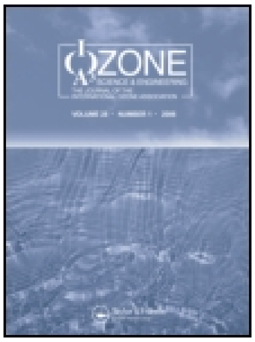

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Ozone Cooling Tower Treatment With And Without Mineral Removal

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Abstract

This paper builds on a prior paper by this author, McGrane (1991). In that paper, ozone is used as the sole means of cooling tower water treatment. The paper discusses water conservation by increased cycles of concentration, greatly increased efficiency through extremely low biological populations, and corrosion data which is compared to ozonated and chemically treated towers.

New in this paper are the results from the combination of a low pressure reverse osmosis system with ozone treatment for cooling tower water. Scale formation has continued to plague cooling towers with high concentrations of calcium in the make-up water. The use of a mineral removal system in cases of extremely hard water has made ozone an attractive alternative to traditional chemicals in many areas.

Introduction

Ozone as a water disinfectant has been used commercially for over 90 years. The City of Los Angeles is currently treating 600 million gallons per day (mgd) using four tons of ozone per day. In the July 1989 issue of *U.S. Water News*, ozone was reported to reduce the production of trihalomethanes, while improving the quality of the water with regard to taste, odor, and turbidity. Ozone is also reported to act as a micro-flocculant. This effect helps to reduce the requirement for filters by 33% and for flocculating chambers by 50%, in subsequent processing steps. Contra Costa County and East Bay Municipal Utility District in Northern California are both in the installation stages of implementing ozone in their water systems.

In a report on ozonation in recirculating water systems for East Bay Municipal Utilities District (EBMUD), Osgood (1989) concluded that there are substantial water savings, low corrosion rates, low scale formation, and vastly improved biological control, when an ozone system is implemented. Reported corrosion rates compare favorably with the chemical industry averages. Biological and scale control both were rated as excellent.

Pacific Gas and Electric (PG&E) has followed preliminary studies with a full scale demonstration of ozone technology (Burda, 1989). Since July 1989, PG&E has successfully replaced chemical treatment on their process tower at the Hinckley Compressor Station. They expect to save approximately $45,000 per year by using ozone, compared to conventional chemical treatment.

To be a complete and effective cooling tower water treatment, ozone must be more than a biocide. It must also limit scale and corrosion. The following authors all have used ozone as a stand-alone treatment with great success.

Coppenger et al. (1989) used ozone as the sole water treatment at a 3,400 ton air conditioning cooling system at the Oak Ridge Y-12 Plant in Oak Ridge, Tennessee. A 21 lb/day ozone generation system with a static-mixer was connected to the system in a side-stream type configuration.

To determine the effectiveness of the ozone treatment, corrosion coupons and instrumentation (corrosion meters) were installed. Copper and carbon steel were used as the test materials. These values are listed in Table I. Meier and Lammering (1987) reported values for copper and mild steel corrosion termed acceptable for well maintained cooling towers with traditional chemical treatment. The Oak Ridge corrosion rates compare well with these published data.

TABLE I. CORROSION RATE (MPY) AT OAK RIDGE AND IBM

Day	Copper		Mild Steel	
	Oak Ridge	IBM	Oak Ridge	IBM
30	0.21	---	2.11	---
60	0.10	---	0.77	---
90	0.13	---	1.11	---
120	0.18	< 0.02	1.34	< 1.0

Microbiological analyses also were conducted. When compared to established chemical treatment reports (Drew, 1979, McCoy, 1974, and NALCO, 1979), the microbiological counts were three orders of magnitude less. Similar results were confirmed independently by Kenny (1983), and Humphrey & French (1979).

Kenny (1983), working for IBM, used side stream ozonation on a system of five cooling towers with a combined cooling of 580 tons. With ozone, the bacterial populations in these towers decreased two orders of magnitude. The amount of water bled to sewer was almost eliminated. The corrosion coupons, when compared to chemical treatments, demonstrated equivalent corrosion in carbon steel and reduced corrosion in copper. These data also are shown in Table I.

Humphrey & French (1979) treated three cooling towers at the Jet Propulsion Laboratory in a manner similar to Coppenger et al. (1989). He also recorded corrosion data, which is presented in Table II. His results were quite similar for carbon steel, but his copper coupons displayed an order of magnitude less corrosion than that at the Oak Ridge Study. He calculated a savings of over $20.00 per ton (of cooling) per year using ozone rather than chemical cooling water treatment. Again the savings were a result of decreased blowdown and the elimination of chemicals.

TABLE II. CORROSION RATE (MPY) AT THE JET PROPULSION LABORATORY

Metal	Tower No. 200	Tower No. 215	Tower No. 238
Copper	0.0346	0.012	0.047
Steel	2.20	1.70	

Edwards (1987) presented a review of different ozonated cooling systems, one of which was the Kennedy Space Center system. Again, the bacteria counts were decreased over three orders of magnitude, while corrosion rates and scaling were minimized.

Merrill and Drago (1979) evaluated several cooling towers in the Southern California area to determine the effectiveness of ozone as the sole water treatment of cooling towers. They noted that biological fouling was minimized and that the appearance of the water was excellent. They also documented the increased cycles of concentration and the inability to use the individual chemical species to determine cycles of concentration due to precipitation.

Wofford et al. (1991) reviewed traditional corrosion theory and applied it specifically to ozonated systems. They reported low corrosion rates consistent with other authors. Reported corrosion control mechanisms included absolute microbiological control, an alkaline environment, and the possible formation of a silicate barrier.

Echols and Mayne (1990 a,b) proposed that as ozone oxidizes biological matter, three groups of chemicals are formed that work as chelants, soaps, and biocides to complex metal ions and sanitize the water. Also, drift and precipitation of sand-like material in the basin accounted for the majority of the supersaturated material in a "no blow-down" scenario.

Reckhow et al. (1986) and Collins et al. (1989) reported ozonation processes that removed individual chemical species from the bulk liquid. These phenomena prevented calcium from becoming saturated in the water and forming hard scale on heat exchange surfaces. Among these processes were:

1. Increased organic oxygenated groups which can complex cations,
2. Decreased molecular weight of dissolved organics, leading to decreased steric stability,
3. Formation of meta stable organics that behave like conventional flocculating polymers,
4. The oxidation of organo-metallic complexes, liberating cations, which act as conventional coagulants.

Tyndall (1989), a microbiologist at the Oak Ridge National Laboratories, studied *Legionella Pneumophila*. He stated that *Legionella* bacteria, the cause of Legionnaires' disease, is found in an increasing number of cooling towers. This claim is also supported by other investigators (Meitz, 1986 and the EPA 1985). Tyndall compared the effectiveness of ozone, free chlorine, and hydrogen peroxide, as bactericides. Ozone was shown to be the most effective bactericide. Since Legionnaires' disease is only contagious when the bacteria are respirated, uncontrolled bacteria bred in the cooling tower and discharged with the drift and water vapor pose a significant health problem.

In a recent article written by the Associated Press, three fatal cases of Legionnaires' disease were reported at a motel in Lamar, Colorado and confirmed by the Centers for Disease Control in Atlanta. *Legionella* bacteria were discovered in large numbers in the cooling tower water.

Each year more information is becoming available concerning ozone and aqueous cooling systems. Rice and Wilkes (1991) explore possible mechanisms for corrosion and scale control. Such contributing factors as carbon dioxide generation, formation of chelants, heavy metal crystal modifiers, and pH neutralization through nitric acid formation are all discussed. Also discussed are "sandy" calcium carbonate deposition and the adverse effects of ozone on scale and corrosion inhibitors. The authors caution that much more work is required before definitive mechanisms on scale and corrosion control with ozone are confirmed.

The year 1991 was the fifth consecutive year of drought in California. Many water districts have mandated water rationing. Surcharges for water use now are commonplace. In several instances, ozone has been shown to conserve large quantities of water without jeopardizing the mechanical elements of the system. On the other hand, there have been several well documented failures with ozone in recirculating water systems. Most notably, these systems have demonstrated a tendency to form hard calcium carbonate scale on the heat exchanger and evaporative areas of the system.

Previous authors (Echols and Mayne, 1990a,b; Wofford et al., 1991) have indicated that the disappearance of the ionic material may be attributed to drift losses and/or basin precipitation. Because neither mechanism has been effectively demonstrated to date, caution should be used against excessively high Langelier Indices.

Experimental

The 600 ton Baltimore AirCoil (BAC) tower at the Hacienda Business Park in Pleasanton, California, was selected as the test tower for ozone alone with the agreement and cooperation of the people at AT&T. Water meters were installed on the makeup water to the tower and the blow-down line to the sewer under the supervision of the Pleasanton Water Department. This enabled the determination of an overall mass balance on the water used by the cooling system. All cycles of concentration ratios were determined by water meter readings. Often ionic species calculations provided conflicting results. Knowing the makeup and blow-down volumes of water, we calculated the evaporation rate and derived the cycles of concentration, which helped in the comparison of water usage between the ozonated tower and the tower prior to ozonation.

The ozone generator and contactor were connected to the tower, Figure 1, and chemical treatment was halted. The cooling system was drained and cleaned. On January 6, 1989, the ozone generation system was started.

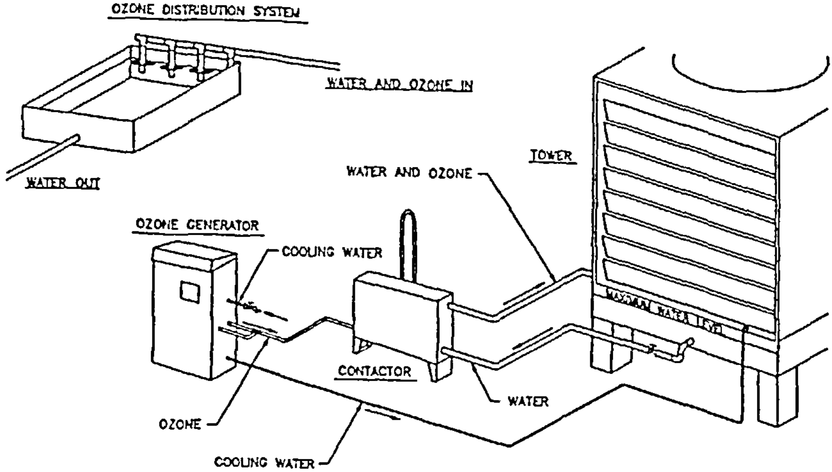
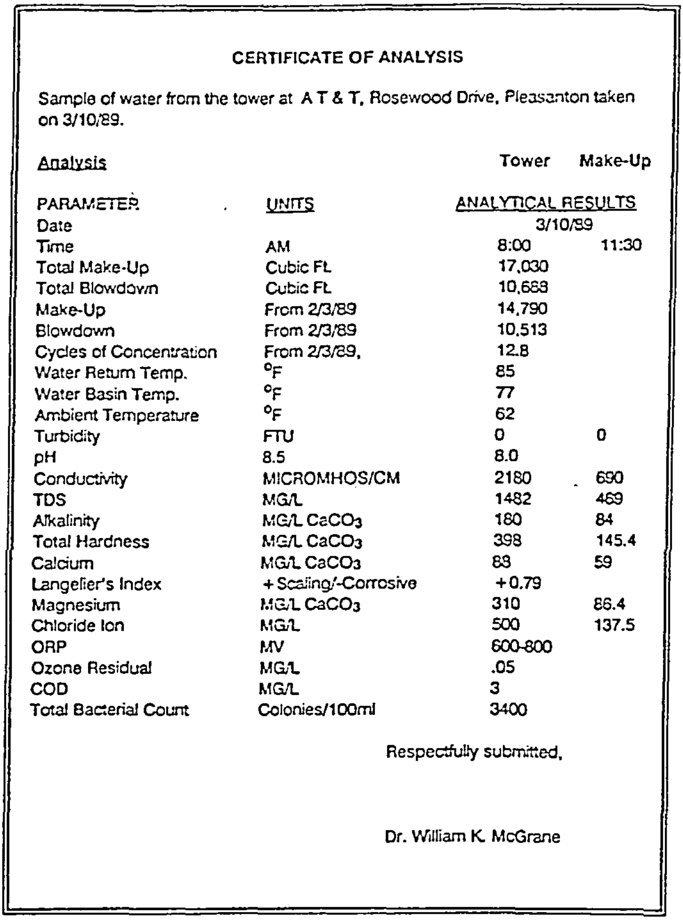


Figure 1. Cooling tower ozonation system.

For the next six months, samples of the basin water were taken daily and analyzed. Water basin samples were taken from areas throughout the tower. Multiple samples were taken to determine uniformity of the water and ionic species. Only the ozone residual samples were not uniform throughout the basin and were averaged in the analysis. ORP (oxidation/reduction potential) was continually monitored and controlled by the sensor in the contactor. These readings were higher than expected due to the proximity of an ozone return line to the contactor suction line.

A typical analysis is presented in Figure 2. These analyses revealed the chemistry of the water as well as any changes, or patterns of changes, that were occurring. The analysis for ozone, turbidity, chloride ion, magnesium, calcium, and chemical oxygen demand were performed using a Hach DR 2000 Spectrophotometer. pH was determined using a Corning 215 pH meter. Conductivity was determined with a Microsensor conductivity probe and verified with a Markson conductivity meter. Alkalinity was determined with the WAT-MP-DR Alkalinity Test Kit from LaMotte Chemical. Bacterial testing was accomplished with total count samplers from Millipore, Inc.



CERTIFICATE OF ANALYSIS

Sample of water from the tower at A T & T, Rosewood Drive, Pleasanton taken on 3/10/89.

Analysis		Tower	Make-Up
PARAMETER	UNITS	ANALYTICAL RESULTS	
Date		3/10/89	
Time	AM	8:00	11:30
Total Make-Up	Cubic Ft.	17,030	
Total Blowdown	Cubic Ft.	10,688	
Make-Up	From 2/3/89	14,790	
Blowdown	From 2/3/89	10,513	
Cycles of Concentration	From 2/3/89,	12.8	
Water Return Temp.	°F	85	
Water Basin Temp.	°F	77	
Ambient Temperature	°F	62	
Turbidity	FTU	0	0
pH	8.5	8.0	
Conductivity	MICROMHOS/CM	2180	690
TDS	MG/L	1482	469
Alkalinity	MG/L $CaCO_3$	180	84
Total Hardness	MG/L $CaCO_3$	398	145.4
Calcium	MG/L $CaCO_3$	88	59
Langelier's Index	+Scaling/-Corrosive	+0.79	
Magnesium	MG/L $CaCO_3$	310	86.4
Chloride Ion	MG/L	500	137.5
ORP	MV	600-800	
Ozone Residual	MG/L	.05	
COD	MG/L	3	
Total Bacterial Count	Colonies/100ml	3400	

Respectfully submitted,

Dr. William K. McGrane

Figure 2. Water analysis.

On January 11, 1989, corrosion coupons were installed in the cooling tower basin. These coupons, made of copper and hot dipped galvanized steel, were purchased from Metal Samples Inc. of Alabama. They were analyzed according to ASTM

G1 Standards using the appropriate cleaning solutions. Eventually, mild steel coupons, also from Metal Samples, were installed in the tower basin on July 24, 1989.

In February 1990, a 600 ton BAC ozonated tower at Tandem was equipped with a mineral removal system (MRS). This system replaces the standard ozone contactor already on site. A corrosion by-pass rack was installed, as were rotameters and water meters.

Like the standard contactor, the MRS contains sensors, a recirculating pump, a venturi, and a motionless mixing system to transfer the ozone into the water. It also contains valves to direct a portion of the water prior to ozonation to a bank of filters. These filters will remove any residual ozone as well as any debris from the water. After the filters, the water is pumped to 200 psia and sent through low pressure reverse osmosis membranes. These membranes concentrate the inorganic ions into the stream used for blow-down. This process reduces the amount of water needed for blow-down. The permeate with extremely low ionic content is returned to the tower. This system is designed to prevent high levels of ionic species from occurring in the tower. This is essential to avoid scale formation in areas that have extremely hard water supplies.

The combination of an ozone system and a low pressure reverse osmosis system on cooling tower water is possible due to the extremely low biological populations in ozonated waters.

Water analyses and corrosion coupon analyses similar to those at AT&T were performed on a weekly basis for the next nine months.

Results

WATER CONSERVATION

To determine water savings at both sites, leakage and drift losses were considered to be minimal. These assumptions are reasonable with newer towers containing drift eliminators, as at AT&T and Tandem. This resulted in:

$$M = B + E$$

where:

M = Make-up (gpm)
B = Blow-down (gpm)
E = Evaporation (gpm)

This overall mass balance was used with species mass balance to yield:

$$B = E/(C-1)$$

$$C = (M - B)/B + 1 = M/B$$

where:

C = Cycles of Concentration

The no-blowdown approach was never seriously considered, largely due to reports of catastrophic failures. Blowdown normally is set to maintain a certain conductivity level of the recirculating water. A conductivity controller keeps the water within certain limits of conductivity. One must balance water conservation against the potential for scale formation, which increases with conductivity and indices like Langelier, Practical, Ryznar, etc.

The results depicted in Figure 3 clearly demonstrate substantial savings based on increased cycles of concentration. For the month prior to ozonation, the system averaged 1.25 cycles of concentration. After ozonation, a monthly average of 8.5 cycles of concentration was attained. These numbers were based solely on water meter readings.

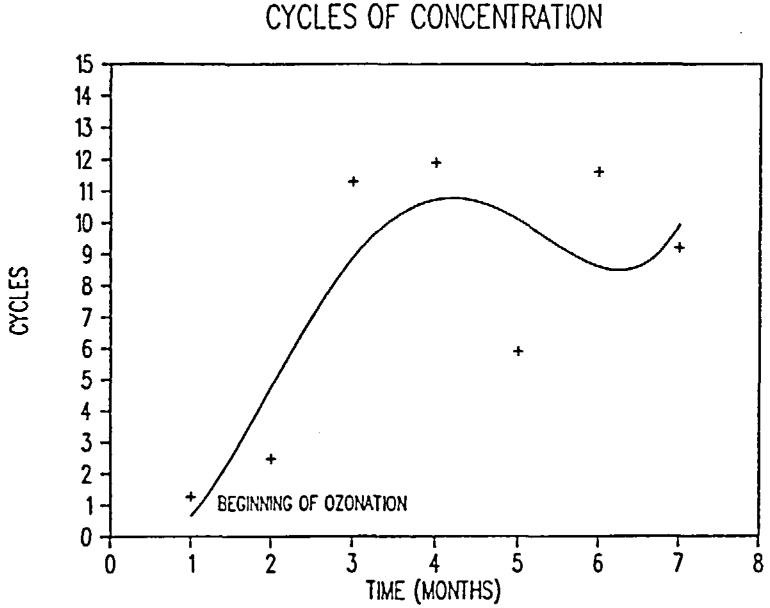


Figure 3. AT&T cooling tower cycles of concentration.

Of important note is that the total amount of water evaporated in this tower is quite small for a tower rated at 600 tons. As the work force at AT&T increased and the load on the tower increased, we began to experience decreased cycles of concentration. The makeup to the tower also began to contain more total dissolved solids. Eventually the tower ran approximately at three cycles. This is much better than the original 1.25 cycles, but clearly not near the 8.25 average. Possible explanations are changes in the incoming water chemistry, or that the drift, while small when a tower is operating at rated capacity, is quite large when a tower is operating at a fraction of its capacity.

Tandem Computers, Sunnyvale, CA, was the site of the first Ozone Generation System complete with a Mineral Removal System (MRS). Again, water meters were used to record makeup and blowdown flows. An antiscalant was used to prevent calcium scale from forming in the membranes. For the nine months trial, a cycles of concentration average of 13.5 was achieved. The membrane system required very little maintenance, other than periodic prefilter cartridge changes. Figure 4 shows the continued high cycles of concentration.

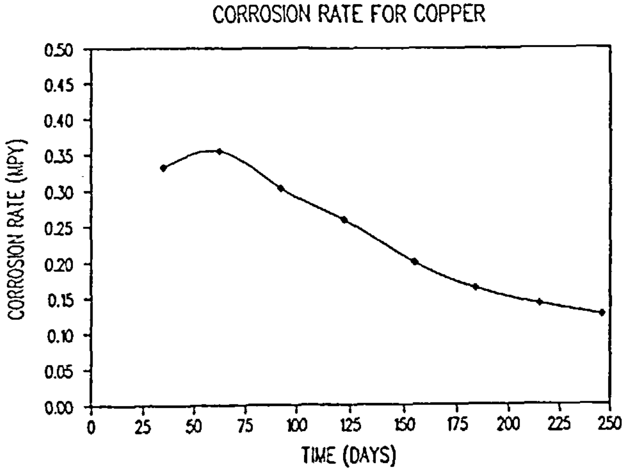


Figure 4. Tandem cooling tower cycles of concentration.

CORROSION

On the positive side, although the water savings had decreased, the corrosion rates at AT&T had remained small. Figures 5 and 6 show that corrosion rates were better than acceptable and continued to improve as the tower load was increased. Corrosion rates of 3.0 mils per year for mild steel and 0.5 mpy for copper are considered acceptable by the chemical treatment industry according to Meier and Lammering (1987).

At Tandem, one set of corrosion coupons was used. The corrosion rate for mild steel was 3.82 mpy, and the corrosion rate for copper was 0.10 mpy. In comparison to towers with chemical treatment, the corrosion rate for mild steel was acceptable, and the corrosion rate for copper was excellent.

BACTERIAL CONTROL

Figure 7 depicts the bacteria counts at AT&T which averaged a remarkable 3,000 counts per 100 mL. This is in sharp contrast to approximately 1,000,000 counts per 100 mL prior to ozonation.

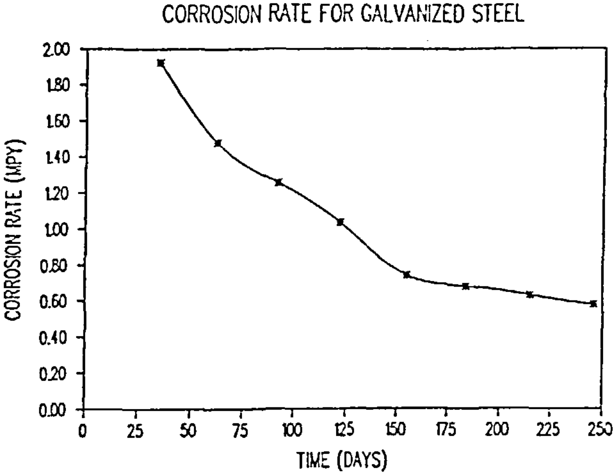


Figure 5. Copper corrosion rate, AT&T cooling tower.

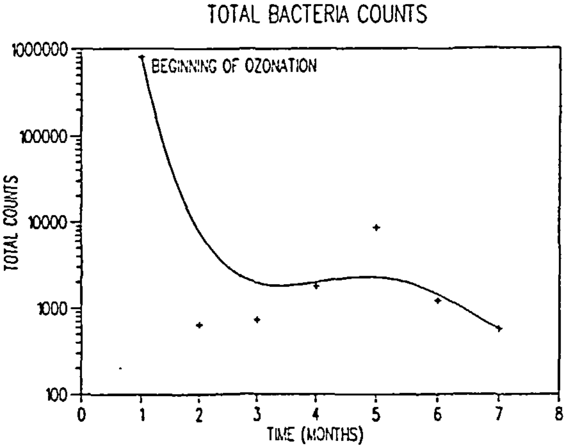


Figure 6. Galvanized steel corrosion rate, AT&T cooling tower.

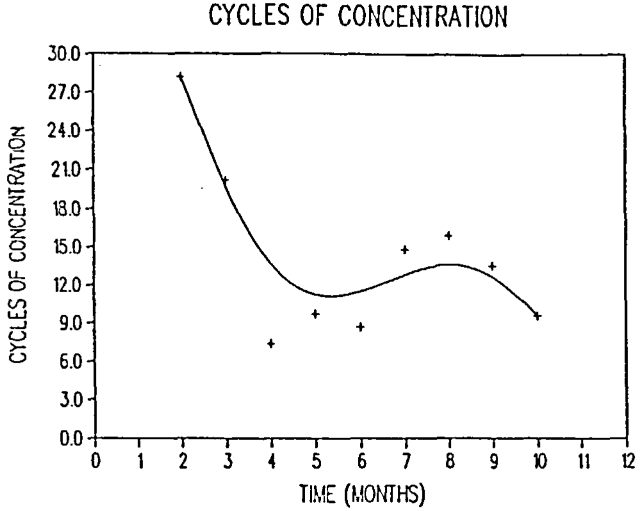


Figure 7. AT&T cooling tower bacteria counts.

There are several reasons why reverse osmosis systems would fail on cooling towers treated with traditional chemicals. Biological counts typical of chemically treated towers would cause severe fouling of the membranes. Most of the oxidizing biocides would tend to oxidize the membranes and cause them to lose their integrity. Thirdly, the membranes will separate the high molecular weight dissolved solids, including scale and corrosion inhibitors, as well as dispersants and non-oxidizing biocides, and send them to the drain with the dissolved electrolytes.

At Tandem, bacterial control was excellent. Figure 8 shows the low biological counts obtained.

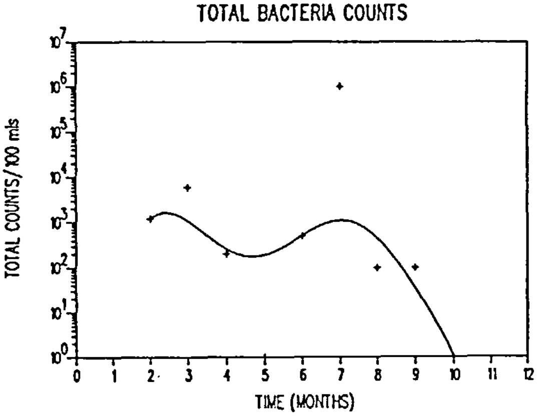


Figure 8. Tandem cooling tower bacteria counts.

Summary

Both locations with ozonation systems saved large amounts of water when compared to their previous water treatment systems. When the AT&T system was operated at a small percentage of the maximum capacity, it operated at an average of over 8 cycles of concentration. As the cooling tower was operated at closer to capacity, and the makeup water increased in total dissolved solids, the cycles declined to between three and four.

At Tandem with the Mineral Removal System, the cycles of concentration averaged 14.2 during the nine months of operation. Bacteria counts averaged slightly over 8 counts per mL and corrosion/scaling was well controlled.

It has become apparent in cooling tower water treatment, that ozone is an exceptional biocide. There is still much debate about how and if ozone can prevent scale formation, when operating in a supersaturated aqueous environment. However, ozone can be used successfully with membrane-type mineral removal systems in areas of hard water, and cautiously as the sole treatment in areas of soft water.

Acknowledgements

The author wishes to thank the City of Pleasanton (California) Water Department for assistance in providing the water meters. We would also like to thank Jerry Taylor for assistance in independently checking bacteria counts, ionic species concentrations, and water meter accuracy.

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Key Words

Ozone, Cooling Towers, Cooling Tower Water Treatment, Reviews, Reverse Osmosis Mineral Removal System, Water Conservation, Corrosion Control, Bacterial Control

Résumé

Cette contribution constitue un prolongement d'une publication précédente du même auteur, McGrane (1991). Dans la description antérieure, l'ozone est utilisé comme seul moyen de traitement des eaux d'une tour de réfrigération. La contribution discutait de l'économie en eau grâce à l'accroissement des cycles; de l'augmentation de l'efficacité, résultat d'une population biologique extrêmement faible; et, de données comparatives en matière de corrosion pour les tours traitées par l'ozone et d'autres produits.

La apport original du présent article se trouve dans les résultats de la combinaison, pour le traitement des eaux de refroidissement, de l'osmose inverse à basse pression et de l'ozone. L'entartrage reste un problème pour les tours de si la teneur en calcium est élevée dans l'eau d'appoint. En appliquant des moyens d'élimination des minéraux en cas d'utilisation d'eaux très dures, l'ozone s'avère un moyen alternatif très attractif par rapport aux produits plus traditionnels.

Zusammenfassung

Das Papier baut auf einer früheren Veröffentlichung des gleichen Autors auf (McGrane, 1991). In jener Veröffentlichung wurde Ozon lediglich zur Kühlwasserbehandlung eingesetzt. Die Veröffentlichung behandelt das Thema Wassereinsparung durch vermehrte Kreislaufführung, verbesserte Wirkungsgrade durch sehr geringe biologische Aktivität und gibt Daten zur Korrosion, indem ozonte und chemisch behandelte Kühlwassersysteme verglichen werden.

Neu sind die Ergebnisse über die Kombination einer Niederdruckumkehrosmose mit Ozonung. Kesselstein belegt die Kühltürme besonders bei hohen Calciumkonzentrationen im Zusatzwasser. Durch die Demineralisierung bei sehr harten Wässern wird Ozon eine attraktive Alternative zur herkömmlichen Behandlung mit Chemikalien.