



Physical water treatment using RF electric fields for the mitigation of CaCO₃ fouling in cooling water

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ABSTRACT

The present study investigated the feasibility of RF electrical fields in mitigating CaCO₃ fouling in cooling water. Three different voltages and two frequencies were used for the RF electric fields produced directly in water with varying cold-side velocity. Artificial hard water was used. Fouling resistances for the PWT-treated cases decreased by 34–88% from the values for no-treatment cases, depending on the cold-side flow velocity. The results showed blunt crystal structures for the PWT-treated cases, while no-treatment cases had sharp and pointed crystal structures. The new PWT method using RF electric fields presents a valid tool to mitigate CaCO₃ fouling in cooling water.

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1. Introduction

Scale formation on heat transfer surfaces of heat exchangers presents a critical concern in industrial operation and maintenance. The scale formation is commonly called as mineral fouling. Circulating water in a cooling tower contains excessive mineral ions especially calcium and magnesium ions as the evaporation of pure water is the primary mode of heat rejection, leaving those mineral ions behind. In particular, calcium ions reacting with carbonate ions in water form layers of CaCO₃ deposit on heat transfer surfaces, decreasing the efficiency of heat exchangers because of the insulating effect of the deposits. Furthermore, the formed deposits reduce the flow area, thus requiring more pumping power to achieve the flowrate of water corresponding to the clean state [1–7]. A 0.8-mm layer of CaCO₃ scale can increase the energy use by about 10% [8]. Steinhagen et al. [9] showed in a New Zealand survey that 90% of heat exchangers had fouling problems. If one can lessen or completely eradicate fouling on heat transfer surfaces, this not only increases heat exchanger efficiency, but also reduces the expenses associated with cleaning of fouled heat exchangers. Furthermore, as the fouling can be mitigated, the cycles of concentration (COC) can be increased, resulting in water savings by reduced make-up and blowdown [7,10–15].

Calcium carbonate is one of the most common scales found in cooling-water applications. It exists in three crystal phases but

the two most common are aragonite and calcite. Aragonite has a specific gravity of 2.95 while calcite has 2.71. The orthorhombic-shaped and denser aragonite tends to be more adherent to heat transfer surfaces than the hexagonal-shaped calcite [6,16]. The chemical reaction for the precipitation of CaCO₃ is found in the literature [3,4,16].

There are several methods to help lessen, control, or prevent the scaling of heat exchangers, which can be primarily divided into two: chemical and non-chemical methods. In the past, the use of scale-inhibiting chemicals like chlorine and brominated compounds was the best choice for the control of mineral fouling. Although it had a high success rate, there were also many disadvantages and concerns in their use. Aside from the high cost of chemicals, more stringent environmental laws increased the costs associated with their storage, handling and disposal. These chemicals or accumulated chemical residues over a long period of time also pose concern to the environment with accidental spills. Thus, there is a need for a new approach that is safe and clean from both environmental and cost points of view in the maintenance of heat exchangers [3,5,8,11,13].

Physical water treatment (PWT) is a non-chemical method to mitigate mineral fouling with the use of electric or magnetic fields, catalytic surfaces, ultrasounds, or sudden pressure changes. Numerous studies have been reported for the effectiveness of the use of permanent magnets [3,4,8,11,17–20], solenoid coils [3,4,8,21–24], catalytic materials like copper, zinc [25,26], and titanium [16], and ultrasounds [10]. In this paper, RF (radio frequency) electric fields generated between two graphite electrode plates

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Nomenclature

A_o	outer surface area of copper tube (m^2)
c_p	specific heat of water ($J/kg\ K$)
d	diameter of copper tube (m)
D	diameter of quartz crystal (m)
f	frequency (Hz)
H	height (m)
L	length (m)
M_w	molecular weight (g/mol)
Q	heat transfer rate (W)
R_f	fouling resistance ($m^2\ K/W$)
ΔT_{LMTD}	log-mean-temperature difference ($^{\circ}C$)
U	overall heat transfer coefficient ($W/m^2\ K$)
W	width (m)

Greek symbol	
θ	diffraction angle ($^{\circ}$)

Subscripts	
c	cold side
f	fouled state
i	initial clean state
i	inner
o	outer
q	quartz crystal
t	tube (copper)

directly in water were used to mitigate mineral fouling in a double-pipe heat exchanger. The new method of using RF electric fields directly in water is a major improvement over the above-mentioned PWT methods because these previous PWT methods produce induced electric fields in water so that the field strength is often very small ($\sim 1\ mV/cm$) and the maximum frequency of the field is limited to approximately 2 kHz due to involved physics laws such as Faraday's law [3,4].

1.1. Objectives

Calcium carbonate fouling is a rampant occurrence for cooling-tower applications. Thus, the present study simulated $CaCO_3$ fouling by preparing artificial hard water through mixing of an appropriate amount of $NaHCO_3$ and $CaCl_2$ powders into a 150-L tank to obtain the desired water hardness. The present study used RF electric fields between two graphite electrode plates positioned parallel to each other at three different voltages (2, 5, and 13 V) and two different frequencies (13.56 and 27.12 MHz). The objective of the present study was to investigate the feasibility of RF electric fields in mitigating $CaCO_3$ fouling in heat exchangers. The specific aims of the present study were to determine the values of voltage and frequency of the RF electric fields that would provide the best results for $CaCO_3$ fouling mitigation, and to investigate the effects of water hardness and flow velocity on the efficacy of the RF electric fields in mitigating $CaCO_3$ fouling at the optimum voltage and frequency.

2. Experimental method

The schematic diagram of the experimental system is shown in Fig. 1. It was composed of a hard water tank, a centrifugal pump, a

rotary flow meter, a two-graphite system to produce RF electric fields, a heat transfer test section, a chiller, a hot water circulating bath, a LabView device, and a personal computer. The hard water tank with a cover was made of plastic with a maximum capacity of 200 L. Inside the tank was a copper coil connected to a chiller to maintain a constant temperature of the hard water during the tests. The centrifugal pump was controlled by an inverter to control the desired flow rate together with the rotary flow meter. The pump in the hot water re-circulating bath was also controlled by an inverter. The flow circulation loop was composed of copper tubes, expandable hoses, and heat-resistant Teflon tubes.

2.1. Calibration of RTD

Four RTD temperature sensors were used to measure the temperatures at the inlet and outlet of the heat transfer test section. The RTD sensors were mounted using a T-shaped compression fitting. The RTDs were calibrated using a temperature calibration block bath and a precision thermometer with an accuracy of $\pm 0.01\ ^{\circ}C$ as the reference together with the LabView Measurement and Automation Explorer (MAX Ver. 4.00) calibration system.

2.2. Preparation for fouling test and heat exchanger efficiency

Before each test, the heat transfer test section was tested for leakage. After ensuring that there was no leakage in the test section, the efficiency of the heat exchanger was tested. Both hot and cold water were kept at constant inlet temperatures of 85.5 ± 0.5 and $23.5 \pm 0.5\ ^{\circ}C$, respectively. The heat transfer test section was covered with a Styrofoam insulation to minimize any heat loss to the surroundings. The RTDs were also covered with Styrofoam to prevent any heat transfer from the surroundings that

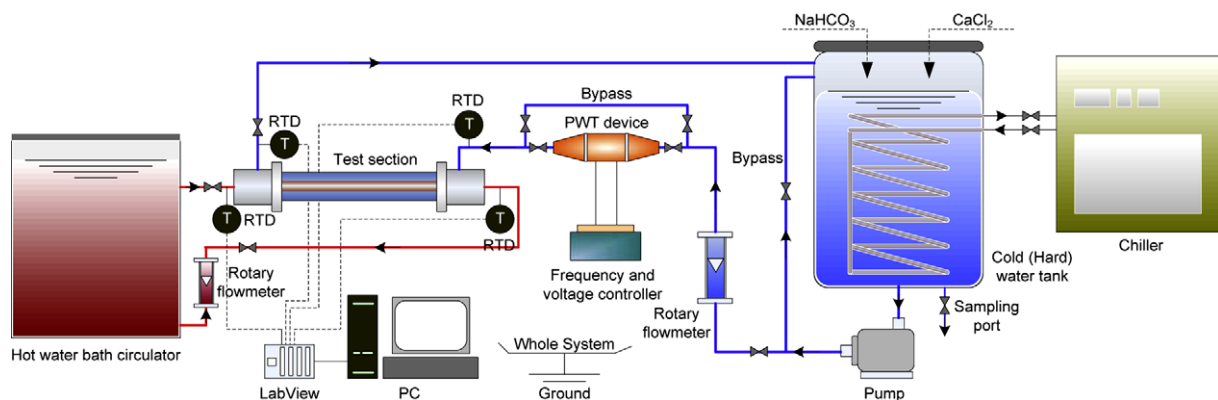


Fig. 1. Schematic diagram of the present experimental set-up.

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