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Technical Paper #1

Effective Water Treatment for Evaporative Condensers

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Abstract

Evaporative condensers are widely used for industrial refrigeration because they are more energy-efficient than air cooled systems. However, to achieve these benefits, effective water treatment is required to maintain maximum heat transfer efficiency, minimize water usage, and protect the system from water related problems. Variations in water quality and the design of evaporative condenser systems present unique water treatment challenges that must be addressed on a plant-by-plant basis. On-site maintenance practices also influence the success of water treatment programs. In many facilities, the water treatment program and on-site maintenance practices can be improved to provide better protection and reduce operating costs.

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Introduction

Like most businesses, food processing plants and cold storage facilities are under continuous pressure to reduce costs and operate in a more environmentally responsible manner. As a major consumer of energy, the refrigeration system can offer significant opportunities to meet these challenges. In facilities that use evaporative condensers as part of the refrigeration system, the water treatment program is often overlooked in the cost saving equation. Effective water treatment is necessary for reliable and efficient operation of these systems and to reduce the risks associated with waterborne pathogens. In many facilities, the water treatment program can be engineered to significantly improve energy and water efficiency. This paper discusses common water-related problems in evaporative condensers and provides practical recommendations to address the concerns associated with water treatment and reducing operational costs.

Importance of Effective Water Treatment

An evaporative condenser is a type of cooling tower used to cool and condense hot refrigerant gas, usually ammonia, by circulating it through a condensing coil over which air is circulated and water is continuously sprayed. A portion of circulating water sprayed over the coil is evaporated, which removes the heat from the hot refrigerant gas causing it to condense into a liquid. The continuous evaporation that occurs in the cooling process causes the dissolved impurities in the circulating water to concentrate. Figure 1 shows a schematic of a typical evaporative condenser.

Evaporative condensers are widely used because they are more energy-efficient than air-cooled refrigeration systems. As compared to air-cooled systems, evaporative condensers provide lower condensing temperatures and can reduce compressor electricity requirements by up to 30%. However, to achieve these cost savings, an effective water treatment program is required to maintain maximum heat transfer efficiency, minimize water usage, and protect the system from water-related

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problems. By reducing energy and water use, effective water treatment also helps reduce the negative environmental impact and carbon dioxide emissions associated with a facility.

Water-Related Problems

The water-related problems that occur in an evaporative condenser can be broadly classified as:

- Scale Deposits
- Corrosion
- Microbiological Growth

These problems are interrelated, with the presence of one contributing to the tendency for the other to occur. The end result of these problems in an evaporative condenser is reduced equipment life and higher operating costs. In some circumstances, unexpected system failure and health hazards can also result. An effective water treatment program must address all three concerns.

Variations in Water Quality

The potential for waterside problems to occur in an evaporative condenser system is a direct function of the type and concentration of impurities in the makeup water. Some water sources have a much greater tendency to cause scale deposit problems than others; some have a tendency to cause corrosion problems; some have a tendency to cause microbiological problems; and some have a tendency to cause all three problems at once or some combination thereof. The makeup water impurities along with the system design, operation, and maintenance practices also dictate the most effective approach for preventing these problems.

Table 1 shows how widely the concentration of common problem-causing impurities varies in water supplies across the United States. Given the wide variability in the factors that influence the potential for water-related problems and determine effective corrective measures, a water treatment professional is typically employed to design and monitor a site-specific treatment program.

Water Treatment Approaches

Chemical treatment is the most broadly accepted method to treat water for evaporative condensers. However, because of the safety and environmental concerns associated with using chemicals, a wide variety of non-chemical devices (NCDs) are also marketed to treat water with varying degrees of success. Some NCDs, such as filters, produce a measurable impact on water quality and have been used with great benefit and little controversy for years. However, the effectiveness of NCDs that do not produce an easily measured physical change in the dissolved or suspended solids content of the treated water is more contentious. Although many case histories documenting poor results and high costs can be found for both chemical and non-chemical water treatment programs, many can also be found illustrating success with both approaches. This supports the conclusion that effective water treatment depends on more than whether chemicals are used.

The complex interaction between the makeup water chemistry, equipment design and operating conditions and maintenance practices means that no one water treatment program is best for all systems and locations. It also means that regardless of whether or not chemicals are used, the effectiveness of a water treatment program is heavily influenced by how well it is designed and managed around these same factors. This paper primarily focuses on the water-related problems associated with evaporative condensers and chemical treatment measures. However, many of the principles discussed also apply to NCD-treated systems.

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Problem-Causing Impurities in Water

Water is an excellent solvent that picks up dissolved and suspended impurities that reflect the substances it contacts as it moves through the hydrologic cycle. Consequently, there is a wide variation in water quality from place to place and even over time. However, in terms of controlling scale deposits and corrosion, just a few of the mineral impurities commonly present in natural water supplies are of concern. These impurities include:

- Calcium Hardness
- Alkalinity
- Silica
- Chlorides
- Conductivity

Calcium Hardness is a common impurity in natural water sources and a major cause of scale deposits in all types of heat exchange equipment. Calcium tends to be a problem because it can form several compounds with a relatively low solubility. For example, calcium carbonate, calcium phosphate, calcium silicate, and calcium sulfate are all low-solubility compounds that can form scale deposits in water. Softeners are a type of pre-treatment equipment that removes hardness.

Alkalinity is another commonly occurring impurity that can cause problems in evaporative condensers. Naturally occurring alkalinity is a function of the amount of carbonate and bicarbonate ions dissolved in the water. As the concentration of these ions increases, so does the alkalinity level. The opposite of alkalinity is acidity. Low alkalinity water tends to have a low pH and be corrosive to metals. High alkalinity water tends to have a high pH and be scale-forming. High alkalinity water can also be corrosive towards certain metallurgies, such as galvanized steel.

Calcium hardness and carbonate alkalinity are the most common sources of mineral scale in evaporative condenser systems. This is because calcium and carbonate alkalinity readily combine to form calcium carbonate, a compound with a low solubility and an inverse solubility relative to temperature. Because of its inverse solubility, calcium carbonate tends to precipitate (come out of solution) and form scale deposits in the hottest parts of the system, which is usually the condenser tubes.

While calcium carbonate normally precipitates on heat exchange surfaces, with some makeup water chemistries and operating conditions it preferentially precipitates in the bulk water. Furthermore, if the makeup calcium and/or alkalinity levels are low enough, calcium carbonate may not precipitate at all unless concentrated to very high levels. Note that chemical water treatment is primarily focused on extending the solubility of calcium carbonate so that it does not precipitate on heat exchange surfaces or in the recirculating water. Non-chemical water treatment methods tend to rely on calcium carbonate precipitating in the bulk water instead of heat exchange surfaces.

Silica is usually found at some level in all natural water sources. Under some conditions, silica can form hard deposits that are extremely insulating and very difficult to remove.

Chloride is common at low levels (< 100 ppm) in all fresh water supplies. In contrast, seawater contains over 20,000 ppm of chloride. Chloride is a very soluble ion that tends not to combine with other substances to form deposits unless at extremely high levels. However, high levels of chloride in water can be very corrosive and most evaporative condenser manufacturers recommend a maximum of 250 ppm of chloride in the recirculating water.

Conductivity measures the ability of a water solution to conduct an electrical current. As the dissolved ion concentration in water increases so does the conductivity. Although conductivity is not specific for any particular impurity, it is an important indicator of the dissolved solids concentration. In general, the greater the

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concentration of dissolved solids in water, the greater the potential for water related problems to occur. Because conductivity is an easily measured property of water, it is widely used in water treatment for monitoring and control purposes.

Scale Deposits

Deposits are a serious concern in evaporative condensers. The continuous evaporation that occurs in the cooling process causes the dissolved solids in the circulating water to become increasingly concentrated. If allowed to over concentrate, some of the dissolved solids will form a solid precipitate.

Depending on the water chemistry and operating conditions, the precipitate can form in the bulk water or as an adherent deposit on the condenser tubes. Unless removed by filtration, any precipitated mineral solids in the bulk water can become incorporated into deposits that subsequently coat the condenser tubes and block the spray nozzles. Waterside deposits can also include dust scrubbed from the air, corrosion by-products, and microbiological matter (slime). Regardless of the source, the end result of these deposits is reduced heat transfer efficiency, increased operating costs, and potential equipment failure.

Payback on Good Deposit Control

The payback associated with water treatment is directly related to maintaining good water flow over clean condenser tubes. Good water flow requires clean spray nozzles. Plugged spray nozzles reduce the surface area of the condenser coil available for cooling the hot refrigerant gas. The reduced water flow associated with plugged spray nozzles also causes deposits and dry spots to form within the condenser tube bundle regardless of the water treatment measures that are taken.

Any deposits on the condensing coil surface significantly reduce the ability of an evaporative condenser to remove heat. For example, 1/32" of mineral scale on the

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condenser tubes reduces its heat transfer capability by about 27%. The efficiency loss is even more pronounced for condenser deposits that contain microbiological slime, which is 3-4 times more insulating than mineral scale. In the absence of extra condensing capacity, condenser deposits force the compressor to work against higher head pressures. This in turn causes the compressor to use more energy and reduces refrigeration output. If the heat transfer loss is great enough, the compressor will shut down due to high head pressure.

Figure 2 illustrates the impact of scaled condenser tubes on compressor energy requirements and output. It shows that 1/32" of mineral scale on the condenser tubes can increase the energy costs by 7% and decrease the available refrigeration capacity (tons) by 1%. This reduction in energy efficiency will occur year round, but may go unnoticed until the capacity loss becomes apparent as the system operates on the hottest days.

An effective water treatment program that provides good water flow and deposit control directly translates into lower energy use and operating costs. Since burning fossil fuels to produce electricity is a major source of greenhouse gas emissions, saving energy also reduces carbon dioxide emissions. Based on U.S. national averages, each kWh reduction in electricity usage reduces carbon dioxide emissions by 1.55 lbs.

Corrosion

Corrosion is the destructive reaction of a metal, such as steel, copper or brass, with its immediate environment. Corrosion rates are affected both by the materials of construction and by the aggressiveness of the surrounding environment.

In the absence of microbiological growth, corrosion is primarily an electrochemical reaction initiated by the presence of naturally occurring impurities, such as oxygen

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or low alkalinity levels in water. Corrosion inhibitors are chemicals designed to work with the naturally occurring water chemistry to help stop corrosion reactions.

Poor deposit control contributes to corrosion by shielding metal surfaces from chemical corrosion inhibitors and by providing an environment for the growth of bacteria that can cause severe corrosion. Regardless of the source, the end result of corrosion is metal loss, which shortens system life and leads to equipment failure. Corrosion by-products like rust also contribute to deposit formation.

Microbiological Growth

Cooling towers and evaporative condensers provide an ideal environment for the growth of bacteria and other microorganisms that can cause major corrosion and deposit problems. Bacteria-laden dirt and other debris are continuously scrubbed from the air during normal operation. Although algae is not a concern in an evaporative condenser since the water is generally not exposed to sunlight, the temperature and pH is ideal for the growth of several types of problem causing bacteria. Contamination with low levels of ammonia can also present serious concerns in an evaporative condenser. Nitrifying bacteria can convert low levels of ammonia into nitric acid, causing the pH of the recirculating water to drop from 8.5 to 3.0 in a matter of days.

In addition to causing corrosion and deposit problems, poor microbiological control also contributes to unsafe operating conditions by allowing the Legionella bacteria, the cause of Legionnaires' disease, to proliferate. The end result of poor microbiological control is reduced equipment life, increased operating costs, unexpected system failure, and increased safety concerns.

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Water Treatment Solutions

Bleed Control and Water Chemistry

As water evaporates from an evaporative condenser, the dissolved solids that enter the system with the makeup water are left behind and concentrate in the remaining water. To prevent the dissolved solids from over concentrating and forming deposits, a portion of the recirculating system water must be sent to drain as bleed. In terms of water conservation, a key water treatment objective is to minimize the amount of system water sent to the drain as bleed. However, in terms of energy efficiency, it is important to keep the condenser tubes and spray nozzles clean and free of deposits.

The bleed rate necessary to control both scale deposits and corrosion is largely a function of the makeup water chemistry and chemical inhibitors being used. For example, evaporative condensers that use makeup water that contains high levels of calcium and alkalinity must operate at relatively high bleed rates to keep the dissolved solids concentration low enough to prevent scale formation. The addition of chemical scale inhibitors significantly extends the solubility of these scale forming ions and can allow operation at much lower bleed rates without precipitation. Carbon steel corrosion tends to be less of a concern in systems that use higher alkalinity, higher calcium makeup water since these dissolved solids tend to buffer the corrosive tendencies of water. However, galvanized corrosion can be a concern if the alkalinity level in the circulating water is too high.

In contrast, evaporative condensers that use makeup water with low calcium and alkalinity levels can operate at low bleed rates without scale problems, in some cases whether or not scale inhibitors are used at all. However, if the makeup calcium and alkalinity levels are too low, corrosion can be a concern. Depending on the metallurgy, chemical corrosion inhibitors may be needed to provide good corrosion control.

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The reality is that makeup water quality varies widely from place to place, even over time, and other impurities besides calcium and alkalinity impact the potential for corrosion and deposits to occur. Consequently, a water treatment professional is required to evaluate the water chemistry along with the system design and operation to determine how much the makeup water impurities can be safely concentrated without deposit and corrosion problems, and the optimum bleed rate for each system.

Cycles of Concentration

The cycles of concentration reflect the degree to which the dissolved solids in the makeup water are concentrated in the recirculating water of an evaporative system. The higher this ratio, the more the dissolved solids in the makeup water are being concentrated in the system water and the lower the bleed rate.

Mathematically, the cycles of concentration are equal to the amount of makeup water entering an evaporative system divided by the amount of bleed. The cycles of concentration in an evaporative condenser are generally estimated by dividing the conductivity of the circulating water by the conductivity of the makeup water.

$$\text{Cycles of Concentration} = \frac{\text{Makeup Rate}}{\text{Bleed Rate}} \approx \frac{\text{System Water Conductivity}}{\text{Makeup Water Conductivity}}$$

As discussed previously, conductivity is an easily measured property of water that is a direct function of the total dissolved solids (TDS) level. As evaporation occurs in an evaporative condenser system, the conductivity of the circulating water will increase as the dissolved solids concentration increases. Knowing the conductivity of the cooling tower water and makeup water, the cycles of concentration can be calculated at any point in time. For example, if the tower water has a conductivity of 1,000 umhos/cm and the makeup water has a conductivity of 200 umhos/cm, then the cooling tower is five times more concentrated than the makeup water and the system is said to be operating at five cycles of concentration (1,000/200 = 5). Automatic bleed controllers are typically used to monitor the conductivity of the recirculating water and initiate bleed as necessary to maintain the cycles of concentration within a target range.

Although evaporative cooling is very efficient, evaporative condensers require an astonishing amount of fresh water to operate. Approximately 1.53 gallons per hour of water is evaporated for each ton of refrigeration. This may not sound like a lot of water until one considers that a 500-ton refrigeration system operating at full load evaporates almost eight million gallons over the course of a year!

The total makeup water requirements for an evaporative condenser equal the amount of water lost due to evaporation plus the amount of water intentionally removed through bleed to control the cycles of concentration. The bleed rate is a direct function of the evaporation rate and the cycles of concentration being maintained. Mathematically, the bleed rate is equal to the evaporation rate divided by the cycles of concentration minus one:

$$\text{Makeup Rate} = \text{Evaporation Rate} + \text{Bleed Rate}$$

$$\text{Bleed Rate} = \frac{\text{Evaporation Rate}}{\text{Cycles of Concentration} - 1}$$

The environmental benefits associated with minimizing the bleed rate and maximizing the tower cycles are significant. Table 2 was prepared to show the water and chemical requirements associated with a 500-ton refrigeration load operating at various cycles of concentration. It shows that maintaining five cycles versus three cycles reduces total water consumption by almost 17% and chemical requirements by 50%. However, insufficient bleed can result in waterside deposits that reduce efficiency and increase energy costs.

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White Rust

Evaporative condensers and condenser coils are typically constructed of galvanized steel. The zinc coating on galvanized steel is intended to provide a corrosion resistant barrier that protects the underlying steel from direct contact with the environment. In atmospheric and potable water service, a non-porous corrosion resistant film forms over time on the surface of new galvanized metal, giving it a dull gray, weathered appearance. However, when galvanized steel is used in recirculating cooling water systems, a unique corrosion phenomenon known as white rust can occur unless the water chemistry is well-controlled during initial startup. White rust is a porous, non-protective white deposit that can form on galvanized steel instead of the desirable corrosion resistant film. White rust is undesirable because it can shorten the life of an evaporative condenser system.

Cooling tower and evaporative condenser manufacturers provide specific water quality guidelines intended to minimize the potential for white rust formation in new systems, and prevent the re-occurrence in systems that continuously operate at about a pH of 8.3. These guidelines generally specify the following water quality parameters be strictly maintained in the recirculating water for the first 6 - 8 weeks of operation:

- Maintain the pH between 7.0 and 8.2.
- Maintain 50 – 300 ppm of calcium hardness. Do not use soft water.
- Maintain 100 – 300 ppm of alkalinity.
- Keep the chloride and sulfate levels $<$ 250 ppm each.

The process of establishing the desired, corrosion resistant film is called passivation and is best done under no-load conditions. The use of inorganic phosphate based pretreatment products is generally recommended to aid passivation. Once the desired passive film has been formed on the galvanized steel, the system can often be operated with a pH $>$ 8.3 for extended periods of time. However, should white rust be detected, the galvanized steel will need to be repassivated.

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Depending on the local makeup water chemistry, it can be very difficult to maintain the water quality guidelines within the specified ranges without extremely high bleed rates and/or the use of pH control. It is very important that your water treatment consultant be contacted prior to starting up a new cooling tower or evaporative condenser containing galvanized metallurgy. Once white rust has started it can be difficult to control. Where appropriate, the use of alternate metallurgy, such as stainless steel, should be considered.

In 2002, the Association of Water Technologies (AWT) published *White Rust: An Industry Update and Guide Paper* that details the complexities surrounding white rust control in recirculating cooling water systems. This document is a good reference when dealing with a white rust problem or concern.

Microbiological Control Measures

Effective microbiological control in an evaporative condenser system generally requires the automatic, controlled addition of EPA registered biocides as part of the overall water management program. Because evaporative condensers have high evaporation rates and low water volumes, it is important to use biocides that act quickly. Fast acting non-oxidizing biocides such as DBNPA (2,2-dibromo-3-nitriloproprionamide) often prove very effective. Because DBNPA degrades quickly, it also has a good environmental profile. Oxidizing biocides, such as chlorine or bromine, can also be a good choice because they kill bacteria quickly and are readily deactivated upon discharge.

System cleanliness has a profound effect on microbiological control. Deposits shield bacteria and encourage their growth. Deposits also become sites for under-deposit corrosion and react with biocides of all types, creating a large biocide demand and reducing their effectiveness. The installation of a side stream filter to remove suspended solids can significantly improve the effectiveness of microbiological control measures as well as reduce cleaning requirements and biocide dosages.

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Filtration can be especially beneficial in NCD treated systems. Regardless of the treatment approach used, it is specifically recommended that all evaporative cooling water systems be cleaned and disinfected at least once per year, with twice per year preferred. Routine system cleaning is particularly important where filtration is not employed.

Routine monitoring is also recommended to determine the effectiveness of microbiological control measures and whether an adjustment to the treatment program is required. This monitoring should include routine determination of the bulk water aerobic bacteria counts in the recirculating water. The biocide and cleaning program should be adjusted to maintain bacteria counts at less than 10,000 CFU/mL, as specified by some best practice guidelines for Legionella control. Monitoring should also include routine visual inspections to verify that surface attached bacteria (slime) is not coating the condenser tubes or blocking the spray nozzles. Bulk water bacteria counts do not always reflect the presence or absence of surface attached bacteria. Clean systems and good control of the overall microbial population is a key to minimizing the risks associated with Legionella bacteria and Legionnaires' disease.

Practical Water Treatment

An effective water treatment program for an evaporative condenser must include provisions for controlling corrosion, deposits, and microbiological growth. Each water treatment program must be tailored to the specific makeup water chemistry at a plant and at a minimum consist of:

- Reliable Bleed Control
- Reliable Chemical Feed and Control
- Routine Onsite Maintenance
- Routine Monitoring

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Reliable Bleed Control

Reliable bleed control is very important. Too much bleed wastes water and increases chemical use. Too little bleed can result in energy-robbing scale deposits. The amount of bleed required to prevent scale deposits is a direct function of the evaporation rate. Because the bleed rate required to maintain the target cycles varies as the tower evaporation rate varies throughout the day and from season to season, an automatic bleed control system is necessary for good bleed control.

Automatic bleed controllers continuously monitor the conductivity of the recirculating water and open a bleed valve whenever the conductivity reaches a set point. The bleed valve remains open until the removal of concentrated system water and the addition of lower conductivity makeup water lowers the conductivity of the system water to a preset amount below the set point. For example, if 5 cycles of concentration are being targeted in an evaporative condenser using makeup water with a conductivity of 200 umhos/cm, then the bleed controller set point would be set on 1,000 umhos/cm. When the conductivity of the recirculating water reaches 1,000 umhos/com, the bleed valve will open discharging 1,000 umhos/cm water and replacing it with 200 umhos/cm makeup water. Once the system water conductivity reaches 950 umhos/cm, the bleed valve will shut off until evaporation causes the conductivity to increases to the set point.

For systems where the makeup water quality changes frequently, advanced water treatment controllers are available that continuously monitor the conductivity of the makeup water and automatically adjust the controller set point to maintain the target cycles.

Reliable Chemical Feed and Control

The addition of chemical inhibitors and biocides allows high cycles to be maintained without efficiency losses and other problems. However, even the best water

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treatment chemicals will not provide good protection if they are improperly applied. Overfeeding water treatment chemicals is wasteful while underfeed can result in corrosion, deposits, and microbiological growth problems.

Automatic water treatment controllers are available to precisely apply treatment chemicals without overfeed. In general, adding corrosion/scale inhibitor products in preparation to makeup water usage will provide excellent control of the treatment residuals. Biocides are typically added one to seven times a week on a slug feed basis.

Advanced data logging water treatment controllers are also available to automatically monitor and log key treatment parameters including water use. These controllers can interface with automation systems and the Internet to enable high-performance water treatment programs. They can warn personnel when upset conditions occur so minor concerns don't turn into major waterside problems. They allow remote access to controller history and settings. Data management and analysis can also be used to help optimize results and reduce costs.

Common Sump Makeup Systems

Ammonia refrigeration systems often consist of multiple evaporative condensers located in clusters. Traditionally, a chemical feed and control system is installed on each evaporative condenser. There are several problems with this arrangement. It requires a separate water treatment controller and multiple chemical feed pumps for each condenser. The flow assembly used for chemical injection and bleed often stops up because it depends on flow from the low head condenser pumps. Each treated system has to be tested and monitored separately, which is time consuming. It is a complicated arrangement that can make effective water treatment difficult.

In plants with multiple evaporative condensers located in clusters, installation of a common sump makeup system will greatly simplify water treatment requirements.

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A typical common sump makeup system uses an open polypropylene sump with a circulating pump that is sized to supply all of the makeup water for all condensers plus continuously circulate water back to the central sump. Makeup water addition is controlled by a liquid level control installed on the sump. A water meter is typically installed to measure makeup water usage and control the amount of scale and corrosion inhibitor going into the system. The bleed valve is installed on the common return water line from the evaporative condensers. Since the water in all condensers is common, a single high-end water treatment controller can be used to control bleed and chemical feed.

Practical Onsite Maintenance

Routine onsite maintenance is an important part of any water treatment program. Regardless of how much the water treatment program is automated or how often the water treatment consultant services a facility, an in-plant monitoring program is necessary to prevent minor concerns from developing into major problems. Here are some practical steps to provide maximum benefit with a minimal investment of time:

1. Check water treatment controller readout for high/low conductivity reading daily. If conductivity is significantly below set point (low), check for leaking bleed valve or high water level in tower sump. Low conductivity indicates excess bleed, which wastes water/chemicals and contributes to corrosion. If conductivity is significantly above set point (high), check for blocked bleed valve. High conductivity indicates inadequate bleed, which can cause scale deposits, fouling, and eventually system shutdown.
2. Check chemical feed equipment daily. Check chemical pumps for prime and operation. Re-prime or repair as needed. Inspect chemical feed system for leaks. Check inventory in chemical feed/storage containers. Verify chemical levels in container are dropping as expected.
3. Regularly inspect the spray nozzles and condenser tubes. Poor water flow over the condenser tubes reduces cooling efficiency and will cause deposits to form

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regardless of water treatment measures. Bugs, cottonwood seeds, scale, or any other foreign material can clog strainers and spray nozzles. A visual inspection of the nozzles while the spray pump is running is the best inspection method.

4. Check heat exchange equipment for signs of fouling, such as a high head pressure and/or approach temperature. Any deterioration of heat transfer is a serious concern that should be addressed immediately.

Conclusion

The water treatment program for an evaporative condenser system is integral to the operation of an energy, water and resource efficient facility. Obtaining good results from the water treatment program has huge economic payoffs and helps meet environmental objectives on many levels. Effective water treatment can help facilities ensure reliable operation of critical refrigeration systems, reduce energy and water use, and minimize greenhouse gas emissions. Effective water treatment is a cost-effective green technology that can offer a substantial return on investment.

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Figure 1: Schematic Typical Evaporative Condenser

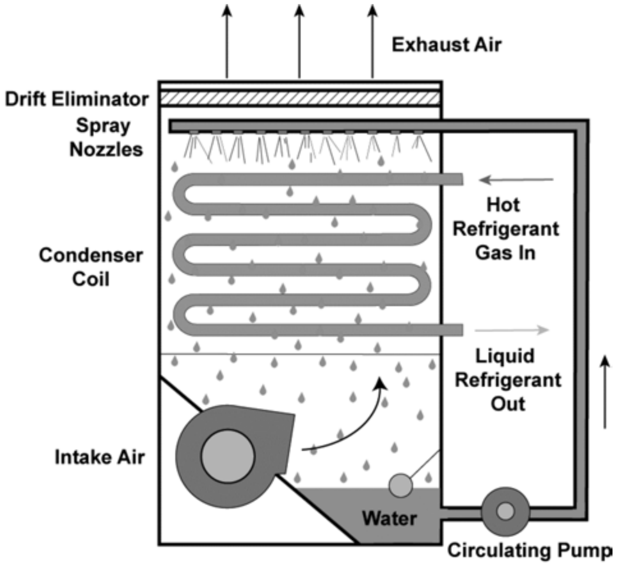

Figure 2: Impact of Condenser Scale Deposits on Compressor Capacity & Horsepower

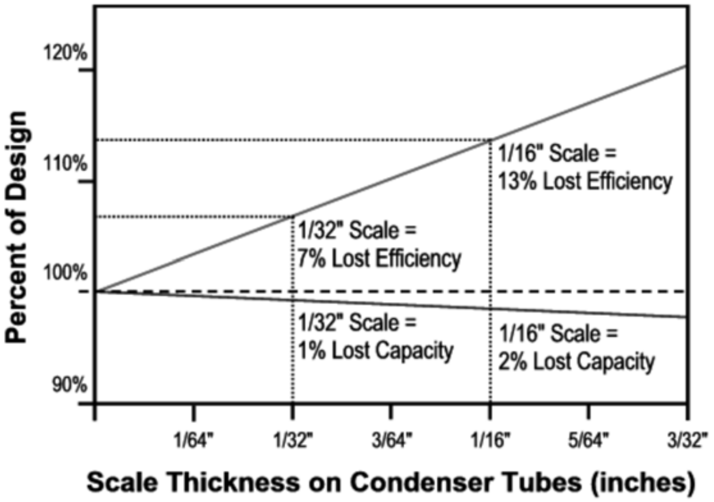

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Table 1: Geographic Variation in Common Problem Causing Impurities in Water

Location	Conductivity (umhos/cm)	Calcium Hardness (ppm as $CaCO_3$)	Total Alkalinity (ppm as $CaCO_3$)	Chloride (ppm as Cl)	Silica (ppm as SiO_2)
Atlanta, GA	85	20	18	5	5.7
Chicago, IL	240	120	100	5	< 1
Indianapolis, IN	750	300	180	74	4.8
Jackson, MS	389	1	190	4	22.5
Jacksonville, FL	1003	152	112	90	17.0
Las Vegas, NV	920	190	135	77	8.3
Los Angeles, CA	500	115	90	20	5.0
New York, NY	80	15	20	4	1.0
San Angelo, TX	2390	104	284	424	6.0
Seattle, WA	70	27	26	6	8.0

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Table 2: Cycles of Concentration vs. Water and Chemical Treatment Requirements

	Water Use				Chemical Use		
Cycles	Bleed (GPD)	Makeup (GPD)	Annual Water Cost	% Reduction Water Cost	Inhibitor (lb/day)	Annual Inhibitor Cost	% Reduction Inhibitor Cost
3	10,800	32,400	$59,130	Base Line	10.8	$15,768	Base Line
4	7,200	28,800	$52,560	11.1%	7.2	$10,512	33.3%
5	5,400	27,000	$49,275	16.7%	5.4	$7,884	50.0%
6	4,320	25,920	$47,304	20.0%	4.3	$6,307	60.0%
8	3,086	24,686	$45,052	23.8%	3.1	$4,506	71.4%
10	2,400	24,000	$43,800	25.9%	2.4	$3,504	77.8%

Based on 500-Ton Refrigeration Load Operating 24 Hours/Day, 365 Days/Year. 21,600 GPD Evaporation. Water Cost = $5.00/1,000 Gallons. Inhibitor Dosage = 120 ppm. Inhibitor Cost = $4.00/lb.

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