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Removal of geosmin and 2-methylisoboneol (2-MIB) by membrane system combined with powdered activated carbon (PAC) for drinking water treatment

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ABSTRACT

Adsorption kinetic tests and step-feeding tests were performed to evaluate adsorption characteristics of geosmin and 2-methylisoborneol (2-MIB). Removal efficiencies of each unit process in powdered activated carbon (PAC) membrane hybrid system were evaluated as well. The hybrid system consists of two unit processes; a coarse powder activated carbon (C-PAC) contactor and a submerged membrane tank. A pilot plant having a capacity of 500 m^3 day^{-1} was installed in W municipal drinking water treatment plant. C-PAC contactor has C-PAC (80–150 mesh) slurry blanket with a high concentration of 30,000 mg L^{-1} and the blanket is maintained in the contactor without loss. After the adsorption capacity of the C-PAC was exhausted, C-PAC turned into a biological activated carbon. In step feeding tests, 2-MIB and geosmin were continuously injected to the raw water as a concentration of 50 ng L^{-1} for 2-MIB and 200 ng L^{-1} for geosmin. Addition of fresh PAC of 15 mg L^{-1} and 5 mg L^{-1} was required to reduce the concentration of 2-MIB or geosmin below odor threshold concentration, respectively. These values are less than half of required dose from kinetic tests. The removal of Geosmin and 2-MIB by the bio-film formed on the C-PAC in the contactor was accounted for approximately up to 25% of the overall removal. As the raw water temperature increased from 5 to 20 °C, the biological removal efficiency was almost doubled. The operating pressure of membrane had been stable when the flux was maintained below 33 L m^{-2} h^{-1} with recovery rate of 98% for three months. The recovery cleaning is expected every 6 months for the long term operation.

1. Introduction

Degradation of surface water quality and improvement of consumers' demand have brought rapid development of various advanced water treatment processes such as activated carbon, ozone/GAC, ozone/UV, H_2O_2/UV and membrane.

Geosmin and 2-methylisoborneol (2-MIB), the representative taste and odor causing compounds (T&Os), in surface water were mainly developed from the metabolism and bio-degradation of cyanobacteria during the water-bloom with the presence of nutrients at warmer water temperatures [1]. Regulations for these two compounds were not established because these are not directly affecting on human health [2]. However, T&Os which can be detected by drinking water consumers at levels as low as 10 ng L^{-1} [3] may cause consumers complaints and distrust in water supplier. Therefore, removing these T&Os from drinking water has become a significant issue for water authorities.

Nevertheless, adsorption by activated carbon, either granular activated carbon (GAC) or powdered activated carbon (PAC) is considered as the best available technology and commonly used for trace organic contaminants removal from surface water. In particular, geosmin and 2-MIB have been identified to be the major T&Os in drinking water [4] and are effectively adsorbed into activated carbon [5].

Since the procedures for analyzing the T&Os are costly and time consuming, many researchers tried to predict proper dose of PAC by using isotherm data and modified models [6–8]. However, generalization of optimum PAC dosage is problematic because the adsorption efficiency is dependent on type of activated carbon and source water characteristics; concentration of NOM [9]. PAC contact time which determined by the operating conditions at each water treatment plant also responsible for the T&Os removal

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efficiency of the plant. Thus, in each drinking water treatment plant, evaluating and understanding of removal characteristic for T&Os are necessary to determine optimum PAC dosage.

The enhanced organic compounds removals by the PAC addition in membrane process for drinking water treatment were commonly reported [10–12]. Campos et al. [13,14] and Chang et al. [15] developed adsorption model for PAC-membrane processes and these model were verified by applying to PAC-membrane system with natural and synthetic water matrix. Also, some researchers reported the removal of organic substances and ammonium by employing biological activated carbon (BAC) converted from GAC [16–18].

While previous studies evaluate the improvement of water quality based on macroscopic water quality parameters such as total organic carbon (TOC) or dissolved organic carbon (DOC), this study focuses on the improvement of water quality based on the removal of two specific organic molecules: 2-MIB and geosmin.

The application of PAC as a pretreatment for membrane process is often considered uneconomical process. Previously published approaches have been of two types: (1) PAC of high concentration is added as a pulse input into the membrane reactor and discharged from the tank as the concentrate [10]; and (2) PAC is injected into the PAC contactor to prolong the retention time of PAC in the system as it travels with treated water into subsequent submerged membrane tank [11]. Since the general recovery rate of single submerged membrane process is 90%, PAC is easily discharged from the system along with the concentrate of the membrane process. In other words, PAC is not kept in the system for long enough time to exhaust the adsorption capacity of the PAC. At the GAC filters which applied after membrane filtration for biological activity, it potentially results in the leaks of microorganisms with biofilm that may grow on the GAC surface into the drinking water distribution system [19].

A hybrid process combining PAC contactor and ultrafiltration for drinking water treatment from surface water was introduced by Ahn et al. [20] as a new advanced water treatment process and is consisted of two unit processes; coarse powder activated carbon (C-PAC) contactor and submerged membrane tank. C-PAC contactor is charged with C-PAC at the initial and has slurry blanket with high concentration of tens of thousands. Kim et al. investigated the geometric and dynamic similarity of C-PAC contactor with different scale and determined few dimensionless numbers as scale-up factor. Also, slurry blanket was developed and stably maintained during more than 7 months operation period in pilot scale contactor [21]. T&Os and other soluble organic matters in raw water are removed by PAC adsorption in the C-PAC contactor. Effluent of the contactor flowed into subsequent submerged membrane tank, and particulates are separated by ultrafiltration membrane. Since surface water was directly used as feed water of the C-PAC contactor without pre-chlorination and the C-PAC slurry was maintained in the contactor without significant losses, C-PAC is converted to biological activated carbon (BAC) after the adsorption capacity was exhausted. In the previous paper [22], the continuous removal of DOC and ammonia by the biofilm in C-PAC contactor was reported and this approach is extended for the removal of 2-MIB and geosmin. Also, the effects of high turbid water on performance of the C-PAC contactor and membrane fouling were evaluated in a pilot scale plant and, operating strategy for the high turbid season was suggested [23].

In the current study, the performance of novel membrane system combined with coarse powder activated carbon (C-PAC) contactor was evaluated with a focus on the enhanced removal of specific organic compounds by additionally employing a biological removal process. The objectives of this study were to evaluate the 2-MIB and geosmin removal efficiency of the C-PAC contactor-membrane hybrid process and to suggest the optimum fresh PAC dosage for eliminating the 2-MIB and geosmin down to odor threshold concentration (OTC) level. Adsorption kinetic tests and step-feeding tests were performed to understand the adsorption characteristics of geosmin and 2-MIB. Transmembrane pressure (TMP) was monitored for three months during the step-feeding tests as well.

2. Materials and methods

2.1. Experimental set-up

Pilot-scale plant having a capacity of 500 m^3 day^{-1} was installed at W drinking water treatment plant in Namyangju, Korea and its schematic diagram was shown in Fig. 1. The raw surface water was directly introduced into the C-PAC contactor from the Paldang reservoir and the effluent of the contactor flew into the subsequent submerged membrane tank. Coagulant and fine fresh PAC were selectively added to upstream of the C-PAC contactor in order to enhance removal efficiency of the trace organics and prevent membrane fouling. These additives flow into the membrane tank with the treated water of C-PAC contactor, and concentrated additives in the membrane tank are intermittently drained from the tank as the 'concentrate'.

The C-PAC contactor having cylindrical shape has a diameter of 3.1 m and effective volume of 16 m^3. The contactor has C-PAC (80∼150 mesh) slurry blanket with a high concentration of 30,000 mg L^{-1} and the blanket is maintained in the contactor without loss. Mixer is rotated not only to build a slurry blanket but also to prevent settling down the C-PAC particles.

A dimensions of the membrane tank are 1.0 m (W) × 2.5 m (L) × 3.0 m (H) with effective height of 2.7 m. The membrane module used in this study was ZeeWeed® 500 C (GE, USA) which configured with 26 of membrane elements. Effective membrane surface area of the module is 603.2 m^2 and nominal pore size of the membrane made from polyvinylidene fluoride (PVDF) is 0.04 μm. Hydraulic retention time (HRT) of the C-PAC contactor and the membrane tank were 45-min and 15-min, respectively.

2.2. Materials

Two types of activated carbon were used in this study. C-PAC having a particle size of 90–180 μm was added in the C-PAC contactor to build up the slurry blanket at the beginning of the operation. Fine fresh PAC was used for the removal of T&Os and injected into the upstream of the C-PAC contactor. The fresh PAC having a particle size of 27 μm was coconut-based and steam activated carbon manufactured by Norit (Darco KB-B, USA).

Particle size distributions of these two activated carbons are shown in Fig. 2. The size distribution of C-PAC and fine PAC were determined by using standard test methods for sieve analysis (ASTM D6913-04) and particle size analyzer (Mastersizer 3000, Malvern Instrument, UK), respectively.

2-MIB (purity: 99.5%) and geosmin (purity: >99%) standards were supplied from Wako Pure Chemical Industries, Ltd (Osaka, Japan). First, the liquid geosmin and crystallized 2-MIB standard chemicals were dissolved in methanol (Fisher Scientific, USA). Then these stock solutions were used for adsorption kinetic and step-feeding tests after diluting with water that had been distilled and passed through an 18 MΩ Milli-Q water purification system.

2.3. Analysis of 2-MIB and geosmin

Samples were filtered with a GF/C filter (Whatman, USA) and these filtrates were filtered again using a 0.45 micron syringe filter