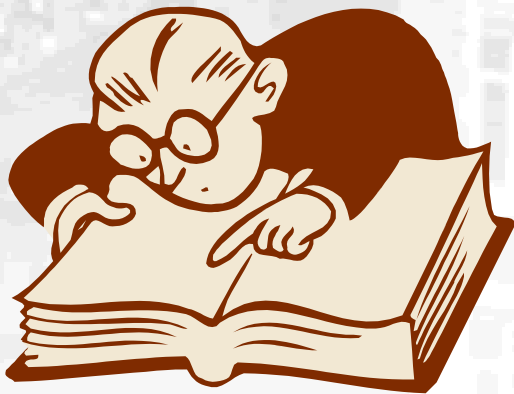




Chapter10. Compressors





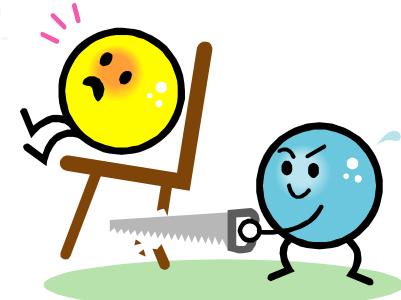
Chapter10. Compressors

- ◆ Reciprocating Compressors
- ◆ Scroll Compressors
- ◆ Screw Compressors
- ◆ Turbo Compressors
- ◆ Roller Type Compressors
- ◆ Vane Type Compressors
- ◆ Inverter Technology and Inverter driven Compressors
- ◆ REFERENCES



Main Types of Compressors

- ◆ The compressor is the heart of a mechanical refrigeration system.
- ◆ There is the need for many types of compressors because of the variety of refrigerants and the capacity, location and application of the systems.
- ◆ Generally, the compressor can be classified into two basic types: positive displacement and roto-dynamic.



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- ◆ As shown in Fig.10-1, the positive displacement family includes reciprocating compressors and rotary compressors.
- ◆ According to the movement of compression components, the rotary compressors can be further classified as scroll, screw, roller-type and vane type.
- ◆ The roto-dynamic compressor which is also called centrifugal or turbo compressor, is classified as radial flow and axial flow types according to the flow arrangement.

Chapter 10. Compressors

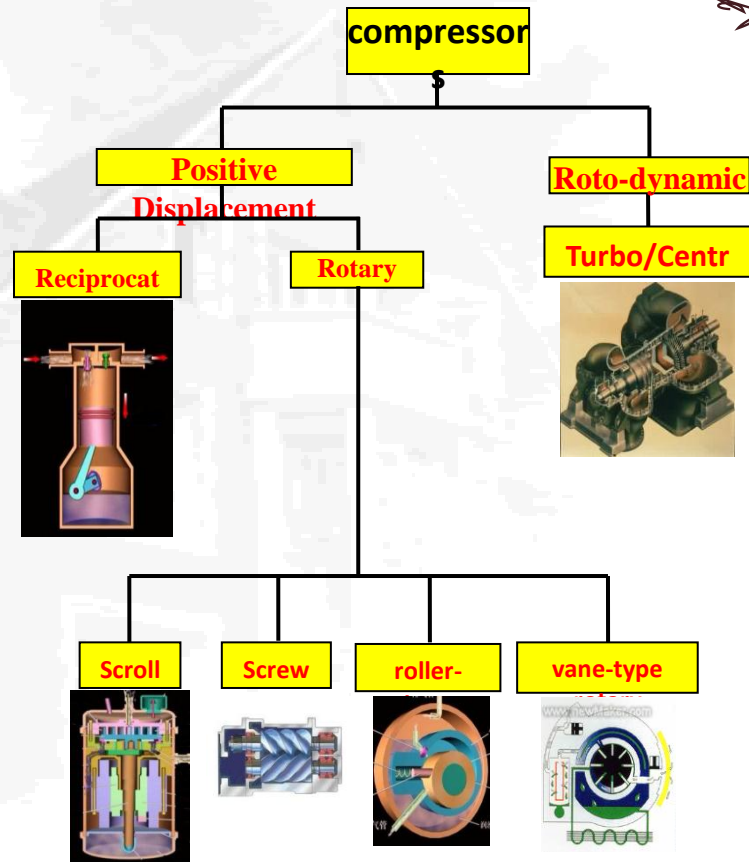
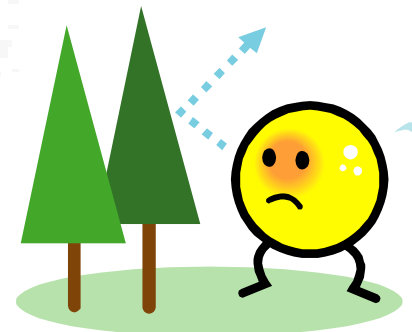


Fig.10-1 .The classification of compressors



10-1. Reciprocating Compressors



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1. The Construction of Reciprocating Compressors

- ◆ Reciprocating compressor compresses the vapor by moving piston in cylinder to change the volume of the compression chamber, as shown in Fig.10-2.
- ◆ The main elements of a reciprocating compressor include piston, cylinder, valves, connecting rod, crankshaft and casing.

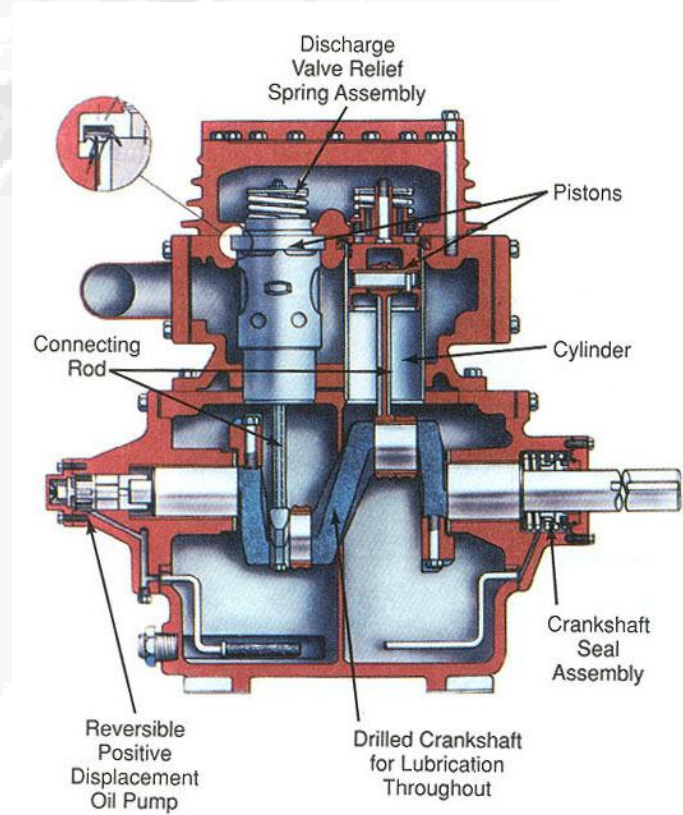


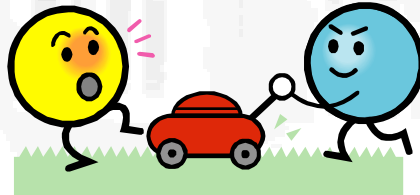
Fig.10-2 Cutaway view of small two-cylinder reciprocating compressor^[12]



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Chapter 10. Compressors

- ◆ A wide variety of compressor designs can be used on the separable unit including horizontal, vertical, semi-radial and V-type.
- ◆ However, the most common design is the horizontal, balanced-opposed compressor because of its stability and reduced vibration.





2. Principle of Operation

- ◆ Fig. 10-3 shows single-acting piston actions in the cylinder of a reciprocating compressor.
- ◆ The piston is driven by a crank shaft via a connecting rod.
- ◆ At the top of the cylinder are a suction valve and a discharge valve.
- ◆ A reciprocating compressor usually has two, three, four, or six cylinders in it.

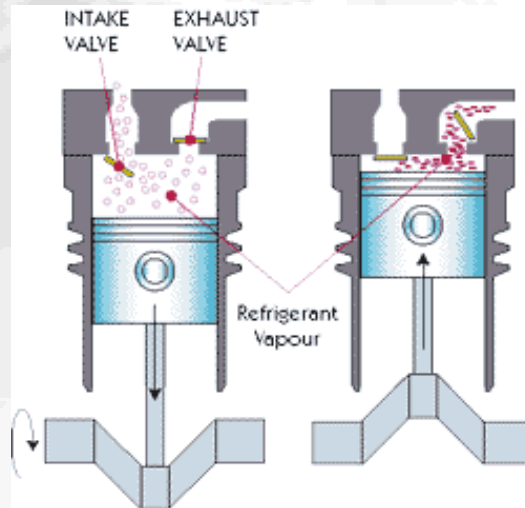


Fig.10-3 The compression cycle [13]



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- The states of the refrigerant in a reciprocating compressor can be expressed by four lines on a PV diagram as shown in Fig.10-4.

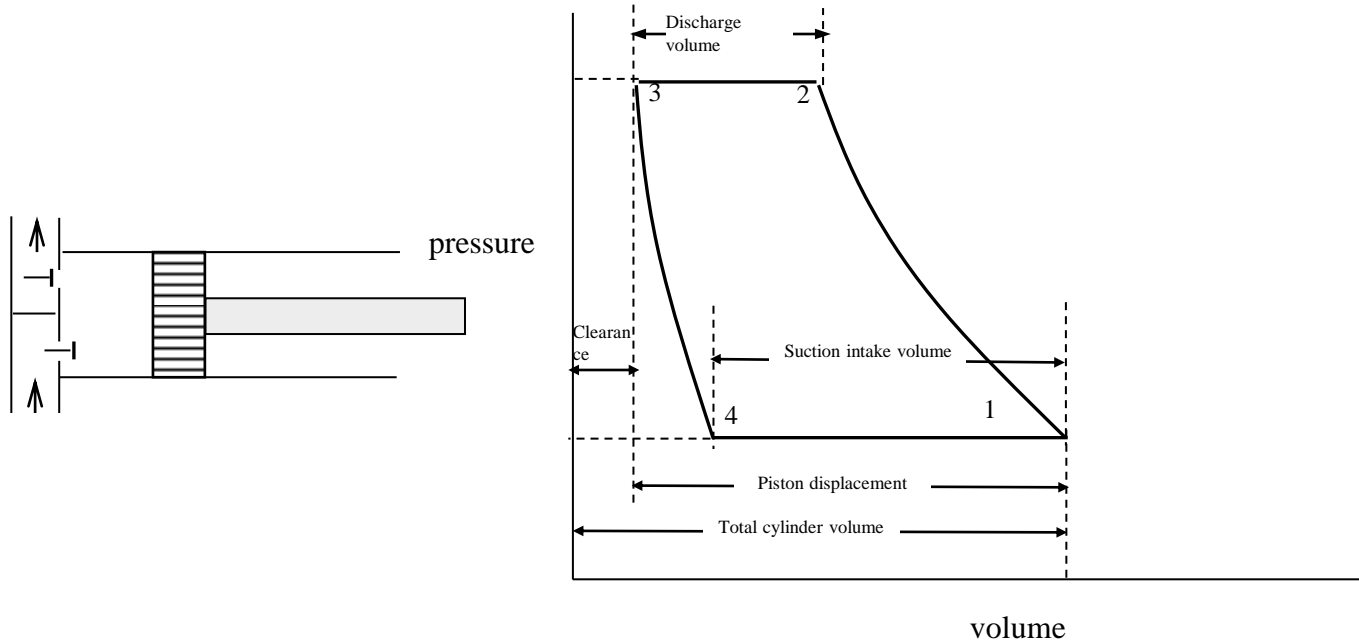


Fig.10-4 Principle of operation of a reciprocating compressor



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Line 4-1:

- ◆ The suction valve opens at point 4.
- ◆ As the piston travels toward the bottom dead center, the volume of the cylinder increases and the vapor flows into the cylinder.
- ◆ The pressure inside the cylinder is slightly less than suction line pressure. The pressure difference pushes the valve open on during the suction stroke.



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Line 1-2:

- ◆ The suction valve returns to close under the spring force as the vapor pressure across the valve is equalized when the piston has reached the bottom dead center.
- ◆ The piston then changes the moving direction at point 1.
- ◆ The cylinder volume decreases as the piston moves towards the top dead center, raising the pressure inside the cylinder.
- ◆ The shape of the compression line (Line 1-2) is determined by the properties of the refrigerant and the compression exponent.



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Line 2-3:

- ◆ At point 2, the pressure inside the cylinder has become slightly greater than discharge line pressure.
- ◆ This causes the valve opening allowing the gas to flow out of the cylinder.
- ◆ The volume continues to decrease toward point 3, maintaining a sufficient pressure difference across the discharge valve to hold it open.



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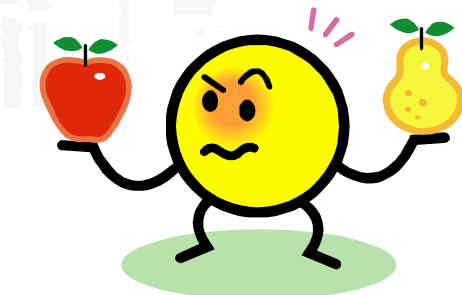
Line 3-4:

- ◆ At point 3, the piston reaches the top dead center and reverses direction.
- ◆ At top dead center, as the piston comes to a complete stop prior to reversing direction, the pressure across the valve is equal.
- ◆ So, the discharge valve is closed.
- ◆ As the piston moves towards point 4, the volume increases and the pressure decreases in the cylinder.
- ◆ The gas trapped in the cylinder expands as the volume increases until to point 4.
- ◆ At point 4, the gas pressure inside the cylinder becomes less than the suction line pressure, so the suction valve opens again.
- ◆ The cycle then starts over again.
- ◆ The shape of the re-expansion line (Line 3-4) is dependent on the same compression exponent that determines the shape of the compression line.



3. Clearance Space and Clearance Fraction

- ◆ In order to prevent the piston from striking the valve plate, a clearance volume must be allowed at the end of the piston compression stroke.
- ◆ Manufacturing design tolerances require this to allow for reasonable bearing wear, which would effectively lengthen the stroke.
- ◆ The space between the bottom and top of the valve assembly adds extra to the clearance volume.





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- ◆ The clearance volume will cause the vapor not being completely discharged after compression.
- ◆ The remaining vapor trapped in the clearance volume will re-expand in the next suction stroke.
- ◆ As a result, the volume of the vapor sucked in by the compressor in each stroke is less than the volume the piston swept through.
- ◆ So the compressor volumetric displacement must be greater than the volume of vapor to be drawn in.
- ◆ Other factors that cause reduction to the compressor capacity are:
- ◆ pressure drop through valves which reduces the amount of vapor sucked or discharged; vapor leaks around closed valves or between the piston and cylinder; refrigerant evaporating out of oil in the cylinder space; the vapor heated by the cylinder walls, thus, increasing its specific volume.

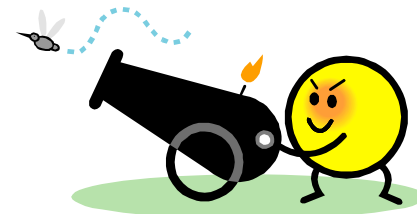


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- ◆ The performance of reciprocating compressors can be described by volumetric efficiency.
- ◆ Here we only consider the actual and the clearance volumetric efficiencies. The actual volumetric efficiency is defined as

$$\eta_{va} = \frac{\text{volume} \cdot \text{flow} \cdot \text{rate} \cdot \text{entering} \cdot \text{compressor}, m^3/s}{\text{displacement} \cdot \text{rate} \cdot \text{of} \cdot \text{compressor}, m^3/s}$$





4. Slugging of Liquid

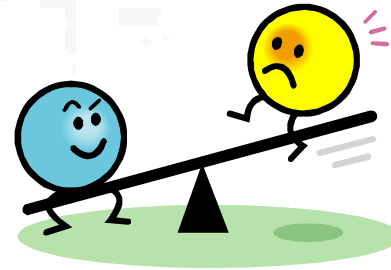
- ◆ Great care should be taken to prevent excess liquid refrigerant from entering reciprocating compressors.
- ◆ When large quantities of liquid suddenly enter the compressor for a short period of time it is called slugging.
- ◆ The force at the end of the discharge stroke could easily break valves and even connecting rods if there is liquid slugging in the cylinder.



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- ◆ A related problem caused by slugging is excess dilution of the lubricating oil by the refrigerant.
- ◆ This may result in ineffective lubrication and rapid wear of bearing or the piston and cylinder.
- ◆ When a compressor is not operating, the pressure in the crankcase is relatively high and the oil is cold.





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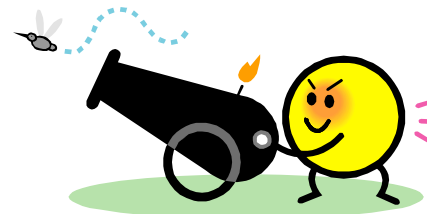
Chapter 10. Compressors

- ◆ Some kinds of refrigerants vapor readily dissolves in the oil, this reduces the crankcase vapor pressure and cause a further pressure difference that enhances the migration of refrigerant vapor.
- ◆ When the compressor starts, the pressure in the crankcase suddenly drops and the refrigerant boils rapidly out of the oil.
- ◆ The vapor bubbles formed cause a foaming or surge of oil and liquid refrigerant out of the crankcase.
- ◆ This may result in liquid slugs entering the compressor on start-up, possibly causing damage.



5. Open, Semi-hermetic and Hermetic Reciprocating Compressors

- ◆ A compressor whose crankshaft extends through the compressor housing so that a motor can be externally coupled to the shaft is called an open-type compressor.
- ◆ A seal must be used where the shaft comes through the compressor housing to prevent refrigerant vapor from leaking out or air from leaking in if the crankcase pressure is lower than atmospheric.





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- ◆ The disadvantage of the hermetic compressors is that it is not serviceable without cutting open the shell.
- ◆ For some hermetic compressors, the cylinder heads are usually removable so that the valves and pistons can be serviced.
- ◆ These compressors are called semi-hermetic compressor (Fig.10-7).
- ◆ It has a cylinder head, and a valve plate which is accessible from the outside by removing the head bolts.
- ◆ The motor stator is either pressed or bolted to the compressor body and the rotor is mounted directly on the compressor crankshaft.
- ◆ The semi-hermetic compressor is made in larger sizes than the hermetic ones.

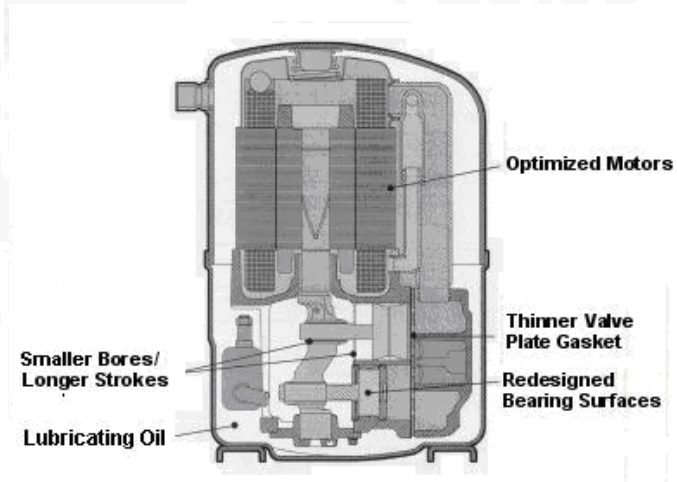
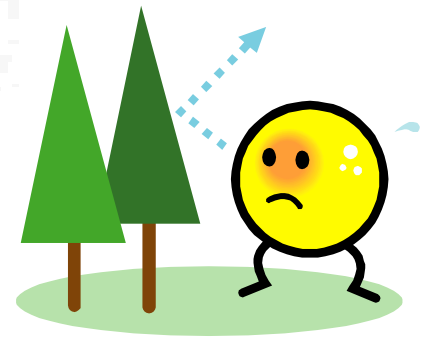


Fig 10-6 A cutting view of the hermetic compressor [14]



10-2. Scroll Compressors





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- ◆ The scroll compressor is a rotary, positive displacement compressor which is used in residential air-conditioning and heat pump systems.
- ◆ A scroll compressor is illustrated in Fig.10-8.
- ◆ It uses two interleaved scrolls to compress fluids.
- ◆ The fundamental shape of a scroll may be involute, archimedean spiral, or hybrid curves.
- ◆ An involute is a curve traced by a point on a thread kept taut as it is unwound from another curve, which is the same profile used in gear teeth.
- ◆ The curve that the thread is unwound from, that is, used for scrolls, is a circle.
- ◆ The radius of the circle is the generating radius.

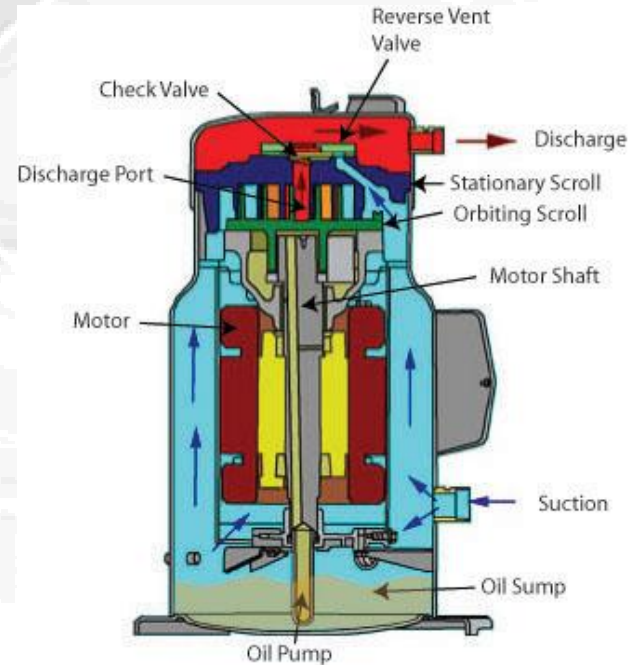


Fig. 10-8 Cutaway view of a scroll compressor [12]

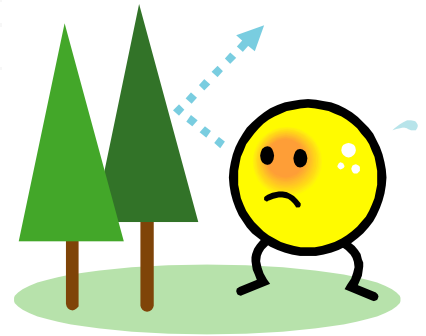


2. Advantages and limitation

- ◆ Scroll compressors can deliver high compression pressure ratio.
- ◆ The pressure ratio is increased by adding spiral wraps to the scroll.
- ◆ Scroll compressors are true rotary motion and can be dynamically balanced for smooth, vibration-free, quiet operation.
- ◆ They have no inlet or discharge valves to break or make noise and no associated valve losses.
- ◆ Although scroll compressors continue to expand into larger and smaller size compressor market, some weak points of scroll compressors could limit this trend.
- ◆ One of them is that the effect of leakage at the apex of the crescent shaped pockets could become so significant in small size compressors that scroll compressors can not be constructed much smaller.



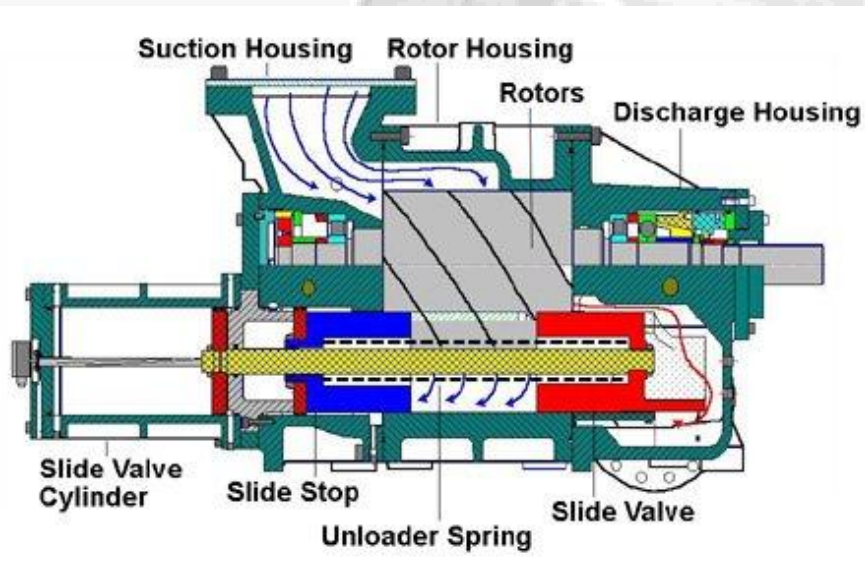
10-3. Screw Compressors



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1. The Construction and operation of Screw Compressors



- ◆ Screw compressors are also belong to the positive displacement compressor family.
- ◆ In screw compressors, the compression is accomplished by the enmeshing of two mating helically grooved rotors suitably housed in a cylinder equipped with appropriated inlet and discharge ports (Fig.10-10).

Fig. 10-10 The Construction of Screw Compressors [17]



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- ◆ The rotors are the main components of the screw compressor.
- ◆ A cross view of the two principle rotating elements of the screw compressor is shown in Fig.10-11.
- ◆ The male rotor is normally the driving rotor and consists of a series of lobes (usually four) along the length of the rotor that mesh with similarly formed corresponding helical flutes (usually six) on the female rotor.

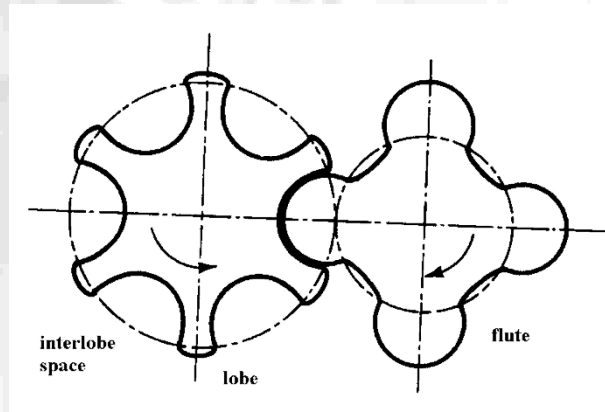


Fig.10-11 Cross section of the two rotors of a screw compressor



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- ◆ As the rotors turn, vapor is drawn through the inlet opening to fill the space between the male lobe and the female flute.
- ◆ As the rotors continue to rotate, the vapor is moved past the suction port and sealed in the interlobe space.
- ◆ The vapor so trapped in the interlobe space is moved both axially and radially and is compressed by direct volume reduction as the enmeshing of the lobes progressively reduced the space occupied by the vapor.

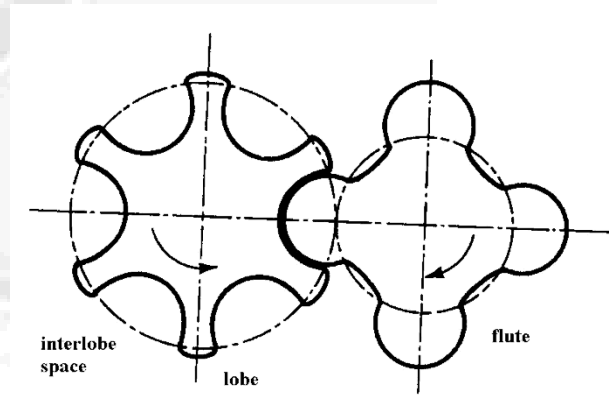


Fig.10-11 Cross section of the two rotors of a screw compressor



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- ◆ Compression of the vapor continues until the interlobe space communicates with the discharge ports in the cylinder and the compressed vapor leaves the cylinder through these ports.
- ◆ The length and diameter of the rotors determine the capacity and the discharge pressure.
- ◆ The longer the rotors, the higher the pressure.
- ◆ The larger the diameter of the rotors, the greater the capacity.

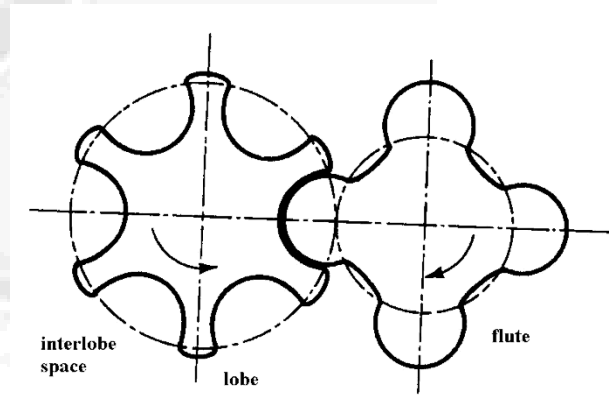


Fig.10-11 Cross section of the two rotors of a screw compressor



2. Advantages of the screw compressor

- ◆ Screw compressors are reliable and compact.
- ◆ Compressor rotors can be manufactured with very small clearances at an economic cost.
- ◆ In many applications, the screw compressor offers significant advantages over reciprocating compressors.
 1. Its fewer moving parts mean less maintenance. There is no need to service the items such as compressor valves, packing and piston rings, and the associated downtime for replacement.
 2. The absence of reciprocating inertial forces allows the screw compressor to run at high speeds. So, it could be constructed more compact.



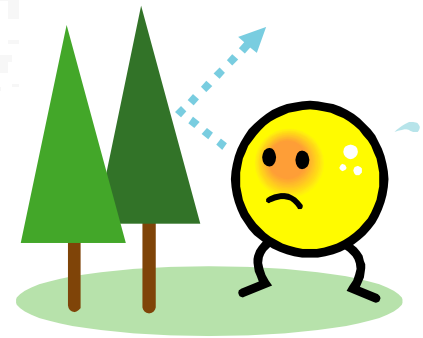
Chapter 10. Compressors

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3. The continuous flow of cooling lubricant allows much higher single-stage compression ratios.
 4. The compactness tends to reduce package costs.
 5. Low vibration due to reducing or eliminating pulsations by screw technology
 6. Higher speeds and compression ratios help to maximize available production horsepower.
- ◆ A major problem with screw compressors is that the pressure difference between entry and exit creates very large radial and axial forces on the rotors whose magnitude and direction is independent of the direction of rotation.



10-4. Turbo Compressors





1. The construction and operation of turbo Compressors

- ◆ “Turbo compressor” as understood in refrigeration industry usually refers to a centrifugal compressor.
- ◆ A schematic diagram of the centrifugal compressor is shown in Fig.10-14.
- ◆ Vapor enters axially at the centre wheel 1 and flows through the passage 3 in the impeller 2.
- ◆ The pressure and absolute velocity of the vapor rises when it passes the impeller because of the centrifugal force.
- ◆ In the stationary diffuser 4 the flow of vapor is decelerated to further raise the vapor pressure.
- ◆ The compressed vapor is collected in the scroll or volute 5 and discharged to the delivery pipe 6.

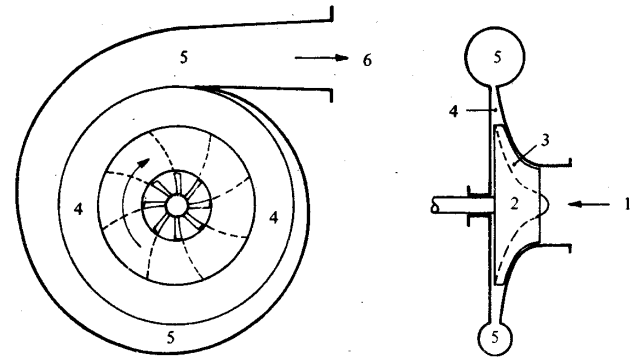
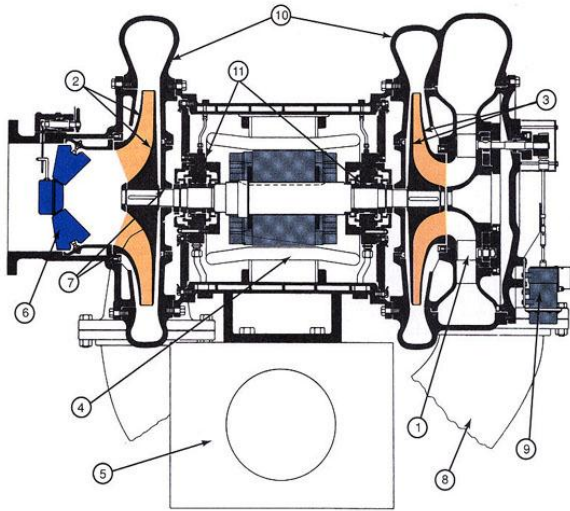


Fig.10-14 Schematic diagram of the centrifugal compressor
 1-eye, inlet cavity. 2-impeller (wheel). 3-blades (or vanes).
 4-diffuser. 5-volute (scroll). 6- outlet cavity.



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- ◆ The major elements of a centrifugal compressor are shown in Fig.10-13.
- ◆ A turbo compressor consists of a housing and at least one rotor of which the shaft is pivotally supported by the housing, with a free shaft end and with a rotor connected with the other end of the rotor shaft.

Fig. 10-13 Two-stage centrifugal compressor
 1-Second-stage variable inlet guide vane. 2-First-stage impeller.
 3-Second-stage impeller. 4-Water-cooled motor.
 5-Base, oil tank, and lubricating oil pump assembly.
 6-First-stage guide vanes and capacity control.
 7-Labyrinth seal. 8-Cross-over connection. 9-Guide vane actuator.
 10-Volute casing. 11-Pressure-lubricated sleeve bearing. The discharge opening is not shown.



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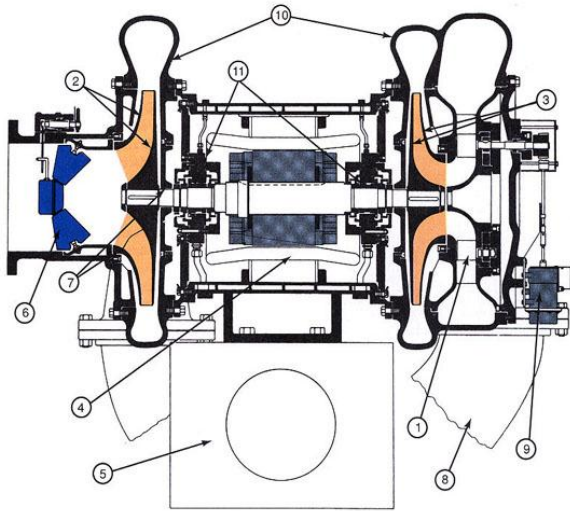


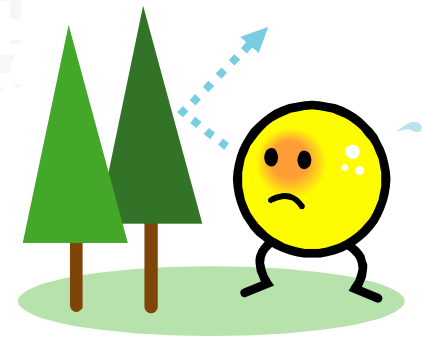
Fig. 10-13 Two-stage centrifugal compressor
 1-Second-stage variable inlet guide vane. 2-First-stage impeller.
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 5-Base, oil tank, and lubricating oil pump assembly.
 6-First-stage guide vanes and capacity control.
 7-Labyrinth seal. 8-Cross-over connection. 9-Guide vane actuator.
 10-Volute casing. 11-Pressure-lubricated sleeve bearing. The discharge opening is not shown.

- ◆ The free end of the rotor shaft facing away from the rotor projects into a pressure chamber connected with the housing, and is acted upon by a pressurized fluid whose force of pressure compensates for the force of the axial thrust acting on the rotor.
- ◆ Thus, the starting friction of the compressor is lower and drive motors of lower output target can be utilized.





10-5. Roller Type Compressors





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- The roller type compressor, which is also called as “blade-type rotary compressor” by some companies, compresses gases by revolving a steel cylindrical roller on an eccentric shaft which is mounted concentrically in a cylinder (Fig.10-15).

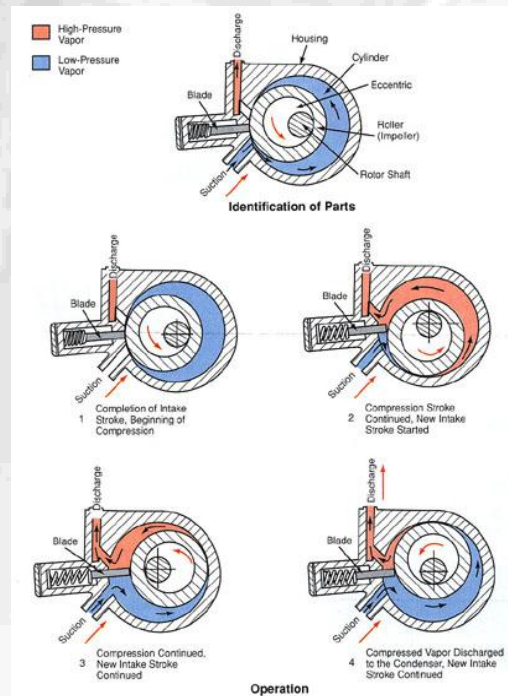


Fig.10-15 Roller-type compressor [18]



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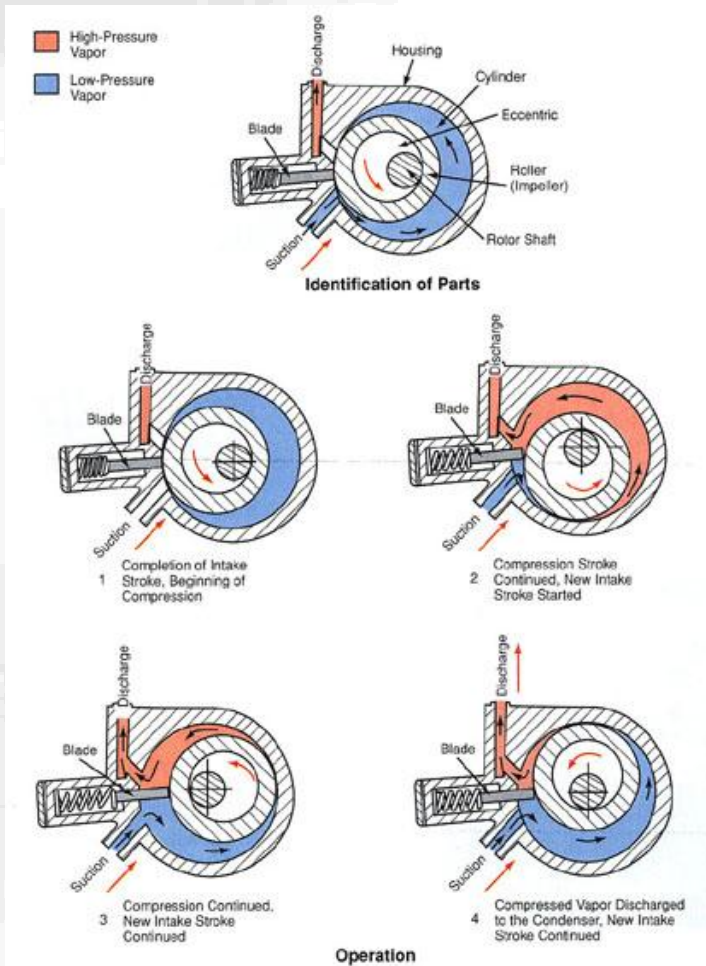


Fig.10-15 Roller-type compressor [18]

- ◆ Because of the shaft being eccentric, the cylinder roller is eccentric with the cylinder as well.
- ◆ The cylinder roller touches the cylinder wall at the point of minimum clearance.
- ◆ As the shaft turns, the roller rolls around the cylinder wall in the direction of shaft rotation, always maintaining contact with the cylinder wall.



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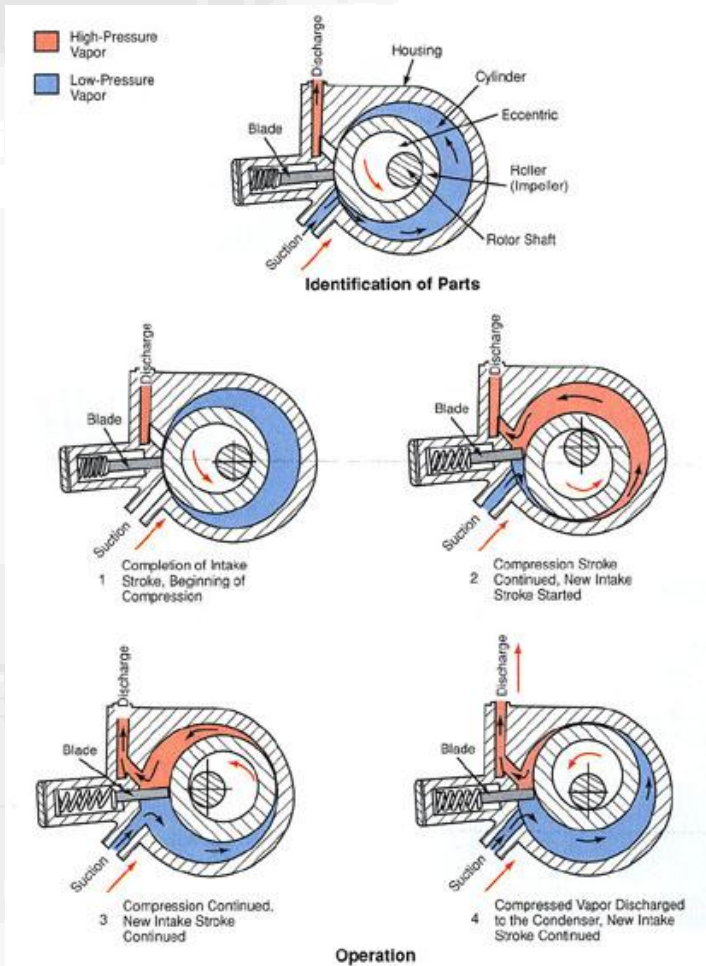


Fig.10-15 Roller-type compressor [18]

- ◆ With relation to the camshaft, the inside surface of the cylinder roller moves counter to the direction of shaft rotation in the manner of a crankpin bearing.
- ◆ A spring-loaded blade mounted in a slot in the cylinder wall, bears firmly against the roller at all times.
- ◆ The blade moves in and out of the cylinder slot to follow the roller as the latter rolls around the cylinder wall.



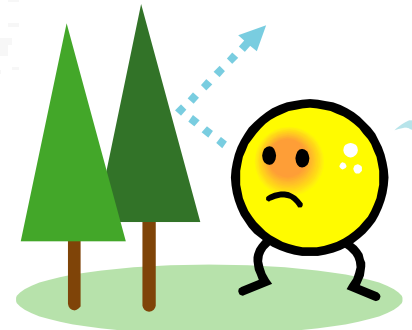
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- ◆ Cylinder heads or end-plates are used to close the cylinder at each end and to serve as supports for the camshaft.
- ◆ Both the roller and blade extend the full length of the cylinder with only working clearance being allowed between these parts and the end-plates.
- ◆ Suction and discharge ports are located in the cylinder wall near the blade slot, but on opposite sides.
- ◆ The flow of vapor through both the suction and discharge ports is continuous, except for the instant that the cylinder at the point of contact between the blade and roller on one side and between the roller and cylinder wall on the other side.



10-6. Vane Type Compressors





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- The vane type compressor, which is also called as “sliding vane compressor” or “multi-vane compressor” by some companies, employs a series of rotating vanes or blades which are installed equidistant around the periphery of a slotted rotor (Fig.10-16).

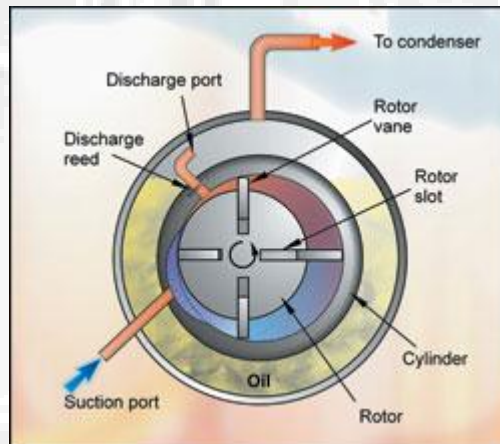


Fig.10-16 vane-type rotary compressor.^[19]



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- ◆ The rotor shaft is mounted eccentrically in a steel cylinder so that the rotor nearly touches the cylinder wall on one side, the two being separated only by an oil film at this point.
- ◆ Directly opposite this point the clearance between the rotor and the cylinder wall is maximum.
- ◆ Heads or end-plates are installed on the ends of the cylinder and to hold the rotor shaft.
- ◆ The vanes move back and forth radially in the rotor slots as they follow the contour of the cylinder wall when the rotor is turning.
- ◆ The vanes are held firmly against the cylinder wall by action of the centrifugal force developed by the rotating rotor.
- ◆ In some instances, the blades are spring-loaded to obtain a more positive seal against the cylinder wall.

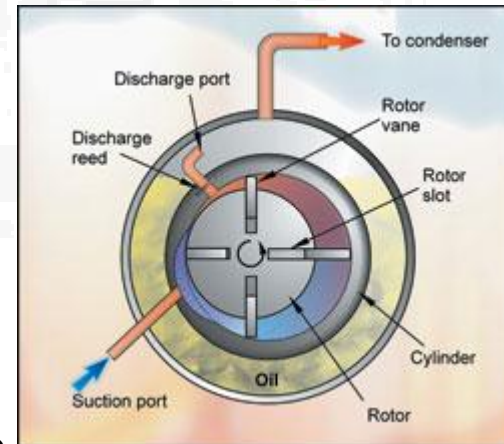


Fig.10-16 vane-type rotary compressor.[19]

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- ◆ The suction vapor drawn into the cylinder through suction ports in the cylinder wall is entrapped between adjacent rotating vanes.
- ◆ The vapor is compressed by the reduction in volume that results as the vanes rotate from the point of maximum rotor clearance to the point of minimum rotor clearance.
- ◆ The compressed vapor is discharged from the cylinder through ports located in the cylinder wall near the point of minimum rotor clearance.

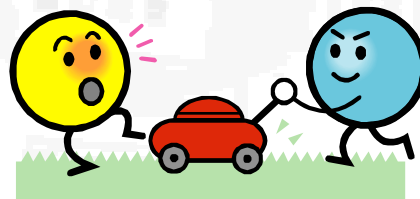


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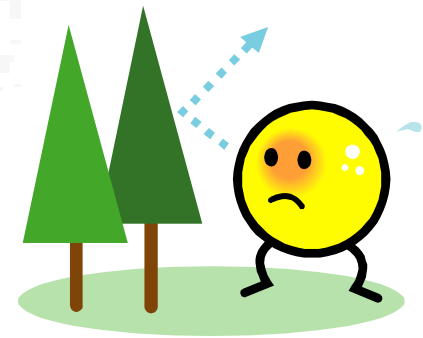


- ◆ The discharge ports are so located as to allow discharge of the compressed vapor at the desired point which is the design point of the compressor during the compressing process.
- ◆ Operation of the compressor at compression ratios above or below the design point will result in compression losses and increasing power consumptions.
- ◆ Current practice limits compression ratios to a maximum of 7 to 1.





10-7. Inverter Technology and Inverter driven Compressors





1. The advantages of inverter compressors

- ◆ It is desirable to have an air-conditioner to operate at low noise, constant temperature control, all-day running, low frequency compensation and instantly achieving the set temperature.
- ◆ The emergency of inverter compressor makes them achievable in an energy efficient way.
- ◆ The inverter compressor can reduce power consumption, power surges (from starting AC motors), and deliver constant pressure.
- ◆ Currently, these advantages are achieved with the technology being heavy expense associated with the drive and the sensitivity of these drives, particularly, to heat and moisture.



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2. Inverter Technology

- ◆ Inverter-driven systems can promote maximum compressor efficiency in term of smooth operation.
- ◆ The system can detect subtle fluctuations in temperatures and adjust its capacity output automatically which lead to constant stable temperature while minimizing power consumption and promoting humidity control.
- ◆ Inverter system can control over room temperature to deliver appropriate capacity which is smart technology that can suitably match cooling and heating performance with operating requirements at specific location so the system can ensure that a room will be never too hot or too cold.
- ◆ Compressor operates at a fixed speed with on and off repetitively, on the other hand, inverter compressor has controller which can control power output to fit with variable operating environment as well.



3. The Inverter's Application in Refrigeration

- ◆ Inverter technology is becoming the new trend in refrigeration and air-conditioning industry.
- ◆ The system can enhance smoothing performance for any cooling or heating applications.
- ◆ For current situation, this technology can decrease the using of energy which not only save money but also friendly to the environment and create less global warming.



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