# Safety of treated water for re-use purposes – comparison of filtration and disinfection processes

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**Abstract** A study was conducted on the distribution of pollutants in treated wastewater and the its safety for re-use purposes. Based on the results of a series of tertiary treatment experiments, the effects of three filtration processes, i.e. coagulation-filtration, ozonation-biological activated carbon filtration ($O_3$-BAC) and ultrafiltration (UF), and two chemical disinfection processes, i.e. chlorination and ozonation, on the safety of water re-use were evaluated. It was found that the concentrations of the main pollutants in the secondary effluent and further filtered water follow a log-normal distribution and, therefore, a log-normal probabilistic function can be used to evaluate the suitability of the treated water for re-use purposes. Among the three filtration processes evaluated, UF is the most effective in turbidity removal but less effective in colour and COD removal, while coagulation-filtration and $O_3$-BAC can ensure a good removal of all these pollutants. Regarding chemical disinfection, although chlorine is very effective in inactivation of coliform bacteria, it can not achieve a substantial decrease in viruses. As ozone is applied, effective virus removal can be achieved.
**Keywords** Disinfection; filtration; log-normal distribution; safety; water re-use water

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## Introduction

Safety of treated water for various re-use purposes is a matter of public concern (Sheikh *et al.*, 1999; Casani *et al.*, 2005). The secondary effluent from a conventional wastewater treatment plant can not usually meet the target of water quality, and tertiary treatment is therefore required for further removal of turbidity, colour and offensive odour, organic matter and pathogenic bacteria and viruses (USEPA and USAID, 1992). Nowadays various filtration and chemical disinfection methods are applied in tertiary wastewater treatment. For a rational selection of treatment processes to meet the water quality goal, it is important to understand the distribution of pollutants in the secondary effluent and that in the finished water after tertiary treatment using a certain method. The assessment of potential adverse health effects from exposure to reclaimed water also requires determining the distribution of pollutants in reclaimed water (Mckone and Bogen, 1991; Pinsky, 2000; Chaouche *et al.*, 2002).

In order to gain knowledge on how to assess the treatability of pollutants in the secondary effluent, and how to select filtration and/or disinfection processes for the tertiary treatment to ensure the safety of the treated water for reuse purposes, the authors conducted a comprehensive study on the distribution of pollutants in water and analysed the probability for the treated water to meet the water quality standard.

## Materials and methods

### Raw water

The raw water for this study is the secondary effluent from Beishiqiao Wastewater Purification Center in Xi'an City, China. Its quality is shown in Table 1, based on the monitoring record during the study.

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**Table 1** Raw water quality (the secondary effluent before chlorimation)

| Parameter | Analysis | Parameter | Analysis |
|---|---|---|---|
| pH | 7.0–7.9 | $COD_{Cr}$ | 10.8–41.2 mg/L |
| Turbidity | 4–20 NTU | $BOD_5$ | 6.0–12.0 mg/L |
| Color | 25–35 c.u. | $NH_3$-N | 0.7–2.0 mg/L |
| $UV_{254}$ | 0.106–0.163 $cm^{-1}$ | Total coliform | $1 \times 10^6 - 1 \times 10^8$ MPN/L |
| DOC | 4.25–9.43 mg/L | Faecal coliform | $9.2 \times 10^5 - 2.4 \times 10^7$ MPN/L |

#### Analytical methods

*Chemical analysis*. Chemical analysis in this study was conducted regarding turbidity, colour and COD of the secondary effluent and treated water. Methods utilised include the following:

- Turbidity: Nephelometic method using a SZD-2 turbidimeter;
- Colour: platinum-cobalt colorimetry method using a Hitachi 2000 spectrophotometer;
- COD: closed reflux, colorimetric method.

*Coliform and faecal coliform analysis*. Total coliform and faecal coliform were analysed by the multiple-tube fermentation technique and the results were recorded in terms of the most probable number (MPN).

*Virus analysis*. In order to evaluate the effects of filtration and disinfection processes on virus removal or inactivation, Coxsackie B3 (CoxB3) virus was used as a virological tracer in this study. The CoxB3 was seeded into the sterilised raw water at a known viral density and then the virus-seeded water was applied for tertiary treatment by filtration and disinfection. Before virus assay, the CoxB3 virus in the water sample was concentrated and recovered using an adsorption-elution disc filter method. A tissue culture infective dose 50 (TCID50) assay was conducted for virus enumeration. Methods of the CoxB3 seeding, recovery and enumeration were reported elsewhere by the authors (Wang *et al*., 2005).

#### Treatment experiment

*Coagulation-filtration*. Coagulation was conducted following a standard jar test procedure: rapid mixing for 1 min, slow mixing for 30 min and settling for 1 h. Polyaluminium chloride was used as coagulant. The supernatant was then collected and filtered by a paper filter before analysis.

*Ozonation-biological activated carbon filtration ($O_3$-BAC)*. A pilot scale $O_3$-BAC system was employed. It consisted of a contact column for reaction with the injected ozone at a dose of 2–3 mg/L with a contact time of 6 min, and a BAC filter with an effective depth of 180 cm at a rate of 8–10 m/h.

*Ultrafiltration (UF)*. A laboratory ultrafiltration unit with a flat polyacrylonitrile (PAN) membrane was employed. The molecular cutoff is 30,000 Daltons.

*Chlorination*. Sodium hypochlorite (12% available chlorine) is used for chlorination of the raw waters in batch operation at a dose of 2–10 mg/L. The contact time was set at 20 min.

*Ozonation*. A laboratory ozone reactor was employed for ozonation of the raw water. The contact time was set at 15 min and ozone dose at 0.11–2.10 mg/L.

## Results and discussions

### Pollutants distribution in the secondary effluent

Regarding turbidity, colour and COD in the secondary effluent from the wastewater treatment plant, we conducted water sampling and water quality analysis routinely over a period of approximately 1 year. Taking turbidity as an example, a total number of 58 measurements ranging from 1.04 to 9.84 NTU were obtained, showing a wide spreading of residual turbidity in the secondary effluent. By arranging all the measurements in an increasing order, calculating the cumulative probability, and plotting them on a log-normal coordinate system, Figure 1 was obtained. We further calculated the logarithmic average and standard deviation of these data as the characteristic parameters of the log-normal distribution. In Figure 1, the dots are the measurement values and the curve is the fitted log-normal cumulative distribution using the calculated parameters. The result shows that the variation of residual turbidity in the secondary effluent follows the log-normal distribution well. It is therefore possible to use the log-normal distribution as a mathematical tool to carry out probabilistic analysis of the data.

Similar analysis was conducted for residual colour and COD in the secondary effluent, as shown in Figure 2. Both the data of colour measurements (79 data) and COD measurements (10 data) fitted the log-normal distribution well.

Regarding total coliform and faecal coliform in the secondary effluent, the log-normal distribution was also applicable (Figure 3).



### Comparison of filtration processes for meeting the water quality target

After filtration, the concentrations of turbidity, colour and COD still followed the log-normal distribution. In this study we compared three typical filtration processes, namely coagulation-filtration, $O_3$-BAC, and UF as mentioned above. By log-normal probabilistic analysis of the water quality data, the effects of these filtration processes on turbidity, colour and COD removal were evaluated.

*Turbidity*. Figure 4 shows the fitted probabilistic curves for turbidity residual in coagulation-filtration, $O_3$-BAC, and UF treated water in comparison with the raw water, i.e. the secondary effluent. Here, we took 5 NTU as the maximum allowable turbidity for urban wastewater reuse according to the Chinese standard (SAC, 2002). From the analysis result it was deduced that the probability for the secondary effluent to meet

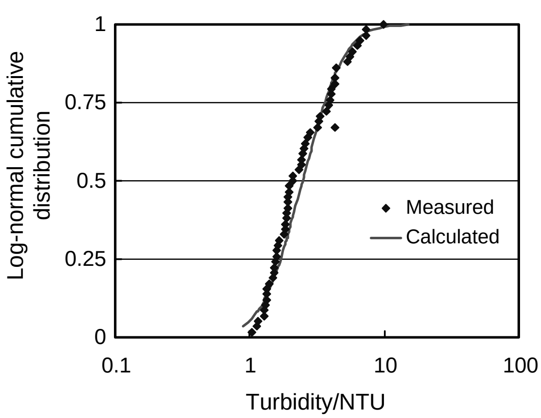


**Figure 1** Log-normal distribution of residual turbidity in the secondary effluent

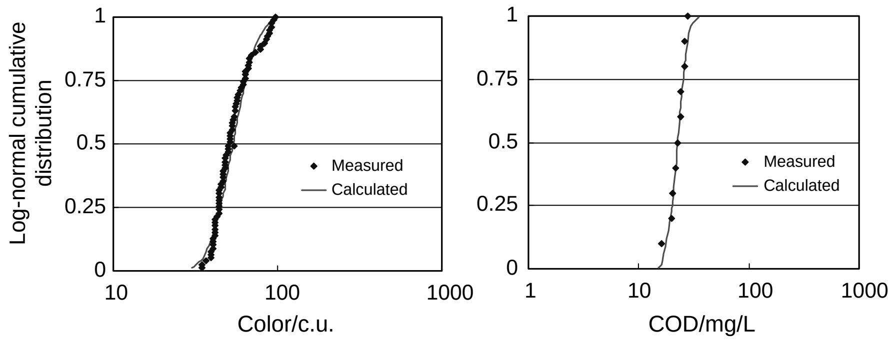


**Figure 2** Log-normal distribution of residual colour and COD in the secondary effluent

the requirement would be 0.896, and as any of the three filtration processes was applied, the turbidity target would be completely achievable.

*Colour*. Regarding colour in the treated water, 30 c.u. was taken as the maximum allowable value for urban wastewater reuse according to the Chinese standard. As shown in Figure 5, the secondary effluent could hardly meet the requirement for wastewater re-use while $O_3$-BAC could completely meet the requirement. For coagulation-filtration and UF, the probabilities to achieve the target of colour would be 0.92 and 0.70, respectively.

*COD*. According to the Chinese standard of treated wastewater for urban re-use, the maximum allowable COD is 50 mg/L. As shown in Figure 6, even the secondary effluent

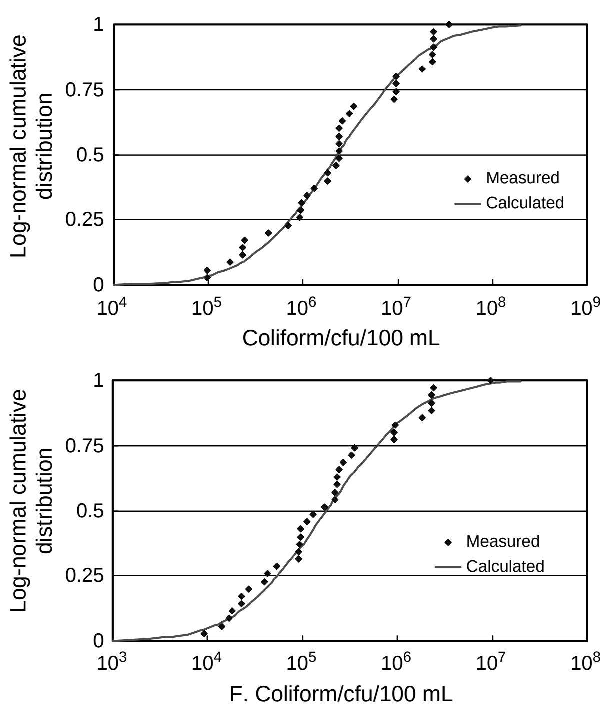


**Figure 3** Log-normal distribution of total coliform and faecal coliform in the secondary effluent

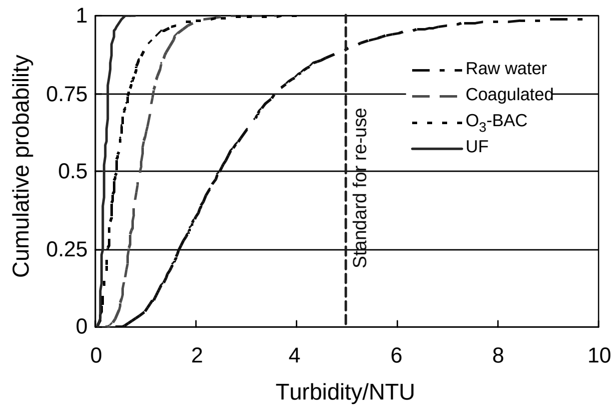


**Figure 4** Comparison of the three filtration processes for meeting the turbidity target

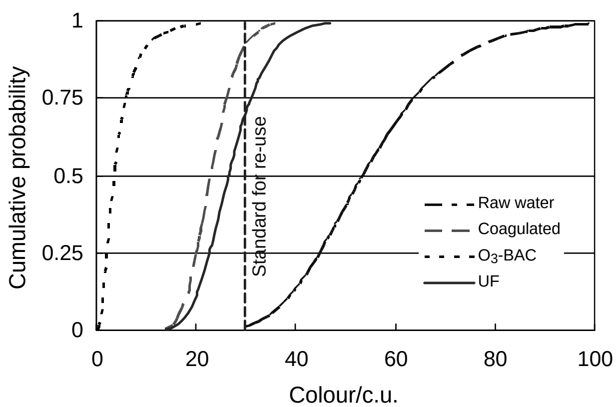


**Figure 5** Comparison of the three filtration processes for meeting the colour target

could meet this requirement. However, treated water with lower organic content is often required. If the target of COD is set as 20 mg/L, which is the limit of source water COD for water supply (SEPAC and SAC, 2002), application of filtration for further COD removal will be necessary, and the probability for UF to achieve this target is evaluated as 94.7% and that for coagulation-filtration and $O_3$-BAC is 100%.

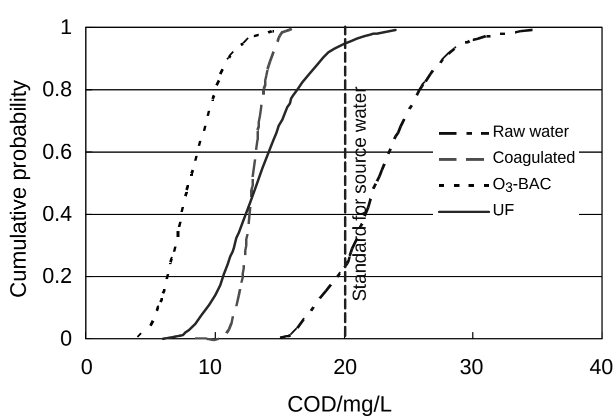


**Figure 6** Comparison of the three filtration processes for meeting the COD target

#### Coliform and virus removal/inactivation

*Coliform and virus removal by filtration processes.* Figure 7 compares the efficiencies of the three filtration methods for the removal of total coliform, faecal coliform and CoxB3 virus from the secondary effluent. There were no data available regarding CoxB3 removal by $O_3$-BAC process due to difficulty of virus seeding to the raw water for biological treatment. It can be seen from Figure 7 that $O_3$-BAC and coagulation-filtration are not so effective in coliforms removal (approximately only 2 to 3-log decrease), while UF shows an excellent effect of almost complete removal of both total coliform and faecal coliform. However, regarding the seeded CoxB3 virus, UF shows almost no advantage over coagulation-filtration. The UF membrane used in this study has a molecular cut off of 30,000 Daltons. Its pore size should be much smaller than the size

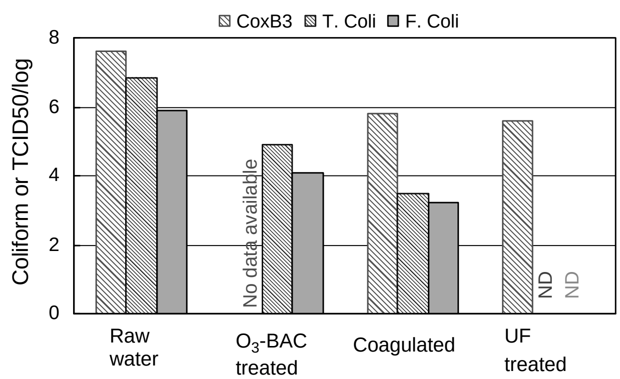


**Figure 7** Comparison of three filtration processes for coliforms and virus removal

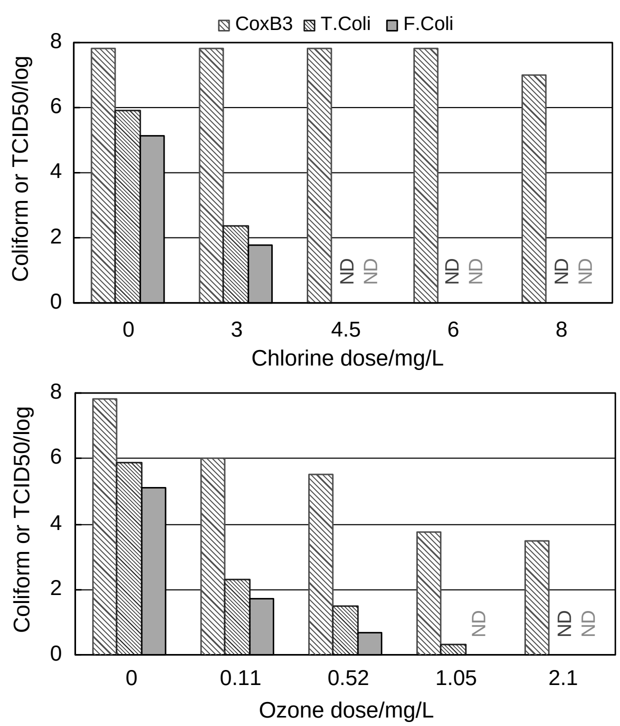


**Figure 8** Comparison of chlorination and ozonation for coliforms and virus removal

of coliform bacteria (usually in the order of 1–10 μm) but larger than the size of viruses (usually in the order of 0.01 μm). Therefore, ultrafiltration can not achieve a high removal of viruses.

*Coliform and virus inactivation by chemical disinfection.* The effects of chlorine and ozone for the inactivation of total coliform, faecal coliform and virus are compared in Figure 8. At a chlorine dose of 4.5 mg/L and above, a complete inactivation of total coliform and faecal coliform was achieved. However, chlorine could hardly inactivate CoxB3 virus at a dose up to 8 mg/L. Comparing with chlorine, ozone had the effect of inactivating not only total coliform and faecal coliform, but also CoxB3 virus. An almost complete inactivation of total coliform and faecal coliform was obtained at an ozone dose above 1.0 mg/L, and, meanwhile, a 4-log inactivation of CoxB3 was achieved. At an ozone dose of 2.1 mg/L, the CoxB3 removal reaches a level of approximately 3.8-log. Further removal may need a higher ozone dose or physicochemical treatment prior to ozonation.



## Conclusion

From the experiment results explained in the former sections, the following conclusions can be drawn:

(1) The concentrations of the main pollutants, such as turbidity colour, and COD, in the secondary effluent and further filtered water have been found to follow the log-normal distribution and therefore, a log-normal probabilistic function can be used to evaluate the suitability of the treated water for re-use purposes.
(2) Three filtration processes, namely coagulation-filtration, $O_3$-BAC filtration and UF, are applicable for tertiary wastewater treatment to achieve effective removal of turbidity, colour and COD, though there is a difference between them in the probability to ensure the treated water quality for domestic re-use. UF is the most effective in turbidity removal but less effective in colour and COD removal, while coagulation-filtration and $O_3$-BAC can ensure a good removal of all these pollutants.
(3) Coliform removal by filtration does not imply a proportional removal of viruses. Among the three filtration processes studied in this paper, UF can achieve a complete removal of total coliform and faecal coliform, but its ability to remove viruses is not high.
(4) Although chlorine is very effective in the inactivation of coliform bacteria, it can not achieve a substantial decrease in viruses. As ozone is applied, effective virus removal can be achieved. A 4-log virus removal is achievable at a dose above 1 mg/L.

## Acknowledgements

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