Compressors

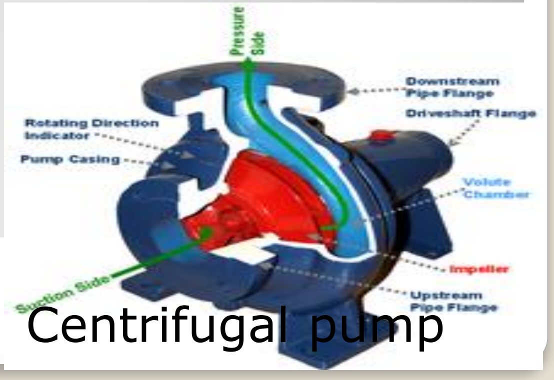
Basic Classification and design overview

What are compressors?

Compressors are mechanical devices that compresses gases. It is widely used in industries and has various applications

How they are different from pumps?

- Major difference is that compressors handles the gases and pumps handles the liquids.
- As gases are compressible, the compressor also reduces the volume of gas.
- Liquids are relatively incompressible; while some can be compressed



Centrifugal pump

What are its applications?

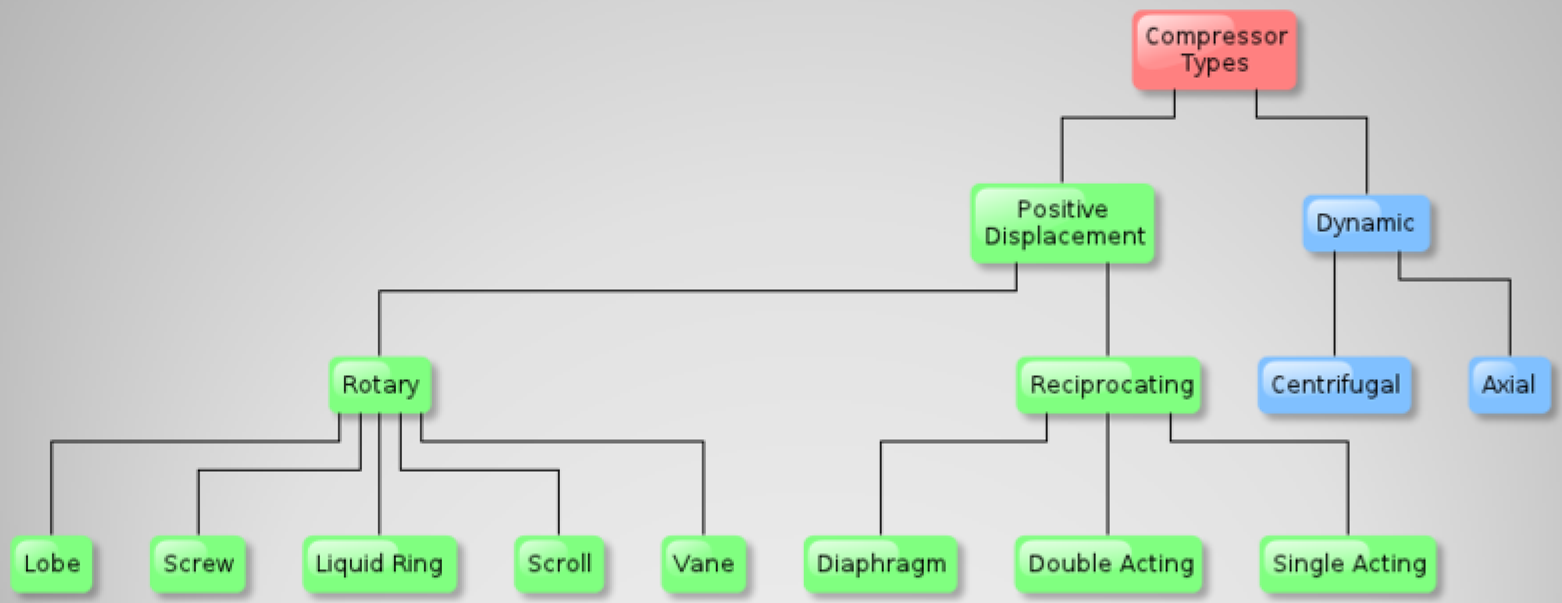
Compressors have many everyday uses, such as in :

- Air conditioners, (car, home)
- Home and industrial refrigeration
- Hydraulic compressors for industrial machines
- Air compressors for industrial manufacturing

Refrigeration compressor

What are its various types?

Compressor classification can be described by following flow chart:



What are dynamic compressors?

The dynamic compressor is continuous flow compressor is characterized by rotating impeller to add velocity and thus pressure to fluid.

It is widely used in chemical and petroleum refinery industry for specific services.

There are two types of dynamic compressors

- Centrifugal Compressor
- Axial Flow Compressor

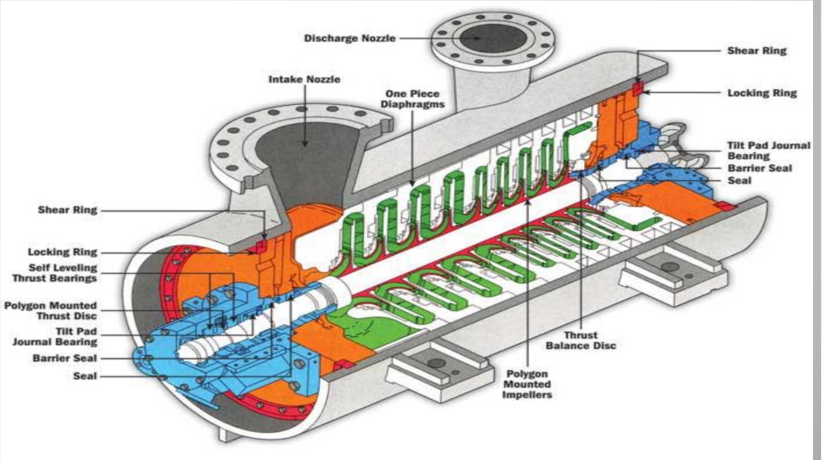


Figure 1. Major Components of Multistage Barrel-type Centrifugal Compressors (Dresser-Rand Co., Olean, NY)

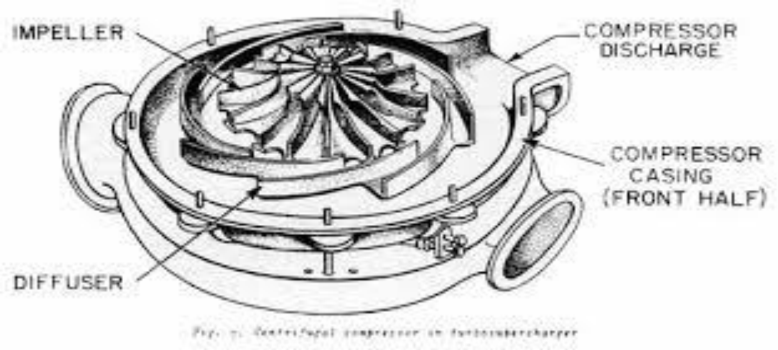
Centrifugal Compressor

- Achieves compression by applying inertial forces to the gas by means of rotating impellers.

- It is multiple stage ; each stage consists of an impeller as the rotating element and the stationary element, i.e. diffuser

- Fluid flow enters the impeller axially and discharged radially

- The gas next flows through a circular chamber (diffuser), where it loses velocity and increases pressure.



Axial flow compressor

- Working fluid principally flows parallel to the axis of rotation.

- The energy level of air or gas flowing through it is increased by the action of the rotor blades which exert a torque on the fluid

- Have the benefits of high efficiency and large mass flow rate

- Require several rows of airfoils to achieve large pressure rises making them complex and expensive

Axial Flow Compressor

Why multistage compressor?

- High temp rise leads into limitation for the maximum achievable pressure rise.
- Discharge temperature shall not exceed 150ºC and should not exceed 135^{0}C for hydrogen rich services
- A multistage centrifugal compressor compresses air to the required pressure in multiple stages.
- Intercoolers are used in between each stage to removes heat and decrease the temperature of gas so that gas could be compressed to higher pressure without much rise in temperature

Intercooler

What are positive displacement compressors?

Positive displacement compressors causes movement by trapping a fixed amount of air then forcing (displacing) that trapped volume into the discharge pipe.

It can be further classified according to the mechanism used to move air.

- Rotary Compressor
- Reciprocating compressor

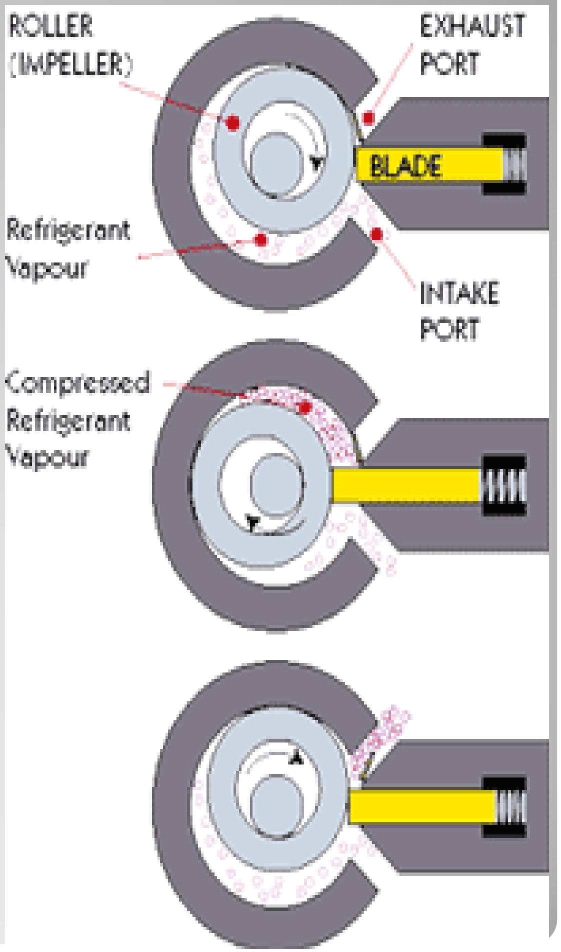
Rotary compressors

- The gas is compressed by the rotating action of a roller inside a cylinder.

- The roller rotates off-centre around a shaft so that part of the roller is always in contact with the cylinder.

- Volume of the gas occupies is reduced and the refrigerant is compressed.

- High efficient as sucking and compressing refrigerant occur simultaneously.



Reciprocating compressor

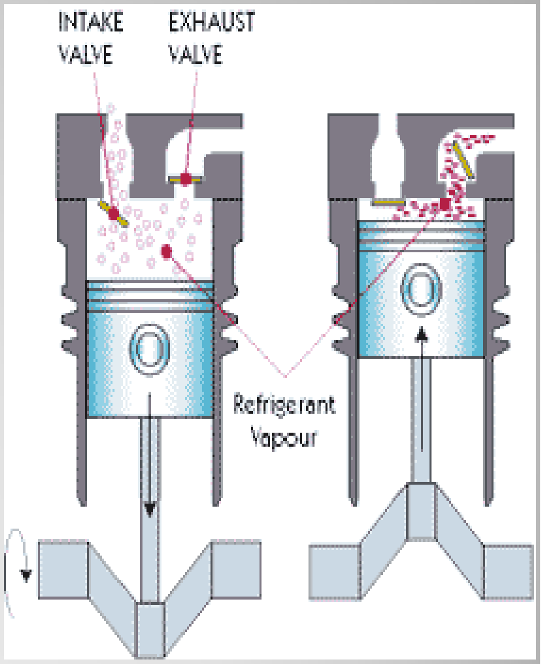
It is a positive-displacement compressor that

- Uses pistons driven by a crankshaft to deliver gases at high pressure.

- The intake gas enters the suction manifold, then flows into the compression cylinder

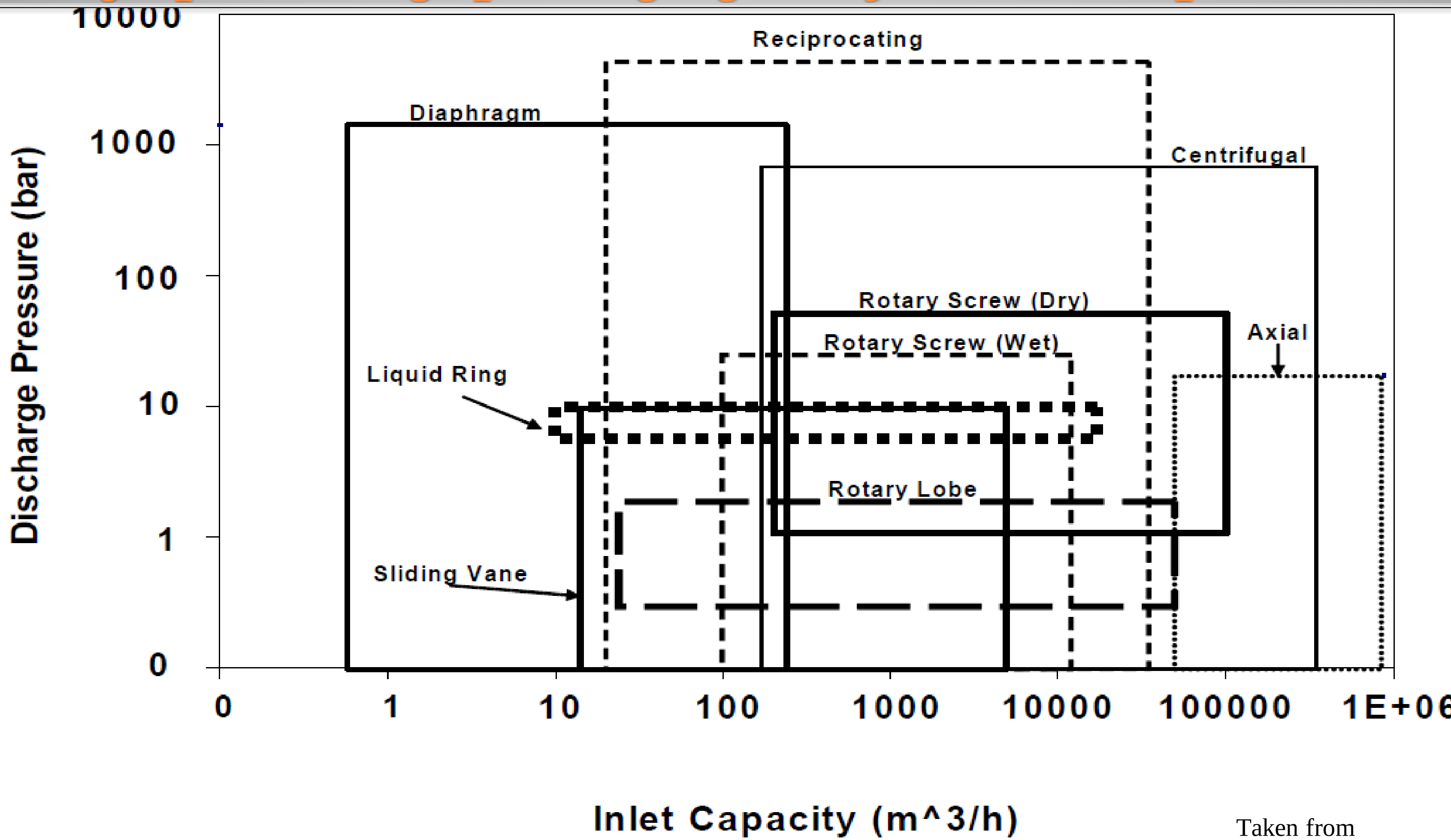
- It gets compressed by a piston driven in a reciprocating motion via a crankshaft,

- Discharged at higher pressure



How to select a particular type of compressor ?

Graph showing operating regions of various compressors



Taken from
PIP REEC001 Compressor Selection Guidelines

Table showing operating conditions of various compressors

Table 1b. Summary of Typical Operating Characteristics of Compressors (US Units)

	Inlet Capacity (acfm)	Maximum Discharge Pressure (psig)	Efficiency (%)	Operating Speed (rpm)	Maximum Power (HP)	Application
Dynamic Compressors						
Centrifugal	100 - 200,000	10,000	70 – 87	1,800 - 50,000	50,000+	Process gas & air
Axial	30,000 - 500,000	250	87 - 90+	1,500 - 10,000	100,000	Mainly air
Positive Displacement Compressors						
Reciprocating (Piston)	10 - 20,000	60,000	80 – 95	200 - 900	20,000	Air & process gas
Diaphragm	0.5 – 150	20,000	60 – 70	300 - 500	2,000	Corrosive & hazardous process gas
Rotary Screw (Wet)	50 - 7,000	350	65 – 70	1,500 - 3,600	2000	Air, refrigeration & process gas
Rotary Screw (Dry)	120 – 58,000	15 – 700	55 – 70	1,000 - 20,000	8,000	Air & dirty process gas
Rotary Lobe	15 - 30,000	5 - 25	55 – 65	300 - 4,000	500	Pneumatic conveying, process gas & vacuum
Sliding Vane	10 - 3,000	150	40 – 70	400 - 1,800	450	Vacuum service & process gas
Liquid Ring	5 - 10,000	80 - 150	25 – 50	200 - 3,600	400	Vacuum service & corrosive process gas

Taken from
PIP REEC001
Compressor Selection Guidelines

Advantages and Disadvantages of dynamic compressors

	Advantages	Disadvantages
Dynamic Compressors		
Centrifugal	•Wide operating range •High reliability •Low Maintenance	•Instability at reduced flow •Sensitive to gas composition change
Axial	•High Capacity for given size •High efficiency •Heavy duty •Low maintenance	•Low Compression ratios •Limited turndown

Advantages and disadvantages of positive displacement type compressor

	Advantages	Disadvantages
Positive displacement compressor		
Reciprocating	•Wide pressure ratios •High efficiency	•Heavy foundation required •Flow pulsation •High maintenance
Diaphragm	•Very high pressure •Low flow •No moving seal	•Limited capacity range •Periodic replacement of diaphragm
Screw	•Wide application •High efficiency •High pressure ratio	•Expensive •Unsuitable for corrosive or dirty gases

Selection Considerations

- **Safety**

  a. Limiting gas properties (e.g., decomposition, flammability, toxicity).

  b. Compatibility of process gas with materials of construction

  c. Over-pressure protection

- **Economics**

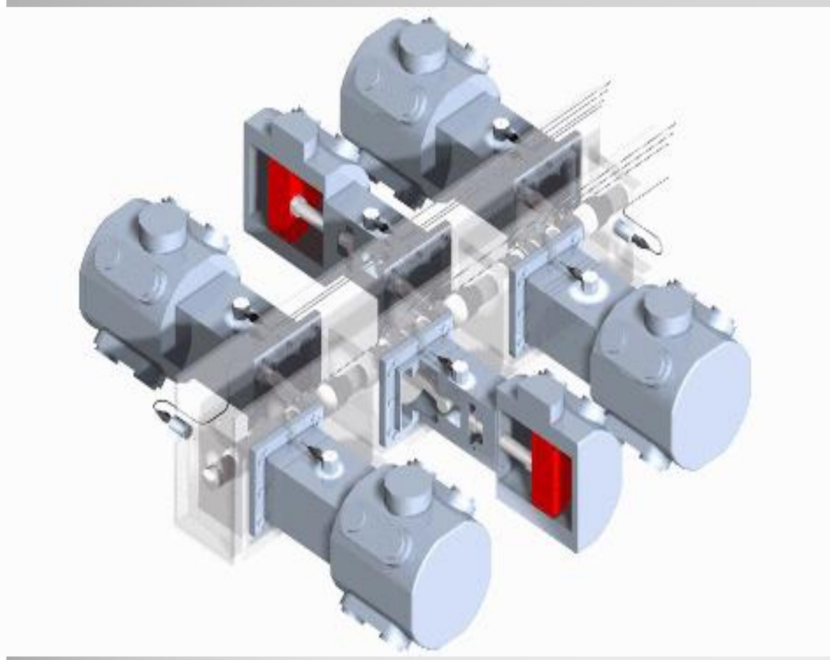
a. Life-cycle cost

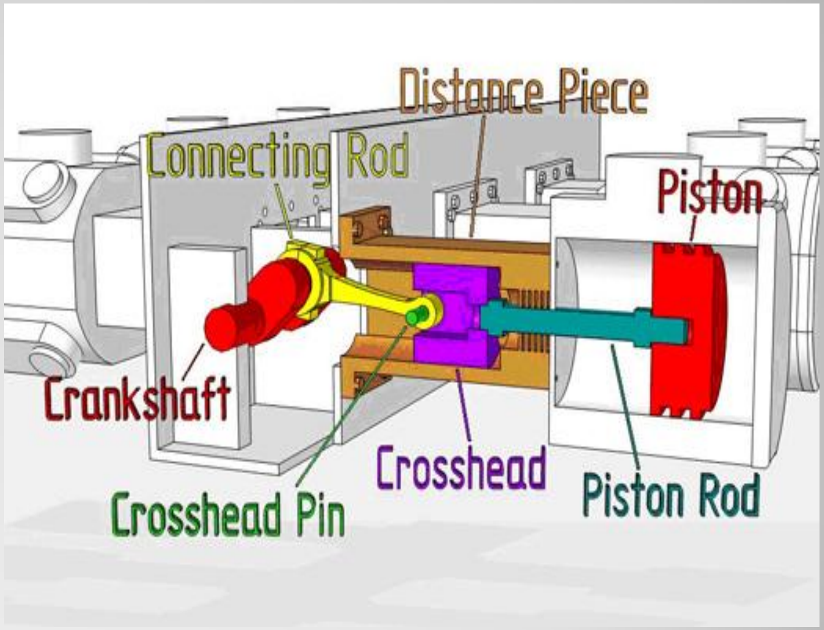
b. User and vendor capabilities and facilities for maintaining equipment

c. Expected equipment reliability

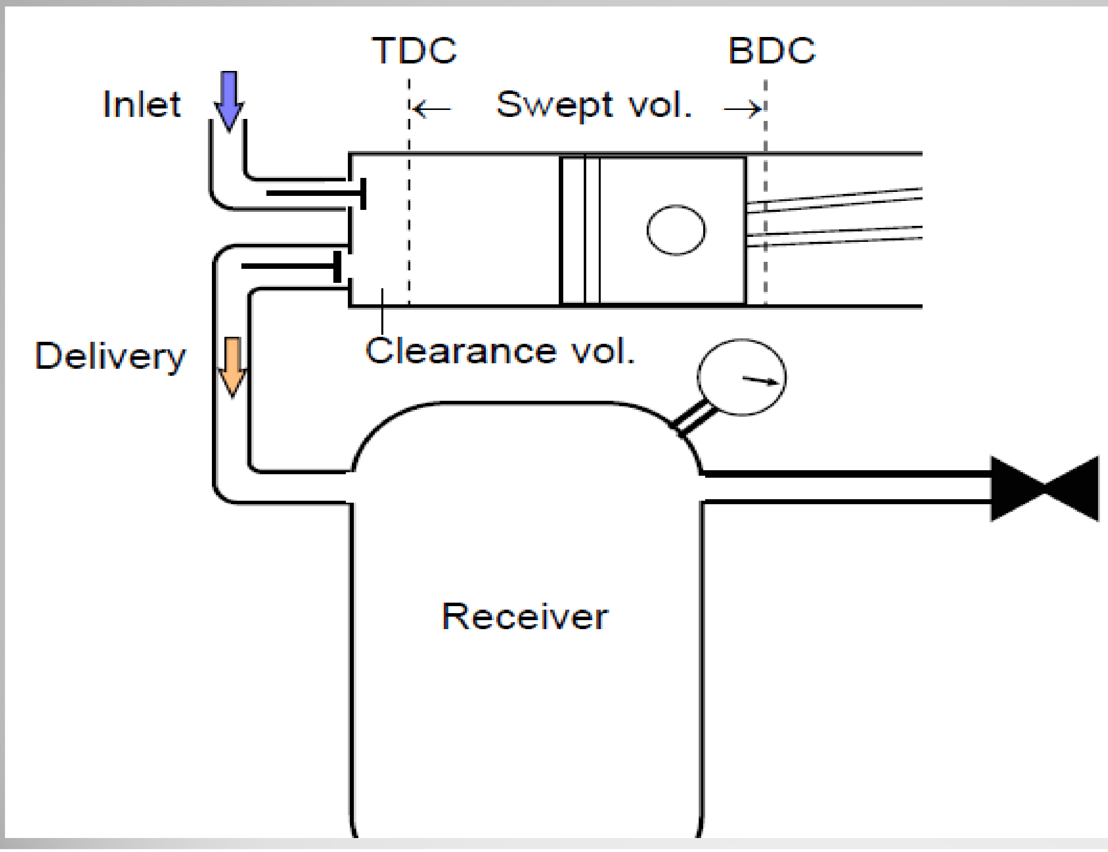
RECIPROCATING COMPRESSORS

Detailed Analysis





Block diagram of reciprocating compressor



It is a piston and cylinder device with (automatic) spring controlled inlet and exhaust valves

There is a **clearance** between the piston crown and the top of the cylinder.

Construction of Reciprocating Compressors

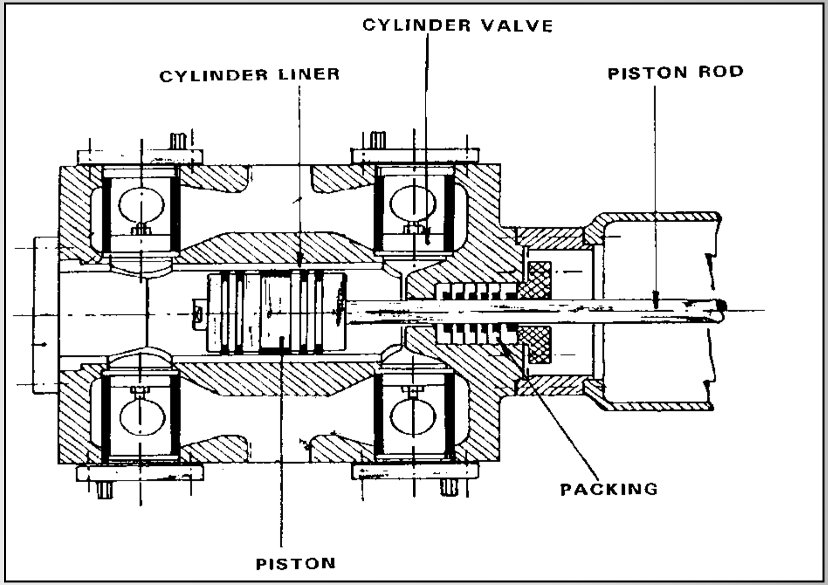
- Reciprocating compressors can be divided into two main groups.

  1. Gas end.
  2. Power end.

Different Parts Of Gas End

Various parts of gas end are:

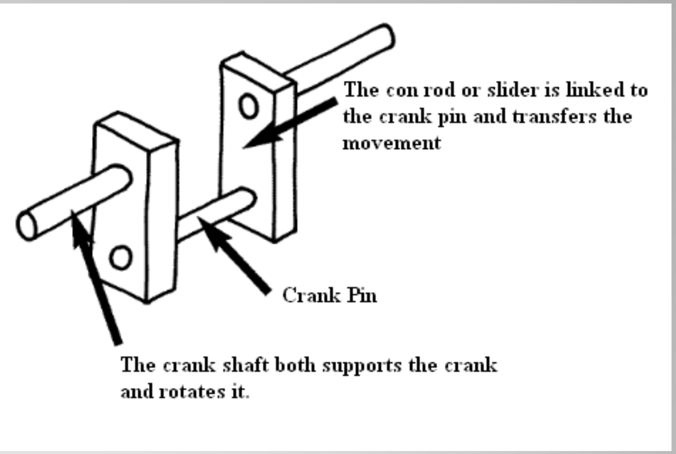
- Cylinder & liner
- Piston
- Piston rod
- Piston rod packing
- Piston rings
- Valves



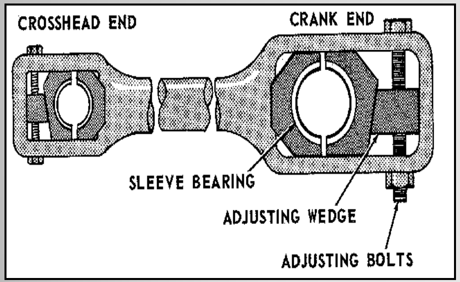
Different Parts of Power End

Various parts of power end are

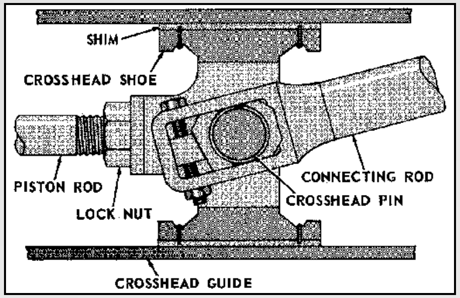
- Crank and Crankshaft
- Connecting rod
- crosshead



Crank and crankshaft



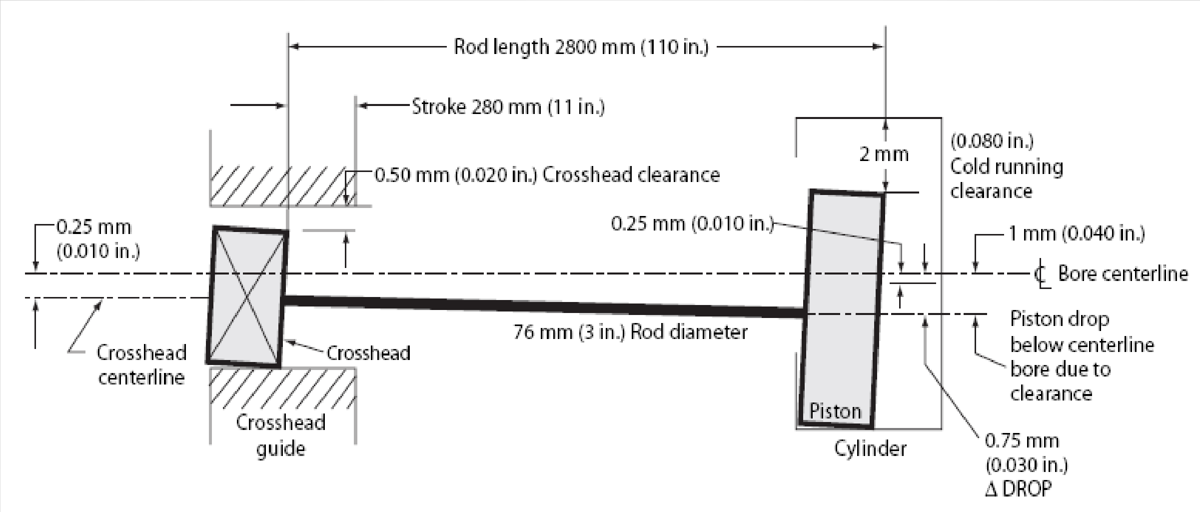
Connecting rod



crosshead

Rod Run Out

- Its a measurement criterion used to determine piston rod running alignment variations relative to cylinder crosshead alignment
- Runout must be checked in both horizontal and vertical directions



Taken from
API standard 618
Fifth Edition

Relief Valve

- Used to control or limit the pressure in a system or vessel
- The pressure is relieved by allowing the pressurized fluid to flow from an auxiliary passage out of the system
- Designed or set to open at a predetermined set pressure

Table showing margin pressure for relief valves

Rated Discharge Gauge Pressure (Each Stage)		**Minimum Relief Valve Set Pressure Margin above Rated Discharge Gauge Pressure**
bar	psig	
≤10	≤150	1 bar (15 psig)
>10 to 170	>150 to 2500	10%
>170 to 240	>2500 to 3500	8%
>240 to 345	>3500 to 5000	6%
>345	>5000	See footnote a

[a] For rated discharge gauge pressures above 345 bar (5000 psig), the relief valve setting shall be agreed on by the purchaser and the vendor.

Taken from
API standard 618
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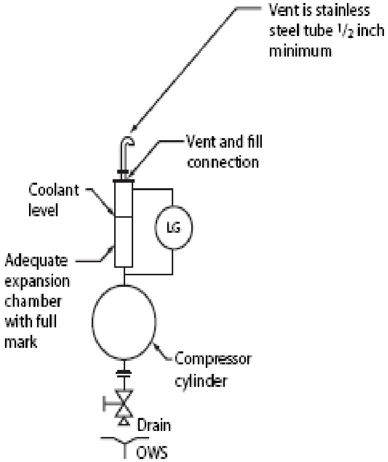
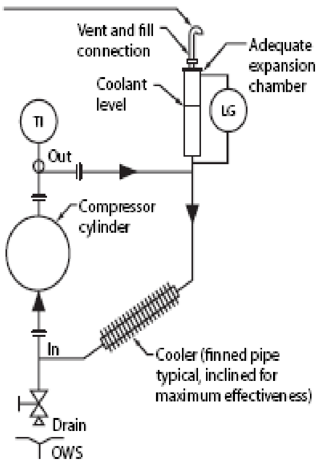
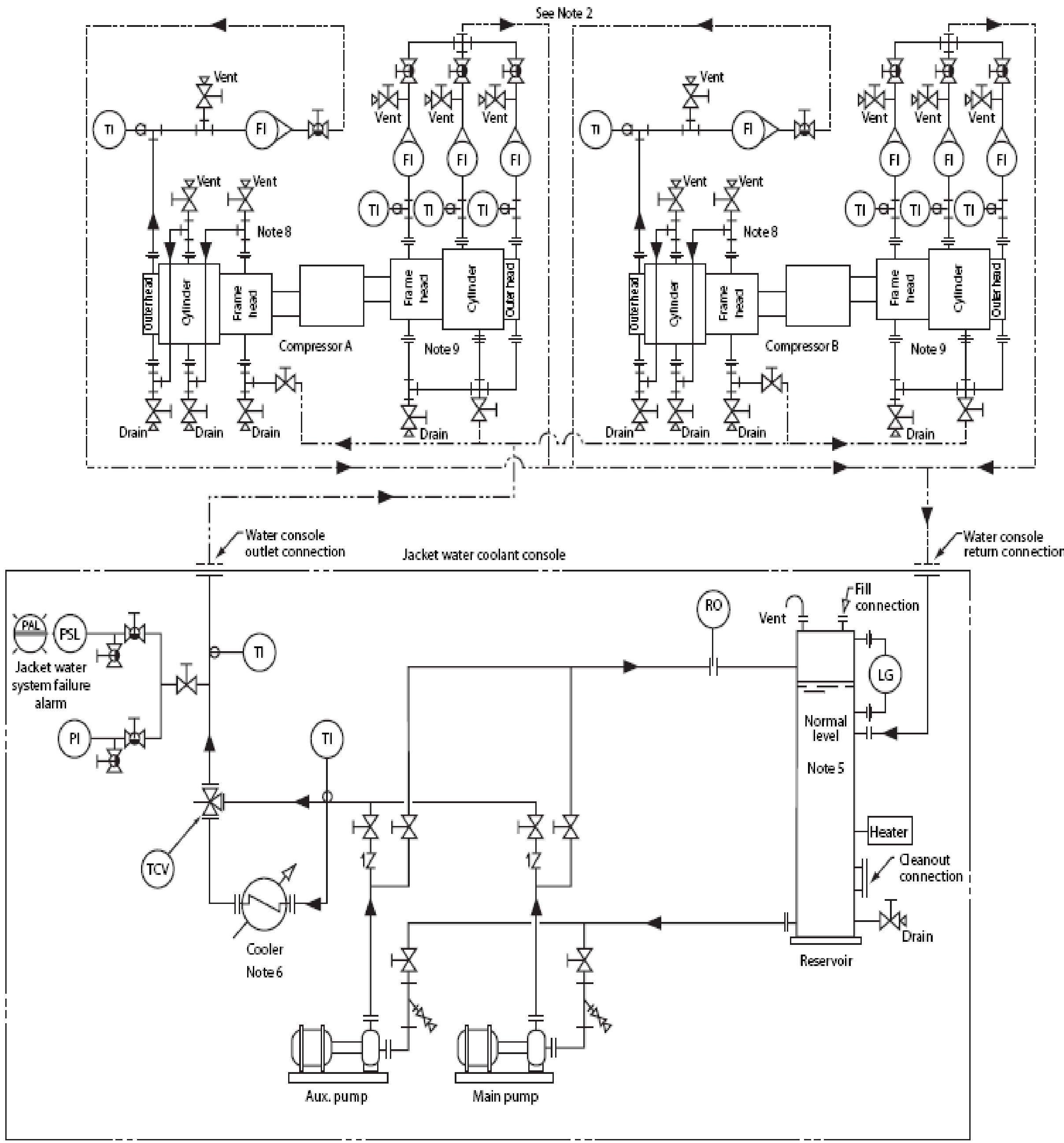
Cooling System



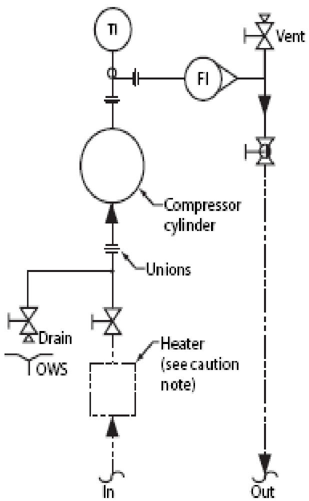
PLAN A
STATIC (STANDPIPE) SYSTEM



PLAN B
THERMOSYPHON SYSTEM



PLAN D
JACKET WATER COOLING SYSTEM



PLAN C
FORCED COOLING SYSTEM

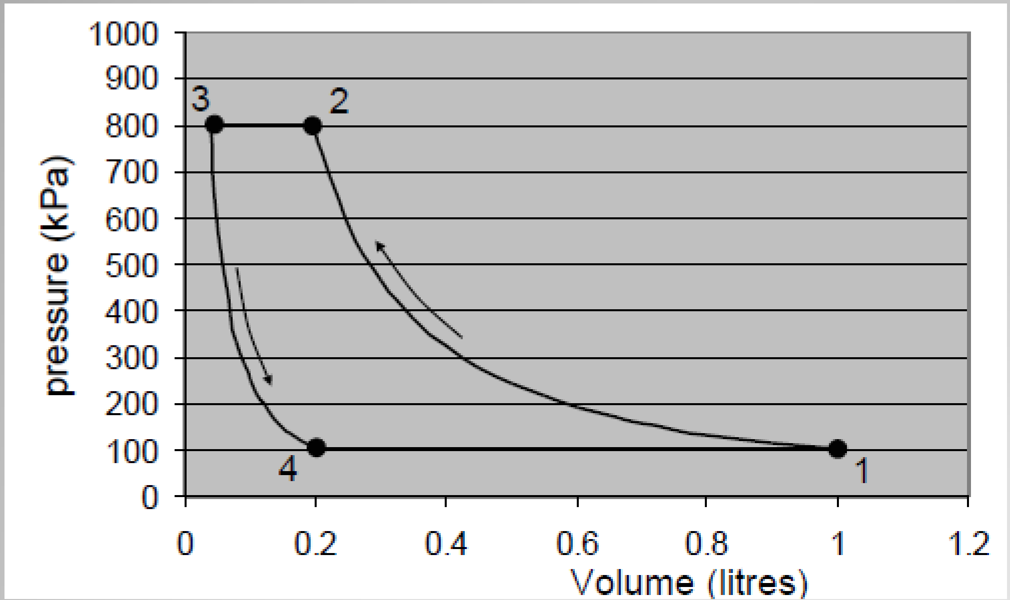
Notes:

1. Instrumentation shown is minimum required. The purchaser may wish to specify additional devices.
2. Flow through cylinders may be either series or parallel.
3. See 6.8.3 and 7.7.4.
4. Heaters used to preheat the cylinder cooling water (if needed to meet the requirements of 6.8.3.4.2 or 6.8.3.5.2) may be electric, hot water, or steam. They must be sized to take into account heat losses of surface areas of the cylinder, pipe, and fittings. Good judgment must be exercised so that heaters will not be undersized.
5. Normal level is above the highest point of the cylinder piping.
6. Cooler to have vents and drains on both shell and tube side.
7. The system shown is typical: more or less equipment may be furnished.
8. Series flow.
9. Parallel flow.

CAUTION: When jacket water temperature is to be controlled by steam sparging, the following precautions should be observed:

a. A silent (water-hammer-cushion type) steam sparger should be placed in the water inlet line to the jacket system.
b. The water flow rate must remain constant in accordance with the manufacturer's requirements.
c. The steam flow into the water should be regulated automatically to maintain the water jacket temperatures in accordance with 6.8.3.5.2.

Cycle Analysis



	process
1->2	compression
2->3	discharge
3->4	expansion
4->1	induction

$$\text{work per cycle} = \frac{n}{n-1}\, p_{in} V_{ind} \{ r_p^{\frac{n-1}{n}} - 1 \}$$

mass delivered = mass induced

$$\frac{p_2(V_2 - V_3)}{RT_2} = \frac{p_1(V_1 - V_4)}{RT_1}$$

Mass Flow Definition

Mass flow rate is the rate at which mass enters the inlet during suction

The mass flow rate is simply given by

$$\dot{m} = f_c \frac{P_1}{RT_1}(V_1 - V_4) = f_c \frac{P_2}{RT_2}(V_2 - V_3),$$

Where f_c is compressor rotational frequency in Hz

Volumetric efficiency

- It is Ratio of the actual volume of gas sucked by it to the theoretical volume that it could have sucked if clearance volume was not present.

$$\eta_V = \frac{V_1 - V_4}{V_1 - V_3}.$$

- It is also defined as ratio of intake mass flow rate to the theoretical swept volume mass flow rate

$$\dot{m}_S = f_c \frac{P_1 V_S}{R T_1}$$

$$\eta_V = \frac{\dot{m}}{\dot{m}_S}.$$

Work and Power Definitions

The theoretical work required for gas compression, W, calculated by integrating the PV curve is

$$\dot{W} = \begin{cases} f_c \dfrac{n}{n-1} P_1 (V_1 - V_4) \left[\left(\dfrac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] & n \neq 1, \\ f_c P_1 (V_1 - V_4) \ln \left(\dfrac{P_2}{P_1} \right) & n = 1. \end{cases}$$

Where n is polytropic exponent

Adiabatic And Isothermal Power

Power supplied in adiabatic compression

$$\dot{W}_{ad,e} = \dot{m}_e c_p T_1 \left[\left(\frac{P_2}{P_1} \right)^{2/7} - 1 \right].$$

Power supplied in isothermal compression

$$\dot{W}_{iso,e} = \dot{m}_e R T_1 \ln \left(\frac{P_2}{P_1} \right).$$

Shaft Power And Actual Power

Shaft power is the experimentally measured power required to run a compressor

It is given by

$$\dot{W}_{shaft,e} = \dot{W}_{actual,e} + \dot{W}_{friction},$$

Actual power is defined as the power required for gas compression only . It is power integrated from an experimentally measured PV curve

Various types of efficiencies

Adiabatic efficiency

$$\eta_{ad,e} = \frac{\dot{W}_{ad,e}}{\dot{W}_{actual,e}},$$

Mechanical efficiency

$$\eta_{mech} = \frac{\dot{W}_{actual,e}}{\dot{W}_{shaft,e}},$$

Isothermal efficiency

$$\eta_{iso,e} = \frac{\dot{W}_{iso,e}}{\dot{W}_{actual,e}},$$

Overall efficiency

$$\eta_{overall,ad,e} = \frac{\dot{W}_{ad,e}}{\dot{W}_{shaft,e}}$$

Thank You