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Legionella and Non-Chemical Water Treatment Devices

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INTRODUCTION

Microbial growth in cooling water systems causes corrosion, decreases energy efficiency, and has the potential to cause human infection, including Legionnaires' disease[1]. Control of microbial growth in these systems is typically achieved with the use of chemical biocides[2]. Non-chemical water treatment methods have been used as an alternative to chemical water treatment, especially as a "Green Building" technology. However, few scientifically objective studies have been performed to verify the efficacy of these devices to control *Legionella* and other microbial growth in cooling towers. Therefore, the specific objective of this investigation was to provide a controlled, independent, and scientific evaluation of several classes of non-chemical treatment devices (NCDs) for controlling *Legionella* and other microbiological activity in a model cooling tower system.

We investigated the efficacy of five (5) non-chemical devices (NCD) to control the planktonic and sessile *Legionella* populations within a pilot-scale cooling tower system. This report presents the results of *Legionella* testing that was performed during, but was independent of, the ASHRAE-sponsored study RP-1361 that investigated the effect of these devices to control heterotrophic plate count bacteria[3]. The devices included magnetic, pulsed electric field, electrostatic, ultrasonic, and hydrodynamic cavitation. Two model cooling towers were designed and operated to simulate field conditions (e.g., heat load, residence time, liquid loading rate, evaporative cooling, blowdown and make-up system). One tower served as the untreated control (T1) while the NCD was installed on the second tower (T2). Each device trial was conducted over a minimum of 4-weeks. *Legionella* and heterotrophic plate counts (HPC) were monitored in both planktonic and biofilm phases. Physicochemical monitoring included temperature, conductivity, pH, alkalinity, hardness, total dissolved solids (TDS), ORP, and chloride. Make-up water for each system was dechlorinated city tap water.

NON-CHEMICAL WATER TREATMENT DEVICES

MAGNETIC TREATMENT

Magnetic water conditioners have been applied to reduce scaling and corrosion in industrial systems for several decades[4,5,6]. Water passes through a fixed magnetic field, which alters the water chemistry to prevent the formation of "hard" scales on cooling surfaces. Manufacturers of magnetic water conditioners generally do not make claims of microbial control.

PULSED POWER AND ELECTROSTATIC TREATMENT

Pulsed-power treatment, also referred to as pulsed electric field (PEF) treatment or electropulse treatment, involves the bombardment of the substance to be disinfected with pulses of electromagnetic energy. These pulses may inactivate microorganisms present in the substance, including pathogens[7]. However, the optimal mechanism by which this process occurs has not been definitively established[8].

ELECTROSTATIC

The mechanisms of operation for electrostatic treatment systems are essentially identical to those involved in the operation of pulsed-power treatment systems[9]. The primary difference is that electrostatic systems apply a static electric field, rather than pulses of energy. The claims of the manufacturers of these devices also include scaling, corrosion, and microbial control.

ULTRASONIC CAVITATION

The use of ultrasonic energy to inactivate microorganisms has been under investigation for several years[10,11]. The interaction of ultrasonic energy with water results in cavitation process through a process known as sonication. It is suggested that the collapse of these cavitation bubbles is responsible for bacterial inactivation.

HYDRODYNAMIC CAVITATION

When fluids are subjected to sudden high pressure changes, very small vapor bubbles may form within the fluid in a process known as cavitation. These bubbles quickly collapse, leading to extremely high local temperatures, pressures, and fluid velocities[12]. The implosion of these small bubbles of fluid vapor within a liquid has been the mechanism attributed to inactivation of surrounding organisms[13].

MATERIALS AND METHODS

SYSTEM DESCRIPTION

Two pilot-scale model cooling tower systems were used to evaluate the performance of each device. The two model cooling towers used in this study were designed to be identical. A schematic outlining the cooling system setup for each tower is shown in **Figure 1**.

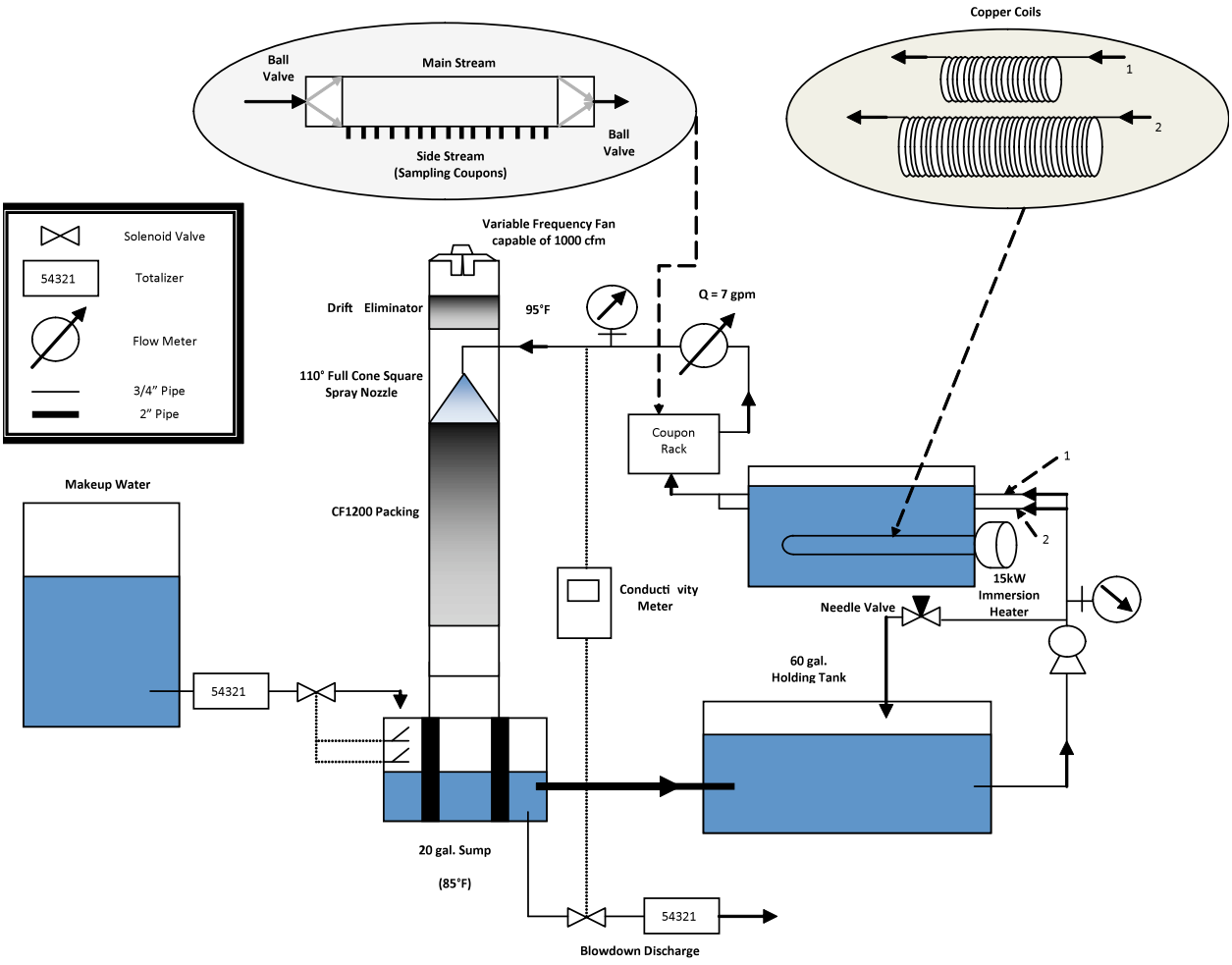

Figure 1 - Pilot-Scale Cooling System Schematic

In each pilot-scale system, water was stored in a 60 gal. holding tank prior to being pumped at a rate of 7 gpm by a 2 hp centrifugal pump into a stainless steel heating bath. The system flow rate was controlled by the use of a side stream placed immediately after the pump discharge. This sidestream returned a portion of the flow back to the 60 gal. holding tank. The rate of return flow was controlled by a needle valve, allowing the tower operator to manually adjust the system flow rate to approximately 7 gpm.

Immediately prior to entering the heating bath, the flow of water was split into two paths, and each flow path continued into a coil of ¾" OD copper tubing. The two coils (approximately 105 ft. and 44 ft.) wrapped around a 15 kW immersion heater, and the entire heating apparatus was surrounded by a stainless steel box containing dechlorinated water. The box was sealed by a lid made of ½ in. thick plexiglass in order to minimize evaporative losses. The immersion heater

was controlled by a thermostat, which was adjusted throughout the experimental trials to maintain a water bath temperature of approximately 120°F. This heating bath temperature provided enough thermal energy to elevate the temperature of the system water to 95-100°F.

Once the system water passed through the two copper coils, the flow paths were combined. The flow was then diverted through a sampling rack containing a series of sampling coupons. The sampling coupons were 5.61 cm^2 stainless steel washers which were scrubbed and autoclaved at 121°F prior to installation in the experimental towers. These coupons were installed at the beginning of each device trial, and they were used to quantify biofilm growth within each of the cooling tower systems. Coupons were installed parallel to the direction of flow.

Upon exiting the sampling rack, the system flow passed through a number of sensors for data collection, including a pH probe, an ORP probe, a conductivity probe, and a thermometer designed to record the water temperature prior to tower entrance. Each of these probes was connected to an AquaTrac Multiflex data collection system, which recorded data at 1-hour intervals. The flow then passed through a flow meter to ensure that system flow rate of 7 gpm was maintained. Immediately prior to the tower entrance, the flow passed over an additional conductivity meter. This conductivity meter was connected to a blowdown control system which used conductivity readings to control when the tower blowdown occurred based on a conductivity set point. The set point was chosen based on the make-up water conductivity, and it was selected to produce 4-5 cycles of concentration in the cooling tower system.

Flow entered each of the cooling towers by way of a 110° full cone square spray nozzle. This allowed the flow to be distributed evenly over the surface of the CF1200 packing (Brentwood Industries) which is installed in each tower. The height of the packing in each tower was adjusted so that the spray from the nozzle contacted the packing at its uppermost edge, diverting flow through the interior of the packing rather than down the side wall of the tower. A total of 3 1 ft^3 units of packing were installed vertically in each tower system, for a total packing height of 3 ft.
Once the water travelled through the packing, it was deposited into a 20 gal. sump. Upon entering the sump, the water temperature decreased to 85-90°F, thereby maintaining a temperature differential across the packing of approximately 10°F. This cooling was accomplished by a variable frequency axial fan placed at the top of the tower, above the water entrance. The rate of airflow generated by this fan was controlled by a potentiometer to produce the desired 10°F temperature differential. The 20 gal. sump was connected to the 60 gal. holding tank via a 2 in. diameter PVC pipe, and as water traveled through the system it was pulled from the 20 gal. sump back into the 60 gal. holding tank, completing the cooling water cycle.

For each device trial, a control tower and a test tower were utilized. The control tower (T1) received no treatment during the testing process, while the device tower (T2) received treatment from the non-chemical device being evaluated. The device was activated at the beginning of the study, and it was not turned off until the investigation had been completed. The control tower in each device trial will be referred to as T1 (Control), and the device tower will be referred to as T2 (Device).

A total of five (5) non-chemical water treatment devices were tested over the course of this investigation (**Table 1**). Before the beginning of each device trial, several measures were taken to ensure consistent starting conditions. Each tower received 4 gal. of dilute acetic acid and 250 mL of 5% sodium hypochlorite solution, and the towers were allowed to operate for several hours in order to eliminate any residual microorganisms present in the system and to remove scale formed during the previous trial. Both towers and their corresponding sumps and holding tanks were scrubbed with 5% acetic acid to remove as much scale as possible. Each system was drained completely using a shop vacuum, and refilled with clean make-up water. The draining and refilling process was repeated a minimum of 2 times for each tower prior to the beginning of a new device trial. Additionally, the plastic packing in each of the towers was replaced prior to the initialization of a new test. The new packing was installed after the tower had been drained and rinsed to reduce the amount of residual solid material which it collected.

Table 1 – Non-chemical device testing schedule

Device Name Abbreviation	Treatment Technology	Test Date Range(s)
MD	Magnetic	3/13/09 - 4/20/09
PEFD	Pulsed Electric Field	5/2/09 - 5/30/09, 6/12/09 - 7/10/09
ED	Static Electric Field	7/18/09 - 8/21/09
UD	Ultrasound	9/2/09 - 10/4/09
HCD	Hydrodynamic Cavitation	10/27/09 - 11/24/09

BIOLOGICAL MONITORING

Bulk water samples were collected twice weekly using sterilized sampling bottles. Biofilm samples were collected weekly by swabbing the biofilm coupon surface and resuspending the material into 10.0 mL of sterile deionized water. All biological samples were kept chilled during transport to the laboratory. Upon arrival, samples were shaken thoroughly and subject to a series of dilutions.

A series of three dilutions was plated for HPC testing of each bulk water and biofilm sample. The range of dilutions used for make-up water analysis was 10^{-2} – 10^{-4} for this investigation, while the bulk water tower dilution range was 10^{-3} – 10^{-5} and the biofilm sample dilution range was 10^{-4} – 10^{-6}. *Legionella* testing was performed using a modified method based upon the International Standards Organization (ISO) Standards 11731-1:1998 and 11731-2:2004. The minimum/maximum concentration limits were 10 CFU/mL />6000 CFU/mL. Heterotrophic plate count bacteria test dilutions were plated according to Standard Method 9215 pour plate protocol. The minimum/maximum concentration limits were 1.0 CFU/mL />300,000 CFU/mL.

NON-CHEMICAL DEVICE DESCRIPTIONS

Magnetic Device (MD)

The magnetic device evaluated in this investigation consists of a 13" flow-through cylinder which exposes water to 4 alternating magnetic poles. The MD is marketed as a scale-inhibiting water conditioner. The manufacturer does not claim that the device is capable of microbiological control. According to the manufacturer, the device operates by keeping mineral ions such as calcium and magnesium in suspension, preventing them from forming scale on cooling surfaces. The magnetic device was installed in the cooling tower system used in this study according to the manufacturer's specifications. The device was placed along the water flow path immediately before entrance into the top of the cooling tower.

Pulsed Electric Field Device (PEFD)

The pulsed electric field non-chemical treatment device evaluated in this investigation is composed of two primary components: a signal generator and a treatment module. The signal generator is housed in a stainless steel box, and it contains all of the system's replaceable parts. The treatment module, which consists of a 1" diameter PVC cylindrical flow-through reactor, is connected to the signal generator via an umbilical cable. According to the manufacturer, the device is capable of controlling scale formation, equipment corrosion, microbial populations, and algal growth in a cooling water system.

The PEFD was installed in the cooling tower system used in this study according to the manufacturer's specifications. The treatment module was placed directly after the centrifugal pump and immediately before the heat bath. According to the manufacturer, the treatment module may also be placed directly after the heat exchanger but before the entrance of water into the cooling tower.

Electrostatic Device (ED)

The ED is an electrostatic treatment device designed to "control scaling, inhibit corrosion, [and] minimize biological fouling without chemical additives". The device was composed of a 1" flow-through reactor vessel. The technology by which the ED operates is similar in principle to that employed by the PEFD. While the PEFD bombards the water with pulses of electromagnetic energy, the ED exposes the water in the reactor chamber to a steady electrostatic field. The ED was installed according to the manufacturer's specifications at the same location as the PEFD, directly after the centrifugal pump but immediately before the water flow entrance into the heat exchanger.

Ultrasonic Device (UD)

The UD operates by diverting water from the cooling system sump or holding tank through a venturi and into an ultrasonic treatment cell. Once the flow velocity has been increased by passing through the venturi, air is introduced into the water stream. According to the manufacturer, the vacuum pressure generated by the venturi during normal operation should be between 0.4 and 0.75 bar below atmospheric pressure. The water/air mixture then enters an ultrasonic treatment chamber containing 6 ceramic transducers. Upon exiting the treatment cell, the water passes through a basket filter prior to discharge back into the cooling system sump.

The ultrasonic device was installed according to the manufacturer's specifications, and a representative from the manufacturer approved the final installation. A sidestream was constructed for the application of this device, with the sidestream intake positioned near the outlet end of the 60 gallon storage tank and the outflow positioned near the storage tank's inlet.

Hydrodynamic Cavitation Device (HCD)

Operation of the HCD involves the diversion of water from the cooling system sump or holding tank into the device, where treatment is administered and the water is returned to the sump from which it was initially withdrawn. Water drawn from the system sump enters a pressure-equalization chamber. The flow of water is then split into two separate streams and each of these streams enters a vortex nozzle. According to the manufacturer, the collision of these two conical streams creates a vacuum region which results in the formation of cavitation bubbles. The collapse of these bubbles generates high shear forces, temperatures, and pressures, leading to microbial inactivation.

CONTROL TOWER (T-1) CONDITIONS

The make-up water quality and performance of T1 (Control) throughout the course of the entire investigation were monitored in order to ensure similar conditions of operation for each individual device trial.

T1 (CONTROL) SYSTEM OPERATION

Average values observed in the control tower (T-1) for all of the combined data runs are shown in Table 2. The target temperature differential throughout the investigation was 10 °F. During all other device trials, a temperature differential of approximately 9-13 °F was maintained.

Table 2 – Average values for T1 (Control)

	T1 (Control)	
	Average	Standard Deviation
Temperature Entering Tower (°F)	99.3	3.1
Sump Temperature (°F)	88.3	3.2
Daily Make-up Water Consumption (gal)	115	7
Daily Blowdown (gal)	17	6
Temperature Differential (°F)	11.0	1.5
Conductivity (mS/cm)	1.174	0.215
pH	8.64	0.10
Alkalinity (mg/L as $CaCO_3$)	113	21
Calcium Hardness (mg/L as $CaCO_3$)	205	88
Magnesium Hardness (mg/L as $CaCO_3$)	122	47
Total Hardness (mg/L as $CaCO_3$)	328	111
TDS (mg/L)	853	165
LSI	1.23	0.29
RSI	6.19	0.52
PSI	7.30	0.56
Planktonic HPC (CFU/mL)	6.77E+05	1.02E+06
Sessile HPC (CFU/cm^2)	2.57E+06	3.66E+06

BIOLOGICAL PARAMETERS

The average log heterotrophic plate count for the make-up water over the course of the investigation was 4.4 log CFU/mL.

Throughout each device trial, a planktonic population of between 10^5 – 10^6 CFU/mL was maintained in the control tower (Figure 2).

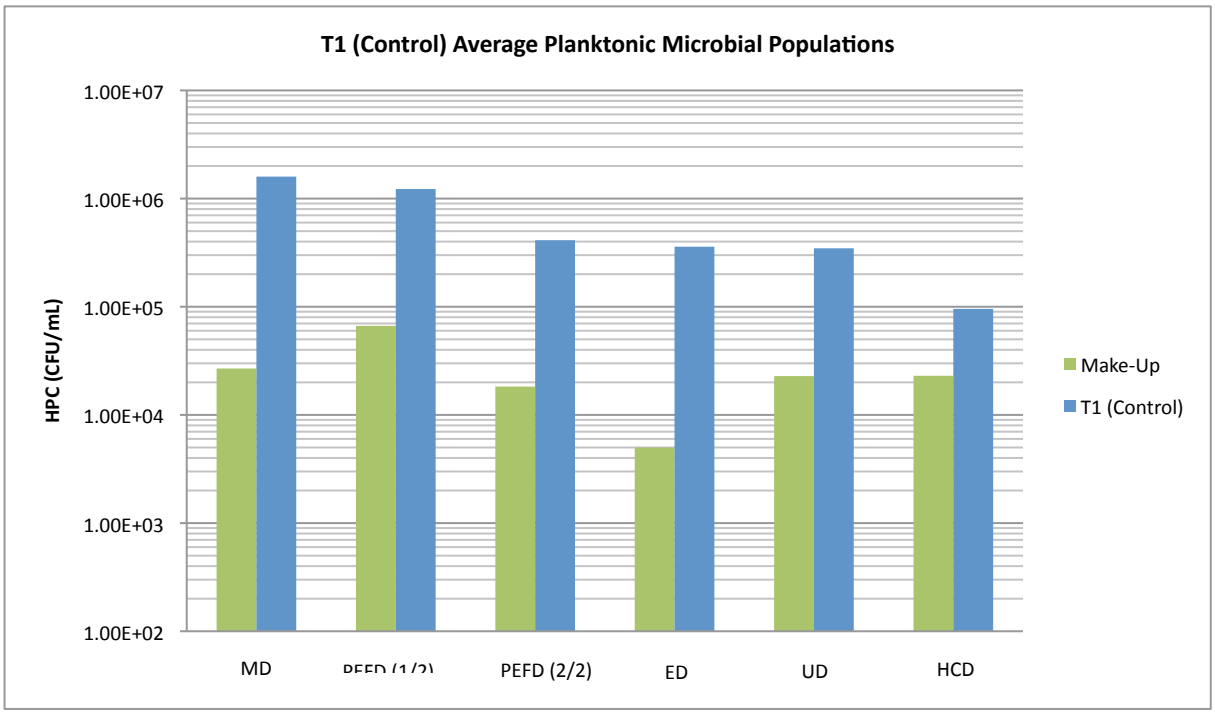

Figure 2 – T1 (Control) average planktonic microbial populations for each device trial

An average sessile heterotrophic plate count of 2.6 x 10^6 CFU/cm^2 was observed for T1 (Control) for the entire investigation.

FIELD SURVEY

Water treatment professionals were asked to submit water samples for Legionella and HPC testing from cooling towers that were treated with non-chemical devices. They were asked to complete a survey form that indicated the type of device being used and whether chemical biocides were also in use. They were requested to submit a sample from a chemically treated tower in the same vicinity for comparison.

RESULTS AND DISCUSSION

CHEMICAL AND OPERATIONAL DATA

Detailed analysis of the chemical and operational data collected during the investigation of the five (5) non-chemical devices can be obtained from our report submitted to the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) report RP-1361. [3]

Legionella RESULTS

Legionella species were isolated from both the bulk water and biofilm samples during each device trial (Tables 3 and 4). When detected, the concentration in the bulk water ranged from 20 - >6000 colony forming units(CFU) per milliliter. *Legionella* species isolated included *L. pneumophila* serogroups 1, 5 and 6 and non-pneumophila species. There was no significant difference in recovery between the control tower and device towers with respect to *Legionella* or heterotrophic plate count bacteria during any of the device trials.

HPC RESULTS

Analysis of the HPC data collected during the evaluation of all of the non-chemical devices indicated no significant difference in planktonic or sessile (biofilm) populations between the control tower (T1) and the device tower (T2). Based on the results of statistical analysis (the paired t-test), there was no significant difference in planktonic heterotrophic plate counts between T1 (Control) and T2 (Device) for any of the trials. These results are presented in detail in the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) report RP-1361. [3]