

PAPER NO: TP03-21

CATEGORY: TREATMENT EVALUATION

COOLING TECHNOLOGY INSTITUTE

CONDENSER WATER TREATMENT USING PULSED POWER

JOHN LANE
CLEARWATER SYSTEMS

DAVID F. PECK
HATCH MOTT MACDONALD



The studies and conclusions reported in this paper are the results of the author's own work. CTI has not investigated, and CTI expressly disclaims any duty to investigate, any product, service process, procedure, design, or the like that may be described herein. The appearance of any technical data, editorial material, or advertisement in this publication does not constitute endorsement, warranty, or guarantee by CTI of any product, service process, procedure, design, or the like. CTI does not warranty that the information in this publication is free of errors, and CTI does not necessarily agree with any statement or opinion in this publication. The user assumes the entire risk of the use of any information in this publication. Copyright 2003. All rights reserved. This paper has been reviewed by members of the Cooling Technology Institute and approved as a valuable contribution to cooling tower literature; and presented by the author at the Annual Conference of CTI.

Presented at the 2003 Cooling Technology Institute Annual Conference
San Antonio, Texas - February 10-13, 2003

Condenser Water Treatment Using Pulsed Power

John Lane, Director of Technology
Clearwater Systems

David Peck, Staff Engineer
Hatch Mott MacDonald

Introduction

Regulatory pressures and economic considerations require industry to become cleaner, more efficient, and more environmentally benign. Such operating principles advance not only good public relations but reduce liability, improve working conditions, and relieve or simplify regulatory reporting obligations.

One area where an environmentally friendly technology has been applied pertains to electronic water treatment in cooling towers. The conventional method for the treatment of recirculating water in cooling towers is with chemical additives. The concentrated forms of these chemicals are often hazardous, and the residual chemicals released by periodic blowdown, evaporation, and drift are problematic. This article describes a non-chemical treatment technology (the Dolphin System™ manufactured by Clearwater Systems of Essex, CT) on cooling tower water in a commercial office building in Pittsburgh, Pennsylvania. The water chemistry and the biological activity resulting from this treatment are also discussed, with appropriate data provided.

Comfort Cooling Systems

The most energy-efficient method to remove waste heat for comfort cooling is via the evaporation of water from a cooling tower. Under a typical arrangement, a chiller using a hydrofluorocarbon (HFC) refrigerant will extract heat from a closed-loop water system (chilled water used to cool the building) and dump that heat into an open-loop system. The heat is removed from the open-loop system by evaporation in a cooling tower, with 1% of the recirculation flow being evaporated per 10° F heat rejection.

For example, a 600-ton chiller needs to dump 9,000,000 Btu's per hour at full load. This requirement is accomplished by raising the temperature of 1,800 gallons per minute (gpm) of water by 10° F. This warm water is then run through a cooling tower where 18 gpm are evaporated, lowering the remaining water by 10° F for reuse in the chiller.

While this method is extremely efficient in removing heat and conserving water, there remains an ongoing need to control the open-loop water chemistry with respect to microbiological growth, scaling, corrosion, and fouling. Traditionally, chemical treatment programs have been employed to accomplish this control.

Periodic or continuous blowdown is required to remove soluble and semi-soluble salts to control water chemistry within the range of effective chemical treatment. Environmental concerns about this blowdown limit the type and strength of chemical treatment that can be used. The previously described 600-ton chiller, operating at 4 cycles of concentration, would require 6 gpm of blowdown. This blowdown would discharge to a publicly owned treatment works (POTW) or receiving stream, subject to discharge approvals.

Standard Method of Water Treatment

The standard chemical treatment method for open-loop systems includes oxidizing biocides (chlorine or bromine), non-oxidizing biocides, corrosion inhibitors, dispersants, and scale inhibitors. Several of these chemicals are often combined in proprietary blends. Care must be taken with the particular chemicals used since some of them often work at cross-purposes. These chemicals are added continually or periodically to the open-loop water. Residual levels of these chemicals found in the

blowdown, air emissions, and drift loss may trigger federal and state discharge regulations. These discharge regulations are a “moving target” of increasing scrutiny with continual pressure by regulators to improve the quality of the discharge and reduce negative environmental impacts. Historically, chemical treatment has been considered to be an accepted and relatively effective way—until recently, perhaps the only way—to control cooling tower water chemistry.

Pulsed-Power Systems

Over the years there has been a plethora of magnetic and other devices alleging to control water chemistry with respect to scaling, corrosion, etc. Many of these items have been permanent magnetic devices with a fixed-field strength. Generally speaking, these devices have been judged as being an untenable, illogical, “black box” approach to water treatment. Most engineers and scientists dismiss these devices as just another gimmick.

In support of the technology discussed in this paper, Maxwell Technologies employs and licenses a pulsed-power device for the cold pasteurization of food products called CoolPure, which meets or exceeds Federal and Drug Administration (FDA) requirements (reference 1). The pulsed-powered system (PPS) described in this article is an adaptation of similar technology to open-loop recirculating cooling water systems, but it utilizes much lower power draw.

PPS equipment imparts pulses of a high frequency, electromagnetic field into the circulating water. What distinguishes this system from magnetic water treatment devices is that the unit sets up a pulsing, coil resonating (or “ringing”) harmonic field across the flow gradient as it passes through the system to which it is installed. The coils are located externally to a pipe in a customized, self-contained spool piece, thus providing a complete non-contact treatment method. The coils operate at a low voltage of less than 45 volts rms.

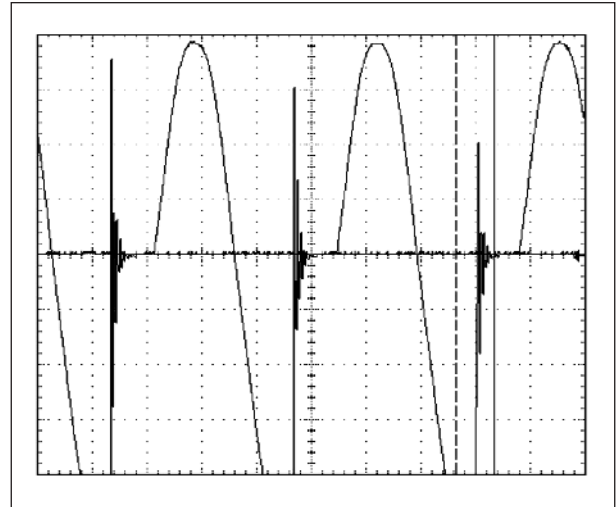


Figure 1 - Electronic Signal from PPS Equipment

The Installation in Pittsburgh

During May of 1998, a pulsed-power system was installed at a major corporate headquarters building in Pittsburgh, on the condenser water loop of their 600-ton cooling system. The installation was in a new office building and cooling system. An 8" diameter pulsed-power unit was installed on the 10" diameter steel condenser water pipe after the chillers and prior to the cooling tower. A second 2" diameter unit was installed on the make-up water line. The driving force for the installation was the elimination of chemical handling in the facility and the discharge of residual chemicals via blowdown into the local POTW.

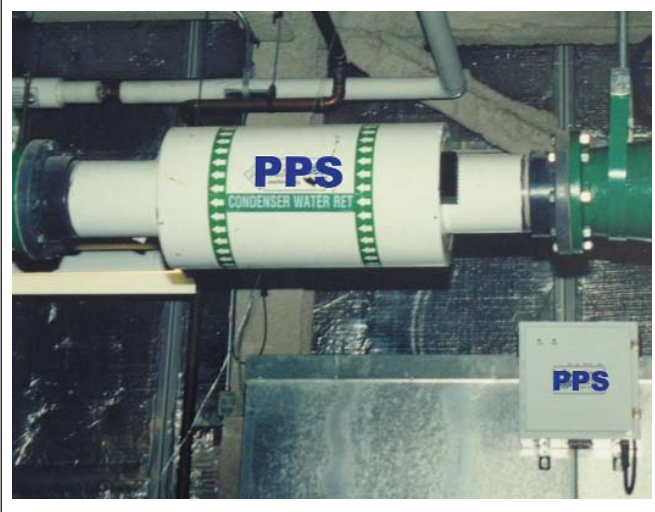


Figure 2 - PPS Equipment Installed in the Recirculating Loop

The system has two chillers, a 400-ton and a 200-ton unit, with a full-flow centrifugal separator prior to each of the chillers and a 600-ton stainless steel tower. A conductivity meter controls blow-down. Each separator operates at a 6-psi pressure drop. A side-stream bag filter on each separator filters approximately 1% of the water flow and returns it to the circulating pump. For the first year of operation, the bag filter inlet was located at the bottom of the separator as a closed-loop recovery arrangement; in this arrangement a 50-micron bag required cleaning every few days. Later the filter inlet was moved to the side of the separator, and the bottom discharge was connected to the sewer system and manually flushed once per day. Later still, the conductivity-controlled blowdown, which was originally located on the combined line prior to the cooling tower, was moved to the bottom of the separators. These steps were taken to reduce the frequency for cleaning the filter bags and proved to be very successful.

The above changes allowed the system to run with a 25-micron bag for over one month between cleanings.

The system is operated or maintained in a ready state year round. The pulsed-power system has been in operation at this installation for over four years. During this period, there have been no chemicals added to the condenser water loop.

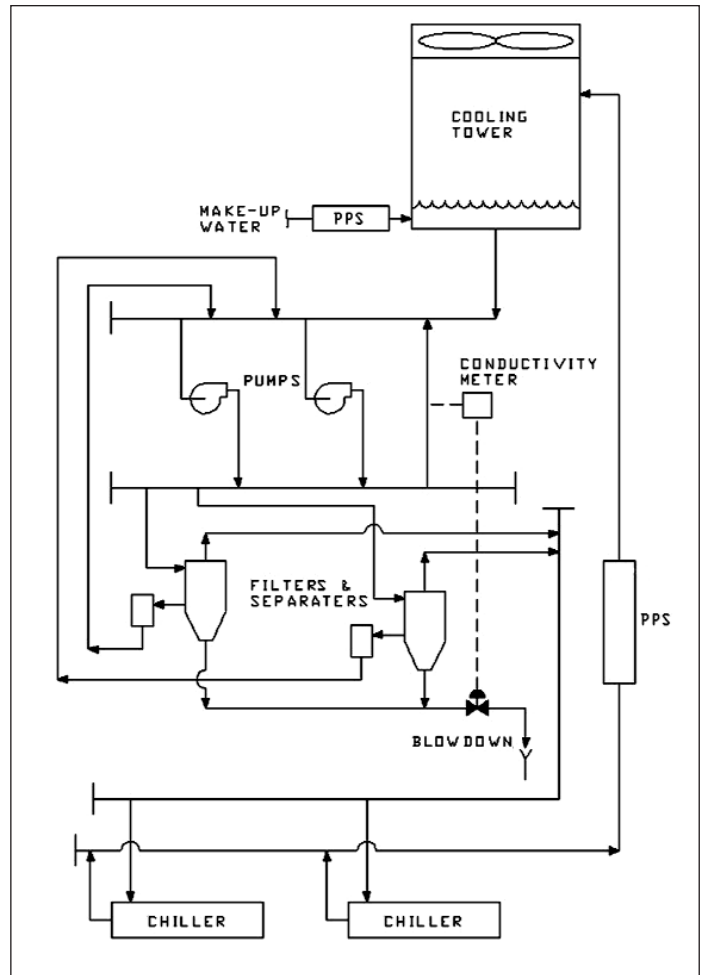


Figure 3 - Schematic of Installation

PPS Water Treatment

“Every technology for cooling tower treatment shall fulfill bio, scale, and corrosion protection while improving energy efficiency and heat transfer of treated systems” (reference 2). To this statement we would also add “maximizing water conservation and minimizing environmental and health and safety impact.”

Scale Control

Applications of PPS equipment to date have demonstrated that the pulsed electromagnetic field alters water chemistry as the recirculating minerals begin to concentrate in the recycle loop. Specifically, it has been demonstrated that PPS does not permit calcium carbonate to supersaturate,

a condition that normally occurs in chemically based treatment programs (reference 3, 4, 5). The chemical treatment programs typically control deposition by altering the crystal structure to inhibit scaling which would normally occur on pipe walls as a hard, smooth deposit. The PPS controlled towers operate at or slightly above the saturation point of calcium carbonate by promoting an in-situ precipitation of this mineral into the bulk solution.

Photomicrographs of the two minerals are shown in the following magnifications



Figure 4a - Typical Surface Scale 60x
 • Chemical Treatment •



Figure 4b - Bulk-Solution Precipitate 60x
 • Pulsed-Power Treatment •

The morphology of these two photos displays (top) the typical layered structure of adherent, surface-nucleating scale, and (bottom) the amorphous,

almost spherical appearance of the pulsed-power induced, bulk-solution precipitate. These samples were collected from cooling towers receiving chemical or pulsed-power treatment, respectively.

The amorphous type scale does not adhere to the pipe wall but remains with the bulk solution and is removed via blowdown and/or side-stream filtration.

Laboratory Tests on Scale Formation

Laboratory tests on the efficacy of PPS equipment to prevent scaling have been run recently using a technique developed at Drexel University (reference 6). This methodology was used in a two-year, ASHRAE-supported research project that was presented at the Winter Meeting of ASHRAE in January 2003. The PPS tests monitor fouling reduction under very controlled conditions. The resistance to heat transfer across a heated copper plate is carefully measured over the approximately 250-hour test period in very scaling water. The conditions of the tower and heat source are controlled to provide identical conditions for the control (no treatment) and with the PPS equipment.

The tests showed that the PPS equipment dramatically reduced the fouling that occurred without treatment. Figure 5 compares an area of the heat transfer surface for the control and PPS tests. Details of the tests are presented in Appendix A.

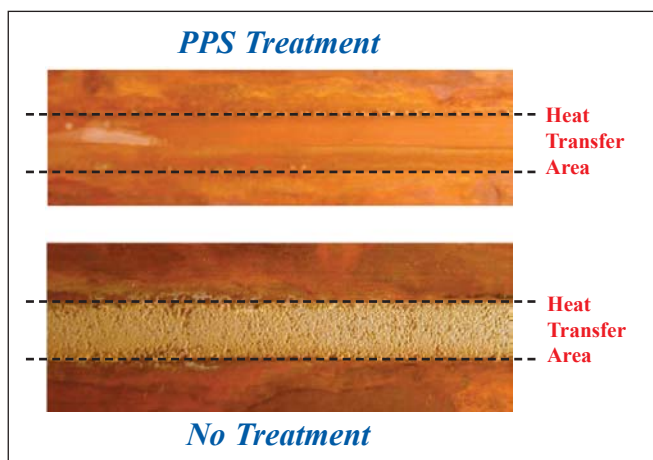


Figure 5 - Copper Heat Transfer Surfaces After Test

Biological Control

There are two major methods of biological control with a PPS: encapsulation and electroporation. As the bulk-solution precipitate forms, it encapsulates particulates and immobilizes bacteria, which act as the nucleating sites for crystal growth. These particles move throughout the system and “scour” the system of both biofilm and free-floating bacteria (reference 5). This effect occurs below saturation by coagulation of small (<10 micron) particles and bacteria. Additionally, the process of electroporation further destroys bacteria, which is similar to the pasteurization technique employed in the previously described CoolPure process. Essentially, the pulsed-power system “shoots holes” through the bacteria, thereby promoting bacterial disintegration through cell lysis.

Corrosion Control

Corrosion inhibition with PPS is accomplished indirectly by maintaining sufficient cycles of concentration to force the system into the alkaline mode at the saturation point of calcium carbonate, which favors scaling over corrosion. This principle is essentially the same one employed in today's chemical treatment programs, since low/neutral pH chromate treatment is no longer allowed. Further, the pulsed-power system reduces total dissolved solids (TDS) by precipitating calcium salts with alkalinity at the saturation point. (TDS causes increased corrosion activity.) Chemical systems inherently maintain higher TDS levels under super-saturated conditions.

Installation Results

Biological Results

Biological samples were taken periodically and analyzed for Heterotrophic Plate Counts (HPC) using the EPA standard method of analysis (SMEWW 9215B) at a Pennsylvania-certified laboratory. The results of these analyses are plotted in Figure 6.

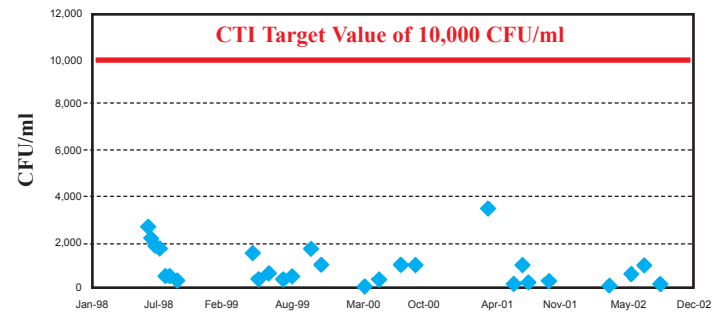


Figure 6 - HPC of Condenser Water

All evaluations were from grab samples taken in accordance with ASTM standards (reference 8) with analysis starting the day of collection.

It is difficult with chemical controls to maintain low microbiological activity on a consistent basis. Chemical control requires maintaining a residual level of biocide in the water and/or slug treatment at higher dosages. The loss of the biocide varies with temperature, pH, heat demand, blowdown, and biological activity. Bacteria often develop resistant strains to the particular biocide being used. Some amount of biofilm will develop, providing an ecosystem for bacteria to flourish and periodically releasing variable quantities of bacteria into the water. Because of these circumstances, excursions of HPC in the 100,000 CFU/ml level are not uncommon in a chemically controlled tower.

The biological data for the pulsed-power system reveal an exceptionally well-maintained cooling loop. The Cooling Technology Institute (CTI) target value for controlling bacteria in recirculating water is less than 10,000 CFU/ml. Over a four-year period this target value was never approached. The average biological value for the entire four years is under 1,000 CFU/ml, only 10% of the CTI target level.

Scaling Control

The system has been operating in the precipitation regime since it has gone on line. Table 1 details chemical analyses from different years of operation. The data show that the calcium is not cycling up but is forming precipitates. Inspection and cleaning of the tower and the chillers have shown that there is no hard scale formation; all the precipitation have been in the form of a bulk-solution powder.

Corrosion Control

Corrosion coupons have been periodically placed in the system. All coupons exhibited generalized attack. Copper corrosion was about 0.1 mpy, mild steel corrosion was about 2 mpy: all well within acceptable standards.

Material	Days Exposure	Corrosion Rate
Copper	58	<0.1 mpy
Copper	485	<0.1 mpy
Copper	553	0.12 mpy
Mild Steel	58	5.2 mpy
Mild Steel	278	1.7 mpy
Mild Steel	421	1.75 mpy
Mild Steel	617	1.07 mpy

In May of 2002 the chiller manufacturer performed an eddy current inspection of one of the chillers. After four years of operation without any chemical treatment ***“There were no measurable defects during this inspection.”***

Water Use

There are two ways that a cooling tower uses water: evaporation and blowdown. Evaporation is how cooling towers are designed to remove heat. Blowdown is the way that dissolved and suspended minerals are removed from the system. Cycle of concentration (COC) is used to measure the efficiency of blowdown. COC is defined as the ratio of the volume of make-up water to the volume of water removed by blowdown and drift. Since all the soluble minerals in the make-up water will be in the blowdown water, an accurate way to measure COC is by the ratio of such a mineral in the blowdown water to the same mineral in the make-up water.

A quick-and-easy method for measuring cycles of concentration is to use the ratio of the recirculating water conductivity to incoming water conductivity. With a chemically controlled system this technique is a reasonable standard of measurement. Chemical control is usually designed to prevent any precipitation so that all the minerals in the incoming water stay in solution until they are removed via blowdown. It can slightly overstate the true cycles since the chemicals themselves will add to the recirculating water conductivity and hence the apparent cycles of concentration but without any real water savings.

The quick-and-easy method using the ratio of conductivities is ***not*** appropriate with PPS control. PPS equipment allows a bulk solution precipitate to form, relieving mineral concentration from the water. Looking at the ratio of soluble ions such as chloride and sulfate is a better method for determining cycles rather than using the conductivity ratio.

Applying this technique to the case study (using the data from 8/31/2000), the true cycles of concentration are seen to be 4.7, not the 3.7 that the ratio of conductivity (using the measured value of 1290) gives. The chart below shows why the ratios for calcium and alkalinity are so different from those for magnesium, sulfate, and chloride.

Analyte	City Water	Actual Tower Water	Expected at 4.7 Cycles	Difference
Calcium hardness (ppm)	110	370	517	147
Alkalinity (ppm)	53.6	104	252	148

Calcium carbonate is being precipitated out of solution at a rate of 147 ppm, thus reducing the mineral content and conductivity of the recirculating water. (Precipitated solids do not add to conductivity.)

Energy Efficiency

Poor water treatment can affect both the chiller and cooling tower performance. On the tower, poor biological and scale control will clog fill material, making evaporation more difficult. This condition will result in higher use time on the tower fan and warmer water being returned to the chiller. Measurement of cooling tower efficiency was not performed; however, the visual appearance of the tower and fill is excellent. The fill had little to no deposits and the basin was very clean.

Poor water treatment will also affect chiller performance. As the heat transfer surface of the tubes becomes fouled, there will be a greater difference between the condensation temperature of the refrigerant and the exit temperature of the condenser water. This temperature difference is called the approach temperature of the chiller. It is often determined by converting the high side pressure of the refrigerant to its saturated vapor temperature, then subtracting the exit condenser water temperature from the chiller. If all things are equal, then this method is an easy measure of condenser tube fouling. There are many other things that can affect this measurement besides water tube fouling, including the following parameters:

- 1) poor calibration of thermal couple or pressure gauge,
- 2) instability in the chiller,
- 3) operating the chiller outside of design parameters,
- 4) improper amount of refrigerant,
- 5) excess non-condensable gas in the system.

If these variables are controlled, then the chiller approach temperature under full load is a quick measurement of tube fouling and chiller efficiency.

Figure 7 shows a graph of the chiller approach temperature for an entire cooling season (2002) for all loading in excess of 88%. The design approach temperature for these chillers is between 1 and 2 degrees Fahrenheit. The chart shows that there was little to no change in approach temperature over the period. The slight upward slope is due to the loading in August of 105% full load while the April to mid July loading was about 90%.

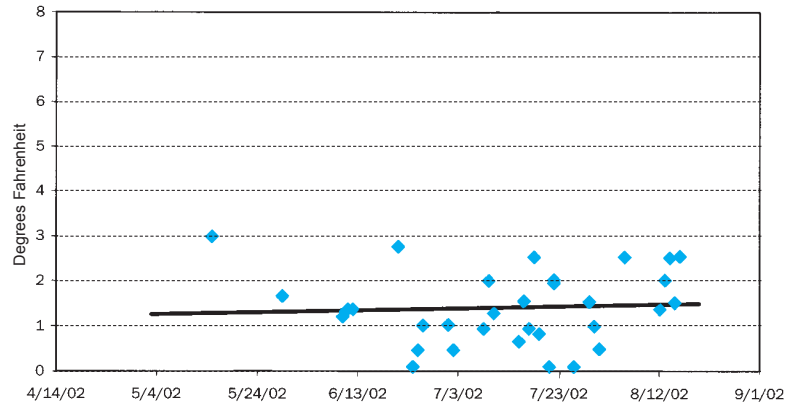


Figure 7 - Approach temperature at Full Load

Observations

Table 1, provided at the end of this report, shows that the detailed water chemistry results are very consistent from year to year. Several points on this issue are noted as follows.

1. Using SO_4 and Cl concentrations more accurately predicts the cycles of concentration, since conductivity and/or TDS are reduced by the in-situ precipitation of calcium carbonate. The recycle system appears to be operating at around 5 cycles, based on SO_4 and Cl levels.
2. Alkalinity is running at less than 2 cycles, and calcium hardness is running between 3 and 4 cycles. This evidence points to a precipitation reaction of calcium carbonate.
3. The bag filter sediment shows an HPC of between 270,000 to 510,000 CFU/ml, thus indicating the encapsulation of bacteria. This result is further evidenced by the supporting high total organic carbon (TOC) and loss on ignition (LOI) [180°C] values in the residue.
4. Turbidity of the recycled water is sometimes less than the city water make-up, indicating the “polishing” effect of the in-situ precipitation process. Microscopic particles (including bacteria) act as nucleating sites for precipitation of calcium carbonate, which is removed in the side-stream filters and blowdown.

5. Since a precipitate is forming in the bulk solution, the Langelier Saturation Index, as expected, is greater than 0.0. The Ryznar and Puckorius indices, which are normally favored in predicting the scale forming/dissolving tendencies of flowing cooling tower water, do not seem to be applicable in evaluating PPS-treated water. Both the Ryznar and Pukorius indices indicate a scale-dissolving water chemistry while at the same time chemical analysis demonstrates that a precipitate is forming.
6. The data using measured make-up water analysis (8/31/00) show that, as expected, silica is not coming out of solution. The other data points, which use the municipal reported analysis for make-up water, are believed to be in error with regards to silica loss.
7. Legionella testing was done using ASTM sampling procedures from the cooling tower basin with analyses performed at nationally recognized laboratories in Phoenix and Georgia. In one test (July of 2000), 4 replicate samples were taken within 5 minutes of each other. The results of the four tests were: 45, 60, 90, and 9 CFU/ml. A month later (August) a single sample was taken with <1 CFU/ml reported.
8. Electrical power costs for operating the PPS were estimated at \$60.00 per month.
9. One significant inference that can be drawn from the test results is the potential to operate the pulsed-power treated system at higher cycles of concentration than would be allowed with a chemical treatment regime, thus reducing make-up and blowdown requirements. Since calcium carbonate, alkalinity, and TDS are being controlled or limited by the pulsed-power system, it would seem that the only limitation to ramping up the cycles would be factors such as chloride level (<500 ppm max preferred) and the product of magnesium and silica (<25,000 preferred). These indicated levels should not be exceeded for reasons relating to corrosion and scaling, respectively.

Operational Characteristics

The system in general has been relatively effortless in human labor and time demands to operate. The routine maintenance consists of cleaning the filter bags and conductivity probe (about once a month) and washing out the tower with a garden hose twice per year. The chillers have been opened during each of the four years in operation. Over the entire four-year period, there was no slime layer or biofilm on the inside of the chiller. The first year there was a small quantity of soft deposit in the chillers. This deposit was removed using a power washer with nylon brushes. During the second year, after the blowdown was moved to the bottom of the separators to reduce the frequency of cleaning of the bag filter, there was less soft deposit and again it was removed with nylon brushes. When the chillers were opened after the third and fourth year, operating for the entire season with the blowdown at the bottom of the separators, there were almost no soft deposits. For the entire four years of operation under potentially scaling conditions, no hard scale was formed. The facility operators are very pleased with the results.

The tower has remained free of slime on all wetted surfaces. There has been no odor associated with the system, and the water is exceptionally clear.

Summary

Pulsed power is an effective technology for the treatment of open loop cooling water systems where effective control of biological and mineral precipitation is paramount. The use of pulsed power completely eliminates the use and discharge of residual biocides and scaling/corrosion inhibitors into the blowdown or into the air while maintaining an exceptionally clean system.

R E F E R E N C E S

1. U.S. FDA, Center for Food Safety and Applied Nutrition, “Kinetics of Microbial Inactivation for Alternative Food Processing Technologies – Pulsed Electric Fields,” June 2, 2000.
2. Burda, P.A., NACE Corrosion 94 Paper No. 461, “Guidelines for Ozone Case Histories in Cooling Water Treatment and Other Applications,” 1994.
3. Dresty, J., “Interim Report: Evaluation of the Parrot Water Treatment System,” Submitted under EPRI Grant No. AGR#W03743-16, Private Communication to Rande J. Wilson, EPRI Northeast Regional Contract Officer, December 1, 1996.
4. Lane, J. and Kutner, G., CTI Paper No. TP00-03, “A Non-Chemical Water Treatment Device,” February 2000.
5. Lane, J. and Opheim, D., International Water Conference Paper No. IWC-01-54, “Biological Control in Cooling Towers Treated with Pulsed-Power Systems,” October 2001.
6. Cho, Y.I.; Kim, W.; Lee, S., ASHRAE Paper CH-03-3-3 (RP-1155) “Physical Water Treatment for the Mitigation of Mineral Fouling in Cooling Tower Water Applications,” January 2003.
7. NACE International Publication 7K189, “Control Factors in Performance Testing of Non-chemical Water Treatment Devices,” Reaffirmed 1997.
8. ASTM Standard D3370-95a, “Standard Practices for Sampling Water from Closed Conduits,” Reapproved 1999.

	November 24, 1999			August 31, 2000			August 28, 2002		
Parameter	Reported City Water Make-up	Recycle Cooling Water	Cycles	Measure City Water Make-up	Recycle Cooling Water	Cycles	Reported City Water Make-up	Recycled Cooling Water	Cycles
Conductivity ($\mu\text{mho/cm}$)	297	1,326	4.5	352	1,290	3.7	410	1,380	3.4
TDS (ppm)	258	904	3.5	174	880	5.1			
Total Alkalinity	48	91.7	1.9	53.6	104	1.9	56	85	1.5
Calcium (as CaCO_3)	84	345	4.1	110	370	3.4	114	277	2.4
pH	8.2	7.5		8.0	8.2		8.4	8.0	
Temperature °F (max.)	53	79			79			88	
Ryznar Index		7.2			6.3			6.8	
Puckorius Index		7.3			7.0			7.5	
Langelier Index		0.2			0.9			0.6	
Chloride (ppm)	43	203	4.7	40.2	189	4.7	55	211	3.8
Sulfate (ppm)	58	364	6.3	63	307	4.9	80	344	4.3
Magnesium (as CaCO_3)	32	141	4.4	35	165	4.7	36	133	3.7
Silica (as SiO_2)	15.1	10.4	0.7	4.22	17.7	4.2	4.2	12.2	2.9
Total Iron (ppm)	0.01	0.07		<0.01	<0.01		<0.01	0.04	
Sodium (ppm)							27	115	4.2
Copper (ppm)							0.01	0.06	
Manganese (ppm)	0.01	0.04	4.0	0.01	0.02	2.0	0.01	.02	2.0
Mg X SiO_2	483	1,466		149	2,925		151	1,623	
Turbidity (NTU)				0.35	0.25		0.065	0.60	
TSS (ppm)				<1.0	<1.0				
HPC (CFU/ml)		1,000			1,000			200	
	Bag Filter Residue			Bag Filter Residue					
Filter Residue - HPC (CFU/ml)	510,000			270,000					
TOC	4.97%			3.59%					
LOI - 180 °C	2.92%			0.77%					

Table 1 - Water Chemistry

Appendix A - Laboratory Tests on Scale Formation

Laboratory tests on the efficacy of PPS equipment to prevent scaling have been recently run by Dr. Young Cho using the technique he developed at Drexel University. The methodology is the same as he used in a two-year, ASHRAE-supported research program that was presented at the ASHRAE Winter Meeting in January 2003. These tests monitor the change in fouling factor on a controlled laboratory set up without any water treatment and then under nearly identical conditions but with a non-chemical water treatment device (reference 6).

Experimental Setup

The setup has a small, approximately 5 foot high, cooling tower with a sump. Cooling water is pumped from the sump, through the treatment device, through a heat exchanger, and back to the tower. Make-up water and blowdown water are measured and analyzed, and a conductivity controller maintains water concentration.

The heat transfer surface is a copper plate. Water channels are formed in plastic plates that are bolted to either side of the copper plate. On one side of the copper plate is hot water at 99° C; on the other is cooling tower water. The flow rate through the cooling channel is maintained at 5 fps. Inlet and outlet temperatures of the hot water and cooling tower water are measured and recorded every 10 minutes. The cooling water channel dimension is approximately 10" x 1/4" x 1/16". There is a viewing window in the center of the heat transfer area and a video camera records microscopic images of the deposit formation in real time. The heat flux is approximately 70,000 Btu/hr/ft², which is significantly higher than the typical HVAC heat flux of 5,000 to 10,000 Btu/hr/ft². The high heat flux is necessary both to ensure that there is a strongly scaling environment and to show the effect of scale formation on heat transfer over an almost two-week period. The cooling water temperature was about 26° C; the cooling water at the surface of the copper plate was estimated to be 59° C. The assembled heat exchanger is shown in Figure A-1.

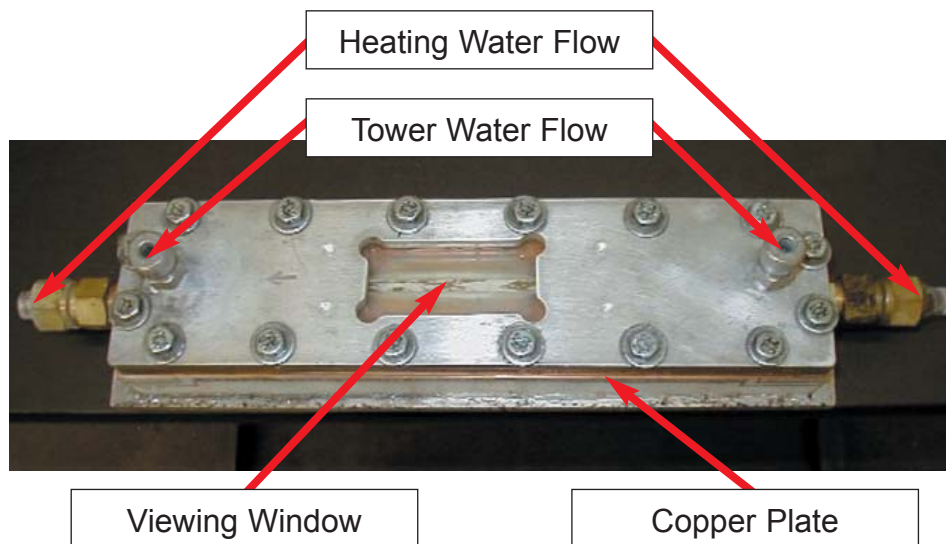


Figure A-1 - Assembled Heat Exchanger

The water chemistries of the tests are shown in the following table:

Attribute	Make-up	Control		PPS	
		Chemistry	Ratio	Chemistry	Ratio
Conductivity	427	4,000	9.4	4,000	9.4
Ca Hardness	165	1,220	7.4	1,320	8.0
Mg Hardness	25	296	11.8	240	9.6
Alkalinity	272	540	2.0	540	2.0
Chloride	84	880	10.5	940	11.2
pH	6.5	7.6		7.7	
LSI @ 138F	-0.11	2.06		2.48	
RSI @ 138F	6.73	3.49		3.32	
PSI @ 138F	5.12	2.55		2.19	

Fouling Factor Determination

The universal heat transfer coefficient (U) is calculated from the temperature measurements taken every 10 minutes. This U data are then used to calculate a fouling factor (R_f) defined by the following formula:

$$R_f = 1/U_{\text{fouled}} - 1/U_{\text{clean}}$$

U_{fouled} is the calculated heat transfer coefficient at a specific time and U_{clean} is the heat transfer coefficient of a clean plate. Figure A-2 shows the variation of the heat transfer coefficient (U) over time for the control test and how U_{clean} is determined.

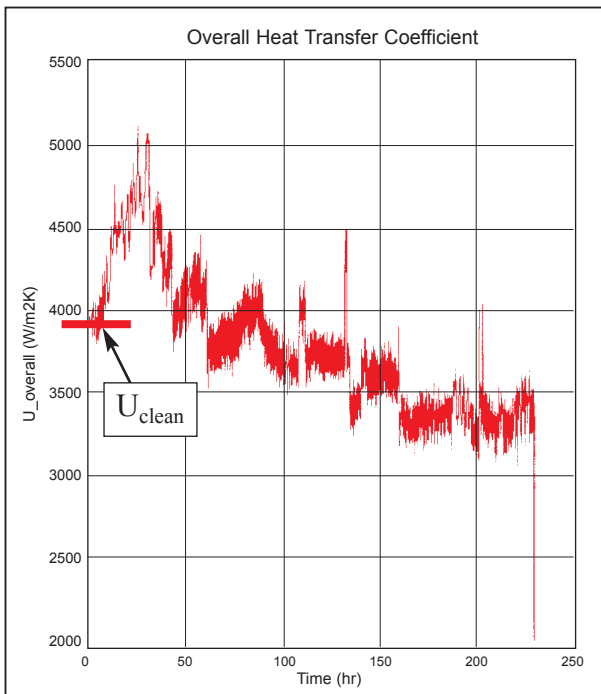


Figure A-2
Heat Transfer Coefficient Curve
No Treatment

Test Results: No Treatment

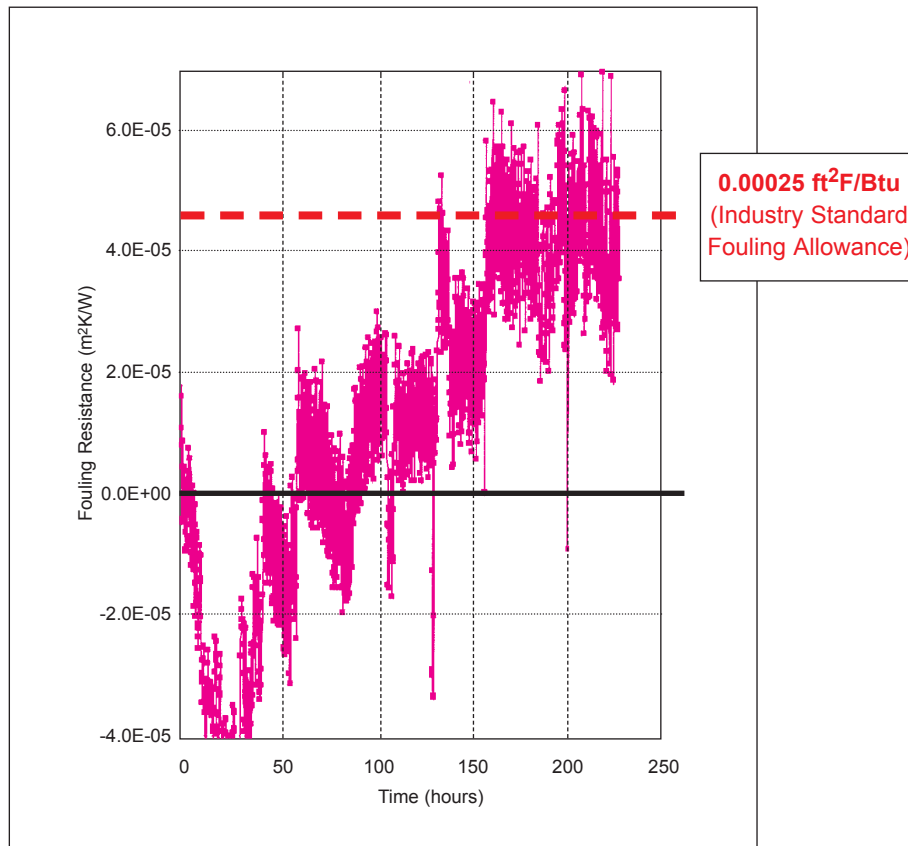


Figure A-3 – Fouling Factor Results for No Treatment

The no-treatment case exhibited a fairly typical R_f curve. For the initial period (up to 25 hours) R_f actually decreases as the heat transfer increases. The cause of this increase in heat transfer is an increase in turbulence at the surface of the plate due to the initiation of crystal growth. With the untreated case, calcium carbonate crystals nucleate and grow from the surface of the heat transfer plate. When this phenomenon starts, it causes increased turbulence at the surface of the plate, which, temporarily, improves heat transfer resulting in a negative R_f value. In a sense, the initial deposits convert a smooth heat transfer surface to an enhanced heat transfer surface.

After the first 25 hours the deposit covers enough of the surface so that the thermal insulating effect of the deposit exceeds the fluid mechanical improvement from a roughened surface.

Real time microscopic examination of the heat transfer surface as the deposit forms supports this hypothesis.

Physical examination of the channel at the end of the test showed that the channel was completely and uniformly covered with a deposit. This deposit was strongly adherent to the plate. The deposit is shown in Figure A-4.

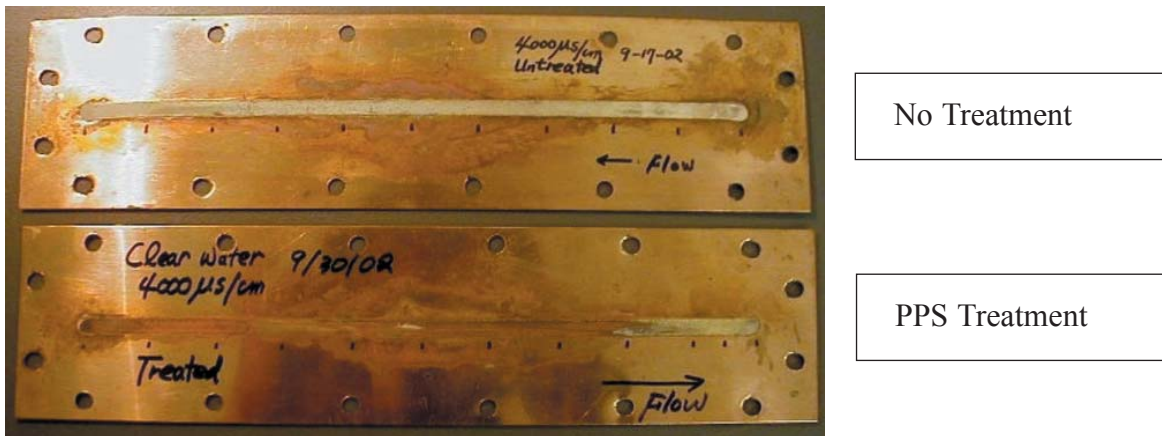


Figure A-4 – Heat Transfer Plates After Tests

Test Results PPS Treatment

The experimental setup was repeated with the only difference being that a PPS device was installed in the cooling tower line prior to the heat exchanger. The fouling factor results from this test are shown in Figure A-5.

The PPS Treatment case did not exhibit an initial drop in R_f because there were no crystals nucleating and growing from the surface of the plate. Real time microscopic examination of the heat transfer surface supports this hypothesis.

The PPS R_f curve does have a hump in the middle. During the entire test, the area of the heat exchanger visible beneath the window remained completely clear. After the test, a visual inspection of the entire heat transfer surface revealed a small

area of what appeared to be impacted particles at the outlet of the channel. It is theorized that this deposit initially caused a small increase in R_f that peaked at 125 hours. After that point the deposit became unstable and was reduced. The removal rate of the deposit was greater than the additional deposit by impaction resulting in R_f returning to approximately its initial start point.

Visual and microscopic examination of the heat transfer area at the end of the test showed that the area was completely free of deposits except for the small area at the outlet where localized turbulence (produced by 90 degree turn of flow) caused some suspended particle deposition. This small deposit was not strongly adherent to the plate. At the end of the test, there was no measured loss of heat transfer.

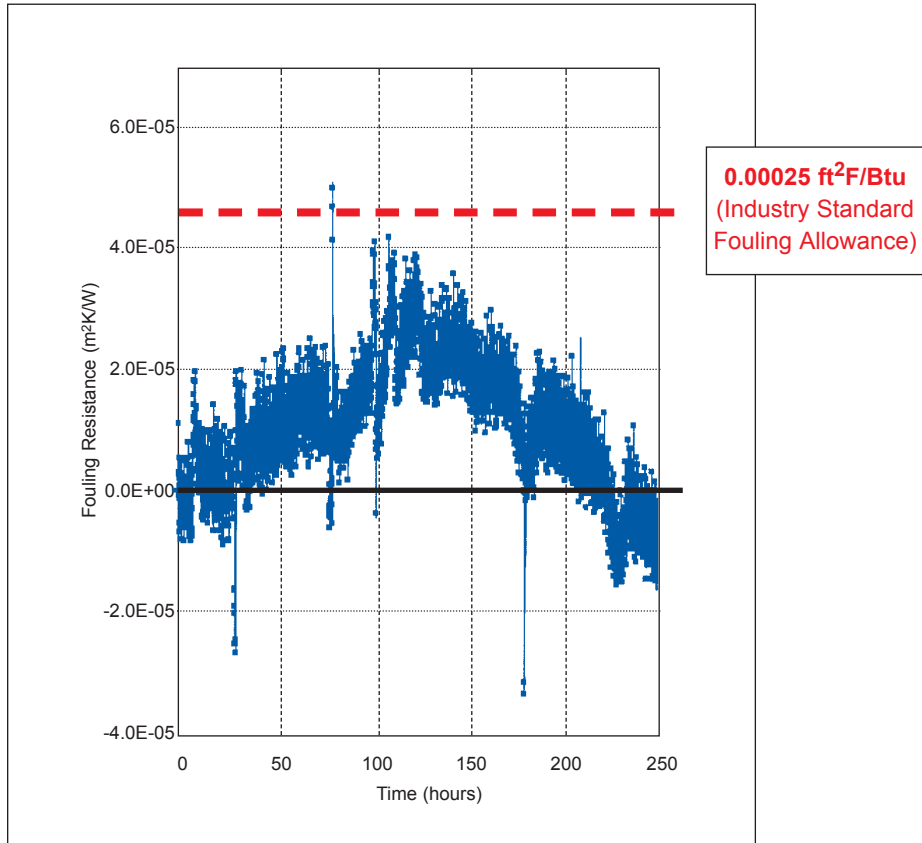


Figure A-5 – Fouling Factor Results for PPS Test

Author

John Lane is the Director of Technology for Clearwater Systems in Essex, Connecticut.

(E-mail address: JWL@clearwater-dolphin.com)

Mr. Lane holds a B.S. in Metallurgy and Material Science from the Massachusetts Institute of Technology. His industrial experience includes: Laboratory Manager at UNC Resources, Uncasville, CT; Research Metallurgist at ASARCO, South Plainfield, NJ; and VP Technology and President at Aerospace Metals, Inc., Hartford, CT.

Author

David F. Peck, P.E., is Staff Engineer - Water and Wastewater Treatment - for Hatch Mott MacDonald, in Pittsburgh, Pennsylvania.

(E-mail address: david.peck@hatchmott.com)

Mr. Peck holds a B.S. degree in Chemical Engineering from Carnegie Institute of Technology and an M.S. degree in Civil/Sanitary Engineering from the University of Pittsburgh. He has over 35 years of consulting and design experience in industrial, municipal, and institutional water and wastewater treatment.

COOLING TECHNOLOGY INSTITUTE

CONDENSER WATER TREATMENT USING PULSED POWER

**JOHN LANE
DIRECTOR OF TECHNOLOGY**

**CLEARWATER SYSTEMS
145 DENNISON ROAD • P.O. BOX 463
ESSEX, CT 06426**

PHONE: 860-767-0850 • FAX: 860-767-8972 • www.clearwater-dolphin.com

**DAVID F. PECK
STAFF ENGINEER, WATER AND WASTEWATER TREATMENT**

**HATCH MOTT MACDONALD
GATEWAY VIEW PLAZA
1600 WEST CARSON STREET
PITTSBURGH, PA 15219**