A dispersed-ozone flotation (DOF) separator for tertiary wastewater treatment

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Abstract A dispersed-ozone flotation (DOF) separator was devised for a pilot study of tertiary wastewater treatment for re-use purposes. As a compact device combining coagulation, ozonation and flotation in an integrated unit, the DOF separator achieved a very high removal of SS, TOC, UV_{254} and colour, as well as effective inactivation of coliform and total bacteria within a short hydraulic retention time of 30 min. The finished water quality is comparable to or better than that by a conventional tertiary treatment process using coagulation, sedimentation, filtration and chlorine disinfection, and meets the quality standards for non-drinkable domestic reuse.

Keywords Dispersed-ozone flotation; tertiary treatment; water reuse

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Introduction

A typical process for tertiary treatment of the secondary effluent usually consists of coagulation, solid/liquid separation and disinfection units for a removal of residual SS, organic matter, colour, offensive odour and microorganisms to meet the requirement of water re-use. Regarding solid/liquid separation, sedimentation/filtration and flotation/filtration are common options, and regarding disinfection, chlorine and ozone are among the disinfectants widely applied. For onsite or decentralised wastewater treatment and re-use, systems with compact configuration and ease of control and operation are expected (Lens *et al.*, 2001).

Comparing with sedimentation, dissolved or dispersed air flotation is often considered to be more suitable for the separation of pollutants with densities similar to or smaller than water. Many studies have shown the advantages of flotation for the treatment of algal rich reservoir stored lowland water (Bauer *et al.*, 1998), low turbidity surface water (Johnson *et al.*, 1995), and taste and odour control (Hargesheimer and Watson, 1996). To enhance pollutants removal by flotation, pre-ozonation has been widely used (Yu *et al.*, 1994; Schmidt *et al.*, 1995). There have also been practices of ozone-induced flotation for water and wastewater treatment (Betzer *et al.*, 1980; Rashid *et al.*, 1990).

Generally speaking, the residual pollutants in the secondary effluent are composed of low concentration suspended solids and organic substances which are less biodegradable and usually cause the problems of colour and offensive odour (Gogate and Pandit, 2004). One idea for effective removal of these pollutants is to seek a combination of coagulation, ozonation and flotation in one treatment unit. This leads to the development of a dispersed-ozone flotation (DOF) separator as is introduced in this paper.

Materials and methods

Dispersed-ozone flotation system

Figure 1 shows the schematic flow chart of the DOF separator for the pilot study at Beishiqiao Wastewater Purification Centre, Xi'an, China. The main body of the DOF

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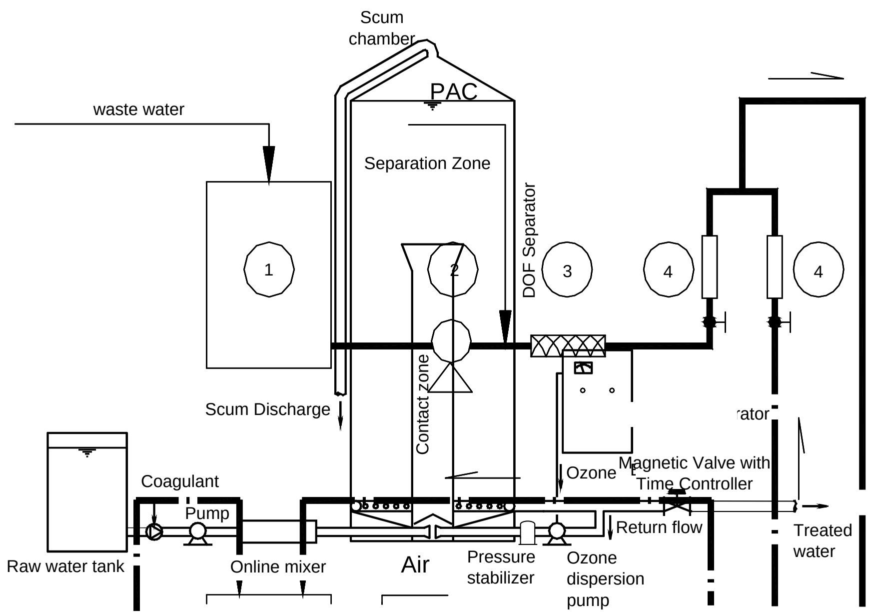

Figure 1 Dispersed-ozone flotation system

separator is a closed cylindrical compartment with an inner column at the centre, thus dividing the cylindrical space into a contact zone and a separation zone. On top of the compartment there is an inversely placed circular cone forming a scum chamber. There are two inlets at the bottom of the separator, one as the entrance for the raw water, i.e. the secondary effluent, after coagulant (polyaluminium chloride, PAC) dosing and mixing through the raw water pump and online hydraulic mixer, another as the entrance for the return flow mixed with dispersed ozone. The two flows are well mixed hydraulically as they enter the contact zone at its bottom. By the ozone dispersion pump, gaseous ozone from an ozone generator is dispersed in water (return flow from the treated water) as micro bubbles. Therefore, a contact reaction of ozone with pollutants and attachment of pollutants onto micro ozone bubbles occurs at the same time in the contact zone. In the separation zone, floated scum accumulates on the top and treated water is collected through the perforated annular pipe at the bottom. A magnetic valve is installed on the treated water pipe. It is automatically controlled by a time controller so that it can be switched "open" and "closed" at prescribed time intervals. As the valve is opened, treated water flows out of the DOF separator at a regular rate and the water level is kept constant in the separator; as the valve is closed, the treated water flow is shut down and the water level begins to rise in the DOF separator (Figure 2a). In this way, scum accumulated on

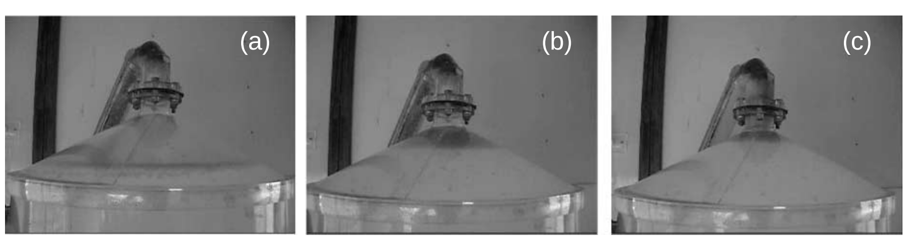

Figure 2 Automatic discharge of accumulated scum through the top outlet of the DOF separator: (a) water level rises as the magnetic valve is closed; (b) water level rises to the outlet; (c) scum being discharged through the outlet

the top is driven to the narrow end of the circular cone (Figure 2b) where it finally flows out through the discharge pipe (Figure 2c). As discharge is finished, the valve is switched open again and the next cycle of operation automatically starts. The time interval is set according to the conditions of scum accumulation.

Table 1 summarises the standard operational condition of the DOF separator. The ozone dispersion pump drew both a return water flow from the treated water pipe and an air stream from the ozone generator. The air stream was kept constant but ozone concentration was adjustable. The micro air bubbles (with an average size of approximately 10 μm) were found to be well dispersed throughout the central column (contact zone) of the DOF separator. In the separation zone, there was a clear boundary between a upper layer of milky dispersion (water with micro air bubble) and a lower layer of transparent water, indicating a very good condition of air bubble flotation.

Raw water

The raw water for this study is the secondary effluent from the sewage treatment plant. Its quality is shown in Table 2, based on the monitoring record during the study.

Analytical methods

Chemical analysis. Chemical analysis in this study was conducted regarding turbidity, colour, TOC and UV_{254} of the raw water and treated water. Methods utilised include the following:

- Turbidity: Nephelometic method using a SZD-2 turbidimeter;
- Colour: platinum-cobalt method using a Hitachi 2000 spectrophotometer at 420 nm;
- TOC: Catalytic combustion method using a Shimadzu TOC-5050 analyser;
- UV_{254}: Using a Hitachi 2000 spectrophotometer at 254 nm (cell length 1 cm).

Total bacteria and coliform analysis. Total bacteria and coliform were analysed by membrane filter technique and the results were recorded in terms of colony forming unit (cfu).

Results and discussion

Pollutants removal by the DOF separator

Turbidity removal. In the raw water, i.e. the secondary effluent, turbidity varied between 2 and 5 NTU. After coagulation, most of the turbid matter was coagulated with organic matter and other pollutants forming micro flocs which were removed by the DOF

Table 1 Standard operational condition

Parameter	Value	Parameter	Value
Raw water flow rate	1 m^3/hr.	Online mixing time	30 s
Air and gaseous ozone flow rate	0.2 m^3/h (at 1 atm)	HRT in the DOF separator	30 min.
Stabilised air pressure	0.3 MPa	Recycle flow rate	0.5 m^3/h

Table 2 Raw water quality (the secondary effluent)

Parameter	Analysis	Parameter	Analysis
pH	7.0–7.9	COD	10.8–41.2 mg/L
Turbidity	4–20 NTU	BOD_5	6.0–12.0 mg/L
Colour	25–35 c.u.	NH_3-N	0.7–2.0 mg/L
UV_{254}	0.106–0.163 cm^{-1}	Total coliform	30,000 cfu/mL
DOC	4.25–9.43 mg/L	Total coliform	600 cfu/100 mL

separator. As shown in Figure 3, under the standard operational condition specified in Table 1, the residual turbidity in the treated water was below 1.0 NTU in the month experimental period (average 3–0.7 NTU).

Colour removal. Figure 4 shows the variation of colour in the raw water and the treated water. It can be seen that the DOF separator performed well in colour removal from the raw water under the above mentioned operational conditions. The average colour in the raw water, i.e. the secondary effluent, was 92.4 c.u. in the experimental period, and the average colour in the treated water was 14.4 c.u. An average colour removal of 84.4% was achieved.

Organic removal. Figure 5 shows the treatment results of organic removal (represented by TOC and UV_{254}) by the DOF separator under the operational conditions as mentioned above. The average TOC and UV_{254} were 11.3 mg/L and 0.219 cm^{-1}, respectively, resulting in a SUVA (specific UV absorbance) ratio of 0.0194, which is slightly lower than the SUVA ratio of organics in natural water (usually with humic substances as the main component) as >0.02 (Jin and Wang, 2004), and indicating the characteristics of the secondary effluent. The DOF separator achieved almost identical removals of TOC and UV_{254} (53.5 and 55.7%, respectively) with the SUVA ratio slightly decreased (SUVA = 0.0183). Many studies have shown that one of the important roles ozone plays is to alter the structure of organic matter and result in a decrease of the SUVA ratio (Owen *et al.*, 1995; Goel *et al.*, 1995). The low decrease of SUVA is considered due to

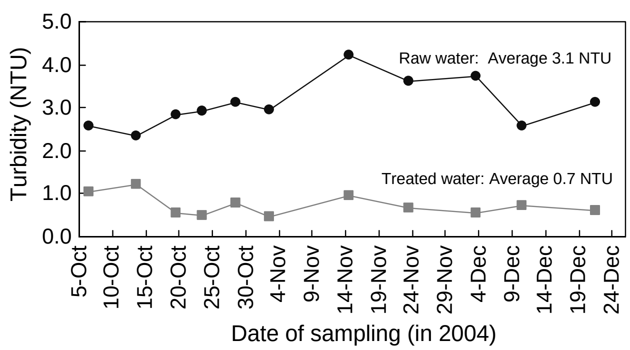

Figure 3 Turbidity removal by DOF separator

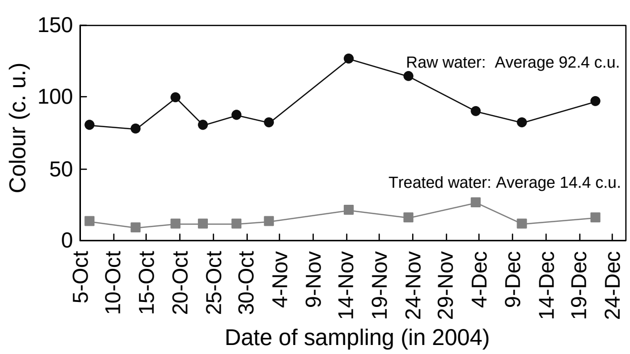

Figure 4 Colour removal by DOF separator

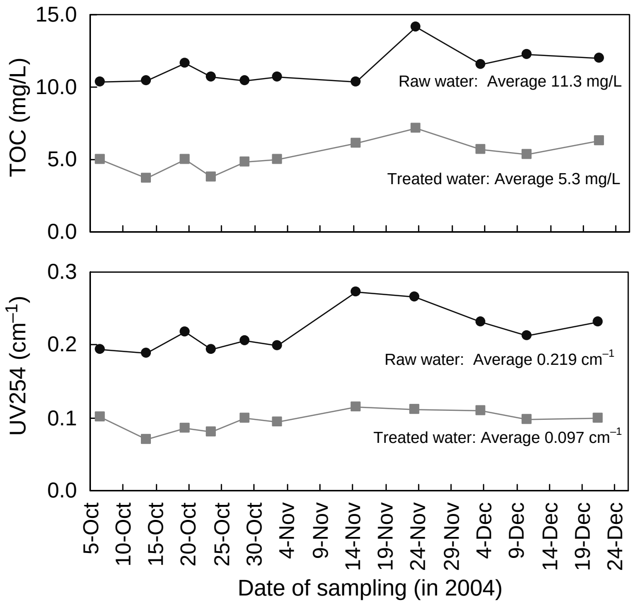

Figure 5 TOC and UV_{254} removal by DOF separator

both the low aromaticity of the raw water and the low ozone dose, 1.6 mg/L, which may not be enough to decompose organic matter. The organic removal was mainly achieved by coagulation and flotation.

Bacteria and coliform inactivation. Figure 6 shows the total bacteria and total coliform counts in the treated water. The DOF achieved a 3-log removal of total bacteria and 2.3-log removal of total coliform in comparison with the bacteria counts shown in Table 1. Due to the limitation of ozone supply capacity of the experimental system, investigation could not be conducted for bacteria and coliform removal at an ozone dose higher than 1.6 mg/L. However, the DOF separator showed its advantage in fulfilling simultaneous disinfection and removal of other pollutants, even at an insufficient ozone dose of 1.6 mg/L.

Evaluation of the DOF separation process

Effect of ozone dose. In the DOF separation process, ozone-rich air is the air source for flotation and ozone also plays the function of oxidation. Figure 7 shows the influence of

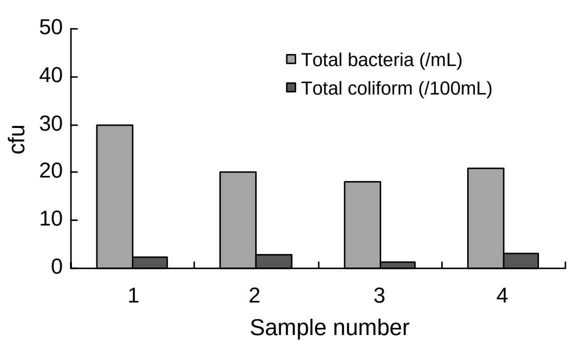

Figure 6 Inactivation of microorganisms by DOF separator

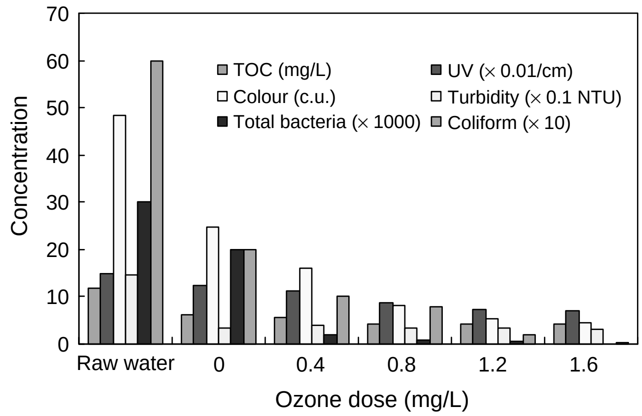

Figure 7 Effect of ozone dose on treated water quality

zone dose on the quality of treated water. With no ozone dose (equivalent to pressured air flotation), the DOF separator could achieve a good removal of turbidity and certain removal of colour, organic matter and bacteria. As the ozone dose increased, the efficiency of colour, organic and bacteria removal was improved. For a further higher removal of coliform bacteria, a higher ozone dose would be needed.

Treated water quality. Table 3 compares the water quality of the DOF separator and the current conventional treatment process (coagulation + sedimentation + filtration + chlorine disinfection) applied in Beishiqiao Wastewater Purification Centre for tertiary wastewater treatment for re-use. It can be seen that the DOF separator process can achieve the very high water quality. Regarding colour, odour and total bacteria, the treated water quality by the DOF separator is better than that by conventional tertiary treatment. The treated water quality meets the Chinese Standard for Domestic Re-use (SAC, 2002). Moreover, the total HRT of the DOF separation process is only 30 min, in comparison with that for the conventional tertiary treatment 2–3 h. High treatment efficiency is one of the important features of the DOF separator.

Summary and conclusion

This paper introduced a compact device for tertiary wastewater treatment utilising a dispersed ozone flotation technique. The DOF separator combines coagulation, ozonation and dispersed air flotation in one treatment unit within a total hydraulic retention time of approximately only 30 min. The following conclusions can be drawn from the current study:

Table 3 Comparison of the water quality of the treated water between DOF separator and conventional process

Parameter	DOF separator	Conventional treatment	Standard for non-drinkable domestic reuse
Colour (unit)	5–10	15–30	30
Odour	None	Slight uncomfortable sell	No offensive odour
Turbidity (NTU)	<0.5	<0.5	5–10
SS (mg/L)	<10	<10	10–15
BOD (mg/L)	<10	<10	10–20
COD (mg/L)	<30	<30	50–60
Total bacterial(cfu/mL)	25	30	–
Coliform (cfu/100 mL)	3	3	5
HRT	30 min	2 – 3 h	–

(1) At an ozone dose of 1.6 mg/L with a PAC dose of 50 mg/L, the DOF separator can achieve very good removals of turbidity, colour, organic matter, total bacteria and coliform bacteria from the secondary effluent. The treated water quality is comparable to, or better than, that by a conventional tertiary treatment process and meets the standard for domestic re-use.
(2) Generation of micro bubbles of ozone-rich air and creation of well dispersed conditions are considered to be the main reason for the high efficiency of disinfection and separation in the DOF separator.
(3) With its compact structure, low HRT and high efficiency of pollutant removal, the DOF separator is recommendable to be used as a treatment unit in an onsite or decentralised system for tertiary wastewater treatment and reuse.

Acknowledgements

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