

trate respectively the performance characteristics, the condenser water requirements, and the steam requirements.

BASIC REFRIGERATION EQUIPMENT

Compression Refrigeration Machines

Compression of the refrigerant gas drawn from the evaporator may be accomplished by one of several means. Positive displacement may be used as in the reciprocating; centrifugal force may be applied as in the centrifugal compressor; an ejector may be used as in the steam jet refrigeration cycle; or absorption of a low pressure refrigerant gas in a secondary fluid, followed by the absorbent's release upon application of heat, may be utilized. A detailed discussion of the equipment required for each of these types of systems is beyond the scope of this chapter. For a more comprehensive treatment, reference may be made to the bibliography. The present discussion is limited to positive displacement reciprocating compressors, and centrifugal compressors.

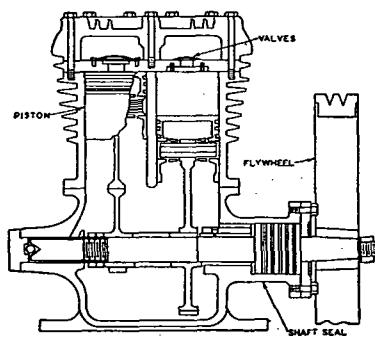


Fig. 13 Diagrammatic View of a Reciprocating Compressor

Reciprocating Compressors

Reciprocating compressors (see Fig. 10) may be classified according to (a) cylinder design, (b) compressor drive, (c) valves, and (d) lubrication and cooling.

Cylinder Design. Cylinder design may vary as to number, arrangement, and action (i.e., single-acting or double-acting). Single-acting compressors usually have their cylinders arranged vertically, radially, or in a V or W shape arrangement. Double-acting compressors, with refrigerant gas drawn in, and compressed on both the head and crank ends of the cylinder, are usually arranged horizontally. Reciprocating units are available with from one to sixteen cylinders with the V, W, or radial arrangements best adapted to the greatest number. The present trend is toward higher operating speeds with a low displacement per cylinder, together with an increase in the number of cylinders. Whereas the original reciprocating compressors were slow-speed (50 to 55 rpm) steam-driven devices, modern electric motor-driven compressors range up to 3500 rpm. Cylinder heads are usually bolted tight to the cylinders, but in some large compressors where there is danger of wet compression or of foreign materials entering the compressor space, a secondary head known as a safety head, may be seated at the end of the cylinder and held in position with heavy springs. Normally, this head remains stationary, but excessive pressures in the clearance space are relieved by

movement of the safety head, and thus prevent damage to the cylinder.

Compressor Drives. Reciprocating compressors may be subdivided on the basis of source of motive power, and whether they are open or hermetic. Practically all modern compressors are electric motor-driven, although a few large, steam-driven compressors are still being installed where steam forms the most economical source of energy.

For summer air conditioning, the compressors may be driven by medium-speed heavy-duty internal combustion engines using natural gas as the fuel. Field tests indicated that fuel consumption of natural gas engine compressor drives is 13,000 Btu per ton-hour.

The natural gas engine compressor drives are designed as packaged units which combine engine speed variation and compressor cylinder unloading to meet fluctuating cooling requirements. Fuel consumption is in direct proportion to the actual cooling load throughout over 80 percent of the capacity range.

The division of compressors into open or closed types is dependent upon whether the motive power is received from an external source, or whether the motor is direct drive and sealed within the housing. In the open type, power is applied from an external source to one end of the compressor crankshaft extending through the crankcase, usually by means of a V-belt drive. The point of emergence of the shaft from the crankcase forms a weak point of refrigerant leakage, and is most frequently sealed with a bellows type crankshaft seal. Horizontal double-acting compressors operate with a sliding piston rod, moving back and forth through a stuffing box. If the motor is direct-drive and enclosed within the compressor housing, the compressor is classified as closed or hermetic. This eliminates the necessity of any shaft seal, and not only prevents refrigerant leakage at this point, but reduces operating noise. One disadvantage is the inaccessibility of moving parts for repairs, but lubrication is greatly simplified since both the motor and compressor operate in a sealed space containing the lubricating oil.

Compressor Valves. All refrigeration compressor valves are dependent for their operation upon a difference in pressure between the inside of the cylinder and the suction or discharge line. Although mechanically-operated valves might have some advantage, they have proved unsatisfactory because each change in the evaporator or condenser operating pressures requires a change of valve setting. The pressure differentials required for operation of the valves depend upon the valve design and the compressor speed. The suction and discharge valves may be arranged with both located in the compressor head, or with the suction valve on the top of the piston and the discharge valve in the compressor head (uniflow arrangement). The valves themselves are usually classified as either poppet, ring-plate, or flexing.

Lubrication and Cooling. Lubrication of modern compressors is accomplished by either splash lubrication or forced lubrication. The latter is used on large compressors, while simple splash lubrication is used in the smaller units.

Large compressors are usually water-cooled with the water jacket either cooling the cylinder walls, or both the cylinder walls and the compressor head. Small compressors are either water-cooled or air-cooled with extended finned surfaces cast on the exterior of the cylinder. In a few cases small compressors may be found in which there is no attempt to add any purposive cooling other than through non-finned surfaces to the lower temperature air.

Water cooling is more effective than air cooling, but even under the best conditions cylinder cooling removes only a portion of the superheat in the refrigerant gas. This removal of heat from the cylinder results in some decrease in the work of compression, as well as reduction in condenser load.

Control of Reciprocating Compressors

Capacity Control of reciprocating compressors to match the imposed load is accomplished by a controller responding to load variations, and operating one of the several means for changing the compressor capacity. This controller may respond to the condition being controlled, such as space temperature in the case of a direct-expansion system, or water temperature in the case of a water chiller; or it may

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respond to suction pressure, which varies with the imposed load. The common methods of varying the compressor capacity are:

1. **Starting and stopping the compressor.** This is more common on small units where frequent cycling of the compressor offers no serious complications. On large installations two or more smaller compressors may be employed and these may be started and stopped in sequence, thus providing more capacity steps. Sequence control of multiple compressors is accomplished by the use of a program or step controller, and in most cases this is arranged to return to the off position when the system is shut down or in the event of power failure, and to provide a suitable time delay between steps on start-up to prevent the full electrical load from being thrown across the line at one time. Means for manually or automatically varying the sequence to equalize wear on the compressors are sometimes employed.

2. **Cylinder Unloaders.** These usually are available on all but the smaller compressors and are used on both single and multiple compressor installations. They consist of a device built into the cylinder head to hold the suction valve open for unloading the cylinder. Oil pressure or head pressure is applied to these devices to load the cylinders, hence the compressor always starts at minimum capacity. Depending upon the make of compressor, the application of pressure to the unloaders is accomplished by:

- a. Solenoid valves usually operated by the program controller in sequence with starting and stopping of the compressor or compressors. The program controller starts the compressor at minimum capacity, then loads the cylinders in sequence as the demand increases. If more than one compressor is used, it starts and loads the second compressor in sequence after the first is fully loaded, etc.

- b. A self-contained stepping valve built into the compressor and actuated by a bellows measuring suction pressure. This valve is supplied with oil pressure from the compressor oil pump and has an oil outlet connection to each cylinder unloader. This valve supplies oil pressure to, or releases it from, the cylinder unloaders progressively as the suction pressure increases or decreases. The suction-pressure bellows is opposed by a spring which has an external manual adjustment for selection of the desired operating range. The other side of the bellows may be open to atmosphere so that the suction pressure is controlled with reference to atmospheric pressure, or it may be sealed and provided with an air connection which permits variation of the operating range as a function of air pressure from a pneumatic controller. For example, if the spring is so adjusted that the basic operating range is 35 to 40 psi suction pressure when the pressure from the pneumatic controller is zero, it will be increased to 45 to 50 psi when the control pressure is 10 psi. Thus these self-contained cylinder unloaders not only can control the suction pressure within a fixed range, but this range can be moved up or down automatically to meet the varying demands on the system. Pneumatic controllers used for this purpose often are supplied with air pressure up to 25 psi to permit a wide range of suction pressure variation. Most of these self-contained cylinder unloaders also can be arranged for mechanically varying the suction pressure by means of an electric motor operator acting against the manual adjustment spring to permit the use of proportional electric or electronic controls.

3. **Speed Control.** Multi-speed motors are sometimes used, actuated by a multi-stage thermostat or a proportional thermostat and a program or step controller.

Safety Controls are provided on reciprocating compressors to stop the motor whenever certain conditions are outside of safe limits. These conditions include:

1. **Low Suction Pressure.** This is a pressure controller responsive to the suction pressure. It stops the compressor when the suction pressure drops below a safe limit. It is sometimes also used as a capacity control, as described in preceding section, (paragraph numbered 1, when it is desired to start and stop the compressor in accordance with the load demand as determined by changes in suction pressure. When other means are provided for starting and stopping the compressor in

accordance with load, the low-pressure control functions solely as a safety device.

2. **High Head Pressure.** This is a pressure controller responsive to the high-side pressure. It stops the compressor when the high-side pressure exceeds a safe limit. This is strictly a safety device and frequently is of the manual-reset type so that the compressor cannot again start until the reset button is manually operated. In many cases the high- and low-pressure switches are combined into a single unit.

3. **Low Oil Pressure.** This is a pressure controller which stops the compressor in the event of low oil pressure. It also is frequently of the manual-reset type.

4. **Low Line Voltage.** This is a low-voltage cutoff which stops the compressor when the line voltage drops below a minimum value.

5. **High Motor Current.** This may be built into the motor or into the motor starter. It stops the motor in the event excessive current persists for more than the brief interval required in starting.

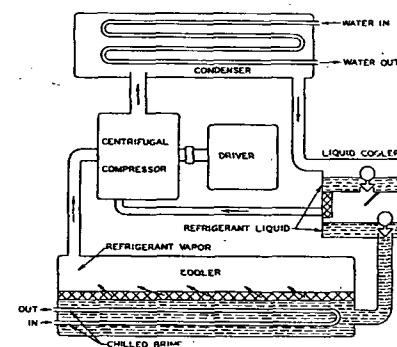


Fig. 14 Enclosed-Type Centrifugal Condensing Unit

6. **High Pressure Relief.** This is a device for preventing damage if excessive head pressures are encountered, and provides protection from damage beyond that provided by the high-pressure cutoff. It may be a relief plug which blows out in the event of excessive pressure. This has the disadvantage of losing the entire refrigerant charge. A relief valve, which functions like a pop-safety valve, is preferred since it wastes only enough refrigerant to relieve the danger.

7. **Low Water Temperature.** If the compressor is used for chilling water, a low-limit thermostat usually is installed in the chiller to stop the compressor in the event a freezing temperature is approached. This is in addition to a controlling thermostat which also may respond to water temperature.

Centrifugal Compressors

Centrifugal compressors are used with very low pressure refrigerants; sometimes both evaporator and condenser work below atmospheric pressure. Trichlorotrifluoroethane ($\text{C}_2\text{Cl}_2\text{F}_4$) and monofluorotrichloromethane (CCl_3F) are the refrigerants commonly used in centrifugal machines.

Centrifugal compressors, like reciprocating compressors, can be divided into two general types, open and enclosed. In general, the open-type compressor is geared to the driving mechanism, and operates at higher speed than the driving