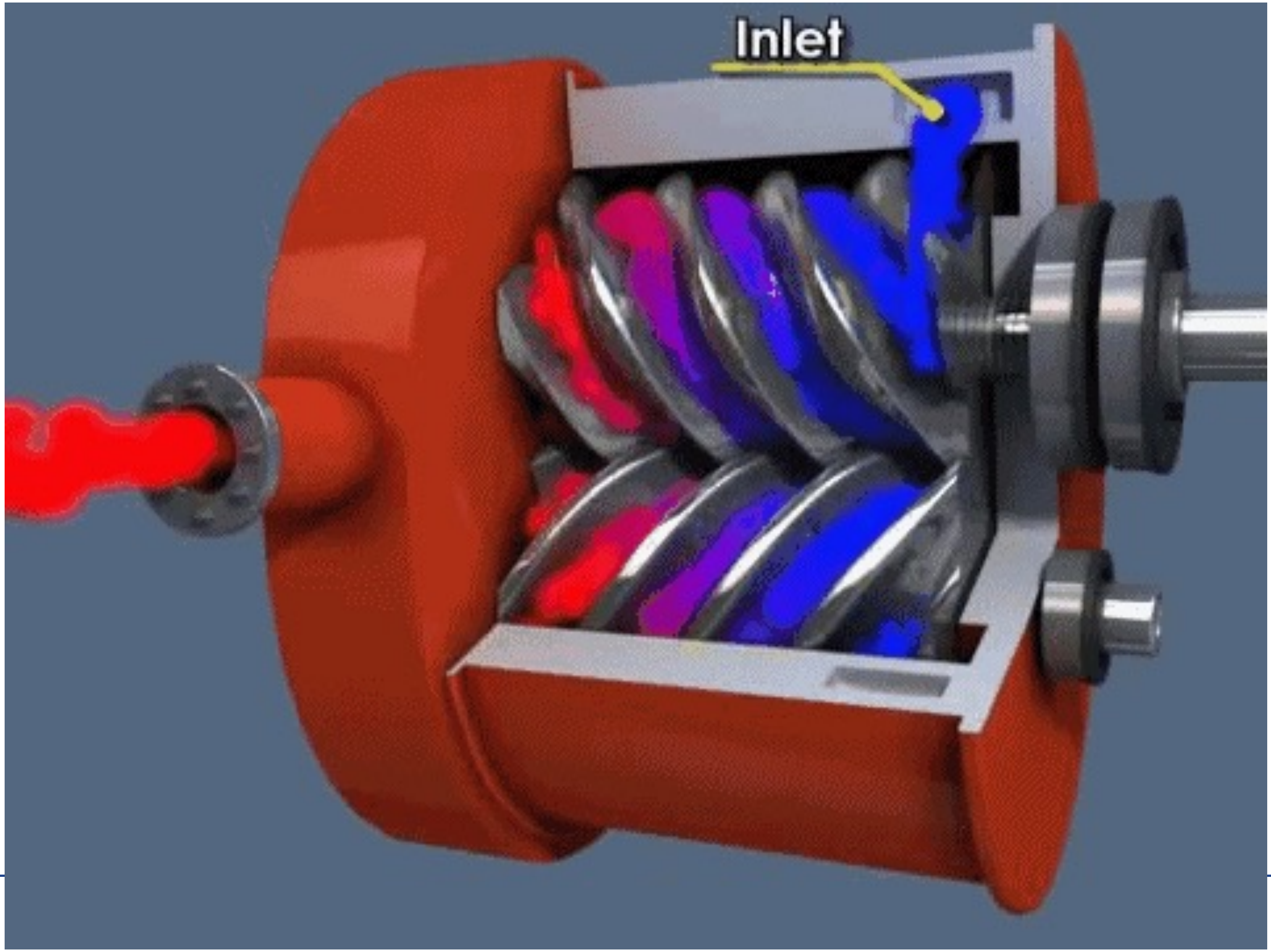
Gear Drive Rotary Screw Air End

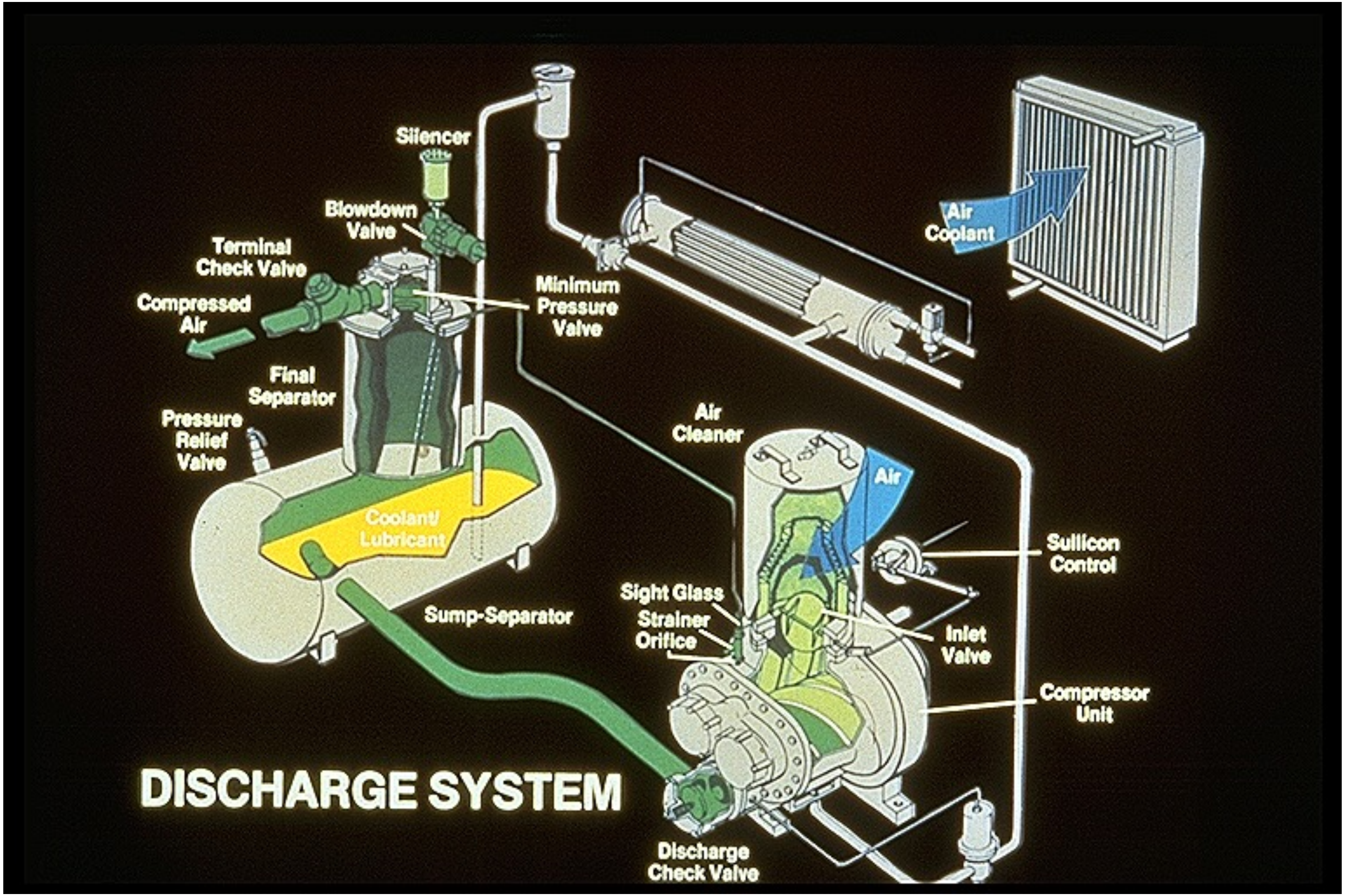


Direct Drive Rotary Screw Air End

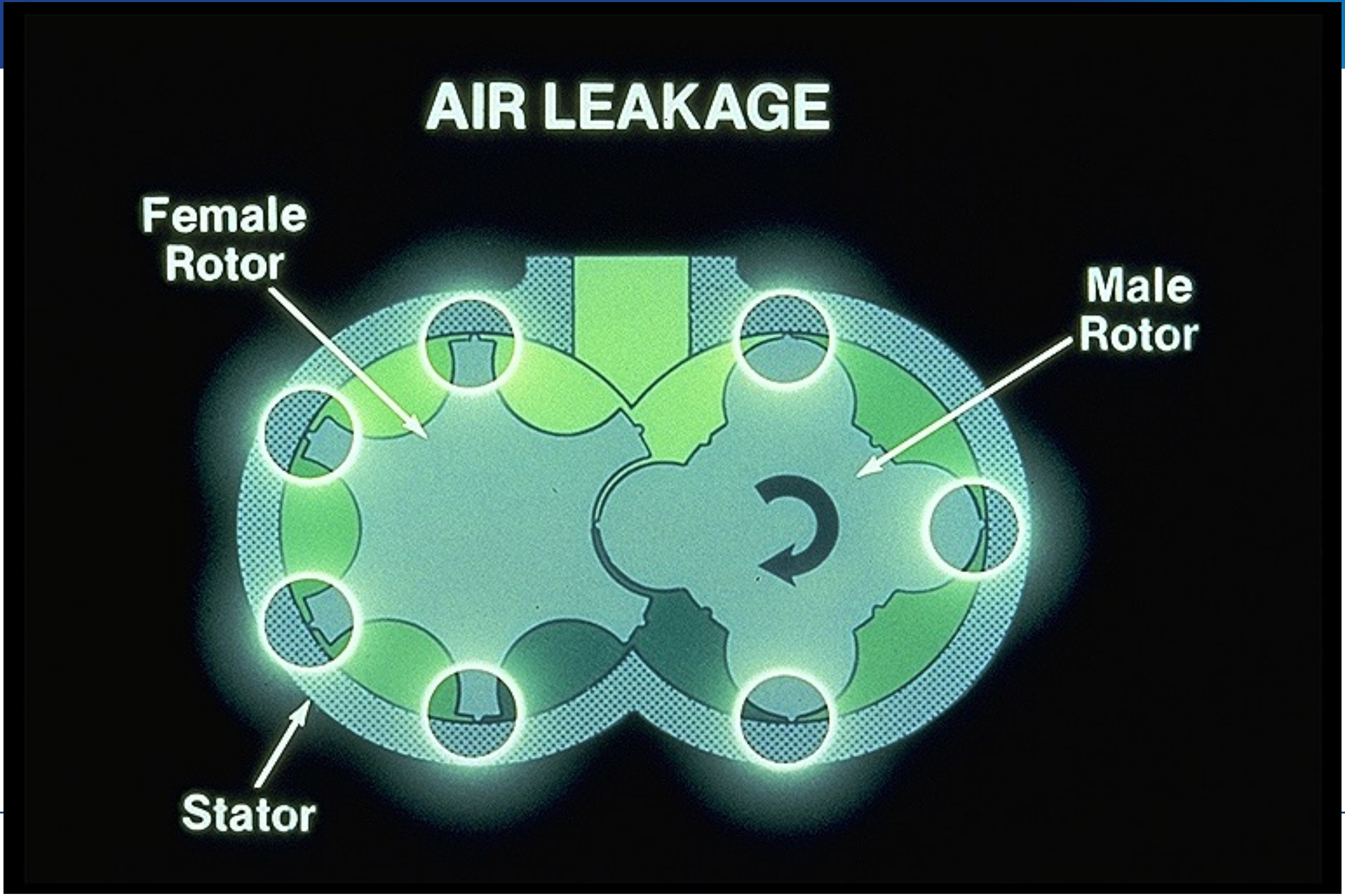


Rotary Screw



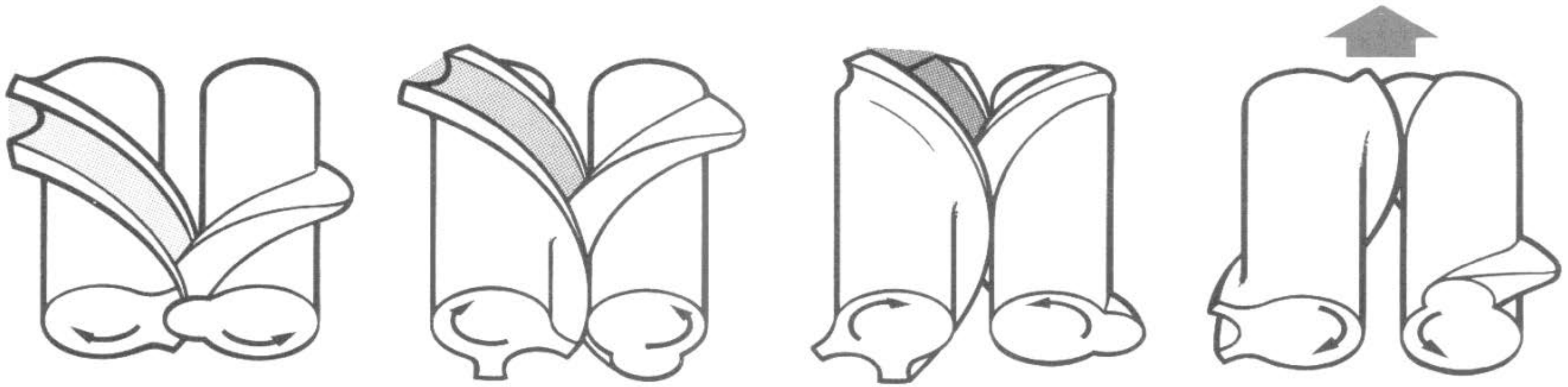


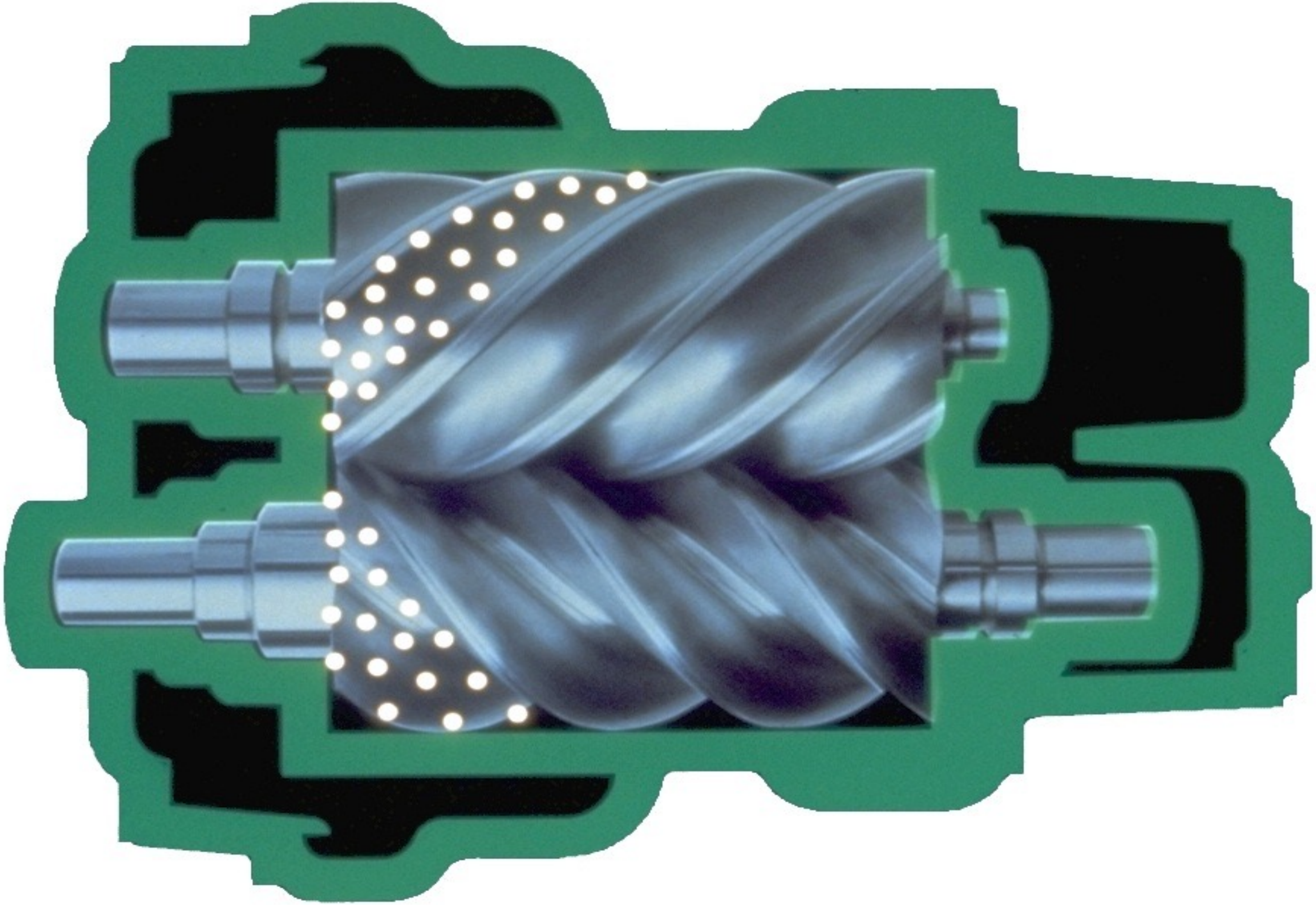
Silencer
Blowdown Valve
Terminal Check Valve
Compressed Air
Minimum Pressure Valve
Air Coolant
Final Separator
Pressure Relief Valve
Air Cleaner
Air
Coolant/ Lubricant
Sullicon Control
Sight Glass
Strainer Orifice
Sump-Separator
Inlet Valve
Compressor Unit
DISCHARGE SYSTEM
Discharge Check Valve


AIR LEAKAGE
Female Rotor
Male Rotor
Stator

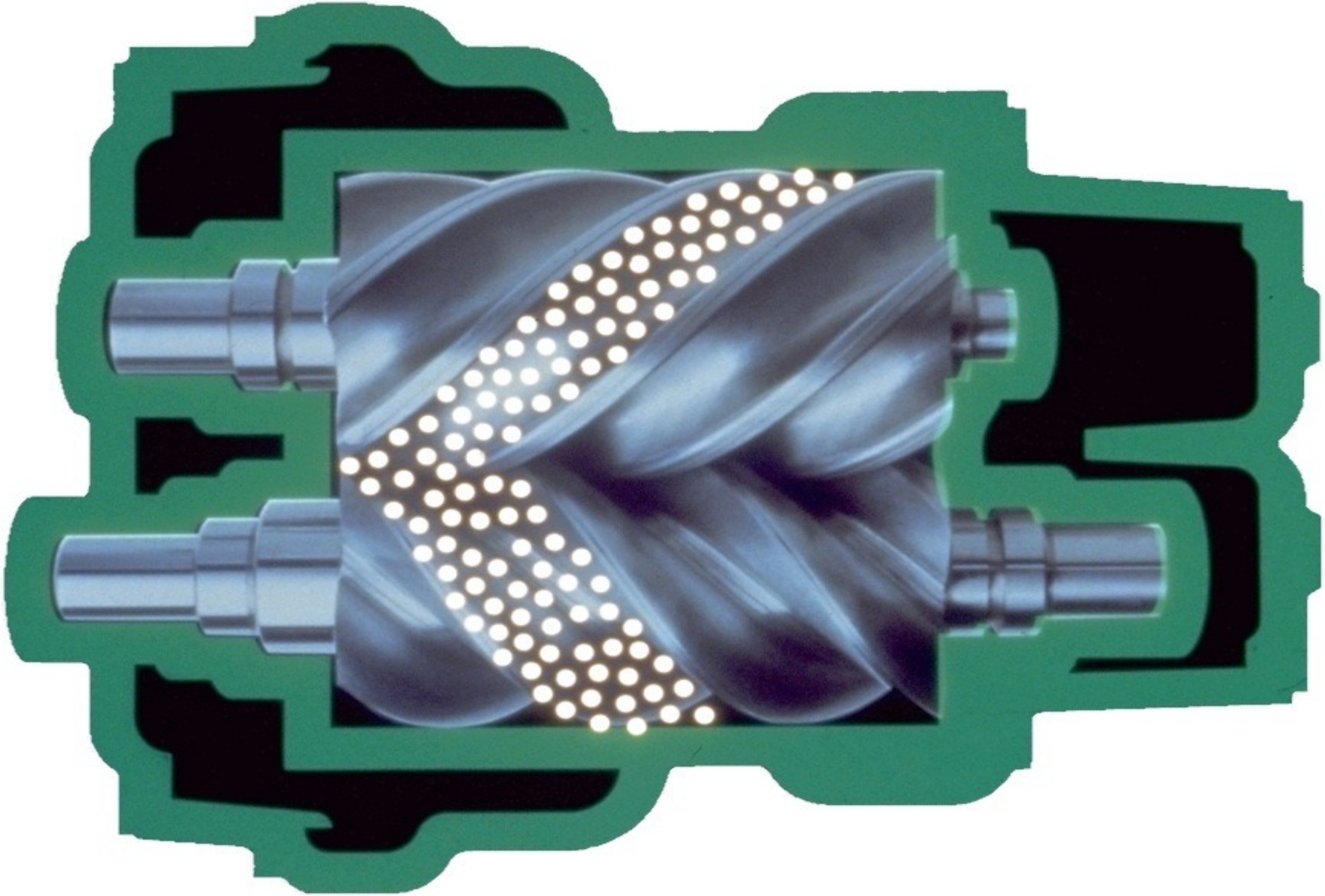
Rotary Screw Compression

- 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.

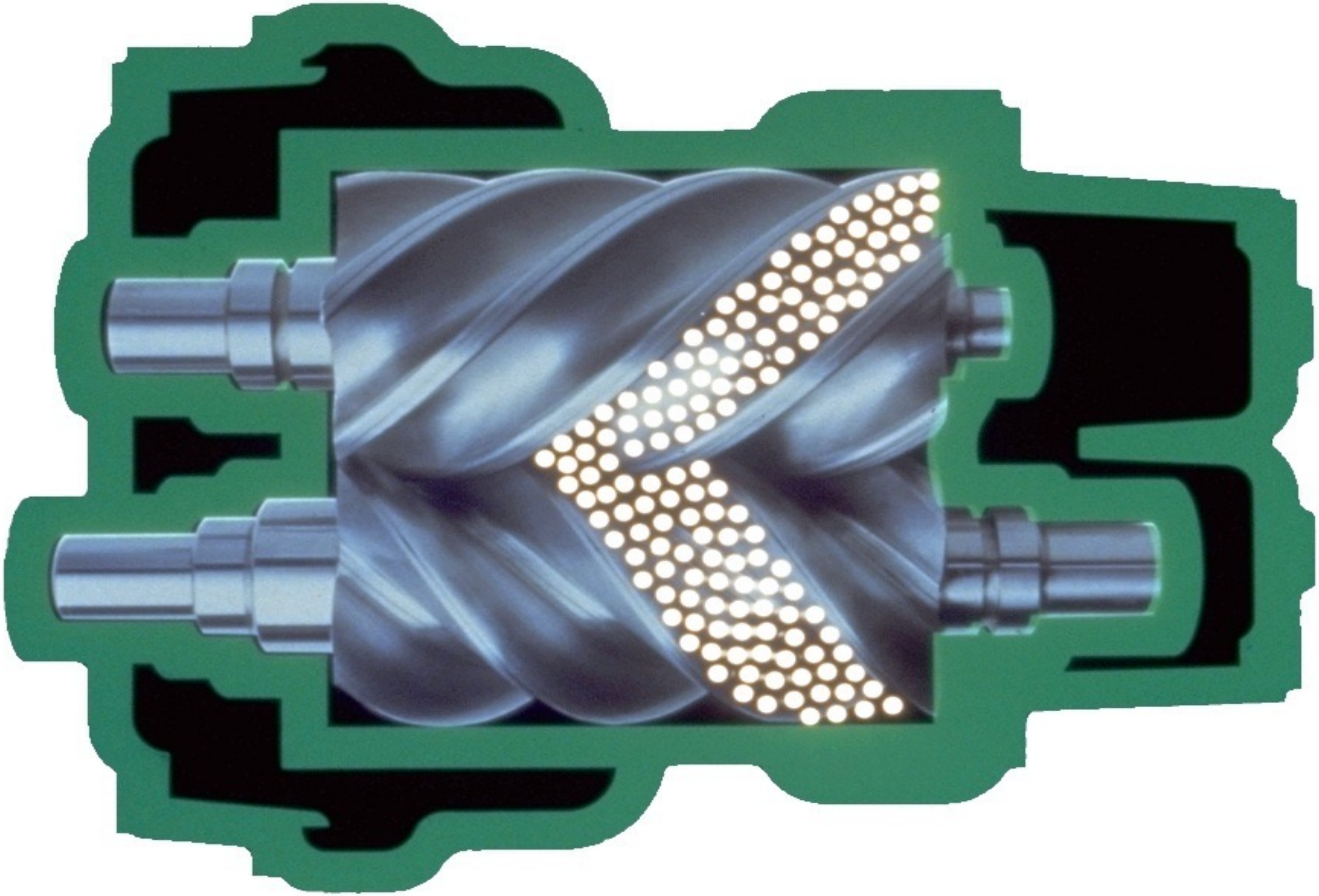




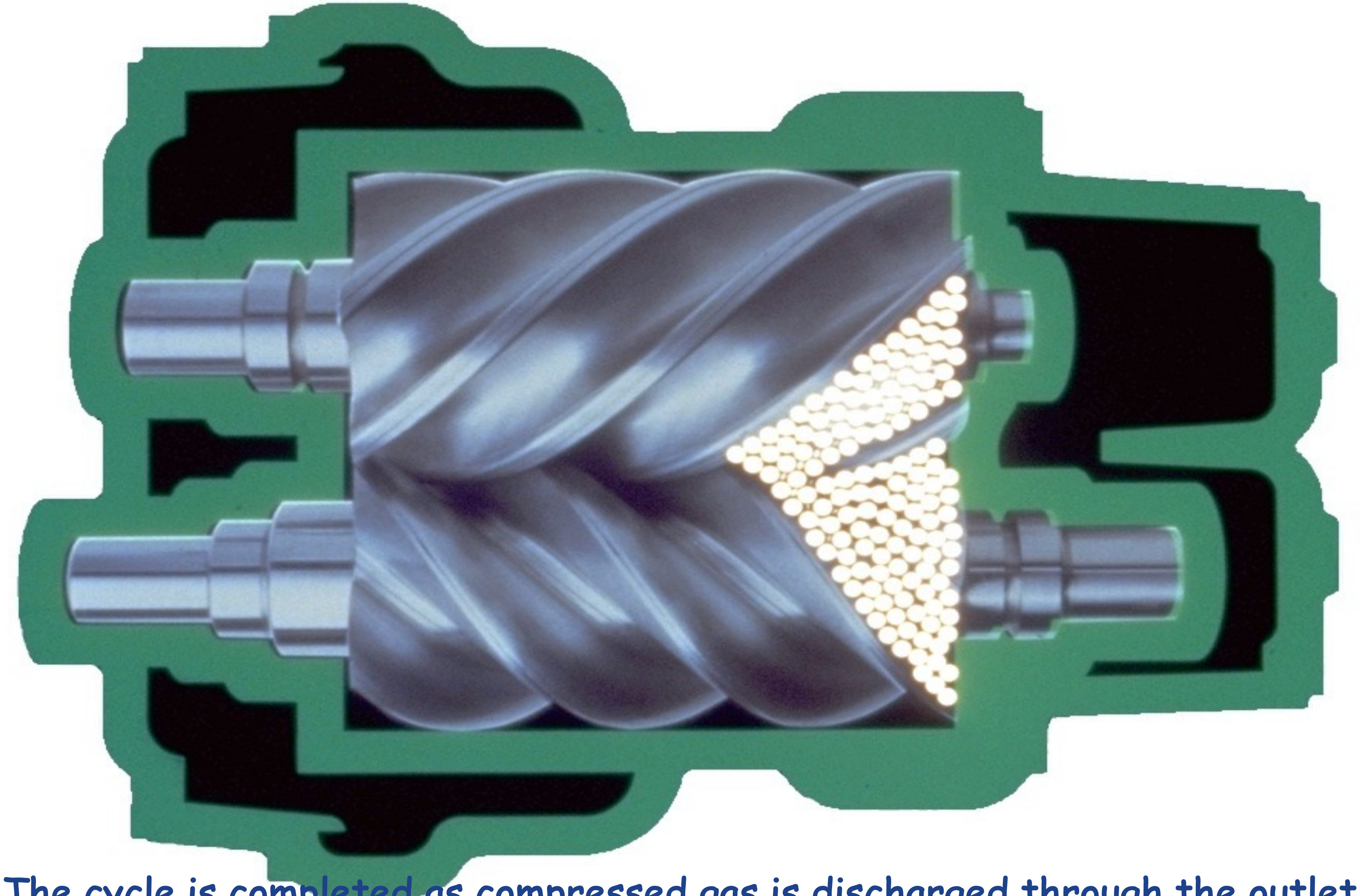
Low pressure gas is drawn axially into the unit as the rotors turn past the intake port in the housing



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



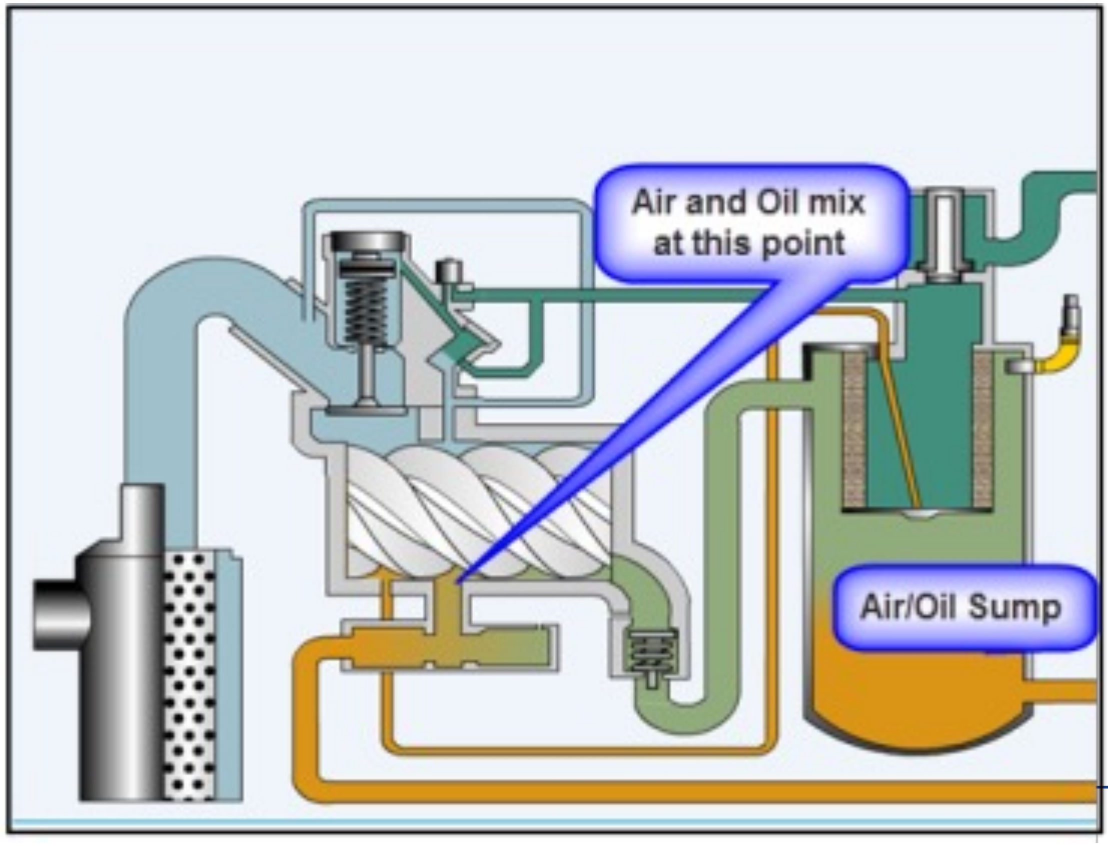
As the rotors continue to turn, lobes reduce the volume in the cavities, raising the pressure of the trapped gas.



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

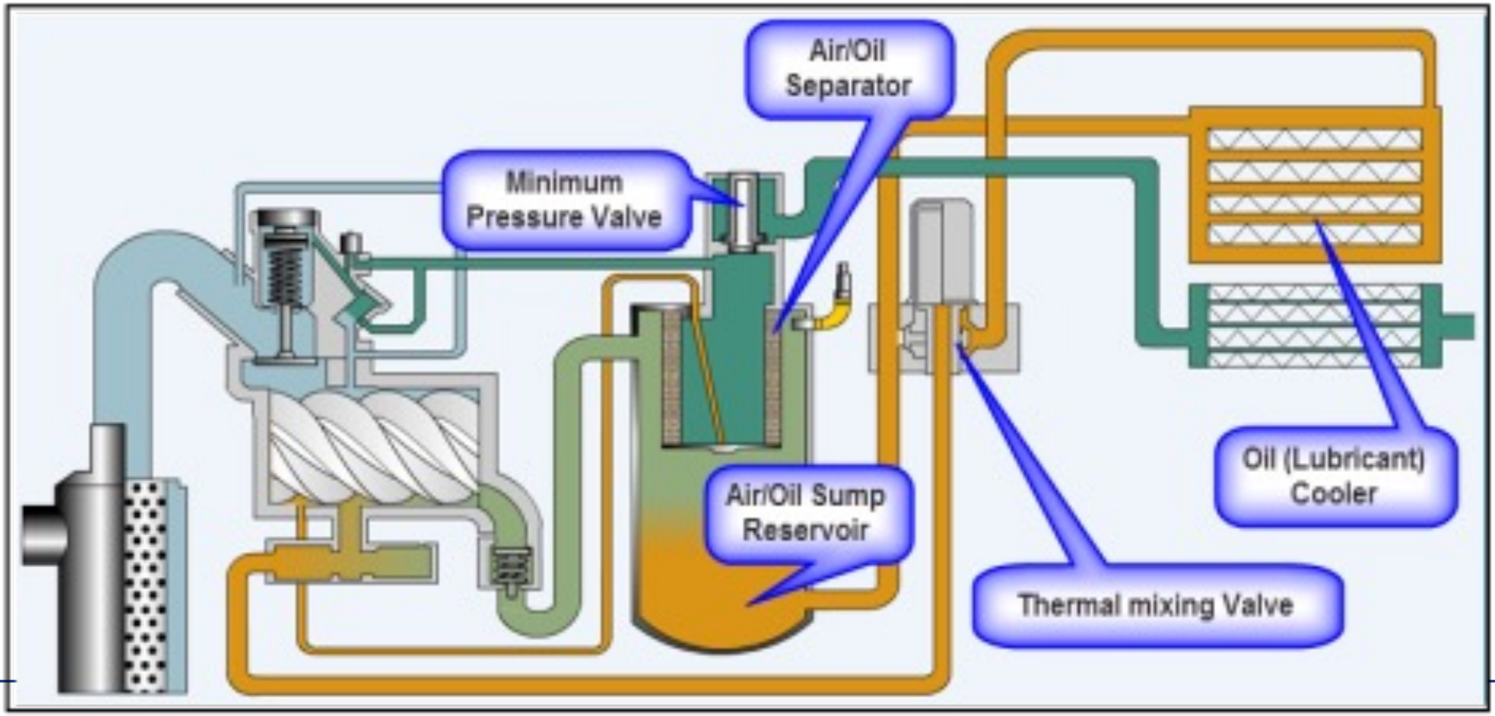
Rotary Screw

- 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.



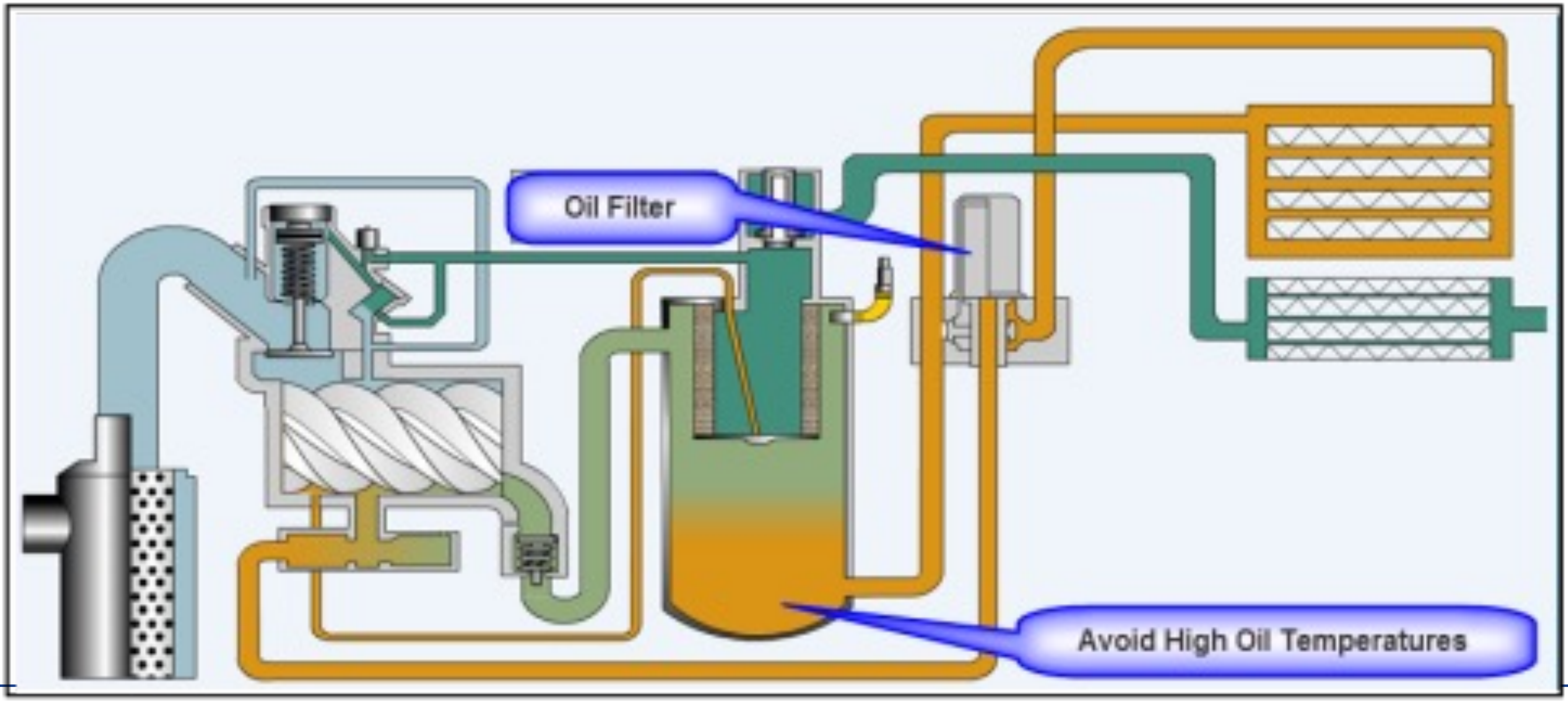
Rotary Screw

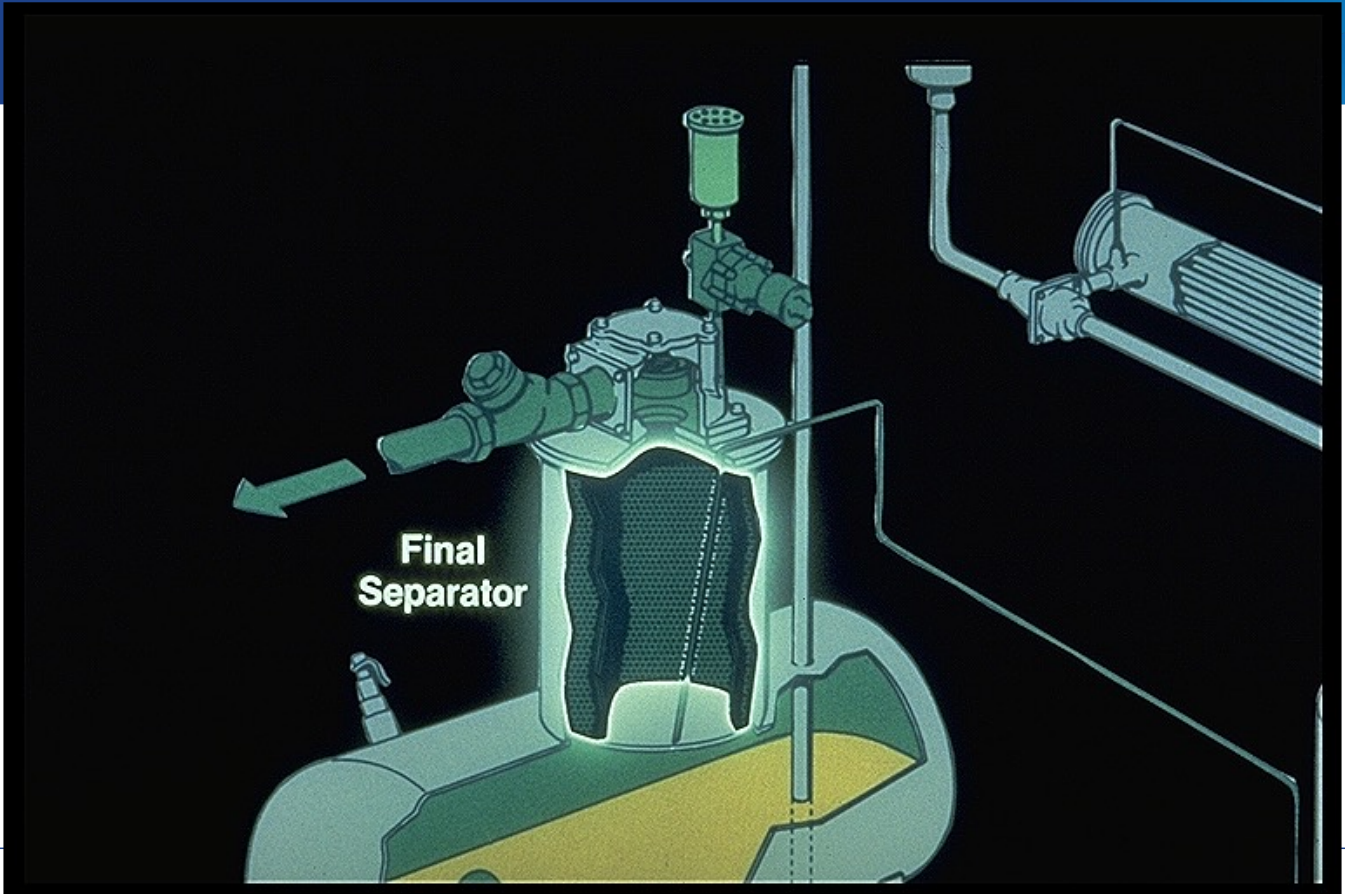
- A minimum pressure valve assures proper lubricant circulation and separation. Once separated, it is returned to the air/oil reservoir.
- A lubricant thermal mixing valve is used to maintain a constant and correct injection temperature.

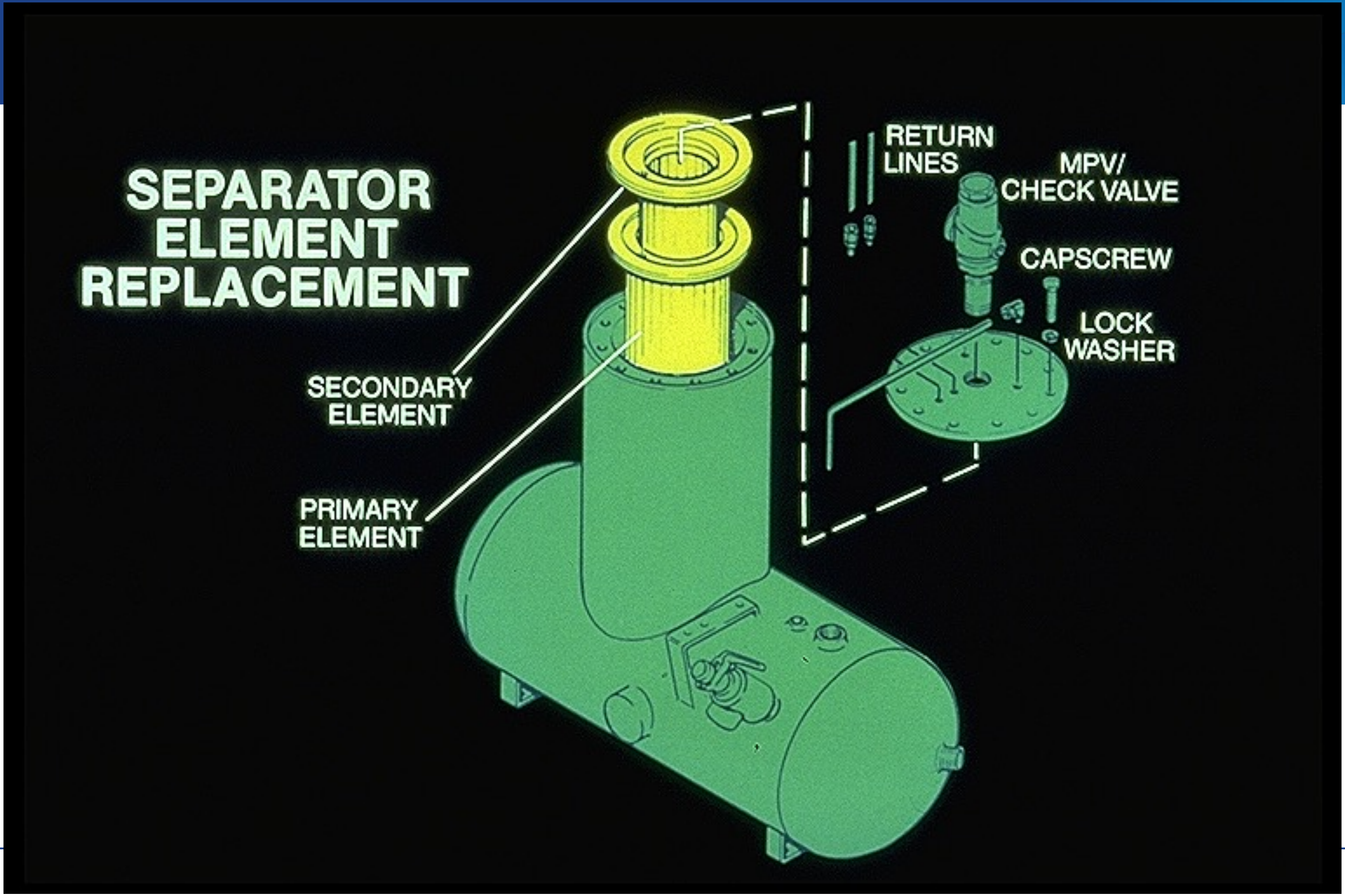


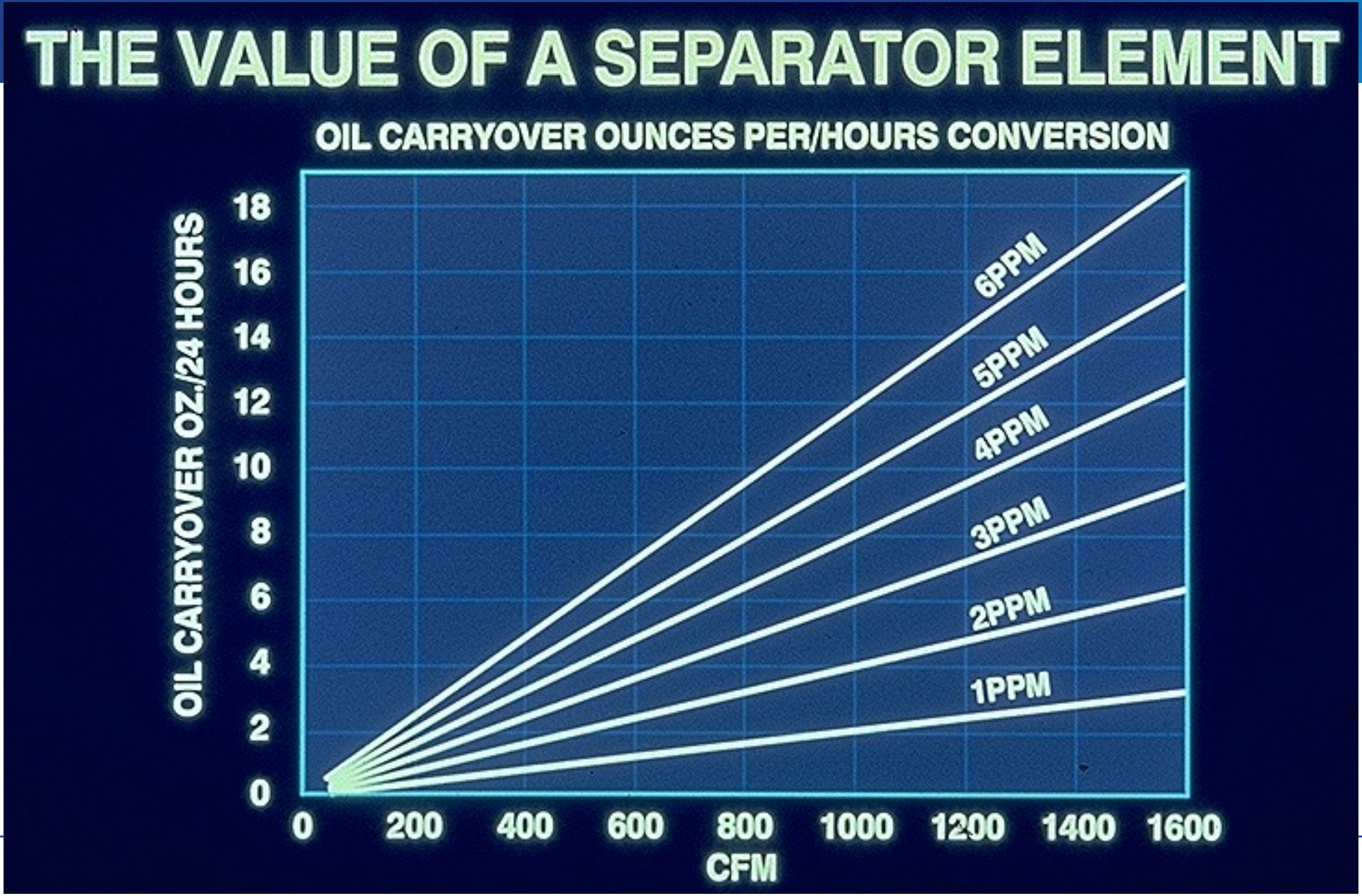
Rotary Screw

- 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.




Final
Separator


SEPARATOR ELEMENT REPLACEMENT
RETURN LINES
MPV/ CHECK VALVE
CAPSCREW
LOCK WASHER
SECONDARY ELEMENT
PRIMARY ELEMENT

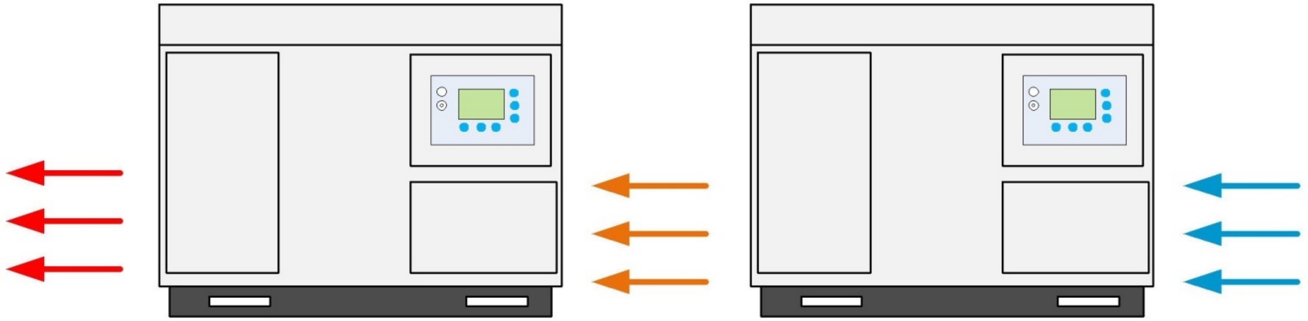

THE VALUE OF A SEPARATOR ELEMENT
OIL CARRYOVER OUNCES PER/HOURS CONVERSION
OIL CARRYOVER OZ./24 HOURS
18
16
14
12
10
8
6
4
2
0
6PPM
5PPM
4PPM
3PPM
2PPM
1PPM
0
200
400
600
800
1000
1200
1400
1600
CFM

Rotary Screw

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

Ventilation

Ventilation

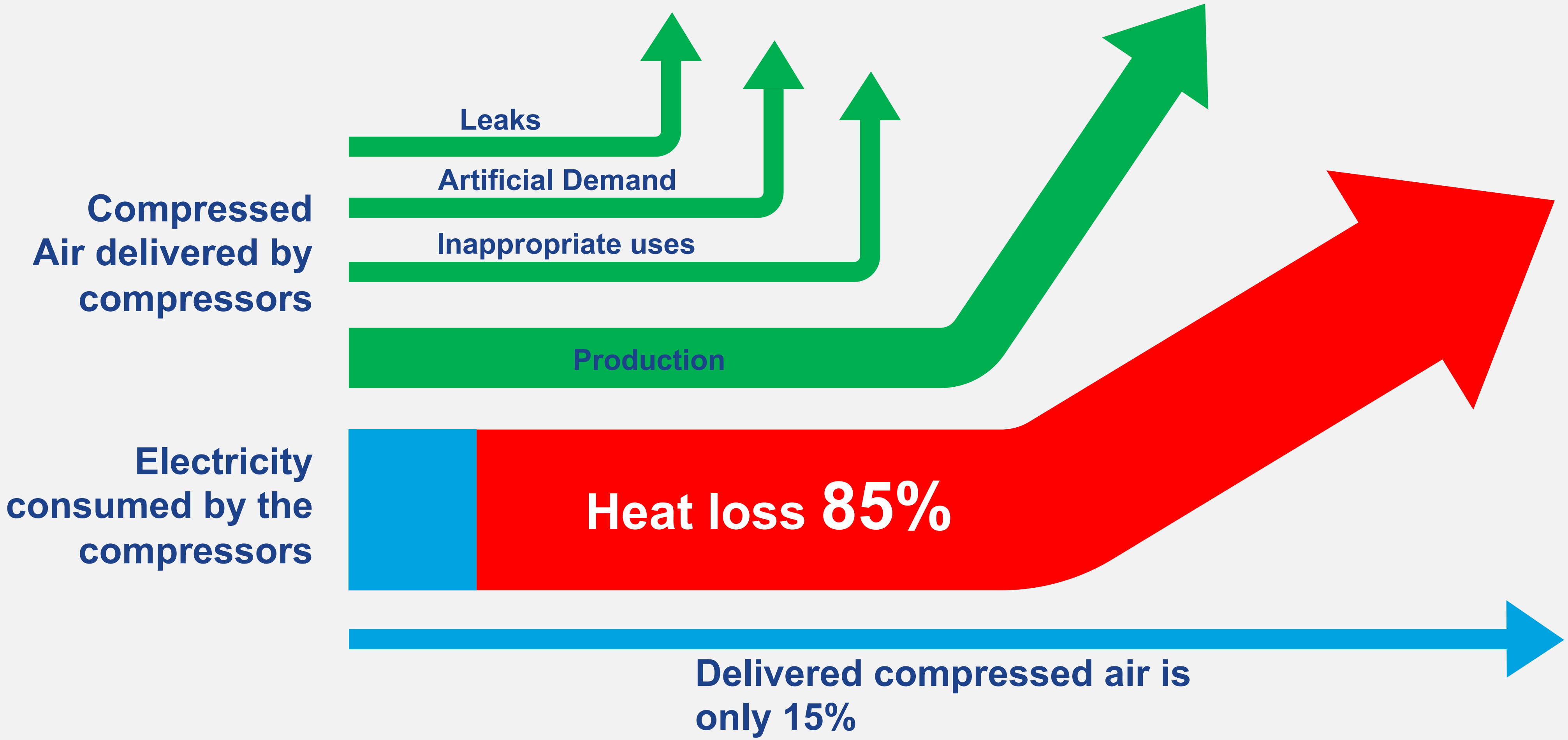


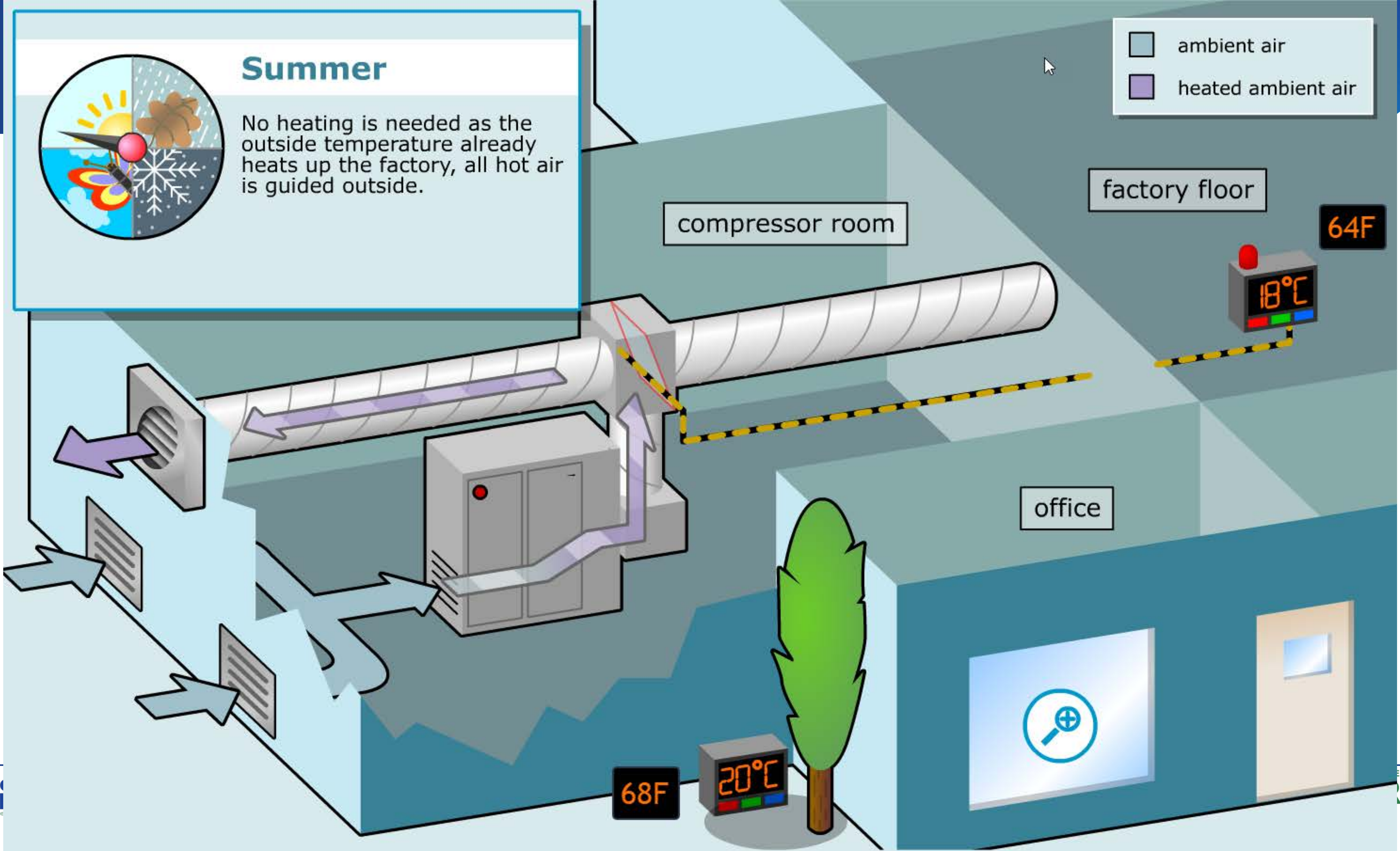
It is important not to block the air flow to the compressor inlet filter. If you have a multiple compressor installation, it is important, especially with air cooled units, that the heat discharge of one compressor does not go directly into the inlet of another compressor. This will cause shutdowns due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

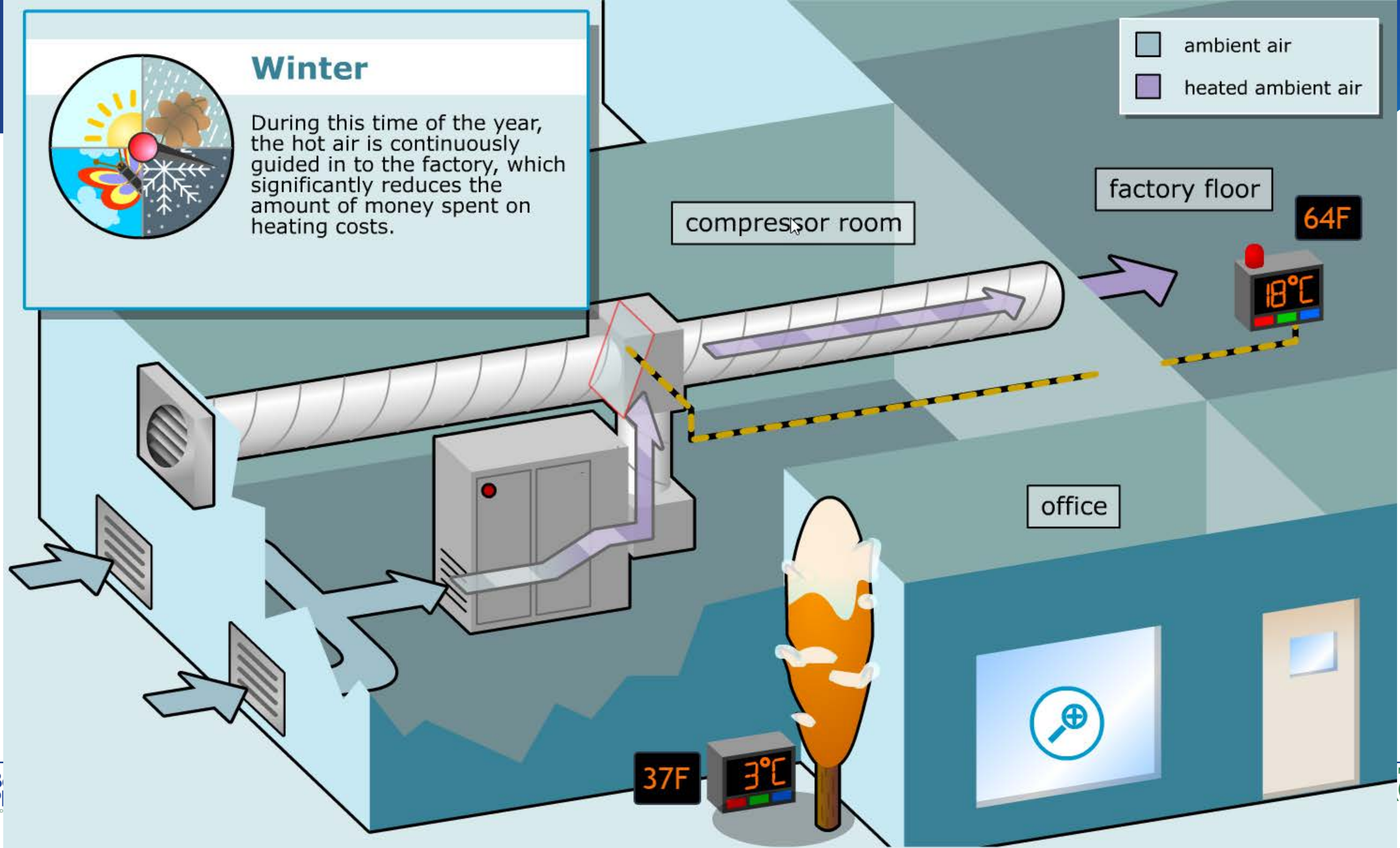
Capturing the Heat

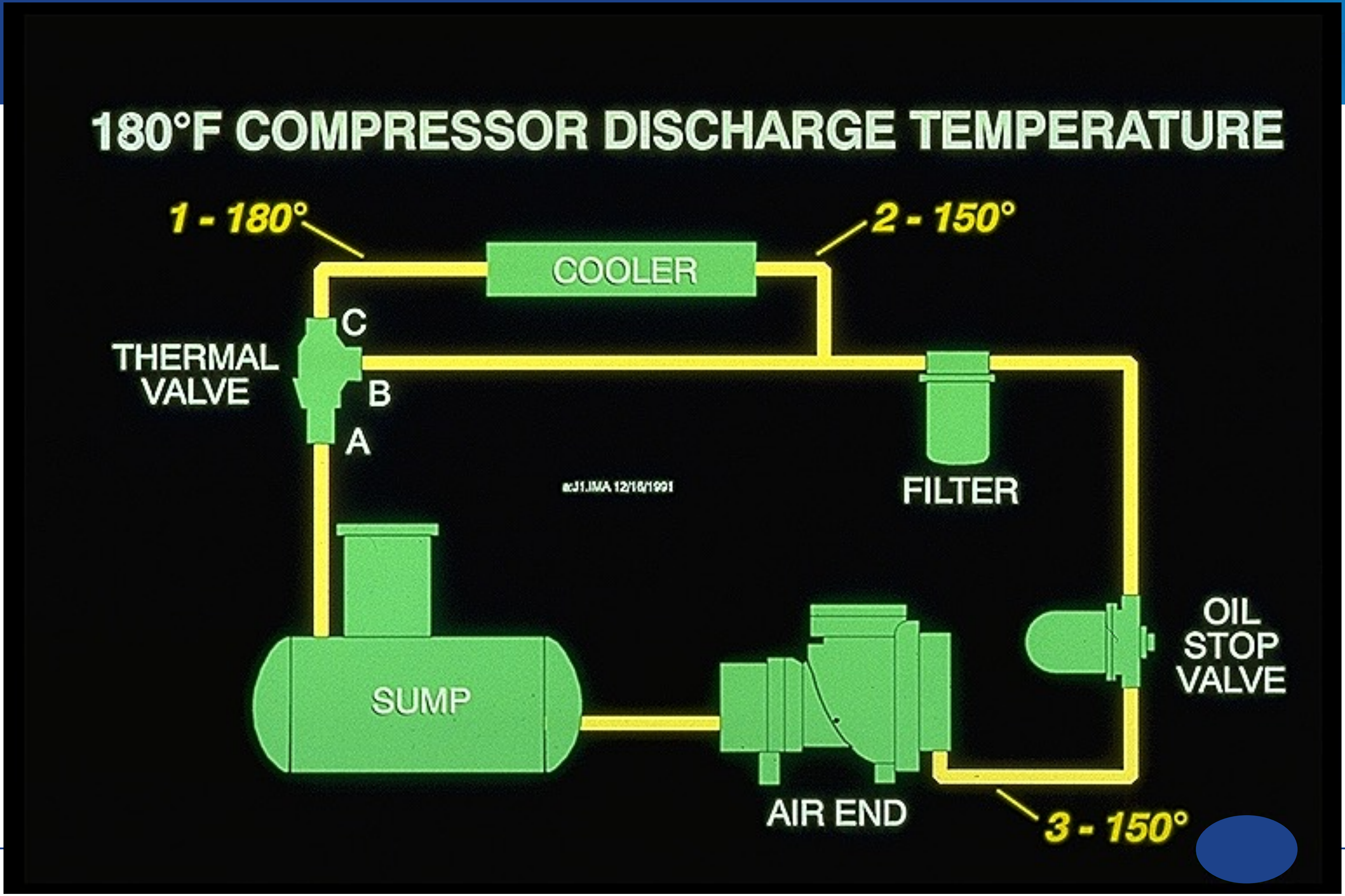
- Air-cooled rotary screw compressors
  - Adding ductwork with auxiliary fans to compressor package
  - Recover to space or reject outdoors with thermostatic controls
- Water-cooled compressors
  - Install heat exchangers to recover to space or reject outdoors
  - Produce non-potable (gray) or potable hot water
  - Compressors using water-cooled motors offer further opportunity (above 1000hp)
- Engine driven compressors
  - Heat can be recovered from engine jackets and exhaust stream

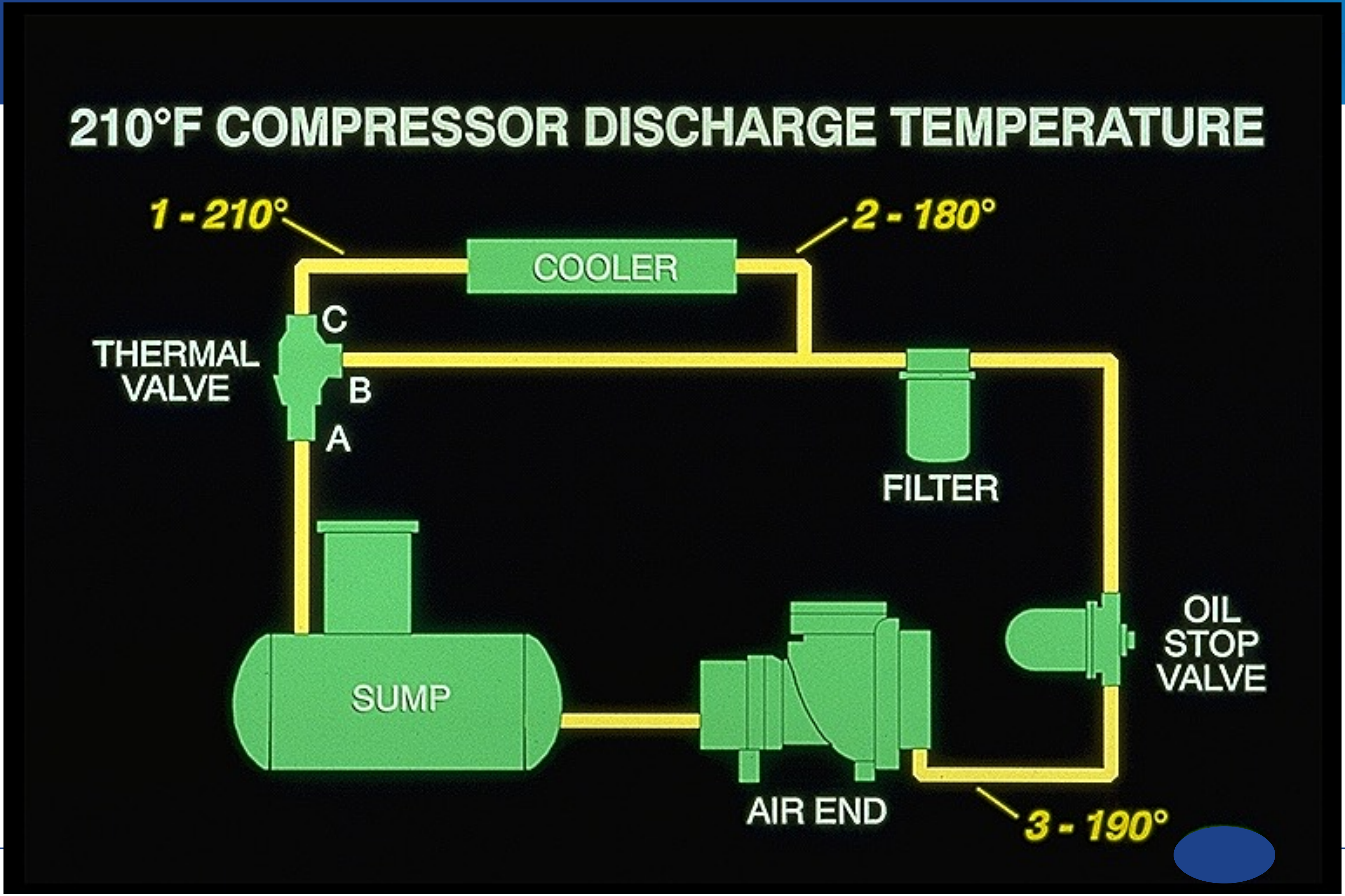
Remember this slide from session one?

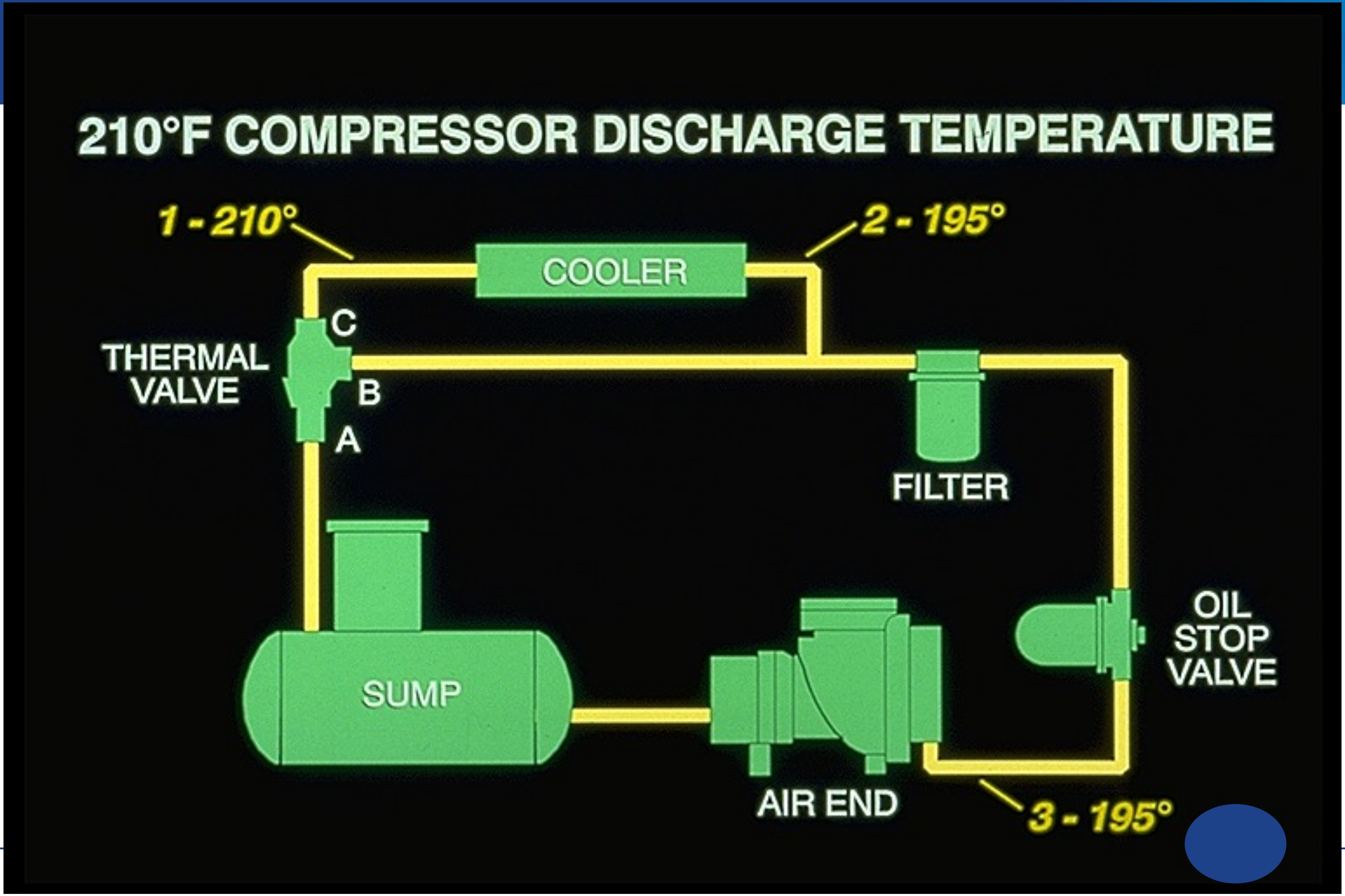


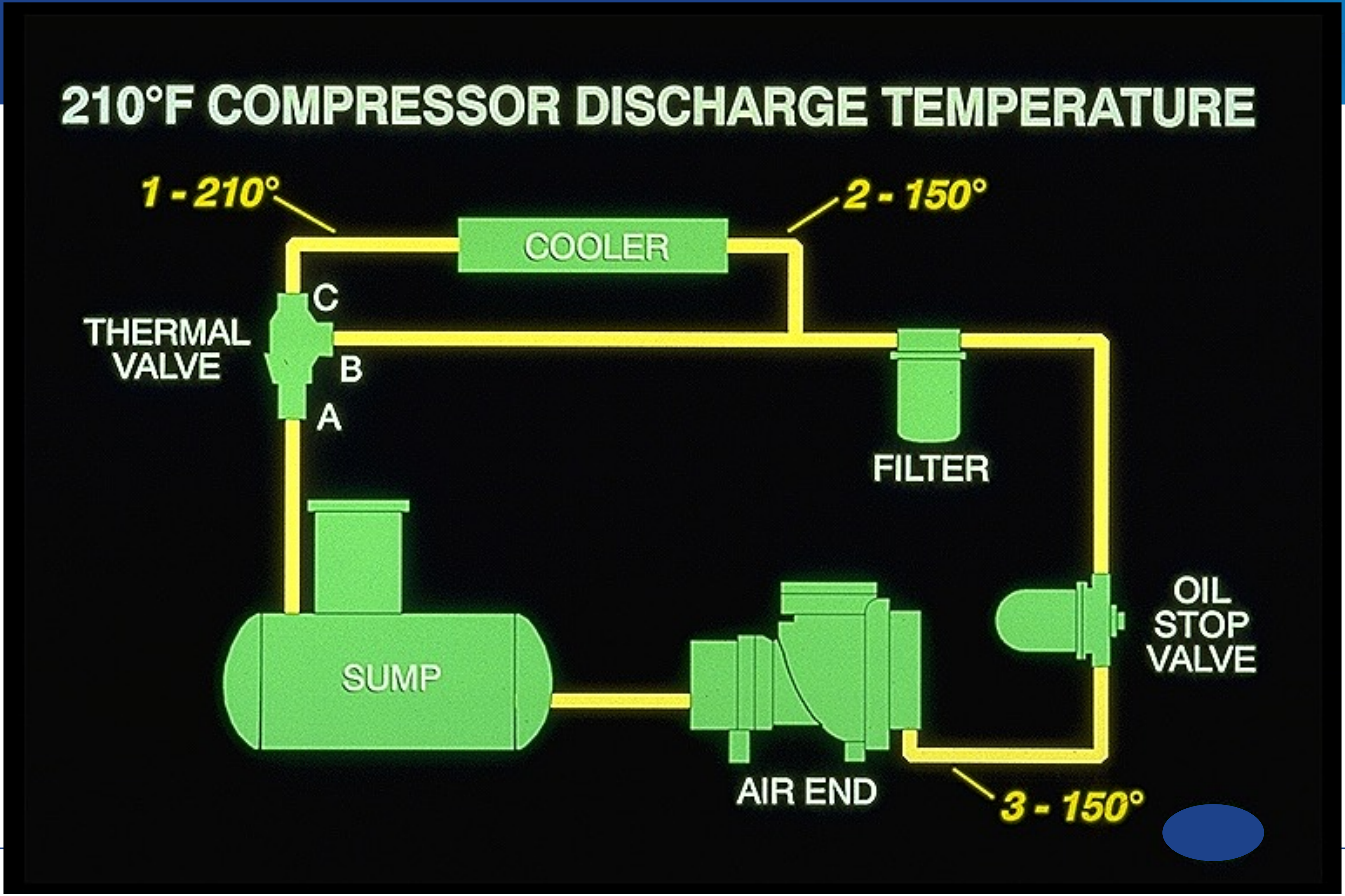

Summer
No heating is needed as the outside temperature already heats up the factory, all hot air is guided outside.
ambient air
heated ambient air
compressor room
factory floor
64F
18°C
office
68F
20°C


Winter
During this time of the year, the hot air is continuously guided in to the factory, which significantly reduces the amount of money spent on heating costs.
ambient air
heated ambient air
compressor room
factory floor
64F
18°C
office
37F
3°C


180°F COMPRESSOR DISCHARGE TEMPERATURE
1 - 180°
2 - 150°
COOLER
C
THERMAL VALVE
B
A
FILTER
SUMP
OIL STOP VALVE
AIR END
3 - 150°


210°F COMPRESSOR DISCHARGE TEMPERATURE
1 - 210°
2 - 180°
COOLER
C
THERMAL VALVE
B
A
FILTER
OIL STOP VALVE
SUMP
AIR END
3 - 190°

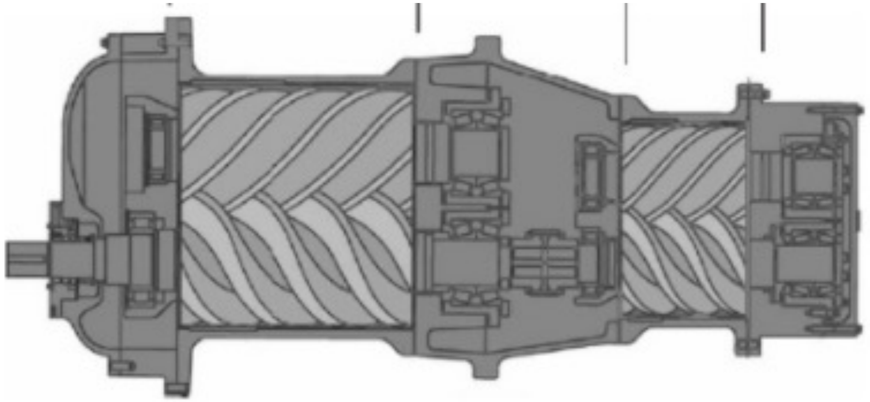

210°F COMPRESSOR DISCHARGE TEMPERATURE
1 - 210°
2 - 195°
COOLER
C
THERMAL VALVE
B
A
FILTER
SUMP
OIL STOP VALVE
AIR END
3 - 195°



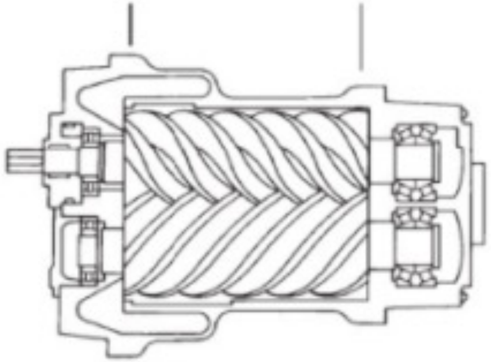
210°F COMPRESSOR DISCHARGE TEMPERATURE
1 - 210°
2 - 150°
COOLER
C
THERMAL VALVE
B
A
FILTER
SUMP
OIL STOP VALVE
AIR END
3 - 150°

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.

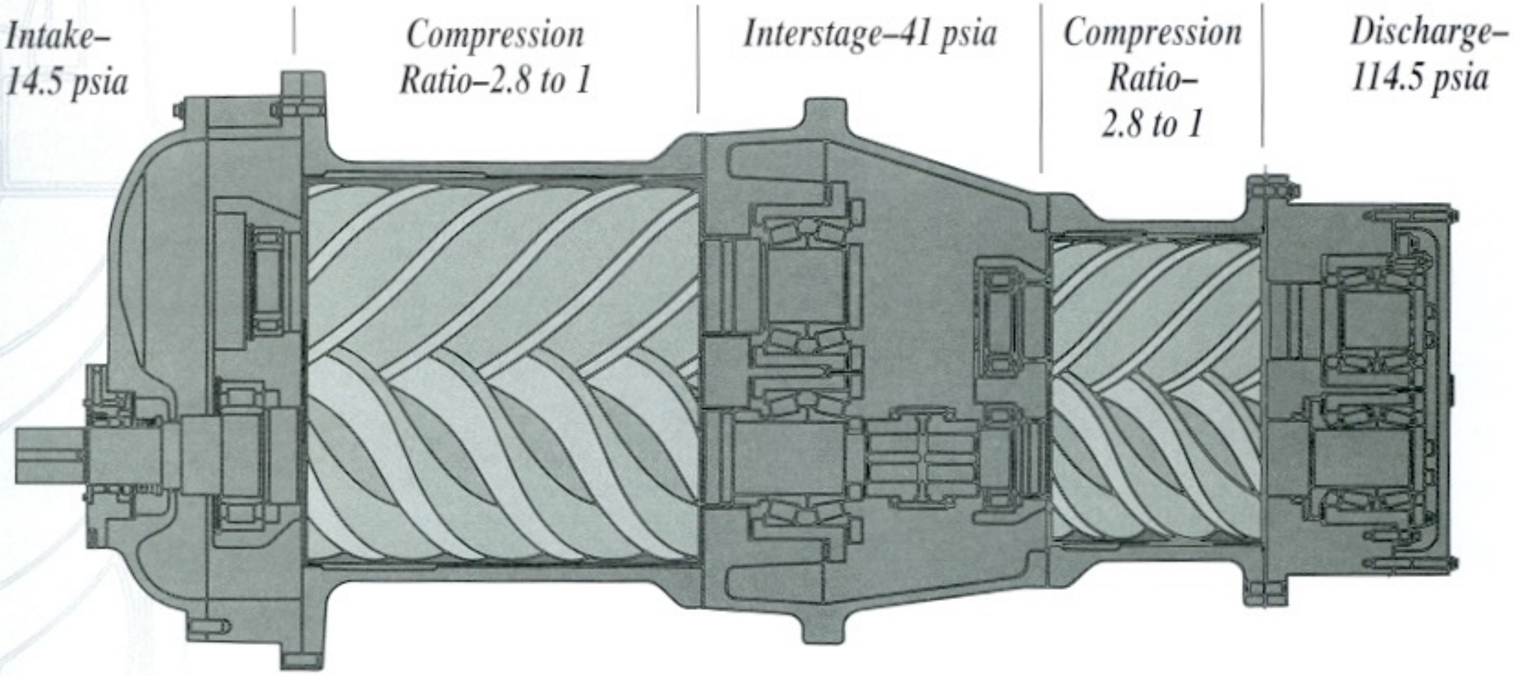


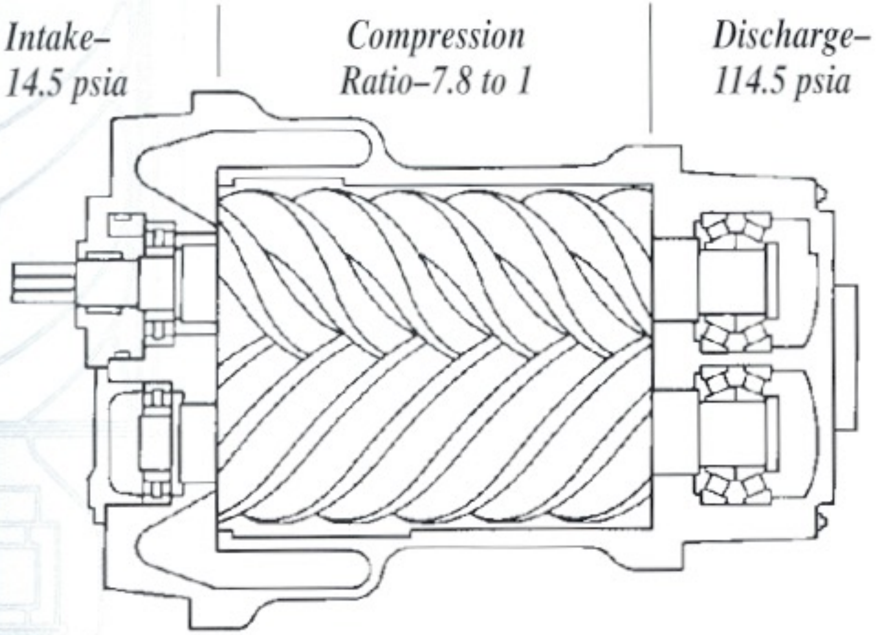
Two Stage Compressor

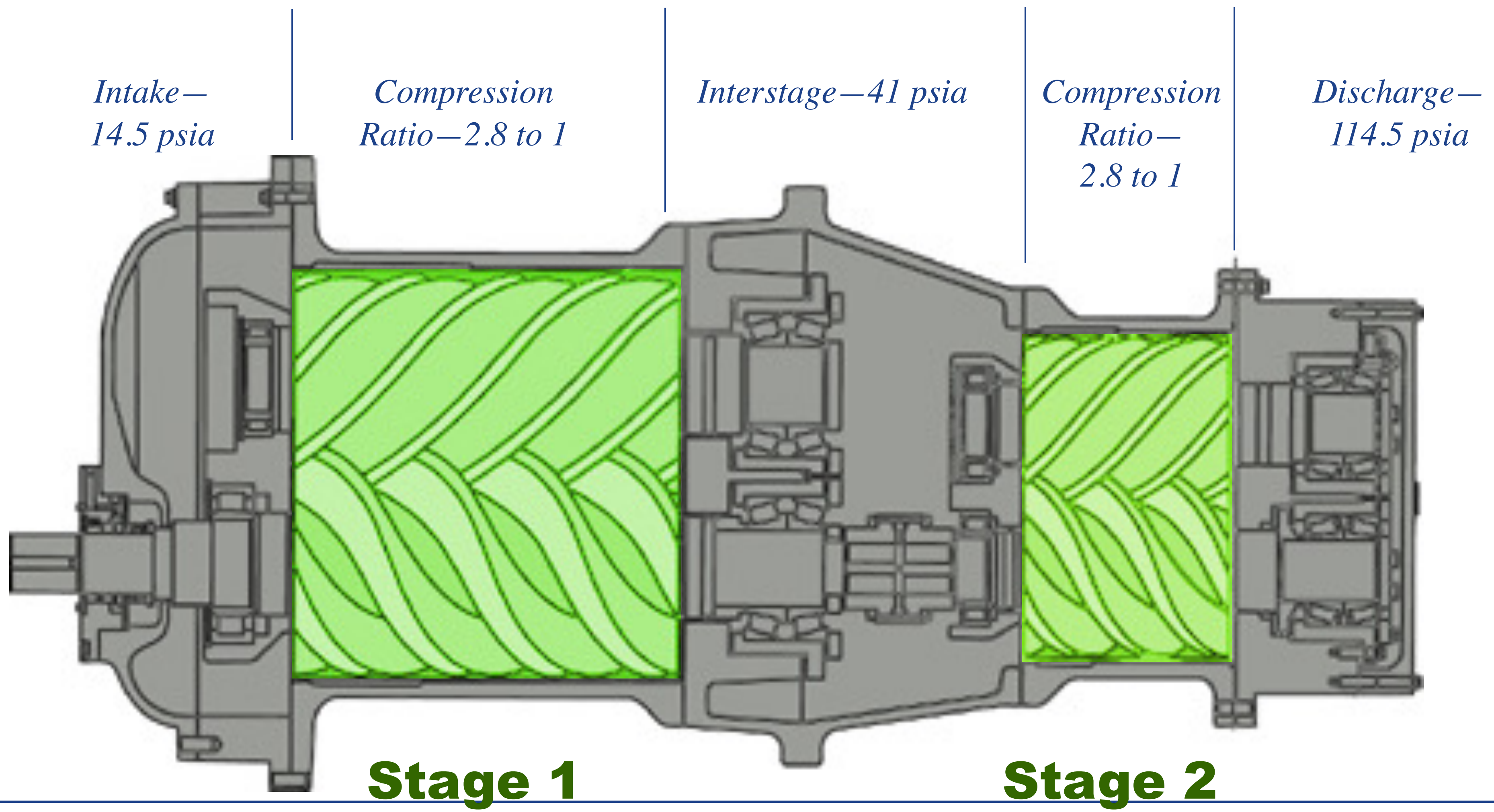


Single Stage Compressor

Two Stage Compressor


Intake–
14.5 psia
Compression
Ratio–2.8 to 1
Interstage–41 psia
Compression
Ratio–
2.8 to 1
Discharge–
114.5 psia


Intake–
14.5 psia
Compression
Ratio–7.8 to 1
Discharge–
114.5 psia



Better Plants U.S. DEPARTMENT OF ENERGY

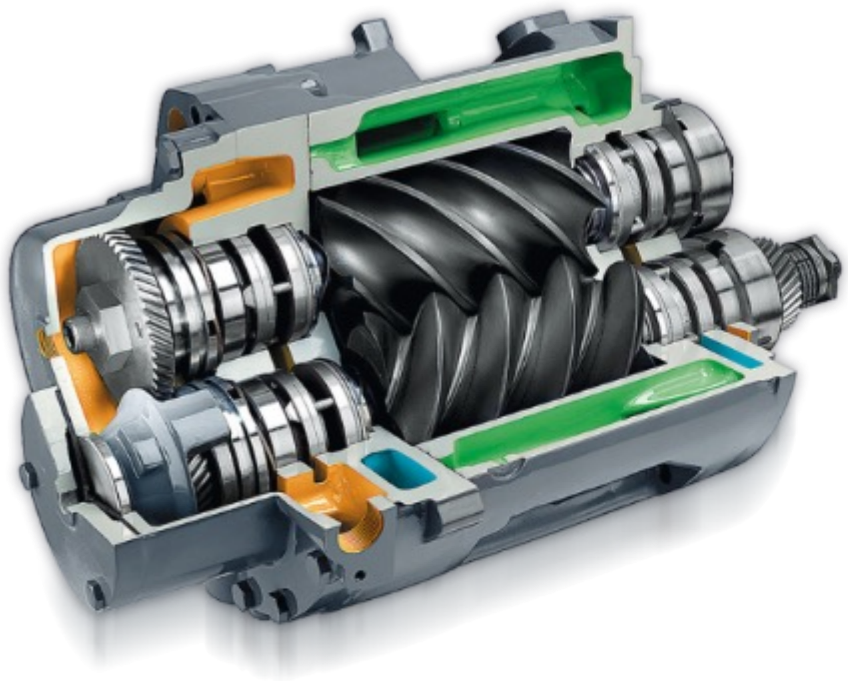
U.S. DEPARTMENT OF ENERGY

Two-stage Compressor

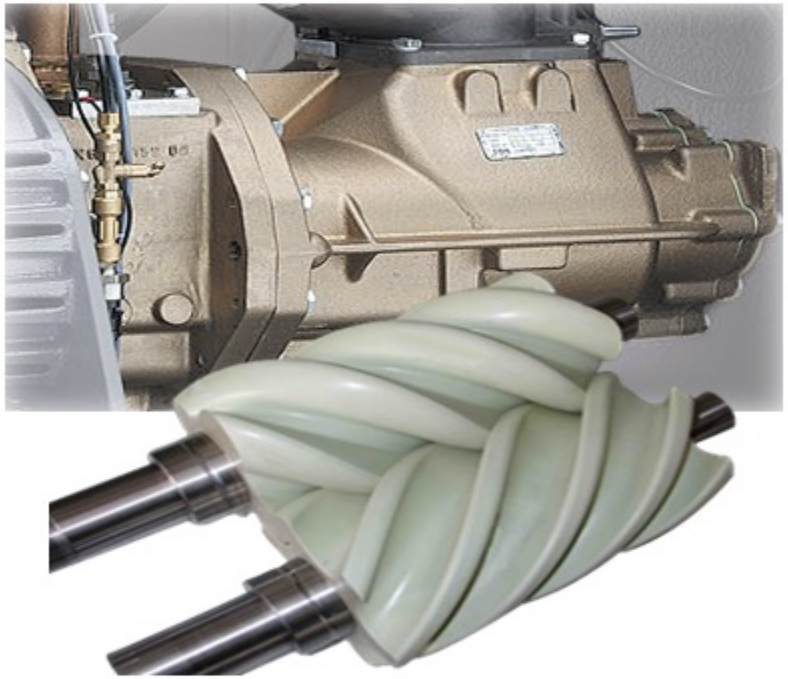
Oil Free Rotary

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

Dry Rotary Screw



Water Injected Screw

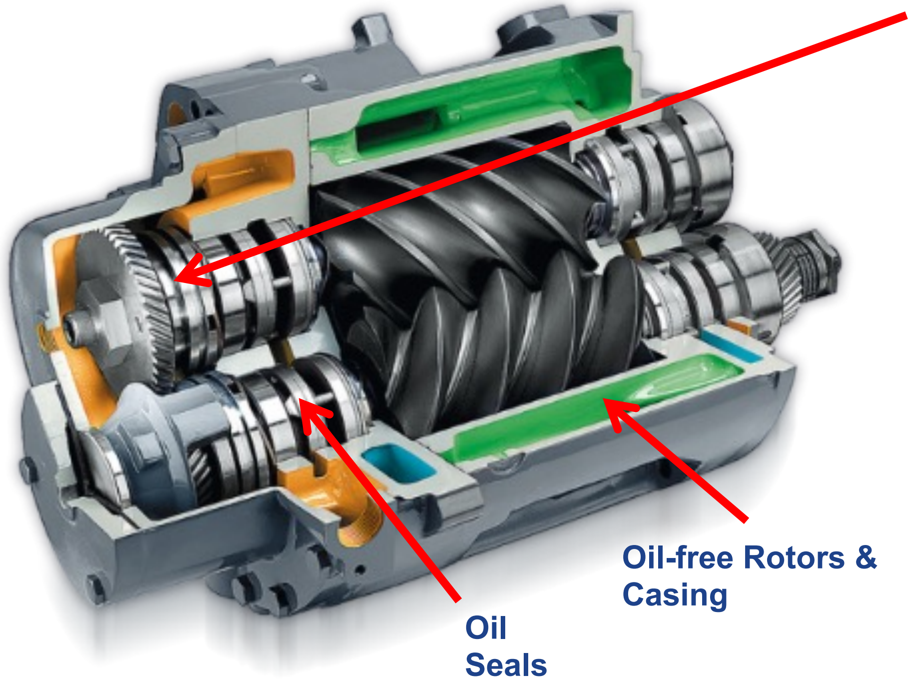


Lubricant-Free Rotary Screw Compressors

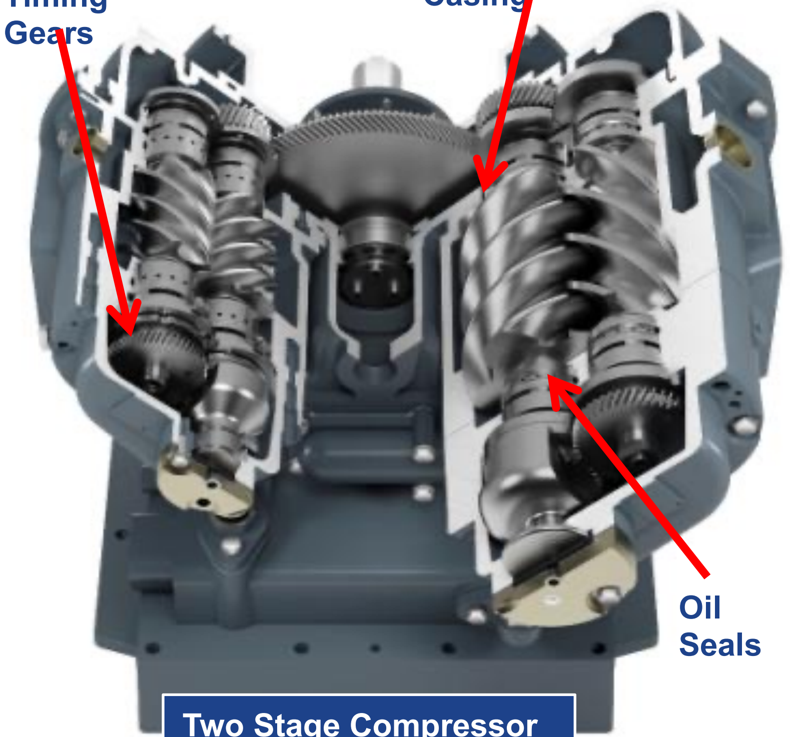
- Since there is no injected fluid to remove the heat of compression as done with lubricant injected two stage compressors, most oil free designs use two stages of compression, with an intercooler between the stages and an aftercooler after the second stage.
- Operating efficiency: 18-22 kW/100 cfm

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.



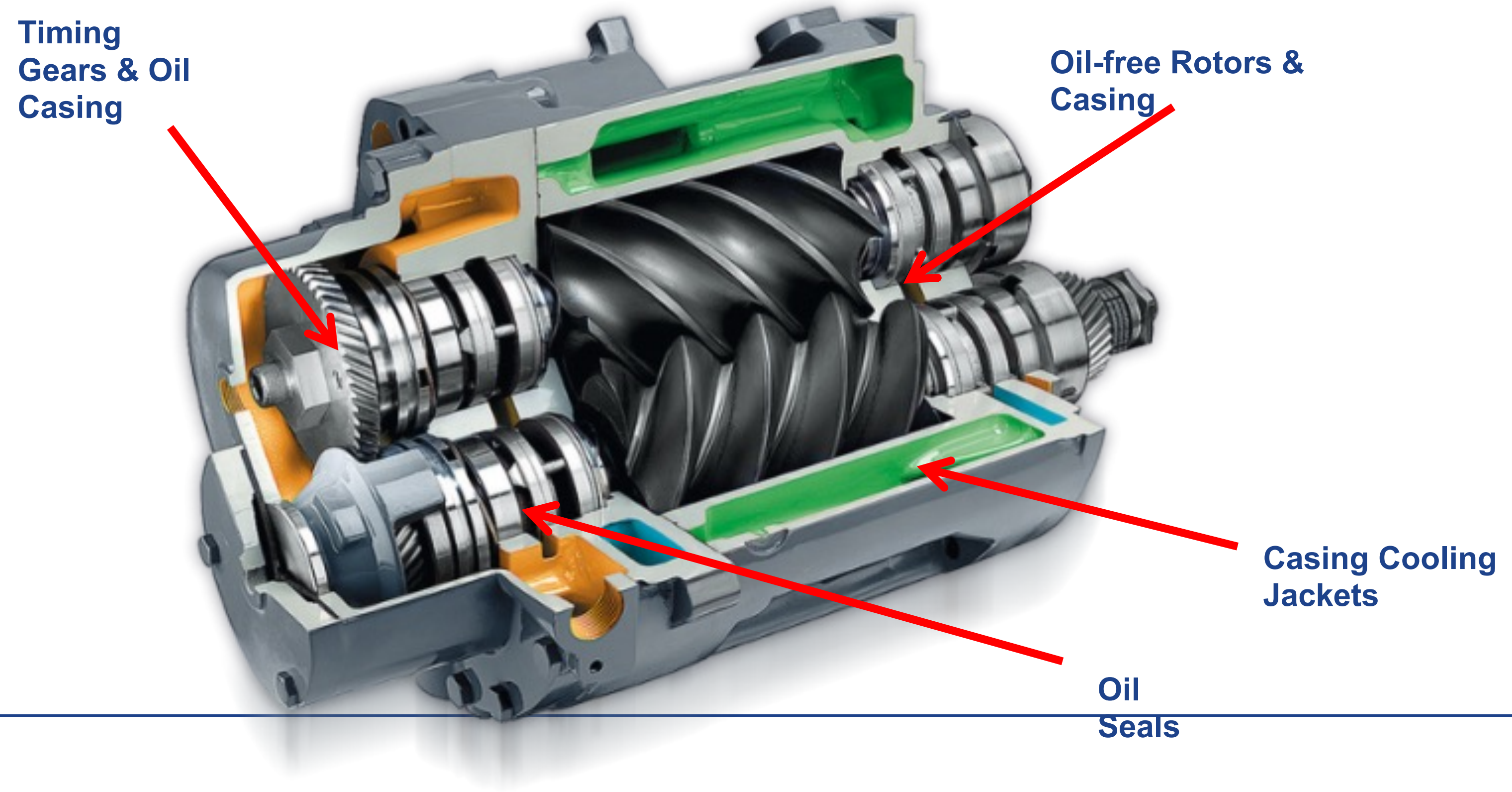
Single Stage Compressor



Two Stage Compressor

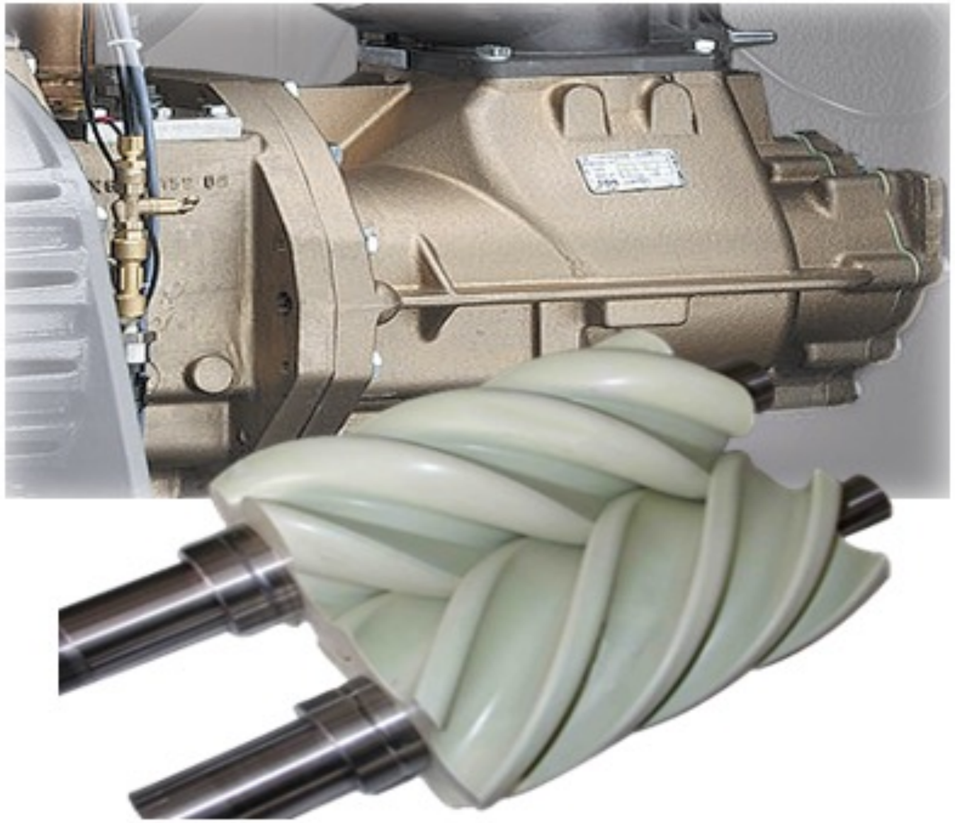
Oil Free Rotary

- Lubricant-free rotary screw compressors ‘do’ utilize lubricants but it’s main purpose is to lubricate bearings, gears and supply casing jacket cooling to help prevent casing thermal growth.



Oil Free Rotary

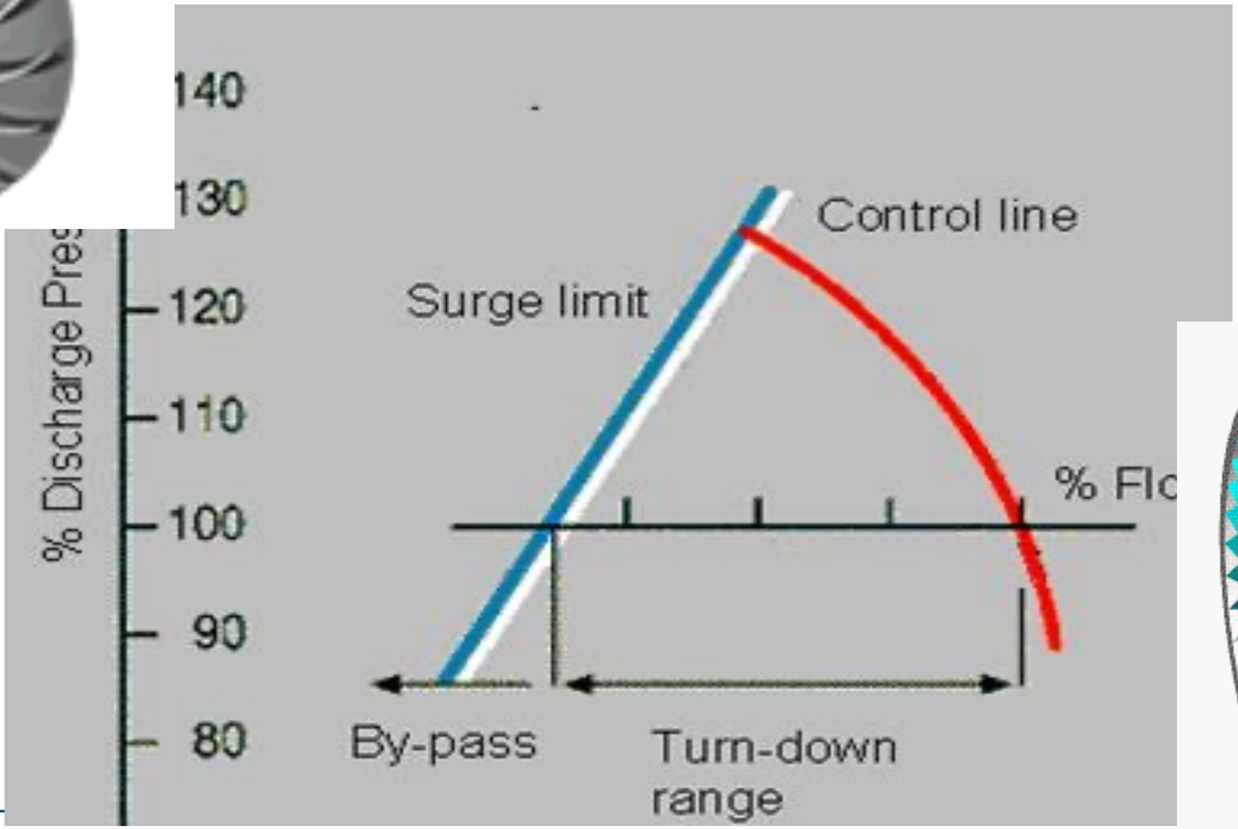
- With water injected rotary screw compressors – liquid (water) is used for cooling, sealing and lubrication. This coolant in the compression chamber allows these single stage designs to operate at higher pressures (150 to 190 psig)

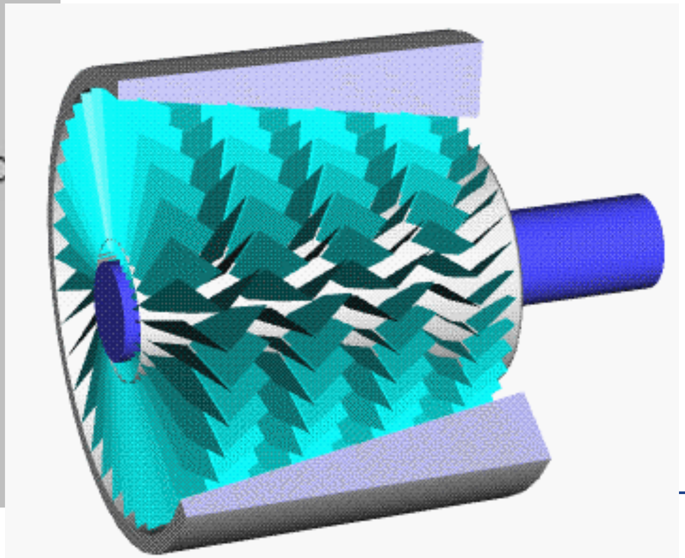


Centrifugal

- 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.

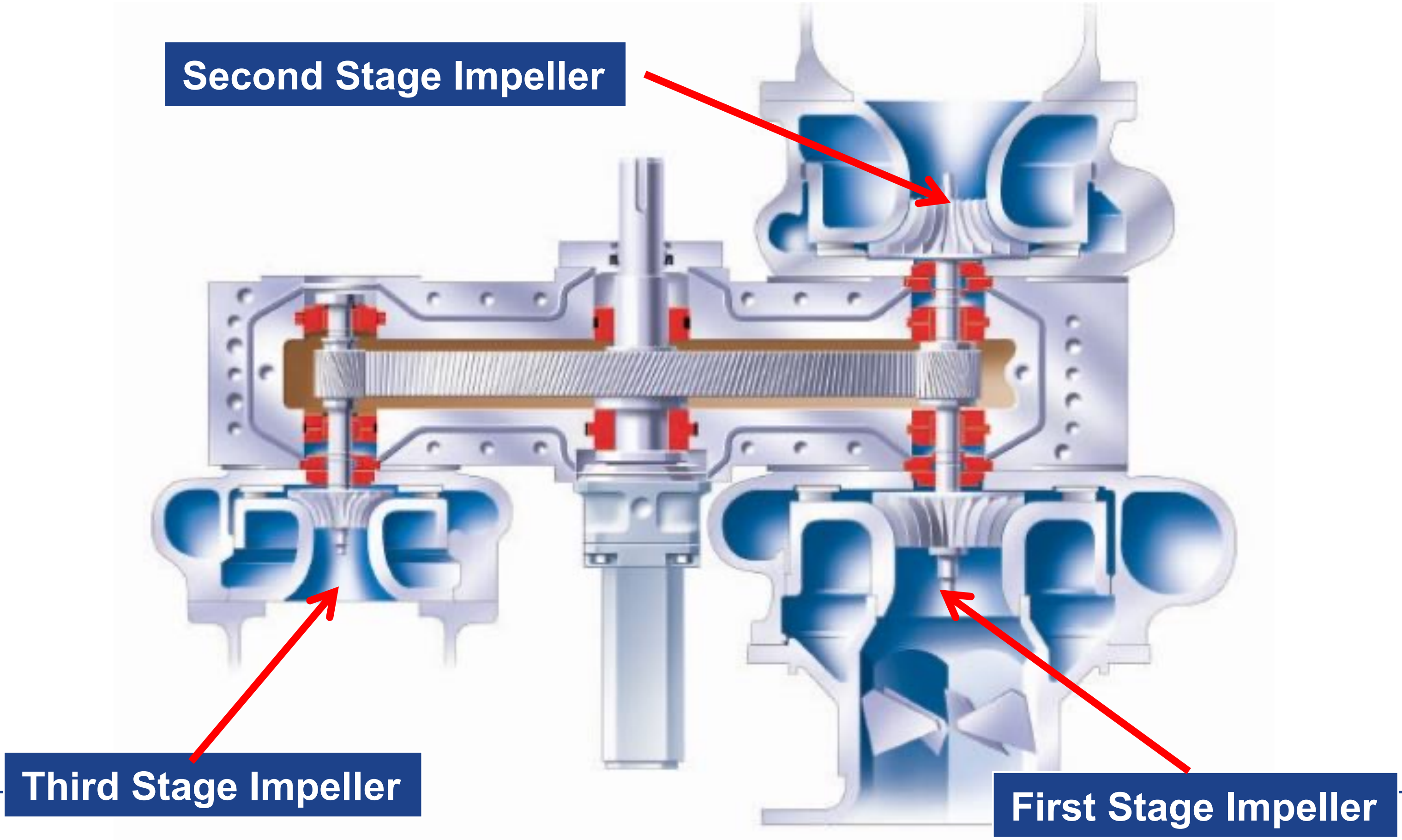
Dynamic Compressors





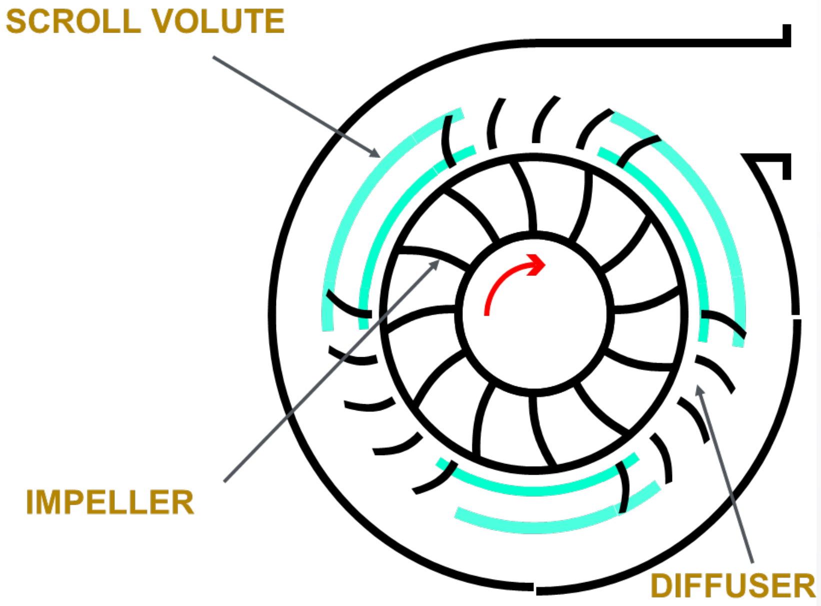
Dynamic Comrpressors

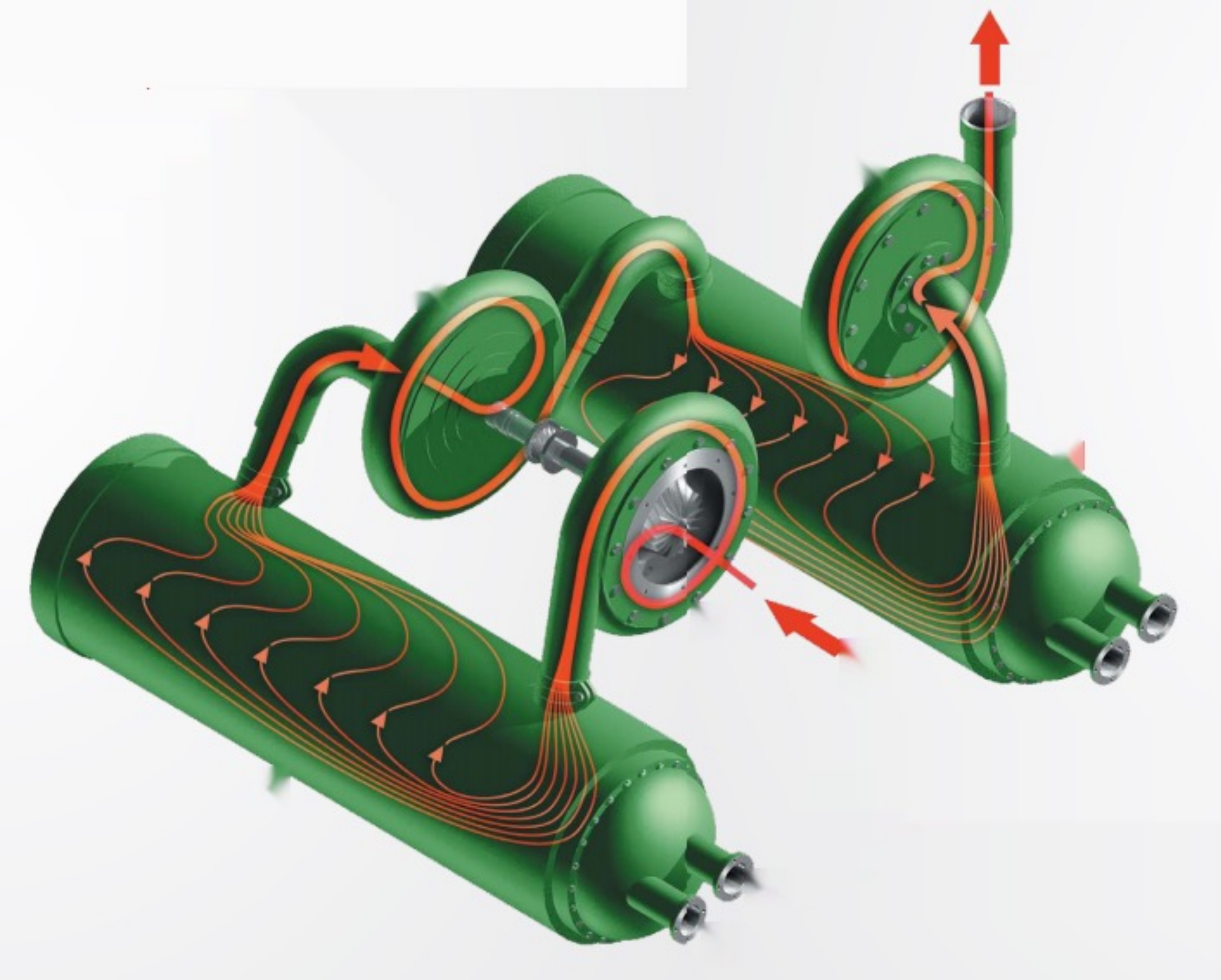
- Dynamic-type compressors are compressors in which air or gas is compressed by mechanical action of rotating impellers. Centrifugal compressors are Dynamic type.



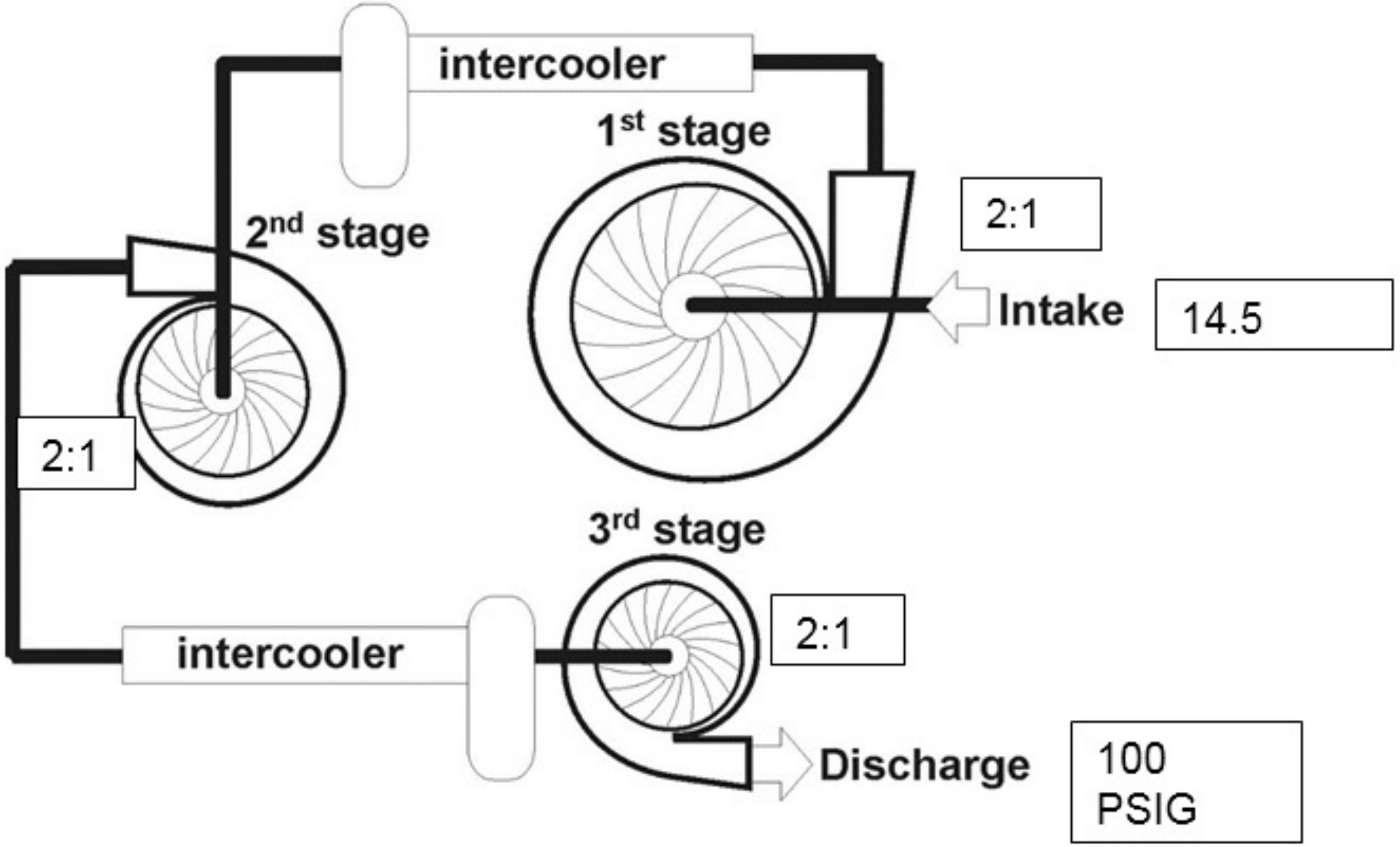
Centrifugal Compressor

Centrifugal Compressor Terminology





Three Stage



Exact Form:

$\sqrt[3]{7.8}$

Decimal Form:

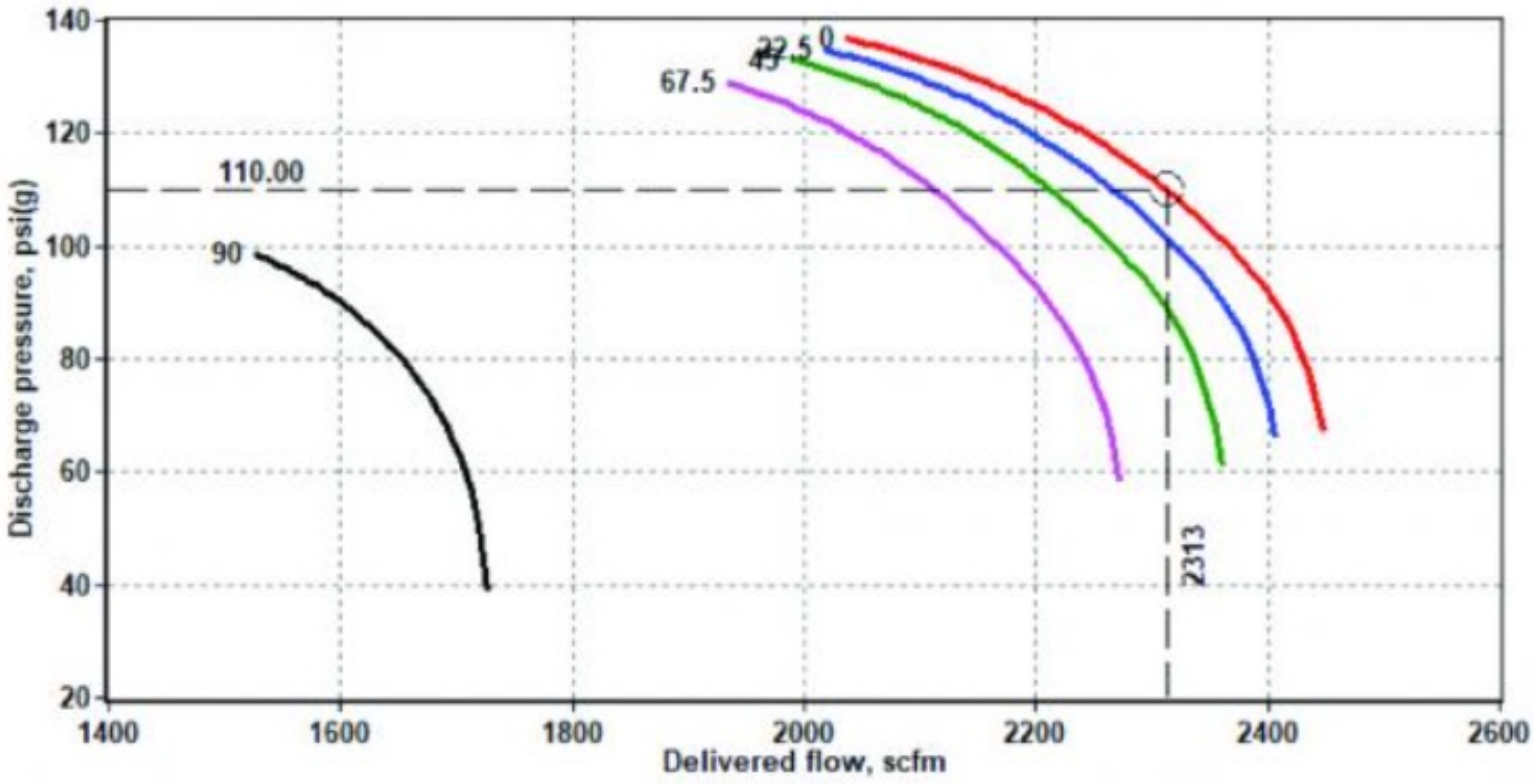
$1.98319248\ldots$

Multi stage centrifugal compressors are designed to try and balance the load between stages

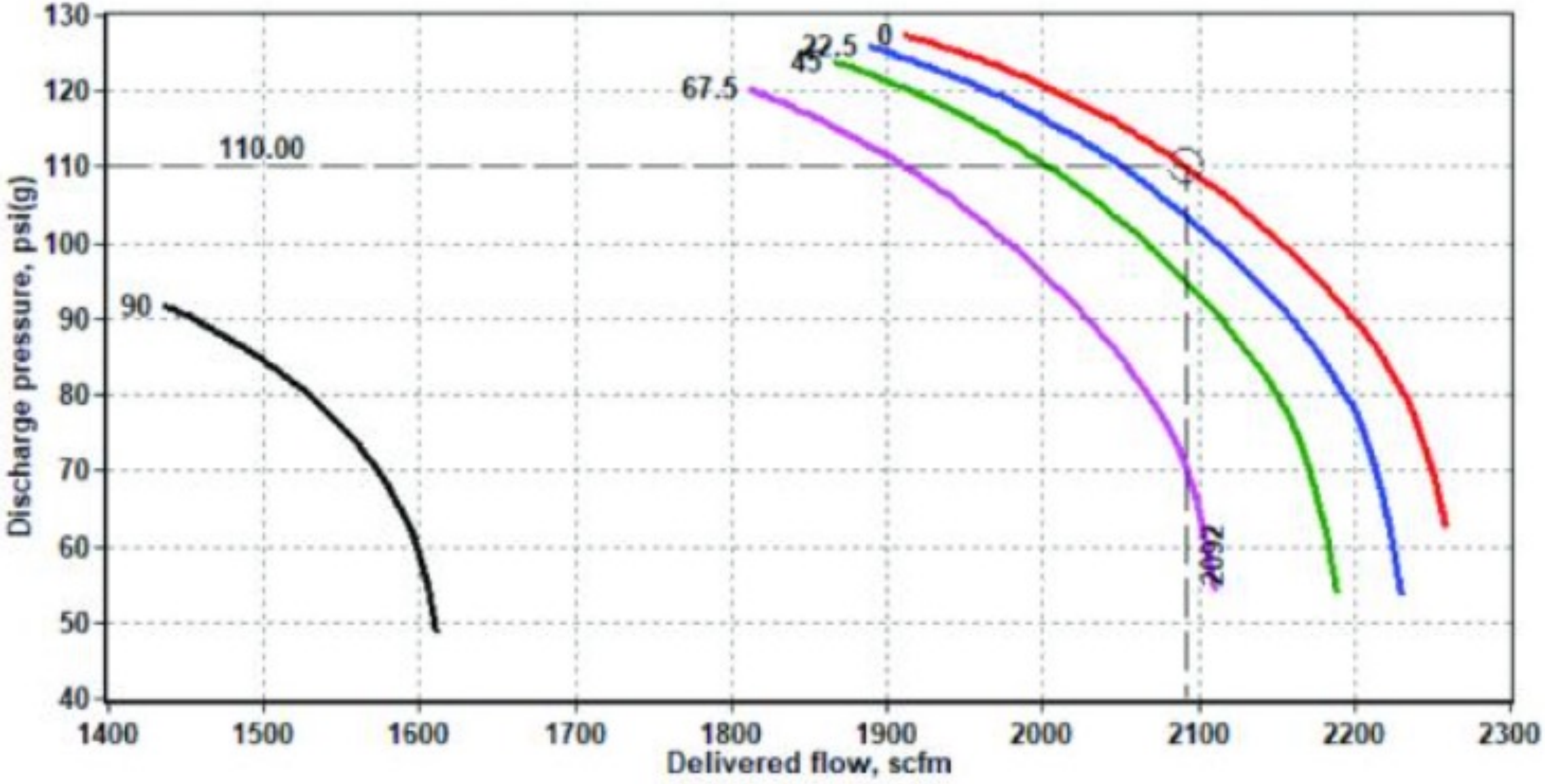
Effects on dynamic compressor performance

- Inlet pressure
- Inlet air temperature
- Cooling water temperature

Curve showing air compressor performance at a 95°F inlet and 110 psig discharge pressure:

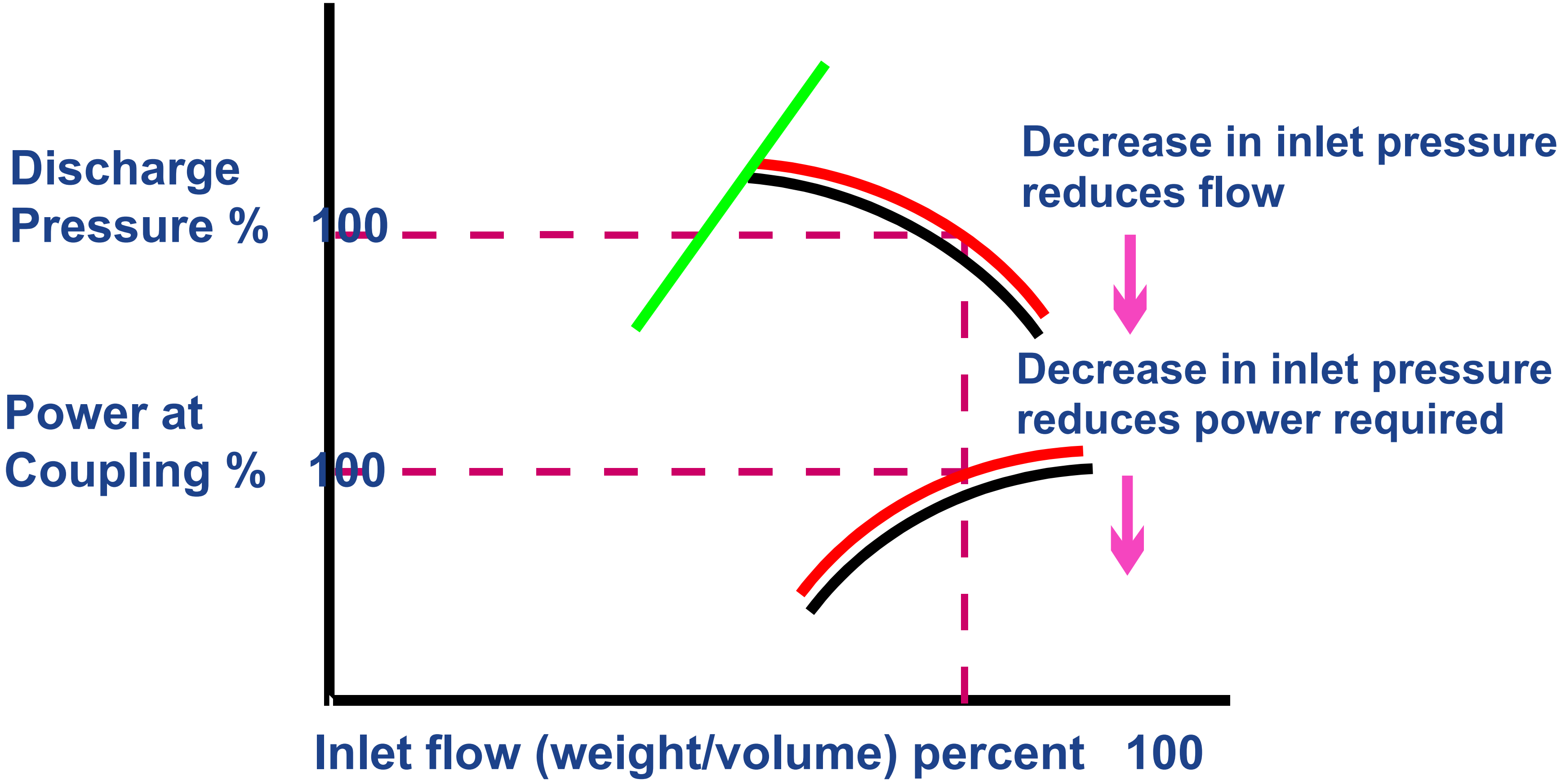


Curve showing air compressor performance at a 119°F inlet and 110 psig discharge pressure:



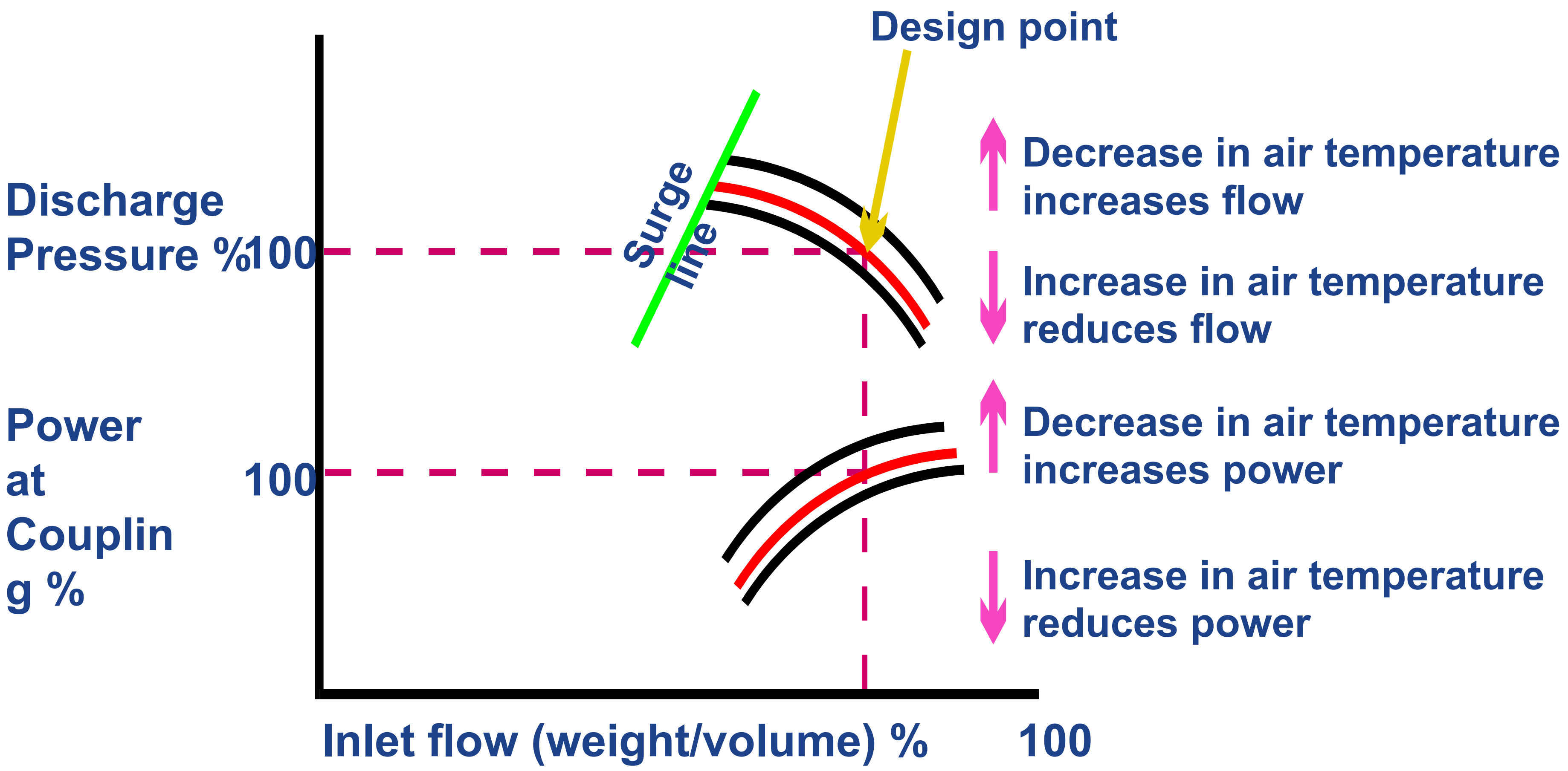
Effects on dynamic compressor performance

Inlet pressure



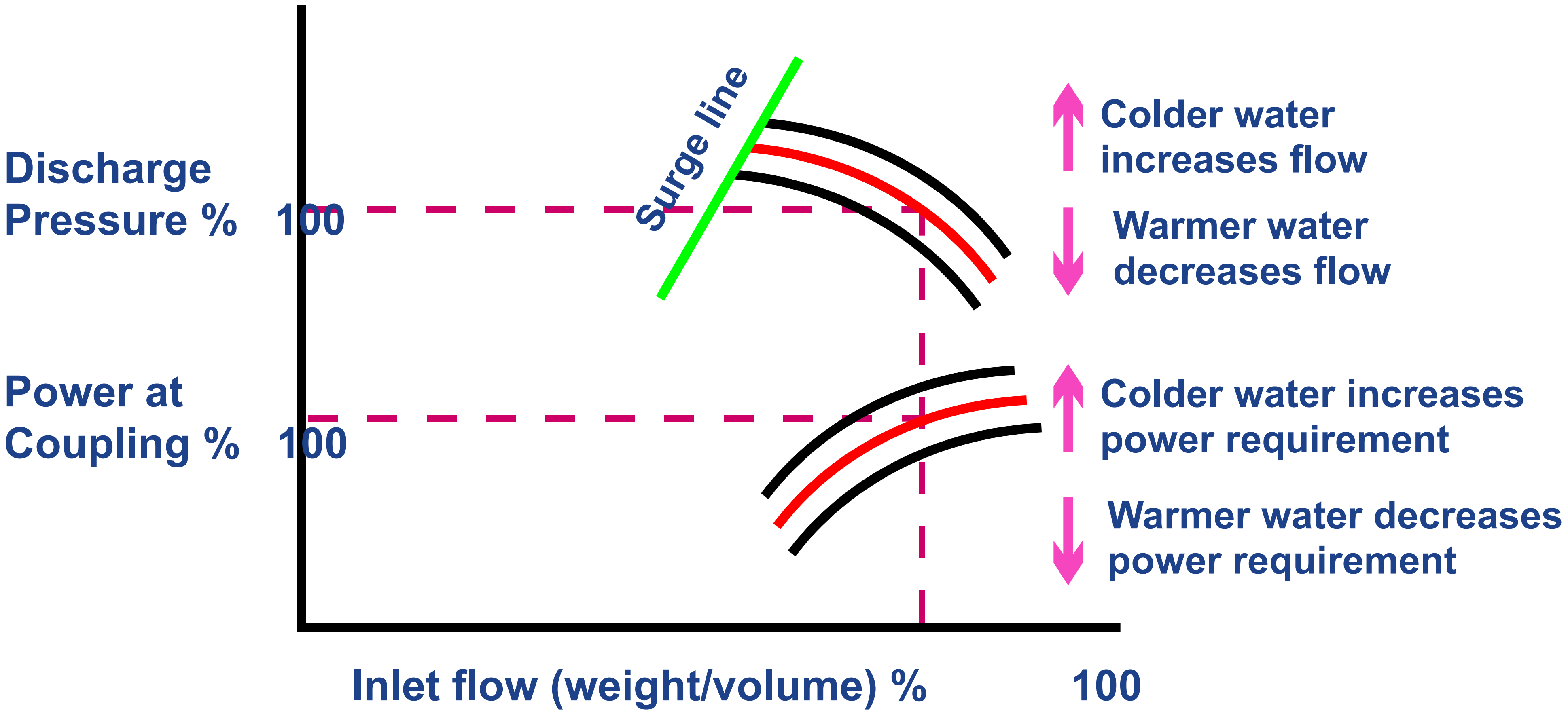
Effects on dynamic compressor performance

Inlet air temperature influence

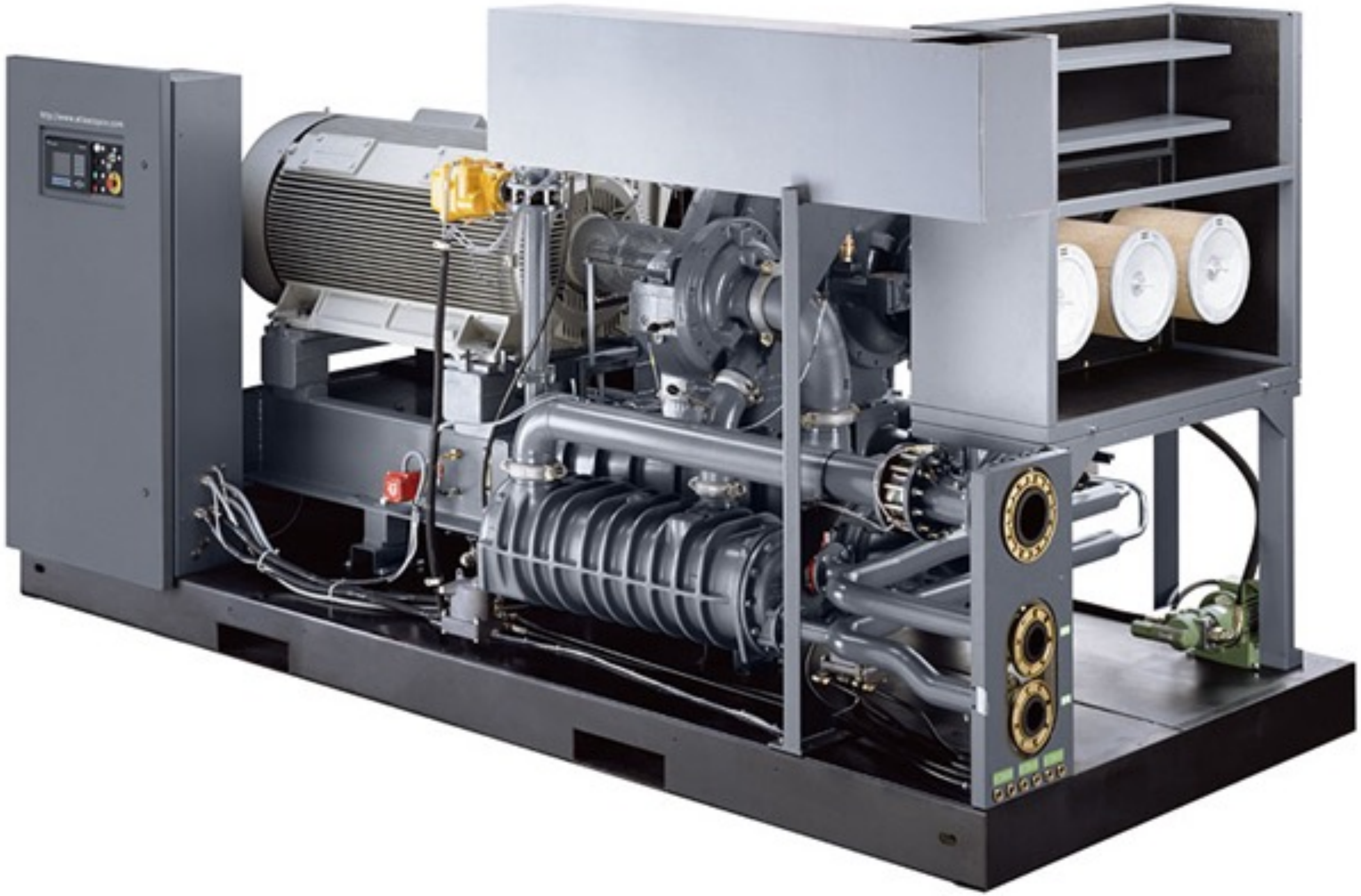


Effects on dynamic compressor performance

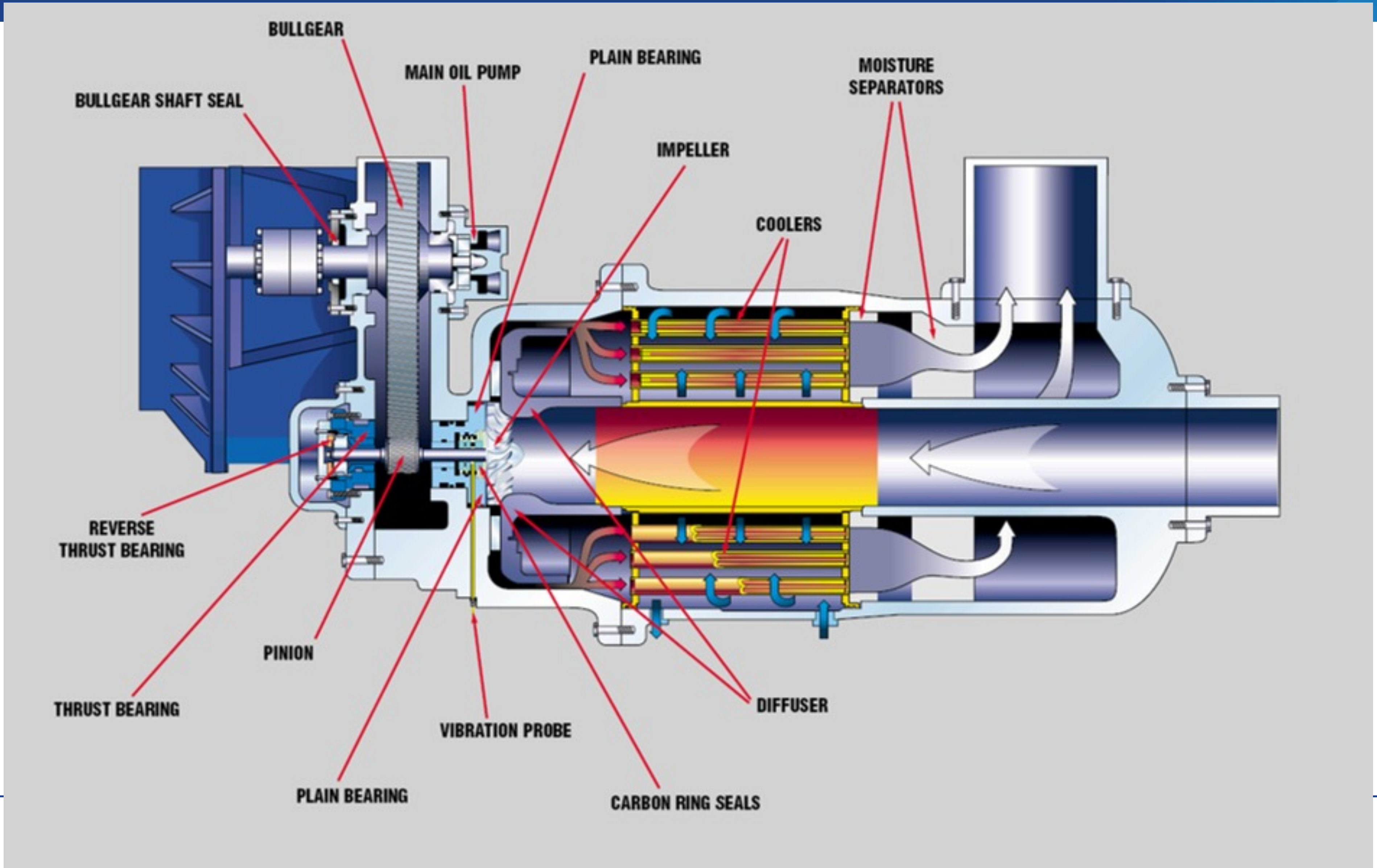
Cooling water temperature



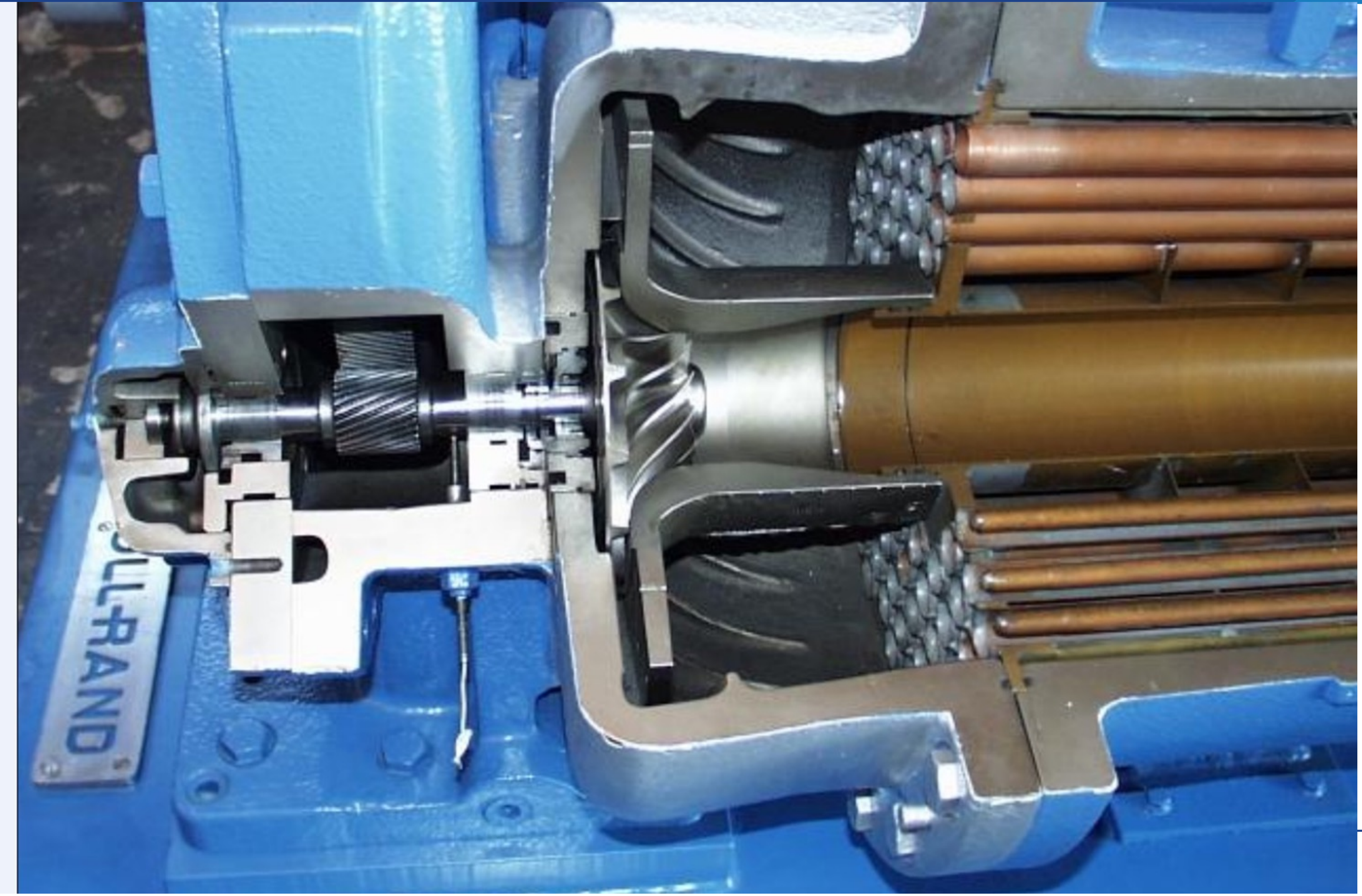
Centrifugal Compressor Terminology



Centrifugal Compressor Terminology



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

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

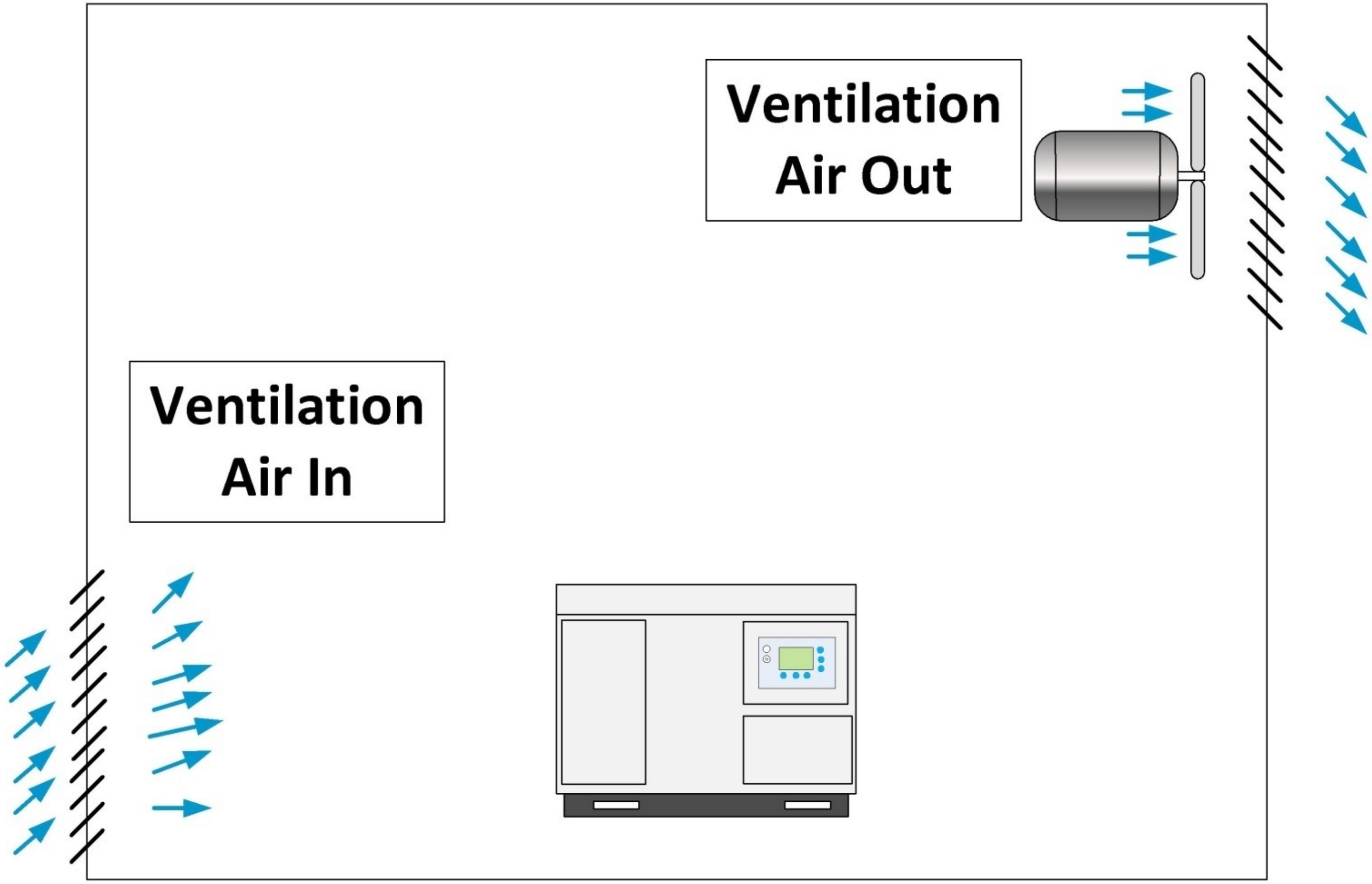
4. Poor Ventilation

- 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

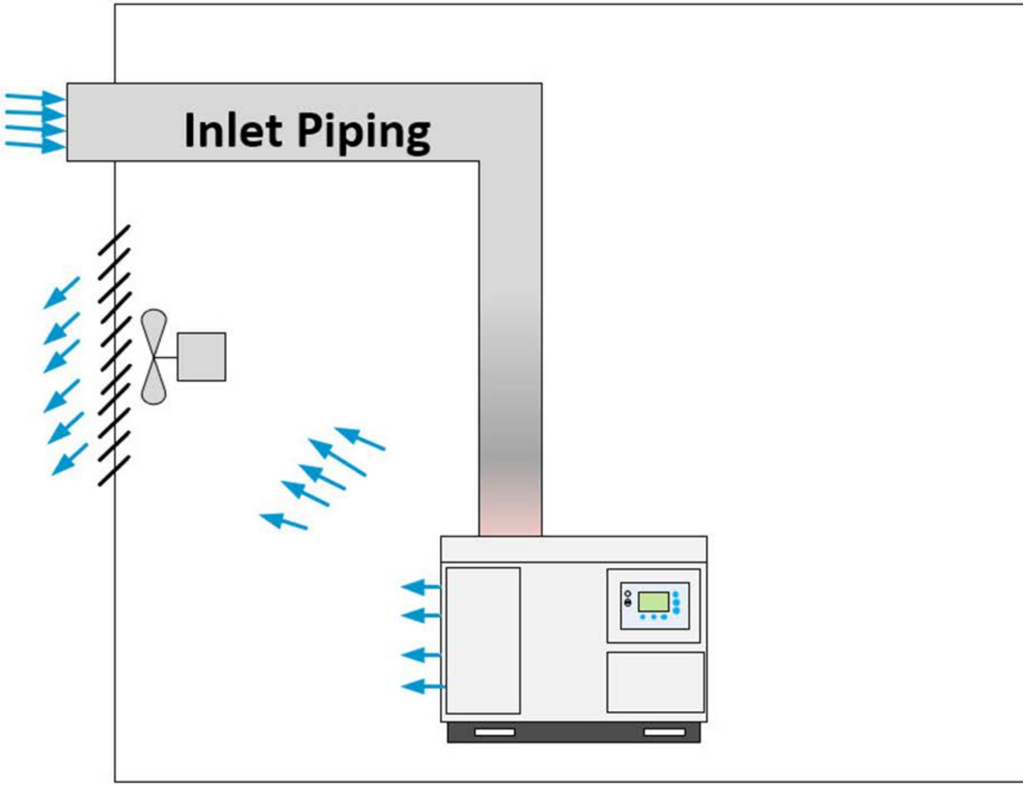
Ventilation

- 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.

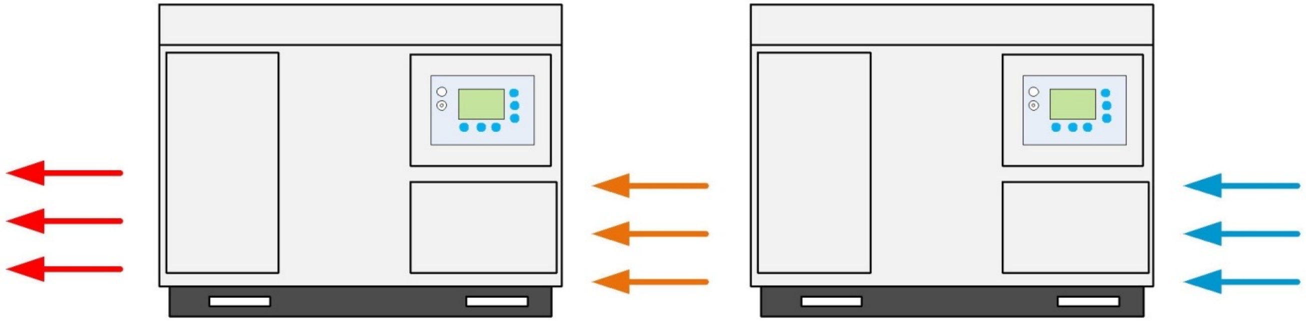
Ventilation



Ventilation



Ventilation

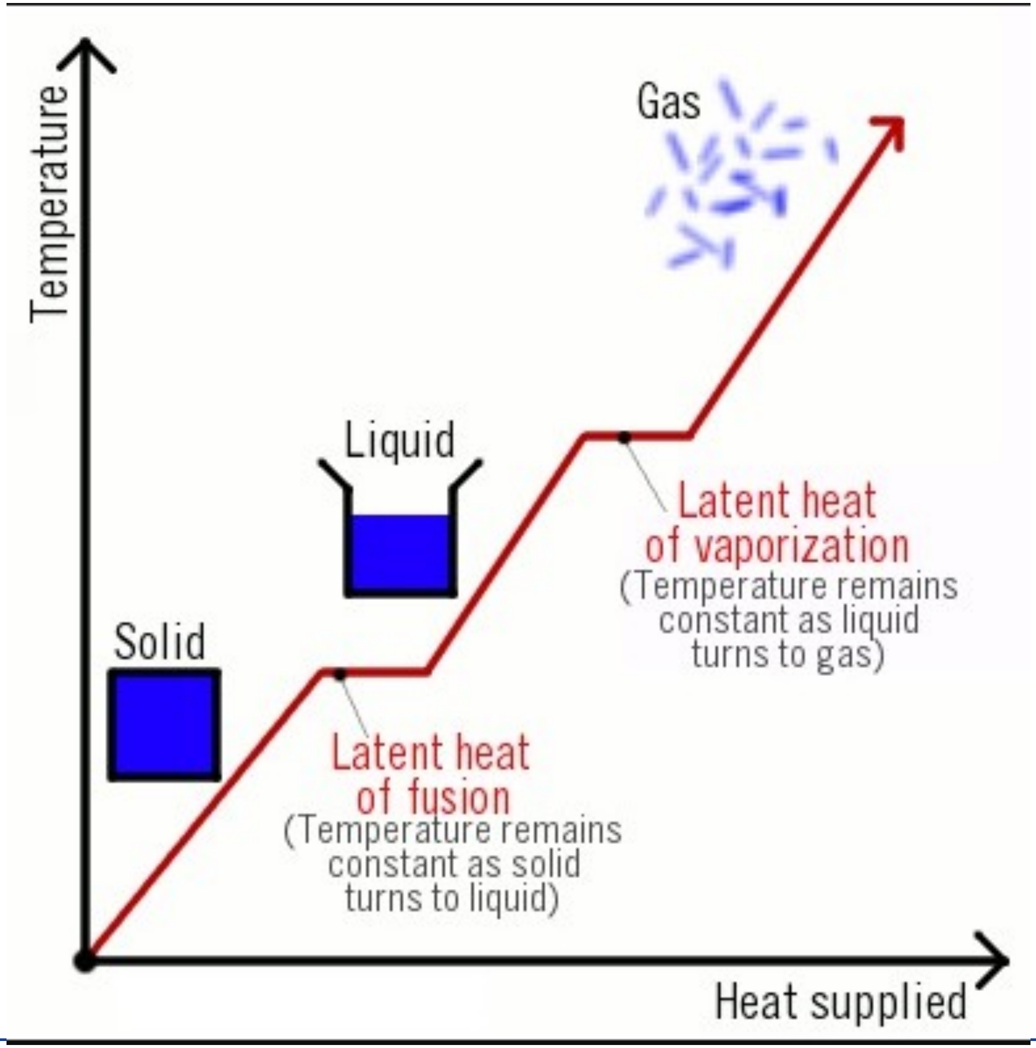


It is important not to block the air flow to the compressor inlet filter. If you have a multiple compressor installation, it is important, especially with air cooled units, that the heat discharge of one compressor does not go directly into the inlet of another compressor. This will cause shutdowns due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

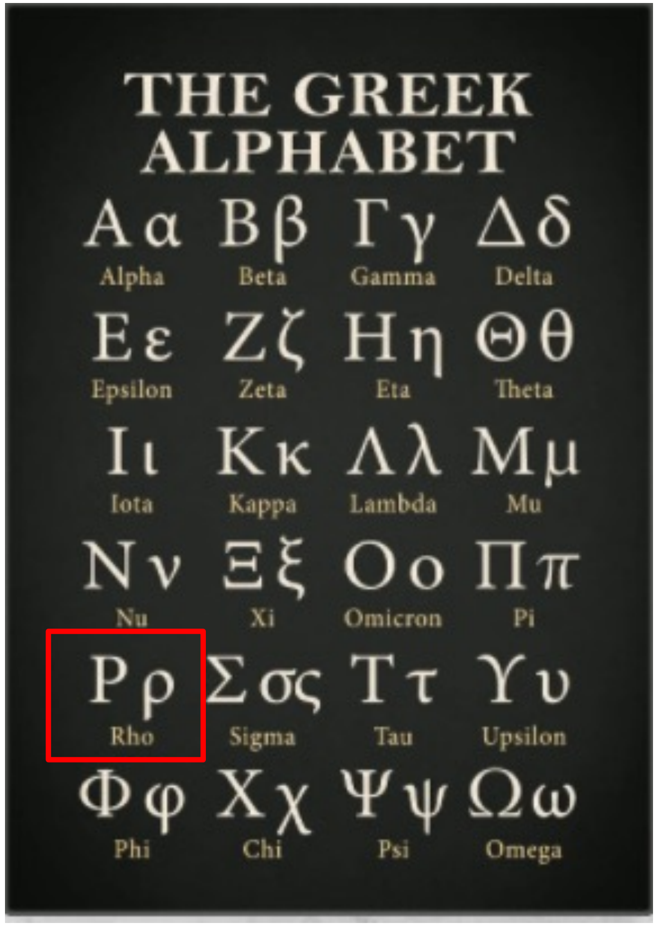
- The sensible heat rise can be determined by the following:

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

Where:

- H_s = sensible heat gain, BTUs per hour
- Q_s = volumetric flow for sensible heat, CFM
- ρ = density of air, lb/ft^3
- 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 ρ = 0.075 lb/ft^3;

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:

Qs → Hs

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

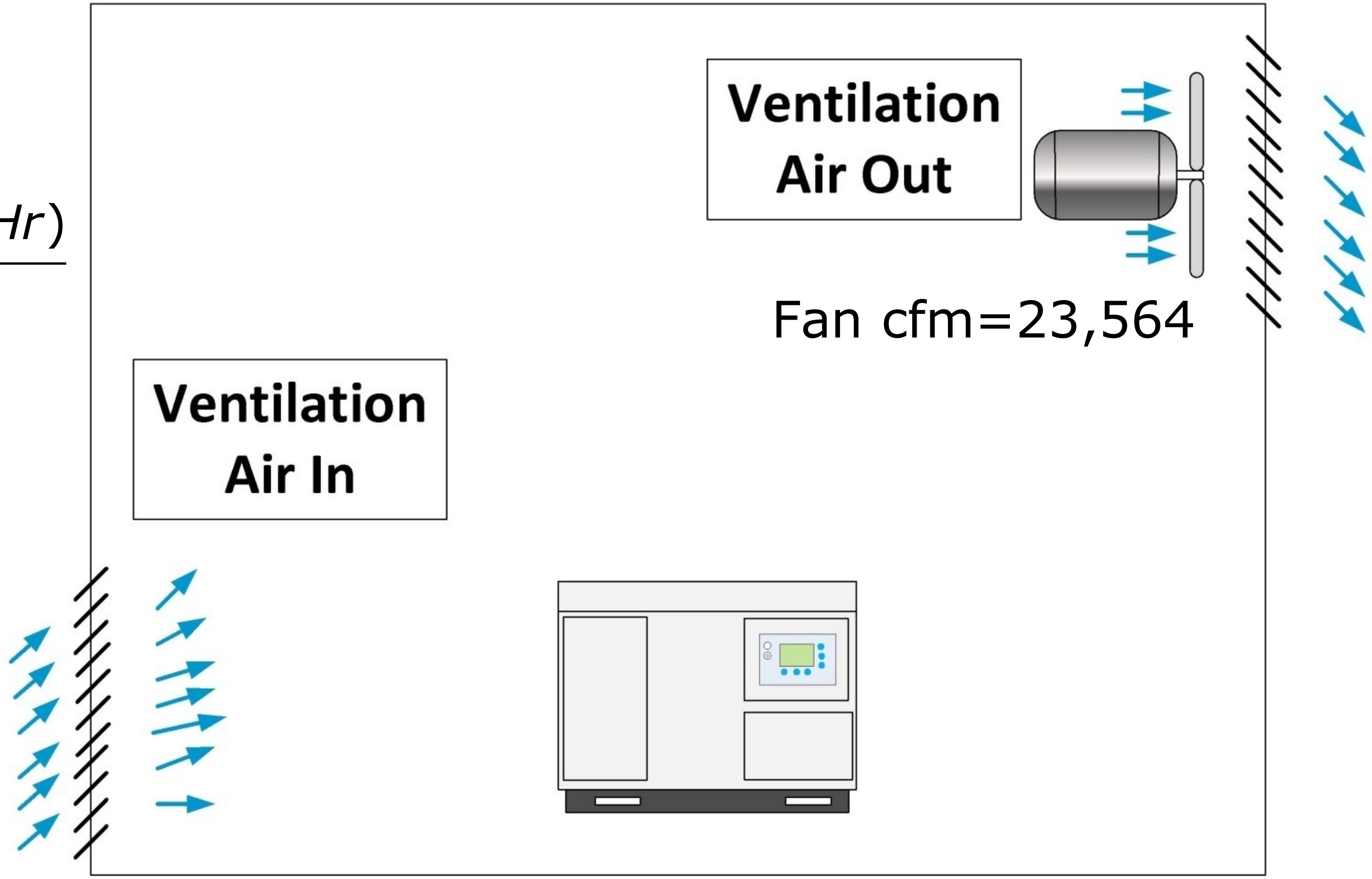
- 1 HP = 2,545 BTU / hr
- The heat load is sensible duty only.
- Temp rise is above make-up air temp.
  - A 10-degree rise is all you really need.

Ventilation Example 100 HP Compressor

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

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

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




TEMPERATURE

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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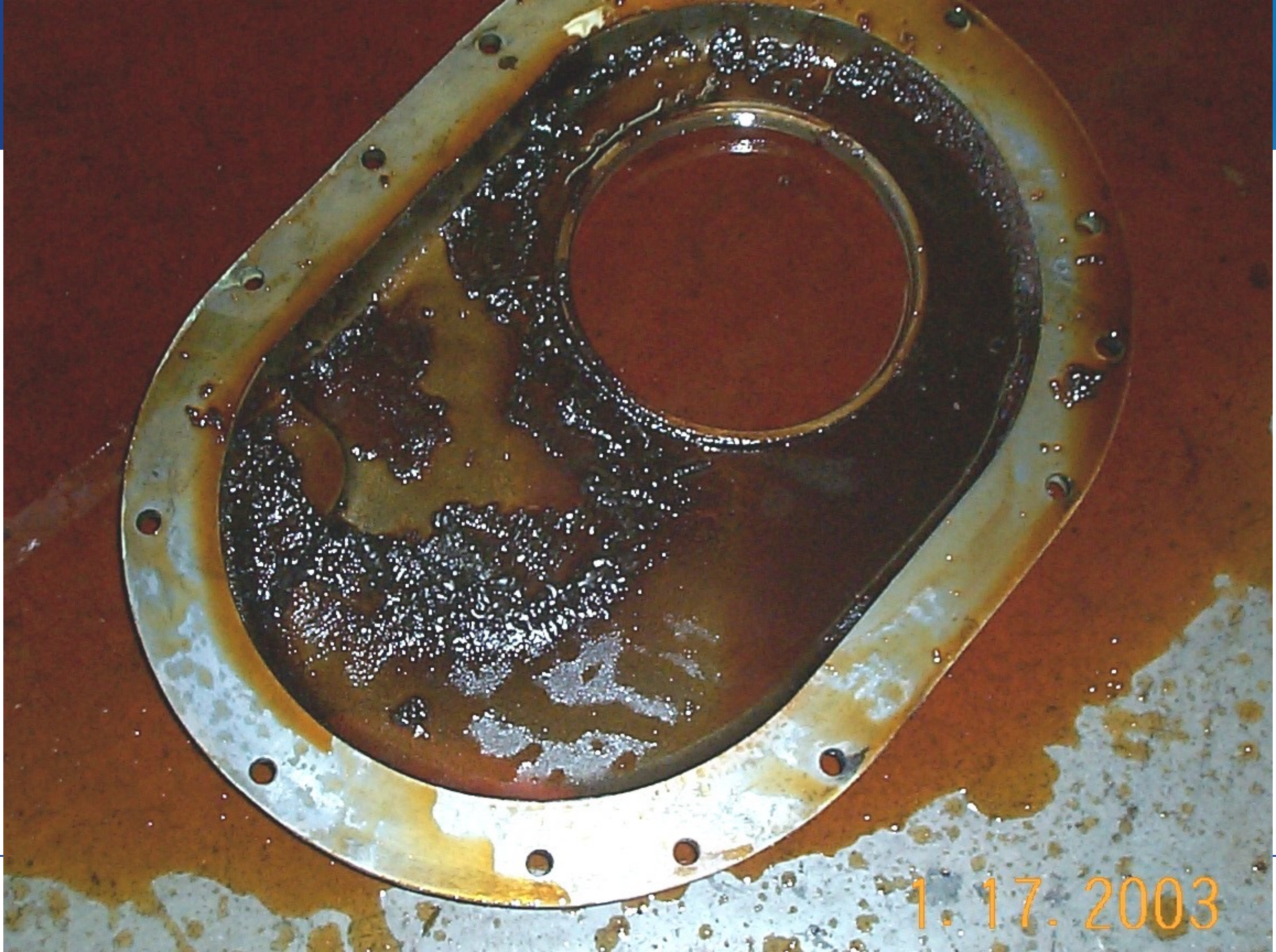
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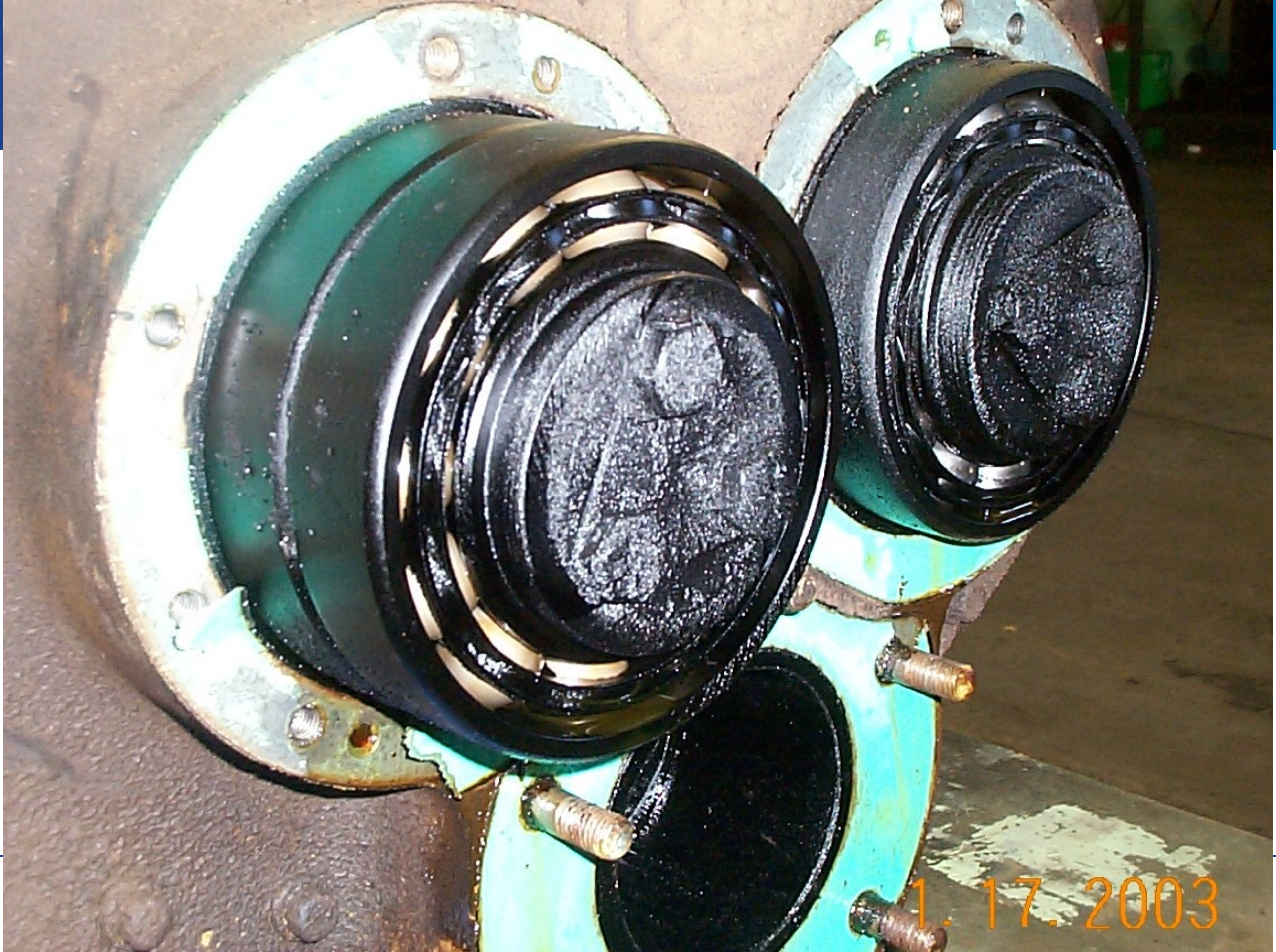
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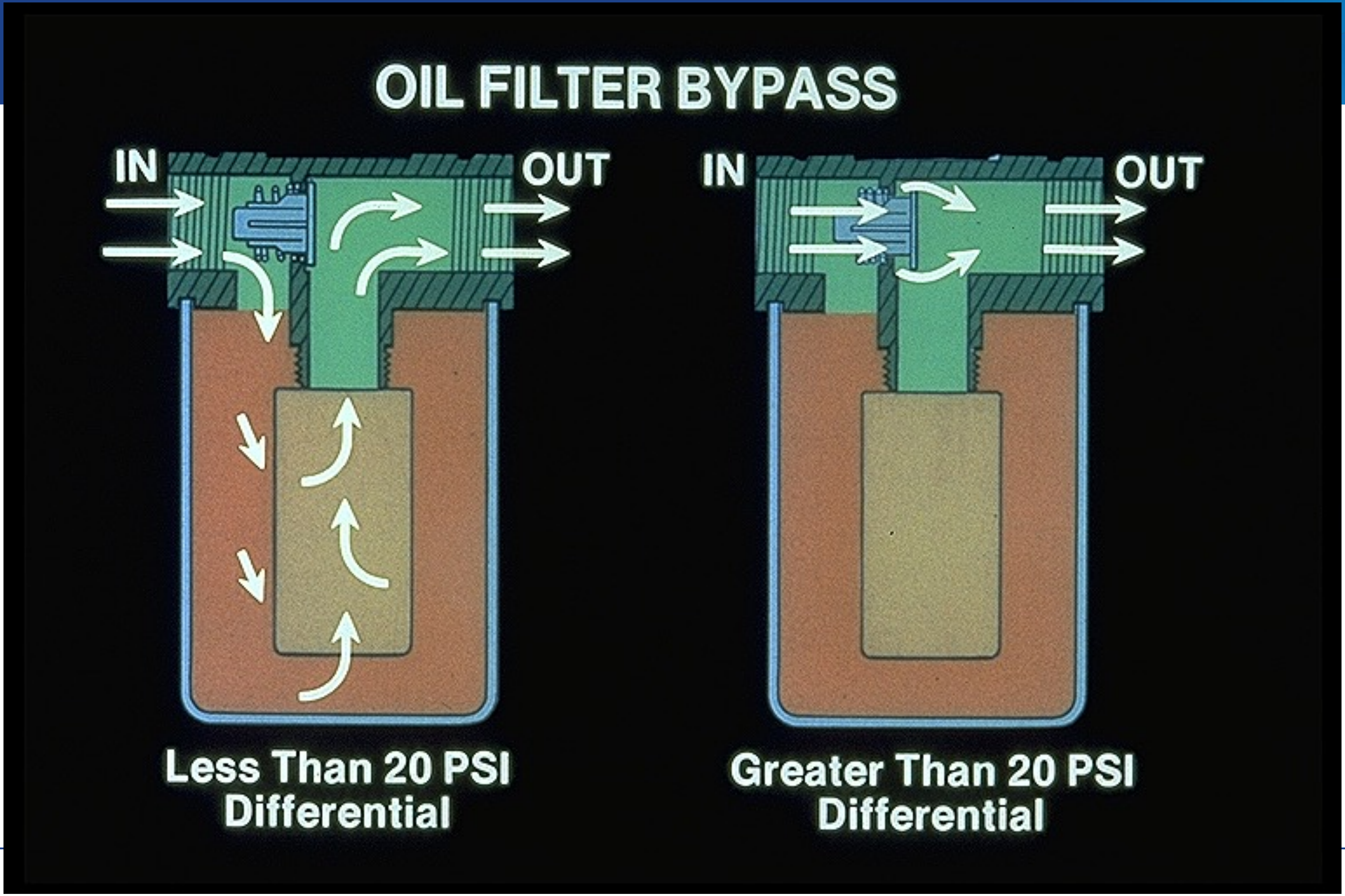
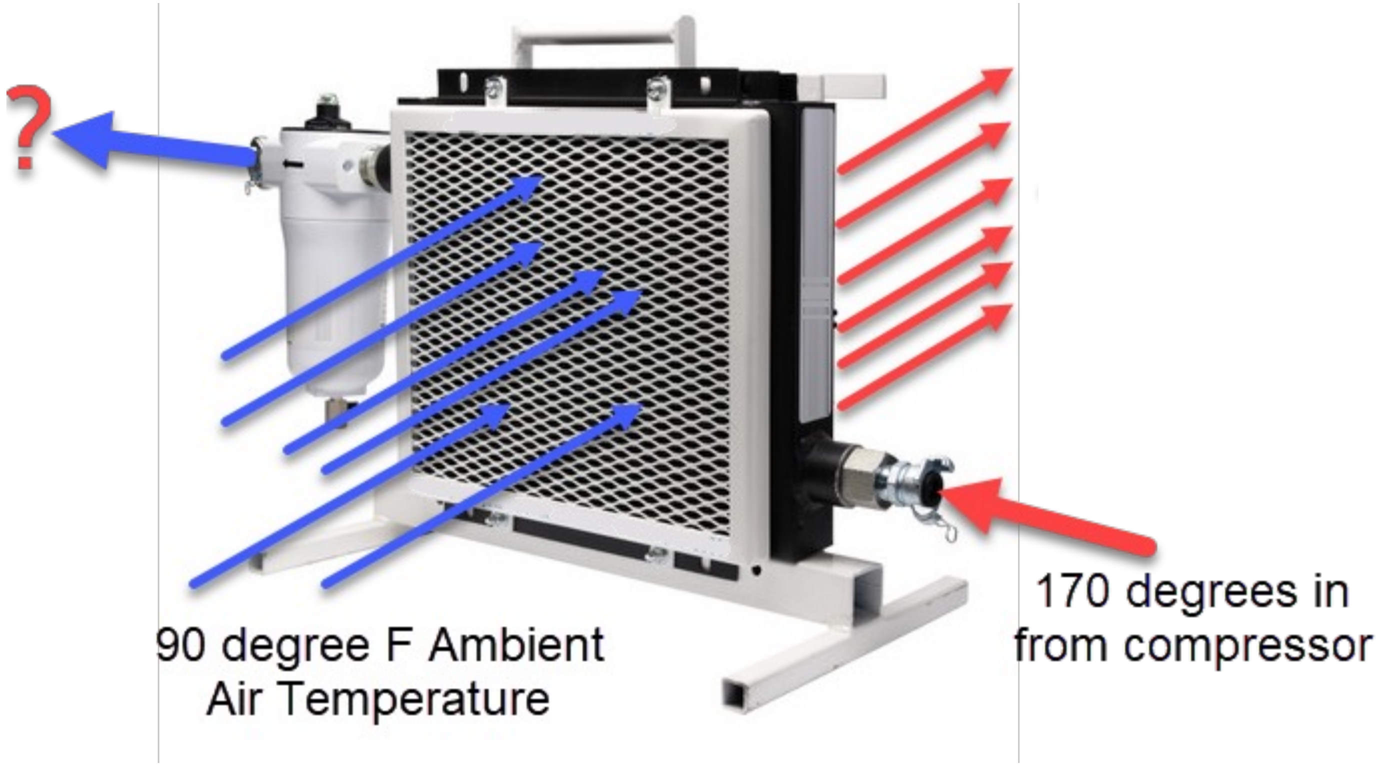

OIL FILTER BYPASS
IN
OUT
IN
OUT
Less Than 20 PSI Differential
Greater Than 20 PSI Differential

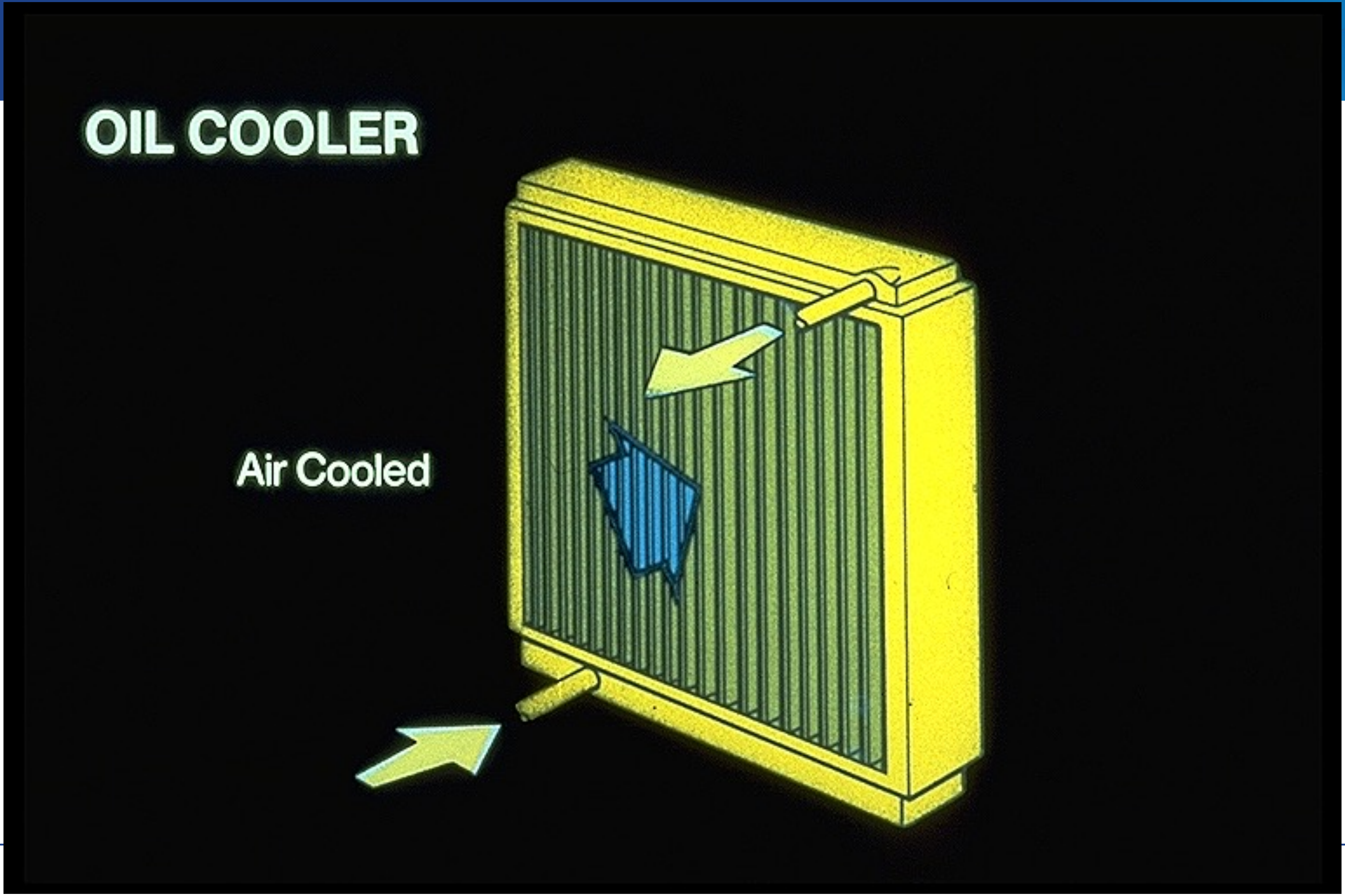
Other Important Maintenance Issues

- Condensate Sampling
- Bearing Analysis (Centrifugals)
- Bearing Analysis – Anti-friction (Rotary Screws)
- Motor Rewinding
- Trending
- Cooler cleaning
- Measuring Approach Temperature or CTD

Approach Temperature

- This after-cooler has a 15-degree Approach Temperature
- What should the temperature of the discharge air be?
- 90 + 15 =105°F




OIL COOLER
Air Cooled

Summary

- Select the right compressor based on your requirements.
- 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

Next Week Session 3 - Compressor Controls

System capacity control is based on:

- Number of compressors in a system
- Type and size of the compressors
- Application requirements

Questions?

U.S. DEPARTMENT OF ENERGY