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Use of RF electric fields for simultaneous mineral and bio-fouling control in a heat exchanger☆

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ABSTRACT

The objective of the present study was to investigate the effectiveness of a physical water treatment (PWT) technology using oscillating RF (radio frequency) electric fields in water to mitigate both mineral and bio-fouling in a cooling water application. Heat transfer tests were conducted using a laboratory-scale cooling tower to determine fouling resistance over time, and bio-fouling tests were performed using a heterotrophic plate count method to measure colony forming units (CFU) values per milliliter of cooling water. The results indicated that the present PWT technology could provide an effective mineral fouling prevention by maintaining 90% of the peak heat transfer performance of a heat exchanger, while effectively controlling water-borne microbial organisms.

1. Introduction

Cooling-water systems are used throughout residential, commercial and industrial buildings. One of the drawbacks of water-cooling systems however is that mineral and bio-fouling tend to develop on and around heat transfer surfaces, which significantly reduces overall heat exchanger performance and increases the operational costs. It is therefore essential to prevent or control both mineral and bio-fouling on and around heat transfer surfaces. Currently, industry-standard practices for preventing mineral and bio-fouling call for the addition of scale-inhibiting chemicals and biocides to circulating cooling water [1,2]. The use of such chemicals contributes to fresh water pollution, a major environmental concern. Several physical water treatment (PWT) methods [3–11] have been introduced in recent years as alternatives to standard chemical water treatment; some of the best results have been documented using solenoid-type PWT technologies using oscillating fields. However, these PWT methods produce relatively weak oscillating magnetic and/or electrical fields due to limitations governed by the laws of physics [12]. Moreover, the effectiveness of such methods on bio-fouling control has not been clearly demonstrated.

The present study introduces a new PWT technology that utilizes two graphite electrode plates immersed in water at a cooling tower sump, applying RF electric fields directly in cooling water, rather than indirectly by means of a solenoid mechanism. The study examines the performance of the new PWT technology for both mineral- and bio-fouling controls. By applying RF electric fields directly in water, it was possible to vary both the strength and frequency of the electric fields over a wide range.

When circulating cooling water is exposed to the RF electric fields, particles of calcium salts have been shown to be produced in the water through the bulk precipitation mechanism [5,8]. Accordingly, the suspended particles tend to form particulate fouling rather than precipitation fouling. In cooling water applications, the particulate fouling often results in soft sludge coating on condenser tubes that can be easily removed by the flow velocity of moving water, thus preventing mineral fouling on the tubes. Previously, microbes have also been reported to be killed by pulse electric fields of in the MHz frequency range [13].

The objective of the present study was to investigate the efficacy of the present PWT method using RF electric fields in water on the prevention of both mineral and bio-fouling in a heat exchanger.

2. Experimental facility and method

The effectiveness of a new PWT technology using RF electric fields was studied in a heat-transfer fouling test (HTFT) setup with a laboratory-scale cooling tower. Fig. 1 shows the test facility, which consisted of a water circulating loop, the new PWT device (i.e., two electrode plates at the tower sump and a control unit), a cooling tower, a pump, a HTFT setup, a conductivity meter, and a floating-ball valve for make-up water. The HTFT system consisted of a water heater and a heat exchanger test section where scale accumulation took place on a copper tube surface. In addition, the HTFT system was equipped with a transparent outer shell through which the fouling process was monitored using a digital camera by directly observing the scale deposition during the fouling test. The HTFT system was also equipped with four temperature sensors for determination of the

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Nomenclature

A_o	outside surface area of copper tube (m^2)
$\dot{m}$	mass flow rate of water (kg/s)
Q	heat transfer rate (W)
R_f	fouling resistance (m^2K/W)
T_i	inlet temperature (°C)
T_i	outlet temperature (°C)
ΔT_{LMTD}	log-mean-temperature difference (°C)
U	overall heat transfer coefficient (W/m^2K)

Subscripts

c	cold side
f	fouled state
h	hot side
i	initial clean state
o	outside

overall heat transfer coefficient. The HTFT system measured and recorded temperature data to a PC via a thermocouple data acquisition board. This HTFT setup is a variant of a cooling water testing facility that was originally developed by research funded by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) and has been used in numerous scholarly scientific research protocols [3–5,8–10].

In the present study, no blowdown was used to accelerate fouling process. Natural well-water in Phoenixville, Pennsylvania, having an initial conductivity of 445 μmhos/cm, was used without artificially hardening the water by adding calcium carbonate. A heterotrophic plate count method [14] was used to determine CFU (colony forming unit) values for both the baseline and PWT-treatment cases. The baseline test was executed to establish a performance basis for comparing the efficacy of the new PWT technology.

2.1. Physical water treatment using RF electric fields

The present PWT technology included a power supply and two graphite plates (i.e., an anode and a cathode) to generate RF electric fields directly in water. The oscillating current was applied to water via two inert graphite electrodes to produce RF electric fields in the water. The power supply with a maximum voltage of 20 V had the frequency and current strength of 3.5 MHz and 600 mA, respectively.

Fig. 2 shows a detailed sketch of the arrangement of two graphite electrodes in the cooling tower sump, where the two electrodes were vertically positioned inside a circular PVC cylinder. The inset in Fig. 1 shows the photograph of two electrodes mounted inside the circular cylinder. Cooling water collected at the bottom of the sump entered through a hole made on the side wall of the PVC cylinder such that the cooling water would enter at the space between the two electrodes and leave through an exit tube located near the bottom of the PVC cylinder. Thus, the cooling water was forced to flow through the gap between the two electrodes for continuous treatment by the RF electric field. Two identical graphite plates were used for the electrodes with a height of 15.24 cm, a width of 7.62 cm and a thickness of 0.635 cm. The gap distance between the two electrode plates was 2.54 cm. The top portions of the two electrodes protruded above water level as shown in Fig. 2 such that the connecting electric wires stayed above water level to avoid electrical leakage as well as electrolysis.

2.2. Mineral and bio-fouling tests

Mineral and bio-fouling tests were conducted simultaneously to determine whether or not the RF electric field could mitigate mineral fouling and at the same time neutralize water-borne bacteria for the prevention of bio-fouling on a heat transfer surface. Threshold bio-count levels of less than 10,000 CFU/mL in bulk water and 100,000 CFU/mL in a sessile water sample [15], which are below the standard guidelines suggested by the Cooling Technology Institute, were used to test whether or not the RF electric field produced by the new PWT technology provided bio-control. After the completion of each test, the system was cleaned with chlorination and rinsed using tap water for the next test.

The flow rate of cooling water was maintained constant at 0.45 m^3/h (i.e., 2 gpm). This was equivalent to a cooling water velocity at the heat transfer test section of 1.1 m/s (Re = 5250). Table 1 shows the equations used for the reduction of heat transfer data in the present study. The fouling resistance was determined by first calculating the heat transfer rates at both the hot and cold sides in the heat exchanger (Eqs. 1 and 2), and then solving for the overall heat transfer coefficient U (Eq. 3) with the help of ΔT_{LMTD} given in Eq. (4). The fouling resistance was determined from the difference in the U values at the

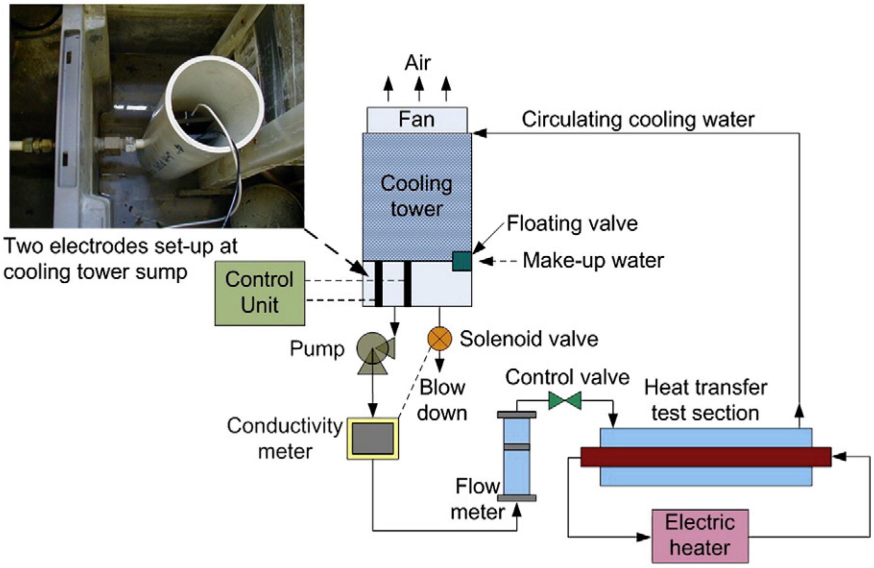

Fig. 1. Sketch of a heat transfer fouling test (HTFT) system.