

**PAPER NO: TP12-16**

**CATEGORY: COOLING TOWER WATER TREATMENT PROGRAMS**

# **COOLING TECHNOLOGY INSTITUTE**

## **GREEN TECHNOLOGIES: ELECTRONIC WATER TREATMENT SYSTEM SUCCESSFULLY EVALUATED FOR WATER CONSERVATION**

**RODRIGO F.V. ROMO  
ZETA CORPORATION**

**SOLOMAN WILLIAMS  
AIR FORCE CIVIL ENGINEER AGENCY (RETIRED)**



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 warrant 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 2012. All rights reserved.

Presented at the 2012 Cooling Technology Institute Annual Conference  
Houston, Texas - February 5-9, 2012

## **ABSTRACT**

The U.S. Army Corps of Engineers Construction Engineering Research Laboratory (USACE-CERL) and the Air Force Civil Engineer Agency (AFCEA) working together with Zeta Corporation evaluated a high voltage capacitance-based water treatment technology in evaporative cooling systems at four military installations in two extended studies spanning over 4 years.

A High Voltage Capacitance Based (HVCB) water treatment technology was evaluated for control and prevention of corrosion, scaling and biological fouling in a side-by-side comparison to standard chemical treatment at four different military installations covering a wide range in evaporative cooling equipment and water quality.

Results confirmed that the technology consistently delivered an average 20% reduction in make-up water and 48% reduction in blow-down wastewater, significantly contributing to water conservation goals for agencies established under Executive Orders 13423 & 13514.

This paper presents the findings from the studies.

## Introduction

Evaporative cooling systems designed for comfort or process cooling typically account for the largest percentage of water used by facilities. While sustainable building design emphasizes low flow fixtures and water efficient landscaping as a means to accomplish water conservation, less attention has been paid to implementing innovative practices for treating process cooling water that would deliver significant reductions in potable water use while enabling opportunities for water re-use.

Presidential Executive Orders, EO 13423<sup>1</sup> and EO 13514<sup>2</sup>, call for Federal facilities to reduce water usage intensity and reduce the quantity of toxic and hazardous chemicals acquired, used or disposed of by the agency. These orders, issued by President Bush and President Obama successively, dictate under Section 2 *Goals for Agencies*:

*(c) beginning in FY 2008, reduce water consumption intensity, relative to the baseline of the agency's water consumption in fiscal year 2007, through life-cycle cost-effective measures by 2 percent annually through the end of fiscal year 2015 or 16 percent by the end of fiscal year 2015; (EO-13423)*

*(e) ensure that the agency (i) reduces the quantity of toxic and hazardous chemicals and materials acquired, used, or disposed of by the agency, (ii) increases diversion of solid waste as appropriate, and (iii) maintains cost-effective waste prevention and recycling programs in its facilities; (EO-13423)*

*(d) improve water use efficiency and management by:*

*(i) reducing potable water consumption intensity by 2 percent annually through fiscal year 2020, or 26% by the end of fiscal year 2020, relative to a baseline of the agency's water consumption in fiscal year 2007, by implementing water management strategies including water-efficient and low flow fixtures and efficient cooling towers. (EO 13514)*

Under Federal Leadership in High Performance and Sustainable Buildings<sup>3</sup>, the government is adopting goals for reducing total ownership cost of facilities; improving water and energy conservation; providing safe, healthy and productive built environments; and, promoting sustainable environmental leadership. While developing strategies for meeting these goals, the Department of Defense (DoD) is also interested in improving the effectiveness of water treatment protocols for the purpose of extending the useful life of the many types of evaporative cooling equipment found at installations worldwide.

Zeta Corporation developed and demonstrated an integrated water management program under a Cooperative Research and Development Agreement (CRADA) with the

---

<sup>1</sup> Federal Register Vol. 72, No. 17, Friday, January 26, 2007, Part II, The President, Executive Order 13423 – Strengthening Federal Environmental, Energy, and Transportation Management. Title 3- Executive Order 13423 of January 24, 2007.

<sup>2</sup> Executive Order (E.O.) 13514; *Federal Leadership in Environmental, Energy, and Economic Performance*; was signed on October 5, 2009. It expanded upon the energy reduction and environmental performance requirements of EO 13423.

<sup>3</sup> Pursuant to Executive Order (E.O.) 13101, *Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition*, HHS is committed to recycling and buying recycled content and environmentally preferable products.

U.S. Army Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) and the Air Force Civil Engineer Agency (AFCEA). Zeta Rod® Water Management Systems combine a patented, high voltage capacitor-based electronic water treatment technology with water management protocols developed to offer continuous remote monitoring of open loop evaporative cooling systems for optimizing water conservation and reduction of chemistry, while protecting equipment from corrosion, scale, bio-fouling, and bio-corrosion.

The two-year study<sup>4</sup>, published in 2009, monitored side-by-side installations of the technology, operating without any chemicals, against the results of chemical water treatment programs on sites chosen at two DoD facilities in the desert Southwest. Additionally, the technology was operated at elevated cycles of concentration to demonstrate water conservation efficiencies beyond what would be available under a chemical program.

Results showed a consistent average of 20% reduction in make-up water usage and 48% reduction in blow-down, while meeting and exceeding criteria for protection of equipment from scale, corrosion and bio-fouling. Measurement and verification capabilities of the water management system documented water usage; and development of a 24/7 wireless remote monitoring and control capability provided management of the water treatment program for efficiency and oversight, while meeting the restrictions of a high security environment.

A two-year extension of the investigation, under the Department of Defense Corrosion Prevention and Control Program, added two additional geographical locations that broadened the range of incoming water qualities from potentially corrosive in nature, to extremely hard. One existing site was converted to a hybrid program to document synergies and compatibility of the technology with a chemical program. Data collection ended in August of 2011 and will be published by ERDC-CERL in December of 2011. Highlighted results of the two study periods are presented herein.

## **Objectives**

The primary objective of any water treatment program is to protect expensive condensers and cooling towers while operating in an efficient manner. Variances in make-up water quality and lack of access or expertise can contribute to inefficiencies and risk to equipment and operators. A persistent challenge for the DoD is premature deterioration of equipment due in part to preventable conditions related to operations, as well as to less predictable environmental conditions; further exacerbating problems with efficiency and preventing achievement of desired equipment life cycles with water and energy conservation savings.

Evaporative cooling equipment that remains consistently free of deposits under a technically advanced water treatment program would hold energy consumption in cooling equipment to original design levels and prevent the increased energy consumption that accompanies even slight levels of scale formation and bio-fouling.

---

<sup>4</sup> [http://www.cecer.army.mil/techreports/erdc-cerl\\_tr-09-20/erdc-cerl\\_tr-09-20.pdf](http://www.cecer.army.mil/techreports/erdc-cerl_tr-09-20/erdc-cerl_tr-09-20.pdf)

Validating a green technology solution for water and energy conservation, while reducing or eliminating chemical requirements would contribute to compliance with EO 13423 and EO 13514, as well as to more ambitious conservation objectives, such as the Army Energy Program, Net Zero water and energy and waste objective.<sup>5</sup>

When operated without chemistry (normal condition) the Zeta Water Management System is designed to meet the primary objective of equipment protection, while offering opportunities for increased water conservation beyond what is capable of being delivered by chemical treatment alone.

## **HVCB TECHNOLOGY**

Zeta Water Management Solutions™ (ZWMS) was developed by Zeta Corporation to meet the requirements set by ERDC CERL for a comprehensive water conservation management program with wireless remote monitoring and control capabilities. Powered by the Zeta Rod®, a patented high voltage capacitor-based technology (HVCB) for fouling prevention in aqueous systems, the combined system provides a fully integrated water management system.

The Zeta Rod system is a modular design that is easily adapted to any cooling system. The system consists of one or more vitrified ceramic electrodes, energized by a 35 kV DC high voltage, low amperage power supply. When the rods are inserted into a conductive, grounded pipe or vessel, the system forms a capacitor; and characteristic of a capacitor, there is no electrical current flowing across the system. The system functions by inducing a time transient alteration of the particle surface charge over the natural state. The effect is expressed on dielectric colloidal particles, as well as on the wetted surfaces of the pipe or vessel.

The conductive lining of the ceramic electrode used in commercial equipment serves as one plate of the capacitor. The dielectric strength of the vitrified ceramic prevents current flow to the other plate of the capacitor. The grounded plane of the capacitor is established by the metal of the pipe or vessel. A direct current power supply charges the capacitor system to a high potential (normally 30 to 35 kV DC). The field strength between the plates of the cylindrical capacitor is a function of charge voltage, system dimensions, and the dielectric constant of the ceramic. Pitts (3) established that at a sufficiently elevated voltage, the field strength across the liquid between the plates of the capacitor influences the Gaussian surface charge of the particle. The result is a significant increase in the surface charge of wetted surfaces and in prevention of agglomeration (flocculation) of particles, impeding adherence of these particles to the walls of their containment.

Although not a biocide, the HVCB system is able to maintain very low bacteria counts in the water by means of preventing the formation of biofilms and the proliferation of organisms within. The mechanisms by which the HVCB technology controls scale deposition, biofouling and corrosion have been described in detail in numerous peer-reviewed journals, papers and conferences (1-7).

---

<sup>5</sup> <http://army-energy.hqda.pentagon.mil/netzero/>

By operating evaporative cooling systems at high cycles of concentration, the water in the cooling tower takes on non-corrosive characteristics as indicated by a positive Langelier Saturation Index (LSI). The HVCB system is capable of controlling corrosion by allowing cooling towers to operate under these non-corrosive conditions, while preventing scaling from taking place.

### **Remote Monitoring and Control**

Evaporative cooling systems require continuous monitoring of the chemistry of the water and the performance indicators of the equipment to ensure that proper control is maintained, thereby preventing potential problems related to scaling, corrosion or biofouling. Metering of the make up and blow down water is desirable in order to document water conservation targets. Corrosion coupons matching the metallurgy of the system are installed and replaced every 90 days to monitor the corrosion rates of the system. Electronic resistance (ER) probes, while not commonly used in conventional chemical treatment programs, provide for online corrosion trend analysis.

A fully integrated water treatment, control and wireless remote monitoring system was developed for this project with the objective of providing continuous monitoring, data collection and alarm capabilities of the systems being treated. The water management system is centered on a controller/data-logger with remote communications capability that can be accessed via static IP address or through a wireless modem. The controller provides the option to control cycles of concentration based on conductivity set point or by volumetric ratio, which was the option adopted for this project. The controller records conductivity, pH and total volume from the make up and blow down water meters and up to four 4-20mA signals. In this case one of the 4-20mA signals was provided by an ER probe monitoring corrosion rate in the system and another was taken from the HVCB high voltage power supply to monitor the high voltage output. Data was accessed and downloaded on a weekly basis. Multiple alarm conditions were programmed into the controller and emails programmed to communicate alarms to multiple recipients. Figures 1 & 2 show the components of the ZWMS in a conventional cooling tower / chiller application.

### **SITE SELECTION**

Davis Monthan Air Force Base, in Tucson, AZ and Fort Huachuca in Southeastern Arizona were selected for the initial CRADA. Each site was selected for being considered to be in the middle of the hard water scale (~120 to 130 mg/L total Hardness), continuous operations of cooling equipment throughout the year, and for its proximity to the HVCB equipment manufacturer location in Tucson, AZ. The CRADA lasted from July 2007 through September 2008. Third party oversight by CERL and Directorates of Public Works on the host bases ensured monitored collection of data and chain of custody for all sampling and site visits.

The complete data, results and findings were published by CERL and can be found in the U.S. Army Corps of Engineers website (7).

The positive results from the first study demonstrated that the HVCB system was capable of providing adequate equipment protection and measured water conservation in moderately hard and scale forming water. However, the question remained as to how the technology would work on the extremes of the water quality spectrum of very hard

water, and in soft, potentially corrosive water. This prompted CERL to expand the evaluation of the technology, under the DoD Corrosion Prevention and Control Program, into two more Military installations. Warner Robins Air Force Base in Warner Robins, GA and Fort Irwin in Barstow, CA were added to the Arizona locations for an additional two-year study period.

The four locations selected provided a wide range in water quality as well as size of the equipment being treated and their cycles of operation. Some of the plants operate year round whereas others are shut down during the winter. This diversity allowed the CERL to evaluate the HVCB technology under different operating scenarios and conditions. Table 1 shows the water composition at all four locations. Warner Robins has the least aggressive water and Fort Irwin the most aggressive with respect to scale and inversely with respect to corrosiveness. The third party oversight by CERL and Directorates of Public Works on the bases ensured monitored collection of data and chain of custody for all sampling and site visits.

Between August 2008 and July 2009 no water samples or corrosion coupons were collected from Ft Huachuca or Davis Monthan. This corresponds to the time between study funding periods. However, remote monitoring of the HVCB Zeta treated sites and the chemically treated control sites (CHEM) continued. Cycles of concentration were lowered during this period of inactivity, while the HVCB System continued to act as the only means of water treatment.

#### **Davis Monthan AFB, Tucson AZ**

Two evaporative condensers were selected for the project. The HVCB system was installed in a 386 kW (110 RT) unit servicing the Fitness Center (Bldg. 2301), while the control unit (CHEM) for the first phase of the project was a 420kW (120 RT) condenser servicing base dormitories (Bldg. 3750). These units have a higher demand use during the summer cooling season, but remain in operation throughout the year.

At the end of the CRADA, the dormitories (CHEM) were torn down and the CHEM control site was transferred to a 386kW (110 RT) condenser servicing Bldg. 1610.

Figure 3 shows the layout of the ZETA demonstration equipment.

#### **Fort Huachuca Army Installation, AZ**

Two Central Plants, the North Central Plant (NCP) and South Central Plant (SCP) were selected as the control (CHEM) and demonstration (HVCB) locations respectively for the project. Equipment was installed in the SCP in July 2007. Each plant has two 1,500kW (425RT) centrifugal chillers. The plants have a thermal cold storage tank, which is cooled down during off-peak hours, allowing the plants to turn the chillers off during peak hours. Plants operate year round. Figure 4 shows the Zeta Rods installed into the condenser water supply lines in the SCP.

#### **Fort Irwin Army Base, Barstow CA**

Two buildings 263 (HVCB) & 273 (CHEM) were selected for the evaluation. Each building has a 1,500kW (425RT) chiller and cooling tower that provides comfort cooling

to living quarters on base. The systems are shut down and drained during the winter. Operation of the chillers starts as early as May and runs through October. Depending on the weather, the running seasons may be increased or decreased. The equipment was installed in August 2009.

### **Warner Robins AFB, Warner Robins GA**

This central plant (Bldg. 177) has seven chillers and cooling towers that can be isolated. Two 5,250 kW (1,500 RT) chillers #2 (HVCB) & #4 (CHEM) were chosen for the evaluation. Although the plant runs year round, the chillers see plenty of downtime during the winter. The two chillers selected for the project were down for most of the time between November and January.

### **EVALUATION PROTOCOL**

A water treatment program should be designed to provide protection against mineral deposits (scaling), corrosion and biofouling while maximizing water conservation. Given these objectives, the test protocol to monitor and evaluate each of those metrics was as follows:

#### **Scaling**

Borescope inspections of the condenser tubes were planned for the beginning of the project to document the condition of the tubes, and then again at 12 and 24 month intervals. However, since the projects started during the middle of the cooling season it was not possible to shut down the chillers for inspection at that time. Instead, inspections took place at 6 and 18 months. A final inspection is scheduled for the fall/winter of 2011. A random set of tubes from each condenser was selected and video files were made to record the condition of those tubes for comparison.

At Davis Monthan there were no borescope inspections performed since any scaling on the evaporative condenser is likely to take place on the outside of the tubes. Instead, some tubes were selected as the “coupons” for the evaluation. Existing deposits were mechanically removed from sections of the tubes and their condition was monitored and documented by photographs throughout the period.

#### **Corrosion**

Conventional 90-day exposure corrosion coupons and on line Electronic Resistance Corrosion Probes<sup>6</sup> were utilized that would allow for instantaneous trend analysis to early detect if any increase in corrosion rate was taking place. Pre-weighed corrosion coupons (Mild Steel and Copper) were replaced every 90 days and sent to an independent lab for weight loss analysis.

Table 2 shows the corrosion target rates utilized during the project for copper and mild steel according to the Standards for Corrosion Rates by Bennett P. Boffardi, PhD., FNACE (9).

---

<sup>6</sup> Electric Resistance Probes and Transmitters by Alabama Specialty Products Inc. Metal Samples® Division, [www.alspi.com/ms.htm](http://www.alspi.com/ms.htm)

## **Biofouling**

Monthly dip slides<sup>7</sup> were collected at each location and incubated for 48 hours as per manufacturer's instructions. Samples for dip slides were collected at the same time and location as the water samples for chemical analysis. Incubation of the dip slides and interpretation of the results for the control and test towers was performed by a third party independent lab.

Dip slides are considered to be a viable monitoring means for microbiological control of cooling towers (10,11); the total aerobic bacteria counts from the dip slides indicate the general cleanliness of a cooling tower and thus the effectiveness of the water treatment program. Monthly samples (11) are recommended to ensure that the total aerobic count is below  $1 \times 10^5$  cfu/ml. McCoy (12) indicates that counts between  $1 \times 10^5$  &  $5 \times 10^5$  indicate a biologically clean system. The target for the evaluation of the HVCB technology was set at  $1 \times 10^5$  cfu/ml.

## **Water Usage**

Contacting-head water meters<sup>8</sup> were installed in the make up and blow down water lines of the control and test cooling towers at all four bases. This was done both to record the amount of water used and discharged at each location, as well as to provide the means to control cycles of concentration in the HVCB treated units.

## **Water Analysis**

A water sample from the make up water at each location was collected at the beginning of the project and monthly water samples were collected from the cooling towers and analyzed by an independent lab for Hardness (CA, Mg, Total), Alkalinity (total), conductivity, chlorides, silica, copper, iron, Ca, Mg, Zinc, and pH. The sampling was done from the water line feeding the conductivity controllers and corrosion coupon holders at all test and control locations. Sampling was done from the same spot throughout the project.

## **Operational Settings**

The blow down to the control cooling towers was maintained by a conductivity setpoint set by, controlled and maintained by the chemical treatment provider at each site. Cycles of concentration were calculated by the chemical treatment provider as the conductivity ratio between the recirculating water and the make up water. These setting were left unchanged during the project and control of the blow down settings, as well as maintenance of the controllers remained under the chemical provider's responsibility.

The test cooling towers were set to operate in a water conservation mode. Higher cycles of concentration were set at each of the HVBC sites and the controllers were set to blow down, not by a conductivity set point, but rather by a volumetric ratio determined by the amount of make up water volume to the amount of blow down volume. Using a volumetric ratio as the blow down parameter ensured that constant cycles were maintained in the evaporative cooling unit regardless of changes in the conductivity of

---

<sup>7</sup> Hach® Paddle Tester, Total Aerobic Bacteria/Yeast & Mold, [www.hach.com](http://www.hach.com)

<sup>8</sup> DLJ Water Meters, [www.watermeters.com](http://www.watermeters.com)

the make up water, or false cycles readings due to precipitation of minerals in the recirculating water.

Table 3 contains a summary of the operational settings used at each location. The table contains the average conductivity of the make up water, the conductivity set point that was present at each location prior to the evaluation (used for the control sites), the volumetric ratio programmed into the controllers at each HVCB site, as well as the average cycles of concentration intended for each site.

It is worth noting the following from the values shown in Table 3:

During the first phase of the project (July 2007 – Sept 2008) the CHEM site evaporative condenser at Davis Monthan had a blow down conductivity set point of 1,000 $\mu$ S. When the second phase of the project started, the new control site was operating with a blow down set point of 1,200 $\mu$ S. The controller at the HVCB unit was set to control cycles based on a volumetric ratio of 5:1.

The HVCB cooling tower at Warner Robins was set to operate at 12 cycles of concentration from September 2009 through February 2010. Upon favorable inspection of the condenser tubes at the 18 month opening it was decided to increase the ratio to 20:1 and see if further water conservation could be achieved without a detrimental effect to the system. The system continues to operate at this setting.

From July 2007 through February 2010 the HVCB system at Fort Huachuca was set to operate at a 4:1 volumetric ratio. In February 2010 the HVCB system was operated with chemistry for a hybrid approach. However, at that time cycle control was returned to the chemical feed controller and was unable to be remotely managed for water conservation. It was set by base personnel to operate at 800 $\mu$ S and continues to operate at this set point.

## **RESULTS**

### **Davis Monthan AFB**

The HVCB system has been installed at this location since July 2007. When the technology was installed, the tubes in the condenser already had an even layer or scale on the surface. Two sections of tubes were mechanically cleaned, marked with zip ties, and photographs were taken of the cleaned sections. The marked sections were photographed periodically throughout the 4 years that the condenser has been treated with the HVCB system.

While comparison of a small section may not fully represent the condition of the tube bundle, the claims made by the HVCB system manufacturer were that no new deposits would form on clean surfaces. By cleaning and marking the tube sections, deposit formation could be monitored. Photographs indicate that no significant amount of new scale has formed on the tube surfaces, indicating that the ZWMS has been effective in controlling scale formation at higher cycles of concentration than those maintained by a chemical treatment program. Figure 5 shows the conditions of the cleaned sections of tubes through time.

Besides the cleaned and marked tubes, the overall condition of the tube bundle was monitored and photographed throughout the duration of the project, Figure 6 shows the overall condition of the tubes as of March 2011 after 3 years and 8 months of operating at high cycles of concentration without chemistry.

### **Warner Robins**

The first borescope inspection (Jan 2010) at this location was made after the HVCB system had been operating for approximately 3 months (Sept – Nov 2009) at 12 cycles of concentration. The second tube inspection (Feb 2011) showed the tubes with no signs of any type of mineral or organic deposit. Based on these findings, the decision was made to increase the cycles to a 20:1 ratio. Based on the approach temperatures maintained in the condenser, plant personnel indicated that the unit continued to operate without any tube fouling. The final borescope inspection performed during December 2011 corroborated that the tubes in the condenser remained free of any mineral or organic deposits on the surfaces.

### **Fort Irwin**

Borescope inspections of the HVCB system (Feb 2010 & Jan 2011) showed no signs of scaling taking place in the condenser tubes operating at 3 cycles of concentration. This proved that the HVCB system was capable of delivering proper scale control while operating at higher cycles of concentration than those maintained by the chemical treatment program at the control site. Figure 7 shows the tube ends of the HVCB condenser (Bldg. 263-HVCB) during the borescope inspections of Feb 2010 and Jan 2011.

An unforeseen event in the CHEM chiller provided valuable information to the determination of the value of the remote monitoring protocol. Between June and August 2010 the chemical feed pump failed. In order to prevent scaling of the tubes, the controller was programmed to operate basically on a once through mode by the chemical service provider with a set point of 1,000 $\mu$ S. This allowed the blow down valve to remain open all the time.

In spite of the lower cycles of concentration maintained, the tubes showed a significant amount of scale formed on their surfaces, especially on those of the second pass of the heat exchanger.

Loss of chemical feed control during the summer months may be seen by some as a reason to nullify the experiment based on the affect it would have on the condenser. However, this event, while unfortunate for the facility, allowed CERL to answer the basic question of whether the HVCB was indeed providing scale protection to the evaluation site. During the entire two year period of the project, the test cooling tower operated without any chemicals and developed no scale formation on any of the tubes as demonstrated in the borescope inspections, the control tower operated without any chemicals for a period of three months and developed a significant amount of scale on the condenser tubes. These results clearly indicate that the water at this location has a strong scaling potential and that if no treatment is provided, scale will take place, thus proving that the HVCB system at the test site was indeed capable of providing adequate scale control. Figure 8 shows the tube ends of the control condenser during the borescope inspections.

The final borescope inspection performed in December 2011 showed the tubes in the test chiller free of any mineral deposits, while the condition of the tubes in the control chiller had significantly deteriorated with respect to the previous inspection.

### **Fort Huachuca**

The HVCB system was installed in the SCP in July 2007 during the first phase of this project. The cooling tower was set to operate at a 4:1 ratio based on volumetric control. The plant was in the process of replacing its two older chillers with new ones. By the time the first borescope inspection took place, one of the chillers had been replaced with a new one and the second chiller was about to be replaced. The borescope inspection on the older chiller showed that some tubes were partially blocked due to cooling tower debris (plastic and other debris) and material from legacy deposits that had shed from the cooling tower fill. Instructions were given by CERL through base personnel to the O&M contractor to clean the debris from the tubes, however this was not adequately accomplished and the chiller was allowed to go back online without proper cleaning.

The next borescope did not take place until February 2010. At that point the older chiller had been decommissioned and a new one had been installed. The tubes in the decommissioned chiller that had previously shown signs of blockage had not been properly cleaned of debris after the previous inspection and their condition had significantly deteriorated due to hot spots that had been created in the plugged tubes. Although there was no scaling in front of the blocked areas, the backside showed severe fouling. Inspection of the new chiller (which had been operating for one year under the HVCB treatment) showed no scale deposition on any of its tubes.

When general, or bulk scaling occurs, it does so evenly on all surfaces (heavier deposits on the second pass of the heat exchanger as seen in Ft Irwin's CHEM chiller) and not selectively in some tubes but not others, this ruled out that the fouling of the affected tubes had been a consequence of the HVCB not being able to prevent scaling. Figure 9 shows some of the plugged tubes in the decommissioned chiller during the Feb 2010 inspection, whereas Figure 10 shows the tubes of the newer chiller during that same inspection to be free of any deposits after having been in operation at high cycles of concentration for one year without any chemical feed.

In spite of the conclusions reached as to the cause of the fouling in the decommissioned chiller tubes, Fort Huachuca personnel chose to reintroduce the chemical treatment program to the SCP and run the HVCB in tandem for a hybrid approach. Blow down control was then transferred to the chemical controller and a conductivity set point for blow down of 800 $\mu$ S was programmed, reducing the cycles of concentration from an average of 4 to an average of 2.4. This effectively eliminated the water conservation benefits that had been obtained under the HVCB treatment program.

During the Borescope inspection of January 2011, the tubes in both HVCB treated condensers were found to be clean and free of any deposits. However, some of the condenser tubes in the NCP chemically treated control site showed similar tube blockages as those previously found in the SCP (HVCB) plant.

### **Corrosion**

While operating at high cycles of concentration and with a pH average of 8.9-9.0, the HVCB treated towers are allowed to operate at conditions under which corrosion is not likely to take place. Mild Steel and Copper Corrosion coupons were installed at each location and left in place for periods of 90 days to evaluate corrosion rates.

Tables 4 & 5 show the corrosion rates for Copper and Mild Steel coupons respectively throughout the two phases of the project. Results show that both the conventional chemical treatment programs and the HVCB program were successful in maintaining corrosion rates well within the set targets.

### **Biofouling**

Table 6 shows the results for the total aerobic bacteria counts from the monthly water samples collected at all four sites from July 2007 through May 2011. For most of the evaluation, all sites maintained bacteria counts below the set target of 100,000 cfu/ml. The cooling towers at all four bases were within close proximity from each other, none of them were more than a mile apart and in the case of Warner Robins they were next to each other. This ensured that the environment to which the towers at each location were exposed to was the same for the evaluation's purposes.

### **Water Conservation**

Water conservation was achieved by operating the HVCB treated towers at higher cycles of concentration than their chemically treated counterparts at each location. Cycles of concentration on the test towers were set by a volumetric ratio in order to ensure that true cycles would be achieved, regardless of the composition of the make up water.

Because of the difference in the water characteristics from the different sites, it was not possible to set all test towers at the same level of water conservation, however, in all four locations it was possible to achieve significant savings in water consumption. Table 3 shows the cycles of concentration that were being maintained in the cooling systems prior to the project and the cycles of concentration to which the test towers were set to operate.

Although the cooling systems within each site were similar in size and design, they still didn't operate for the exact same number of hours or at the same load. In order to calculate the water savings achieved by the HVCB treated towers the following equations were used:

$$\text{MUP} = \text{BD} + \text{EV} \quad [1]$$

$$\text{CC} = \text{MUP}/\text{BD} \quad [2]$$

Where:

MUP - Make Up      BD – Blow Down      EV – Evaporation      CC – Cycles of Concentration

For purposes of these calculations, drift losses are not taken into consideration. From [1] & [2] the following equation can be obtained:

$$\text{BD} = \text{EV}/(\text{CC}-1) \quad [3]$$

For each HVCB evaluation site the volume of BD & MUP are known. Therefore, CC can be calculated. Assuming that the evaporation rate remains constant for that site, one may back-calculate the water volume required for blow down if the tower had operated

at lower cycles of concentration. Once that calculated value of BD is obtained, then the new value of MUP corresponding to the lower cycles can be calculated, and thereby the percentage of water savings obtained may be determined for that particular tower, operating at higher cycles.

Using these assumptions the following water savings can be calculated for each one of the four Zeta HVCB sites:

- Davis Monthan: Make Up 18.4%, Blow Down 52.6% (July 2007-July 2011)
- Fort Huachuca, SCP: Make Up 12.6%, Blow Down 34.2% (July 2007-July 2011)
- Fort Irwin, Bldg. 263: Make Up 42.3%, Blow Down 66% (August 2009 – July 2011)
- Warner Robins AFB, CT#2: Make Up 11.8%, Blow Down 61.4% (September 2009 – 2011)

Tables 7-9 show the estimated water saving percentages and volume values for the four test sites during different periods of the project.

## **Conclusions**

At each of the four locations where the Zeta Rod Water Management system was demonstrated, the results met objectives set by CERL for this project. In spite of a wide range of water composition, inconsistent environmental conditions and variable operating schedules the technology delivered equal or better levels of protection with regards to scaling, corrosion and biofouling as were delivered by the parallel chemical treatment programs. The ZWMS demonstrated persistent and reliable operations through diverse challenging conditions.

Most importantly, the HVCB technology was able to deliver significant water conservation and chemical elimination to the four locations beyond what would normally be available under a similar chemical program. Furthermore, the chemistry-free blow down water from these cooling towers is now suitable for water re-use opportunities such as landscape irrigation or other gray water applications.

The remote monitoring and alarm capabilities of the ZWMS proved, in more than one occasion, to be critical to the success of the program. On more than one occasion problems associated with malfunctioning blow down valves, stuck float valves and other O&M type problems were promptly detected (both in test and control sites), provided alarms and notifications, and potential major problems were averted.

Validation of the HVCB system will assist the DoD in implementing water conservation throughout sites, to advance the DoD operations from Best Management Practices to that of Best Available Technology. Broad deployment of the ZWMS through DoD facilities will enhance resource intensity reductions, improve monitoring and verification of existing systems, and greatly improve the carbon footprint of HVAC plant operations, and reduce required maintenance resource requirements while extending equipment life cycles.

## **Notes**

A fair analysis would conclude that cooling tower maintenance and cleaning are an important component of an effective water management program and that no method of water treatment should be expected to prevent mechanical fouling of a chiller.

## TABLES & FIGURES

**Table 1:** Make Up Water Composition at Military Test Sites.

	Warner Robins AFB	Davis Monthan AFB	Fort Huachuca	Fort Irwin
<b>Make Up Water Composition</b>				
Conductivity (uS)	115	350	330	960
TDS ppm	57.5	175	165	480
pH	6.5	7.2	8.2	8
Hardness Ca	9.5	95	98	61
Hardness Ca & Mg	11	120	130	78
Ca		38	39	24
Mg		5.6	8.1	4.2
Chloride	31.7	5.4	6.9	100
Alkalinity Bicarbonate	54	140	150	130
Alkalinity Total	54	140	150	130
Silica	3.6	23	26	49

**Table 2:** Standards for Corrosion Rates (mpy), by Bennett P. Boffardi, Ph.D., FNACE

Description	Carbon Steel	Copper Alloys
Negligible or Excellent	Less than or equal to 1	Less than or equal to 0.1
Mild or Very Good	1 to 3	0.1 to 0.25
Good	3 to 5	0.25 to 0.35
Moderate to Fair	5 to 8	0.35 to 0.5
Poor	8 to 10	0.5 to 1
Very Poor to Severe	>10	>1

**Table 3:** Make Up Water Conductivity and Blow Down Settings for Each Location

	Warner Robins AFB	Davis Monthan AFB	Ft. Huachuca	Ft. Irwin
Make Up Conductivity (μS)	115	350	330	960
<b>Blow Down Setpoint</b>				
<b>CHEM</b> (μS)	600	1,000 / 1,200	900	1,500
Avg Cycles of Concentration	5.2	2.85 / 3.42	2.72	1.56
<b>HVCB</b> (Volumetric Ratio)	12:1 / 20:1	5:1	4:1 / 800	3:1
Avg Cycles of Concentration	12 / 20	5	4 / 2.42	3

**Table 4:** Copper Coupon Corrosion Rates (mpy) All Sites. No coupons were installed or collected in the period between the two phases of the project (Sep 2008 – Aug 2009). DM HVCB condenser does not have copper tubes, therefore no copper coupons were installed at that site. For the control site at DM corrosion rates on copper have been running high for all of the second phase of the project.

	DM		FH		FI		WR	
	Ctrl	HVCB	Ctrl	HVCB	Ctrl	HVCB	Ctrl	HVCB
Jul-Oct 07	0.2076	NA	0.0746	0.1525	-	-	-	-
Oct-Jan 08	0.2686	NA	0.0876	0.228	-	-	-	-
Jan-Apr 08	0.2691	NA	0.1157	0.113	-	-	-	-
Apr-Jul 08	0.1913	NA	0.1705	0.1627	-	-	-	-
Jul-Sep 08	0.1913	NA	0.3773	0.1892	-	-	-	-
Aug-Nov 09	0.3254	NA	0.3347	0.2925	0.2067	0.2959	0.2468	0.3314
Nov-Apr 10	0.2893	NA	0.0667	0.0579	0.0491	0.0665	0.1131	0.1435
Apr-Jul 10	0.3889	NA	0.2013	0.1968	0.3137	0.2685	0.1762	0.2038
Jul-Oct 10	0.2985	NA	0.0876	0.1148	0.6485	0.5557	0.1908	0.2055
Oct-Jan 11	0.2705	NA	0.1593	0.1593	0.2634	0.367	0.1351	0.1266
Jan-May 11	0.7462	NA	0.1294	0.1165	0.126	0.1298	0.2529	0.1861

**Table 5:** Mild Steel Coupon Corrosion Rates (mpy) all sites. Galvanized coupons were installed for the HVCB treated condenser at Davis Monthan since this is the material of the condenser tubes. The control condenser at DM has stainless steel tubes, therefore no Mild Steel Coupons were installed.

	DM		FH		FI		WR	
	Ctrl	HVCB	Ctrl	HVCB	Ctrl	HVCB	Ctrl	HVCB
Jul-Oct 07	NA	2.7416	0.232	0.0901	-	-	-	-
Oct-Jan 08	NA	1.732	0.1745	0.1521	-	-	-	-
Jan-Apr 08	NA	0.2543	0.226	0.2024	-	-	-	-
Apr-Jul 08	NA	2.3949	0.164	0.1365	-	-	-	-
Jul-Sep 08	NA	2.3949	0.3222	0.2184	-	-	-	-
Aug-Nov 09	NA	2.5978	0.2257	0.7043	0.3585	0.2968	0.4212	0.4599
Nov-Apr 10	NA	0.6312	0.1311	0.2506	0.1857	0.2111	0.6081	1.1123
Apr-Jul 10	NA	2.2581	0.3388	0.3818	2.0699	1.4226	0.7812	0.7804
Jul-Oct 10	NA	2.6670	0.267	0.3217	1.6195	0.3558	2.3209	1.2503
Oct-Jan 11	NA	1.7890	0.2017	0.2872	0.7599	0.6782	0.1793	1.1058
Jan-May 11	NA	1.0377	0.4855	0.2038	0.194	0.8322	0.4477	0.6949

**Table 6:** Total Aerobic bacteria counts (cfu/ml) from monthly water samples for all sites.  
No water samples collected between Aug 2008 and Aug 2009.

	DM		FH		FI		WR	
	Ctrl	HVCB	Ctrl	HVCB	Ctrl	HVCB	Ctrl	HVCB
Jul-07	0	0	0	10,000	-	-	-	-
Aug-07	0	0	0	0	-	-	-	-
Sep-07	0	0	100,000	100,000	-	-	-	-
Oct-07	0	0	0	10,000	-	-	-	-
Nov-07	0	0	1,000	10,000	-	-	-	-
Dec-07	0	0	0	10,000	-	-	-	-
Jan-08	0	0	1,000,000	0	-	-	-	-
Feb-08	1,000	0	1,000	0	-	-	-	-
Mar-08	0	0	0	0	-	-	-	-
Apr-08	100	0	0	0	-	-	-	-
May-08	1,000	0	10,000	0	-	-	-	-
Jun-08	0	0	0	0	-	-	-	-
Jul-08	0	0	1,000	1,000	-	-	-	-
Aug-08	10,000	1,000,000	100,000	10,000	-	-	-	-
Aug-09	0	1,000,000	0	0	0	1,000,000		-
Sep-09	0	0	0	0	0	100	-	-
Oct-09	100	0	0	0	0	1,000,000	0	0
Nov-09	0	0	1,000	0	1,000	100	100	100
Dec-09	10,000	10	1,000	0	-	-	0	0
Jan-10	0	0	0	0	-	-	0	100
Feb-10	0	0	0	0	-	-	100	0
Mar-10	10,000,000	10,000	0	0	-	-	0	10
Apr-10	0	10,000,000	0	100	-	-	750	0
May-10	100	0	0	0	-	-	10,000	100,000
Jun-10	100	0	1,000	1,000	0	100	300	500
Jul-10	0	100	100	0	0	100	100,000	100
Aug-10	0	0	0	0			300	20
Sep-10	0	0	100	0			50	2,500
Oct-10	100	0	0	0	0	0	0	50
Nov-10	0	0	0	0			10	0
Dec-10	0	0	0	0			10	0
Jan-11	0	0	100	100			0	0
Feb-11	10	0	0	0			10	0
Mar-11	0	0	0	0			100	300
Apr-11	0	10	0	0			5,000	100
May-11			0	0			50	1,000

**Table 7:** Estimated water savings at Davis Monthan AFB Bldg 2301 by running the evaporative condenser at high cycles of concentration.

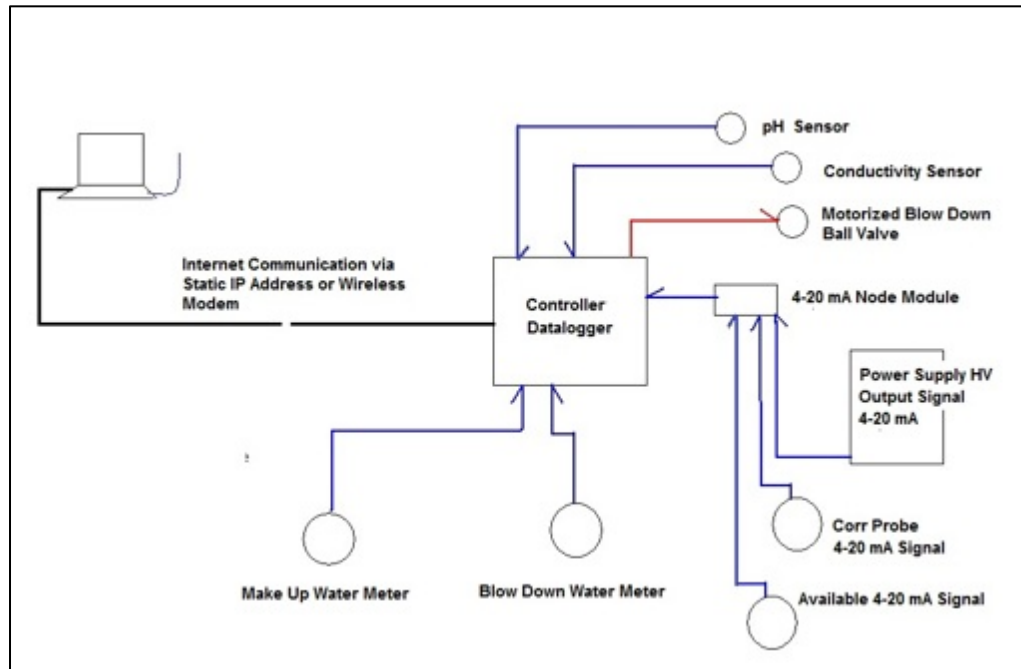
DM Fitness Center (Bldg 2301)											
Period	Actual Water Use (m3)					Calculated Water Use (m3) @ Lower Cycles				Savings % /m3	
	MUP	BD	EV	CC		MUP	BD	EV	CC	MUP	BD
Jul07-Aug08	3,561	792	2,769	4.49		4,266	1,497	2,769	2.85	16.5%	47.1%
Avg/month	274	61	213			328	115	213		704	704
Aug08-Aug09	4,699	1,280	3,420	3.67		5,268	1,849	3,420	2.85	10.8%	30.8%
Avg/month	392	107	285			439	154	285		569	569
Aug09-Jul11	4,396	511	3,885	8.60		5,985	2,100	3,885	2.85	26.5%	75.6%
Avg/month	191	22	169			260	91	169		1,589	1,589
Jul07-Jul11	12,657	2,583	10,074	4.90		15,519	5,445	10,074	2.85	18.4%	52.6%
Avg/month	264	54	210			323	113	210		2,862	2,862

**Table 8:** Estimated water savings at Fort Huachuca SCP by running the evaporative condenser at high cycles of concentration.

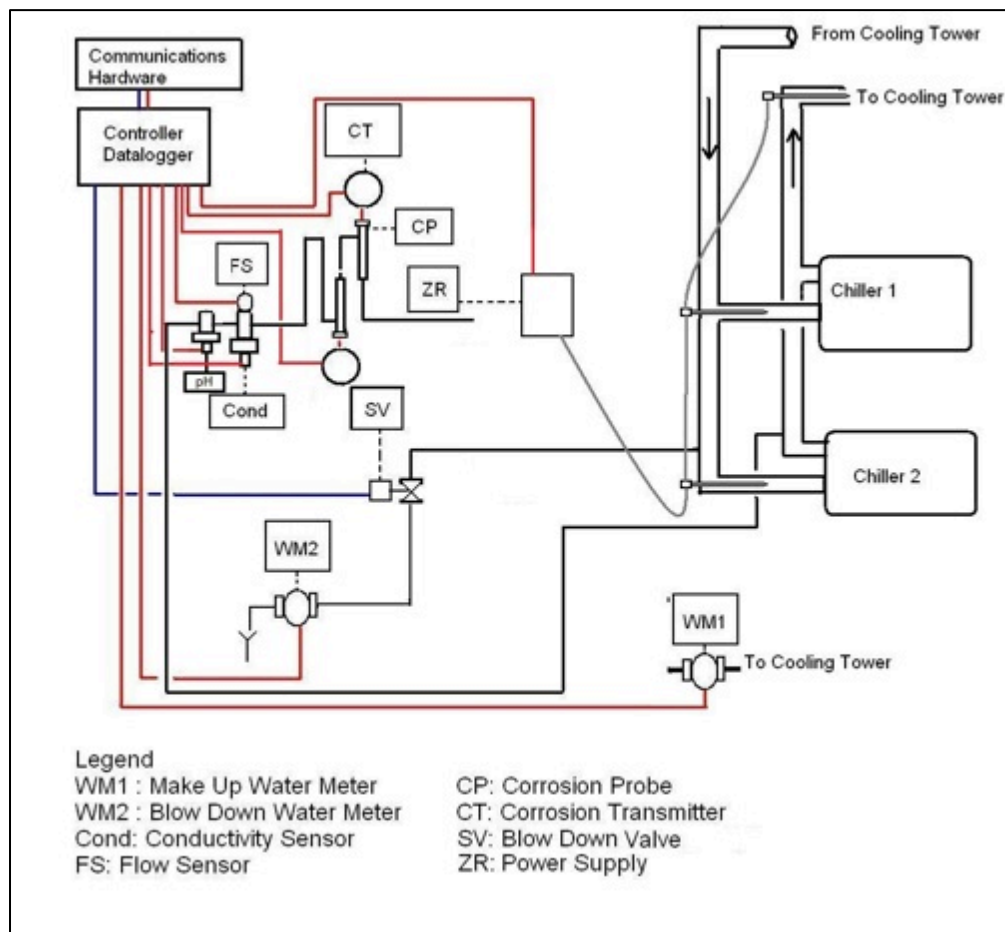
Fort Huachuca SCP											
Period	Actual Water Use (m3)					Calculated Water Use (m3) @ Lower Cycles				Savings %	
	MUP	BD	EV	CC		MUP	BD	EV	CC	MUP	BD
Jul 07 - Aug 08	18,445	2,922	15,523	6.31		24,548	9,025	15,523	2.72	24.9%	67.6%
Avg/month	1,419	225	1,194			1,888	694	1,194		6,103	6,103
Aug 08 - Aug 09	21,922	6,933	14,989	3.16		23,703	8,714	14,989	2.72	7.5%	20.4%
Avg/month	1,827	578	1,249			1,975	726	1,249		1,781	1,781
Aug 09 - Dec 09	3,007	617	2,390	4.87		3,779	1,389	2,390	2.72	20.4%	55.6%
Avg/month	131	27	104			164	60	104		772	772
Dec 09 - Jul 11	32,561	10,547	22,015	3.09		34,814	12,799	22,015	2.72	6.5%	17.6%
Avg/month	678	220	459			725	267	459		2,253	2,253
Jul 07 / Jul 11	75,935	21,019	54,916	3.61		86,844	31,928	54,916	2.72	12.6%	34.2%
Avg/month	1,582	438	1,144			1,809	665	1,144		10,909	10,909

**Table 9:** Estimated water savings at Fort Irwin Bldg 263 & Warner Robins AFB CT#2 by running the evaporative condenser at high cycles of concentration.

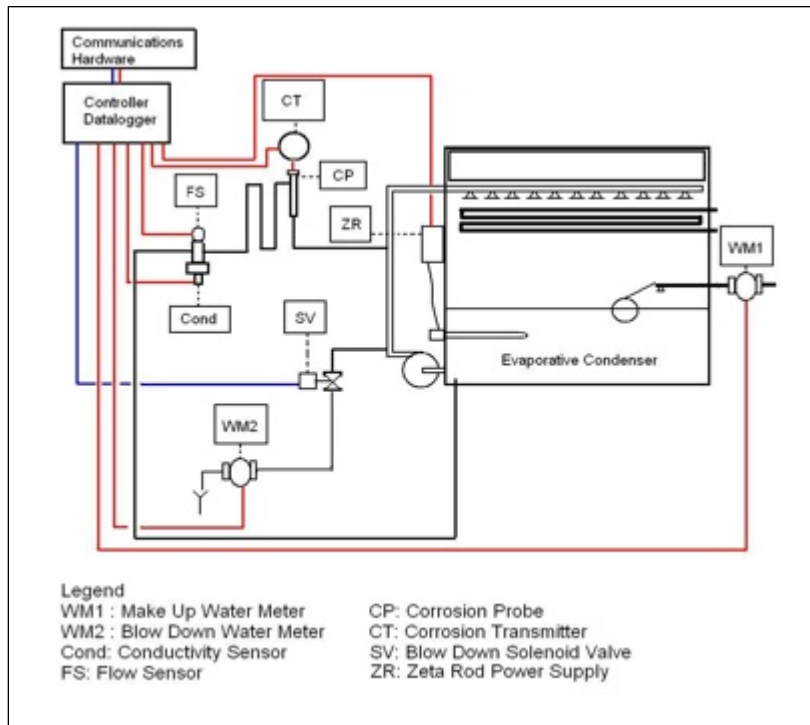
Fort Irwin Bldg 263											
Period	Actual Water Use (m3)					Calculated Water Use (m3) @ Lower Cycles				Savings %	
	MUP	BD	EV	CC		MUP	BD	EV	CC	MUP	BD
Jul 09 - Jul 11	7,128	2,692	4,436	2.65		12,357	7,921	4,436	1.56	42.3%	66.0%
Avg/month	548	207	341			951	609	341		5,229	5,229
Warner Robins CT#2											
Sep 09 - Jan 11	30,390	3,226	27,164	9.42		33,631	6,468	27,164	5.2	9.6%	50.1%
Avg/month	2,533	269	2,264			2,803	539	2,264		3,241	3,241
Jan 11 - Jul 11	21,253	1,119	20,134	19.00		24,928	4,794	20,134	5.2	14.7%	76.7%
Avg/month	924	49	875			1,084	208	875		3,675	3,675
Jul 09 - Jul 11	51,643	4,345	47,298	11.89		58,559	11,261	47,298	5.2	11.8%	61.4%
Avg/month	1,076	91	985			1,220	235	985		6,916	6,916



**Figure 1: ZWMS Components**



**Figure 2: Typical layout of ZWMS in Cooling Tower – Chiller System**



**Figure 3:** ZWMS layout as used at Davis Monthan AFB Bldg 2301.



**Figure 4:** Zeta Rod electrodes mounted on 1 1/2" thread-o-let fitting in cws & cwr lines at Fort Huachuca SCP.



**Figure 5:** Time progression of Evaporative Condenser Tubes in Test (Bldg 2301) unit at Davis Monthan AFB. Dates pictures were taken (clockwise from upper left) Sept 2007, June 2008, March 09, March 2011



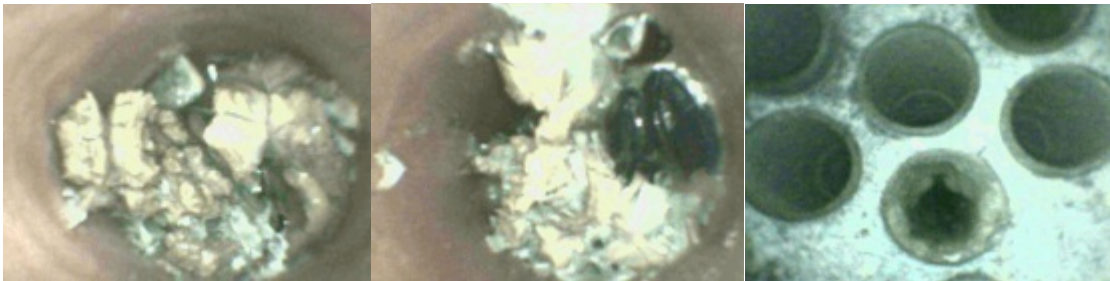
**Figure 6:** General condition of the tubes at Davis Monthan Bldg 2301 after 44 months of operating at an average of 5 cycles of concentration with no chemicals (March 2011)



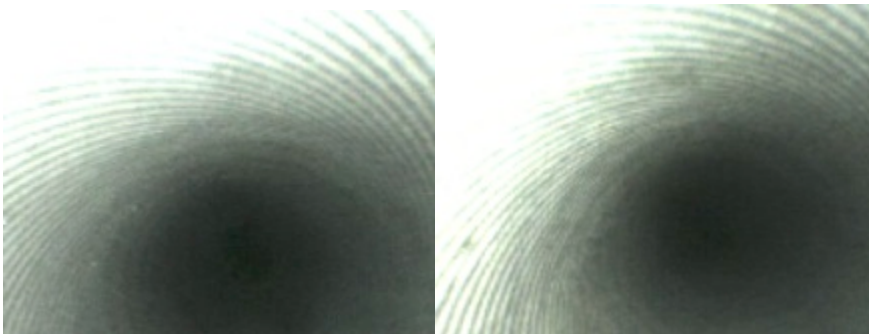
**Figure 7:** Ft Irwin Bldg 263 (test) condenser tubes during Borescope inspections Feb 2010 (left) and Jan 2011 (right),



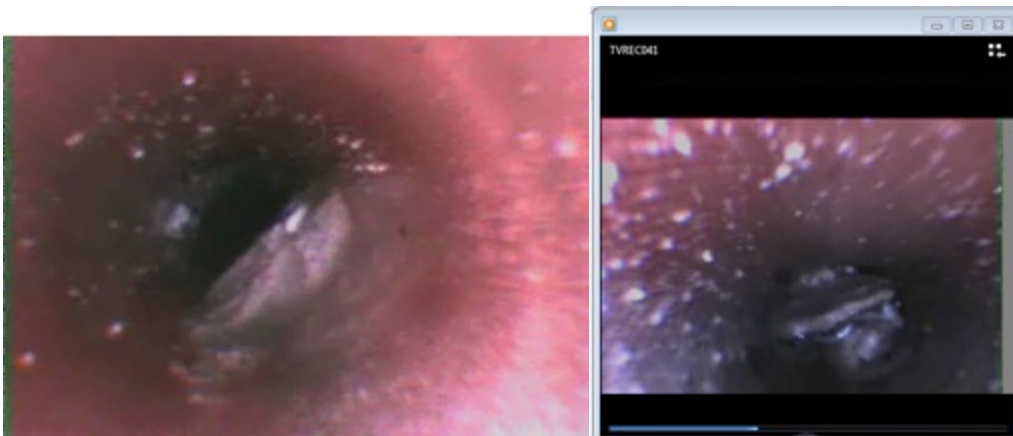
**Figure 8:** Ft Irwin Bldg 273 (Ctrl) condenser tubes. Feb 2010 (left) scale can be seen on the tube surfaces, a section of one of the tubes was mechanically cleaned to show the copper surface free of scale. Jan 2011 (right) shows the condenser tubes with scale more visible on the second pass of the heat exchanger (lower half) after the condenser ran for approximately 90 days with no treatment and at low cycles of concentration. The outermost section of the tube in the middle was mechanically cleaned to show the copper surface without scale.



**Figure 9:** Ft Huachuca SCP (HVCB), Feb 2010. Tubes from decommissioned chiller showing debris plugging the tubes. Two images from the left show the upstream end of the plug, notice how no scale is formed on the clean copper section of the tube prior to the plug. Picture on the far right, shows the back end of one of the plugged tubes. The hot no flow zone created by the plug lead to the mineral accumulation on the tube wall. Tubes surrounding the plugged tube show no scale formation on their surfaces, indicating that this was not the result of bulk scaling.



**Figure 10:** Ft Huachuca SCP (test), Feb 2010. Tubes from the newer chiller which had been operating at an average of 4 cycles of concentration for one year under the HVCB only program show no signs of mineral fouling on the surfaces, indicating proper scale control provided under the treatment program.



**Figure 11:** Ft Huachuca NCP (Control), Jan 2011. Tubes from the control chiller show partial blockage by debris from the water. A similar situation as the one found in the SCP during the Feb 2010 inspection.

## REFERENCES

1. Romo R., Pitts M., Handagama N., 2007, Biofouling Control in Heat Exchangers Using High Voltage Capacitance Based Technology, ECI Symposium Series, Volume RP5, Proceedings of 7<sup>th</sup> International Conference on Heat Exchanger Fouling and Cleaning, Engineering Conferences International, Tomar, Portugal July 1-6, 2007.
2. Pitts M. M., 1992, Solids Control in Solvent Extraction Circuits Using Electrostatic Dispersion. Presented at the Society for Mining, Metallurgy, and Exploration Inc. Annual Meeting. Phoenix, AZ .
3. Pitts M. M., 1995, Fouling Mitigation in Aqueous Systems Using Electrochemical Water Treatment. Presented at the Engineering Foundation Conference on Fouling Mitigation of Industrial Heat Exchangers. Shell Beach, CA.
4. Romo R., Pitts M. M., Hector M. G., 2002, Composite Fouling Control in RO Membranes with High Voltage Capacitance Based Technology. Presented at the Ultrapure Water Executive Forum. Orlando, FL.
5. Romo R., Pitts M.M., 1999, Application of Electrotechnology for Removal and Prevention of Reverse Osmosis Biofouling. Environmental Progress. 31(12):107-111 .
6. Romo R., Pitts M.M., 2000, Clean membranes produced from electro-dispersion in conformity with colloid behavior theory. Presented at the American Desalting Association, North America Biennial Conference & Exposition – Session 1B: Development and innovative use of membranes. South Lake Tahoe, NV.
7. Demonstration of Electronic Capacitor-Based Water Treatment System for Application at Military Installations, Beitelman, A.D., Pitts, M.M, Romo, R.F.V., Pitts, C.B, [http://www.cecer.army.mil/techreports/erdc-cerl\\_tr-09-20/erdc-cerl\\_tr-09-20.pdf](http://www.cecer.army.mil/techreports/erdc-cerl_tr-09-20/erdc-cerl_tr-09-20.pdf)
8. Schrader G., 2006, Fouling Control in Nanofiltration Using a High Voltage Static Electric Field Device, Chapter 4 in his Ph. D. Thesis “Direct Nanofiltration of Waste Water Treatment Plant Effluent”, University of Twente, The Netherlands, pp 91-117.
9. Boffardi B.P, Standards for Corrosion Rates, Produced by the AWT Technical Committee under the Direction of the Cooling Water Subcommittee Head, Bennet P. Boffardi, Ph.D., FNACE.
10. Mueller, S.A.; Anderson, J.E.; Kim, B.R.; Ball, J.C.; Comparison of plate counts, Petrifilm, dipslides, and adenosine triphosphate bioluminescence for monitoring bacteria in cooling-tower water; Journal Water Environment Research 2009, Vol 81, No 4 pp. 401-406
11. Freije, M.R.; Legionellae Control in Health Care Facilities, A Guide for Minimizing Risk; HC Information Resources Inc.; 1996.

12. McCoy, J.W.; The Chemical Treatment of Cooling Water (2<sup>nd</sup> Edition), Chemical Publishing Co.; New York, NY, 1983.