

Factors Influencing UV Transmittance in Chemically-Enhanced Primary Treatment Effluents

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ABSTRACT

Low ultraviolet transmittance (UVT) in effluents of chemically-enhanced primary treatment (CEPT) plants can cause unsatisfactory UV disinfection performance. This paper investigates factors influencing the UVT in saline CEPT effluents using ferric chloride or alum as the coagulant. UVT loss is not associated with the chemical compositions in seawater. Dissolved iron is a strong UV absorber. However, the remaining iron in particulate and soluble forms in the supernatants was in very small quantities and contributed approximately 2-4% additional UVT losses. On the other hand, UVT is significantly affected by two major components: remaining dissolved organic carbons and suspended solids in the CEPT effluents. 50% UVT losses are attributable to the dissolved effluent organic matter (EfOM) in the CEPT effluents, which cannot be substantially removed by the CEPT processes. 20-40% UVT losses are attributable to the remaining suspended solids and UVT increases with decreasing suspended solid concentration in the effluents. Results from jar tests with different dosages of ferric chloride- and alum-based coagulation revealed that the UVT in the ferric chloride-coagulated effluent is similar to or lower than that in the alum-coagulated effluent. Larger volume percentages of particles with diameters less than 10 μm were found in the effluents coagulated with ferric chloride than those coagulated with alum and particles with this size range have larger impacts on UVT than those with relatively larger diameters do.

Key words: ultraviolet; ultraviolet transmittance; coagulation; disinfection; sewage; wastewater

INTRODUCTION

Pilot tests on UV disinfection performance were conducted in two chemically-enhanced primary treatment (CEPT) plants in Hong Kong - Siu Ho Wan Sewage Treatment Plant SHWSTW (using alum as the coagulant) and Stonecutters Island Sewage Treatment Works SCISTW (using ferric chloride as the coagulant). Ultraviolet transmittances (UVT) of the effluents in both plants are sometimes below 30%.

Ultraviolet transmittance (UVT) of a solution is the percentage of light intensity that can pass through a 10 mm path length of the solution over the initial light intensity of the blank, measured by a spectrophotometer using a specified wavelength of 254 nm (Whitby & Palmateer, 1993). It indicates the percentage of UV energy in the water that is available for inactivation of pathogens. The main constituents in wastewater that affect UVT include suspended solids, iron and humic materials, etc. (Savoye et al., 2001). Suspended particles in unfiltered water reduce the effectiveness of UV disinfection because they absorb, scatter, and block UV lights (Qualls et al., 1983). UV lights absorbed by particles are not available for

disinfection. Scattered lights reduce available UV energy by increasing the path length of traveling through a water medium, leading to dissipation of UV energy into the water column (Huber & Frost, 1998). Suspended particles also block UV lights by shading and shielding microorganisms. Numerous attempts have been made and demonstrated that suspended particles with diameters greater than 10 μm shield coliform bacteria from UV exposure, particularly when bacteria are closely associated with particles (Jolis et al., 2001; Emmerick et al., 2000). Particles smaller than 2 μm in diameter are sufficient to protect viruses from UV lights (Templeton et al., 2005). Iron possesses strong UV-absorbing characteristics (Jacangelo et al., 1995; Clarins et al., 1993) and different floc structure enmeshes phages and protects them from UV lights to different extents (Templeton et al., 2005). Effluent organic matter (EfOM) comprises a wide range from low to high molecular weight compounds. Examples of such compounds include polysaccharides, proteins, amino-sugars, nucleic acids, humic and fulvic acids, organic acids, and cell components (Barker et al., 2000; Rebhun & Manka, 1971). Humic substances are a major portion of dissolved organic carbon (DOC) in secondary wastewater effluents and the most UV-

absorbing organic substances (Templeton et al., 2005; Qualls et al., 1983; Bitton et al., 1972). The more aromatic and hydrophobic the EfOM of the effluent, the higher the UV absorbance (Krasner et al. 1996).

This study investigates factors influencing UVT in CEPT effluents using either ferric chloride or alum as the coagulant. Since seawater is used for flushing purposes and contributes to 25-30% of the saline sewage flow, the effects of seawater compositions on UVT are also evaluated. The contributions of UVT losses from seawater compositions, residual coagulants, suspended solids, and EfOM are assigned.

METHODS AND MATERIALS

All chemicals used were reagent-grade and used without further purification. Dilutions were achieved with Maxima Ultra Pure water. Solutions were stored in 4°C and were brought back to room temperature before uses.

Collection and Characterization of Effluents and Seawater

Raw sewage and effluent samples were collected from three sewage treatment plants in Hong Kong. All sewage samples were preserved at 4°C. Suspended solids (SS), turbidity, DOC, UVT and iron content of raw sewage and effluent samples were measured. Seawater samples were collected from the Port Shelter near the Hong Kong University of Science and Technology, Hong Kong. Concentrations of sodium, magnesium, calcium, potassium, chloride, sulfate, bicarbonate and bromide ions in the filtered seawater samples were checked.

Jar Test Procedure

A standard jar testing device (Stuart Scientific) was used to simulate a conventional coagulation/flocculation/sedimentation process that is used as the CEPT process in Hong Kong. The jar testing procedure was initiated with rapid mixing at 120 rpm for 1 min, immediately followed by slow mixing at 30 rpm for 20 min and then settling for 30 min. A control without coagulants was also conducted in parallel. Different amounts of coagulants (ferric chloride and alum) were added and tested. The jar tests were carried out at 21±1°C and the solution pH was unadjusted. After each test, the supernatants were sampled and subjected to measurement of SS, volatile suspended solids (VSS), turbidity, particle size distribution, DOC, pH, total iron content (if ferric chloride was used) and unfiltered UVT. In addition, soluble iron content (if ferric chloride was used) and filtered UVT were measured after samples were filtered with 0.45 µm glass fiber filters. The difference between the concentrations of total and soluble iron is assigned as the concentration of particulate iron.

Chemical Analyses

Suspended solids and VSS were measured according to the Standard Methods (APHA, 1995). Turbidity was measured using a turbidimeter (Hach model 2100A). DOC was

determined by a Total Organic Carbon Analyzer (Shimadzu TOC-5000A). UVT was analyzed with a UV-Visible Spectrophotometer (MultiSpec-1501, Shimadzu or Spectronic 3000, Milton Roy) at a wavelength of 254 nm using a standard 1-cm quartz cuvette. The pH was measured with a pH meter equipped with a high performance probe (Corning 350). A particle size analyzer (Coulter LS230) was used to determine the particle size distribution of samples. Soluble metallic ion content was analyzed using an atomic absorption spectrometer (Hitachi, Z-8200) equipped with a nitrous-oxide/acetylene flame after filtration. A microwave digestion system (MDS2000) was employed in total iron measurement to dissolve particulate iron into the soluble form. Concentrations of anions were examined by ion chromatograph (Dionex DX 500) using the IonPac AS9-HC column. All water quality parameters were measured in triplicate and the arithmetic mean was reported.

RESULTS AND DISCUSSION

Effect of Seawater Compositions

As expected, the eight major ions in seawater individually gave UVT at 254 nm of over 98% at their concentrations measured and the overall UVT at 254 nm of seawater collected in Hong Kong is 94%. Thus, the contribution of UVT losses from seawater in the Hong Kong saline sewage is expected to be less than 2% and is negligible, since at most 30% of the saline sewage is seawater.

Effect of Coagulant Dosages and Concentrations

Different dosages of alum (50, 75, 100, 125 and 150mg/L) and ferric chloride (20, 40, 60 and 80mg/L) were added in the jar tests to evaluate the effects of coagulant types and concentrations. Increasing coagulant dosage improved suspended solid removal and resulted in higher UVT values (Figure 1). However, the concentrations of DOC remain relatively constant (with slight decline), indicating the UVT losses attributable to DOC cannot be controlled by the CEPT process. Figure 2 summarizes the relationship between the remaining SS concentrations of unfiltered supernatants versus the UVT values of the filtered and unfiltered supernatants collected at different coagulant dosages. The filtration step removed SS from and left dissolved materials in the supernatants and thus the UVT values in the filtered supernatants remained relatively constant. The remaining dissolved materials, presumably strong UV-absorbing organic matter measured as DOC in majority, contribute to around 50% of UVT losses. Another dissolved material that may contribute to the UVT losses in the filtered supernatants is the remaining dissolved or particulate iron. However, based on the concentrations of residual dissolved and total iron in the CEPT effluents, their contribution to the UVT losses are calculated to be no more than 3.8%. Residual alum does not reduce UVT.

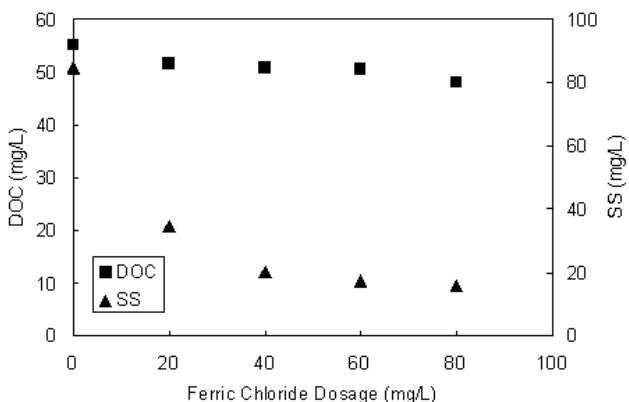
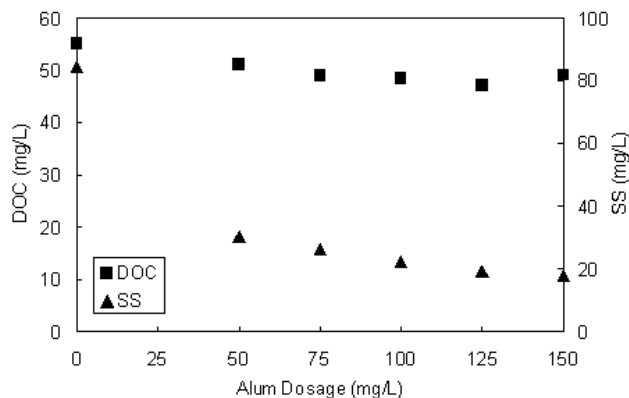


Figure 1: Concentrations of DOC and SS in coagulated effluents as a function of a) alum and b) ferric chloride dosages.

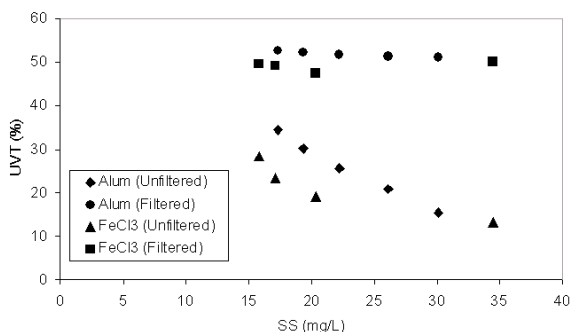


Figure 2: Relationship between UVT and concentrations of suspended solids in filtered and unfiltered CEPT effluents.

Figure 2 also shows that decreasing SS concentrations increases UVT values. By subtraction of UVT losses attributable to the dissolved materials (measured after filtration) from the overall UVT losses, the net UVT losses attributable to SS are also significant (approximately 20-40%).

An interesting observation in **Figure 2** is that, at some similar remaining SS concentrations, the remaining SS in the ferric chloride-coagulated supernatant gave more UVT losses (approximately 10% more) than that in the alum-coagulated supernatant. These 10% more UVT losses can be

partially attributed to the residual iron in the supernatant, which gives less than 4% UVT losses, as aforementioned. Another contribution is the difference in particle size distribution. **Figure 3** displays the particle size distributions of the supernatants treated with 150 mg/L alum and 60 mg/L ferric chloride. It should be noted that the remaining SS concentrations of the two supernatants are similar and about 17 mg/L. As shown, the ferric chloride-coagulated supernatant has larger volume percentages of particles in diameters of less than 10 μm and the alum-coagulated one has larger volume percentages of particles in diameters of 10-40 μm . Our side experiment shows that particles with smaller diameters have larger impacts on UVT than that with larger diameters do, in consistency with the observation above.

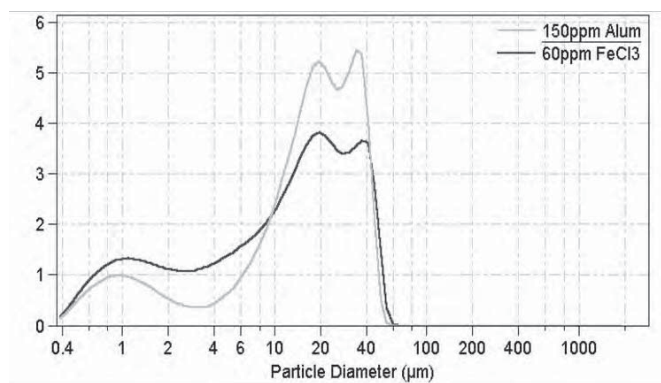


Figure 3: Particle size distributions in coagulated effluents treated by adding 60mg/L ferric chloride and 150mg/L alum.

SUMMARY

In saline CEPT effluents, contributions of UVT losses from compositions in seawater and from residual iron (if ferric chloride is used) are negligible and minor, respectively. Two major reasons attributable to low UVT in the CEPT effluents are: 1) the dissolved UV absorbing substances, presumably EfOM, that cannot be removed by the CEPT process and contribute to 50% UVT losses (in the current study) and 2) the remaining suspended solids that contributes to 20-40% UVT losses, depending on the remaining suspended solid concentrations. Ferric chloride-based coagulation yielded higher UVT losses than did alum-based coagulation at the same remaining SS concentrations. The presence of more particles in diameters less than 10 μm after ferric chloride-based coagulation contributes the additional difference.

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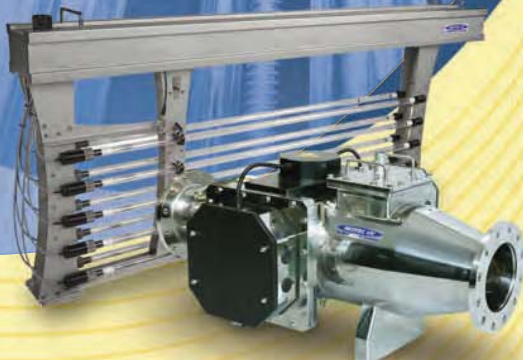
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