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A novel design for an ozone contact reactor and its performance on hydrodynamics, disinfection, bromate formation and oxidation

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HIGHLIGHTS

- We propose a novel ozone contact reactor in this work.
- The novel reactor has a much higher hydraulic efficiency than the original one.
- 70–147% higher log inactivation levels were observed in the novel contact reactor.
- For a given level of log inactivation, the novel reactor produced lower bromate.
- The novel reactor has a better performance on oxidation of refractory contaminants.

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ABSTRACT

This work proposed a novel design for an ozone contact reactor, which employed a porous zone for water flow distribution and parallel-arranged perforated tubes as the outlet. Experiments were conducted in the novel contact reactor to examine its performance on hydraulics, disinfection, bromate formation and oxidation. An original contact reactor with common designs was selected to serve as a reference. Results showed that the novel contact reactor had a more steady and higher hydraulic efficiency than the original one. The baffle factors (T_{10}/HRT) ranged from 0.83 to 0.85 in the novel contact reactor and from 0.34 to 0.57 in the original one at different flow rates. The analysis of particle image velocimetry (PIV) demonstrated the existence of the flow irregularities in the original contact reactor and the uniform flow in the novel one. The dissolved ozone distribution kept closed in the novel contact reactor, but varied greatly in the original one. The log inactivation levels were observed 70–147% higher in the novel contact reactor than in the original one. For a given level of log inactivation, the novel contact reactor required 33–50% less ozone dosages and produced 43–54% lower concentrations of bromate than the original one. The degradation of the ozone-refractory organic contaminant was observed 49–130% higher in the novel contact reactor than in the original one. Consequently, the novel contact reactor proposed in this study has a better performance on hydrodynamics, disinfection, and oxidation than the original one with common designs, and thus is appropriate for extensive application in water treatment.

1. Introduction

The hydraulic efficiency of an ozone contact reactor has been demonstrated to play a significant role in its disinfection and oxidation [1–5]. Good performance on the hydraulic efficiency allows a reactor for a smaller chemical reactant dose or less reacting time, and thus reducing its operational cost and formation of undesired byproducts [6–9]. However, there is a prevalent existence of flow irregularities in a contact reactor, including short-circuiting and recirculation [10–13]. Short-circuiting as a consequence of a faster flow through a part of the reactor poses a negative effect on the disinfection of a contact reactor [14]. Flow recirculation is regarded as a contributor to the formation of a dead zone, where the reactants are suspended to stagnate for longer residence time [15].

In response to the challenges caused by flow irregularities, a number of studies have been performed to optimize the configuration of a contact reactor to improve its hydraulic efficiency, and

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thus enhancing its performance on disinfection and oxidation. For example, increasing the height to width ratio (H/D) of a contact reactor has been adopted through dividing the reactor into several chambers in many previous studies [3,16,17]. This optimization method reduced the occurrences of short-circuiting and recirculation flow to a large extent and thus improved the hydraulic conditions in a contact reactor [18]. Some other researchers proposed the application of additional guide plates as an alternative method to optimize the flow pattern in a contact reactor [19,20]. An improvement in hydraulic efficiency of a contact reactor has been achieved through the addition of guide plates with an increase from 0.40 to 0.66 on the baffle factor (T_{10}/HRT). However, water packets are forced to experience a sharp turn when flowing through each baffle wall in a baffled reactor even after the optimization in its configuration as mentioned above. The sharp turns result in water packets on the outside of turns travel faster than that on the inside. As a consequence, the occurrences of recirculation flow and short-circuiting are still inevitable in a baffle reactor due to various detention times of water packets caused by the sharp turns.

A novel design of an ozone contact reactor is proposed in this study to reduce the occurrences of recirculation flow and short-circuiting caused by the sharp turns. We conducted experiments to examine the performance of the novel ozone contact reactor on hydrodynamics, disinfection, bromate formation, oxidation and compared with that in an original one with common designs.

2. Materials and methods

2.1. Contact reactors

Fig. 1 shows the panorama configuration of the novel ozone contact reactor. As shown in Fig. 1(c), the novel geometry proposed in this paper applied a porous zone placed above the bottom of the third chamber. The porous zone including a perforated plate and a packing layer with silica sand would provide a comparatively uniform velocity distribution on the cross section, since water packets experienced different degrees of resistances depending on their velocities when traveling through the porous zone. Additionally, parallel-arranged perforated tubes with the same distance were evenly set spanning the length of the main chamber to replace the overflow weir as presented in Fig. 1(b). It is believed to be beneficial for a contact reactor to reduce its occurrences of recirculation and short-circuiting caused by sudden contraction in the flow width at the outlet.

An original ozone contact reactor was constructed to serve as a reference. The two contact reactors were made of organic glass and had the same size with a width of 0.3 m, a length of 1.3 m and a height of 1.2 m. Ozone gas, produced from pure oxygen with a generator (CF-G-3-30g; Ozone generator, Guolin, China) was fed into the contact reactors through a side-stream venture injector.

2.2. Sampling campaigns

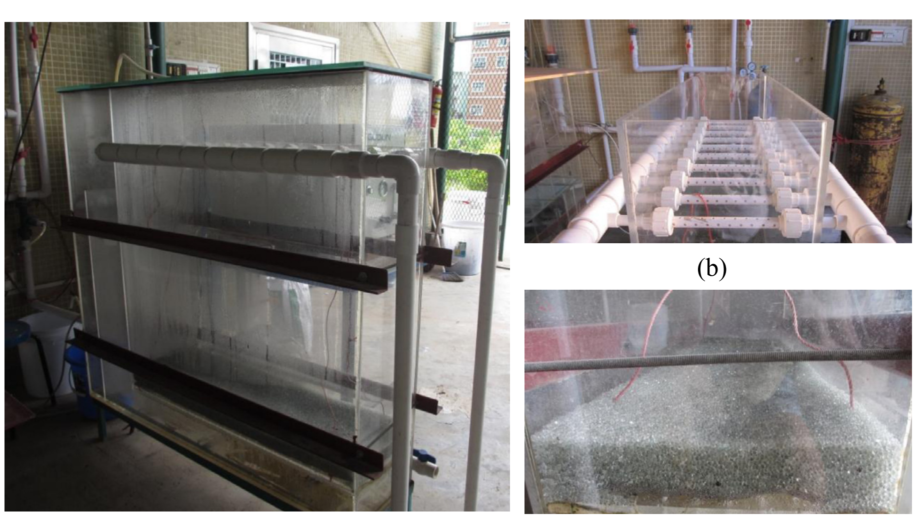
For gaining the information involving flow feature and dissolved ozone residual in two contact reactors, six sampling points were selected in each of two contact reactors. As observed in Fig. 2, the point sampling strategy for the original contact reactor varied from that for the novel one. The results from the previous studies and modeling by computational fluid dynamics indicated that a large recirculation flow and a flow close to the plug flow existed in the original and novel geometry, respectively [21]. As a consequence, four sampling points in the corners and two in the center of cell 3 in the original contact reactor were arranged to grab the recirculation flow, while the strategy that every three sampling points located at the same height in the novel contact reactor was taken to capture the flow close to the plug flow.

2.3. Water quality

All the experiments were conducted with tap water as the water source in this study. The tap water was characterized as following: pH 7.0, DOC = 1.54 mg/L, alkalinity = 0.18 mM ($CaCO_3$), the initial concentration of bromide = 12 μg/L. The initial concentration of bromate was not detectable.

2.4. Tracer tests

The tracer tests, commonly used in other studies to characterize the hydraulic behaviors, were performed using potassium chlorine as the conservative tracer. A 50 mL saturated potassium chloride solution was introduced as a pulse input from the water inlet. The concentration of the tracer was monitored on line at the effluent using a conductivity meter. The tracer tests were performed at three different flow rates (3 m^3/h, 6 m^3/h, 8 m^3/h) in both two contact reactors to compare their hydraulic stability.



(a) (b) (c)

Fig. 1. The panorama configuration (a), the parallel-arranged perforated tube (b), and the porous zone (c) of the novel contact reactor.