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Evaluation of drinking water treatment combined filter backwash water recycling technology based on comet and micronucleus assay

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ABSTRACT

Based on the fact that recycling of combined filter backwash water (CFBW) directly to drinking water treatment plants (WTP) is considered to be a feasible method to enhance pollutant removal efficiency, we were motivated to evaluate the genotoxicity of water samples from two pilot-scale drinking water treatment systems, one with recycling of combined backwash water, the other one with a conventional process. An integrated approach of the comet and micronucleus (MN) assays was used with zebrafish (*Danio rerio*) to investigate the water genotoxicity in this study. The total organic carbon (TOC), dissolved organic carbon (DOC), and trihalomethane formation potential (THMFP), of the recycling process were lower than that of the conventional process. All the results showed that there was no statistically significant difference ($P > 0.05$) between the conventional and recycling processes, and indicated that the genotoxicity of water samples from the recycling process did not accumulate in 15 day continuous recycling trial. It was worth noting that there was correlation between the concentrations of TOC, DOC, UV_{254}, and THMFPs in water and the DNA damage score, with corresponding R^2 values of 0.68, 0.63, 0.28, and 0.64. Nevertheless, both DNA strand breaks and MN frequency of all water samples after disinfection were higher than that of water samples from the two treatment units, which meant that the disinfection by-products (DBPs) formed by disinfection could increase the DNA damage. Both the comet and MN tests suggest that the recycling process did not increase the genotoxicity risk, compared to the traditional process.

Introduction

For low turbidity water, the removal ability for particulates is weaker during the traditional coagulation process compared to high turbidity water, due to the relatively slow hydrolysis of coagulant, stronger water viscosity and slower settling velocity of flocs (Xiao et al., 2009). Consequently, the corresponding chemical stability of the effluent could be reduced dramatically. Based on this phenomenon, recycling of the combined filter backwash water from WTP was proposed as a

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novel method to improve the traditional treatment technology for treating low turbidity water. Some previous studies explored the removal efficiency of organics, Giardia cysts and Cryptosporidium oocysts, and some routinely determined parameters to evaluate the water quality safety after recycling of sludge (Cornwell and Lee, 1994a; Cornwell et al., 1987; Walsh and Gagnon, 2006). Gottfried et al. (Gottfried et al., 2008) stated that the addition of reused backwash water solids was beneficial in increasing the collision and adhesion probabilities of suspended particles to further enhance the traditional treatment technology, and notably higher removal efficiency for DOC and UV_{254} was found, when the raw water blended with 5% and 10% by volume of filter backwash water was re-input into the conventional drinking water treatment. Xu et al. (2009) and Zhou et al. (2012) thought that the remaining amorphous aluminum and ferric hydroxide in the waste sludge probably did not fully react during the traditional process, and thus could be used as aggregated cores in the recycling process, enhancing the collision probabilities among particles. According to other studies, the removal of *Cryptosporidium* oocysts could be enhanced by 4.3%–20% when untreated filter backwash water was recycled to the input of the coagulation process (Cornwell and Lee, 1994; Cornwell et al., 1987; Cristale et al., 2013). As mentioned above, recycling CFBW is a feasible practice, and there may be optimum operating conditions and water quality ranges with regard to the recycling process, which can not only improve the coagulation efficiency for treating low turbidity water, but also save water resources and the cost of coagulants. However, some unknown toxic substances may accumulate in the recycling process, and these contaminants may influence the effluent quality, which could pose a potential threat to human health on conditions of long-time exposure, owing to waste residuals from CFBW raw water pollution that can be produced during drinking water treatment (Buschini et al., 2008). Furthermore, that may be interactive effects among the components, although the individual physico-chemical parameters meet the water quality guidelines (Routledge et al., 1998). Therefore, toxicity evaluation of the recycling process is a useful tool to determine the comprehensive risk.

To evaluate the toxicity of water samples treated by the recycling process and compare the toxicity of water from two pilot-scale WTP, comet and micronucleus (MN) assays have proved to be highly sensitive means to detect DNA damaged by a mixture of pollutants (Andrighetti-Fröhner et al., 2006; Biscardi et al., 2003). In fact, genotoxicity has also been measured directly in treated water using *in vivo* tests with fish, newts, *Vicia faba*, *Allium cepa* and so on (Monarca et al., 2004). The comet assay can detect primary DNA lesions (*i.e.*, single or double strand breaks) by measuring the migration of DNA fragments from immobilized nuclear DNA (Singh et al., 1988). The MN assay has been extensively used to study the clastogenic effects as micronuclei derived from chromosome breakages, which in fish and freshwater mussel gill cells have demonstrated high sensitivity for monitoring surface water and detecting the genotoxicity of drinking water (Minissi et al., 1998). Some studies have appeared that employed the comet and MN assays on zebra fish to evaluate the removal efficiency of genotoxicity in the anoxic–oxic process, showing a high incidence of MN frequency when the peripheral erythrocytes of fish were exposed to pollutants (Zhang et al., 2013). In addition, the MN frequency is associated with cancer prediction (Bolt et al., 2011).

This study was focused on application of a combined bioassay and chemical analysis approach to evaluate the potential genotoxicity and water quality risk of water samples treated by the recycling process in comparison with water samples treated by a conventional process. Based on this, a pilot WTP was constructed to conduct 15-day continuous recycling trials, and the genotoxicity of different water samples was assessed by comet and MN assays of zebra fish.

1. Materials and methods

1.1. Pilot-scale experimental setup and physico-chemical analysis

1.1.1. Pilot-scale experimental setup and procedure

A sketch of the pilot treatment processes is shown in Fig. 1, illustrating the conventional and recycling drinking water treatment processes, respectively. The design parameters of the recycling process units were the same as for the conventional process. The influent flow rate was 5 m^3/hr. The A unit contains two parts: one is a grid flocculation tank, with a bottom length of 1100 mm, a bottom width of 400 mm and a liquid height of 1700 mm, the other is a plate sedimentation tank, with a bottom length of 2100 mm, a bottom width of 800 mm and a height of 1600 mm. The plate component is composed of 63 plates with a tilt angle of 60° and interval of 20 mm. The B unit is a rapid filter tank with filtration velocity of 8 m/hr. The recycled sludge was stored in two custom-built sludge storage tanks, with a diameter of 1500 mm and a height of 1500 mm. The sludge was pumped to the head of the static pipeline mixer after being completely mixed. The whole process cycle time was 44 min. The WTP waste residual was collected in the grid flocculation tank (label A in Fig. 1) and rapid sand filter (label B in Fig. 1) of the recycling process every 24 hr, and then the waste residual was released to the sludge storage tank (label E in Fig. 1) and filter backwash water tank (label D in Fig. 1), respectively, through a diameter 100 mm PVC pipe.

The water treatment plant (WTP) waste residuals were recycled from tanks D and E to the head of the static mixer by a peristaltic pump *via* a rubber hose of diameter 10 mm and ensured that the residual could be completely reused under the optimal treatment combination. With this method, this pilot plant test was continuously operated for 15 days and the WTP waste residual could be repeatedly used many times until the determined parameters exceeded the sanitary standards for drinking water of China. To test the water quality stability of the recycling process and compare it with the conventional process, the turbidity, TOC, DOC, UV_{254}, SUVA and THMFPs of water from different sampling points (label C1, C2, C3, R1, R2, R3 and R4 in Fig. 1) were determined every day. However, for genotoxicity evaluation, the day 5, day 10, and day 15 were chosen as sampling times.

1.1.2. Coagulant and characterization of drinking water treatment plant (WTP) waste residuals

The polyferric aluminum chloride (PFAC) used was industrial grade (with content of 8.1% Fe_2O_3 and 3.3% Al_2O_3, basicity