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HVAC

CHILLER SYSTEMS

Contents

1 Introduction

Chillers are devices that remove the heat that is gained by a recirculating chilled water system as it cools a building. Two types of refrigeration cycles can be used by chillers: either the compression cycle or the absorption cycle.

The term "chiller" is used in connection with a complete chiller package, which includes the following: compressor, condenser, evaporator, internal piping, and controls. "Chiller" is also used when all these components are used with a cooling tower.

Compression Cycle

Liquid refrigerant, at a relatively high pressure and temperature, flows through a restriction called the flow control device or expansion valve. The flow control device separates the high-pressure side of the system from the low-pressure side. It acts as a pressure reducing valve because the pressure of the liquid flowing through it is lowered, and only a small portion of the refrigerant flows through the valve into the evaporator.

The refrigerant that flows through the evaporator is vaporized by the heat flowing through the walls of the evaporator. After leaving the evaporator, the refrigerant is a gas at a low temperature and pressure. To be able to use it again to achieve the refrigerating effect, it must be brought back to a high-pressure liquid. Refrigerant flows from the evaporator to a compressor where the pressure is increased. Compressing the gas also increases the temperature. The refrigerant travels to a condenser after leaving the compressor and flows through one circuit in the condenser. In the other circuit, a cooling fluid (either air or water) flows at a temperature lower than the refrigerant. Heat transfers from the refrigerant to the cooling fluid, and the refrigerant condenses to a liquid. Figure C-1 shows the compression cycle.

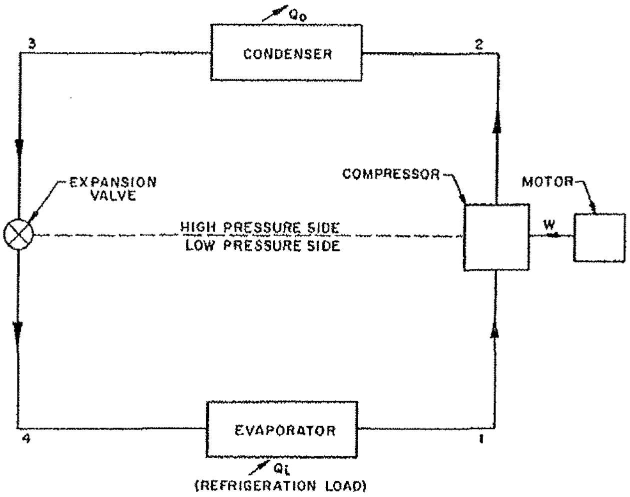

Figure C-1. Compression Refrigeration Cycle.

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Centrifugal Compressors

Centrifugal compressors are variable displacement machines that provide pressure through the action of rotating impellers. The fundamental design of the centrifugal compressor is similar to that of a centrifugal pump (Figure C-2).

Refrigerant vapor enters the compressor through suction passages, and passes into the impeller. The impellers increase the velocity of the vapor. The velocity energy resulting from this increase is converted to a pressure increase. Centrifugal compressors are designated by their number of stages, with one stage for each impeller.

Reciprocating Compressors

The definition of reciprocating is a back and forth motion in a straight line. Reciprocating compressors are positive displacement machines that provide compression through the action of a piston squeezing refrigerant in a cylinder. Construction is similar to the reciprocating engine of a vehicle, with pistons, cylinders, valves, connecting rods, and crankshaft (Figure C-3).

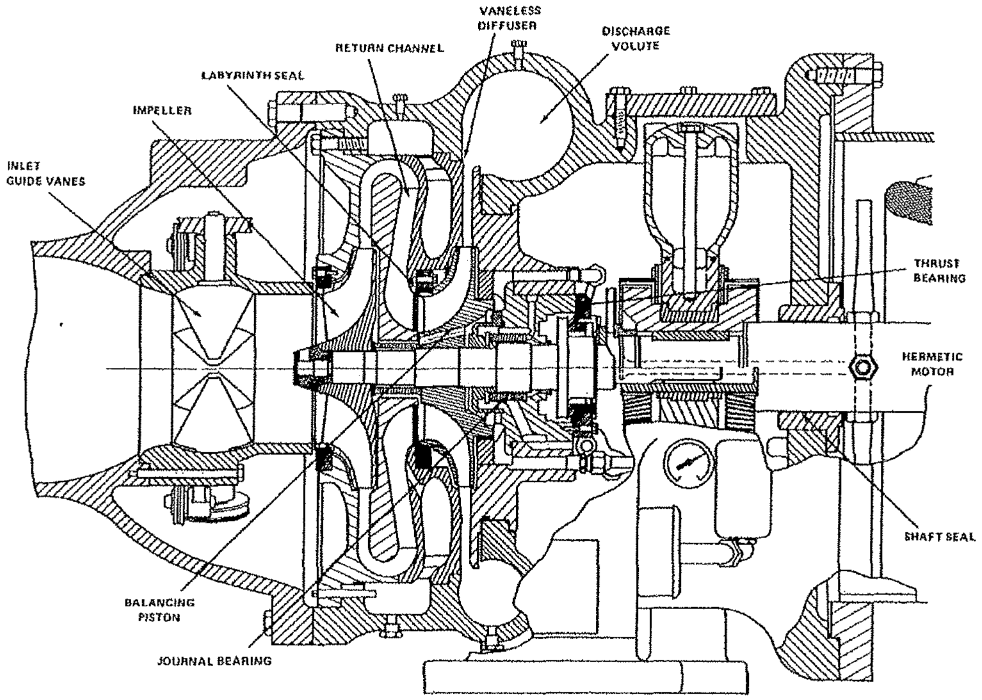

Figure C-2. Centrifugal Compressor.

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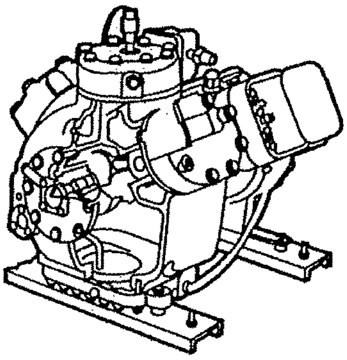

Figure C-3. Reciprocating Compressor.

Carrier Corporation, Syracuse, NY. Used with permission.

As the piston moves out of the cylinder, refrigerant vapor is drawn in. As the piston moves in, the refrigerant is compressed. In most cases, the suction and discharge valves are either thin plates or reeds that will open and close easily and quickly.

The reciprocating compressor is the most widely used type, available in sizes from fractional horsepower and tonnage up to a few hundred tons.

Screw Compressors

Screw compressors can be used in the compression cycle in a complete chiller package. They come in two main types: single screw and twin screw.

Single screw. The single screw compressor (Figure C-4) consists of a single cylindrical main rotor that works with a pair of gate rotors. The compressor is driven through the main rotor shaft and the gate rotors follow. Refrigerant vapor enters the suction chamber. As the main rotor turns, vapor is trapped in the space formed by the three sides of the flutes, casing, and gate rotor tooth. As rotation continues, the flute volume decreases and compression occurs as illustrated in Figure C-5.

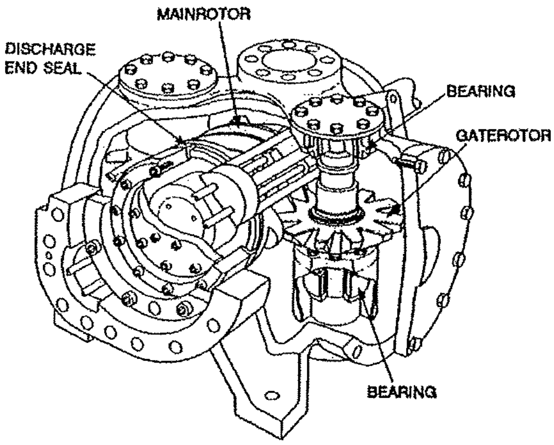

Figure C-4. Single-Screw Compressors.
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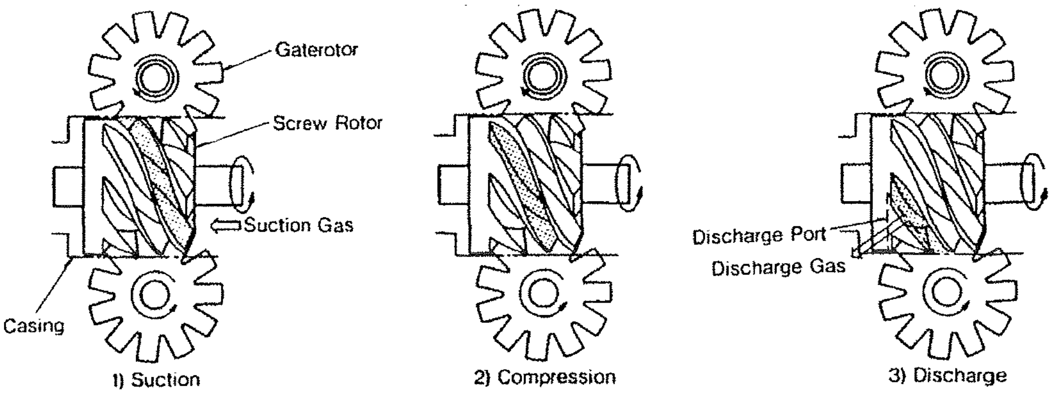


1) Suction 2) Compression 3) Discharge

Figure C-5. Single Screw Compressor Sequence of Operation.
Reprinted with permission from the 1992 *ASHRAE HVAC Systems and Equipment Handbook.*

Twin screw. The twin screw compressor (Figure C-6) consists of two mating helical grooved rotors, a male and a female, in a stationary housing with inlet and outlet ports. As the two rotors (screws) rotate, the volume between the screws decreases toward the discharge end, and the vapor is compressed.

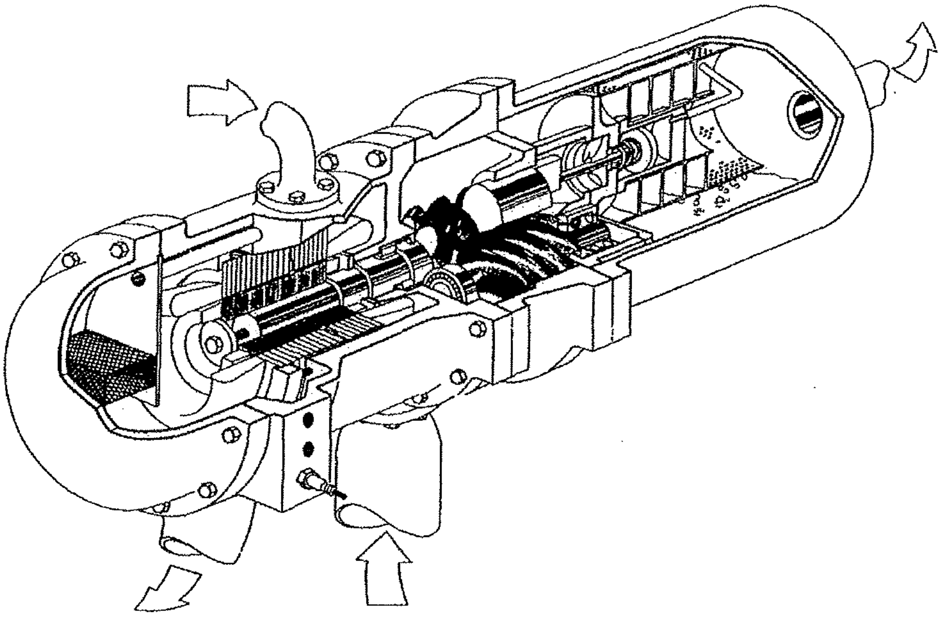


Figure C-6. Twin Screw Compressor.
Reprinted with permission from the 1996 *ASHRAE Systems and Equipment Handbook.*

Scroll Compressors

The scroll compressor is another type of compressor primarily used in residential and automotive air-conditioning.

Absorption Cycle

Similar to the compression refrigeration cycle, the absorption cycle has a low-and high-pressure side. The main difference between the mechanical and absorption cycles is the way refrigerant vapor is elevated from the low- to the high-pressure side of the system. A compression system pumps vapor directly from the low-pressure evaporator to the high-pressure condenser. Absorption systems are commonly found in single shell or two shell arrangements (Figure C-7).

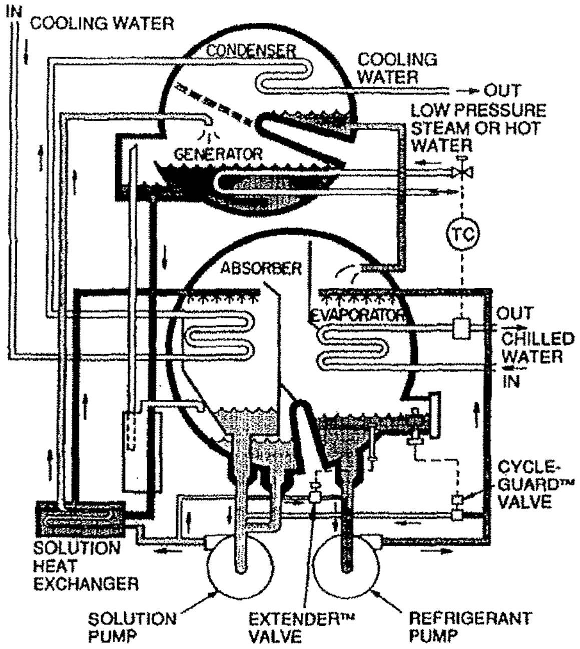


Figure C-7. Absorption Cycle.

Source: Carrier Corporation, Syracuse, NY. Used with permission.

Because absorption processes are often not well understood, a detailed discussion of the absorption cycle will be provided here. Absorption is defined as "the taking up of matter or energy by penetration into an absorbing medium, so that the absorbed matter or energy apparently disappears" (Encyclopedia Americana 1982).

In chemical processes, absorption refers to the solution of a gas in a liquid, the solution being obtained by the washing or intimate contact (scrubbing) of a gas mixture with the liquid. In the ideal situation, an equilibrium is attained, and there is a definite relationship between the concentrations of the gas phase and the liquid phase of the absorbed component.

Gas-liquid absorption is accomplished in vertical counter-current flow patterns through packed, plate, or spray towers. The packed tower is a shell filled with specifically shaped packing materials. Plate towers contain plates at various heights within the tower. In spray towers, the liquid surface is increased by forcing it through spray nozzles to form many tiny droplets that fall through the rising gas stream.

In the absorption system, the low-pressure vapor is absorbed and transported to the high-pressure side in a solution. Once it is on the high-pressure side, it is recovered as a high-pressure liquid refrigerant. In connection with the low side is an evaporator and an absorber. The constituent parts of the high side are the concentrator and the condenser. Excluding energy consumption and efficiency, the absorption process produces the same results as the compression cycle.

Fluids of the Absorption Cycle

Absorption machines use distilled water as a refrigerant. Water is a stable compound having a 1000 Btu per pound of latent heat of vaporization.

Large amounts of water are readily absorbed and separated from the absorbent solution. In the evaporator of an absorption machine, water usually boils at 40 °F, and a pressure equivalent to 1/100 of normal atmospheric pressure. It is also a nontoxic and low cost refrigerant.

The second fluid used in an absorption machine is an absorbent, which is lithium bromide salt in a water solution. The lithium bromide solution is confined to the absorber-concentrator sections of the machine and is the transporter of refrigerant from the low- to the high-pressure side.

Evaporator (low-pressure side)

As with the compression refrigeration cycle, high-pressure liquid refrigerant is passed from the condenser through an orifice (expansion valve) into the lower pressure evaporator. System water having a temperature of about 54 °F enters the evaporator tubes to be chilled while the refrigerant's temperature is at about 40 °F. Because the temperature of the water is higher than that of the refrigerant, heat transfers through the tubes to the refrigerant. The refrigerant then becomes vaporized.

The evaporator tubes are continuously wetted by spraying refrigerant over the tube bundles. The refrigerant and vapor generated in this evaporative cooling process pass downward to the absorber, where the pressure is lowest in the system.

Absorber (low-pressure side)

This area of the machine is at a slightly lower pressure than that of the evaporator due to the absorption of vapor in the absorber. The pressure in this space, which is the rate of absorption, is controlled through the regulation of the absorbent solution concentration and temperature.

As the refrigerant vapor is absorbed, it is also condensed, releasing the heat of vaporization it acquired in the evaporator. This heat is rejected to the cooling tower water, which is circulated through the absorber tube bundle.

The absorber pump delivers large amounts of intermediate solution to the sprayers. A maximum surface area of solution is produced by spraying the solution over the tube bundle. This is necessary because absorption occurs only on the surface of the absorbent solution. This method also provides maximum heat transfer to the cooling tower water.

It is important to spray an intermediate solution rather than a concentrated solution for two reasons. First, a greater amount of solution is required to wet the tubes than is available from the concentrator. Second, if concentrated solution were sprayed directly onto the absorber tubes, it would be subjected to temperatures that could cause it to crystallize into a solidification of the lithium bromide.

Concentrator (high-pressure side)

To remove the refrigerant from the absorbent solution, diluted solution is pumped up to the concentrator. This diluted solution is then boiled, causing the refrigerant to leave the concentrator in the form of steam or hot water. When the steam or hot water leaves the concentrator, the solution left behind becomes more concentrated. The concentrated solution is then taken down and mixed again with dilute solution and re-enters the absorber as intermediate solution.

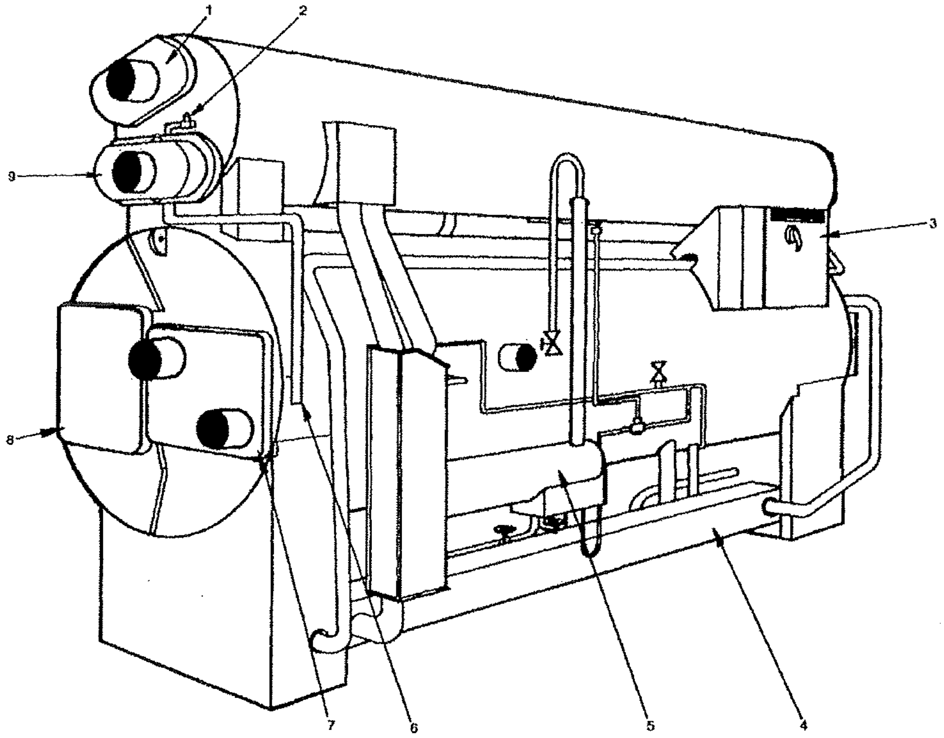
As the concentrated solution goes down and the dilute solution is pumped up, their pipes pass through a heat exchanger. Heat is transferred from the concentrator solution to the dilute solution, making the process more energy efficient.

Condenser (high-pressure side)

The refrigerant vapor that was produced in the concentrator migrates over to the cooler condenser where it clings to the tubes as it condenses. The cooling water is the same that was circulated in a bundle through the absorber, so the water in the condenser bundle is at a higher temperature than that of the absorber. The condensed refrigerant is then passed through the orifice into the evaporator. At the low pressure in this location, some of the refrigerant flashes and cools the remainder of the refrigerant to evaporator temperature. This cooled refrigerant falls into the evaporator pan, ready to be sprayed over the tube bundle.

Pressure on the high side of the system is approximately 10 times higher than that of the low side, yet both are well below atmospheric pressure.

To get a better understanding of the absorption machine and visualize its actual appearance, see Figure C-8.



LEGEND
1 — Condenser
2 — Steam Box Vacuum Breaker
3 — Control Center
4 — Solution Heat Exchanger
5 — Purge Storage Chamber
6 — Condensate Drain Line
7 — Absorber
8 — Evaporator
9 — Steam Generator

Figure C-8. Profile of Absorption Machine.

Source: Carrier Corporation, Syracuse, NY. Used with permission.

2 Applications of Chillers

Centrifugal

Heat recovery is one special application of centrifugal chillers. A separate closed condenser cooling water circuit is heated by the condensing refrigerant instead of rejecting all heat extracted from the chilled liquid to a cooling tower. This circuit is used for comfort heating, reheating, or preheating. Only one unit is designed for heat recovery in multiple packages.

Centrifugal chillers are capable of free cooling, which is cooling without the operation of the compressor. The chiller can operate as a thermal siphon when a supply of condenser water is available at a temperature below that of the needed chilled water temperature. Free cooling is limited to about 10 to 30 percent of the chiller design capacity.

Although the majority of centrifugal chilling units are for water-chilling applications, they can also be applied to brine cooling. Higher compressor speeds and more stages may be required due to the greater temperature lift.

Air-cooled centrifugal systems that are directly air-cooled eliminate the intermediate heat exchanger and condenser water pumps, which leads to lower power requirements. Condenser and refrigerant piping leaks have to be given special attention with this type of system. Also, this type of system should allow the condensing temperature to fall to around 70 °F during colder weather, which will lead to a decrease in compressor power consumption.

Reciprocating

Multiple reciprocating compressor units are widely used for the following reasons:

1. The number of capacity increments are greater, allowing extra standby capacity, lower power consumption, closer liquid temperature control, and less current in-rush during starting.

2. The potential for limited servicing or maintenance of some components while maintaining cooling is gained by multiple refrigerant circuits.

Reciprocating liquid chillers retain nearly full cooling capacity because pressure rise has only a slight influence on the volume flow rate of the compressor. These chillers are well suited for low-temperature refrigeration and air-cooled condenser applications.

The relationship between system demand vs. performance for a reciprocating liquid chiller is shown in Figure C-9 below. As cooling loads drop, compressor capacity also drops.

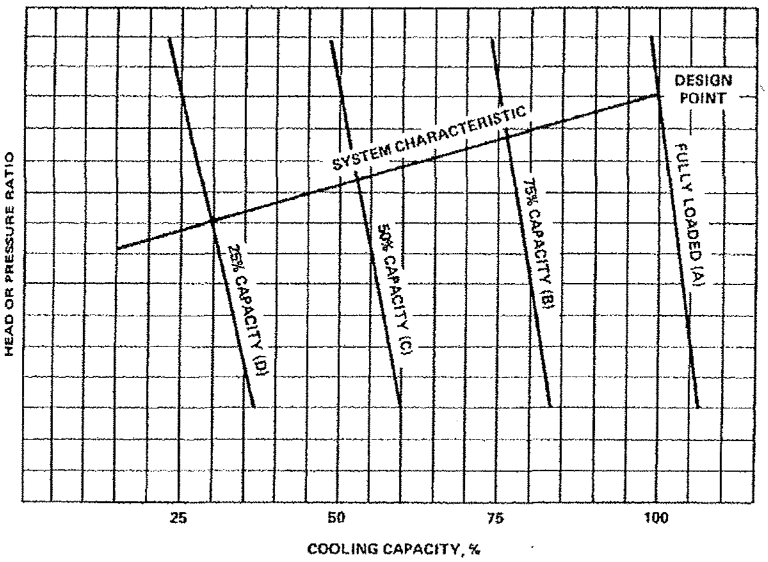


Figure C-9. Cooling Capacity vs. Performance for Reciprocating Chillers.

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Screw

Screw compressors are being used for many applications due to its reasonable compressor cost, and no surge characteristics. Some of these areas are:

1. Heat-recovery installations
2. Air-Cooled
   a. Split packages with field-installed interconnecting piping
   b. Factory built rooftop packages
3. Low-temperature brine chillers for process cooling

Screw compressors are quieter and have only one-tenth the moving parts required in reciprocating compressors.

Absorption

The coefficient of performance (COP, see the efficiency section for further explanation) of absorption machines is lower than compression refrigeration systems. The COP for a large absorption machine is typically 0.65, while that of a large compressor driven water chiller may be 3.5 or higher. The energy use advantage of the compression refrigeration system is greatly reduced in actuality, and must be considered in application.

Moderate temperatures, supplied by flatplate solar collectors, can cool the water-lithium bromide absorption cycle at a high COP. The high COP is not as important in this case since there is no depletable fuel used.

Absorption-centrifugal combinations can be an efficient combination of refrigeration sources for air conditioning in some cases.

An absorption machine requires a larger cooling tower compared to that needed for a compression cycle machine. This is due to the larger quantity of heat that must be rejected from the absorber and condenser combined.

The choice of whether to use an absorption or vapor compression machine (or combination) for a specific application depends mainly on economics, which is a function of relative fuel costs.

3 Efficiency

Chiller efficiency (kW/ton) is a function of the percent of full load on the chiller and the refrigerant head. The refrigerant head is the refrigerant pressure difference between the condenser and evaporator, which is commonly represented by condenser water leaving temperature minus chilled water supply temperature (Figure C-10).

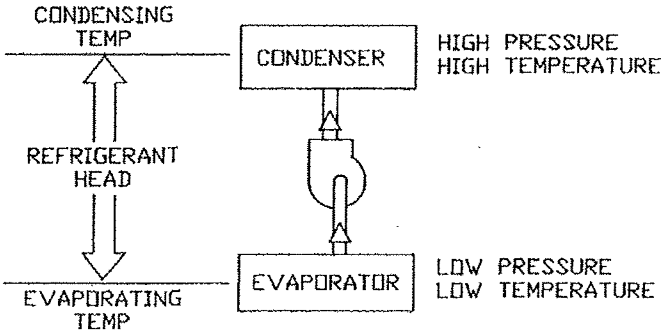

Figure C-10. Refrigerant Head.

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The chilled water supply temperature must be increased and/or the condenser water temperature decreased to reduce the refrigerant head. The gain is 1 to 2 percent energy savings for each degree Fahrenheit reduction in temperature.

Multiple chiller plants should be operated at the most efficient point on the part-load curve. The point at which a chiller should be added or dropped is shown in Figure C-11.

Coefficient of Performance (COP)

The COP is a factor that measures refrigeration requirements with power input. The COP is defined as:

$$\text{COP} = \frac{\text{Refrigeration Capacity}}{\text{Equivalent Power Input to Compressor}}$$

For a given refrigeration requirement, a greater power is necessary for a lower COP of a refrigeration unit.

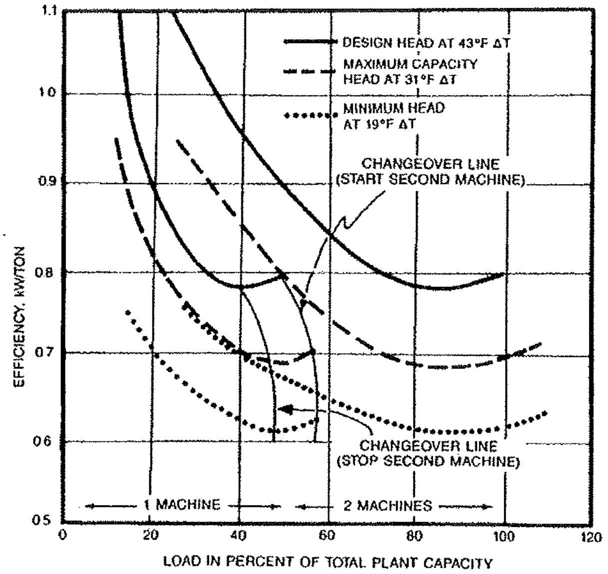

Figure C-11. Multiple Chiller Operation Changeover Point—Two Equal Sized Chillers.

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Example 1

A packaged chiller is known to have a 28.1 ton capacity. The chiller requires 25.1 kW to operate at this capacity.

$$\text{capacity} = 28.1 \text{ tons x } 12{,}000 \frac{\text{Btu/hr}}{\text{ton}} = 337{,}200 \text{ Btu/hr}^{*}$$

$$\text{power input} = 25.1 \text{ KW x } 3{,}410 \frac{\text{Btu/hr}}{\text{KW}} = 85{,}590 \text{ Btu/hr}^{**}$$

$$\text{COP} = \frac{337{,}200 \text{ Btu / hr}}{85{,}590 \text{ Btu / hr}} = 3.94$$

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[*] Enthalpy of fusion for water = 144 Btu/lb (required energy)

$$1 \text{ ton} = 1 \text{ ton x } \frac{2000 \text{ lb}}{\text{ton}} \text{ x } \frac{144 \text{ Btu}}{\text{lb}} \text{ x } \frac{1}{24 \text{ hr}} = 12{,}000 \text{ Btu/hr}$$

[**] KW = power; conversion: 1 KW = 3,410 Btu/hr

4 Chiller Components

Types of Compressors

Compressors may be classified as open, hermetic, or semihermetic.

Open Compressors

Open compressors (Figure C-12) require an external driver. Electric motors are most common, but steam or internal combustion engines can also be used. The external driver is attached to the compressor crank shaft either directly with a coupling or belt driven to operate at a specific speed. The external drive and compressor are in two separate housings. Open compressors are generally more expensive than hermetic and semihermetic compressors because of these separate housings.

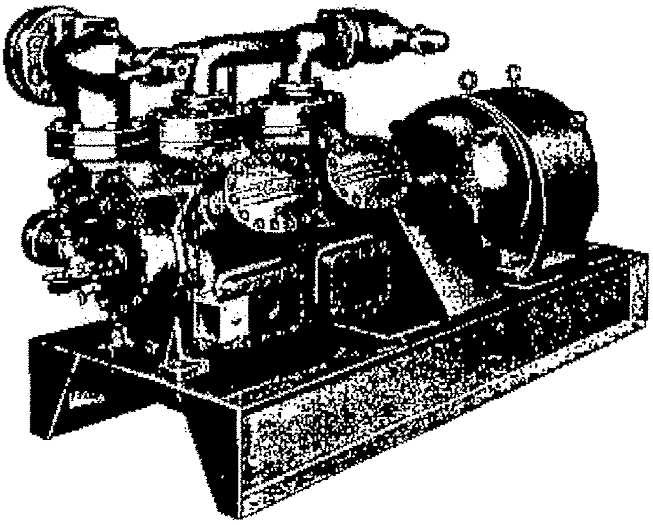


Figure C-12. Open Compressor Unit.

Source: The Trane Company, La Crosse, WI. Used with permission.

Hermetic Compressors

Hermetic compressors (Figure C-13) have the motor and compressor enclosed in one housing. The compressor and motor share a common shaft and bearings.

Motors are usually suction gas cooled as the rotor is mounted on the compressor crankshaft. Generally the horsepower of the motor is matched to the compressor and refrigerant. The only external connections required are wiring and piping. Factory repairs are necessary as the compressor is hermetically sealed (welded).

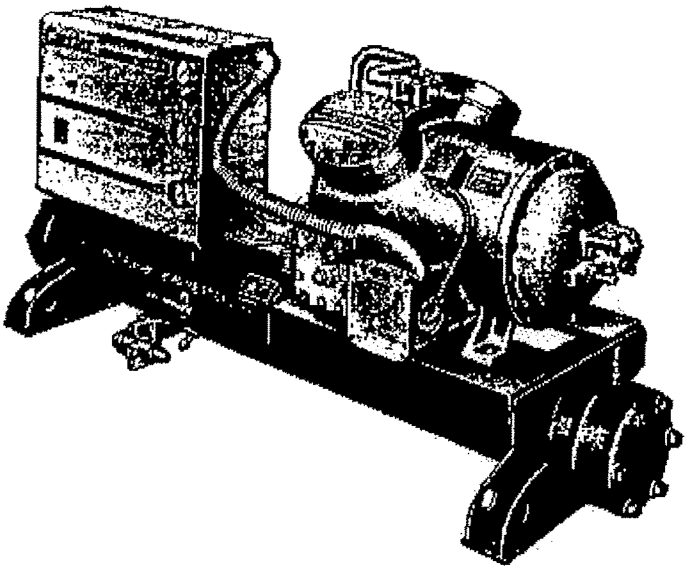


Figure C-13. Hermetic Compressor Unit.

Source: The Trane Company, La Crosse, WI. Used with permission.

Semihermetic Compressors

The difference between hermetic and semihermetic compressors is that semihermetic compressors may be serviced in the field because they are manufactured with bolted means of access. With proper controls, all forms of compressors can be used in all applications. In some cases, the size of the compressor will determine what type of compressor is used.

Condenser

The condenser is the component of the mechanical refrigeration cycle that rejects and removes heat. This includes heat from the evaporator plus the heat equivalent of the work of compression. The three basic types of condensers are:

1. Water-cooled
2. Air-cooled
3. Evaporative.

Water-Cooled

Most water-cooled condensers in use today can be classified into two categories: shell-and-coil or shell-and-tube.

Shell-and-coil condensers circulate cooling water through one or more continuous or assembled coils. Refrigerant vapor is condensed outside the tubes contained within the steel shell. Horizontal or vertical shell arrangements are available in sizes ranging anywhere up to 20 tons. This type of condenser is small, compact, and efficient and may be cleaned by chemical means.

Shell-and-tube condensers (Figure C-14) circulate cooling water through tubes in a single- or multi-pass circuit. Water flows within the tubes, and refrigerant vapor fills the space between the shell and the tubes.

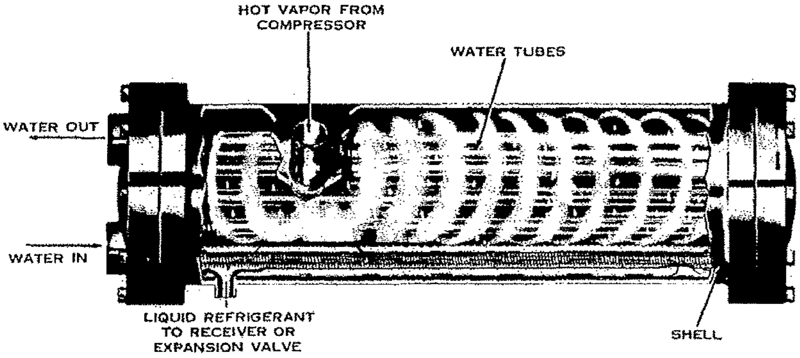


Figure C-14. Shell-and-tube Condenser.
Enrivonmental Systems Technology, W. D. Bevirt, 1984. Reprinted with permission of the National Environmental Balancing Bureau.

A pickup tube or sump is usually provided at the bottom of the shell to collect the condensed refrigerant. Horizontal arrangements are typical for shell-and-tube condensers. Sizes range anywhere up to 10,000 tons, and tubes may be cleaned mechanically. Cooling towers are commonly used with both types.

Air-Cooled

Air-cooled condensers (Figure C-15) operate by circulating refrigerant through a coil, with air flowing across the outside of the tubing. Coils are commonly made of copper, aluminum, or steel tubes with diameters ranging from 0.25 to 0.75 in.

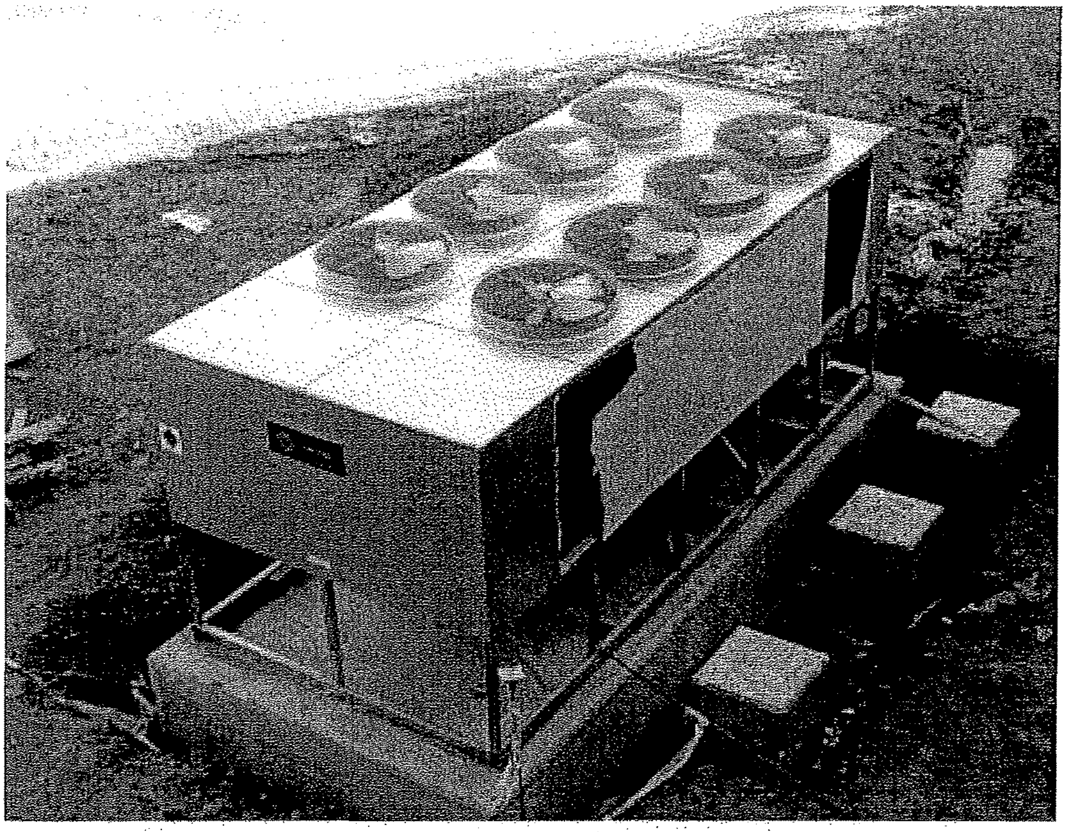


Figure C-15. Air-cooled Condenser.

Air-cooled condensers produce air motion by natural convection or by the use of a fan. Natural convection condensers are limited to smaller capacities. Indoor or outdoor locations can be used. In outdoor applications, a clean area should be selected that positions the condenser towards prevailing winds. Compressor capacity can be increased by adding a liquid subcooling circuit.

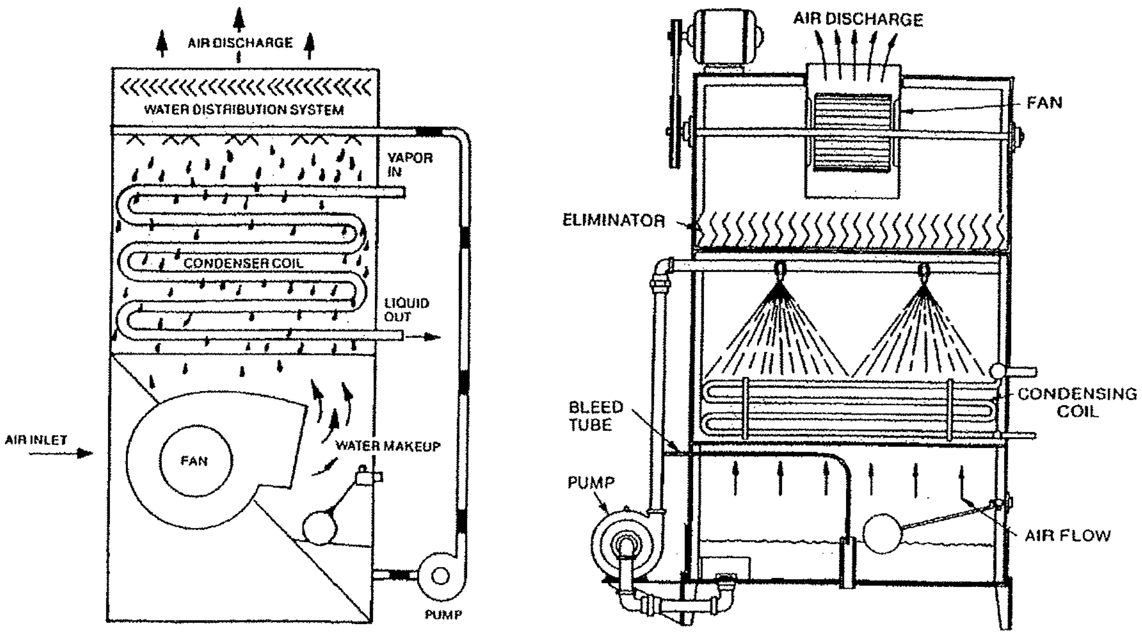
Forced-air condensers are typically used when the condenser is remote from the compressor. Remote condensers can be located indoors or outdoors. The greater the distance between the condenser and compressor, the greater the first cost and operating cost.

Maintenance for air-cooled condensers is simple. They do not have to be started up in the spring or winterized in the fall. The only connections required are refrigerant and power, and they are easy to install.

Evaporative

Refrigerant vapor from the compressor enters the top of a coil and condenses to a liquid as it flows through the coil. Water is sprayed down over the refrigerant coil with the spray water falling into a water tank to be picked up by a pump and returned to the spray nozzles. Air is simultaneously directed over the coil, causing a small portion of the recirculated water to evaporate. This evaporation removes heat from the coil, cooling and condensing the vapor. The liquid refrigerant then drains to a receiver.

Coils are commonly made of steel or copper tubing. Evaporative condensers (Figure C-16) can be arranged horizontally or vertically. Outdoor installation is commonly used, and freeze-up problems must be considered.



(a) Blow-through Type (b) Draw-through Type

Figure C-16. Evaporative Condensers.

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Flow Components

Figure C-17 shows a chiller's flow components, which are described below.

Flow Control Device

This restricting device regulates the refrigerant flow according to the load and causes the pressure drop of the refrigerant. Some common types used are:

1. Thermostatic expansion valve
2. Capillary tube
3. Low-side float valve.

Thermostatic expansion valve. The thermostatic expansion valve (Figure C-18) is used in direct-expansion systems. Refrigerant flow is regulated automatically by the valve reaction to the pressure variations in the remote bulb being transmitted through the tube to the thermal valve. When the bulb senses a temperature below the control point, the thermal valve is throttled.

Capillary tube. The capillary tube is a small-diameter tube that connects the outlet of the condenser to the inlet of the evaporator, resulting in the required pressure drop. It is used with direct-expansion systems.

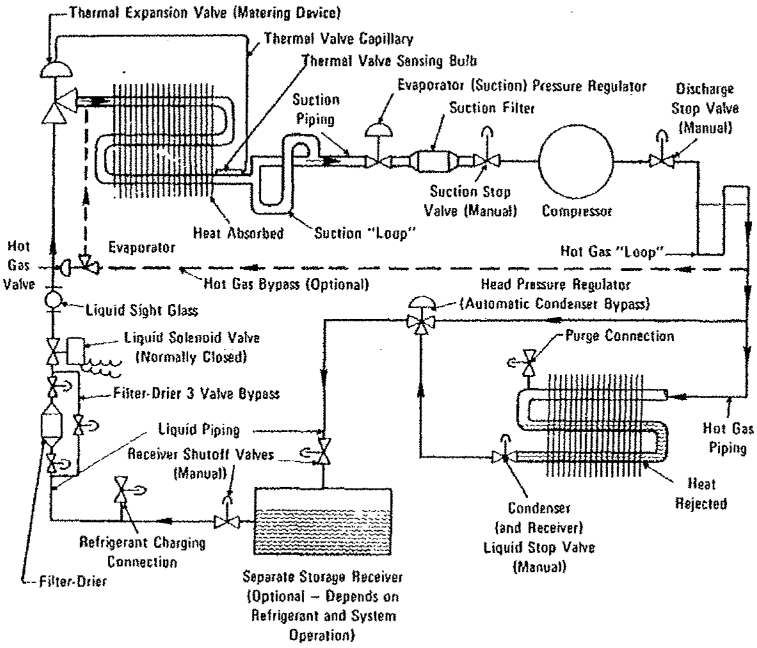

Figure C-17. Flow Components.

Enrivonmental Systems Technology, W. D. Bevirt, 1984. Reprinted with permission of the National Environmental Balancing Bureau.

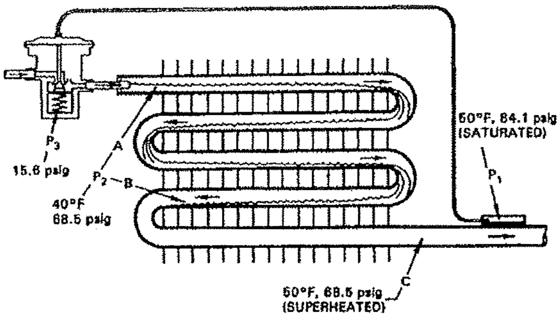

Figure C-18. Thermostatic Expansion Valve.

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Low-side float valve. Low-side float valves are used with flooded systems. If flow is not adequate and too much liquid accumulates, the float rises and a connecting linkage opens the valve, allowing more flow.

Suction Piping

This piping returns refrigerant vapor to the compressor. It is the most important piping in the system because it has to be large enough to maintain minimum friction to prevent reduced compressor capacity, but also must be small enough to generate enough gas velocity to return the system oil to the compressor.

Evaporator Pressure Regulator

This automatic pressure regulator maintains constant pressure in the evaporator. It helps prevent freezing of water and limits minimum relative humidity at light loads in any refrigeration system.

Suction Line Filter

This filter is generally used with steel piping systems to remove rust. Pressure drops in the line are associated with this device.

Discharge Stop Valve

The manual service valve at the leaving connection of the compressor.

Suction Stop Valve

Manual service valve at the inlet side of the compressor.

Receiver

An auxiliary storage space to store refrigerant when system is shut down, or needs to be opened for servicing.

Refrigerant Charging Connection

Manual valve that introduces refrigerant into the system.

Filter-Drier

This device used to strain and remove moisture. It is normally used with a three valve bypass to allow removal when in operation. This device does not need to be used on smaller systems but is recommended for all systems.

Liquid Solenoid Valve

Electrically operated control valve located in the liquid piping that can stop refrigerant flow.

Liquid Sight Glass

Glass-ported fitting in the liquid refrigerant line, located immediately ahead of the expansion valve, that provides a means for viewing the liquid flow.

Hot Gas Bypass and Valve

The piping and manual (but more often automatic) valve used to introduce compressor discharge gas directly into the evaporator.

Relief Devices

Relief valves or rupture discs are used to relieve excess pressure and are commonly piped to the outdoors. These devices are required by code.

Cooler (Evaporator)

Refrigerant is vaporized in the cooler. Refrigerant evaporates inside the tubes of a direct expansion cooler. These coolers are usually used with positive-displacement compressors to cool water or brine. In a flooded cooler, the refrigerant vaporizes on the outside of tubes, which are submerged in liquid refrigerant within a closed shell. Flooded coolers are usually used with screw or centrifugal compressors. Direct-expansion coolers do not require liquid storage, whereas flooded coolers maintain a liquid pool of refrigerant. The four basic types of coolers are: (1) Shell-and-Tube Cooler (DX, Flooded), (2) Baudelot Cooler (DX, Flooded), (3) Shell-and-Coil Cooler, and (4) Direct Expansion Cooling Coil.

Shell-and-Tube Cooler

In a direct-expansion shell-and-tube cooler (Figure C-19), refrigerant circulates through the tubes in a single or multi-pass circuit. Fluid baffles (plates used to control liquid flow) on the outside of the tubes channel fluid flow and, in turn, increase the velocity of the fluid. Refrigerant distribution is critical, as tubes that are fed more refrigerant than others tend to bleed into the suction line.

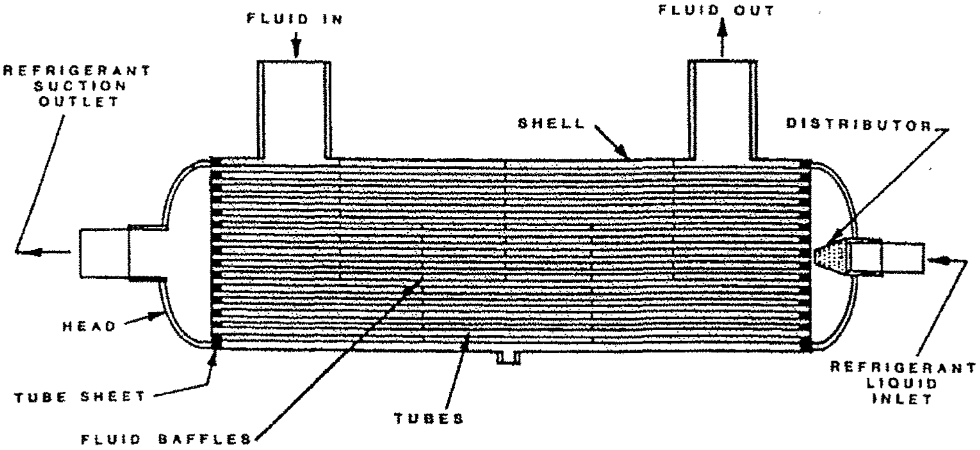

Figure C-19. Direct-Expansion Shell-and-Tube Cooler.
Reprinted with permission from the 1996 *ASHRAE Systems and Equipment Handbook*.

Flooded shell-and-tube coolers (Figure C-20) vaporize refrigerant on the outside of tubes. Fluid flows through the tubes, which are submerged in refrigerant, and all are contained in a closed shell. Refrigerant is usually fed into the bottom of the shell by a distributor that equally distributes it under the tubes. Warm fluid in the tubes heats the refrigerant, causing it to boil.

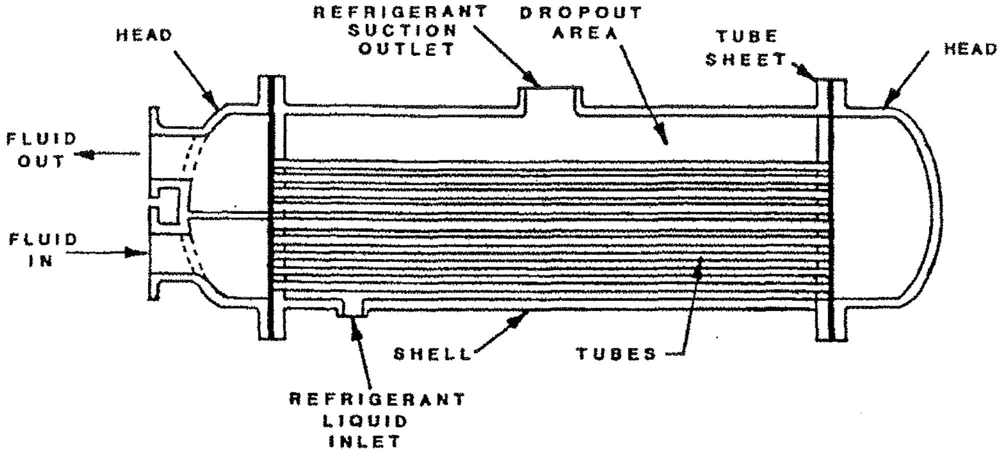

Figure C-20. Flooded Shell-and-Tube Cooler.

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Baudelot Cooler

Baudelot coolers (Figure C-21) may be set up for flooded or direct-expansion operation. The fluid to be cooled is distributed over the heat exchanger and then flows by gravity to a collection plate below. Vertical plates or horizontal tubes are used in the heat exchanger to allow easy cleaning.

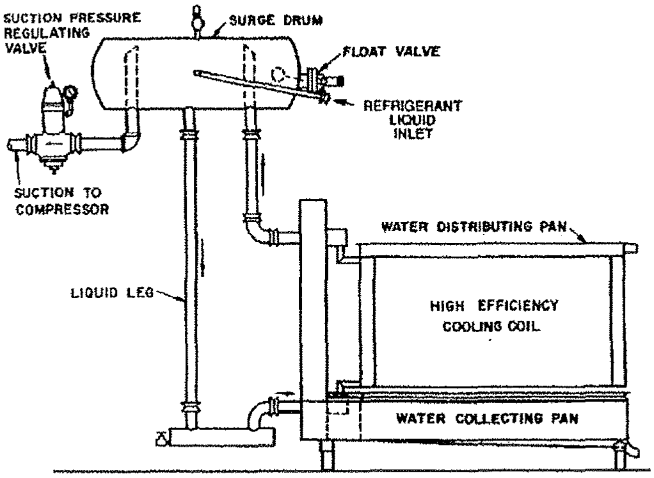

Figure C-21. Flooded Baudelot Cooler.

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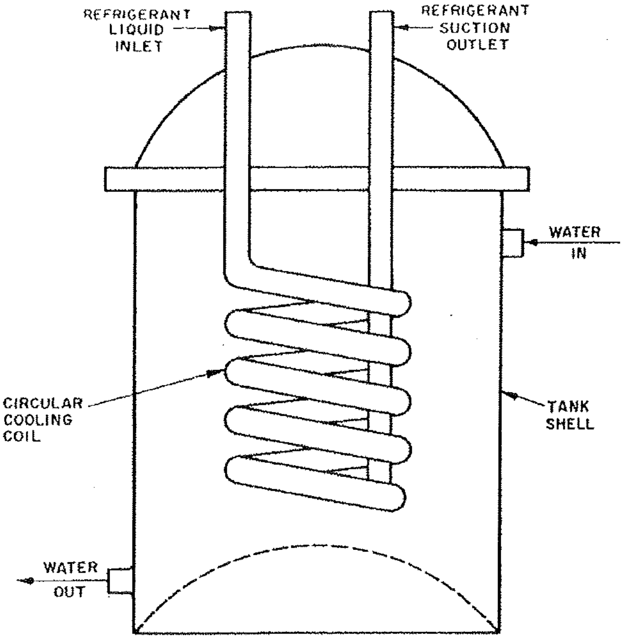

Figure C-22. Shell-and-Coil Cooler.

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Shell-and-Coil Cooler

Shell-and-coil coolers (Figure C-22) consist of a coiled tube in which the refrigerant flows and a tank that contains the fluid to be cooled. The coiled tube can be located either outside or inside the tank. In some cases, the tank can be opened for cleaning.

Direct Expansion Cooling Coil

Coil equipment (Figure C-23) used for cooling an airstream under forced convection may consist of a single coil section or a number of individual coil sections built up into banks and assembled in the field. Coils are used to cool air whereas coolers cool water or brine.

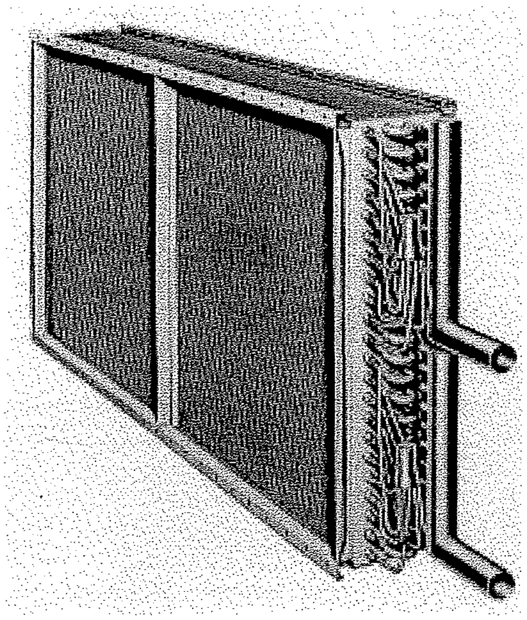


Figure C-23. Direct Expansion Cooling Coil.

Enrivonmental Systems Technology, W. D. Bevirt, 1984. Reprinted with permission of the National Environmental Balancing Bureau.

Cooling Towers

The heat generated by the operation of HVAC systems must be dissipated. Water is commonly used as a heat transfer medium to remove heat from refrigerant condensers or heat exchangers. In the past, this was accomplished by bringing large amounts of water from a natural or infinite source, heating it by thermodynamic heat transfer processes, and then discarding it back to the natural environment. Today the cost of water from utility services, and the cost of disposing it, is very high and unreasonable for cooling a large system.

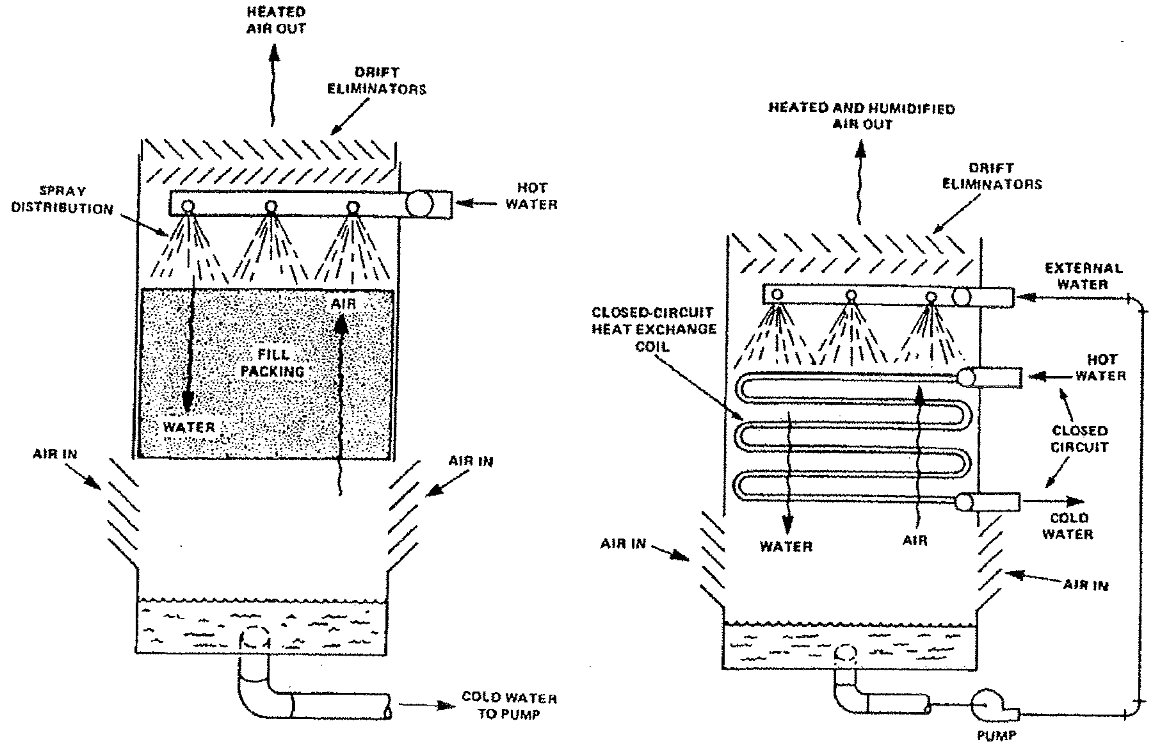
Cooling towers overcame several problems that became apparent with the old methods of cooing a system. The water consumption rate of a cooling tower system is only about 5 percent of that of a once-through system, making it the least expensive system to operate with purchased water supplies (ASHRAE 1988). Also, cooling towers can cool water to within 5 to 10 °F of the ambient wet-bulb temperature or about 35 °F lower than air-cooled systems of reasonable size.

Types of Cooling Towers

Figure C-24 shows the two basic types of evaporative cooling:

1. An external circuit which exposes water to the atmosphere as it cascades over the tubes of a coil bundle (direct-contact evaporative cooling tower).
2. An internal circuit in which fluid to be cooled is circulated inside the tubes of the coil bundle (indirect-contact evaporative cooling tower).

The internal fluid circuit is advantageous when the fluid inside the tubes is used to cool fluids other than water and to prevent contamination of the primary cooling circuit with airborne dirt and impurities. Heat transfers through the pipe walls from the internal fluid to the walls of the pipe and is finally absorbed into the external water circuit, which is cooled evaporatively.



(a) Direct-Contact Evaporative Cooling Tower (b) Indirect-Contact Evaporative Cooling Tower

Figure C-24. Cooling Tower Types.

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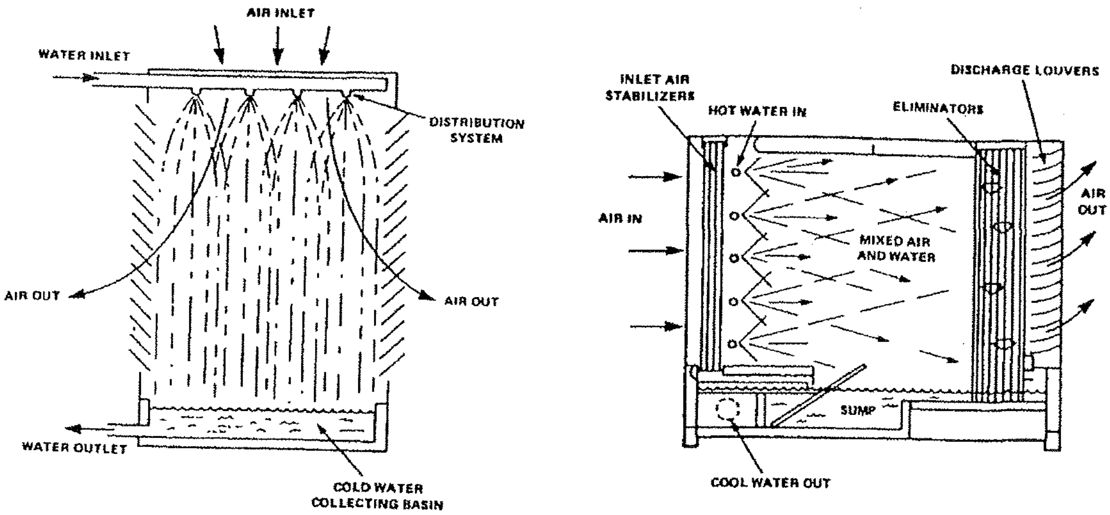
Spray-filled towers are a common method of exposing water to air in direct-contact devices where water is exposed to air without use of a heat transfer medium. There are several ways to increase contact surfaces as well as time of exposure of the water. One method is to use a heat transfer medium or fill by installing it below the water distribution system in the path of the air.

Two types of fill are splash-type and film-type. The splash-type fill maximizes contact area and time by forcing water to cascade through successive elevations of splash bars arranged in staggered rows. Film-type fills cause the same effect by having the water flow in a thin layer over closely spaced sheets (usually PVC) that are arranged vertically.

For thermal performance levels usually found in air conditioning and refrigeration, the tower with film-type fill is usually more compact. Splash-type fill is less sensitive to initial air and water distribution and is usually the fill of choice for water qualities that are conducive to plugging.

Direct Contact Cooling Towers

Nonmechanical draft towers. This type of cooling tower is aspirated by sprays or density differential and does not contain a fill or use of a mechanical device such as a fan. The aspirating effect of the water spray, either vertically or horizontally, induces airflow through the tower in a parallel flow pattern as depicted below in Figure C-25.



(a) Vertical Spray Tower (b) Horizontal Spray Tower

Figure C-25. Nonmechanical Draft Towers.

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Mechanical draft towers. When the fan in a cooling tower is on the inlet air side, it is called forced-draft. When the fan is on the exit air side, it is known as induced draft. Depending on the external pressure needs and sound level acceptance, a centrifugal or axial fan is chosen.

In mechanical draft towers, water flow is downward and airflow is either upward (counterflow heat transfer) or horizontal (crossflow heat transfer). Air may enter one side or two sides of the tower.

Towers are classified as either factory-assembled or field-erected. Figure C-26 shows the various types of mechanical draft cooling towers.

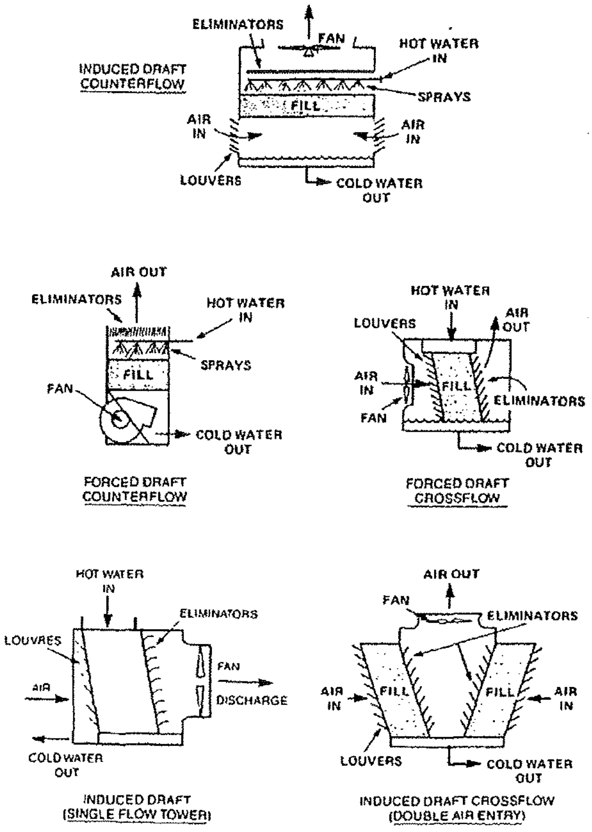

Figure C-26. Conventional Mechanical Draft Cooling Towers.

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Indirect Contact Cooling Towers

Closed circuit fluid coolers (mechanical draft). Counterflow and crossflow types are used in forced and induced fan arrangements as in Figure C-24. The tubular heat exchangers are typically serpentine bundles, usually arranged for free gravity internal drainage. Pumps are used to transport water from the lower collection basin to the upper distribution basin or sprays. The internal coils are predominantly fabricated of galvanized steel or copper. Closed circuit fluid coolers that are similar to evaporative condensers are increasingly used on heat pump systems and screw compressors.

Coil shed towers (mechanical draft). In coil shed towers, both crossflow and counterflow types are available with either induced or forced fan arrangements. These towers usually have isolated coil sections that are nonventilated, and are located beneath a conventional cooling tower.

Redistribution water pans located at the tower's base feed cooled water by gravity flow to the tubular heat exchange bundle (coils). These units are typically arranged as field-erected, multifan cell towers and are used primarily in the process cooling industry.

Selection Considerations

Choosing the right water-cooling equipment for a specific application requires some insight into the cooling duty, economics, required service, and environmental conditions. Although each of these considerations are integrated in some respects, they should be evaluated separately.

Also influencing the selection of equipment will be other physical parameters such as size, height, length, width, plan area, volume of airflow, fan and pump energy consumption, materials of construction, water quality, and availability.

The optimum choice is generally made after an economic evaluation is completed. Some initial cost considerations might include:

1. Erected cost of equipment
2. Cost of interphase with other equipment or subsystems that include:
    a. Basin grillage* and value of space occupied.
    b. Cost of pumps.
    c. Electrical wiring to pump and fan motors.
    d. Electrical controls and switch gear.
    e. Cost of piping to and from tower.
    f. Tower basin, sump screens, overflow piping, and makeup lines (if not provided by the manufacturer).
    g. Shut off and control valves (when not furnished by the manufacturer).
    h. Walkways, ladders, etc. to provide access to the tower.

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* Basin grillage is used to reduce turbulence in the basin.

Ownership and Maintenance Costs

Things to consider in the long term of ownership are system energy costs (fans, pumps, etc.) on the basis of operating hours per year, demand charges, expected equipment life, maintenance and repair costs, and initial costs.

In addition to the long-term costs, some elements are required by code. Note the following:

- Safety features and safety codes
- Conformity to building codes
- General design and rigidity of structures
- Relative effect of corrosion, scale, or deterioration on service life
- Availability of spare parts
- Reliability of manufacturers.

Refrigerants

Refrigerants are the working fluids in refrigeration systems. They absorb heat from the system by evaporating and then dispose of the heat by condensing from a vapor back into a liquid. This process can occur in both the mechanical compression system and the absorption system.

Choosing a refrigerant for a particular application depends on several properties:

- *Flammability:* Ability to burn or support combustion.
- *Toxicity:* Poison content.
- *Specific Volume:* Volume of fluid per unit mass.
- *Normal Boiling Point:* Temperature at which the vapor pressure of a fluid is one standard atmosphere (14.696 psi). This measurement can be a direct indicator of the temperature level at which a refrigerant can be used.
- *Viscosity:* Internal frictional resistance exhibited by a fluid in resisting a force that tends to cause the liquid to flow.

Compressors can use refrigerants with properties besides those listed above. The choice of refrigerant will depend on the specific characteristics of that system and the system's cooling requirements.

Centrifugal

Centrifugal compressors work well in handling relatively high flow rates of suction vapor. Volumetric flow of suction vapor increases with lower suction temperatures and higher capacities, and higher pressure refrigerants like R-12 and R-22 work well.

The weight of refrigerant piping as well as the physical size and other components of the refrigeration system are reduced by the use of higher pressure refrigerants. R-113, R-11, R-114, R-12, R-500, or R-22 are commonly used due to this reason.

Reciprocating

The compressor size can be reduced and the total chiller price is low if the compressor displacement required for a given capacity is minimized. R-22 is commonly used for this reason. R-717 has the same advantage, but it is incompatible with copper and has an unpleasant odor.

Low temperature applications usually use R-22, R-502, and R-717. High condensing temperature applications, such as heat recovery units or heat pumps, can use R-12 or R-500 due to lower discharge temperatures and condensing pressures.

Discharge gas temperatures do not increase rapidly with the compression ratio and make R-12 and R-502 suitable for low evaporating and high condensing temperature applications.

Screw

R-500 and R-12 are usually used in heat-recovery installations where temperatures of the heat-transfer media range up to 158 °F. R-22 and R-717 are commonly used since screw compressor sizes are relatively small.

Alternative Refrigerants

As the production of chlorofluorocarbons (CFCs) is reducing, existing chillers need to be retrofitted with alternative refrigerants. The Clean Air Act of 1990 established legislation on the elimination of the use of CFCs. The Act calls for incrementally reducing and then terminating all production of CFCs, halons, and other ozone-destructive chemicals by the year 2000 in developed nations, and by 2010 for developing nations. This accelerated phaseout is expected to cause shortages of CFCs before the end of the decade. Also, an increasing tax rate went into effect in 1990 to discourage their use.

Substitute refrigerants have been developed to replace those with CFCs. One of these substitutes is HFC-134a (R-134a), which contains no chlorine, and has no effects on the ozone layer. Other substitutes are HCFC-123 (R-123) and HCFC-22 (R-22), which do contain chlorine, but break down in the atmosphere much faster than CFCs. These substitutes, while effective in reducing the amount of CFCs in the atmosphere, operate less efficiently than current refrigerants. This means that more fossil fuels are burned to make up for the lower efficiency. This increased fossil fuel consumption limits the effectiveness of these substitutes as viable alternatives.

These substitute refrigerants are limited in use as well by the Clean Air Act. The Act allows manufacturers to sell (until 2020) new refrigeration equipment that uses HCFCs. After 2020, only service on existing equipment will be allowed. The Act also freezes production levels of HCFCs beginning in 2015 and bans all production in 2030. The final solution to this problem has yet to be determined, but it will have a large effect on all refrigeration systems.

Retrofitting equipment currently using R-11 may involve replacing seals, gaskets, bushings, motor insulation, compressor motor, or diaphragms to use R-123. Because of its pressure rating, R-123 is the only alternative for R-11 at this time. R-123 has a higher specific volume and lower acoustic velocity than R-11. An R-123 compressor will have to circulate 10 to 15 percent more inlet cubic feet per minute and generate about 7 percent more lift or head given the same capacity requirements. Compressor capacity losses range from 0 to 18 percent.

Medium pressure chillers, which now use R-12 or R-500, will be retrofitted with R-134a. Changing to this refrigerant will typically require a gear drive change. The combination of higher acoustic velocity and higher suction specific volume, (characteristics of R-134a) results in a higher required compressor lift or head.

5 Design

Sizing and Specifying Chillers

Costs

In times of energy awareness and cost-effective spending, it is important that the cooling load size be calculated accurately. If the total required chiller capacity is not known accurately, the chiller owning cost may be unnecessarily high, as cooling load size is one of the largest factors in the cost of owning a chiller.

Oversized equipment can cause problems. One problem is the surging or frequent on/off cycling of centrifugal machines at low loads. When methods of estimating loads are used, the practice of adding a 10 to 20 percent safety factor is unnecessary because of the availability of accurate methods. Adding the safety factor also proportionately increases the cost of purchase, installation, and poor efficiency from wasted power.

The undersizing of equipment should be considered unacceptable in practice, yet the problem of undersizing is not of such serious consequences as oversizing. The consequence of a small underestimation is the increase in chilled liquid temperatures for a few design load days of the year.

The total cost of ownership is the primary criterion for equipment selection. Such criterion is comprised of the following:

- *Purchase Price:* Each machine type and manufacturer's model should include all the necessary auxiliaries such as starters and vibration mounts. If they are not included, their price should be added to the base price.

- *Installation Cost:* Factory-packaged machines are less expensive to install and usually considerably more compact, resulting in space savings. The cost of field assembly of field erected chillers should also be evaluated.

- *Energy Cost:* If using an estimated load schedule and part-load power consumption curves furnished by the manufacturer, a year's energy cost should be calculated.

- *Maintenance Cost:* Each bidder could be asked to quote on a maintenance contract on a competitive basis.

- *Insurance and Taxes:* Hermetic units often require higher insurance premiums.[*] Purchase price is the most used criterion, yet the cost of energy is causing the operating cost to be more deeply scrutinized in certain sectors. Package arrangements and accessories which offer increased operating economy are increasing in use.

Methods of Selection

The following is used as a guide for determining the types of liquid chillers generally used for air conditioning:

up to 25 tons (88 kW)	Reciprocating
25 to 80 tons (88 to 280 kW)	Reciprocating or Screw
80 to 200 tons (280 to 700 kW)	Reciprocating, Screw, or Centrifugal
200 to 800 tons (700 to 2800 kW)	Screw or Centrifugal
above 800 tons (2800 kW)	Centrifugal

For air-cooled condenser duty, brine chilling, or other high head applications from 80 to 200 tons (280 to 700 kW), reciprocating and screw liquid chillers are more frequently installed than centrifugal.

Reciprocating. Two types of ratings are published:

- *Packaged Liquid Chiller:* This lists values of capacity and power consumption for many combinations of leaving condenser water and chilled water temperatures.

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[*] When the unit breaks down, the entire unit must be replaced.

- *Capacity and Power Consumption at Varying Temperature:* Specific equipment such as remote condenser, evaporative, water-cooled, or air-cooled chillers are selected to achieve these requirements.

With all liquid chilling systems, condensing temperature increase means greater power consumption. So, the smallest packaged chiller, with the lowest ratio of input to cooling capacity, can be used for the following: low condenser water temperature, relatively large remote air-cooled condenser, or when leaving chilled water temperature is high. Just because the liquid chiller cost is minimized does not mean the cost of the total system will be low. For example, an increase in cooling tower or fan coil cost will reduce or offset the benefits of reduced compression ratio.

Centrifugal. The details specified for centrifugal systems include the number of passes in each of the heat exchangers and may include changes in rated motor kilowatt capacity of turbine size, code indication for driving gear ratio, and code indication of impeller diameters.

The maximum number of condenser and cooler water passes should be used without producing excessive water pressure drop. The greater the number of waterside passes, the less the power consumption.

Noise and vibration control are another consideration in selecting equipment (see acoustics in the **Installation** section).

Screw. Screw chiller ratings are presented similarly to those of the centrifugal-chiller ratings. Tabular values of capacity and power consumption at various chilled water and condenser water temperatures are given.

In addition, ratings are given for packages minus the condenser, listing capacity, and power vs. chilled water temperature and condensing temperature. Ratings for compressors alone are also common.

Codes

Refrigerants

The 1988 edition of the Uniform Mechanical Code (UMC) requires that refrigerants be classified in the following two groups.

Group 1: Refrigerants are noncorrosive, nonflammable, nontoxic, nonexplosive, and can be used in HVAC systems.

R-11
R-12
R-13
R-13B1
R-14
R-21
R-22
R-30
R-113
R-114
R-115
R-C318
R-500
R-502
R-744

Group 2: Refrigerants can be used in some process installations but are generally not used in HVAC systems because they are toxic.

R-40
R-611
R-717 (ammonia)
R-764

The most common refrigerants used in HVAC systems are R-11, R-12, R-22, R-113, R-114, and R-500.

Condensing units or combinations of refrigerant-interconnected condensing units that contain a Group 1 refrigerant and totals a 100 horsepower rating or more shall be enclosed in a refrigeration machinery room (exceptions to this are allowed; consult UMC).

A refrigerating system containing a Group 2 refrigerant will not be located within a building unless all refrigerant-containing portions of the system are enclosed in a refrigeration machinery room. If installed outside, it shall be located 20 ft or farther from any window, ventilating-air inlet, or exit door in a building.

Machinery Rooms

Code required machinery rooms will be built of 1-hour (or greater) fire-resistive construction. Doors will open in the direction of egress, and comply with the Uniform Building Code (UBC). Openings that would permit the passage of escaping refrigerant to other parts of the building are not allowed. Machinery rooms will be 50 sq ft in area or larger.

All moving machinery contained in these rooms will have at least a 2 ft 6 in. wide by 7 ft high unobstructed working space extending around two adjacent sides of the equipment.

At least one exit door 3 ft by 6 ft 8 in. or larger shall be used with equipment containing Group 1 refrigerants. At least two exit doors, located at least one-fifth the perimeter of the room apart, shall be used with equipment containing Group 2 refrigerants. These doors will be at least 3 ft wide by 6 ft 8 in. in height.

Absorption systems containing a Group 2 refrigerant will be installed in a refrigeration machinery room.

Section 1507 of the UMC states that: "There shall be no direct opening between a refrigeration machinery room containing a Group 2 refrigerant, and a room or space in which there is an open flame, spark-producing device, or heating surface hotter than 800 °F."

Ventilation requirements for machinery rooms and other rooms containing portions of a condensing unit should be followed. Restrictions concerning the location of electrical equipment within a machinery room should also be followed.

Clearances and Supports

The 1988 edition of the UMC requires that: "A compressor or portion of a condensing unit supported from the ground shall rest on a concrete or other approved base extending not less than 3 inches above the adjoining ground level." This requirement also pertains to absorption systems. In addition to this, aboveground platforms used for evaporative coolers will be 6 in. above the adjoining ground level.

UMC also required that a 2 ft or greater unobstructed access opening and passageway be provided and maintained to a compressor.

Absorption systems containing a Group 2 refrigerant weighing more than 20 lb will be located 20 ft or more from any window, door, or ventilating air inlet to a building. Absorption systems containing a Group 2 refrigerant will not be located in any building unless installed within a mechanical room.

Equipment

Piping and tubing shall have points of support every 15 ft or less. A securely fastened permanent support shall be provided within 6 ft following the first bend in tubing from the compressor, and each other bend or angle shall have these supports within 2 ft. Piping crossing an open passageway shall be a minimum of 7-1/2 ft above the floor unless it is against the ceiling in the space. Piping and tubing should be checked with UMC pertaining to size, use, refrigerant, and material.

A stop valve will be installed in refrigerant piping at the outlet and inlet of every positive-displacement type compressor; at each refrigerant outlet from a receiver; and at each refrigerant inlet of a pressure vessel containing liquid refrigerant and in excess of 3 cu ft in internal gross volume. Stop valves made of copper tubing 3/4 in. or less outside diameter will be supported independent of the tubing or piping connected to the valve.

A pressure-limiting device will be installed on a positive displacement refrigerant compressor that is a portion of: a system containing Group 2 refrigerant, an air-cooled system containing Group 1 refrigerant that is of 10 hp or more in rating, or a water-cooled system containing Group 1 refrigerant with a rating of 3 hp or more. A stop or shutoff valve will not be placed between a pressure-limiting device and the compressor it serves.

Sections 1515-1517 of the UMC should be consulted for various pressure-relief valve and pressure-relief device requirements.

Refrigerating systems containing a Group 2 refrigerant or carbon dioxide and located inside a building are required to have a means for manual discharge of the refrigerant into the atmosphere. These systems will also be equipped with manual means of releasing the refrigerant from the high-pressure side of the system to the low-pressure side.

6 Installation

Testing, Adjusting, and Balancing (TAB)

The following is a preliminary check list to aid in the preparation for TAB:

1. Obtain a piping flow diagram showing all equipment. Record flow rates and temperatures on the diagram.
2. Obtain all equipment data from the manufacturers, and from the design specifications.
3. Obtain and calibrate the instrumentation that applies best to each TAB task.
4. Decide where all measurements will be taken, and check to see if access is possible.
5. Make sure all valves and controls are in correct position.

The following is a basic TAB procedure to ensure proper flow through the chiller:

1. Check pump speed with condenser and chilled water design.
2. Slowly close the pump discharge balancing valve, recording discharge and suction heads, motor amps, and volts. Repeat this for various settings from valve fully closed to fully open. This information can be used to plot a pump performance curve. The pump head can then be corrected for any differences in velocity heads entering and leaving.
3. Adjust the system flow to approximately 110 percent of design GPM (according to pump curve).
4. Check and balance flow rates through large coils and chiller. Adjust balancing valves to within ± 10 percent of design GPM.
5. Check and balance flow rates to terminal units and adjust to within ± 10 percent of design GPM.
6. Repeat the balancing process until no change is found.
7. Measure and adjust water flow to cooling tower. Check performance of cooling tower by measuring water flow rate and temperatures, and air dry-bulb and wet-bulb temperatures in and out.
8. Carry out performance tests of chiller(s) and cooling tower(s) with the help of manufacturer's field engineers.

Acoustics

Because of their noise, it is highly advisable to locate chillers far away from any noise-sensitive area.

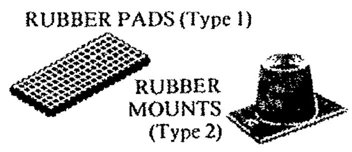
Two forms of vibration reduction—damping and isolation—can be used. Damping is accomplished by rigidly coupling the vibrating source to a large mass, often referred to as an inertia block. A great amount of the energy is absorbed and dissipated as friction. The remaining vibration results in lower-amplitude vibration. Isolation is accomplished by supporting the vibrating mass on resilient supports. Figure C-27 shows examples of vibration reduction applications.

Machines can be supported on fibrous, rubber, or steel vibration isolators, and the entire mass can be supported on a floating floor that rests on resilient vibration isolators. Flexible joints in all pipes and ducts connected to a vibrating machine are mandatory.

Large machines are supported on special commercial "sandwiches" of lead, cork, and other resilient materials. Machines with a dominant vibrational frequency can have special springs designed to give maximum isolation and damping at that frequency. Massive machines and impacting devices use huge inertia blocks and even separate foundations to isolate their vibration.

Reciprocating and centrifugal chillers are among the mechanical equipment that require the most concern with respect to acoustical considerations. As is true with all mechanical equipment, the quality of noise data available from manufacturers varies tremendously. Some manufacturers perform exhaustive tests according to specific test standards and can provide very useful test data. With other manufacturers, caution should be exercised in looking at their data.

Reciprocating chillers are most commonly seen in applications requiring small cooling capacities, generally below 300 tons. The reciprocating motion of this chiller generates a great amount of noise and vibration. This makes the location of the equipment critical if noise intrusion into adjacent spaces is going to be a problem. These chillers are best installed only in slab-on-grade or basement locations where the vibration isolation can be accomplished easily. Even in basement locations, spring isolators will probably be required along with resilient flexible connections for all piping, electrical, and plumbing connections to the chiller.

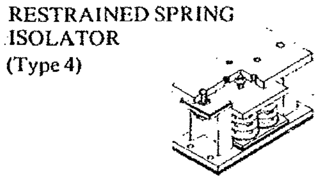


Note 20. Rubber isolators are available in pad (Type 1) and molded (Type 2) configurations. Pads are used in single or multiple layers. Molded isolators come in a range of 30 to 70 durometer (a measure of stiffness). Material in excess of 70 durometer is usually ineffective as an isolator. Isolators are designed for up to 0.5-in. deflection, but are used where 0.3-in. or less deflection is required. Solid rubber and composite fabric and rubber pads are also available. They provide high load capacities with small deflection and are used as noise barriers under columns and for pipe supports. These pad types work well only when they are properly loaded and the weight load is evenly distributed over the entire pad surface. Metal loading plates can be used for this purpose.

Note 21. Precompressed glass fiber isolation pads (Type 1) constitute inorganic inert material and are available in various sizes in thicknesses of 1 to 4 in., and in capacities of up to 500 psi. Their manufacturing process assures long life and a constant natural frequency of 7 to 15 Hz over the entire recommended load range. Pads are covered with an elastomeric coating to increase damping and to protect the glass fiber. Glass fiber pads are most often used for the isolation of concrete foundations and floating floor construction.

Note 22. Steel springs are the most popular and versatile isolators for HVAC applications because they are available for almost any deflection and have a virtually unlimited life. All spring isolators should have a rubber acoustical barrier to reduce transmission of high-frequency vibration and noise that can migrate down the steel spring coil. They should be corrosion-protected if installed outdoors or in a corrosive environment. The basic types include

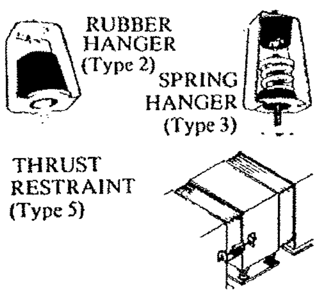
1. **Note 23.** Open spring isolators (Type 3) consist of a top and bottom load plate with an adjustment bolt for leveling. Springs should be designed with a horizontal stiffness at least 100% of the vertical stiffness to assure stability, 50% travel beyond rated load and safe solid stresses.



2. **Note 24.** Restrained spring isolators (Type 4) have hold-down bolts to limit vertical movement. They are used with (a) equipment with large variations in mass (boilers, refrigeration machines) to restrict movement and prevent strain on piping when water is removed, and (b) outdoor equipment, such as cooling towers, to prevent excessive movement because of wind load. Spring criteria should be the same as for open spring isolators, and restraints should have adequate clearance so that they are activated only when a temporary restraint is needed.

3. Housed spring isolators consist of two telescoping housings separated by a resilient material. Depending on design and installation, housed spring isolators can bind and short circuit. Their use should be avoided.

Air springs can be designed for any frequency but are economical only in applications with natural frequencies of 1.33 Hz or less (6-in. or greater deflection). Their use is advantageous in that they do not transmit high-frequency noise and are often used to replace high deflection springs on problem jobs. Constant air supply is required, and there should be an air dryer in the air supply.



Note 25. Isolation hangers (Types 2 and 3) are used for suspended pipe and equipment and have rubber, springs, or a combination of spring and rubber elements. Criteria should be the same as for open spring isolators. To avoid short circuiting, hangers should be designed for 20 to 35° angular hanger rod misalignment. Swivel or traveler arrangements may be necessary for connections to piping systems subject to large thermal movements.

Note 26. Thrust restraints (Type 5) are similar to spring hangers or isolators and are installed in pairs to resist the thrust caused by air pressure.

Figure C-27. Vibration Reduction Applications.

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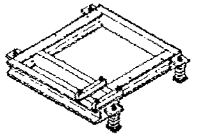
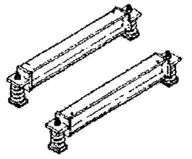
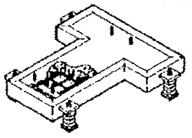
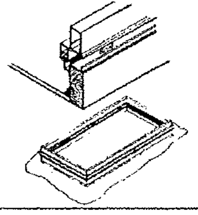
STRUCTURAL BASES (Type B) 	**Note 28.** Structural bases (Type B) are used where equipment cannot be supported at individual locations and/or where some means is necessary to maintain alignment of component parts in equipment. These bases can be used with spring or rubber isolators (Types 2 and 3) and should have enough rigidity to resist all starting and operating forces without supplemental hold-down devices. Bases are made in rectangular configurations using structural members with a depth equal to one-tenth the longest span between isolators, with a minimum depth of 4 in. Maximum depth is limited to 12 in., except where structural or alignment considerations dictate otherwise.
STRUCTURAL RAILS (Type B) 	**Note 29.** Structural rails (Type B) are used to support equipment that does not require a unitary base or where the isolators are outside the equipment and the rails act as a cradle. Structural rails can be used with spring or rubber isolators and should be rigid enough to support the equipment without flexing. Usual industry practice is to use structural members with a depth one-tenth of the longest span between isolators with a minimum depth of 4 in. Maximum depth is limited to 12 in., except where structural considerations dictate otherwise.
CONCRETE BASES (Type C) 	**Note 30.** Concrete bases (Type C) consist of a steel pouring form usually with welded-in reinforcing bars, provision for equipment hold-down, and isolator brackets. Like structural bases, concrete bases should be rectangular or T-shaped and, for rigidity, have a depth equal to one-tenth the longest span between isolators, with a minimum of 6 in. Base depth need not exceed 12 in. unless it is specifically required for mass, rigidity, or component alignment.
CURB ISOLATION (Type D) 	**Note 31.** Curb isolation systems (Type D) are specifically designed for curb-supported rooftop equipment and have spring isolation with a watertight and airtight curb assembly. The roof curbs are narrow to accommodate the small diameter of the springs within the rails, with static deflection in the 1- to 3-in. range to meet the design criteria described for Type 3.

Figure C-27. Vibration Reduction Applications (continued)

Because turbulence in the chilled water pipes can be significant, it is necessary in a majority of cases also to isolate the pipes from the supporting structure with spring hangers. If the chiller is located anywhere close to a sensitive area, care must be exercised in assuring that adequate isolation is provided.

For applications where over 300 tons of cooling is necessary, centrifugal chillers are generally chosen. These are either direct or gear driven machines. All centrifugal chillers have a smooth rotary motion to their operation, which generates far less vibration than the reciprocating chillers. Centrifugal chillers also generate less low-frequency noise than reciprocating chillers. The higher operating speed of centrifugal chillers puts the majority of their generated noise in the mid-frequency range.

7 Operation and Maintenance

Controls for Chillers

Chiller Plants

Chiller plants are generally specified as variable flow or constant flow (Figures C-28 and C-29). The type of control of the remote load is the determining factor. Remote loads with two-way control valves require variable flow, whereas remote loads with three-way valves permit constant flow.

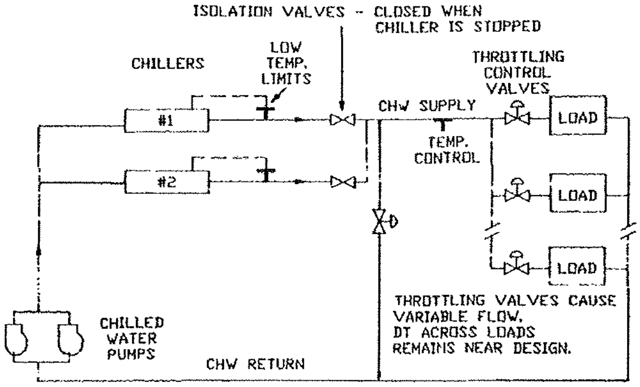


Figure C-28. Variable Flow Chilled Water System (Parallel Flow).

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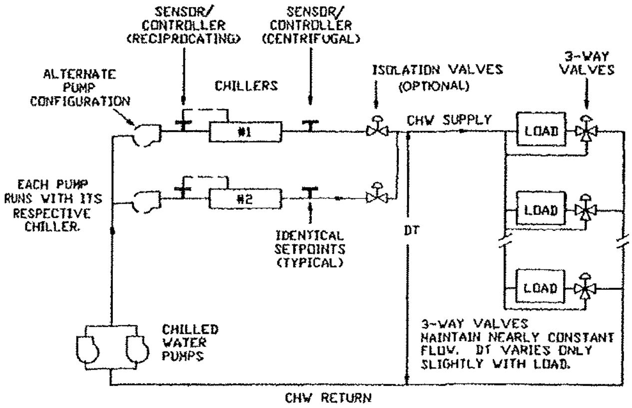

Figure C-29. Constant Flow Chilled Water System (Parallel Flow).

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Liquid Chillers

Some common controls for liquid chillers are:

- *Chilled Liquid Temperature Sensor:* Sends signal to the control circuit, which modulates compressor capacity.
- *Water Temperature Controller:* Cycles the compressor(s) when the cooling load drops below a minimum.
- *Anti-Recycle Timer:* Limits starting frequency.
- *Current Limiter:* Limits compressor capacity during periods of high power consumption.
- *High Pressure Cut-Out:* Pressure actuated switch used to protect the compressor from pressures caused by lack of water or air, or high condenser temperatures.
- *Low Pressure Cut-Out:* Pressure or temperature actuated device used in the evaporator to protect it from freezing chilled water. Direct-expansion systems cannot use this device.
- *High Oil Temperature:* Protects the compressor if loss of oil cut-out cooling occurs or if a bearing failure causes excessive heat generation.
- *Oil Failure Switch:* Shuts down the compressor if oil pressure drops below a minimum value, or if sufficient oil pressure is not developed shortly after compressor start-up.
- *High Motor Temperature Sensor:* Shuts down machine if loss of motor cooling, or overload because of a failure of operating controls occurs.
- *Low Oil Sump Temperature Switch:* Protects against an oil heater failure, or prevents starting after a prolonged shutdown before the oil heaters have had time to drive off refrigerant dissolved in the oil.
- *Chilled Liquid Flow Interlock Switch:* Protects external piping against a cooler freeze-up in the event of a liquid flow stoppage.

These devices may or may not be furnished with the liquid chilling package. The chiller type will determine which ones need to be used.

Centrifugal and screw chillers have a wide range of capacity through continuous modulation. Reciprocating chiller capacity reductions are limited to specific values. Temperature control is therefore set up differently in these systems.

Each central chiller plant is different, with different characteristics of sizes, manufacturers, chiller types, cooling towers, drives, piping configurations, and loads, so controls are custom designed for each plant.

Absorption

Absorption units usually come with a control panel containing electric motor starters, fuses, and other controls that can be grouped in a panel. A control voltage transformer and disconnect switch may also be included. These are all factory wired and installed. Additional controls commonly available are:

1. Condensing water-flow switch
2. Controls for series or parallel unit operation
3. Solution flow control
4. Automatic de-crystallization control
5. Steam demand limiter.

Some typical protective controls for absorption cooling are:

- *Low Temperature Cut-Out:* Thermostat that stops the unit when the evaporator temperature falls too low.
- *Cooling-Water Switch:* Stops the unit when the cooling water supply fails.
- *Chilled-Water Switch:* Stops the unit when the chilled water flow drops below design limits.
- *Concentration Limiters:* Sensors that indicate limiting conditions of absorbent concentration. They reset when the limiting conditions no longer exist.
- *Overflow Piping ("J" Loop):* Allows hot solution from the generator to overflow to the absorber in case another control fails.
- *Hot Water Cut-Out:* For machines with heating capabilities, temperature cutout limits the temperature and restarts the machine when an acceptable level is reached.
- *Protective Devices for Direct-Fired Machines:*
  - Low level switch (for solution)
  - High pressure switch
  - High temperature control
  - Flame ignition and monitoring control.

Computer Applications for Chillers

The use of computers as a management tool allows a building to be viewed as a complete system by monitoring loads and trends, and by rapidly providing operational profiles. The energy usage and performance of chiller components within a system can be monitored by a computer. The organized relationship of the coils with the central chiller plant, and with one another, is the major influence in an energy conservation program.

The following is a basic evaluation procedure for a central processor managing a chiller:

1. Total all loads.
2. Total load is matched with a list of available sources to match current source capacity most efficiently with total load.
3. Downtime and demand considerations are taken into account when a list of available sources is being generated.
4. If downtime or demand considerations call for stopping a given chilled water source, the source is removed from the list until it is available again.
5. Start no source that has been recently stopped.
6. Stop no source that has been recently started.
7. Select sources by considering expected load changes based on time-of-day experiences and outside conditions.
8. Communicate start/stop requests to stand alone microprocessors.

In addition to operating the equipment, the following information could be obtained from the central processor:
- Building load vs. time of day
- Total load vs. time of day
- Building demand vs. time of day
- Total demand vs. time of day
- Individual source total operating time.

Maintenance

Reciprocating, Centrifugal, and Screw Chillers

As with the absorption chiller, the manufacturer's specific recommendations should be followed. Below is a list of general maintenance specifications that apply equally to reciprocating, centrifugal, and screw chillers. In general, equipment should be neither overmaintained nor neglected.

Continual Monitoring:

1. Condenser water treatment is determined specifically for the condenser water used.
2. Operating conditions - daily log sheets are recommended.

Periodic Checks:

1. Leak check
2. System dryness
3. Oil level
4. Oil filter pressure drop
5. Refrigerant quantity or level
6. System pressures and temperatures
7. Water flows
8. Expansion valves operation.

Regularly Scheduled Maintenance:

1. Condenser and oil cooler cleaning
2. Calibrating pressure, temperature, and flow controls
3. Tightening wires and power connections
4. Inspection of starter contacts and action
5. Dielectric checking of hermetic and open motors
6. Oil filters and drier change
7. Analysis of oil and refrigerant
8. Seal inspection
9. Partial or complete valve or bearing inspection
10. Manufacturer's recommendations.

Screw Chillers

Some maintenance for screw chillers differs substantially from reciprocating or centrifugal units, so special attention is given to the maintenance of the screw-type chiller.

Due to the large oil flows that are a part of the screw compressor system, the oil filter pressure drop should be monitored carefully and the elements changed periodically. This maintenance is very important in the first few months after start-up of any factory-built package and is absolutely essential on field-erected systems.

The oil and refrigeration systems merge at the compressor. Therefore, much of the loose dirt and fine contaminants in the system eventually find their way to the oil sump, where they are removed by the oil filter. The filter-drier cartridges should also be monitored for pressure drop and moisture during initial start-up, and regularly in the future life of the unit. If a system reaches a certain level of dryness where the amount of moisture in the system is not detrimental to proper functioning of the machine, then the dryness level is acceptable. Oil does not have to be changed unless it becomes contaminated by water, acid, or metallic particles. It is good practice to check the oil for acidity periodically, using commercially available acid test kits.

Absorption

The length of a machine's useful life and the extent to which it performs trouble-free is related directly to the care taken in maintaining the unit's cleanliness and tightness. Internal cleanliness and leak tightness that last the life of the unit are the most important considerations for operation and maintenance.

Before absorption machines are sent out from the manufacturer, rigid standards of manufacture are ensured by testing the product with sophisticated equipment. Electronic halide leak detectors and helium mass spectrometers are used to ensure that the equipment has no leaks before shipment from the factory. Vacuum integrity and internal cleanliness are also checked.

In addition to the many initial checks and assurances of the manufacturer, the owner must do many things to assure a long life for the equipment. As is true in any case, the manufacturer's instructions should be followed for any specific piece of equipment.

Units built most recently will use corrosion inhibitors to help protect the internal parts from corrosive attack. Even though a corrosion inhibitor is used in the system, proper maintenance with regard to purging and leak tightness still must be used.

When a machine is opened to the atmosphere for repair and maintenance, nitrogen should be used to break the vacuum. Nitrogen is used because it is an inert gas and will prevent corrosive attack on internal parts while they are exposed to the atmosphere.

Since purging is so important, the manufacturer's instructions on purge system maintenance should be followed, and the effectiveness of the purge system should be verified periodically. Leak tightness should also be evaluated periodically. All manufacturers describe procedures for measuring the leak rate, bubble count, or noncondensable accumulation rate of their machines. If the measured leak rate is excessive, it is important to find and repair the leak as soon as possible.

Internal cooling-water surfaces of the absorber usually require periodic cleaning by mechanical, chemical, or both means regardless of the effectiveness of the water treatment practices followed. The more effective the water treatment, the longer the allowable period between the cleaning.

Crystallization is the precipitation of salt crystals from absorbent. It is a slush-like mixture that can plug up pipelines and other fluid passages in the machine and cause it to stop operating. Crystallization used to occur in earlier models of absorption machines and may still occur in more recent models if they are not properly maintained. However, crystallization is not as common in the newer models.

Some models have a bypass pipe that will cause the solution to bypass the crystallization that usually occurs in the heat exchanger. The heat exchanger will naturally de-crystallize itself through the bypass process. Other manufacturers provide concentration control to avoid crystallization. The control of concentration is achieved by placing a device between the concentrator and the heat exchanger to sense and control the level of concentrate to the heat exchanger.

If a crystallization condition develops, the liquid level rises within the concentrated solution line as resistance to flow within the heat exchanger increases. The increase in level is sensed by the sensing device that opens the valve. The opening of the valve allows refrigerant to flow into the concentrated solution line, and reduces the solution concentrate. If crystallization does occur, it may be necessary to add water and heat to the part of the machine crystallized (usually the heat exchanger).

Crystallization does not harm the equipment, but it is a symptom of trouble and its cause should be found and corrected. The most common causes are controls that are improperly set or malfunctioning, sudden drops in cooling-water temperature, atmospheric air leaks into the machine, and electrical power failure.

Fouling of external or machine-side tube surfaces of an absorption machine is not a problem because there is no continuous source of scale-forming substances such as algae. Nevertheless, as with all heat-transfer devices involving the heating of water inside tubes, it is necessary to use good water treatment practices on the internal or water side of the absorber and condenser tubes.

Water Treatment

Closed Systems

Closed cooling systems confine cooling water within the system pipes and heat exchanger. Although generally defined as systems that require less than 5 percent makeup per year, it is not uncommon to have a closed system loose up to 25 percent per month. Therefore, it is desirable to treat the water in these systems.

Corrosion and corrosion product deposit are the most serious problems encountered. Corrosion is a process in which metal returns to its original state. The actual disintegration of the metal will only happen at the anode. Cathode and anode areas can shift, which allows uniform corrosion. Water characteristics that influence the rate of corrosion are: temperature, water velocity, amount of suspended solids, degree of acidity, presence of microbial growths, and the presence of O_2.

When corrosion happens, corrosion products can build up in the system and form deposits throughout the heat exchanger and piping. Glycol and alcohol solutions are commonly used in closed systems to prevent corrosion. Chromate inhibitors are the most effective, but cannot be used in locations where drainage water can cause pollution. Softeners should be added to makeup water to prevent scale.

Open Systems

Open circulating systems include cooling towers, evaporative condensers, or spray ponds. Water is continuously reused in these systems, but is also exposed to air. Makeup water must continuously be added to replace evaporated water and water lost through leaks.

Cooling tower problems are commonly classified into three categories: deposit formation, corrosion, and biological deposition.

Deposit formation. Deposit formation includes fouling and scale. Fouling is the accumulation of water-suspended materials on heat-exchanger surfaces. Scale is a coating of mainly inorganic materials, and results from supersaturation of water-soluble minerals. Deposits of both types reduce efficiency by reducing the rate of heat transfer within the heat exchanger. Fouling also aides in equipment deterioration.

Reduction of scale forming particles can be accomplished by lime-soda softening, ion exchange, or reverse osmosis. Solubilizing chemicals are also used to keep scale-forming materials in solution. The most commonly used are polymeric organics and organic phosphorus compounds. Crystal modifiers can also be used. These modifiers allow scale to form, but then deform the crystal structure, changing the scale into sludge. Sludge usually does not build up on heat-exchange surfaces. Polymaleic acids and sulfonated polystyrene are both effective modifiers.

Filters are widely used on cooling waters to remove foulants. Another technique for controlling fouling is injecting small rubber balls into and through heat exchanger tubes during operation, which wipes the tubes clean as they pass through. Chemical treatment is also used in controlling fouling. Fouling conditions and the particular foulant involved must be properly matched, as no one chemical is known to work on all foulant control problems.

Corrosion. Noncorrosive metals can be used in the design of a system to help minimize corrosion. Paint, epoxy, or metal plating can also be applied to help reduce corrosion. Another method is the application of cathodic-protection, which uses induced electrical currents.

Chemical inhibitors are another highly used technique, which allow a protective film to be formed over the metal. Inhibitors are fed into the cooling water and transported to the metal surfaces. Cathodic inhibitors interfere with cathodic reactions. These inhibitors reduce the corrosion rate in direct proportion to the reduction of the unprotected cathodic area. Anodic inhibitors are often considered dangerous. If used incorrectly, severe corrosion can occur in small, unprotected areas. This can lead to the metal perforating in a very short time. General corrosion inhibitors can also be used, which will protect both anodic and cathodic surfaces.

Biological deposition. Biological deposition includes macrobiological fouling of discharge and intake canals, and microbiological fouling of heat exchangers. When algae, bacteria, fungi, and other organisms enter a system, they search for the best environment suited to their growth. Treatment against these falls into three main categories: chemical, mechanical, and thermal.

Chemical treatment is very effective in dealing with biological deposition. Regulated limitations have been set on this type of treatment due to the increasing concern for environmental effects. Temperature, pH, system design, and limitations on the discharge of toxic substances should be considered when selecting a chemical treatment.

Mechanical methods include rakes, trash bars, and strainers. Physical cleanup is usually the most effective mechanical approach. This involves the use of brushes, scrapers, and sponge balls in the cleanup of accumulated inorganic foulants.

Thermal methods involve temperature elevation, which is based on the fact that some organisms cannot survive when exposed to extreme temperatures. This approach is often combined with a thermal-backwash procedure, in which reversible gates are used to alternate coolant-flow direction, which gives a flushing action.

8 Acceptance Testing

When testing a chiller, it is important for the instruments used in testing the equipment to be calibrated and functioning properly. It is also important that the testing personnel understand the functions of the instruments, and how to operate and collect data from them.

A report worksheet that lists all the data that need to be collected to analyze the operation of the chiller should be used by the testing personnel. The following worksheet contains four sections. Each section requires design data to be recorded and actual operating data to be collected. This allows a comparison to be made between the two sets of data. If the actual operating data differ significantly from the design data, the actual data should be measured again to make sure the test instruments are functioning properly. If the test instruments are found to be working properly and the actual data is still significantly different, then there is a need to troubleshoot the chiller to determine the reason for the discrepancy.

CHILLER SYSTEM ACCEPTANCE TESTING CHECKLIST

PROJECT:____
LOCATION:_______________________________________
NAME:____

		Correct		Date Checked
A. Evaporator		yes	no	
1. Installed gauges and controls				
2. Entering/leaving water temperature				
3. Water temperature, ΔT				
4. Correct flow (gpm)	Design	TAB	Actual	

		Correct		Date Checked
B. Condenser		yes	no	
1. Installed gauges and controls				
2. Entering/leaving water temperature				
3. Water temperature, ΔT				
4. Correct flow (gpm)	Design	TAB	Actual	

	Correct		Date Checked
C. Compressor	yes	no	
1. Installed gauges and controls			
2. Make/model			
3. Serial number			
4. Voltage: T_1-T_2, T_2-T_3 T_3-T_1			
5. Amps: T_1, T_2, T_3			

	Correct		Date Checked
D. Pumps-Motors	yes	no	
1. Make, model numbers, etc.			
2. Clean and free of foreign objects			
3. Rotation			
4. Lubrication			
5. Alignment/securely fastened			
6. Guards in place			
7. Pressure gauges installed			
8. Power available			
9. Disconnects installed and labeled			
10. Interlocks functional			

E. Pumps-Piping	Correct yes	 no	Date Checked
1. Flexible connectors			
2. Connections			
3. Pressure and temperature at pump inlet			
4. Air bled from casing where required			
5. Free of leaks			
6. Strainer clean			
7. Air vented			
8. Piping system pressure tested			
9. Pipes labeled			
10. Valves tagged			
11. Chemical treatment system installed			
12. Water treatment report submitted			
13. "TAB" complete and approved			
14. Correct flow (gpm)			

F. Cooling Tower/Evaporative Condenser	Correct yes	 no	Date Checked
1. Correct flow and connections			
2. Valves open or set			
3. Leakage			
4. Provisions made for "TAB" measurements			
5. Sump water level			
6. Spray nozzles			
7. Fan/pump rotation			
8. Motor/fan lubrication			
9. Drives and alignment			
10. Guards in place			
11. Starters and disconnect switches			
12. Electrical connections			
13. Nameplate data			

NOTES

- Compressor: Nameplate information may be checked to see that the proper chiller was installed.

- The voltage, amps, and kW input may be measured and evaluated by use of a voltammeter, which is an electrical, clamp-on type measuring device. With this device, transformer currents may be read without interrupting electrical services. When using this device, safety precautions must be taken. These precautions and testing procedures are found in many texts (SMACNA 1983; NEBB 1984).

- To measure voltage, set the meter to the most reasonable range, connect the test lead probes firmly against the terminals or other surfaces of the line being tested, and read the meter. Be sure to read the correct scale if the meter has more than one scale. When reading single-phase voltage, the leads should be applied to the two load terminals. When reading three-phase current, it is necessary to apply the probes to the terminal poles No. 1 and No. 2; then to poles No. 2 and No. 3; and finally to poles No. 1 and No. 3. The three readings that are obtained will probably be slightly different but close to each other. For practical purposes, the readings may be averaged. From the design data, determine if the voltage is high or low.

Glossary

ACOUSTIC VELOCITY: Velocity of sound; the practical velocity of a gas through openings or in piping is limited by this velocity.

BTU (BRITISH THERMAL UNIT): Energy; the amount of heat required to raise one pound of water by one degree F.

BTU/H: Power; used to express the total heat loss or gain of a building.

COEFFICIENT OF PERFORMANCE (COP): A factor that measures refrigeration requirements with power input.

COMPRESSOR: The pump in a mechanical refrigeration system that compresses the refrigerant vapor into a smaller volume, thereby raising the pressure of the refrigerant and consequently its boiling temperature. The compressor is the separation between the high and low side.

DAMPING: Diminishing by some means the activity caused by the introduction of energy to a system.

DOWNTIME: The increment of time a system or component of a system is not functioning or being utilized.

HEAD: Dynamic or total; in flowing fluids the sum of the static and velocity heads at the point of measurement.

HEAD, STATIC: The static pressure of fluid expressed in terms of the height of a column of fluid.

HEAD, VELOCITY: In a flowing fluid, the height of the fluid or of some manometric fluid equivalent to its velocity pressure.

HEAT EXCHANGER: A device specifically designed to transfer heat between two physically separated fluids.

MODULATION: Of a control, tending to adjust by increments and decrements.

NATURAL CONVECTION: Circulation of gas or liquid (usually air or water) due to differences in density resulting from temperature changes.

POSITIVE DISPLACEMENT COMPRESSOR: Increases the pressure of the refrigerant vapor by reducing the volume of the compression chamber by a fixed amount. Includes reciprocating and screw compressors.

PURGE: To free of sediment or relieve trapped air by bleeding.

REFRIGERANT, ABSORPTION CYCLE: Distilled water.

REFRIGERANT, REFRIGERATION CYCLE: A volatile substance that absorbs heat from a place where it is not wanted, and disposes of it in another place.

RESILIENCE: Ability to recover from or adjust to deformation usually caused by compression.

TESTING, ADJUSTING, AND BALANCING (TAB): Testing, adjusting, and balancing a system.

THERMAL EXPANSION VALVE: The metering device or flow control that regulates the amount of liquid refrigerant which is allowed to enter the evaporator.

TON, REFRIGERANT: One ton of refrigerant is the amount of cooling required to change one ton of water into one ton of ice over a 24 hour period.

VAPOR: A gas, particularly one near equilibrium with the liquid phase of the substance, and which does not follow the gas laws.

VARIABLE DISPLACEMENT COMPRESSOR: Uses force to raise the pressure of the refrigerant. Includes centrifugal compressors.

VIBRATION: An oscillatory motion generated by the introduction of energy to the piece affected.

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