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Characterization of membrane foulants in a pilot-scale tunnel construction wastewater treatment process

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HIGHLIGHTS

- Tunnel construction wastewater was treated by a combined MF–RO process.
- This system produced water acceptable for reuse application of reclaimed wastewater.
- Characterization of membrane fouling could improve understanding of foulants.
- The main inorganic foulants on MF membrane consisted of Si, Al and Fe.
- Inorganic matter in the feed water required pretreatment to decrease fouling.

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ABSTRACT

A pilot-scale combination of a microfiltration (MF) and a reverse osmosis (RO) membrane system was applied on-site to treat tunnel construction wastewater. The MF membrane system initially removed contaminants (turbidity of less than 0.3 NTU) in the form of particulate materials in the feed water, thereby allowing the combined MF–RO system to efficiently remove more than 99% of known organic and inorganic contaminants and qualify the reclaimed water for reuse. The MF membrane autopsy analysis using X-ray fluorescence (XRF) and inductively coupled plasma-mass spectrometry (ICP-MS) revealed that the dominant foulants were inorganic deposits involving Si, Al and Fe, comprising the main components of cement materials, as well as deposits involving heavy metals such as Mn, Cu and Zn in the form of particles. Thus, thick cake contaminants shown by field emission scanning electron microscope (FE-SEM) images might be induced via suspended solids consisting of cement and clay materials and metals.

1. Introduction

The increase in population, expansion of industries and climate change all have contributed to the gradual depletion of usable water. Thus, wastewater reclamation and reuse is considered to be as an essential component of sustainable and integrated water resource management. It is particularly attractive in situations where the available water supply is already overcommitted and cannot meet expanding water demands in a growing community.

Wastewater targeted in this study was generated during tunnel construction such as tunneling excavation, draining and grouting to seal in water (Yi-Wen et al., 2012). Besides seepage or discharge of wastewater, chemical grouting agents may leak, releasing large amounts of chemicals into surrounding aquatic environments (Sverdrup et al., 2000). Although containing low concentrations of organic contaminants, tunnel construction wastewater is generally quite turbid, a result of high concentrations of suspended solids (SS) containing significant amounts of fine cement and sand (Yi-Wen et al., 2012; Lee et al., 2013). Coupling of physical–chemical methods such as coagulation–filtration has been widely used to treat quite turbid wastewater (Li et al., 2010; Yang et al., 2012), but its efficiency may not be satisfactory for reclaimed water reuse (Yi-Wen et al., 2012). In particular, since the tunnel

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construction site targeted was located in a coastal area, salinity in the generated wastewater posed an additional challenge with its concentration varying depending on the specific site of the excavation work.

Generally, a reverse osmosis (RO) membrane process is selected to remove dissolved ions such as salt as well as micropollutants (Chon et al., 2013; Hwang et al., 2013). Thus, an RO-based wastewater reclamation system was employed in this coastal site to regenerate the terminal discharge of tunnel construction wastewater into high-quality water for reuse with the dual aim of helping to extend available water supplies and reduce the contamination rate of the environment. One of the major issues in designing an RO-based wastewater reclamation system is minimizing membrane fouling (Hwang et al., 2013). Thus, adequate pretreatment is required to lower RO membrane fouling since this membrane is very sensitive to foulants such as colloids and inorganic scale (Xie et al., 2009; Kim et al., 2011). Recently, membrane-based pretreatment such as microfiltration (MF) has been preferred to achieve minimizing the potential for RO membrane fouling as well as producing high quality water (Hwang et al., 2013).

Although many studies of wastewater reclamation using membrane processes have been performed to investigate fouling mitigation and removal of water contaminants (Acero et al., 2012; Chon et al., 2013; Xiao et al., 2014), reclamation of tunnel construction wastewater having distinctive characteristics such as high concentrations of both SS and salinity has not yet been studied. In this study, a combined coagulation–filtration (C–F) and membrane (MF–RO) process was applied to treat tunnel construction wastewater for water reclamation and reuse. The primary objectives of this study are to: (1) evaluate the feasibility of a combined membrane (MF–RO) process through a pilot-scale investigation; (2) identify the fouling behavior and dominant fouling mechanisms of an MF membrane which complicate the pretreatment for an RO membrane.

2. Methods

2.1. Set-up and operation of a pilot-scale tunnel construction wastewater treatment process

A pilot-scale combined process, consisting of a coagulation process, a zeocarbon filtration, and MF and RO membranes, was designed and operated to reclaim tunnel construction wastewater (Fig. 1). The wastewater having an average salinity of 12.4‰ was generated at the rate of approximate 1000 m^3/day from an on-site, coastal area, Yeongdo, Busan, South Korea. The tunnel with a total length of 1480 m and a depth of 60 m below ground level was constructed to lay electrical power or telecommunication cables.

The coagulation process was sequentially arranged with two columns having a height of 2.0 m; an inside diameter of 0.45 m; an upflow velocity of 300 m/day and a hydraulic retention time (HRT) of approximately 20 min. Aluminum sulfate (7% Alum, $Al_2(SO4)_3$) as a coagulant was added with the optimal dosage of 20 mg/L determined by the Jar-test (data not shown). Coagulated particles and remaining contaminants passed through the filtration process having a bed depth of 1.0 m; a height of 2.0 m; an inside diameter of 0.2 m; a filtration velocity of 300 m/day and an HRT of approximately 20 min. An activated carbon charcoal and zeolite mixture, zeocarbon was selected as a filtering material, having a particle size of 8–20 mesh; a hardness of 99%; an apparent density of 0.75 g/cm^3; and a specific surface areas of 600 m^2/g.

Effluent which had passed through the C–F process was subsequently filtered with the spiral-wound type polypropylene MF membranes having a pore size of 0.5 μm (Woongjin Chemical Co. Ltd., Korea). Two MF modules were operated in dead-end mode; backwashing was performed with air stripping. Permeate from the MF membrane modules was further treated using spiral-wound polyamide type thin-film composite RO membranes (Woongin Chemial Co. Ltd., Korea) to remove micropollutants, heavy metals, metalloids as well as salinity (effective membrane areas of 2.2 m^2; permeate flux of 1.9 m^3/day; 99.6% salt rejection using 32,000 mg/L NaCl solution at applied pressure of 5.5 MPa).

During operations, the concentration of SS in the raw wastewater averaged 569 mg/L corresponding to a turbidity of 814 NTU. Organic compounds and nutrients (total nitrogen (TN); total phosphorus (TP)) were in the low concentration range (chemical oxygen demand (COD_{Mn}): 13.8 ± 3.95 mg/L; TN: 3.2 mg/L ± 1.42 mg/L; TP: 0.31 ± 0.21 mg/L). The pH of wastewater was 7.48 ± 0.27 and the temperature range lay between 18 and 24.5 °C with little fluctuation due to its generation from the underground, minimally influenced by seasonal change. In this study, effluent collected from the C–F process as feed water was used for the combined MF–RO membrane process to evaluate its feasibility for water reclamation and reuse (Table 1).

2.2. Analytical methods

Water temperature and pH were measured by a portable meter (HM-21P, TOA-DKK Co., Hong K). Turbidity was determined using a laboratory turbidity meter (2100AN, HACH, USA). Concentrations of SS, NH_4^+-N, TN, TP, Al, Fe and Mn were determined according to the methods recommended by APHA, 1998. COD was quantified by the oxidation of organic contents using trivalent manganese (manganese III method). Na, Ca, K, Mg and Cl were measured with an ion chromatograph (ICS-1000, Dionex Co., USA). Salinity was determined using a portable digital refractometer (PR-100SA, Atago, Japan). To analyze chemical characterizations of fouled MF membrane elements, both virgin and fouled spiral-wound MF membranes were selected. Surface structure and morphology analysis of the membranes' samples were conducted using a field emission scanning electron microscope (FE-SEM, JSM-6700F, JEOL Ltd., Japan). Functional group characteristics were measured using a Fourier transform infrared (FT-IR) spectrometer (Nicolet™ 6700 FT-IR, Thermo Scientific Inc., USA). The elemental composition of the fouling layer on the membrane was determined by semi-quantitative analysis using an X-ray fluorescence (XRF)

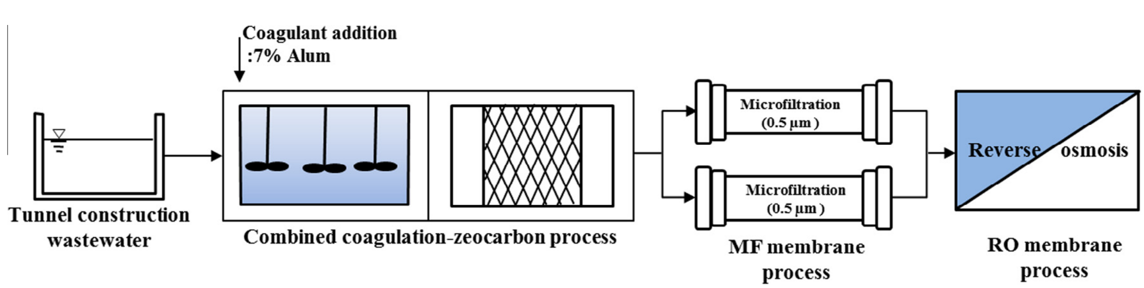

Fig. 1. Diagram of the pilot-scale tunnel construction wastewater reclamation system.