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Resilience of SBR Activated Sludge System against the Presence of Engineered Iron-Oxide Nanoparticles

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Abstract. Lab-scale sequencing batch reactors (SBR) were tested for their resilience against the presence of engineered iron-oxide nanoparticles coated with a surfactant ($ENP_{Fe\text{-}surf}$) at 29.6 mg/L as soluble Fe. Impacts of the presence of $ENP_{Fe\text{-}surf}$ during SBR operation were tested at two different SBR contact times (3 or 6 hrs) with respect to physiochemical effluent water quality parameters. Results indicated that 7.8% of the dosed $ENP_{Fe\text{-}surf}$ were present in the effluent from the SBR run at 3 hrs of contact time, whereas 9.2% were from the SBR run at 6 hrs of contact time. $ENP_{Fe\text{-}surf}$ did not produce toxic effect on SBR mixed liquors, showing resilience of SBR activated sludge against $ENP_{Fe\text{-}surf}$. Rather the oxygen uptake rates of mixed liquors were slightly enhanced in the presence of $ENP_{Fe\text{-}surf}$. Nevertheless, those $ENP_{Fe\text{-}surf}$ fractions in the effluent caused increased in turbidity, chemical oxygen demand, and biological oxygen demand.

Keywords: Effluent Water Quality, Engineered Nanoparticles, Sequencing Batch Reactor

1. Introduction

Wastewater treatment plants can play an important role in fate and transport of ENPs as the main receptor of used ENPs in industrial applications and household commodities [1-3]. Stable ENPs present in the treated effluent will be released to the aquatic environment, whereas ENPs incorporated in wastewater sludge may affect terrestrial environment once disposed of [4]. In addition, the presence of ENPs itself may negatively affect wastewater treatment processes leading to deterioration of effluent water quality.

Despite widespread applications of magnetic nanoparticles [5] and their potential occurrence in environmental receptors [6], limited studies have been conducted to assess their fate and impact on biological wastewater treatment. In a previous study [7], it was found that ~8.7% of engineered iron oxide nanoparticles coated with surfactants ($ENP_{Fe\text{-}surf}$) initially dosed at 1.5 mL per L of mixed liquor were present in the effluent stream from a lab-scale sequencing batch reactor (SBR). Consequently, aqueous $ENP_{Fe\text{-}surf}$ deteriorated the effluent water quality at a statistically significant level ($p<0.05$) with respect to soluble chemical oxygen demand (SCOD), turbidity, and apparent color [7]. The current research further expanded the previous study with SBR operations at two different cycles (4 and 7 hrs) at a lower $ENP_{Fe\text{-}surf}$ dosage of 0.5 mL per L of mixed liquor.

2. Materials and Method

2.1. Nanoparticles and Wastewater

Commercially available iron oxide nanoparticles (Ferrotec MSG W11) coated with proprietary surfactants were used as the model ENP. The main characteristics are as follows: magnetite 2.8-3.5, surfactant 2-4 and water 92.5-95.2 (% vol.); nominal particle diameter 10 nm; density 1.17 g/mL; pH 10.

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Total soluble iron (Fe) content was determined to be 59.3 mg Fe per L of $ENP_{Fe\text{-}surf}$ according to the Phenanthroline Method [8].

Influent to the activated sludge system (influent, hereafter) and mixed liquor in the aeration tank were collected from a local wastewater treatment plant (Mayagüez, PR). The influent had SCOD, soluble biological oxygen demand (SBOD), suspended solids (SS), and pH of 144 ± 24 (n=7), 84 ± 31 (n=12), 49 ± 14 (n = 10), and 6.6 ± 0.1 (n = 5), respectively. The mixed liquor had mixed liquor suspended solids (MLSS), sludge volume index, and pH of 2,249 ± 849 (n = 8), 183 ± 19 (n = 2), and 6.4 ± 0.2 (n = 5), respectively.

2.2. Sequencing Batch Reactor

The Phipps & Bird 2000 ml B-Ker2® Lab Jars were used as lab-scale SBRs. Initially, SBRs were received 200 mL mixed liquor and 1,800 mL influent. SBRs were run at room temperature (25 ± 1 ^{o}C) and aeration was provided to maintain a dissolved oxygen concentration of ~5 mg/L during the "aeration" sequence. SBRs were run with a 4-hr cycle that consisted of a 3-hr aeration, a 0.5-hr sedimentation, and a 0.5-hr decant/refill, whereas those run with a 7-hr cycle had a 6-hr aeration, a 0.5-hr sedimentation, and a 0.5-hr decant/refill. Using a sidewall on the SBR, 67% of the supernatant were decanted during the "decant" sequence for analysis of effluent water qualities and the influent was added to the SBRs during the "refill" sequence.

A previous experiment [7] showed that the SBRs run with a 4-hr cycle, were stabilized after the 6th sequence, resulting in constant SCOD and SS concentrations in the effluent. In this regard, multiple SBRs were run in the same operating manner up to the 6th sequence with either a 4-hr or a 7-hr cycle but, from the 7th to 10th sequences, the treatment SBRs were received $ENP_{Fe\text{-}surf}$ dosage of 0.5 mL per L of MLSS. Control SBRs without $ENP_{Fe\text{-}surf}$ addition were also run in parallel.

2.3. Analysis

SBR effluents were analyzed for SCOD, SBOD, SS, were analyzed in accordance to the Standard Methods [8]. pH values were measured with an ion selective electrode connected to the Orion Model 720A pH meter. A HACH 2100P Turbidimeter was used for turbidity measurement. Apparent color was determined according to the HACH Method 8025. Hydrodynamic particle diameters were determined by dynamic light scattering (Brookhaven Instruments BI-90 Plus Particle Size Analyzer) with the autocorrelation function of the intensity fluctuation of the scattered light. Oxygen uptake rate (OUR) assays were run to assess the impact of $ENP_{Fe\text{-}surf}$ on mixed liquors respiration. OUR was determined through the slope of the linear portion of the DO versus time curve.

3. Results and Discussion

3.1. Effluent Water Quality

As shown in Fig. 1, turbidity, SCOD, soluble Fe, and mean hydrodynamic particle diameter were higher in the effluent of the SBRs dosed with $ENP_{Fe\text{-}surf}$ than those of the control SBR. SBOD concentration showed a similar trend to those of turbidity and SCOD. Deteriorated effluent water quality (i.e., higher turbidity, SCOD and SBOD) can be originated to possible toxic effects of $ENP_{Fe\text{-}surf}$ on the wastewater activated sludge (bacteria) or can be simply attributed to the presence of $ENP_{Fe\text{-}surf}$ in the effluent. However, the OUR experiment revealed that the presence of $ENP_{Fe\text{-}surf}$ did not exert toxic effects on activated sludge mixed liquor (Fig. 2). Rather, $ENP_{Fe\text{-}surf}$ slightly increased the OUR. In a separate experiment, an increase of COD was observed proportional to the amount of $ENP_{Fe\text{-}surf}$ added to DI water. Therefore, the increased SCOD concentrations in the treatment SBR effluent were attributed to COD exerted from the oxidation of both inorganic Fe and organic surfactants on $ENP_{Fe\text{-}surf}$. Perhaps, the increased SBOD was also due to the organic surfactants on $ENP_{Fe\text{-}surf}$.

3.2. Presence of $ENP_{Fe\text{-}surf}$ in Effluent

Soluble Fe concentrations and mean hydrodynamic particle diameter analysis (Fig. 1) revealed the physical presence of $ENP_{Fe\text{-}surf}$ in the SBR effluent. Mass balance on total soluble Fe concentrations in the treatment SBR effluent revealed that up to 7.8% wt. (on average) of the applied $ENP_{Fe\text{-}surf}$ were present in the effluent from the SBR run with 3 hrs of reaction. In comparison, 9.2% were present with 6 hrs of reaction.

Therefore, it is construed that $ENP_{Fe\text{-}surf}$ did not produce toxic effects on SBR activated sludge at an $ENP_{Fe\text{-}surf}$ dosage of 0.5 mL per L of mixed liquor, corresponding to 29.6 mg soluble Fe/L of mixed liquor. However, wastewater quality was deteriorated due to the physical presence of stable fractions of $ENP_{Fe\text{-}surf}$ in the effluent.

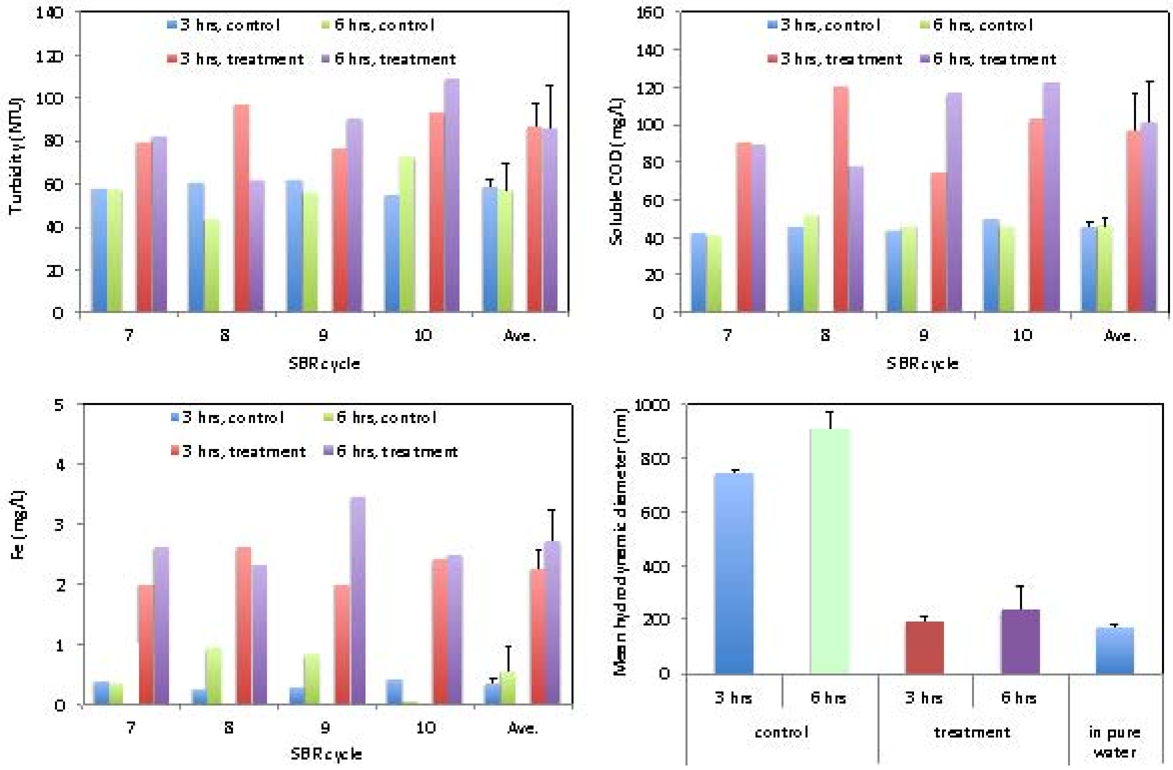

Fig. 1: Trend of physiochemical water quality parameters. “3 hrs” means a 3-hr reaction in the total 4-hr SBR cycle, whereas “6 hrs” means a 6-hr reaction in the total 7-hr SBR cycle.

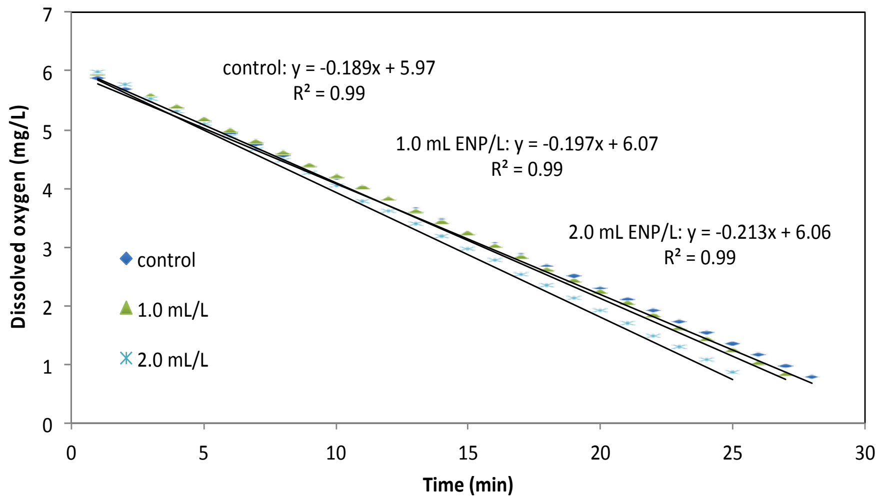

Fig. 2: Results from the oxygen uptake rate (OUR) experiment.

4. Acknowledgements

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