6. Chillers

6.1 Explanation of Use

Refrigeration systems in the chemical industry range in capacity from one ton to thousands of tons. Typically, most of these are specially engineered, one-of-a-kind systems; equipment used in normal commercial applications may be unacceptable for chemical plant service. (2002 ASHRAE Refrigeration Handbook). Two types of systems are commonly found in this industry, mechanical and absorption. Recently, absorption equipment has seen little use in chemical plants, even in settings where waste process heat may be available to operate it because of the proximity of the heat source to the refrigeration requirements (2002 ASHRAE Refrigeration Handbook).

Chillers are typical refrigerant equipment that uses heat transfer between two different fluids to achieve desired temperatures. Chillers are air-cooled or water-cooled, depending on the capacity of the refrigeration system as well as the operating conditions of the system. The three primary components of a chiller are condensers, compressors, and evaporators (see Figure 6.1).

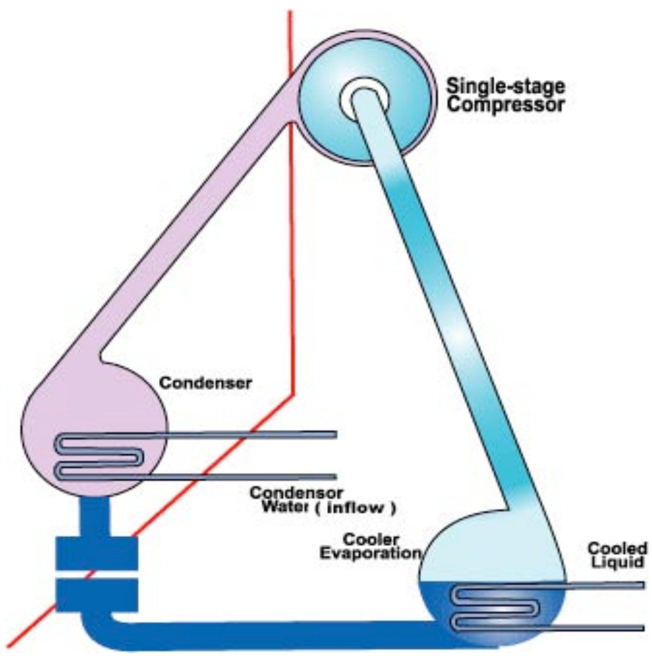

Figure 6.1 Centrifugal Single-Stage Compressors Diagram[35]

Typical chiller operation follows this general cycle:

1. Refrigerant flows over evaporator tube bundle and evaporates, removing heat energy from the fluid.

[35] Illustration recreated for the web sit for FEMP O&M Best Practices website by Technologist Inc. using graphics supplied by The boiler Efficiency Institute, Auburn, Alabama to PNL, for use on FEMP O&M website as a model at http://www.eere.energy.gov/femp/operations_maintenance/technologies/chillers/types.cfm

2. The refrigerant vapor is drawn out of the evaporator by a compressor that “pumps” the vapor to the condenser.
3. The refrigerant condenses on the condenser cooling coils giving its heat energy to the cooling fluid; the condensed refrigerant heads back to the evaporator.

6.2 Chiller Best Practices

6.2.1 Maintain an Accurate Log of System Operations

Proper maintenance procedures and accurate operating logs are important tools in any approach to improving chiller and cooling system efficiency. Proper maintenance ensures that a system operates as designed. To monitor and/or improve efficiency, you first must have accurate records of operating conditions. A daily operating log is the best method of tracking performance and detecting any changes. Without this information, system deficiencies cannot be readily detected. Maintenance needs may go unnoticed, increasing operating costs and risking major damage. Without accurate logs, it will be difficult to execute energy-saving strategies.

Best Practice—System Logs

- Maintain an accurate log of the primary indications of system operations. This should include condenser and evaporator entering and leaving temperatures, chiller load, various pressures (oil, refrigerant, etc) depending on chiller type, equipment in operation, motor voltage and amperage, weather conditions, and any other important factors.

6.2.2 Demand Limiters and Staggered Start

Most electric utilities base their demand charges on the amount of energy used during any 15- or 30-minute interval. This may be monthly or, in some instances, the demand rate may be set annually. Peak demand occurs during chiller startup; the most severe demand usually occurs on a hot summer morning when chillers are started and the system water is warm.

Best Practice—Use of Demand Limiters and Staggered Start

- The use of demand limiting can save significantly energy cost on utility bills in the category of demand charges. Most centrifugal chillers have either manual or automatic demand limiters. The use of these limiters can reduce the demand in any one period. When starting multiple chillers, stagger the starts at least by one demand period. Start the second chiller after the first has loaded.

6.2.3 Chill Water Reset

Many chiller and tower systems are designed for peak conditions that are experienced only a few days per year. At reduced loads, the cooling coils can produce the required cooling at higher chilled water temperatures because there is less need for dehumidification. Raising the chilled water temperature lowers the compressor head, resulting in decreased energy consumption. For centrifugal chillers at constant speed (not VSD equipped chillers), this strategy saves 0.5% to 0.75% per degree of reset. The efficiency of a constant-speed chiller, operating below 40% load, may lose efficiency by increasing the leaving chilled water temperature.

Centrifugal chillers equipped with variable-speed drives and operating at loads of 80% down to 10% will consume 2% to 3% less energy per degree of chilled water reset.

Best Practice—Chill Water Reset

- Reset the chill water temperature to the maximum that is required to meet the load on the system. This is best accomplished with automated controls and programming to reset on a dynamic basis.

6.2.4 Monitor for Refrigerant and Air Leaks

Any leaks in the closed-loop refrigerant system should be eliminated. In high-pressure chillers, refrigerant will leak out, reducing refrigerant charge, and air will leak into low-pressure chillers. In low-pressure refrigerant chillers, air collects in the condenser and displaces refrigerant vapor, resulting in higher condenser pressure and temperature. For every 1°F increase in condenser leaving temperature, energy consumption increases about 1.5%. Most low-pressure chillers use a purge unit to remove air. To reduce air problems, ensure the purge unit is functioning properly.

Best Practice—Monitor for Refrigerant and Air Leaks

- Periodically check low-pressure systems for excess air and high-pressure systems for proper refrigerant levels. Maintain a log of the results.

6.2.5 Monitor Refrigerant Levels

Incorrect levels of refrigerant limit a chiller's capacity, increasing head pressure and energy consumption. Incorrect levels also can decrease the evaporator temperature. For every 1°F that the evaporator temperature can be raised, 1.5% of the full-load energy can be saved.

Best Practice—Refrigerant Level Monitoring

- For centrifugal chillers, monitor and log the sight glass levels in the evaporator shell. Check for bubbles in the liquid line sight glass on reciprocating units, which indicate low level and high discharge pressure or low refrigerant temperature leaving the condenser for high levels. Maintain the level according to the manufacturer's instructions.

6.2.6 Use Optimum Condenser Temperature

Chiller manufacturers specify a minimum temperature for condenser water flowing into each chiller. Check with the manufacturer for recommended minimums for your model. Energy consumption is a function of the condenser pressure and temperature. Lowering the condenser water temperature reduces the refrigerant condensing temperature and condensing pressure. This reduces the lift required by the compressor and results in lower head pressure and reduced compressor energy consumption. Energy savings, at full-load, will be 1.5% per degree of reduction in entering condenser water temperature.

Best Practice—Condenser (cooling tower) Temperature

- Maintain the lowest condenser temperature recommended by the chiller manufacturer. Tower fans may consume some of the increased energy, but savings from the much larger compressor will offset it.

6.2.7 Maintain Optimum Cooling Tower Discharge Temperature

Condenser water temperature should be monitored at the cooling tower and at the condenser inlet to ensure that the lowest possible temperature is being maintained. If the entering condenser water temperature is more than 1-2°F higher than the temperature at the cooling tower, identify the cause and take corrective action. Many systems have a cooling tower bypass valve to mix warm return water with the water to the condenser for startup or cold weather operation. Check this valve for proper operation and adjustment. Pipe insulation may be warranted.

Best Practice—Maintain Cooling Tower Discharge Temperature

- Ensure that neither mechanical nor insulation issues are responsible for any temperature increases between the cooling tower and the chiller.

6.2.8 Maintain Chiller Condenser Tubes

Fouling of the condenser tubes (e.g., scale formation, sedimentation, slime, and algae growth) results from poor water treatment and/or poor maintenance of the system's waterside. Fouling is an insulator that impedes transfer between the refrigerant and the water. It increases both the condensing temperature and the head pressure. Increasing head pressure increases compressor energy use. Fouling can increase the temperature difference needed between the leaving condenser water temperature and the refrigerant condensing temperature to maintain the same cooling load. Each increase in temperature of 1°F increases the full load energy consumed by 1%.

Best Practice—Maintain Chiller Condenser Tubes in a Clean Condition

- The first line of defense is to follow good water treatment practices. This includes taking steps to control biocides, algae, and suspended solids. Filtration will assist in suspended solids control. Brush or high-pressure water cleaning of condenser tubes should be done annually at a minimum.

6.2.9 Maintain Optimum Condenser Water Flow Rate

Low water flow in the condenser increases head pressure and therefore energy consumption. A 20% reduction in the condenser flow rate will increase full-load energy consumption by 3%. Common causes of reduced flow are partially closed or damaged valves, clogged hot-deck nozzles in the cooling tower, clogged line strainers, sediment in the condenser tubes, and air in the system piping.

Best Practice—Condenser Water Flow

- Verify the condenser water flow by measuring it at least annually. A clamp-on or insertion flow meter can achieve this, if permanent measurement tools are not installed.

6.2.10 Monitor Motor Cooling

Chiller motor maintenance is a major area that is often neglected. The compressor motor is the largest energy consumer in the chiller system. Motor cooling is the most common cause of declining motor efficiency. If an increase in current draw is noted without a decrease in voltage, the motor may have a cooling problem brought on by blocked refrigerant lines in hermetic chillers, dirt-clogged air passages, or blocked air filters. Poor chiller room ventilation may also contribute to the cooling issue.

Best Practice—Motor Cooling

- When reviewing chiller logs, pay particular attention to the motor amperage vs. voltage to detect increases in amp draw. Check the motor for cooling problems. This should be a part of all annual chiller reviews.

6.2.11 Optimize Chiller Sequencing

Employing a chiller sequence can have a major impact on overall energy efficiency of the chiller plant. Usually, a centrifugal chiller is more efficient at full or nearly full load, while rotary screw chillers usually have the best efficiency at partial load. Reciprocating chillers vary and the exact unit specifications should be verified. When operating multiple chillers, always load the one that has the best efficiency for the current cooling demand before loading the other chillers, which use more energy. When starting a second or subsequent chiller, consider the characteristics of the other chillers. Operate the centrifugal chillers at full load and swing with the screw chiller if available. The use of variable speed drive chillers provides the ultimate in chiller employment efficiency.

Best Practice—Chiller Employment

- Always consider efficiency vs. load when starting and stopping chillers. Various chiller designs have different partial load and full load efficiencies. Also, consider the efficiency of the chillers on line as a group. Choose the best combination for the best energy efficiency.

6.2.12 Chiller Water Flow Isolation

Effective management of water flow to the chiller is a source of potential energy savings. Start and stop chill water and condenser pumps when the associated chiller is operated. Isolate inactive chillers from the chill water and condenser water loops when they are not in operation. Water pumped through idle chillers consumes unnecessary energy by adding temperature to the water. This can be as much as 2-2.5°F. The use of automatic shut-off valves is recommended.

Best Practice—Chiller Water Flow Isolation

- Isolate both the chiller evaporator and condenser from the system when the chiller is not in service. Automatic valves are the ideal solution.

6.2.13 Variable Speed Drive Chillers

The use of chillers equipped with variable speed drives greatly enhances their energy efficiency. This enables the chiller to match the speed of the compressor to the load at the maximum efficiency. It also allows the chiller to function, without damage, at much lower condenser water temperatures. This further reduces operating costs.

Best Practice—Variable Speed Drive Chillers

- The availability of variable speed chillers has improved in recent years, thus reducing initial purchase costs. The use of drives allows the chiller to exactly match the compressor speed to the load and provides the ultimate in employment matching. When using multiple chillers, employment can be controlled to use the VSD-equipped chiller as the swing chiller and maximize the benefit if only one chiller is equipped with a VSD.

6.2.14 Automate Chiller System

The use of automation for chiller employment and control can significantly reduce energy consumption. An automation system can provide 24-hour electronic monitoring and control of chiller plant operation, and can report information to a control center or cell phone. This type of system can report operational problems and even dispatch a service call. It can detect and report problems earlier and prevent equipment damage. Control functions include employment (on-off), demand limiting, chill water reset, pump employment, and water flow control. Additional duties can be monitoring of maintenance items, filters, oil changes and out of range conditions. Automated systems can also pickup many of the logging duties for operators. A control system does not replace a good operator and/or the normal inspections required for sound operating practices.

Best Practice—Chiller Plant Automation, Reporting, and Control

- The use of a well-designed automation package can greatly reduce the energy consumption of a chiller plant and provide an improved level of monitoring and reliability.

6.2.15 Automatic Tube Cleaning Systems

Automatic tube cleaning systems consisting of captured brushes in each tube and a flow-reversing valve with controls are excellent energy savers in cases where chiller or condenser fouling is a problem. The system typically cleans the tubes four times per day. Common applications are river water condensers, process evaporators, and condensers on towers or systems where fouling is critical. Energy savings commonly range from 15-20% on condensers and 15%-plus on process evaporators. Additional savings from reduced maintenance and less downtime are possible.

Best Practice—Automatic Tube Cleaning Systems

- On evaporators and condensers in high fouling applications, automatic tube cleaning systems can save significant energy by maintaining tube heat transfers surfaces in clean condition.

6.2.16 Free-Cooling With a Plate Heat Exchanger

Free-cooling (systems above 36°F) for systems that are not equipped to use outside air can be done by utilizing a plate-heat exchanger and a cooling tower. The tower must be setup for cold operation and have sufficient heater capacity to prevent freezing in cases of low load and severely cold weather. The effectiveness of free-cooling depends on the chill water temperature required in winter months and the hours of wet bulb temperatures for the location. The plate-heat exchanger is used like a chiller but the heat exchanger does not require additional power input.

Best Practice—Free Cooling on the Waterside

- A careful analysis of free-cooling opportunities is required when winter cooling is needed and outside air is not available (or cannot be used for other reasons). Attention should be paid to the required chill water temperature in cold weather, as typically the chill water temperature can be higher than in the summer months. This is usually due to lower loads in the winter. The warmer the chill water temperature required, the longer free-cooling can be used. Free-cooling applications have been used successfully in the southeastern U.S. for many years. Depending on the application and installation, paybacks of less than one year have been achieved. Automation of the controls for change over is recommended, as it will greatly increase the number of hours of use.

6.2.17 Free Cooling With Fin-Fan Coils

Free-cooling (systems below 36°F) can be achieved with fin-fan coils. This is usually applied on systems that are operating below freezing and are using a brine solution (glycol/water, etc.) The brine is circulated to a fin-fan coil outside and cooled by cold air that's forced over a coil.

Best Practice—Free Cooling for Low Temperatures

- The use of a fin-fan coil to cool brine solutions to temperatures below 36°F is a source of winter energy savings. The outside coil acts as the chiller and only requires a small amount of energy for the fan(s).

6.3 Cooling Tower Best Practices

Cooling towers are heat rejection devices that divert waste process heat into the atmosphere. They are commonly used in air-conditioning, manufacturing, and electric power generation. Cooling towers may be direct (open circuit) or indirect (closed circuit), depending on the specific application. Direct-cooling towers require the cooling fluid to have direct contact with air; in indirect-cooling towers air and cooling fluid are separated.

6.3.1 Cooling Tower Water Filtration

Cooling tower water filtration is the single most effective way to reduce fouling and maintenance on a cooling water system. The dirt particles typically found in cooling water consist of airborne dust, pollen, dirt, bacteria, and other organic material ingested by the tower. The typical cooling tower moves millions of cubic feet of air each day. All of the foreign material in air is washed out into the cooling water. This material provides food for the bacteria normally present in cooling tower water. It also forms a sludge blanket in the basin or tower sump, which harbors bacteria and corrosion-causing conditions. If a sludge blanket becomes an inch or more thick, biocides can no longer penetrate it to kill bacteria.

Best Practice—Cooling Tower Water Filtration

- The use of side-stream sand filters is the most effective way to remove the suspended solids in cooling tower water. Filters designed for this purpose can remove 90-95% of all suspend solids larger than 5 microns. This level of filtration, which is equal to or better than drinking water, will eliminate the problems associated with dirty cooling tower water. Selection and sizing is site-, equipment-, and location-dependant. Because the solids are small and airborne (making them low in specific gravity), centrifugal separators are not effective for this application.
- A filtration system should include a properly designed basin sweeper system to reduce or eliminate the sludge blanket that forms in tower basins.

6.3.2 Cooling Tower Hot Deck Covers

Cooling tower hot decks provide another defense against airborne solids and algae growth. Hot decks are a common method of water distribution in most cooling towers (some towers use pressure nozzle system). Algae cannot grow in cooling water without sunlight. The most common source of sunlight in cooling towers is uncovered hot decks.

Best Practice—Hot Deck Covers

- On cooling towers with hot decks, install and maintain hot deck covers. Ensure that procedures require the replacement of the covers following maintenance activities.

6.3.3 Monitor Hot Deck Nozzles

To ensure efficient operation of a cooling tower, the tower must have the appropriate flow of water and air in the fill at all times. The most common disruption to adequate water flow is hot deck nozzle plugging (in towers with hot decks). This causes unbalanced and uneven water flow through the fill affecting the tower performance. This nozzle plugging is usually large pipe scale pieces and other debris in the system that cannot pass through deck nozzles. Regular monitoring of hot deck conditions is recommended.

Best Practice—Hot Deck Nozzles

- Hot deck nozzles should be inspected on a monthly basis in normal operating conditions. Where frequent problems are encountered with nozzle plugging, install a line strainer on the return line to the tower. The perforations in the strainer should be one-half the size of the smallest opening in the hot deck nozzle. Install a 2-inch ball valve in a convenient location for blow down of the strainer, and check it frequently.

6.3.4 Cooling Tower Basins

Cooling tower basins usually collect a large amount of dirt and sludge from the solids washed out of the airflow. These solids create a sludge blanket on the bottom of the tower basin. When sludge thickness reaches 1-inch, the biocide and corrosion inhibitor used as cooling water treatment cannot reach the basin bottom. If the basin is galvanized steel, rapid corrosion can cause severe damage in a short time. The most common form is anaerobic bacterial corrosion. This is caused from the growth of bacteria, which thrives in an atmosphere with no oxygen. The first-line defense for this occurrence is the use of stainless steel basins and filtration with a basin sweeper system.

Best Practice—Cooling Tower Basins

- Order new cooling towers with stainless steel basin for longer life and reduced maintenance costs. Use epoxy or elastomeric coatings to extend the life of galvanized cooling tower basins. See also “Cooling tower water filtration.”

6.3.5 Cooling Tower Selection

The design of the cooling tower has an impact on energy efficiency. The most efficient design is the induced draft, counter-flow design. For most applications, this is also the most cost-effective tower design if lifecycle costing is used. It may not be the lowest first-cost unit. In some instances, there may be site restrictions or conditions that would affect this choice.

Best Practice—Cooling Tower Type Selection

- The most efficient tower type, for most conditions, is the induced draft, counter-flow design. Consider operating efficiency and lifecycle costs when selecting a cooling tower design.

6.3.6 Shutdown Vibration Switches

Most cooling towers use fans to push or pull air through the fill, and cool the water by evaporation. Fan blades are subject to fatigue, other mechanical stresses, and manufacturing defects. When a fan blade loses a blade tip or experiences abnormal wear, it becomes unbalanced. This causes excessive vibration in the gearbox, mounting, and other structures.

Best Practice—Vibration Switches

- All cooling tower fans should be equipped with a shutdown vibration switch. In the event of an unbalanced situation, the fan will shut down before causing additional blade failure and the possibility of a safety hazard. Care should be taken to install the vibration switch in the correct plane for cooling towers. Switches installed in the wrong plane will not function. Switches should be checked on an annual basis for correct operation.

6.3.7 Upgrading Cooling Tower Capacity

Cooling tower performance may require improvement if loads have increased over time. There are a number of options to improve the capacity of an existing cooling tower. These include fill upgrades, fan blade adjustment, fan and motor replacement, etc.

Best Practice—Cooling Tower Upgrades

- Consult a knowledgeable company to evaluate the improvements available to enhance the capacity of an existing cooling tower.

6.3.8 Drift Elimination

Water lost through the cooling tower fan is called drift. This water, when excessive, reduces the overall efficiency to the cooling tower. Water use rises, chemical costs increase, and environmental damage can occur from the water droplets.

Best Practice—Drift Control

- Maintain drift eliminators in good condition. If drift is a problem, consider replacing the drift eliminators. Drift eliminators affect the tower performance by increasing the pressure drop and, therefore, the airflow across the tower. There is a trade-off between energy, performance, and drift control. Use the type of drift eliminator that meets the requirements, not necessarily the best one available.

6.3.9 Drain Basin Tanks

Drain-back tanks are useful in cold climates where tower freezing is an issue. The use of polyethylene tanks to hold the sump water is an effective method of eliminating the basin heaters and heater controls. Locate the tank in an area that is heated.

Best Practice—Winter Tower Freeze Control

- The use of a drain-back tank is a cost-effective way to avoid tower freezing and the cost of heaters, controls, and heater operation. Space must be available in a heated area at an elevation lower than the base of the tower.

6.3.10 Cooling Tower Cleaning

Cooling towers should be cleaned at least annually. New standards from the Cooling Tower Institute suggest that more frequent cleaning may be warranted. Cleaning schedules will vary depending on the tower load, location, the use of filtration, and other environmental conditions.

Best Practice—Cooling Tower Cleaning

- The cleaning of cooling towers should be done often enough to prevent any significant buildup of dirt in the tower and tower fill.

6.4 Heat Exchanger Best Practices

6.4.1 Heat Exchanger Selection

Heat exchanger selection is an increasingly difficult task. Many types of heat exchangers are available and each type is outstanding for select applications. For liquid-to-liquid applications where solids are not a problem, plate heat exchangers excel. When cleaning or solids are an issue, spiral plate heat exchangers are an excellent choice. Applications with a large approach are suited for tube-and-shell heat exchangers.

Best Practice—Heat Exchangers

- The various types of heat exchangers should be considered before purchasing a unit. For most HVAC applications, plate-and-frame units or tube-and-shell units are the most common. A variation on the plate-and-frame heat exchanger, the brazed plate heat exchanger, is an excellent unit for small heating, cooling, and condensing applications.

6.4.1 Back Flushing System

Heat exchangers that are subject to frequent fouling can benefit from back flushing. The use of a four-way valve to periodically reverse flow to dislodge fouling and sediment allows cleaning on-line. This can be applied to most heat exchangers. On some tube-and-shell type heat exchangers, catch baskets and brushes can be installed to brush the tubes when the flow reverses.

Best Practice—On-line Heat Exchanger Cleaning

- When using dirty or fouling-type liquids in heat exchangers, consider using back flushing for on-line cleaning. In certain tube-and-shell units, captured brushes can be used.

6.4.1 Fluid Selection

The use various additives to prevent freezing of fluids affect the heat transfer capabilities of the solution. Ethylene and propylene glycol are the most commonly used fluids. As the temperature of operation decreases, greater amounts of glycol are required. As this percentage increases, the heat transfer abilities decline and flow must be increased.

Freezing Point

Concentration by volume	Ethylene Glycol	Propylene Glycol
55%	-50F	-40F
50%	-37F	-28F
40%	-14F	-13F
30%	+2F	+4F
20%	+15F	+17F

Glycol Properties

	Ethylene Glycol	Propylene Glycol
Heat transfer @180F with no increase in flow rate		
20% solution	.96	.97
50% solution	.87	.90
Flow Rate Correction Required (with no change in pump curve)		
100F	116%	
140F	115%	
180F	114%	110%
Pump Head Correction Required (with increase in flow)		
100F	149%	
140F	132%	
180F	123%	123%
Specific Gravity @ STP	1.125 -1.135	1.045 -1.055
Pounds/Gallon @ 60	9.42	8.77
pH (of glycol concentrate)	9.3	9.5
Note: Except as indicated, comparisons are of 50% glycol solution to water.		

Best Practice—Glycol Additions for Antifreeze

- Use the least amount of glycol possible to prevent freezing, to maximize heat transfer and minimize the flow required for the application.