Cooling Towers

Water is the favored heat-transfer medium for many chemical process industries (CPI) applications because of its availability, its high heat capacity, and its relatively low cost. CPI plants often use evaporative water-cooled cooling towers to remove heat from products and processes. Here we look at two aspects of cooling towers.

"Correctly Operate Cooling Towers at High Cycles of Concentration," by John E. Hoots, Donald A. Johnson, J. Dean Lammering, and Daniel A. Meier of Nalco Chemical Co. (pp. 30–36), discusses some of the factors that can limit cooling tower operation and offers solutions that can extend or eliminate those limits.

"Monitor Cooling Towers for Environmental Compliance," by Allen C. Hile, Karl Kolmetz, and Jeffrey S. Walker of Westlake Group and Lytton Lai of ABB Lummus Global, Inc. (pp. 37–41), covers environmental aspects of cooling tower operation and provides guidance on setting up a cooling-tower monitoring program.

Operate Cooling Towers Correctly at High Cycles of Concentration

Photo courtesy of Marley Cooling Tower.

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Here's how to avoid potential scaling and corrosion problems and control costs.

This article is based on a paper presented as part of the 60th Annual International Water Conference, which took place in Pittsburgh, PA, Oct. 16–20, 1999.

Operating recirculating cooling systems at higher and higher concentration cycles provides many economic and environmental benefits. The need to lower operating costs to increase a plant's profitability and remain competitive in the marketplace, fresh water shortages, stricter environmental regulations, and a plant's desire to be a good neighbor in the community are all incentives for facilities to conserve water.

Increased cycles of concentration can reduce operating costs through water savings, reduced water discharges, and reduced chemical discharges. In some cases, the cost saving resulting from reduced water consumption and discharge is many times the cost of chemical treatment.

When considering a plant's cooling tower as a potential candidate to reduce water consumption, the engineer must manage various technical issues in order to prevent increased waterside problems. These problems can result in reduced plant efficiency, reliability, and longevity.

This article explores the practical and technical issues that can limit cooling tower operation and presents some new and novel solutions that can extend or eliminate these limits. Keep in mind that each system is unique and that a package of appropriate technologies must be tailored to the individual cooling system.

Characterizing the system

To understand how efficiently your cooling tower is using water, you must first characterize the present system and operating parameters. A basic knowledge of the movement and usage of water in a cooling water system is essential to maximizing the control over the system in preparation for running a high-cycle operation.

Operation at high cycles in a cooling tower can increase the corrosion and scaling tendencies of the water. Therefore, exchangers that experience second- or third-pass water can incur more problems when operating at higher cycles. Additionally, exchangers whose flow is regulated to control process-side temperature can also experience more problems. Repiping these systems to eliminate problems is certainly one alternative, but this is not always practical or economically feasible.

Measurements of makeup water, blowdown, and evaporation should be done on a seasonal basis to help determine the environmental effects throughout a year's operation. Measuring makeup water rates can be difficult, since water meters can lose calibration or wear with use, so periodic calibration will be needed to maintain accuracy.

The measurement of blowdown is even more complicated. While meters can be placed on the main blowdown line, various other sources of blowdown exist in a plant. These include such sources as piping leaks, pump seal losses, cooling water used as wash-down water, and so on. Control over leaks and other sources of unaccounted-for blowdown is critical for operation at high cycles. Often, the limiting factors for increasing cycles are these leaks and unaccounted-for blowdown losses. Leaks must be fixed to control the system during high-cycle operation.

In general, the factors that can limit cooling-tower concentration cycles can be divided into three categories:

- hydraulic factors;
- time-related factors; and
- water chemistry factors.

The operating limits for these factors help determine the water use efficiency of a cooling tower system.

Hydraulic factors

The efficiency of water use is determined by the hydraulic concentration factor (C_H) of a tower. It is represented by the expression:

$$C_H = \Sigma MF/\Sigma NEL \qquad (1)$$

where MF = the rate at which water is added to the tower from all sources and NEL = the total flow rate of nonevaporative water losses from the tower.

Both the makeup and loss flow rates are comprised of controlled and unintentional components. The effective makeup flow rate might be increased by sources such as condensate streams or rainfall. The effective nonevaporative loss rate is the metered blowdown and unmetered streams such as drift, leaks, filter backwash, and removal of cooling water from the system for other uses.

Many tower systems have enough unintentional water losses to limit their C_H to only a few cycles even with no intentional removal of blowdown. Until these losses are identified, characterized, and managed, expenditure of time and resources on a cycle maximization project is not likely to result in any significant gains.

Drift. Every cooling tower loses some amount of recirculating water to drift. Drift is defined as "water lost from the tower as liquid droplets entrained in the exhaust air. It is independent of water lost by evaporation *(1)*."

The amount of water lost to drift is normally expressed as a percentage of the recirculation rate, and typically ranges between 0.1% and 0.001% of the recirculation rate. The rate of loss by drift depends on system-specific factors such as the age and design of the tower, particularly the drift eliminators, and on condition-dependent factors such as the direction and velocity of the wind.

Unknown and uncontrolled water losses. Drift is only one source of unknown water losses. Others include filter backwash, leaking pump glands or other equipment, overflows, and a host of other sources.

Another problem associated with high-cycle operation in leaky towers is the difficulty of maintaining control. As cycles increase, the fraction of total water removal under control of the blowdown valve decreases, as illustrated in Figure 1. This loss of control capability impacts the ability to control a concentration strategy that depends on volumetric measurement or control of blowdown.

Time-related factors

One of the main problems with high-cycle operation is the increase in Holding Time Index (HTI). The HTI is de-

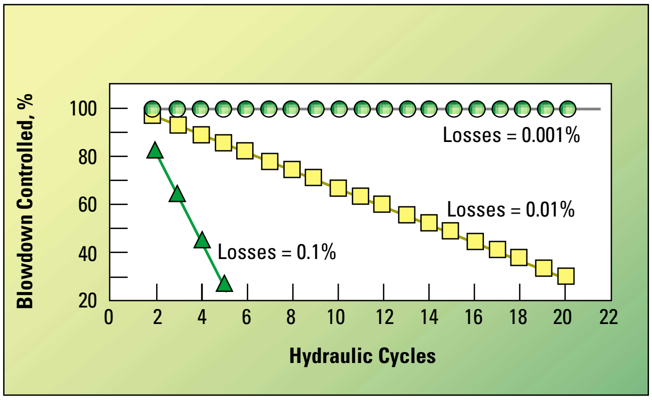

Figure 1. Total water losses under blowdown valve control.

fined as the half-life of an ion in the system. Mathematically, it is described by the equation:

$$HTI = 0.693\ V_T/B_T \quad (2)$$

where V_T = total system volume and B_T = total water loss.

Figure 2 illustrates the impact of increased cycling on the HTI of a typical cooling tower system. Increasing the concentration factor from 5 to 15 effectively triples the holding time index, increasing the average time a molecule spends in the system by a factor of three. This can affect the management of the scale- and corrosion-inhibitor programs.

Most industrial cooling systems operate with an HTI of 48 h or less. As the HTI increases, additional stresses are placed on the organic portions of the treatment regime (polymer, phosphonates, azoles) of the cooling water program. This is because the treatment-program active components must stay viable for longer periods of time before being replaced.

The other major problem with increased HTI is that fewer solids are removed from the system because of reduced blowdown. While blowdown itself does not remove a tremendous amount of solids, it does help control solids buildup in the recirculating water loops. In high-cycle operation, side-stream filtration can be used to help control solids buildup.

As cycles increase, any type of process contamination can significantly impair the ability of the program to operate effectively. Depending on the type of contamination and the system HTI, the contaminants will stay in the system for a longer period of time. Many contaminants increase the microbiological growth in a system by scavenging halogen, which is used for bio-control, or by providing a nutrient source for growth. Leaks of H_2S are extremely corrosive and recovery from these leaks can take as long as six months. Procedures must be in place to allow for a high volume of blowdown water to rid the system of harmful process contaminants.

Water chemistry factors

By far the biggest impact of increasing HTI is on the active components of the treatment program. These materials

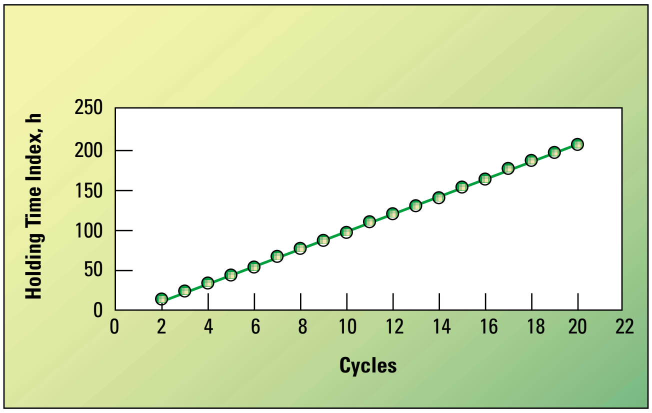

Figure 2. Increased cycling increases the holding time index.

help control corrosion and minimize fouling on heat-transfer surfaces. They are consumed by various factors, including soluble iron, halogenation, potential microbial degradation, suspended solids, and adsorption on system surfaces.

At high HTIs, these materials can be consumed before being replaced. As this occurs, more severe corrosion and fouling can result. Monitoring and control of program actives is critical in high-cycle operation to maintain the needed actives for system control.

Any increase in the concentrations of scalants raises the saturation factor of minerals, thereby increasing the severity of potential scaling problems. The concentration factors in systems using medium or hard water without pH control are typically most severely limited by scalant supersaturation because of the pH dependence of calcium carbonate and calcium phosphate solubility.

Precipitation inhibitors extend the solubility limits of scaling species. Operation at higher supersaturation levels may require modification of the inhibitor program for compatibility with the conditions present. Increased supersaturation requires either higher dosages of inhibitor or a change to higher quality inhibitors. Although inhibitors extend the saturation limits of scaling species, there are limiting scalant supersaturation factors beyond which they cease to function. Figure 3 illustrates the effect of increased cycles on the saturation of $CaCO_3$ in pH-controlled and alkaline environments *(2)*. Other scaling species that can become limiting in high-cycle situations are calcium sulfates, silica, and magnesium silicate.

Weighing of credits and debits. Preparing a site for high-cycle operation requires tradeoffs from an economic point of view. Simply closing a valve may increase cycles, but operational problems will likely be seen within a few months. Some of the credits will be less water usage, reduced blowdown, and lower blowdown-treatment costs. The cooling water treatment program costs may or may not come down, depending on the quality of the water used. Low-quality water is likely to need more corrosion and scale inhibitors, a more-aggressive biocide approach, and additional capi-

Photo courtesy of Marley Cooling Tower.

Photo courtesy of Marley Cooling Tower.

tal equipment such as side-stream filtration. Additional monitoring will be needed to increase the reliability of the treatment feed, but its cost should be offset by the increased reliability of the equipment.

Setting rational goals

When setting out to reduce water consumption and increase cycles of concentration in a cooling water system, one should set reasonable and rational goals.

At the outset, a detailed inventory of water consumption in the plant should be performed. This includes makeup to the cooling tower, evaporative losses, and all blowdown sources. By far the biggest problem will be in identifying the sources of losses.

A detailed study of water losses from the plant should be completed. This includes the main blowdown valve, losses from pump seals and valves, and other plant uses such as washdown water. An inventory of cooling-water monitoring equipment and operational procedures will identify areas needed for upgrading. After this is complete, a plan should be formulated and implemented to eliminate system leaks and upgrade system equipment and operation. Then, a review of the gains is necessary to evaluate the success of the upgrades. After this is complete, increasing the cycles of concentration can be started.

Progress should be evaluated on a stepwise basis. For example, if the system were to go to 12 cycles from a starting point of 6, a reasonable goal for the first one to two months would be to operate successfully at 8 cycles. If corrosion and scale are well controlled, an increase to 10 cycles can follow with evaluation of success again after a significant period of time. This process is repeated until the target cycles of concentration is reached.

In this way, enough time is allowed to implement changes and evaluate the success of each change. There is less danger of severe corrosion or scale formation using this stepwise process.

Choosing a compatible treatment program

To successfully treat a high-cycle system, a compatible treatment program must be in place. This includes a combination of stress-tolerant treatment actives and monitoring equipment for the active material. Online measurement of the actives is at least as important as the treatment, as it allows for a rapid response to changing conditions in the plant. One does not have to rely on a bleed and feed mechanism for inhibitor replacement. The treatment programs will typically be based on a stabilized phosphate or alkaline phosphate approach.

Stress-compatible inhibitor technology

Some inhibitor technologies are easier to implement and provide better results under high-stress conditions than others. For example, the use of blended products may provide the correct amount of polymeric dispersant but add unnecessary amounts of other inhibitors, increasing the overall costs.

A better approach may be to design on-site the specific inhibitors needed through a flexible product addition regime. In this concept, the needed corrosion and scale protection are achieved by adding each individual active and monitoring the active residuals. In this way, the correct inhibitor is added for the specific stress condition in the cooling system. However, monitoring of treatment actives is not enough. Treatment product dosages must be measured to determine the actual actives consumption levels and to optimize program economies.

Recently developed stress-tolerant inhibitors are part of this approach. New dispersants have been shown to work under a variety of stress conditions, such as high calcium (>1,500 ppm as $CaCO_3$), high water temperature (>150°F), extended HTI (>72 h), etc. *(3)*. These dispersants allow operation at lower dosages and provide better performance.

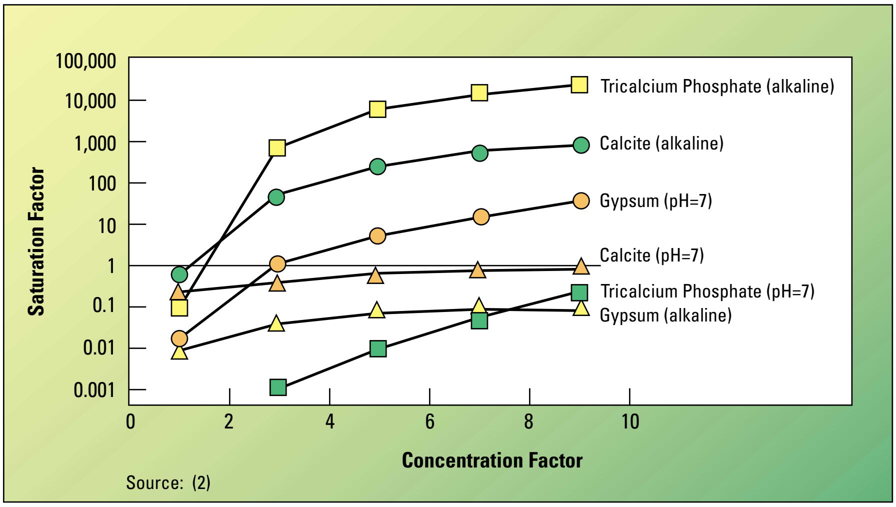

Figure 3. Impact of cycling on saturation factors of scalants. Source: *(2)*.

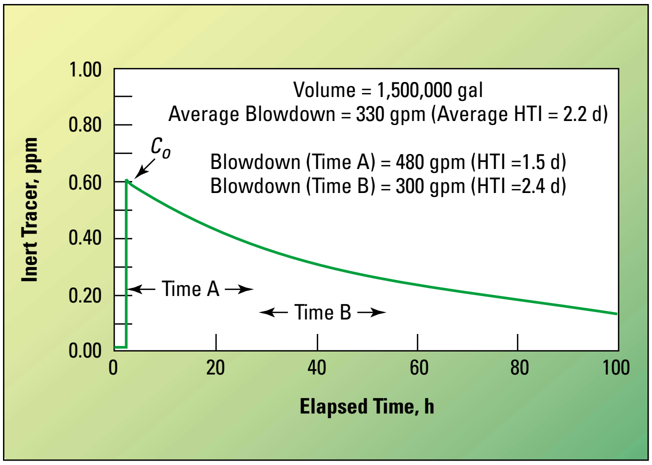

Figure 4. Diagnostic tracer study of total system volume and blowdown rate.

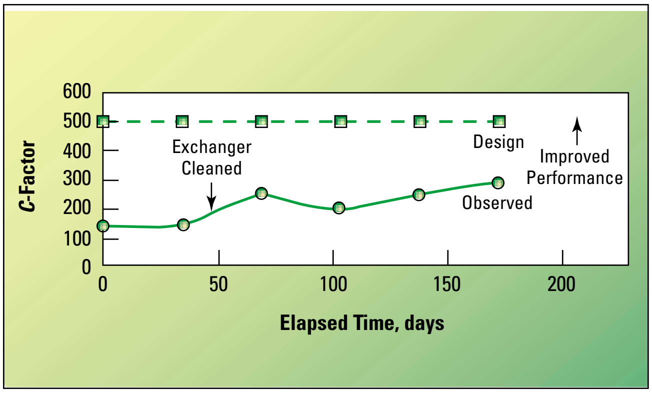

Figure 5. Diagnostic study of heat exchanger *C*-factors with fluorescent inert tracers.

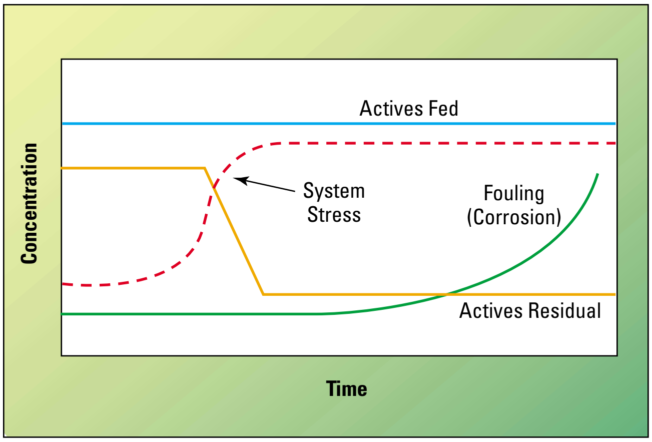

Figure 6. Effect of increased system stress on treatment dosage, actives consumption, and performance.

New corrosion inhibitors have also been found that are stress tolerant. Some materials demonstrate high halogen resistance and remain stable under long HTI (>150 h) conditions.

Diagnostic tools

At higher cycles and stressed conditions, it becomes increasingly essential that treatment programs and cooling water systems be used within recommended guidelines. For this, it is essential that the cooling water system is properly characterized. This involves evaluating the following key operating parameters:

- system volume;
- total and unaccounted for blowdown rates (including drift);
- holding time index;
- true cycles of concentration;
- recirculating-cooling-water flow rate;
- cooling-water flow rate through heat exchangers;
- liquid/gas ratios in cooling towers; and
- heat exchanger performance (*C* factor).

Inert fluorescent tracers have been used in approximately 6,000 applications to characterize one or more of these cooling system operating parameters *(4–5)*. They are also used in about 10,000 cooling water systems to ensure that specified treatment dosages are continuously and automatically maintained.

The use of inert tracers to characterize system operating parameters is illustrated in Figure 4. A known amount of tracer or treatment product containing a tracer is added to the system. Changes in the inert tracer readings are measured instantaneously and continuously. These readings will decrease over time as cooling water containing the tracer is lost through blowdown, drift, and leakage. Measuring system volume is important in order to quantify water losses from the system and ensure that any treatments being slug-fed to the system are added at the proper dosage.

Cooling-water flow rates can also be measured by adding an inert tracer to the system *(5)*. Determining the total recirculation rate of cooling water is useful in estimating cooling tower drift and water losses (by comparison of drift rate with total water losses). Determining the source and magnitude of water losses (as well as controlling them) will ultimately determine the maximum cycles of concentration that a cooling tower can attain.

Measuring cooling-water flow rates across heat exchangers can help determine exchanger performance in several ways:

- whether performance is being limited by insufficient cooling-water flow rate;
- whether fouling is caused by excessive throttling of cooling-water flow rate or incorrect exchanger design;
- water-side fouling of heat-exchangers based on *C*-factor changes [C = flow rate/(pressure drop)$^{0.5}$]; and

• efficiency changes by measuring cooling-water flow rate, process-fluid flow rate, and temperature drops.

Measuring heat exchanger performance and detecting (and rapidly correcting) problems leading to performance losses become increasingly important in cooling water systems operating at higher cycles and increased stress levels. An example of *C*-factor measurement and changes in performance is shown in Figure 5 *(4)*.

Advanced measurement and control

In addition to measuring and adjusting system operating parameters, online monitoring and control of treatment dosages is essential to operating high-cycle and stressed cooling water systems at optimal cost and performance. The following provide useful information for maintaining system performance:

• total treatment dosage (using inert tracers);
• residual treatment actives; and
• consumption of treatment actives.

Fluorescence-based technologies have been very useful in online monitoring and control of these dosages *(6–10)*. Excessive consumption of treatment actives (*e.g.*, dispersant polymer, phosphate, zinc, phosphonates, triazoles, etc.) is a leading indicator of cost and performance problems (including scaling, corrosion, fouling, and microbiological control problems), as illustrated in Figure 6.

In cooling water systems where consumption of actives is significant in magnitude or variability, the goal is to optimize performance by automatically adjusting product dosages or operating parameters to reduce the effects of consumption (Figure 7).

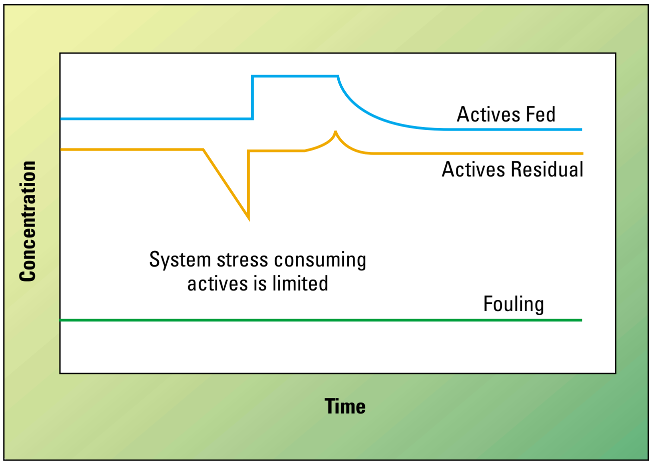

Figure 7. Treatment dosage and actives consumption measurements to automatically respond to system stresses.

Example. A chemical process industries (CPI) plant wanted to reduce water usage by increasing cycles of concentration in the cooling water system from approximately 15 cycles to 25 cycles. This change was tested prior to installation of online monitoring and control equipment for treatment dosage. The increased system stress resulted in the formation of significant amounts of hard-to-remove "chip" scale.

After the necessary online dosage monitoring and control equipment was installed (based on tests with fluorescent tracers), a second test of operation at increased cycles was conducted. The results of a controlled increase in pH and then cycles (from about 15 cycles to 20 cycles) are shown in Figure 8. The consumption of dispersant polymer (polymer added minus residual polymer) was less than 5% during "typical" operation of the system at about 15 cycles. The consumption of polymer increased to about 15% as the system stresses increased, then returned to the previous level when the cycles and stresses returned to more typical values.

Monitoring progress

Once high-cycle operation is achieved, maintenance of the high cycles is critical to realize water savings. For example, if the system operates at 15-gpm blowdown at 15 cycles, operation at 13 cycles results in a 17.3-gpm blowdown rate, or a difference of 3,300 gal/d. A system leak or use of washdown water will cut into the apparent cycles of concentration. Routine evaluation and maintenance of system control equipment like a conductivity controller is important to help maintain water savings. Monthly logs are important to monitor and document water usage over time and through seasonal changes.

While the documented goal is usually water savings and the resulting reduced water costs, high-cycle operation may not decrease chemical costs or total treatment costs for the system. Experience has shown that for systems operating above about 7–8 cycles, normal treatment dosages need to be greatly increased, particularly for corrosion inhibitors and, more importantly, dispersants. An example of this is where a program may typically call for 50 ppm of a dispersant at 600 ppm calcium at 5 cycles, but 75 ppm of disper-

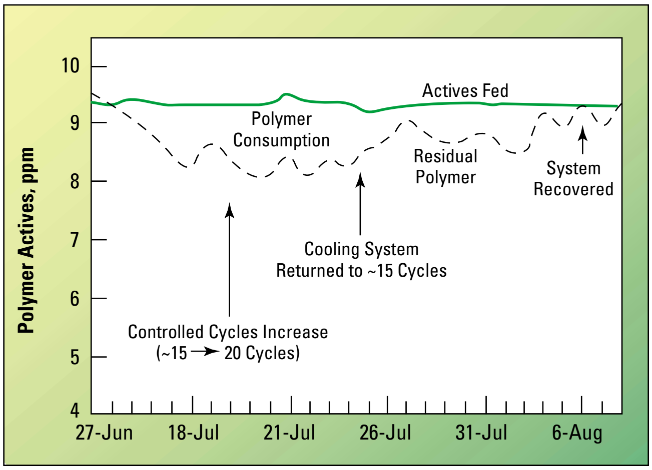

Figure 8. Effect of increased then decreased cycles of concentration on dispersant polymer consumption.

sant at 10 cycles. Demand for the dispersant and consumption in the system necessitate the increased amount. The best case is where the treatment is cost-neutral with a decrease in water usage, although even in this case the treatment program's overall cost increases.

For the example discussed above, increasing from 10 cycles in just one cooling tower reduces operating costs by $54,000 at 12.5 cycles, by $90,000 at 15 cycles, by $116,000 at 17.5 cycles, and by $135,000 at 20 cycles.

The overall treatment cost of the operation of a high-cycle cooling system will often be higher than at low cycles. This is due to the increased need for inhibitors and dispersants, a more-aggressive bio-control approach, and the installation of capital equipment like side-stream filters. If the overall treatment is done correctly, troublefree operation will be realized.

Final words

The effect on plant longevity and reliability will often be better if the proper steps are implemented and shortcuts are not taken when operating at high cycles. Without the proper precautions and operational standards, more problems will be seen when operating at high cycles of concentration. These include increased scaling and corrosion. In some cases, corrosion, scaling, and microbial control will suffer due to inadequate safeguards in the system. **CEP**

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Further Reading

The last three items are available from the authors' company by calling (800) 732-5572 or faxing (800) 732-5573.

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