Chemical vs. Non-chemical Cooling Water Treatments – a Side-by-Side Comparison

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ABSTRACT: Two non-chemical cooling water treatment technologies, a pulsed power system, and a hydrodynamic cavitation device, were evaluated against conventional chemical treatment in a detailed six-month study. The comparison was conducted at Alcoa's Mt. Holly Works in Goose Creek, SC. Three identical, non-contact, evaporative coolers used to cool air compressor systems were used as the test sites. The three technologies were installed on the external 600-gpm spray water loop in these towers. The towers were operated at a range of setpoints representing between 4 – 20 cycles of concentration. Water quality parameters, corrosion, scaling indices, microbiological (aerobic and anaerobic planktonic and sessile, Legionella), and aquatic toxicity data/results will be presented for the different operating conditions. Operating cost comparisons will also be shared. Conclusions and Recommendations will be presented.

BACKGROUND

With the rising cost of chemical treatment additives for cooling water systems, and Alcoa's announced goal of reducing water usage and wastewater discharges by 60% by 2008, locations were eager to explore alternatives for reducing their water treatment costs and achieving the Company's conservation goals. Spurred by the perceived successes of two non-chemical, mechanical/electrical cooling water treatment devices at the Alcoa Corporate Center, and an extrusion plant in Louisiana, other locations were anxious to install their own systems. These devices were reported to successfully control scaling, corrosion, and microbiological growth in recirculating cooling water systems. Ten more units were installed in 2001, and approximately the same number installed in 2002.

These non-chemical devices were being installed at such a rapid pace, that there was little opportunity to gather historical performance data beyond the claims and testimonials provided by the manufacturers. Because of the great interest in these technologies corporate-wide and the potential for significant cost savings and environmental benefits, it was decided to perform a side-by-side evaluation of two technologies. These were an electromagnetic pulsed power system (herein after called PP), and a hydrodynamic cavitation unit (herein after called HDC). Both were compared to conventional chemical treatment.

Mt. Holly Works was selected for the test site because they had three identical, but segregated (i.e. separate influent and effluent water lines with no interconnection between the basins) cooling towers serving their air compressor systems, and they were interested in evaluating these non-chemical technologies.

PROJECT OBJECTIVE(S)

The objectives of this study were to evaluate the effectiveness of commercially available mechanical/electrical treatment devices for controlling corrosion, scale formation, and microbiological growth in recirculating cooling water systems, and to substantiate the following performance claims made by both non-chemical treatment suppliers:

- Eliminates essentially all chemical additives with the associated cost savings
- Eliminates most of the employee health, safety, and environmental issues typically associated with the storage and use of chemicals
- Reduces water consumption through operation at higher cycles of concentration. Blowdown reduced 80% and Makeup by 40% when cycles increase from 2 to 6
- Reduces or eliminates the toxicity of blowdown to aquatic life in receiving streams
- Degrades and removes old scale encrustations and bio-film from wetted pipes and tower surfaces
- Overall lower operating costs including savings in water and sewer charges, maintenance, chemicals, and labor.

PROJECT APPROACH

A. MT. HOLLY'S COOLING TOWERS.

Mt. Holly has three, Baltimore Aircoil (BAC) Model F1463 – PR evaporative coolers serving their air compressor system (see Figure 1). A closed internal loop cools the main air compressors and air dryers. The internal loop is comprised of 10 pass cooling coils. Each coil is a 1.05 in. external diameter tube with 2 in. spacing between the coils. Hot internal loop water from the combined compressor system is returned and distributed across the three segregated, independently functioning, BAC towers.

Figure 1. BAC Towers (back)

Water in each 1,200 gallon basin is recirculated to the top of the tower at 610 gpm, distributed through a piping manifold, and then sprayed through a series of nozzles over the closed loop coils. Fans (3) at the base of each tower, blow air upwards against the falling spray water. Drift eliminators placed above the pipe manifold trap water droplets and return them to the tower basin. This comprises the outer loop cooling circuit, and the chemical characteristics and microbiological content of this spray water was the subject of this six-month study.

The towers were installed in 1996, with design specifications to cool 343 gpm of internal loop water from 116 ^{0}F to 90 ^{0}F at an 80 ^{0}F wet bulb. Each tower has a design heat load of 4.45 MM BTU/hr. or approximately 297 Tons of cooling. At design conditions of a 26-degree change in temperature, and 343 gpm flow rate the estimated evaporation rate of the recirculated water is approximately 12,800 gpd. Design drift loss is 0.001% or 0.006 gpm (~9.0 gpd). The basins of all three towers were flushed and thoroughly cleaned before the test program began.

B. TREATMENT ALTERNATIVES.

Chemical Treatment. Chemical treatment is presently used in the external loop spray water in all three towers. The following control ranges for the chemical treatment program are maintained:

pH = 6.5 – 9.0
Conductivity = 400 – 1,000 umhos
Molybdate = 2.0 – 5.0 mg/l

A corrosion/scale inhibitor is continuously fed to maintain molybdate levels in the desired control range. In addition to sodium molybdate and a phosphate compound for mild steel corrosion control, the corrosion inhibitor contains a triazole for copper corrosion protection, and an acrylic polymer for scale control. Chemical treatment also includes two non-oxidizing biocides, isothiazolin and glutaraldehyde, on an alternating, batch dosage basis to maintain microbiological control in the three towers. Under this control program the towers normally operate at 3 to 5 cycles of concentration with a typical discharge (blowdown) rate of 3,200 – 6,400 gallons per day.

As part of this investigation the middle tower was left on the chemical treatment program while the West and East towers were converted to the mechanical/electrical treatment approaches. The performance of the two non-chemically treated towers was measured against that of the conventional, chemically treated middle tower.

Pulsed Power. The pulsed power (PP) system was installed on the West tower (see Figure 2). The PP imparts a pulsed, high frequency (100,000 hz) electromagnetic energy into the circulating water by inducing varying magnetic fields 60 times per second. The system is normally sized according to the pipe diameter of the recirculating cooling water. The coils operate at a low voltage of less than 45 volts rms[1].

Figure 2. 3" PP with Insulated Cyclonic Separator

The PP supplier prefers to size their units to turn over the system volume once every 15 minutes for good microbiological control. The initial 110 gpm flow rate through the 3 in. unit created a 10-minute turnover frequency. When a larger 6-inch unit was installed, the turnover frequency increased to once every 2 minutes.

A centrifugal pump draws water from a 3 in. drain connection on the bottom of the tower, and directs it through the 3 inch PP unit, and then to a cyclonic separator for solids removal before returning the treated water back to the tower basin. The reason for installing the separator was to achieve results that could be compared to the hydrodynamic cavitation system (discussed next). The hydrodynamic cavitation system typically is installed with a solids separation device.

Hydrodynamic Cavitation. The hydro-dynamic cavitation (HDC) system was installed on the East tower. The HDC unit is based on the principle of controlled hydrodynamic cavitation. Cavitation is the dynamic process of the formation, growth, and collapse of micro-sized bubbles in a fluid. Studies have shown that when a liquid moves fast enough, gas bubbles will form and collapse creating a process called cavitation. In turbulent liquid flows, and notably at high velocity, hydrodynamic cavitation will occur[2].

Figure 3. HDC System with Bag Filters and Cyclonic Separator

A 20 gpm unit was sized and selected by the supplier for Mt. Holly. HDC units are sized to treat the entire system volume seven times a day plus an allowance for makeup water. Based on the size of this tower and expected heat load this would have calculated to a 15 gpm unit, but the HDC supplier elected to increase to the next larger size in their product line, a 20 gpm unit, rather than use their smallest 10 gpm model.

The HDC unit was installed with 2 process loops. One circuit draws water from the tower basin through a 3 in. strainer, and pumps it through a cyclonic separator and then through duplex bag filters before returning it through a piping manifold into the bottom of the tower basin. The second process water loop draws water from the tower basin through a 2-in. strainer before entering the HDC unit.

C. SAMPLING AND MONITORING.

The following parameters were monitored:

- Water meter readings were recorded at least 5 times per week and included make-up and blowdown.
- Water temperatures were monitored continuously from various points in each tower.
- pH and conductivity were measured from makeup supply, and outer loop spray water from all three towers on a daily basis.
- Corrosion was measured using a rack that contained slots for five (0.5 in. x 3.0 in.) coupons. A mild steel coupon occupied one slot, an aluminum coupon another, and a steel electrode used in conjunction with a Corrater®[3] meter a third. Corrater® readings were taken once per week.
- Microbiological analysis included a variety of techniques to measure planktonic and sessile organisms, both aerobic and anaerobic. Two perforated steel coupons were used to provide a growth substrate for sessile organisms.
- Aquatic Toxicity of the tower blowdowns was also measured during the study.

D. OPERATING SET POINTS

Before the trial, the three towers were operating between 3-5 cycles of concentration as determined by comparing the conductivities of the water in the recirculating spray loop with that of the makeup water.

The intent of the trial was to operate the three towers at increasingly higher cycles of concentration to see how the different treatment technologies would perform under increasing scale-forming potentials. Corrosion rates and microbiological control for both planktonic and sessile organisms were also measured during these different operating periods. The different operating settings were controlled by adjusting the conductivity setpoint on the continuous conductivity monitor in each tower. When the conductivity of the recirculating spray water reached the setpoint, the conductivity controlled blowdown valve would automatically open and some high conductivity water would be purged from the tower, and sent to drain. Since the blowdown setpoint (based on conductivity) was set the same for all three towers, it was considered an independent variable of this test.

Conductivity controllers were initially set at 1,000 umhos to approximate 5.0 cycles of concentration. The following table lists the dates and setpoints for the operating periods used during this study.

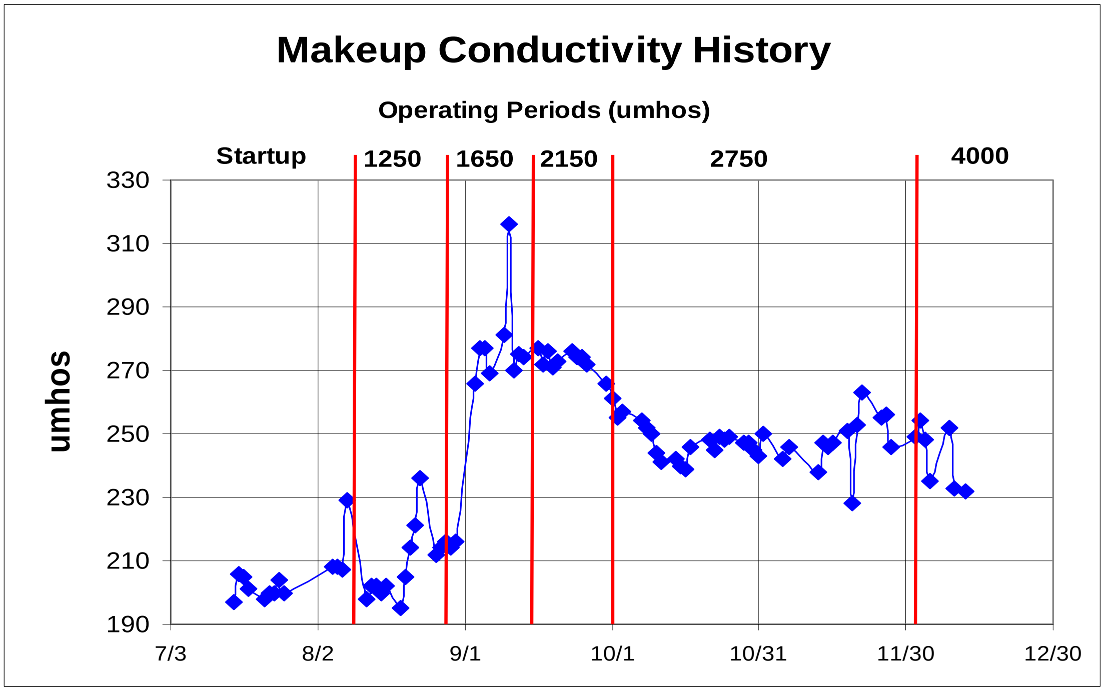
Table 1. Conductivity Setpoints

Dates 2002	Conductivity Setpoint (umhos)	Intended Cycles of Concentration
6/24 – 8/4	1,000	5.0
8/5 – 8/26	1,250	6.0
8/27 – 9/12	1,650	8.0
9/13 – 9/23	2,150	8.0
9/24 – 12/5	2,750[1]	10.0
12/6 – 12/20	4,000[2]	16.0
12/21	2,150	Test over

Notes:

1. The Chemical tower was set back to 2,150 umhos on November 1, due to excessive buildup of suspended solids in the recirculating spray water loop.
2. Only the PP and HDC non-chemical towers were operated at 4,000 umhos

Figure 4. History of Makeup Conductivity



In early September, the conductivity of the makeup water increased dramatically as shown in Figure 4 necessitating an increase in the conductivity setpoints of the three towers on September 13, in order to maintain 8.0 cycles of concentration. The 2,750 umhos operating period lasted the longest - 73 days – as a variety of tests and observations were made during that time frame. The last operating period was used to try to "stress" the non-Chemical towers to see how they would perform under high scaling conditions.

TECHNICAL RESULTS OR FINDINGS

A. CYCLES OF CONCENTRATION.

Cycles initially based on water meter readings were calculated by dividing the makeup water by the blowdown + solids separator purge + drift losses. Only the PP and HDC towers had solids separators, which contributed small daily purges of 26 and 73 gpd respectively. Drift losses were calculated as 9 gpd for all towers, which was the designed drift loss specified by the manufacturer. While it was initially thought that cycles based on water meter readings would be the most accurate, unmeasured leakage and observed drift losses that appeared higher than calculated likely contributed to higher values using this method.

When the conductivity settings were moved to 1,250 umhos during the next operating period, cycles based on magnesium, sodium, sulfate, and potassium concentrations were also calculated and compared against cycles based on conductivity for each of the operating periods. These are plotted in Figure 5. The similarity amongst towers of cycles based on salts verified that this was the best way to measure true cycles during this test.

Note that potassium values from the Chemical tower were not used in the calculation on Figure 5 since potassium was a component of the chemical additives used in this tower.

The quick and easy method of using the ratio of conductivities was not appropriate for calculating cycles, particularly as the test program moved into potentially higher scaling regimes. It was determined that for all of the operating periods starting with 1,250 umhos that cycles based on magnesium, potassium (not including Chemical tower), sodium, and sulfate were the most representative of the true operating concentration factors in the towers.

Note that as the conductivity settings are increased in later operating periods, the cycles determined from the constituent values increase progressively higher than the conductivity values. This was taken as an indication that calcium carbonate and other compounds were precipitating at higher chemical saturation levels, thereby lowering conductivity values, and yielding lower than actual cycles of concentration determinations. This precipitation might have been via nucleation in the recirculating water as the non-chemical vendors claim, or simply scaling on the heat exchangers. Additional discussion on scale is provided later in this text. Two values are plotted for the Chemical Tower during the 2,150 umhos operating period. As was mentioned previously, the Chemical Tower was only operated at the 2,750 umhos setpoint for a limited time, and was dropped back to 2,150 umhos on November 1.

B. WATER METER READINGS.

Figure 6 shows the average daily blowdowns for each of the three towers during the various operating periods. This blowdown includes discharge from the solids separator devices from the non-chemical units. The only statistical difference (95% confidence) was between the PP and HDC tower during the startup period. It is not clear why this might have occurred, however it can be assumed that the three towers were not completely in control during this time period so some anomaly during startup caused the difference. Similarly there was no statistical difference in make-up water usage between the three towers.

Figure 5. Cycles of Concentration History

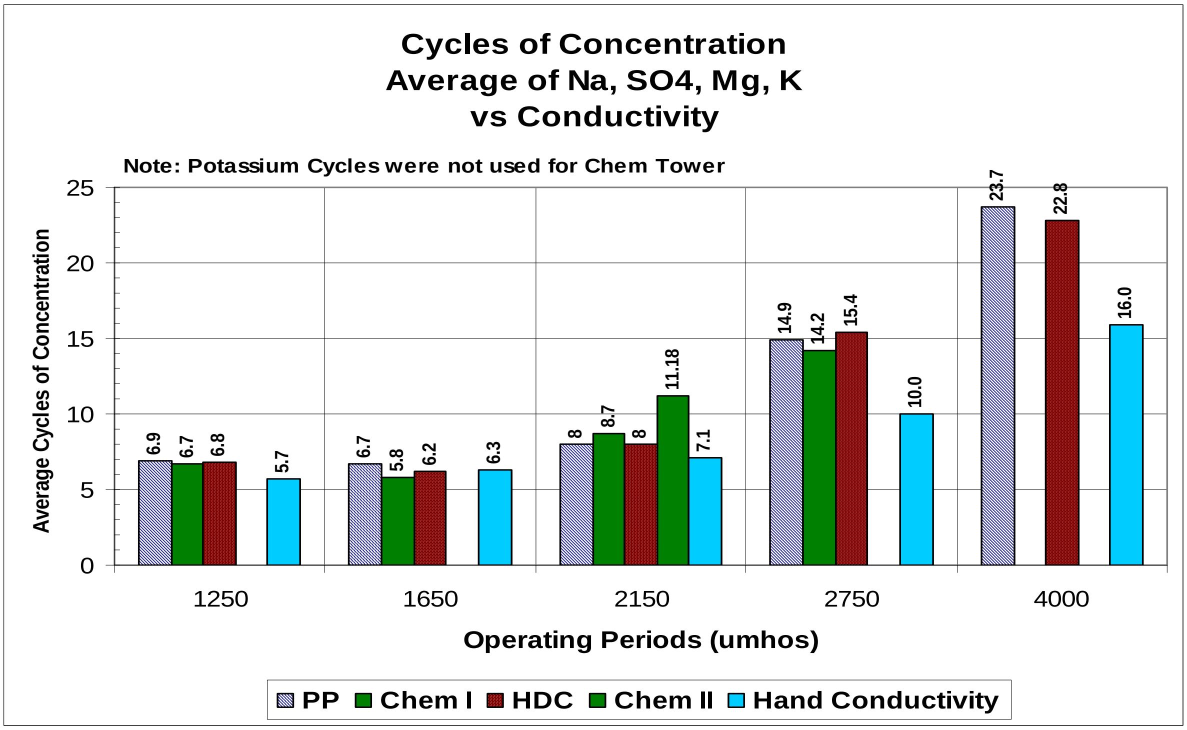
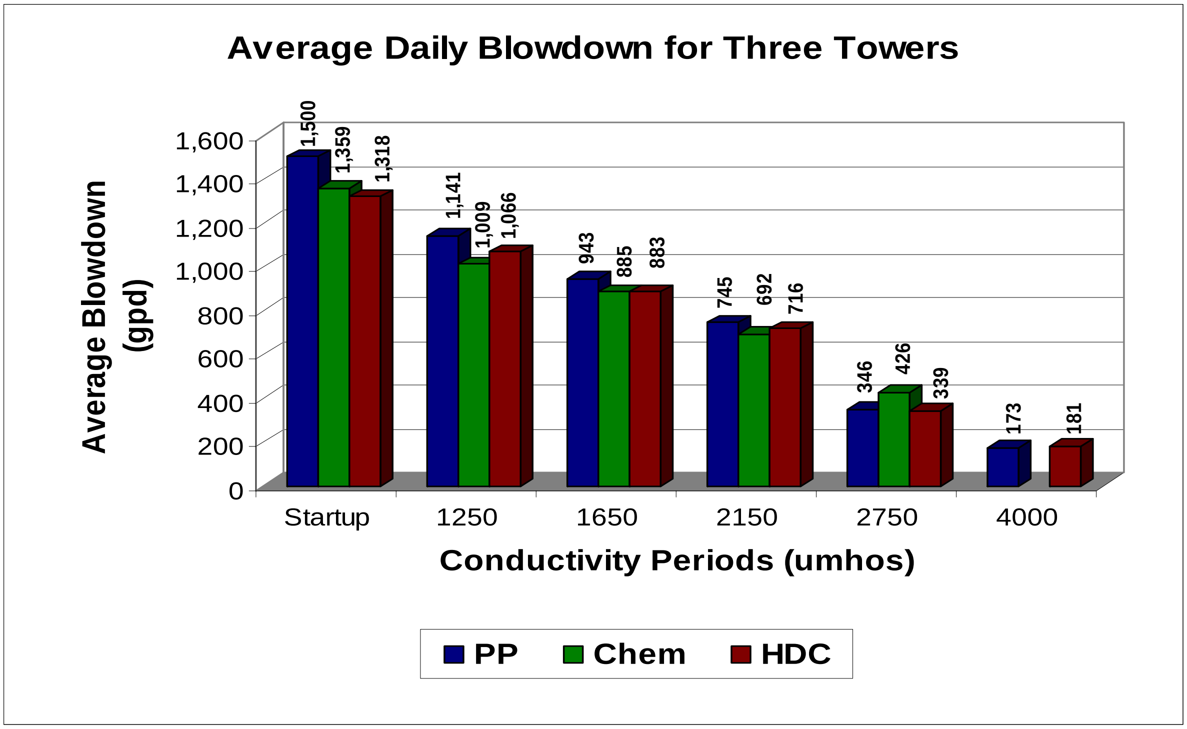


Figure 6. Average Daily Blowdowns



C. WATER QUALITY DATA.

In a further attempt to identify any performance differences between the three towers, water samples were taken an average of twice per week from the makeup source as well as the three towers and the following parameters were measured: alkalinity, total dissolved solids (TDS), total hardness, calcium hardness, and turbidity.

The average values for all parameters showed a steady increase across the operating periods as the cycles of concentration were raised. TDS, total alkalinity, total hardness, calcium hardness and conductivity were scrutinized statistically and generally showed no difference between all three towers for each operating period respectively. A few exceptions are as follows. First, during the 2,750 umhos time frame the alkalinity for the Chemical tower was higher than that of either non-chemical tower. The reason for this is likely due to the scale inhibitors keeping scale forming elements in solution for the Chemical tower, while scale or other precipitates were forming in the non-chemical towers.

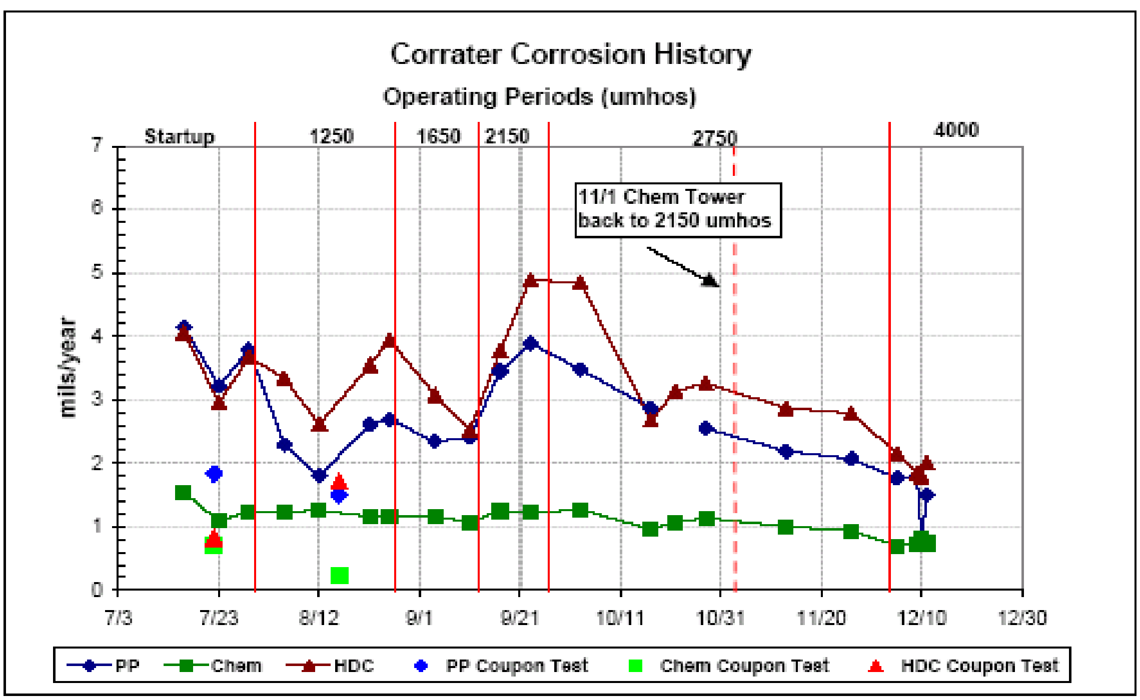
Second, while the turbidity levels track fairly closely across the towers at average values below 10 NTU over the first two periods, the Chemical tower began to show some elevated spikes during the 1,650 umhos period. As the conductivity controlled blowdown volumes continued to decrease with increasing cycles, the adverse affect of not having a sidestream solids separator became more pronounced in the Chemical tower. Finally at the 2,750 umhos control point while both non-chemical towers were still operating below 10 NTU, the Chemical tower recorded spikes above 120 NTU with an average over 70 NTU. After five weeks of operation at these elevated cycles (~14), the chemical supplier recommended reducing the setpoint back to 2,150 umhos so that their chemical treatment program would not be compromised. Within days of returning to this lower setpoint, the affect of larger volume blowdowns successfully reduced turbidity levels below 20 NTU where they stayed for the remainder of the study. The ambient air scrubbing affect of the cooling towers, and the close proximity of the three towers to a carbon silo may have exaggerated the high turbidity levels observed in the Chemical tower due to lack of side stream filtration on this unit.

D. CORROSION CONTROL.

Weekly Corrater® readings were used to supplement the corrosion results determined by weight loss of the mild steel coupons. The mild steel coupons were removed and replaced three times at various intervals during the study period. The aluminum coupons were only removed once, after 77 days in the rack. Unfortunately, the last set of coupons, steel and aluminum, were lost in transit and never recovered.

Figure 7 is a graphical presentation of all of the corrosion rate data obtained during the study. The Chemical tower exhibited excellent control averaging < 1.3 mils/year over the entire study period based on Corrater® readings. The rate exhibited a gradual decline from approximately 1.3 mils/year at the start of the study to < 0.8 mils/year during the final month. This extraordinary rate was partly attributable to the fact that the chemical supplier did not adjust the feed rate of their

Figure 7. Corrater Corrosion History



corrosion inhibitor for most of the study. Thus as blowdown volumes decreased, the concentration of corrosion inhibitor increased. While the stated control range was 3-5 mg/l of molybdate, they ranged from 3.0 – 18.5 mg/l concentration with an average of 8.5 mg/l.

Corrater® readings for the two non-chemical towers also exhibited an overall decrease over the study period, although the decline was not as consistent. Initial readings were at the 3.7 to 3.6 mils/year for the PP and HDC towers respectively, and they dropped to 1.4 and 1.9 mils/year respectively at the conclusion of the study. However, the HDC tower spiked to almost 5.0 mils/year for two weeks midway through the study. The overall decrease in corrosion rates could be attributed to either or both of two mechanisms: 1) further passivation from operation in moderate to severe calcium carbonate scaling regimes over the course of the study, and 2) cycling up of the ortho-phosphate levels in the makeup water which acted as a passivating anodic inhibitor and provided another measure of corrosion protection. Corrosion rates between 1 - 3.0 mils/year for mild steel are considered very good control. Excellent control is < 1.0 mils/year.
Corrosion coupon results are also shown on the Figure 7. These results are summarized below on Table 2.

Table 2 – Corrosion Coupon Results

	PP	Chem	HDC
Mild steel @ 28 days	1.84	0.72	0.83
Mild steel @ 72 days	1.50	0.22	1.71

Note: All results in mils/year

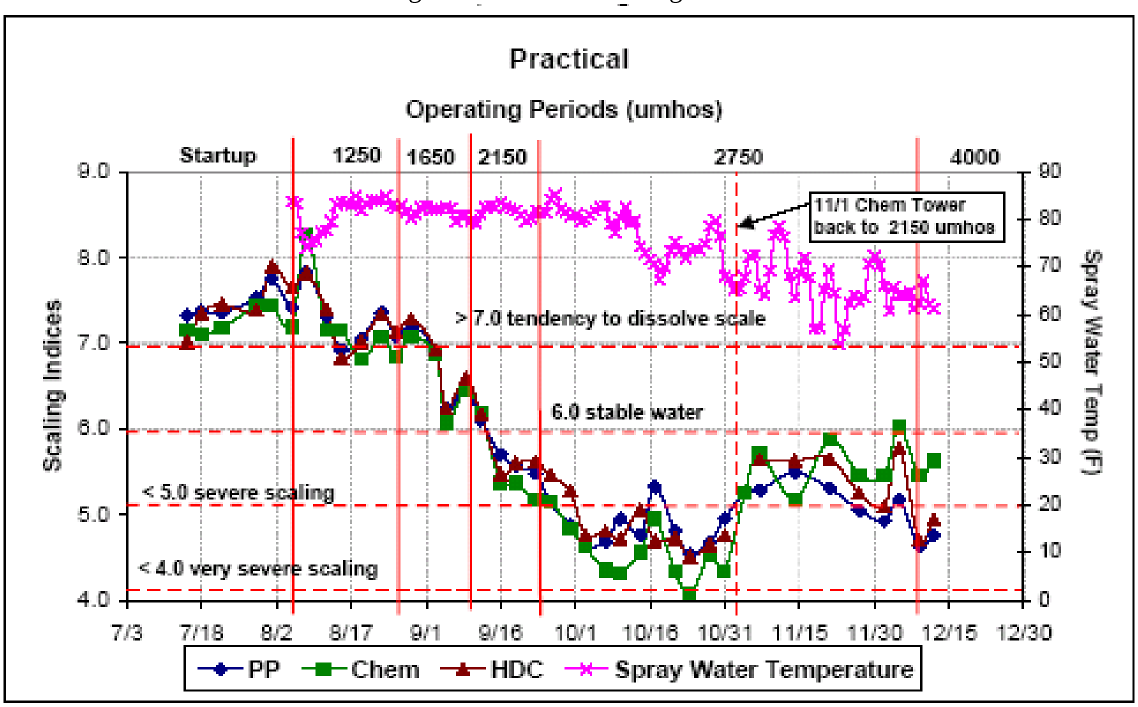
E. SCALE CONTROL.

Precipitated solids form both soft and hard scale deposits on the heat transfer surfaces, which increases the resistance to heat transfer, thereby decreasing the thermal efficiency of the equipment. One of the claims of the non-chemical water treatment manufacturers is that their devices prevent the formation of scale on heat transfer surfaces, allowing the dissolved solids (calcium carbonate) to be precipitated in the bulk water, and then purged from the systems via blowdown or in sidestream solids removal devices. To be effective from the standpoint of corrosion control, and in some cases microbiological control too, non-chemical cooling water treatment systems must operate in an alkaline pH range, which encourages scale formation.

A convenient place to start when evaluating scale is a scaling index. For purposes of this paper, only the Practical Scaling Index (PSI[4]) will be discussed, although both the Langelier and Ryznar indices were also calculated and produced similar results as the PSI.

The PSI showed steady movement into increasingly severe scaling regimes until about the third week in October or approximately midway through the 2,750 umhos operating period. At this time a change in direction toward lower scaling conditions is noted (see Figure 8). This shift could be somewhat explainable for the Chemical tower, because that operating setpoint was reduced back to 2,150 umhos on November 1st due to high turbidity resulting from reduced blowdown rates as described above. Lower operating cycles of concentration created by this shift, should translate into lower scaling indices, but it initially was puzzling why the two non-chemical towers followed the same pattern.

Figure 8. Practical Scaling Index



A possible explanation may be found by looking at the alkalinity and calcium hardness levels, which both took a dramatic downward turn at the same time. These variables are believed to have precipitated the changes in the PSI. Figures 9 and 10 plot the history of alkalinity and calcium hardness levels in the three towers over the study period.

Alkalinity levels in the makeup water remain fairly steady at 60 mg/l from the middle of September until dropping to 50 mg/l after December 5th. Makeup calcium hardness peaks on October 24, at 73 mg/l and then begins a steady drop to 44 mg/l by the end of the study. These changes in the make-up water, particularly for calcium hardness, could partially account for the observed drop in their respective concentrations in the tower spray water. Another possible explanation for the drop in these values for the spray water in the two non-chemical towers was the fact that the treatment devices were turned OFF from November 6 – 21 to determine what, if any, influence they were having on the water chemistry in those two towers. Without any "treatment" from the non-chemical devices, and with the recirculating spray water at saturation levels for calcium carbonate as determined by the scaling indices, its possible that calcium carbonate may have precipitated from the bulk water onto heat transfer surfaces. This is evidenced by a reduction in carbonate and alkalinity as shown in Figures 9 and 10 during the period when the non-chemical devices were shut OFF. When the non-chemical devices were turned back ON, their respective "treatments" kept the calcium carbonate in solution and the levels of alkalinity and calcium hardness began to increase slightly again for the PP and HDC towers. However when the towers were increased to the 4,000 umhos operating mode, the calcium levels increased substantially while the alkalinity levels remained steady (Figure 9). This indicates that calcium carbonate was being formed and remained in the recirculating water where it would be measured by the test for calcium, but not measured in the standard titration test for alkalinity. The alkalinity test most likely did not dissolve all of the calcium carbonate in the recirculating water, thus resulting in a lower alkalinity measurement.

The significance of this finding is that it has been hypothesized that certain non-chemical treatment devices accelerate the coagulation-flocculation of solid particles suspended in water, and increase the crystal formation in the bulk solution instead of deposition as scale on heat-transfer surfaces. [5]

F. TEMPERATURE OBSERVATIONS.

Cooling efficiency is presented in Figure 11, which plots the Return (to tower) minus the Supply (to process) water temperatures for the study period. This differential is a good measure of the cooling efficiency of each tower. All three towers delivered 17-21 degrees of cooling until late in October when the PP tower started to have a drop-off in efficiency. Water supplied back to the compressors from the PP tower was 3 to 9 degrees warmer compared to the HDC tower, while the Chemical tower remained in the middle of the pack at 2 to 4 degrees warmer than the HDC tower. In an attempt to correct what we interpreted as an indication of scale formation on the heat exchange tubing in the PP tower, a larger (6 inch) PP unit was installed on the Spray Water loop on November 26. Nothing else was done to clean the tubes at that time. The temperature differential for the PP tower began to improve, even when the operating setpoint was increased to 4,000 umhos. Water temperature monitoring was continued after the test program was concluded, and a noticeable although somewhat erratic improvement for the PP tower continued. This could be construed that the larger, greater powered PP unit removed some of the previously formed scale on the heat exchange surfaces.

Figure 9. Alkalinity History

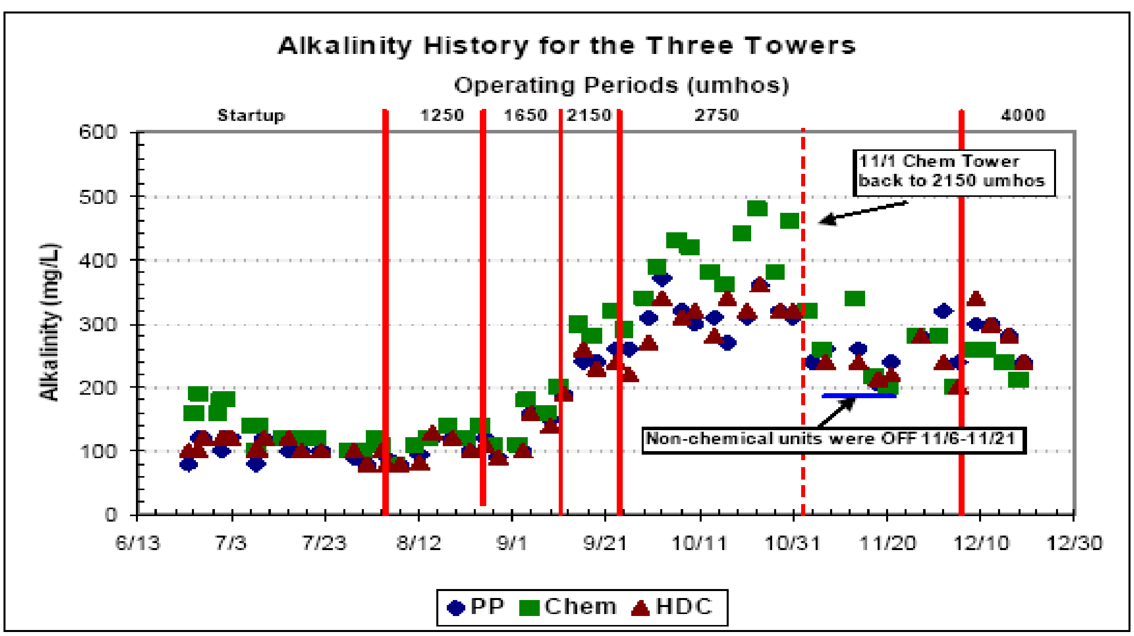


Figure 10. Calcium Hardness History

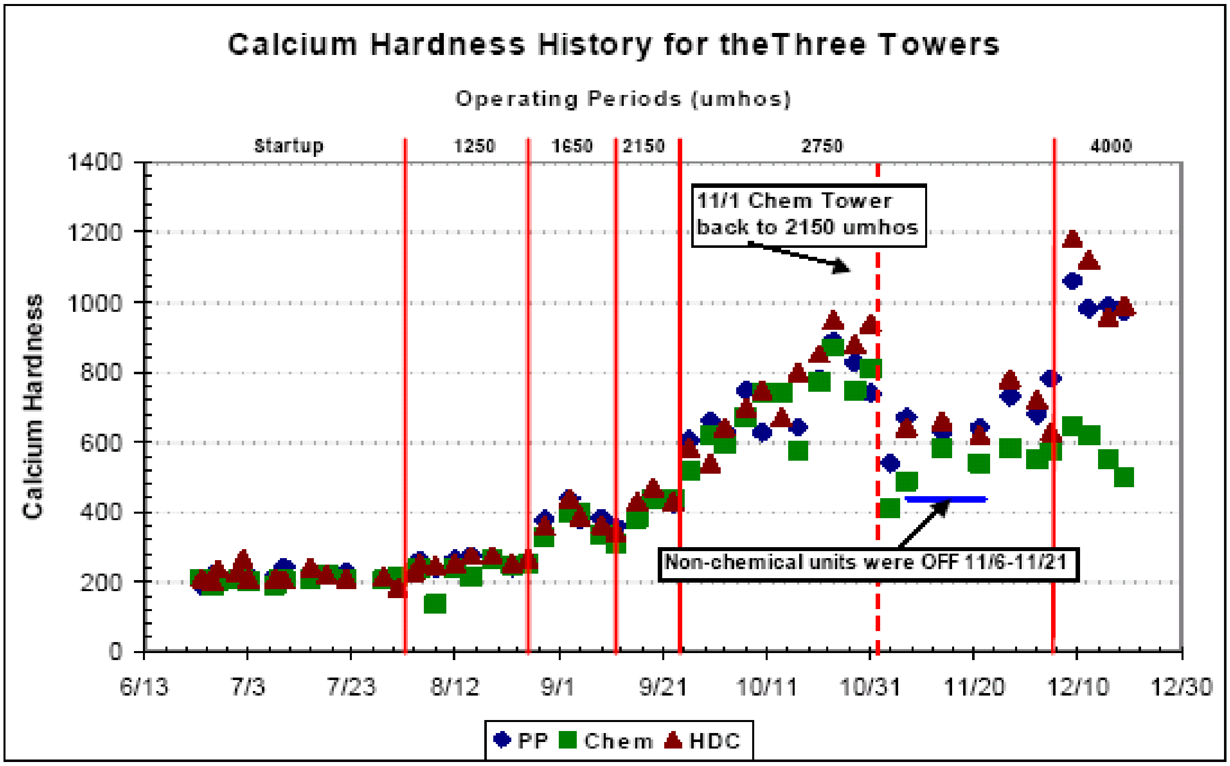
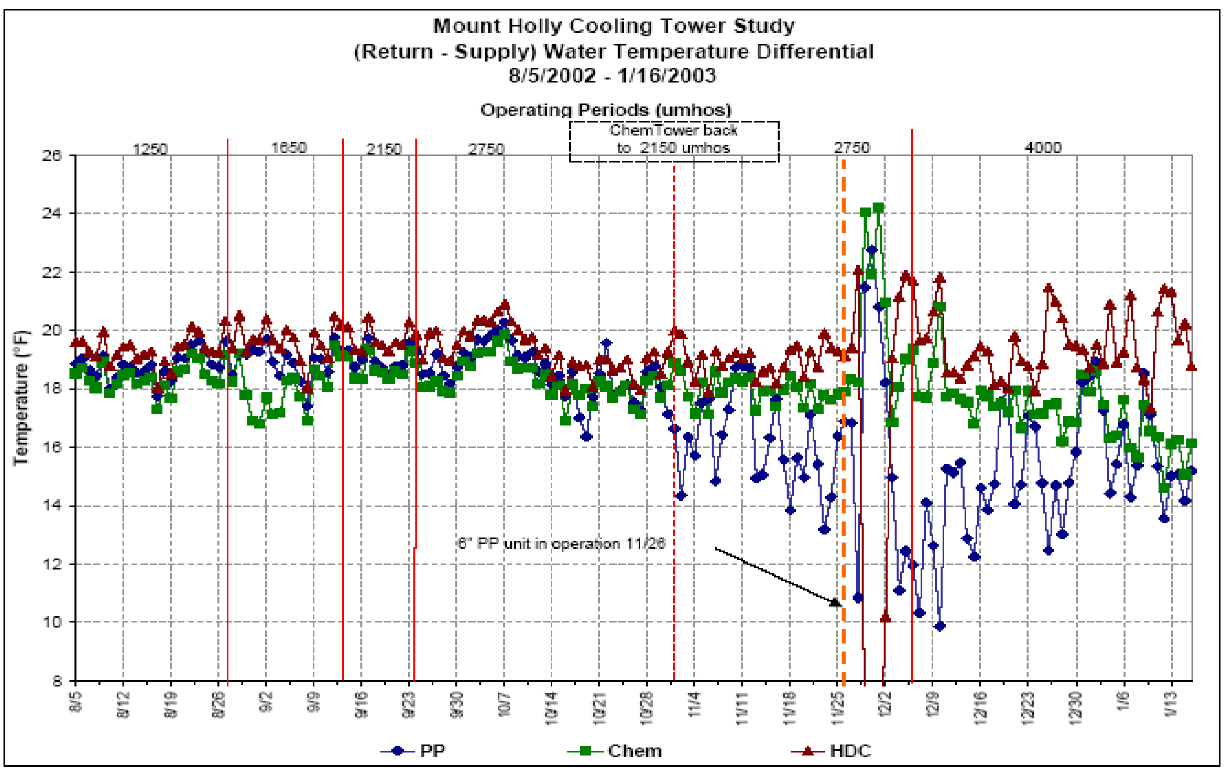


Figure 11. Return – Supply Water Temperature Differential



The HDC tower consistently had the best cooling performance across the entire study, and their differential increased to 20 – 22 degrees during the last six weeks.

G. SCALE OBSERVATIONS.

After the test program was completed, the towers were opened to observe the presence of any scale accumulation. Both the PP and HDC towers appear to have more tube scale than the Chemical tower, perhaps an indication that the scale inhibitor in the chemical treatment program was performing as intended. Alternatively this could be due to the fact that the non-chemical towers were operated in severe scaling regimes for longer time periods. However, close scrutiny of the sidewall scale shows distinctive differences between the three towers. The sidewall scale in both the PP and HDC towers had a sparkling, crystalline appearance compared to the dull, flat white scale in the Chemical tower. See figures 12, 13, and 14.

Figure 12. PP Tower – Scale in Sidewall.

Figure 13. HDC Tower – Scale on Sidewall

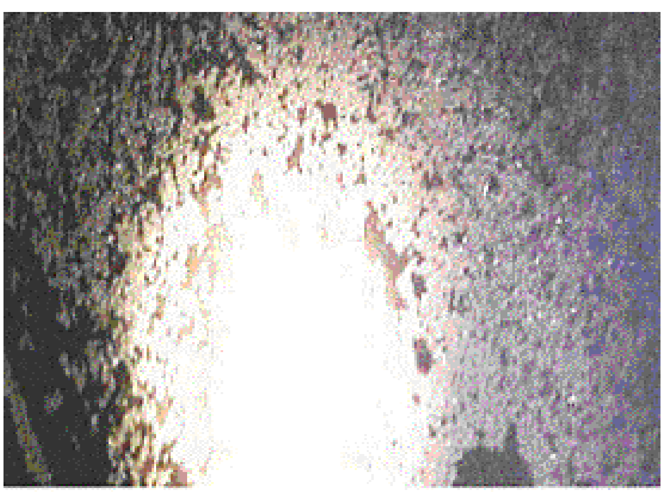


Figure 14. Chemical Tower – Scale on Sidewall

Mt. Holly Maintenance cleaned the towers shortly after the test, and an effort was made to qualify the cleaning procedures required to remove the scale in the three towers. The entire top layer and some of the bottom layer of "sparkling – crystalline" scale in the PP and HDC towers were removable by water under "garden hose" pressure. However, there were some spots of tenacious scale that required "water blast" pressure for removal and not all scale was accessible for removal. The Chemical tower didn't have as much scale, but it was more difficult to remove and required water blasting. The smaller amount of scale in this tower was expected, due to both the scale inhibitor included in the chemical treatment additive, and the fact that this tower did not operate at the length and severity of the scaling regimes selected for the PP and HDC towers. No acid cleaning was done on any of the towers, and according to plant maintenance staff, some scale had been present on the heat exchanger tubes and sidewalls of all three towers before the study began (although all three towers where cleaned and flushed prior to the study).

Samples of scale were obtained from both of the non-chemical towers and analyzed by X-ray diffraction (XRD) at the Alcoa Technical Center. The results show that the majority of scale was calcite, which is a typical form of calcium carbonate in cooling water. Calcite is characterized by its crystal formation rather than chemical composition. There was a significant amount of carbon in the sample, which was confirmed visually by its blackish-gray color. It's possible that carbon was part of the particulate that was "trapped" in the scale matrix.

H. MICROBIOLOGICAL CONTROL.

Cooling water systems, particularly open recirculating systems, provide a favorable environment for the growth of microorganisms. Microbial growth on wetted surfaces leads to the formation of biofilms. If uncontrolled, such films cause biofouling, which can adversely affect equipment performance (i.e. increased pump pressures, heat transfer problems, etc.), promote metal corrosion (i.e. microbial induced corrosion or MIC), accelerate wood deterioration, and cause pathogen concerns (e.g. *Legionella*). There have also been increasing federal and state regulatory restrictions regarding chemical use in cooling towers, aimed at reducing the aquatic toxicity of effluent discharges to receiving waters. This has made microbiological control in cooling towers more difficult, and encouraged searches for alternatives to current treatment methods.

As was mentioned earlier, the PP and HDC technologies claim different mechanisms for controlling microbiological growth. Both technologies were compared against a conventional chemical approach involving alternating two non-oxidizing biocides - isothiazolin and glutaraldehyde.

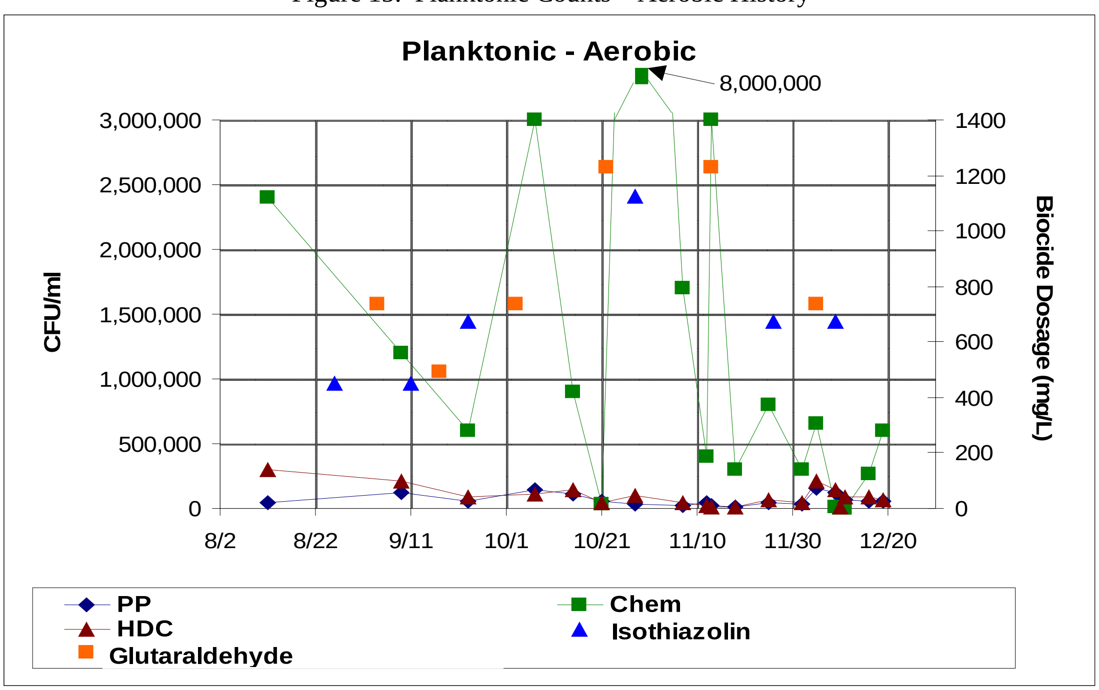
Analytical Methods. There are a variety of techniques available for measuring microbiological activity in cooling towers. For this investigation the bulk recirculating spray water was analyzed for aerobic free floating or planktonic organisms by an FDA approved procedure (FDA Bacteriological Analytical Manual, 8th Ed. Chapter 3) which utilizes "Standard Plate Count Agar," with a 48 hr. incubation period @ 35C. Anaerobic planktonic bacteria were also measured using *Standard Methods* "Standard Plate Count Agar" with a 48 hr. incubation period in an anaerobic environment, @ 35C. All results were reported in colony forming units per milliliter (CFU/ ml). Planktonic samples were generally taken every two weeks.

Attached, slime forming, or sessile organisms colonize wetted surfaces and are primarily responsible for biofouling. While some information was available on the effectiveness of non-chemical treatment devices against planktonic organisms, very little information had been collected on their ability to control sessile organisms. Perforated steel coupons were included in the coupon racks and one additional coupon was hung inside the cooling loop coil pack to encourage sessile growth. The coupons were routinely removed, after approximately four weeks of exposure to the flowing spray water and shipped to an independent laboratory. Upon receipt by the laboratory, both sides of the coupon were swabbed and the swabs returned to the buffer solution used for shipment. A vortex mixer was used to remove the organisms from the swabs. This "inoculated" solution was then tested using *Standard Methods* procedure for Heterotrophic Plate Count. The results were expressed as CFU/cm^2. The sessile samples were also analyzed for sulfate-reducing bacteria with their presence reported as a simple Positive or Negative result.

Planktonic Results. Figure 15 provides a graphic summary of the planktonic aerobic results for all three towers over the course of the study.

The chemical supplier was alternating two non-oxidizing biocides (isothiazolin and glutaraldehyde) each week. Note that both non-chemical towers were able to control aerobic planktonic organisms with PP averaging approximately 65,000 CFU/ml and HDC averaging approximately 95,500 CFU/ml. Plate counts < 100,000 CFU/ml are considered good control. In contrast the Chemical tower suffered through swings in aerobic counts, ranging from a low of 7 CFU/ml to a high of 8,000,000 CFU/ml. The average count for the Chemical tower was approximately 1,270,000 CFU/ml. The type and dosage of chemical biocides is also recorded on Figure 15. The chemical supplier applied some extremely high dosages (>1,200 mg/l) in an effort to get the tower under control, but the correlation of plate counts with biocide doses was mixed. Generally, one would expect to see lower counts shortly after biocide addition. However, isothiazolin is a slow acting product,

Figure 15. Planktonic Counts – Aerobic History



and a significant bacterium kill usually required 16-20 hours of contact. Glutaraldehyde is a faster acting product, and will provide a significant reduction in the bacteria population within 2-6 hours. So sampling time relative to specific microbiocide addition has a significant impact on the measured results. It is important to alternate non-oxidizing biocides as the organisms can develop immunity to a single product over time.

Note that all of these results were cultured from unfiltered samples, which put the Chemical tower at somewhat of a disadvantage, because their higher turbidity levels due to lack of a sidestream solids removal device. These particulates gave bacteria a place to "hide-out" as neither of the biocides are considered to be effective to penetrate the interstices of the particles. This certainly became more evident as cycles of concentration were increased with a concurrent reduction in blowdown rates. Shortly after the operating set point was increased to 2,750 umhos on September 24, equivalent to approximately 14 cycles in the Chemical tower, turbidity levels steadily increased to over 100 NTU while planktonic counts soared reaching a peak of 8,000,000 CFU/ml on October 28. The following table compares the average turbidity levels with average planktonic counts during the 2,750 umhos operating period for the three towers.

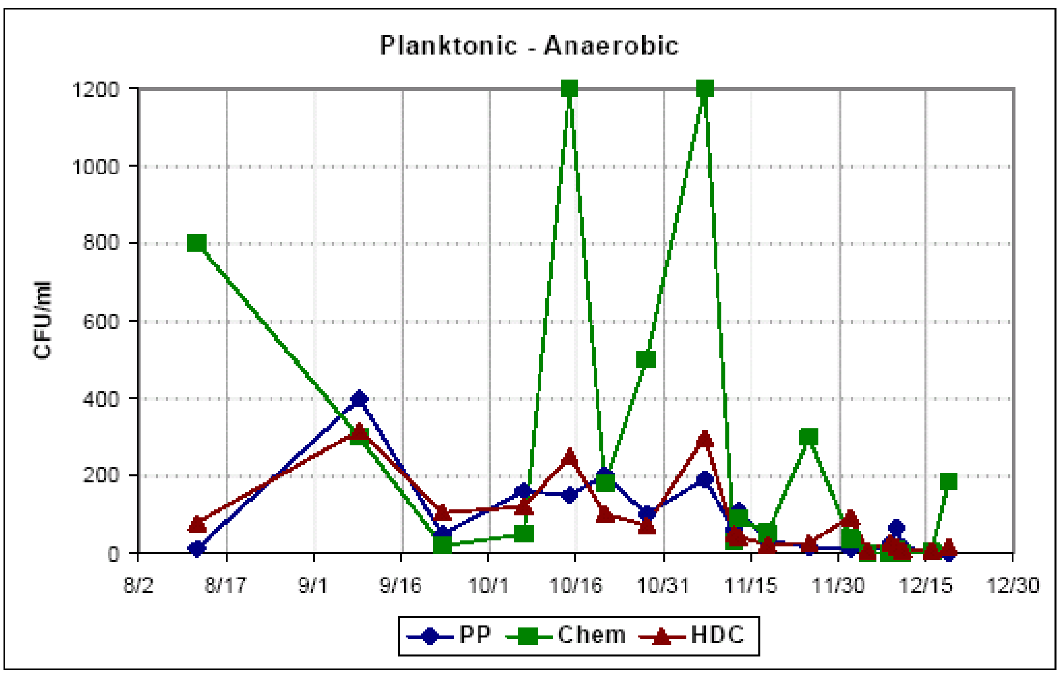
Table 3 - Average Turbidity and Planktonic Values @ 2,750 umhos Operating Setpoint

Tower	Turbidity (NTU)	Planktonic Aerobes (CFU/ml)
PP	10.7	70,000
Chemical	71.1	2,600,000
HDC	14.7	80,000

With conditions in the Chemical tower steadily worsening, the decision was made to drop the control point back to 2,150 umhos to increase the blowdown rates and help purge the tower. Conditions showed a steady improvement from that point to the end of the study, but this experience served to emphasize the importance of a sidestream solids removal device for maintaining tower cleanliness.

Figure 16 shows a similar history for planktonic anaerobic results. Once again the non-chemical towers provided more consistent control averaging 85 and 87 CFU/ml respectively for the PP and HDC towers. The Chemical tower exhibited wide swings for anaerobes ranging from <1 to 1,200 CFU/ml with an average of 290 CFU/ml for the study period.

Figure 16. Planktonic Counts – Anaerobic History



Sessile Results. The following table summarizes the sessile aerobic results for all three towers over the course of the study. All results are presented as colony forming units per square centimeter (CFU/cm^2). The area of the 0.5" x 3.0" perforated, mild steel coupon used to attract sessile growth was 21.8 cm^2 (including both sides and edges minus perforations). The coupons designated as "cold" were located in the coupon racks with the corrosion coupons through which a sidestream of recirculating spray water (~ 5.0 gpm) was sent. The "hot" coupons were suspended approximately mid-way in the cooling coil pack at the top of the tower. These coupons were difficult to locate, and toward the end of the study, they were subjected to alternating "wet" and "dry" conditions as the spray water pumps and fans turned "OFF" and "ON" based on temperature settings during cold mornings to minimize potential icing problems. These set points were eventually lowered to permit more continuous water flow, but the "hot" coupons were not analyzed during this period.

The results indicate that with only a few exceptions, the non-chemical devices provided effective biofilm control. The HDC system delivered the best results of all three technologies with all of their coupons measuring less than $1x\ 10^6$ CFU/cm^2 (Average = 1.9×10^5 CFU/cm^2) which is an accepted industry standard for control of slime forming organisms[6]. The PP system performed almost as well with only two coupons measuring over 10^6 organisms / cm^2. However, the last sample is difficult to explain, as it is two orders of magnitude higher than another coupon removed from the same rack after an identical four-week exposure period. The average results for the PP tower with and without the last sample were 2.7×10^6 and 5.9×10^5 CFU/cm^2 respectively. By contrast the majority (62%) of the coupons from the Chemical tower were above the target $1x\ 10^6$ CFU/cm^2 control point with a calculated average = 2.5×10^6 CFU/cm^2.

All coupons were tested for sulfate reducing bacteria (SRBs). The presence of SRBs is an indication of anaerobic conditions, which can promote corrosion of fouled metal surfaces. As shown in the above table, seven coupons tested positive for SRBs, no indications of MIC were observed. Four of the seven coupons were from the Chemical tower.

Analyses conducted by Ecole Polytechnique for planktonic, heterotrophic organisms indicated that only a moderate level of disinfection was occurring across all of the towers with a significant proportion of the population remaining viable/active. This is consistent with PP claims that their process is more bacteriostatic than bactericidal. However, HDC claim of destroying microbial populations by high temperature, pressure, and vacuum is not as evident [7,8]

Seven samples taken from each of the three towers tested for *Legionella.* None tested positive (> 1.0 CFU/50 ml.). However, the study protocols were not specifically designed to determine the efficacy of these chemical and non-chemical technologies toward controlling *Legionella* organisms[9].

Algae Control. Although these Baltimore Aircoil Towers were closed on four sides, the exposed moist drift eliminators on the top of the tower afforded a perfect haven for algae growth. The non-oxidizing biocides added to the Chemical tower and carried in the drift were effective algaecides as indicated by the stark black color of the drift eliminators on top of the Chemical tower. The PP and HDC towers on the other hand showed patches of green algae, with the PP showing the most extensive coverage. Although neither non-chemical supplier claims efficacy for algae control, algae growth will require additional maintenance (e.g. physical cleaning or periodic use of an algaecide).

I. WHOLE EFFLUENT TOXICITY (WET) TESTS.

As effluent discharge limits become more stringent, and facilities strive toward greater water conservation on the way to "zero liquid discharge" the quality of our cooling tower blowdown waters will play a more significant role in attaining "zero non-compliance." One of the anticipated advantages of using non-chemical cooling water treatments is the elimination of aquatic toxicity concerns, and a test program was developed to validate this premise.

Table 4 – Summary of Sessile Results

Date Removed	PP		Chemical		HDC	
	Cold	Hot	Cold	Hot	Cold	Hot
7/9	$9.5x10^4$		$1x10^3$		$8x10^4$	
8/5	$2.6x10^5$		$4.1x10^5$		$1.8x10^5$	
9/5	$8x10^4$		$2x10^5$**		$1.6x10^4$	
9/23	$6.8x10^5$	$1.2x10^5$	$1x10^6$	$9x10^5$	$1.6x10^5$	$1.5x10^5$
10/21	$2x10^6$		$1.1x10^6$		$7.5x10^5$**	
10/28	$4.5x10^5$	$1.3x10^4$	$2.1x10^6$**	$1.6x10^5$	$1.3x10^5$	$7x10^4$
11/25	$4.5x10^5$**		$8.1x10^6$**		$1.4x10^5$	
11/25	*$1.7x10^7$*		$6.8x10^6$**		$8.6x10^4$**	

Concentration < $1x10^6$ = Biofilm Control - EFFECTIVE

$1x10^6$ < Conc.< $1x10^7$ = Biofilm Control - CONSIDER MODIFICATION for IMPROVEMENT

Concentration > $1x10^7$ = Biofilm Control - *IMPROVEMENT REQUIRED*

** Sulfate Reducing Bacteria tested positive in these samples

Whole effluent toxicity (WET) procedures were run using static acute definitive toxicity tests (96 hours for Pimephales promelas, and 48 hours for Ceriodaphnia dubia) at the following concentrations of blowdown: 6.25%, 12.5%, 25%, 50%, and 100%. With the Chemical tower the time of sampling relative to the time of biocide application has a great impact on blowdown toxicity. Three samples were sent for testing. Two were taken on the same day after biocide addition (isothiazolin), and the last one six days after biocide addition (glutaraldehyde). The first sampling event was corrupted for the PP tower. The results of the last two tests are summarized in Table 5 below.

Note that both non-chemical treatment systems were shut down during the last sample taken on November 19, and had been off since November 6. This is not expected to impact the results of blowdown toxicity. Blowdowns from all three towers exhibited toxicity to Ceriodaphnia in all three samples. This can be explained by the effect of salinity on freshwater organisms. The improved survival of Pimephales Promelas (i.e. fathead minnow) from the Chemical tower is evident on the last test. This is due to taking the sample 6-days after biocide addition, compared to taking the sample right after addition on October 28th. A value of >100.0 means that all organisms survived at all blowdown concentrations.

J. OPERATING AND MAINTENANCE COST COMPARISONS.

Another important aspect of this study, in addition to a performance evaluation of the three technologies, was to determine the costs to install, operate, and maintain them. A number of cost categories were established to provide a basis for comparison. These included: depreciation, supplies, makeup water, blowdown water (assuming treatment / surcharge costs), power consumption, R&M materials, labor charges (i.e. O/M, supervisory, contracted services, and administrative oversight), and costs to address toxic blowdown. Table 6 below summarizes the results of the net costs (+) or savings (-) to operate the two non-chemical devices compared to conventional chemical treatment, all at 4 cycles of concentration.

A few notes on the tables. Recall that this study involved a 1,600-gallon system. At this size, in this location, neither non-chemical device is competitive with chemical treatment, because the capital costs for the chemical system were fully depreciated. For the extrapolations starting at a 2,500-gallon system, capital costs for all three systems are included and depreciated over a 10-year period. All costs for the extrapolation were based on this study except that capital costs were based on vendor input. Installation costs were extrapolated from the cost of the Mt. Holly system based on six-tenths rule applied to the ratio of model sizes (e.g. square of diameters for PP and flow rates for HDC). Comparison was made for oxidizing and non-oxidizing biocides in order to capture costs or savings based on this

Table 5 – Summary of Toxicity Test

	% of blowdown corresponding to 50% mortality (LC50)					
	October 28, 2002			November 19, 2002		
	2,750 umhos			2,750 umhos	2,150 umhos	2,750 umhos
	PP	Chemical	HDC	PP	Chemical	HDC
Pimephales Promelas (96 hour LC 50)	>100.0	70.8	>100.0	>100.0	>100.0	>100.0
Ceriodaphnia Dubia (48 hour LC50)	36.6	11.3	35.4	29.0	9.5	21.0

Table 6 – Cost Comparison at 4 Cycles of Concentration

Size System (gallons)	Chemical System Comparison	Pulsed Power		HDC
		Annual Cost (+) or Savings (-)	Simple Payback (yrs)	Annual Cost (+)
2,500 gal	Oxidizing	$161	NA	$3,049
2,500 gal	Non-Oxidizing	-$114	295	$2,774
10,000 gal	Oxidizing	-$1,749	24	$2,754
10,000 gal	Non-Oxidizing	-$2,851	15	$1,652
50,000 gal.	Oxidizing	-$5,432	12	$10,904
50,000 gal.	Non-Oxidizing	-$10,931	6	$14,567
100,000 gal.	Oxidizing	-$10,884	7	$21,541
100,000 gal.	Non-Oxidizing	-$21,899	4	$10,525

variable. It must be noted however that although oxidizing biocides (such as bleach) are generally cheaper, they require much more containment, ventilation and controls. The costs for this infrastructure were included in the comparison. Finally maintenance labor and materials costs for the HDC unit for this test were high due to the presence of the carbon particles and their effect on the pumps and the HDC hardware. Subsequent to our field trial, the HDC manufacturer made improvements to their design, which eliminated the need for one of their high maintenance filtration devices. For the cost analysis above, essentially similar maintenance costs were used for both non-chemical systems. A significant portion of the maintenance expenses for the chemical system was assumed to be included in the unit cost of the chemicals.

Non-chemical suppliers claim they can run at 6 to 8 cycles of concentration, which this study shows is feasible. The chemical systems typically run at 3 to 5 cycles, which was where the chemically treated towers where running prior to this test. Cost comparison at 8 cycles for non-chemical and 4 cycles for chemical treated systems is shown in Table 7. Recall from Figure 6 that going from 8 to 4 cycles for these towers resulted in an approximate 50% blowdown reduction.

As shown on the tables, the HDC does not seem to have the economies of scale that the PP unit does. This is due to the significant capital cost increases required by the HDC suppliers to move into the larger systems. In addition to capital cost, the power costs are also higher for the HDC units to run the extra pumps required. Both non-chemical systems would compare even more favorably if consideration was given to potential fines levied for violations of WET test standards associated with toxic blowdowns discharged from chemically treated cooling towers. Another potential benefit of non-chemical treatment is a reduction in amount of reportable chemicals into the environment as reported in the annual Toxic Release Inventory (TRI) report (e.g.chlorine from bleach). Lastly, the better heat transfer results exhibited by the HDC system during this trial, while difficult to quantify, could also favorably impact their overall operating costs.

SUMMARY AND CONCLUSIONS

Based upon the results and findings of this twenty-six week study we offer the following conclusions:

A general observation was that fugitive dusts emanating from a nearby carbon silo were readily drawn into the three cooling towers by the air scrubbing action of the tower fans. While the abrasive carbon fines caused some operating difficulties for pumps associated with the PP and HDC systems, the lack of a sidestream solids removal device severely compromised operation of the Chemical tower at elevated cycles creating unacceptable (>120 NTU) turbidity levels.

The make-up (MU) and blowdown (BD) volumes across all three towers were statistically the same (95% CI) at all setpoints. This is expected, as conductivity setpoints were the same across all three towers.

Conductivity is not reflective of true cycles of concentration in higher cycles (greater than 7 cycles at this site). Additionally, make-up and blowdown in this study proved to be an inaccurate measure of cycles of concentration due to possible unquantified leaks and drift loss. The best way to track cycles of concentration at higher cycles is by comparing salt (Mg, Na, K, SO4, etc) contents of the make-up and blowdown.

TDS, total alkalinity, total hardness, calcium hardness and conductivity were scrutinized statistically, and showed no difference between all three towers for each operating period respectively, with a couple exceptions. During the 2,750 umhos time frame the alkalinity for the Chemical tower was higher than that of either non-chemical tower. The reason for this is likely due to the scale inhibitors keeping scale forming elements in solution for the Chemical tower, while scale or other precipitates were forming in the non-chemical towers. Turbidity was higher in the Chemical tower at higher cycles due to the lack of a solids separation device.

Table 7 – Cost Comparison at 8 Cycles for Non-Chemical and 4 Cycles for Chemical Treated Systems

Size System (gallons)	Chemical System Comparison	Pulsed Power		HDC	
		Annual Cost (+) or Savings (-)	Simple Payback (yrs)	Annual Cost (+) or Savings (-)	Simple Payback (yrs)
2,500 gal	Oxidizing	-$8,168	4	-$5,280	9
2,500 gal	Non-Oxidizing	-$8,443	4	-$5,556	8
10,000 gal	Oxidizing	-$22,253	2	-$17,750	4
10,000 gal	Non-Oxidizing	-$23,354	2	-$18,851	4
50,000 gal.	Oxidizing	-$34,897	2	-$18,570	9
50,000 gal.	Non-Oxidizing	-$40,404	2	-$24,078	7
100,000 gal.	Oxidizing	-$49,328	2	-$16,903	17
100,000 gal.	Non-Oxidizing	-$60,343	1	-$27,919	10

The Chemical tower provided the best corrosion control with rates averaging 1.1 mils/year over the entire study period. Corrosion rates for the non-chemical devices were higher, but still within industry standards. This may have been due to the action of the non-chemical devices in operating in moderate to severe calcium carbonate scaling regimes, or simply cycling up of the ortho-phosphate levels in the makeup water, which acted as an anodic inhibitor.

Both the PP and HDC towers showed a greater potential for scale formation when these non-chemical devices were turned OFF from November 6-21. This is inferred from the reduction in both alkalinity and calcium hardness during that time (i.e.presumably scale was forming on the surfaces when the devices were OFF). However when the devices were turned back on and moved up to 4,000 umhos calcium hardness increased, while alkalinity stayed low. A reasonable explanation of this result is that calcium carbonate was forming in the water column (very small particulate) as suppliers had claimed. Additional evidence for scale control could be inferred by the effect a larger PP unit had on improving heat transfer of its respective tower.

The sidewall scale in both the PP and HDC towers had a sparkling, crystalline appearance compared to the dull white scale of the Chemical tower. The buildup in the PP scale may have been an example of the "ripening" affect whereby the crystal size of the precipitate increases. The entire top layer and some of the bottom layer of "sparkling – crystalline" scale in the PP and HDC towers was removable by water under "garden hose" pressure. However, there were some spots of tenacious scale that required "water blast" pressure to remove. The Chemical tower had less scale accumulation, probably as a result of operating at lower cycles of concentration for extended periods, and the affects of the scale inhibitor additive. However, this scale was difficult to remove and required water blasting.

Both of the non-chemical towers delivered better and more consistent microbiological control for both aerobic and anaerobic planktonic organisms compared to the Chemical tower. There was no statistical difference in the microbiological control performance between the PP and HDC technologies. Despite alternating two non-oxidizing biocides, microbiological control performance in the Chemical tower suffered due to higher turbidity levels created by lack of a sidestream solids removal device. While there was some correlation between these high turbidity levels and high microbiological counts, this does not appear to fully explain all the biological variability in the Chemical tower.

Microbiological control for slime forming, sessile organisms was better and more consistent for the non-chemical systems. There were only a few instances where the non-chemical treatment systems did not provide effective control, and both instances occurred in the PP tower. The HDC technology delivered the best results with all of their test coupons measuring < $1x10^6$ CFU/cm^2, which is considered the standard for effective biofilm control.

Seven of thirty (23%) sessile coupons tested positive for sulfate reducing bacteria (SRB), which is an indicator of anaerobic conditions that can promote corrosion of fouled metal surfaces. Of these seven positive coupons, four were from the Chemical tower, two were from the HDC and one was from the PP.

The non-oxidizing biocides added to the Chemical tower appeared to also serve as effective algaecides as evidenced by the stark, black surface of the drift eliminators on this tower. The top of the drift eliminators on the PP and HDC towers exhibited scattered patches of green algae with the largest coverage on the PP tower.

The results showed a clear cost savings advantage for the PP systems against the other two technologies across all system sizes.

RECOMMENDATIONS

As locations implement water conservation measures by operating their cooling towers at higher cycles of concentration, they should strongly consider installing side stream solids removal devices to improve system cleanliness at reduced blowdown levels.

Locations considering new applications of these non-chemical approaches as a water conservation measure should carefully evaluate their source of makeup water and the overall system economics. Makeup water with reasonable levels of hardness (40 – 50 mg/l) and ortho-phosphate (0.5-1.0 mg/l) will result in better corrosion control than soft water without any additives. Addition of a sidestream solids removal device is also highly recommended. In very abrasive environments (i.e. lots of dust/sand in the air) the standard sidestream removal may not be enough to protect mechanical non-chemical treatment devices. Locations currently experiencing algal control problems should be aware that these non-chemical technologies may not provide effective algal control.

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