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Design and evaluation of hydraulic baffled-channel PAC contactor for taste and odor removal from drinking water supplies

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ARTICLE INFO

Article history:
Received 4 August 2006
Received in revised form
6 February 2007
Accepted 7 February 2007
Available online 2 April 2007

Keywords:
Taste and odor (T&O)
Velocity gradient
Powdered activated carbon (PAC)
Optimal design
Baffled-channel PAC contactor

ABSTRACT

Based on the concept of hydraulic flocculator, a baffled-channel powdered activated carbon (PAC) contactor, placed before the rapid-mixing basin, was designed and evaluated for removal of taste and odor (T&O) in drinking water. PAC adsorption kinetic tests for raw water samples were conducted for selection of design parameters related to contact time and degree of mixing. Within the tested range of velocity gradient (G) from 18 to 83 s^{-1}, mixing had a relatively minor effect on the adsorption kinetics of the PAC. The hydrodynamic characteristics of the pilot-scale horizontally and vertically baffled-channel PAC contactor were investigated by tracer tests. It was found that the plug flow fractions of vertically baffled-channel PAC contactor (vBPC) were higher than those of the horizontally baffled-channel PAC contactor (hBPC) for the same bend width or bend height. However, the hBPC seems to be more appropriate than the vBPC in terms of construction and maintenance. The geosmin and MIB removal rate increased with the number of baffles, PAC dose and contact time increased regardless of bend width in the pilot-scale hBPC. The pair of full-scale hBPCs at Pohang water treatment plant, having a design capacity of $6.5 \times 10^4\,m^3/d$ with 20 min of hydraulic retention time with a safety factor of 2, was designed based on lab- and pilot-scale experimental results. Under a velocity gradient of 20 s^{-1}, the number of baffles to be installed was calculated to be 20 with a space of about 2 m between each baffle, resulting in a hydraulic head loss through the contactor of about 0.056 m. The successful application of hBPC for T&O removal from drinking water supplies should provide momentum for developing more effective treatment methods.

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1. Introduction

Taste and odor (T&O) problems caused by eutrophication of drinking water supplies have become increasingly important because such aesthetic qualities are the primary measures by which consumers estimate the quality of their drinking water (Mallevialle and Suffet, 1987). Powdered activated carbon (PAC) has been widely used for T&O removal despite its relatively high cost, due mainly to the advantage that PAC can be applied only as needed (Suffet et al., 1995). In conventional water treatment plants (WTP), PAC is most commonly added either at the intake, rapid-mixing basin or filter inlet. Another point of addition that should be considered, although it is not commonly used, is immediately before the rapid-mixing

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doi:10.1016/j.watres.2007.02.005

basin. It is also true that PAC is often added to the rapid-mixing basin simultaneously with coagulants, alkaline chemicals and chlorine, and the question has been raised whether the adsorption efficiency of PAC may be adversely affected by those chemicals (Najm et al., 1991).

To reduce this uncertainty and to maximize adsorption efficiency of PAC for T&O removal by minimization of interference with other water treatment chemicals, a separated baffled-channel contactor based on the concept of a hydraulic flocculator was proposed for inclusion in a newly constructed WTP in Korea. The hydraulic baffled-channel contactor, which would use only hydraulic energy for mixing raw water and PAC, was to be located immediately before the rapid-mixing basin. The advantages of such a baffled-channel contactor include good performance if the flowrate is reasonably constant, minimal maintenance due to lack of mechanical equipment and minimal short circuiting. Although some information related to velocity gradient and retention time for flocculation in pilot- or full-scale baffled-channel flocculators has been published (Bhargava and Ojha, 1993; Haarhoff, 1998; McConnachie et al., 1999; McConnachie and Liu, 2000), results from experimental research for T&O removal in drinking water using hydraulic baffled-channel contactors have not.

The goal of this research was to gather data to inform optimal design and operation of a full-scale baffled-channel PAC contactor (BPC) specifically for T&O removal. The data were provided by experiments using two pilot-scale BPCs. In one design, channel baffles were vertical, while in the other design, baffles were horizontal. In both designs, optimum flow was the focus in experiments during which the number of baffles and the dimensions of the flow paths (bend height or width) were varied. Similarly, removal of given amounts of introduced T&O compounds in a pilot-scale horizontally baffled channel PAC contactor (hBPC) was the focus in experiments during which PAC dose and contact time were varied.

2. Materials and methods

2.1. Batch PAC adsorption kinetics

Batch PAC adsorption kinetic tests were conducted to obtain optimal mixing rate expressed by velocity gradient (G, sec^{-1}) and contact time. Raw water samples were taken from the Daechung Reservoir. The pH, turbidity, dissolved organic matter (DOC), UV_{254} and threshold odor number (TON) of the raw water were 7.3, 3.1 NTU, 3.65 mg/L, $0.044\,cm^{-1}$ and 200, respectively. Because the analytical instruments were not available during these tests, a sensory method was used.

A domestic coconut-based PAC (Shinki Chemical Industrial Corporation, Korea) was used in this study. For experiments that required carbon slurries, slurry of 2000 mg/L was used. These slurries were prepared by mixing 2 g of the carbon in 1 L of organic-free water. The device used for the batch kinetic experiments was a jar test apparatus (PB900TM Programmable Jar Tester, 7790-912, Phipps & Bird, VA, USA) and modified square jars (B-KER2, Phipps & Bird, VA, USA). Each jar was filled with 2 L of raw water from Daechung Reservoir at room temperature. PAC was added from a 2000 mg/L slurry stock solution to produce concentrations of 5, 10 and 15 mg/L. TON and UV_{254} were determined for samples collected at 2, 5, 10, 20 and 30 min. PAC was removed from the samples prior to analysis of T&O using GF/C filter paper and 0.45 μm membrane filters (Millipore HA type, MA, USA). The rpm values of the 2 L square jars were converted to velocity gradient following the procedure proposed by Hudson (1981).

2.2. Pilot-scale BPC

Based on the concept of a baffled-channel flocculator using hydraulic energy for mixing (Schulz and Okun, 1984; Kawamura, 2000), a pilot-scale BPC with a working volume of 288 L was manufactured, as depicted in Figs. 1 and 2. The plan area of the PAC contactor was 1600 mm × 650 mm and the height was 400 mm, with a total water path of 3200 mm and effective cross section of 300 mm × 300 mm. To install various sized baffles, 25 grooves were provided on the inside walls of the contactor. The effluent was withdrawn over a weir located at the end of the contactor.

2.3. Tracer tests of pilot-scale BPC

The step input tracer tests were conducted for pilot-scale horizontally (horizontal-flow with around-the-end baffles) and vertically (vertical-flow with over-and-under baffles) BPC with a working volume of 288 L at 20 min of contact time using 4 mg/L of phenol as a tracer. For each flow type, several combinations of number of baffles, bend height (the distance between the end of baffle and the bottom of contactor) and bend width (the distance between the end of baffle and the side wall of contactor) were evaluated. Bend heights of 60 and 90 mm for the vertically baffled-channel PAC contactor (vBPC) and bend widths of 30, 60 and 90 mm for the horizontally baffled-channel PAC contactor (hBPC) were each tested with sets of 13, 20 and 25 baffles. Samples of effluent were taken every 2 min and analyzed for the concentration of phenol. Generally, step inputs were done to analyze the retention time distribution (RTD) of effluent water in the PAC contactor. Especially, the complete mixing and plug flow fractions were estimated using both index analysis and graphic analysis (Rebhun and Argaman, 1965).

2.4. Evaluation performance of pilot-scale hBPC for T&O removal

After tracer tests at the lab, the pilot-scale hBPC was moved to the Suji WTP in order to evaluate performance of pilot-scale hBPC for T&O removal in drinking water supplies. At Suji WTP, taking raw water from the Paldang Reservoir, extensive studies on T&O removal were being conducted by a government research institute. During this experiment, temperature, pH, turbidity, alkalinity, DOC and UV_{254} of raw water were $15.6 \pm 2.6\,^{\circ}C$, 7.7 ± 0.4, 4.97 ± 1.02 NTU, 45.5 ± 5.1 mg/L, 1.58 ± 0.19 mg/L and $0.029 \pm 0.004\,cm^{-1}$, respectively. Raw water spiked with geosmin or MIB flowed continuously into the pilot-scale hBPC to an initial concentration range of

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