Water Treatment 101

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Water treatment is a mystery to many consulting engineers, but is required for many reasons. In HVAC systems the most common goals of water treatment are to maintain peak performance, reduce water consumption and minimize corrosion, scale, and fouling while controlling microbial growth. This column summarizes the most important items for the HVAC designer to know and improve their master specifications for water treatment.

Different methods of water treatment are required for each HVAC system due to the many variables of design such as different materials of construction, various water temperatures, water versus glycol systems, steam versus hot water systems, makeup water sources and, of course, whether the system is open loop or closed loop.

Closed Water Systems

Closed systems are isolated from the atmosphere, minimizing the introduction of oxygen. These systems typically require small amounts of makeup water for times when maintenance is performed on pumps, strainers or valves. Treatment design depends on the materials of construction, the makeup water quality and the maximum water temperature.

For heating water systems, if they deliver >150°F (65.7°C) water, biocidal treatment may not be needed. But for the newer low-temperature heating water systems that use condensing boilers and/or energy recovery chillers, a biocide is required, and we (those involved in the design of systems) generally avoid corrosion* inhibitors that add nutrients to the water, i.e., molybdate is preferred over nitrite. We normally allow both sodium nitrite (aka nitrite) and molybdate as corrosion inhibitors in systems that occasionally reach 180°F (82.2°C), but only allow molybdate in systems that never get above approximately 140°F (60°C). This is because nitrite is a close cousin to the nitrogen that farmers inject into their fields, and it can be a nutrient for nitrogen-reducing microbes.

On the flip side, some municipalities may restrict or prohibit discharge of molybdate. In these cases, alternate forms of corrosion control may need to be used such as orthophosphate, zinc phosphate, or sodium silicates. These alternate forms are safer to discharge but can be harder to control and may be less effective. Nitrite is also preferred for heating water systems because heat drives oxygen out of the system, and nitrite can donate its own oxygen to form an inhibition layer on metal surfaces.

For chilled water systems, treatment design will be like hot water systems being dependent on materials of construction, the makeup water quality, and design water temperature. Due to the lower temperatures compared to hot water systems, the water treatment program

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*Corrosion: the deterioration of materials, usually metals, by reaction with their environment.

will need to consider microbiological issues. For chilled water, nitrite is not a preferred corrosion inhibitor because of the risk of "bloom" where nitrite provides food for nitrogen-reducing microbes. Maintaining corrosion inhibitor levels within recommended limits is important. Careful control of the nitrite level is required to prevent metabolism of the nitrogen and can be difficult to maintain at all points in large systems. We normally only allow molybdate as a corrosion inhibitor.

Copper pipe and/or coils are often used in chilled water systems, and a yellow metal corrosion inhibitor is included. And, chemicals such as methylbenzotriazole (MBT) or tolyltriazole (TT) can protect copper and brass and minimize dielectric pitting of steel. This applies to heating, cooling and glycol water systems.

Glycol Systems

Systems filled with water-glycol-based heat transfer fluids require less ongoing treatment but are not immune to design and maintenance problems. Glycol is an additive to water that alters the freezing and boiling points of the fluid. However, glycol on its own is not enough for a healthy hydronic loop. Glycol must be combined with buffering (alkalinity[†]) agents, corrosion inhibitors, alkalinity boosters, and various other chemistries to become a good heat transfer fluid. Heat transfer fluids should be designed for the metallurgy of the loop, the intended temperature range, and sensitivity for environmental discharge or human/animal consumption. Many manufacturers provide a heat transfer solution ready for use in a hydronic loop that contains the necessary constituents to ensure the fluid performs as designed.

Glycol belongs to the alcohol chemical family, but should not be confused with ethanol-based antifreeze (i.e., RV antifreeze). Typical use concentrations are 25% to 50%. Concentrations over 50% raise the freeze and burst temperatures. (Freezing and bursting are different things. Freezing means that liquid stops flowing. Bursting means that you have a mess to clean up, a coil to patch or replace, and possibly expensive building damage.) When the concentration gets below approximately 22%, glycol can "ferment like bad wine" as bacteria feast on the glycol. You will then have a wonderful green, brown, black substance to clean out of your piping system. To avoid concentration dilution, use a premixed tank for maintaining system pressure and never connect domestic water to a glycol system like you would for a water hydronic system. Otherwise, every time a strainer is cleaned or a pump is serviced, the glycol percentage will decrease and you will slowly lose both corrosion and freeze protection.

Ethylene glycol has better heat transfer and pumping characteristics than propylene glycol, but propylene glycol and in some cases food-grade propylene glycol is needed because ethylene glycol is toxic. Geothermal systems in many states require propylene glycol or even food-grade propylene glycol. Do not use automotive antifreeze in non-automotive applications. It does not contain the same level or quality of corrosion inhibitors, is incompatible with most industrial heat transfer fluids, and is not designed for commercial and industrial use.

In no case should propylene and ethylene glycol be mixed in the same system. Although generally compatible, system efficiency is reduced, the fluid is still toxic, and freeze/burst point identification becomes extremely difficult. Additionally, each manufacturer uses different inhibitor, buffer, and stabilizer packages, which may not be compatible with one another and can lead to system damage. Clearly mark the system for operators as to which aqueous glycol solution is used.

Good glycol-based heat transfer fluids will contain yellow metal inhibitors initially but will still need occasional testing and addition of inhibitors.

Condenser Water Systems and Other Open Loop Systems

Cooling towers, evaporative condensers and fluid coolers use less energy than dry cooling systems. But they present unique challenges because the recirculating spray systems are open to the environment and susceptible to contamination, often operate within temperature ranges suitable for microbiological growth, and can consume large volumes of water, which can introduce large quantities of deposit-forming material, such as mineral hardness.[‡] These systems are also designed to evaporate water for heat rejection, which

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[†] Alkalinity: a measure of water's ability to resist pH changes due to addition of acids and bases. Alkalinity is unaffected by changes in temperature, pressure, or pH and is easily experimentally determined. I (Jeff) tend to think of alkalinity as buffering ability, like buffered aspirin.

[‡] Hardness: The concentration of cations in water (cations carry a positive charge), usually expressed as $CaCO_3$ (calcium carbonate) equivalent hardness in grains per gallon (gpg) or parts per million (ppm). 1 gpg = 17.1 ppm.

adds treatment considerations to minimize deposits and fouling on heat transfer surfaces, while balancing efficient water use.

Due to the dynamic operating conditions of most evaporative cooling systems, the water treatment program should be fully automated to ensure ideal water conditions are maintained at all times.

The three major goals of an evaporative cooling water treatment program are 1. Prevention of scale and deposit formation, 2. Minimization of corrosion within the wetted system components and 3. Control of microbiological organisms in the circulating water. Since these systems are designed to lose water via evaporation, concentration of total dissolved solids[§] will occur over time, which requires a proportional bleed off/blowdown[#] stream to remove the excess dissolved solids from the system.

Water leaving the system via evaporation is pure, containing no dissolved solids or microbes, whereas the makeup water contains varying amounts of dissolved solids and potentially microbes. Insufficient bleed off/blowdown from the evaporative cooling system will result in sludge/scale formation as the dissolved solids concentrate above the saturation point. This concentration effect is referred to as cycles of concentration and is most commonly measured by conductivity. The conductivity of the condenser water, divided by the conductivity of the makeup water equals the cycles of concentration, e.g., 10 gallons of makeup with 2 gallons of bleed off = 5 cycles of concentration. Bleed off can be fully automated using an online conductivity controller, which continuously monitors the conductivity of the condenser water, comparing that reading to a desired setpoint.

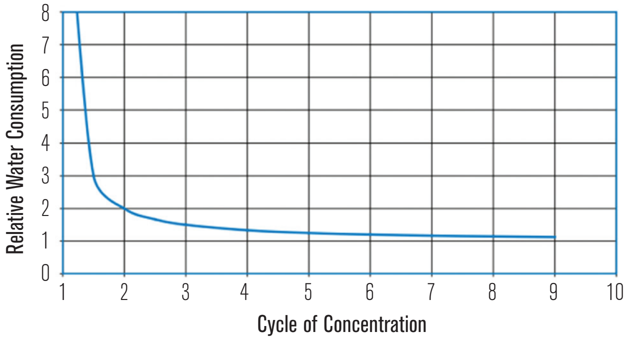
[§] Total dissolved solids (TDS): TDS is a measure of the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations; and carbonate, chloride, sulfate and nitrate anions (anions carry a negative charge). These are not removed by filters, except reverse osmosis filters.

[#] Bleed off/Blowdown: Water intentionally discharged from a cooling tower or boiler system to limit buildup of dissolved solids.

Once the conductivity of the condenser water rises above the setpoint, the controller opens a bleed/blowdown valve to discharge a controlled volume of water from the system. This liquid water loss forces additional makeup into the system, diluting the concentration of the minerals in the system and lowering the conductivity below the setpoint.

Each makeup water source varies in quality as dissolved solids increase and decrease based on the materials in the local water. Typically well water is high in dissolved solids and surface waters are lower in dissolved solids. The higher the level of dissolved solids in the makeup water, the higher the level of water consumption by the evaporative cooling system due to the lower cycles achievable. Mineral hardness in the makeup water is a limiting factor for water savings and increased cycles of concentration. This is because mineral hardness readily forms scale on heat exchange surfaces once the concentration begins to increase due to evaporation. As can be seen in *Figure 1*, the water saving potential of operating with higher cycles of concentration drops off above about six cycles, yet the risk of scaling increases significantly, which needs to be taken into account in the water treatment program.

FIGURE 1 Cycles of concentration vs. water use.



Water treatment chemicals can help reduce water consumption by holding minerals in solution longer as cycles of concentration increase. In addition to water treatment chemicals, water softeners can be beneficial on some sites to reduce the incoming mineral hardness in the makeup water. Oversoftening the water, i.e.,

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complete removal of mineral hardness, or "dead soft water," can be detrimental to evaporative cooling system components. When using a water softener, a blending valve should be used that can reliably control a small bypass stream around the softener to reintroduce some mineral hardness to the outlet stream of the softener. This will allow the makeup water to be dialed in to the correct amount of hardness to enable increased cycles of concentration and efficiency, while minimizing scale formation.

Evaporative condenser systems often contain many dissimilar metals, and as such the water treatment program will need to contain sufficient corrosion inhibitors to protect the various metals present. Consultation with a water treatment professional is recommended when designing an overall program. Modern evaporative cooling systems use galvanized metal in the construction of the fluid coolers, cooling towers, and evaporative condensers, and as such, additional control is required to ensure longevity of the galvanized surfaces. Each evaporative cooling device manufacturer has published detailed startup and operating requirements, and each O&M manual should be reviewed prior to operation.

Most notably, new galvanized systems should be passivated,[II] typically for six to eight weeks, prior to putting the cooling system into full service. The passivation process establishes a protective layer on the zinc surface, turning the reactive and "shiny" zinc to a dull gray, avoiding the formation of white rust. Passivation typically requires precise control of pH,[**] hardness, alkalinity, biological activity and phosphate levels to ensure a proper passivation. The incoming water quality, especially the pH, will determine the time and efforts required to maintain the proper water conditions during the passivation period. These passivation procedures are well documented by each manufacturer.

Evaporative heat rejection systems also require consistent control of biological activity since they operate at ideal growth conditions for most aquatic organisms, and the operating environment can provide nutrients for their growth. Poor control of microbiological organisms can lead to increased corrosion, fouling of the heat exchange surfaces and potentially dangerous conditions for human health. *Legionella* can amplify in cooling water systems and therefore must be controlled. Refer to ASHRAE Guideline 12-2020, *Managing the Risk of Legionellosis Associated with Building Water Systems*, and CTI Guideline 159 for additional information.

Makeup for condenser systems are also excellent targets for water reuse, and water treatment professionals should be consulted to assist in the design of treatment systems specifically for the purpose of water recovery and reuse within condenser water systems. One good example is pumping cooling coil condensate, which has essentially no dissolved solids, into evaporative cooling equipment to minimize domestic water use and increase cycles of concentration.

Steam Systems

The most common issues in steam systems are corrosion, fouling and inefficient operation resulting in increased fuel costs. Due to the high heat flux of modern steam boilers, complete mineral hardness removal is required at the makeup source, which requires water softening at an absolute minimum. Many steam systems provide humidification of building spaces, which leads to additional considerations for steam purity, added makeup water consumption, and condensate return system design. Traditional steam boiler systems rely on a water softener to remove hardness, a sulfite-based oxygen scavenger to remove dissolved oxygen, and polymeric dispersants and anti-foulants to prevent sludge formation in the boiler.

Depending on the steam use and the makeup source, neutralizing amines (cyclohexylamine, morpholine and/or DEA) are usually needed to optimize the condensate return pH and prevent system damage from carbonic acid formation in the condensate. If amines cannot be used due to OSHA or FDA regulations, then a chloride-cycle dealkalizer can be installed immediately downstream of the water softener to reduce the incoming carbonate and bicarbonate alkalinity in the makeup water.

Needs of Different Materials

Steel corrosion rates are minimized in higher pH solutions, whereas aluminum corrosion rates are minimized in neutral pH solutions. This is a problem with some of the new boilers with aluminum heat exchangers. It then

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[II] Passivity: The tendency of a metal to become inactive (not corrode).

[**] pH: $-\log_{10} = \log(1/H^+)$ (hydrogen ion activity); which is basically the ratio of H^+ to OH^-. The scale is logarithmic, so a pH of 6 is 10 times as acidic as a pH of 7. Natural waters are usually in the 6 to 8 range.

requires a much narrower pH range than for systems with only steel and copper materials.

Obtaining Local Makeup Water Quality Data

Many location-specific variables must be considered when designing an HVAC system. However, the most important variable pertaining to this column is local makeup water quality. Water quality varies tremendously throughout North America and the world, and failure to consider the specific water quality supplied to the intended HVAC system will result in premature failure, or missed opportunities to reduce water, energy, and chemical consumption.

Local water analyses can be obtained by directly sampling the water from a nearby or existing building and sending to a laboratory for a full analysis of total dissolved solids (TDS) and total suspended solids (TSS)[‡‡]/particulate. Many utilities also provide detailed analyses; however, they often omit one or more critical parameters, e.g., alkalinity.

Bypass Feeders

We always recommend a bypass feeder in closed water systems. They have two purposes. They can add chemicals to the closed water system, typically on a one-year test and adjust cycle, and the modern units include a filter. Even though they only flow 5 gpm (0.3 L/s) or even less, eventually a good filter will clean the system of particles that are too small to be caught by strainers. One of the authors did a prepurchase survey of a condominium, and the facility manager said he was replacing control valves frequently due to erosion because of material left in the system.

The authors suggested adding a filter-feeder (*Figure 2*) with a 20 micron filter. The facility manager said he had

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[‡‡] Total suspended solids: TSS is a measure of the particles (by weight) that *can* be filtered by a non-reverse osmosis filter. Water is poured through a filter, and then deionized water is poured through to remove TDS that would be left behind in water on the filter. The filter is then dried and the before and after weights are compared. The intent is to *not* include TDS in the measurement.

to replace the filter twice weekly at first, then he changed to 10 micron, and eventually to 2 micron. Since then, he has replaced zero control valves. This is an extremely cheap option to add to your master specs.

A good starting point for sufficient filtration in closed loops is to direct 2% to 5% of the circulation rate for the main pumps through a filter system. These bypass filters can be installed across the supply and return sides of a pump, or directly at the end of main legs/risers in the system, to ensure dirt and debris are removed quickly from the system.

Corrosion Rate Monitoring

The inclusion of a corrosion coupon rack for all water systems (even specially designed racks for condensate return loops) should be part of every large or open hydronic system. Coupon racks are inexpensive and when installed correctly at the start of a project, they provide real-time performance data for the health of the water loop before failures occur.

Figure 3 is a typical four-port corrosion coupon rack with particulate filter and flow regulator to ensure the environment the coupons are exposed to is consistent each time the coupons are checked. Coupons for each metal used in the system (i.e., black steel, copper, etc.) should be included in the rack. Corrosion of the coupons is indicative of the corrosion of these metals elsewhere in the system. Coupon studies can then be performed in 90 to 360 day intervals to quantify the corrosion rates of each metal. Each coupon is cleaned and weighed to determine the loss of material, so changes to the system chemistry can be made as necessary.

Makeup Metering

Aside from glycol loops, which should only makeup premixed glycol from a tank, the inclusion of a makeup meter for all water systems is a staple of modern design. Many of the problems encountered in the water systems discussed in this column can be traced back to the fact that the system loses water, either by design, failure, or error. Tracking the volume, frequency, and severity of makeup water is critical for correct adjustments to treatment programs, and for identifying leaks. Makeup water meters as shown in *Figure 4* are low cost and easily installed on any water system. These meters display an "odometer" locally and can send a digital pulse based on volume to any building automation or water treatment control system.

One author had a project where the owner complained that he had to bleed air out of his compression tank every week. After thinking about it, he realized that the only possible source of air was makeup water, so we went to look for the leak. He had a preheat coil that had partially frozen and was leaking. The cooling coil drain pan in his AHU extended under the heating coil also, so the leak wasn't noticed. If this had continued, the continued addition of oxygen to the system could have greatly accelerated system corrosion.

Summary

Water treatment is complex. This column summarizes the most important items for HVAC designers to know and improve their master specifications for water treatment. Hydronic systems offer significant energy benefits compared to alternatives, and proper water treatment helps ensure these benefits are fully realized. Owners and operators should always consult a qualified water treatment professional. We also direct you to the reorganized, improved water treatment chapter in the *2019 ASHRAE Handbook—HVAC Applications*, Chapter 50. ■

FIGURE 2 Bypass filter-feeders and filter housing.

FIGURE 3 Typical corrosion coupon rack. (Image courtesy of DuBois Chemicals.)

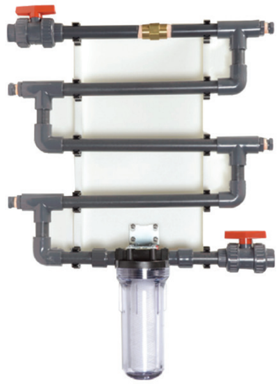

FIGURE 4 Contacting makeup water meter. (Courtesy of DuBois Chemicals.)