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Performance assessment of oxidants as a biocide for biofouling control in industrial seawater cooling towers

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ABSTRACT

Biofouling can significantly hamper the efficiency of seawater cooling towers. The aim of this study was to investigate the effectiveness of alternative oxidants (i.e. ozone (O_3) and chlorine dioxide (ClO_2)) comparing with commonly being used chlorine in biofouling control. Effects of cycle of concentration, temperature and oxidant dosage along with residual decay and kinetics were studied. Even at lower oxidant dosage (total residual oxidant equivalent = 0.1 mg/l Cl_2), ClO_2 showed a better disinfection effect compared to chlorine and O_3. Results of bench-scale studies will be helpful in the selection of appropriate oxidant for seawater cooling tower operation.
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Introduction

The use of seawater as an alternative make-up water in cooling tower systems has rapidly increased over last decades, especially in the Gulf Cooperating Council (GCC) countries. Conventional seawater cooling has been achieved using a once through cooling system in process industries, removing process heat via heat exchangers and discharging back into the sea [1]. However, such systems have suffered from high pumping costs and ambient-dependent seawater temperature. Recycling cooling systems offer better solutions because of much lower flow rates required, primarily higher potential effect from evaporation, as well as minimizing thermal pollution of coastal waters [2–5]. Seawater cooling towers have faced more challenges compared to systems using freshwater, particularly due to high scaling and fouling potentials caused by higher dissolved cations and anions present in seawater [6]. Moreover, organic and inorganic contents in seawater fed to cooling towers make them prone to corrosion and biofouling [7]. Biofouling (i.e. biofilm formation/growth) and scaling in cooling tower pipes, basin and heat exchangers can also lead to significant reduction in heat transfer efficiencies [8,9]. A previous report shows that annual maintenance costs of undesired scaling and fouling of cooling towers can be up to billions of dollars [4]. In addition, disinfection is needed to inactivate and control the potential growth of pathogenic organisms [10], as microbial communities thrive in cooling towers due to the warmer water temperatures and excessive nutrients in the tower basins [11].

Chlorination is one of the well-known biofouling control methods and commonly being applied in many places. However, an excessive chlorination may cause the formation of harmful disinfection byproducts (DBPs), where 1% dosage of chlorine in the cooling tower systems can react to form trihalomethanes, haloacetate-trails, halocarbons, halophenols and haloacetic acids [12]. Although a continuous chlorine dosage of 0.2 mg/l suppresses mussels growth in seawater [13], it also results in DBPs formation which is a major environmental concern [14,15]. Trihalomethanes (THM) formation can be reduced in the cooling tower by targeting appropriate dose of chlorination at certain times [16].

Ozone (O_3) has been used as an oxidant for drinking water disinfectant since the late 1800s [17]. O_3 is known to be a highly efficient disinfectant in drinking water, with a reactivity level up to 300 times greater than chlorine at the same dosage concentration [18]. However, there is limited information in the literature concerning fouling control with O_3 in seawater intake pipes. Sugita

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et al. claimed that a residual O_3 equivalent of 1.0 mg/l of total residual oxidant (TRO) was sufficient to disinfect seawater for marine culture [19]. A study indicated that a high O_3 dosage of 5 mg/l, applied less than 5 min per day, was a sufficient disinfection interval to keep the surfaces of titanium, aluminum, brass and epoxy coated PVC cooling tubes clean [20]. The O_3 chemistry in seawater is significantly different than that in freshwater because of the presence of bromide [21]. Chlorine dioxide (ClO_2) is an alternative oxidant that has been used for microbial control in seawater and drinking water disinfection [22–24]. Yu et al. reported an increasing use of ClO_2 as disinfectant in distillation plants in the Gulf region, particularly in the UAE [24]. The effectiveness of ClO_2 can be similar to chlorine but applied at lower dosage concentrations. Key advantages compared to chlorine are; (i) less contact time and (ii) good solubility in water. In addition, ClO_2 does not react with bromides to form hypobromites and is more efficient at higher temperatures and pH [25,26]. For these reasons, ClO_2 is currently used as a disinfectant in many applications; dairy, fruit and vegetable, poultry, food, potable water treatment and industrial waste treatment [15]. Disinfection of oysters with ClO_2 can extend the shelf life up to 12 days. Due to its lower reactivity with organic matter [27], it has been reported that THM formation in ClO_2 treatment is lower compared to chlorine, however, it is less favored in drinking water treatment due to the potential of harmful DBPs formation, as well as problems with taste and odor. Furthermore, it is known that ClO_2 is less efficient against protozoa like Cryptosporidium.

As mentioned earlier, the research was initiated in addressing several industrial seawater cooling tower facilities' issues in Middle East countries (i.e. Saudi Arabia) where are using sodium hypochlorite (i.e., chlorine) generation systems in controlling the biofouling and microbial fouling. Recently, the environmental regulation of TRO at seawater cooling tower discharge has been lowered to 0.2 mg/l. This change affects the performance of the chlorination in the biofouling control in the cooling towers. The goal of this research, therefore, is to find alternative chemical disinfect to meet the environmental regulation (0.2 mg/l of TRO at discharge) with high performance of biofouling control.

In this regard, the study was started with two alternative oxidants; O_3 and ClO_2 comparing with an existing disinfectant type, sodium hypochlorite and to assess their performances in seawater cooling towers for biofouling mitigation and control. The results shows the comparison between the three oxidants revealed that chlorine dioxide performed the best (in terms of TRO) compared to chlorine and ozone, which is one of key important findings.

Methodology

Bench scale setup

A laboratory bench-scale study was carried out to assess various key factors in seawater cooling tower operation. The customized batch reactor is mainly made of glass with inlet and outlet of hot water, temperature probe, oxidant injection, and operated by using real seawater, same as the cooling tower feed (Fig. 1). The batch reactor was placed on a magnetic stirrer to ensure completely mixed conditions. The bench-scale studies were conducted in theoretical steady-state conditions for a full-scale plant as shown in Fig. 2. The customized batch reactor was designed to investigate three parameters; effects of cycle of concentration, temperature and oxidant dosage along with residual decay and kinetics that might improve the feed seawater quality. This lab scale design is not to simulate the pilot cooling tower design, rather to study the above parameters that affecting the operational conditions of the cooling tower to improve the pretreatment efficacy.

Tests were conducted at two temperatures (e.g. 32 °C for inlet seawater, and 48 °C for outlet seawater) to emulate the cooling

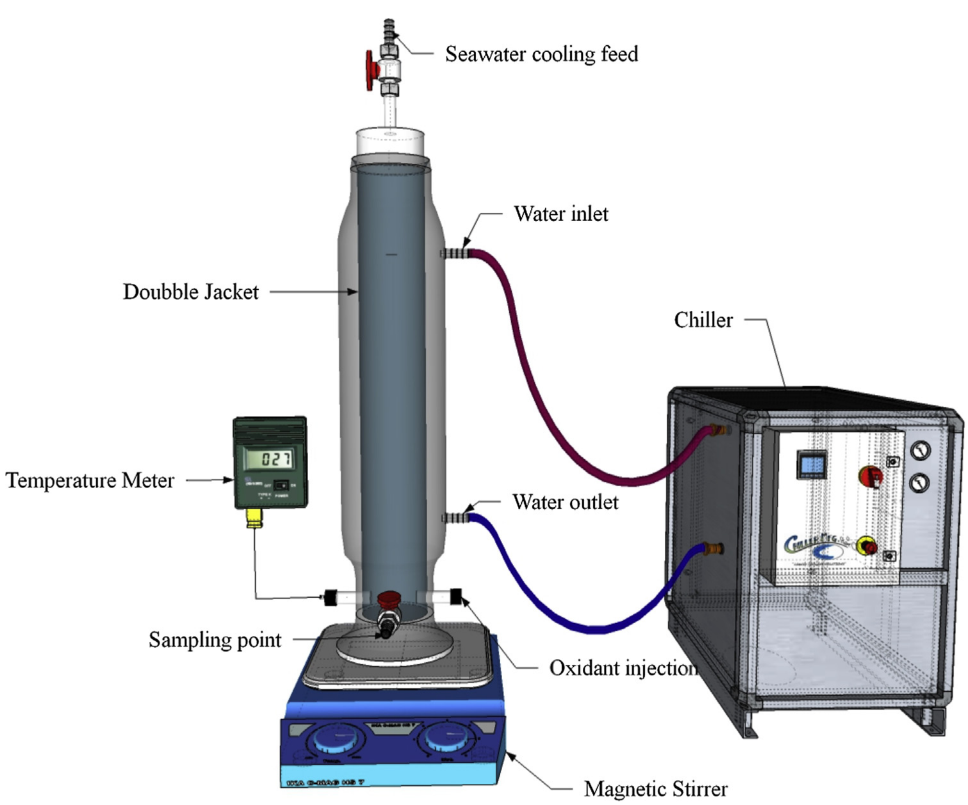

Fig. 1. Double jacket bench reactor for decay tests.

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