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Effect of suspended solids in secondary wastewater effluent on DOC removal by enhanced coagulation

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ABSTRACT

Wastewater recycling is increasingly seen as a sustainable solution to meet the increasing water demand. However, organic matters and suspended solids (SS) affects its treatment, distribution and use in many different ways, including fouling of membrane when membrane process is adopted. Enhanced coagulation can effectively remove both SS and organic matters, consequently increasing the performance of membrane. However, it is still unknown how dissolved organic carbon (DOC) removal is affected by the presence of SS, especially when microbes and bio-molecules are present in the effluent. Thus, this study aims to investigate the impact of SS on DOC removal by enhanced coagulation (with ferric chloride), from secondary wastewater effluent (SWWE). Results indicated two-stage DOC removal for a single coagulation pH over lower and higher doses of coagulant. In the first stage, DOC removal was compromised when SS was present at concentrations as low as 8.8 mg/L, suggesting removal of SS prior to coagulation is important for effective DOC removal and sludge reduction.

Keywords: Enhanced coagulation; Suspended solids; DOC removal; Adsorption

1. Introduction

Wastewater reuse is increasingly seen as an essential strategy for the sustainable use of limited fresh water resources. However, the SWWE needs additional treatment to remove various organic matters and SS although majority of them were removed during conventional treatment process. In this context, physico-chemical treatment such as enhanced coagulation may offer promising solution in wastewater recycling in removing these residual from SWWE.

Coagulation is the destabilization of colloidal particles usually of very small size often encountered in water and wastewater treatment [1]. Those colloidal particles in wastewater are known to carry an electrical charge in aqueous solution. Most of them carry negative charge. However, the primary charges on the particle are counter balanced by charges in aqueous phase resulting in an electric double layer at every interface between solid and water. The forces of diffusion and electrostatic attraction spread the charge in the water around each particle in diffusion layer [2]. This process continually changes the colloids chemically and makes them able to overcome the forces maintaining the stable suspension, promoting ag-

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gregation and the formation of larger particles called floc. Such removal achieved through series of destabilization and precipitation, particularly compression of diffusion layer, adsorption to produce charge neutralization, enmeshment of precipitate and adsorption to permit inter particle bridging [1,3,4].

An essential feature of wastewater coagulation is the elimination of SS and much of the organic material as possible [5]. Coagulation with hydrolysing metal salt followed by sedimentation and filtration has traditionally been used to remove suspended particles, which cause turbidity in source water [6]. Later, it has been extensively used with higher doses of coagulant with pH adjustment for the removal of organic matters in addition to suspended solids [7–9]. Thus, it is an important process in wastewater recycling considering its ability to remove organic matters.

The removal of organic matters by coagulation depends on various factors such as DOC concentration, the nature of the DOC, coagulant type, dose and pH of the solution. In addition, the chemical properties of organic matter that provide negative charge to the functional groups such as molecular weight size and hydrophobicity also influence the coagulation [10,11].

Further, the removal of organic matters has become increasingly important in light of its potential to form carcinogenic DBPs [12], to reduce membrane fouling [13] and to reduce biofouling of conduits carrying recycled water pipes. The US Environmental Protection Agency (USEPA) Disinfectants/DBP (D/DBP) Rule of 1998 mandates that utilities remove pre-determined concentrations of total organic carbon (TOC) as a means to reduce DBP precursors [14] and identifies enhanced coagulation as the best available technology for drinking water treatment. More the removal of DOC, better will be the disinfectant decay and hence less DBP production [15].

The previous investigations showed that the broad principles of enhanced coagulation are now reasonably well understood. However, the uncertainties resulted due to suspended solids on enhanced coagulation has still been overlooked. As a result, more coagulant is needed for the removal of given DOC. The optimization of coagulant is a great deal of concern for the efficient removal of organic matter as it reduces the sludge. Thus, this study aims to investigate the quantitative effects on DOC removal efficiency during enhanced coagulation resulted due to SS present in SWWE.

2. Study and objectives

The performance of enhanced coagulation was studied over two different SWWE. The investigation was undertaken for SWWE with or without SS. Thus, the aim of this study was to understand the quantitative effect of SS on reducing the efficiency of coagulant in terms of DOC removal in SWWE.

3. Material and methods

3.1. Source water

The SWWE from Beenyup wastewater treatment plant (BWTP) was mainly used in this investigation, although wastewater from Woodman Point Wastewater Treatment Plant (WPWTP) was used for the generalization of the experimental results. The wastewater in both plants predominantly came from household kitchens, bathrooms, toilets and laundries. Wastewater entering the plant contained more than 99% of water. The BWTP uses an advanced secondary treatment incorporating a conventional activated sludge process with biological nutrient removal. The primarily treated wastewater is blended with the microbiological biomass, to form mixed liquor in reinforced concrete aeration tank. The diffused air is applied to provide oxygen for the microbiological process that breaks down the organic compounds in the primarily treated wastewater. Then, biologically active sludge that settles in these tanks is continuously removed and returned to the aeration tanks to sustain microbiological population there and the overflow from the sedimentation tanks is the final treated SWWE. In WPWTP, it is first aerated before being settled. The settling allows the purifying micro organisms to settle to the bottom of tank and clean, treated wastewater is then decanted from the top.

3.2. Analytical measurements

Two parameters mainly DOC and SS were measured in this investigation. DOC was measured using 5310C laboratory total carbon analyser connected to auto sampler. The instrument measures total carbon (TC) and inorganic carbon (IC), and subtracts IC from TC to determine DOC. As samples were analysed after filtering through the 0.45 μm pre-washed (with 200 mL of milli-Q water to eliminate contamination from membrane) cellulose acetate (CA) filter paper, the measured value is the DOC. This machine uses UV persulphate oxidation for the measurement of DOC. This instrument has an analytical range of 30 ppb to 50 ppm and utilises SM5130 for USEPA compliance monitoring of raw and finished drinking water. The instrument's measurement error is within 5%. SS was measured following Standard Methods 2540 D [16]. Filter paper was first washed with DI water then dried for 1.5 h at 105°C followed by weight measurement. Then sample was filtered through pre-washed dried filter and dried at 105°C again. The increase in weight was measured again. The process was repeated for three samples to minimize the error and weight was also measured in triplicate. Then, SS present in the sample was calculated by taking an average of three different samples. The pH of the sample was measured using Hach® pH meter.

3.3. Enhanced coagulation

The enhanced coagulation/flocculation process was undertaken by applying various doses of ferric chloride ($FeCl_3.6H_2O$) between 2.5 mg/L and 160 mg/L. The pH was adjusted using sodium hydroxide and sulphuric acid, each with 1 M concentration. Samples were then put into jar tester and stirred at 200 rpm for 2 min followed by 20 rpm for another 20 min. The pH of coagulated water was also measured during the mixing and was adjusted continuously. Then, these samples were allowed to settle for 30 min before filtration for measurements for DOC.

4. Result and discussion

4.1. DOC removal in BWTP and WPWTP

This section basically deals with the performance of coagulant on SWWE obtained from BWTP and WPWTP. The pH was varied from 5 to 9 and the coagulant was added within the range of 2.5–160 mg/L. The result obtained during the jar test is presented in Fig. 1. This figure clearly illustrates the two-stage DOC removal for lower and higher range of coagulant dose. The first one covers 0–10 mg/L coagulant dosing. In this step, about 6% DOC was removed by 2.5 mg/L dose, but a further increase in dose up to 10 mg/L did not impact the removal as DOC was reduced only by 1%. The second step covers the dose more than 10 mg/L. Beyond this range increased coagulant dose continuously increased the DOC removal.

Similarly, SWWE of WPWTP was also analysed to know if it also shows two stage DOC removal or not for the two different range of coagulant. Enhanced coagulation was undertaken over a pH range of 5–9 and coagulant dose of 2.5–80 mg/L. The previous trend of DOC removal repeated despite a different SWWE. As illustrated in Fig. 2, the first stage continued until 10 mg/L as in BWTP effluent with no significant improvement in DOC removal on increasing coagulant dose. Increasing coagulant dose beyond this dose showed similar trend and achieved better DOC removal (65%) at a coagulant dose of 80 mg/L. As more DOC removal was obtained at pH 5, the rest of the investigation was undertaken only at this pH.

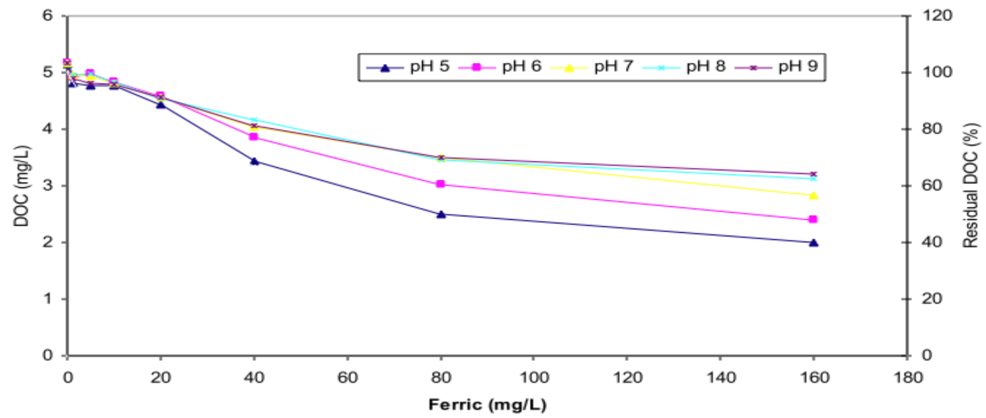

Fig. 1. DOC removal for Beenyup secondary wastewater effluent.

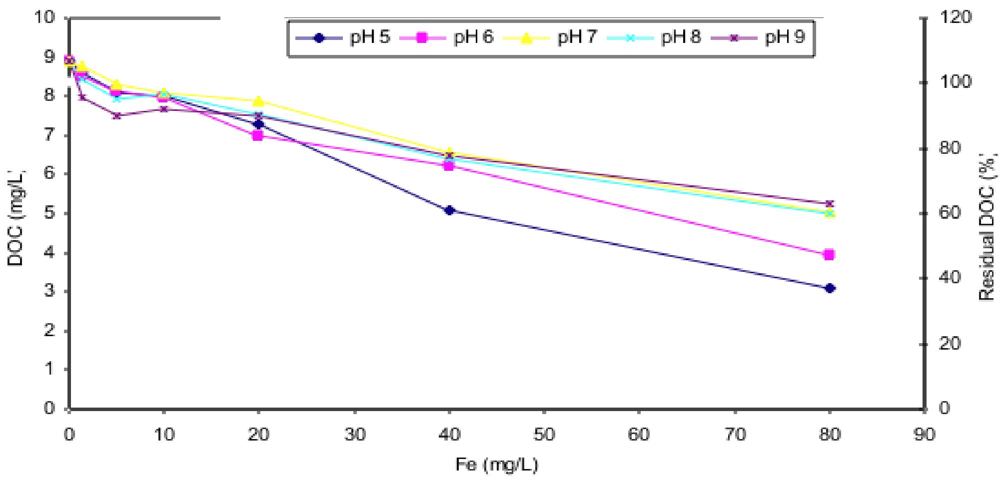

Fig. 2. DOC removal in Woodman Point secondary wastewater effluent.

4.2. Anomalous behaviour of wastewater for lower range of coagulant

Fig. 3. juxtaposes the normalized performance of coagulant of North Richmond (NR) drinking water and wastewater collected from BWTP and WPWTP. As can be seen in the figure, increased coagulant in NR water resulted in increased DOC removal indicating normal behaviour with single stage DOC removal. However, DOC removal from SWWE passed through two different stages. This abnormal phenomenon was found to be present in both wastewater effluents indicating some reasons behind the increased coagulant demand with uncertainties in DOC removal. This could possibly be due to the SS present in a SWWE, which is very much different from widely reported SS in surface waters. As a result, smaller doses of coagulant were ineffective, only to overcome an impact of such SS, especially the bacterial flocs. In order to understand this, another experiment was undertaken by filtering the SWWE, which is explained in Section 4.3.

4.3. DOC removal in 0.45 μm filtered wastewater effluent

The ineffective performance of coagulant over a lower dose undertaken in two different secondary effluents indicated additional coagulant demand to overcome initial resistance exerted, possibly due to additional SS. Thus, their possible impact was evaluated by removing them prior to enhanced coagulation. For this, SWWE was first filtered using 0.45 μm pre-washed CA filter paper in order to remove all SS present in it and filtered water was then subjected to enhanced coagulation.

The performance of coagulant was then studied within the range of 2.5–80 mg/L at pH 5. The result is presented in Fig. 4. Overall removal of 60% was achieved and residual DOC was reduced to 3.37 mg/L from 8.35 mg/L with addition of 80 mg/L coagulant, which is more than

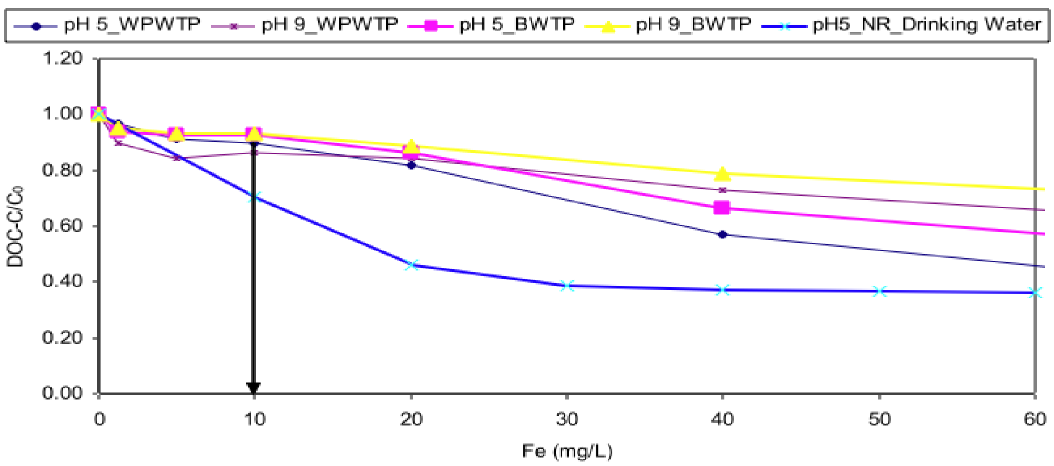

Fig. 3. Normal and anomalous behaviour of coagulant in drinking and wastewater (NR result was adopted from Kastl et al. [17])..

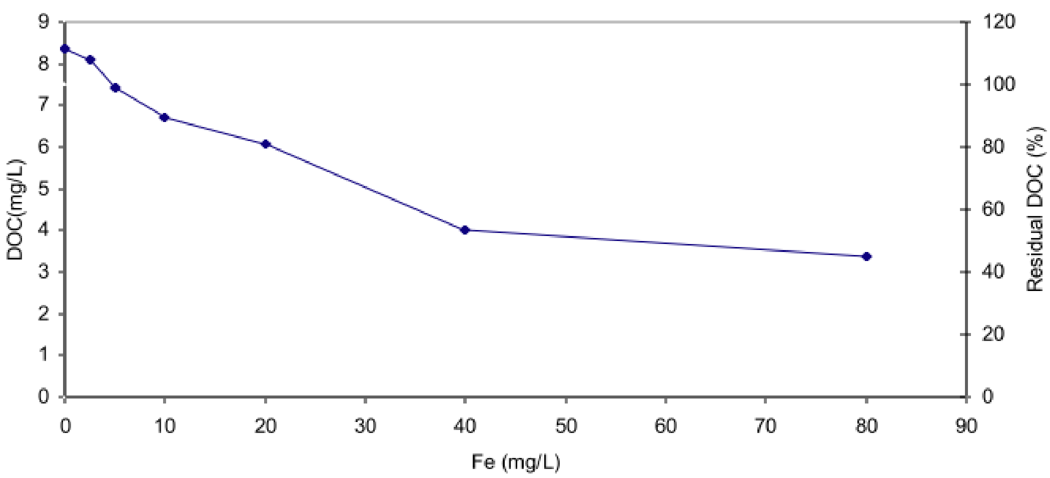

Fig. 4. Performance of enhanced coagulation on filtered SWWE.

the percentage removal in unfiltered secondary effluent. In addition, the experimental result clearly showed the single stage DOC removal, unlike in unfiltered effluent. For both lower and higher dose of coagulant range residual DOC was decreased with increased coagulant dose. This indicates the initial disturbance resulted in unfiltered sample was due to SS present in it.

4.4. Role of suspended solid on performance of enhanced coagulation

Fig. 5 illustrates the normalized DOC removal obtained during enhanced coagulation over filtered and unfiltered sample and the improved performance resulted due to removal of SS. The SS was measured to be around 8.8 mg/L in unfiltered secondary wastewater effluent, and was removed by filtration through 0.45 μm filter paper. Then the performance of coagulation was evaluated over the same range of coagulant at pH 5. As can be seen in the figure, addition of 2.5 mg/L coagulant in unfiltered SWWE removed 3% DOC. Increasing the coagulant dose to 10 mg/L achieved no additional removal. Only beyond this point DOC removal increased with coagulant dose. However, 2.5 mg/L coagulant in filtered sample removed 3% DOC and doubling the dose increased the removal efficiency to 11% which is significantly higher than the efficiency in unfiltered sample. Similar enhanced performance was observed throughout the applied range of coagulant with single stage DOC removal regardless of lower or higher coagulant dose.

Experimental evidence showed that, the initial disturbance for the lower doses was due to SS present in SWWE. The SS, about 8.8 mg/L, possibly used certain amount of coagulant for charge neutralisation and consequently deprived DOC removal resulting in inefficiency particularly in lower range of coagulant dose. This resulted in two-stage DOC removal in the wastewater. Apart from this, the efficiency of DOC removal was increased after the filtration of SS. The overall removal efficiency with addition of 80 mg/L coagulant at pH 5 was also increased from 55% to 60% with filtration. This clearly indicates the role of SS in wastewater effluent on reducing the efficiency of DOC removal by coagulation, by changing the flocs capability to adsorb dissolved organics. It, therefore, leads to the hypothesis that DOC removal is not achieved by charge neutralisation but by adsorption onto ferric hydroxide flocs as proposed by Kastl et al. [18]. Coagulant demand by SS or colloids present in the water sample for charge neutralisation can seriously affect the DOC removal by enhanced coagulation.

5. Conclusions

Wastewater effluent contains varying levels of SS and dissolved organic matter, depending on the performance of wastewater treatment plant performance. SS and dissolved organic carbon can significantly affect many end uses, treatment and distribution needs. Enhanced coagulation is one of the cheap options. An investigation was undertaken to quantify the effect of SS on DOC removal. The experimental results showed SS, as low as 9 mg/L, can greatly increase the coagulant demand by showing two-stage DOC removal behaviour. The behaviour in the first stage (0–10 mg/L coagulant dose) showed increase of coagulant did not significantly increase the DOC removal. In addition, its prior removal can greatly enhance the DOC removal of coagulant.

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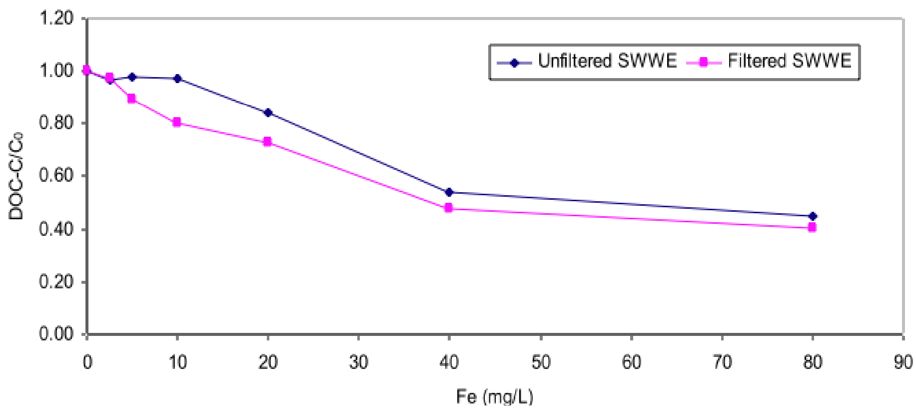

Fig. 5. Improved performance of enhanced coagulation after filtration.

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