motor or turbine. A *modern, completely enclosed*, direct-driven centrifugal compressor is illustrated in Fig. 14.

Compression of the refrigerant is accomplished by means of centrifugal force; therefore, this type of compressor is inherently suitable for large volumes of refrigerant at low pressure differentials. Two or more stages are usually required and high speeds are necessary to obtain good efficiency.

The evaporator is usually constructed as an integral part of the centrifugal-type condensing unit, to chill water which is then circulated to the air-conditioning system. This is *done because it would not be economical to pipe these large* volumes of refrigerant any distance.

Centrifugal refrigeration compressors are particularly well suited to direct steam-turbine drive because of their high operating speed. Water cooling equipment of one design is operated between 3500 and 4000 rpm for units developing 1000 to 2000 tons capacity, and from 7000 to 8000 rpm for units developing 100 to 200 tons capacity. However, a great many applications, particularly in the smaller sizes, are electric motor-driven and equipped with standard gear-type *speed increasers. Centrifugal systems* are particularly well adapted to large capacities (up to 3000 tons) although it is also possible to secure units as low as 50 tons in rating. Because centrifugal units operate best with refrigerants possessing a high specific volume, and because of the simplification of lubrication difficulties, they are frequently used for extremely low temperature applications. They are adaptable to a wide range of temperatures from *−130 F to 50 F. One* important advantage is their flexibility under varying loads, since units may be designed to operate with reasonable efficiency at capacities as low as 20 percent of normal load.

Control of Centrifugal Compressors

Capacity Control usually is accomplished by a *controller* actuated by the chilled water temperature or evaporator pressure and either (1) varying the flow of vapor from the chiller to the compressor or (2) varying the compressor speed.

1. *Vapor flow control* for compressors driven by constant-speed motors is accomplished by the use of suction dampers or inlet vanes which are positioned by automatic operators to maintain constant water temperature leaving the chiller or constant suction pressure in the evaporator.

2. *Speed Control* for compressors driven by constant-speed motors may be accomplished through the use of an eddy current clutch or a hydraulic coupling under control of an automatic operator. Variable-speed motors for speed control are more common on the larger machines. Steam turbines for driving compressors can operate at various speeds under control of an automatic valve in the governor oil circuit.

Safety Controls provide protection for the compressor by stopping the motor or reducing the capacity through the capacity-control system. Those which usually stop the motor are similar to those described for reciprocating compressors and respond to (1) low oil pressure, (2) low refrigerant temperature, (3) low chilled water temperature, (4) high condensing temperature, (5) high motor temperature, (6) high *motor current, and (7) low line voltage. Frequently controls* are used that are actuated by some of these conditions to reduce capacity before the limit is reached in order to prevent system shutdown.

In addition to the above safety-controls most centrifugal machines have thermostatically controlled heating and cooling of the oil, and some have water-cooled motors with the water sometimes thermostatically controlled. Usually there is a system of interlocks which prevents the compressor from starting unless the condenser water pump and the chilled water pump are running.

Condensers

Condensers used for liquefying the refrigerant are of three general types: (1) air cooled, (2) water cooled, and (3) evaporative.

1. *Air-Cooled Condensers* are readily available in unitary equipment in capacities up to 20 tons of refrigeration. They are *also available as separate* assemblies for field-assembled systems in capacities up to over 100 tons per condenser. Air-cooled condensers first became popular on self-contained room air conditioners and they are now used almost exclusively on this type of equipment. The use of air-cooled condensers for larger equipment was introduced only recently but is rapidly gaining in usage where an adequate water supply is costly to obtain or where other water problems are encountered.

The conventional air-cooled condenser consists of an extended-surface coil across which air is blown by a fan. The hot discharge gas enters the coil at the top and, as it is condensed, flows to a receiver located below the condenser. Air-cooled condensers should always be located in a well ventilated space so that the heated air may escape and be replaced by ambient temperature air.

When adequate supply of city or acceptable well water is readily available at a moderate cost, it is still the preferred condensing medium. However, where some form of water saving is required, the air-cooled condensers are rapidly gaining favor over the cooling tower and evaporative condenser methods in the smaller and medium tonnage classes. Where some form of water saving is required, the capacity of the equipment, under the design conditions of higher wet-bulb weather in the case of cooling towers and evaporative condensers and higher dry-bulb in the case of air-cooled condensers, must be taken into account. *The air-cooled condensing equipment* does have a higher peak current demand per ton over the cooling tower and evaporative condenser methods, but there is some evidence that in actual installations, it does not have *any materially higher seasonal* power consumption per ton than the other methods of water saving in the warm-humid and hot-humid areas. The principal advantages of the air-cooled condensers are low installation costs, lower maintenance costs and simplicity, and for these reasons they are used almost exclusively in small self-contained units and frequently in the larger sizes of compression refrigerating equipment.

2. *Water-Cooled Condensers* are commonly used with compressors of one horsepower or larger in size, and they are found almost exclusively on large installations. Although water-cooled condensers may be of many designs, the shell-and-coil and the shell-and-tube are most commonly found in present day practice.

The amount and temperature of the condensing water determine the condensing temperature and pressure, and indirectly the power required for compression. It is therefore necessary to determine a balance so that the quantity of water insures economical compressor operation.

City water is often used as the condensing medium in the smaller capacities providing an adequate water supply and means for its disposal are available, its cost is not prohibitive, and there are no restrictions against its use.

Because there is a decided trend toward restricting the use of city water for air conditioning and refrigeration purposes, cooling towers are almost universally used with water-cooled condensers in the larger sizes. Since cooling towers produce the warmest condensing water during periods of greatest load, the refrigeration equipment must be designed to meet the maximum load at abnormal condensing water temperature. This makes little difference in efficiency of operation except at those times when the condensing water temperature is highest. In many localities this occurs for only about 5 per cent of the entire cooling period and can be disregarded as a factor in establishing yearly operating costs. *Further information on* cooling towers is contained in Chapter 40.

3. *Evaporative Condensers* provide another means of conserving water used for condensing purposes. In effect they combine the condenser and cooling tower in a single unit.

The fan draws air over the condenser coil which is kept wet by a water spray.

Evaporative condensers are made in sizes up to 300 tons or more. They must be located where air is available and usually at not too great a distance from the compressor to avoid long refrigerant lines. *Like cooling towers* they result in least efficiency at periods of maximum load. Chapter 40 provides additional information on evaporative condensers.

Evaporators and Coolers

Refrigeration evaporators must be designed for efficient removal of heat from the medium being cooled, as well as effective *boiling* of the *refrigerant* and a *minimum* drop of pressure through the coil. There are two general types of evaporators, dry and flooded. In the dry evaporator the refrigerant enters in the liquid state, and the design provides for complete evaporation with the vapors leaving slightly superheated. In flooded evaporators not all of the refrigerant is evaporated, the liquid-vapor mixture leaving the evaporator flows into a surge drum from which the vapors are drawn into the compressor suction line, and the liquid is recirculated through the evaporator.

The *types of coolers* used in connection with air-conditioning work fall into three general groups: (1) direct water coolers, (2) direct air coolers, and (3) brine coolers for circulation of the brine in a closed system, and thus cooling indirectly either water or air.

1. *Water coolers*. One method of the direct cooling of water is to install direct expansion coils in the spray chamber so that the water sprayed into the air comes in direct contact with the cooling coils. Another common and efficient method of cooling spray water is to use a Baudelot type of heat absorber where the water flows over direct expansion coils at a rate *sufficiently high to give efficient heat transfer from* water to refrigerant.

Another type of spray-water cooler is the shell-and-tube heat exchanger in which the refrigerant is expanded into a shell *enclosing the tubes through which the water flows.* The velocity of the water in the tubes affects the rate of heat transfer, and as the refrigerant is in the shell completely surrounding the tubes at all times, good contact and a high rate of heat transfer are insured. The disadvantage of such a system is that with the falling off of load on the compressor, the suction temperature or the temperature in the evaporator drops, and there is a possibility of freezing the water in the tubes, which, of course, might split the tubes and allow the refrigerant to escape into the water passage. This danger can be eliminated by automatic safety devices.

Another system of cooling spray water is to submerge coils in the spray-collecting tank, or in a separate tank used for storage. The heat transmission through the walls of the coils, however, is low and a great deal more surface is required than for any other type of cooler. However, with large storage tanks this type of cooling can be utilized to advantage.

2. *Air coolers*. When direct cooling of air is employed, the refrigerant is inside the coil and the air passes over it. Cooling depends upon convection and conduction for removing the heat from the air. The type of coil used can be either smooth or finned, the finned coil being more economical in space requirement than the smooth coil. The fins, however, must be far enough apart so as not to retain the moisture which condenses out of the air.

When refrigeration evaporators are used for cooling air or other gases by forced convection, they are usually termed blast coils or unit coolers. A blast coil may be placed in a duct or in an assembled unit, and the air forced across the coil and discharged through distributing ducts or directly into the space to be conditioned. Unit coolers, designed much like unit heaters, consist of a finned coil, propeller fan, and controls suspended directly in the space to be cooled.

3. *Indirect brine coolers*. The indirect cooler, where brine is cooled by the refrigerant and the resulting cold brine is used to cool either air or water, introduces several other considerations. It is not the most economical from a power consumption standpoint, as it is necessary to cool the brine to a temperature sufficiently low so that there is an appreciable difference between the average brine temperature and that of the substance being cooled. This requires that the temperature of the refrigerant must be still lower, and consequently the amount of power required to produce a given amount of refrigeration increases due to the higher compression ratio. There are other considerations which make such a system desirable. In the first place, where a toxic refrigerant is undesirable or cannot be used because of fire or other risks, especially in densely populated areas, the brine can be cooled *in an isolated room* or building and can then be circulated through the air-conditioning equipment. This arrangement eliminates any possibility of direct contact between the air and refrigerant.

REFRIGERATION CONTROL

Expansion Devices

In addition to means of controlling the compressor capacity and the necessary limit and safety controls as outlined under the section describing the compressors, reciprocating compressor refrigeration systems require a device for *controlling the expansion of the refrigerant* from the high liquid pressure to the low evaporator pressure.

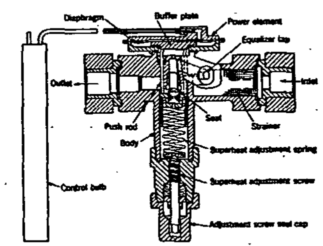

Fig. 15 . . . . Typical Thermostatic Expansion Valve

Automatic Expansion Valves. An automatic or pressure-controlled *expansion* valve *operates* to maintain a constant pressure in the evaporator. The liquid refrigerant passes through an orifice, the opening size of which is controlled by means of a needle valve connected to a flexible bellows. This bellows expands or contracts with variations in the evaporator pressure transmitted to the expansion chamber through the refrigerant outlet from the evaporator. The position of this needle valve is controlled by the degree of compression in an adjusted spring, balanced against the bellows, and these two forces operate to maintain a constant pressure in the evaporator by increasing or decreasing the flow of liquid refrigerant. Such an expansion valve is usually applied to evaporators of the direct-expansion type, but is not satisfactory for fluctuating loads such as are encountered in air-conditioning installations.

Thermostatic Expansion Valves. A thermostatic expansion valve controls the flow of liquid refrigerant to the evaporator so as to maintain the entire coil filled with evaporating refrigerant, and to keep a constant superheat in the refrigerant gas leaving the coil. The construction of such a valve is shown in Fig. 15 and is similar to that for an automatic expansion valve but incorporates, in addition, a power element *responsive* to changes in the degree of superheat of the refrigerant gas leaving the coil. This power element consists of a bellows connected by means of a capillary tube to a feeler bulb fastened to the *suction line from the evaporator*. The bulb, bellows, and tube are usually charged with the same liquid refrigerant used in the evaporator itself. A starved condition in the evaporator results in a greater superheat in the gas leaving the