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Mineral scaling mitigation in cooling systems using tertiary-treated municipal wastewater

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ABSTRACT

Treated municipal wastewater (MWW) is recognized as a significant potential source of cooling water for power generation. One of the key challenges for the successful use of the effluent from wastewater treatment facilities for cooling is the potential for significant mineral scaling when the raw water is concentrated as much as 4–6 times in recirculating cooling systems. Previous bench- and pilot-scale tests have shown that commonly used phosphorus- and polymer- based scaling inhibitors are ineffective when secondary-treated municipal wastewater (MWW) is used as make-up. In this study, two types of tertiary-treated municipal wastewaters, namely secondary-treated MWW with pH adjustment (MWW_pH) and secondary-treated MWW subjected to nitrification and sand filtration (MWW_NF) were evaluated as the sole source of make-up water for recirculating cooling systems. Both laboratory studies and pilot-scale tests revealed that adjusting the pH to 7.8 could reduce the mineral scaling rate by more than 80% without causing any significant corrosion problems. In contrast to MWW, where calcium carbonate was the dominant scaling mineral, the main component of mineral scale in MWW_pH was calcium phosphate. Both static and dynamic bench-scale tests indicated that scaling would not be a significant concern when MWW_NF is used as the make-up water in recirculating cooling systems operated at 4–6 cycles of concentration (CoC). Extended pilot-scale studies confirmed that MWW_NF is suitable makeup water for power plant cooling systems and that no anti-scaling chemicals would be required.

1. Introduction

Treated municipal wastewater (MWW) is a promising candidate to replace freshwater for power plant cooling due to its widespread availability and consistent quality (Li et al., 2011a; EPRI, 2008). Because thermoelectric power generation is among the largest water users in the U.S. (Kenny et al., 2009), the reclamation of MWW in cooling systems represents a viable, long-term solution to the challenges presented by growing municipal, industrial, and agricultural demands for water. Power plant cooling demands large quantities of relatively low quality water when compared to other uses of water. Use of treated MWW as make-up water for cooling in power plants has been in full-scale operation for several decades (Ehrhardt et al., 1986). However, these power plants typically use treated MWW only as a fraction of the total makeup water needed or only after significant additional treatment before addition to the recirculating cooling systems (Wijesinghe et al., 1996; Li et al., 2011a). Few studies have focused on the feasibility of using treated MWW as the dominant makeup water with or without additional prior treatment.

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Secondary treatment is the most common method for municipal wastewater treatment in the U.S. Secondary-treated MWW is characterized by low to moderate content of total suspended solids (TSS) and organic matter, but moderate to high content of dissolved solids, alkalinity, and hardness. Under typical recirculating cooling conditions (i.e., elevated temperature and evaporative loss of water), a significant concern when using secondary MWW is the potential for severe mineral scaling. Among methods used to prevent scale formation and deposition, antiscalants have been proven effective when traditional water source (i.e., freshwater) was employed in cooling systems (Shakkthivel and Vasudevan, 2006; Moudgil et al., 2009). However, their effectiveness can be seriously compromised when secondary-treated MWW is used instead. Among common antiscalants, phosphate- or phosphonate- based agents could react with calcium ions to form insoluble precipitates and exacerbate the scaling problem, especially in concentrated MWW with high concentration of calcium and phosphate (Selby et al., 1996; Zhang et al., 2010). In a previous study by Li et al. (2011b), carboxylic polymers, like polymaleic acid (PMA), have been shown to significantly reduce scaling in bench-scale tests with synthetic secondary-treated MWW. However, these antiscalants were not as effective during extended pilot-scale tests with secondary-treated MWW. Therefore, development and demonstration of effective scaling control approaches are needed for treated MWW to advance the reuse of this water source for power plant cooling.

Previous studies have shown that the major mineral scales formed in recirculating cooling systems using secondary-treated MWW as make-up water are calcium carbonate and to a lesser extent calcium phosphate (Li et al., 2011b). Chemical species distribution for these precipitation reactions is highly dependent on the solution pH. It is reasonable to assume that lowering the solution pH should lower the formation of the inorganic precipitates by lowering alkalinity and thus lowering the driving force for scale formation. However, concerns like enhanced corrosion rates would arise at lower pH (Troup and Richardson, 1978; Hsieh et al., 2010). Although the impact of pH reduction on scaling control is well known, proper acid dosing and the combined effects of acid addition and other chemical treatment programs, such as antiscalants, corrosion inhibitors and biocides, in cooling systems using tertiary-treated MWW have not been investigated before.

It has been reported that the ammonia concentration in the secondary-treated MWW can be as high as 10–30 mg N/L (Selby et al., 1996). Biological nitrification processes for ammonia removal have been adopted by many wastewater treatment plants faced with more stringent requirement (Office of Water Programs at California State University Sacramento, 2009). From the prospective of mineral scaling control, tertiary treatment of the MWW by nitrification would depress the pH and alkalinity and thus reduce the scaling propensity in recirculating cooling systems (Metcalf and Eddy, 2004). There are currently no studies that offer guidance on the scaling behavior of tertiary-treated MWW when used as make-up water in recirculating cooling systems. In addition, there is no information about suitable scaling control methods that are demonstrated under relevant process conditions.

The focus of this study was on mineral deposition on pipes and tower packing at bulk water conditions when tertiary-treated MWW is used as the sole make-up water. Types of tertiary treatment considered were pH adjustment (MWW_pH) and nitrification followed by filtration (MWW_NF). Batch tests and bench-scale recirculating system studies were conducted to determine the desired pH range and the synergism between pH adjustment and antiscalant addition on scaling mitigation when using MWW_pH as make-up water in recirculating cooling systems. In addition, the precipitation and deposition potential of secondary-treated MWW subjected to nitrification and sand filtration (MWW_NF) was also studied under well-controlled laboratory conditions. Pilot-scale cooling tower tests were then conducted to evaluate the applicability of selected scaling mitigation strategies in the field and to test their compatibility with corrosion and biofouling control methods in the integrated chemical regimen for tertiary-treated MWW reuse in recirculating cooling systems.

2. Materials and methods

2.1. *Secondary and tertiary-treated MWW*

Secondary-treated MWW (biological trickling filter followed by secondary clarification) from Franklin Township Sanitary Authority, Murrysville, PA, was used in pilot-scale tests and as a model for typical secondary-treated municipal effluent (Metcalf and Eddy, 2004). Key characteristics of this water and the tertiary-treated MWW_NF water (secondary treatment followed by nitrification and sand filtration) from the same wastewater treatment facility are shown in Table 1.

Typical operation of a recirculating cooling system will concentrate the feed water as much as 4–6 times due to evaporative losses in the system. A synthetic wastewater (Table 2) was prepared to represent secondary-treated MWW at 4 cycles of concentration (CoC 4) in terms of its mineral content for detailed investigation in laboratory tests (Li et al., 2011b). Chemical composition of synthetic MWW_NF at CoC 4 for laboratory studies is also shown in Table 2. Both synthetic waters were prepared based on the characteristics of the actual wastewaters shown in Table 1.

2.2. *Laboratory experimental systems*

Precipitation behavior of MWW_pH at CoC 4 was first studied in a 1.4 L beaker covered with plastic wrap to minimize water loss due to evaporation. The contents in the beaker were completely mixed with a magnetic stirrer and the bulk temperature was controlled at 40 °C (typical bulk temperature of power plant recirculating cooling water) using the heating plate. The experiments were always initiated by adding all the salts listed in Table 2 except for $CaCl_2$. For the tests intended to study the impact of pH on precipitation behavior of MWW_pH at CoC 4, the solution pH was then lowered to 6.8 with 0.5 M hydrochloric acid (previous tests have shown that there will be no immediate bulk precipitation at pH 6.8) followed by the addition of $CaCl_2$. pH of the synthetic solution was then adjusted and maintained at a desired pH with 0.5 M