Effect of coagulant and flocculant addition scheme on the treatment of dairy farm wastewater
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ABSTRACT

Our group was approached by a manufacturer of treatment trains to recycle wastewater from dairy farm manure. Company X treatment trains consist of microscreening, sedimentation and filtration units attached to a reverse osmosis (RO) membrane. To enhance screening, a coagulant and a flocculant are added to the stream feeding the microscreen. However, their customers experience foaming on the microscreen as well as frequent fouling of the RO membranes. This study aimed to identify the source of foaming and to optimize the performance of the treatment train. Results show that interactions between the alum coagulant, the polymer flocculant and the contaminants are the cause of foaming. Addition of silicon polymer antifoam A effectively reduced foaming, while maintaining the same removal of total suspended solids (TSS) and total organic carbon (TOC). Alternatively, we proposed a new reagent addition scheme which circumvents back-to-back addition of the polymer flocculant and the alum coagulant. The proposed scheme resulted in significant reduction in foaming and ~50% increase in TSS and TOC removal, even at the 40% lower dose of the cationic polymer. In addition to the economic benefit, a low concentration of left-over polymer should alleviate the fouling of the RO membrane.

Key words | antifoam, coagulation, flocculation, membrane, total organic carbon, total suspended solids

INTRODUCTION

Description of the problem

Company X builds trains targeting the treatment of wastewater from livestock farming. The treated water may be reused in the barn, while recovering raw manure and a concentrated fertilizer stream for land spreading. Their train removes coarse and fine suspended solids, dissolved solids and soluble organics. The treatment process consists of the following major units: bulk solids removal, fine solids removal, polishing filter, reverse osmosis (RO), final water polishing and a reject water concentrator. Figure 1 is a flow diagram showing the major units of the company X treatment train. The coarse and fine solids removal units include a microscreen followed by a sedimentation tank. The wastewater stream feeding the microscreen from an equalization tank is almost simultaneously impregnated with alum as a coagulant and cationic polymer flocculants, in order to promote large floc formation and separation on the screens. The same chemicals also promote separation of the fine solids in the clarifier. Of course, part of the added flocculant will travel with the water stream as a water-soluble polymer and will likely make it to the RO unit. However, RO manufacturers warn against the use of cationic polymer flocculants, since they interact with the membrane material leading to low recovery ratios. In addition, customers complain about frequent foam buildup on the microscreen.

Foam adversely impacts the performance of the micro-screen and the clarifier. Foam blocks screen openings and, hence, hinders the flow of solid-free water and leads to messy spills. Furthermore, foam traps air which causes fine solids to float rather than settle in the clarifier unit.
Foaming ultimately results in loss of water and ineffective settling of fine solids, which contribute to lower overall recycling capability as well as lower efficiency of the downstream units, including the polishing and the RO membrane filtration. In addition to foam formation, possible adsorption of the cationic flocculant onto the RO membrane material leads to a lower recovery ratio. We hypothesize that the added chemicals, i.e. coagulant and flocculant, and/or interactions between the added chemicals and the wastewater result in the formation of surface active products that are capable of trapping air and producing foam. Further, an overdose of the flocculant promotes the migration of un-flocculated cationic polymers to the RO unit. Therefore, two objectives were set for this study. The first looked at identifying the source of foam formation, its stability and its impact on the settling process. The second explored optimizing the treatment train through manipulating the amount and location of coagulant and flocculant addition.

LITERATURE REVIEW

Coagulation, flocculation and screening

The use of coagulation and flocculation in wastewater treatment is well established. The reagents involved destabilize colloidal suspensions as well as soluble contaminants and produce big flocs that are easily removed by settling or filtration. Metal salts are effective coagulants and function through neutralizing the surface of the colloids and soluble species by virtue of their hydrolysis of monomeric and polymeric species (Stumm & O’Melia 1968; Tchobanoglous et al. 2003; Crittenden et al. 2005). For example, alum removed 42% of chemical oxygen demand (COD) from textile wastewater (Altinbas et al. 1993), and 50 ppm FeCl₃ removed 60% of COD from slaughterhouse wastewater (Núñez et al. 1999). The use of limestone powder achieved as high as 90% total solids removal from swine manure, where CaO in the powder acted as a coagulant and the other insoluble constituents helped to enmesh the colloidal particles (Barrington et al. 2004). Polymer coagulants and flocculents, on the other hand, destabilize colloids through surface neutralization and interparticle bridging, especially ionic polymers (Stumm & O’Melia 1968; Reynolds & Richards 1996; Tchobanoglous et al. 2003; Crittenden & Harza 2005). Polymer CupriDyne™ superabsorbent, for example, removed 32% of the total suspended solids (TSS) from a concentrated swine manure stream and 80% from a diluted stream (Chelme-Ayala et al. 2011). Combining the two types of reagents may prove even more effective. A combination of alum and cationic polymers removed 40% of the dissolved organic nitrogen and dissolved organic carbon from surface water (Lee & Westerhoff 2006). Metal salt coagulants followed by cationic polymer flocculants were also effective for the removal of suspended solids and nutrient...
from manure streams (Jordaan et al. 2010). For example, alum resulted in almost 80% TSS removal from swine manure and the addition of cationic polymers increased the removal to 95% (Jin 2005). The use of metal salts and polymers for manure pretreatment before gravity drainage and press filtration resulted in sludge with low water content (Hjorth et al. 2008). In addition, the metal salts neutralized the charged particles and precipitated phosphorous in the form of $\text{PO}_4^{3-}$. The polymers, on the other hand, increased the size of the flocs and, hence, the efficiency of settling and filtration. It is believed that flocculation was mainly accomplished by interparticle bridging, since optimum removal was achieved at 30% of the dose needed for complete neutralization. Upon increasing the polymer charge density, less polymer was needed to achieve optimum turbidity removal. The addition of $\text{FeCl}_3$ increased phosphorous removal, whereas it had no significant effect on turbidity removal unless a branched polymer was used. Finally, overdosing the polymers resulted in de-flocculation, where smaller floc size formed due to curling of the polymers.

Sedimentation is an effective solid–liquid separation technique for manure treatment. Sedimentation was reported to remove 64% of the total solids (Mukhtar et al. 1999). Alternatively, mechanical screening can be used. The addition of coagulant, such as alum or $\text{FeCl}_3$ and polymers, increased the screening efficiency as a result of forming a dense floc. The TSS removal of a dairy manure having 3.2% (wt/wt) total solids increased from 64.1 to 98.7% upon the addition of 540 mg/l of chitosan, a natural flocculant, to the stream feeding the 0.25 mm screen (Garcia et al. 2009). Approximately 98% removal of TSS was achieved by addition of polyacrylamide followed by sand filtration and 1 mm screening (Vanotti et al. 2002). For nutrients, polyacrylamide addition achieved 62 and 76% total nitrogen and phosphorus removal, respectively, which corresponded to 89 and 91% organic nitrogen and phosphorus removal, respectively. In addition, the use of polymer prior to sand filtration improved liquid drainage and prevented filter clogging (Vanotti et al. 2002). Lastly, a combination of alum and Colfloc RD-Ciba cationic polymer was used to treat dye; however, the precipitation and filtration were hindered by foaming (Golob et al. 2005). The use of antifoaming agent, nevertheless, improved precipitation and filtration performance.

**Foaming and coagulant effect on foam stability**

The occurrence of foam is attributed to the presence of surface active agents in the water, where their molecules get adsorbed onto the water–air interface resulting in repulsive forces among approaching bubbles. High molecular weight surfactant, e.g. beta lactoglobuline and sodium lauryl sulfate, and proteins produce more stable foam than foam stabilized by commercial detergents (Prins 1999). Systems containing either polymers or surfactants produce more stable foam than when the two are combined (Wilde 2000). For example, rod-like polymers stabilize foam better than spherical particles (Horozov 2008). Nevertheless, upon addition of sodium dodecylsulfate (SDS), the foam destabilized. Adsorption of the polymer onto SDS made the polymer more hydrophilic, and hence polymer molecules migrated to the bulk aqueous phase leaving behind less stable air bubbles. Hydrophobic solid particles produce an even more stable foam than surfactants, since the solids tend to be more hydrophobic (Horozov 2008) and their adsorption onto surfaces is irreversible (Binks & Murakami 2006; Binks et al. 2010). In presence of hydrophobic silica nanoparticles, greater foam stability was achieved relative to the surfactant alone, due to the reduction in the desorption rate (Binks et al. 2010). Furthermore, high surfactant concentration leads to water drainage from among the air bubbles and foam destabilization. At the other extreme, highly hydrophobic particles may also work as antifoaming agents and destabilize foam sustained by surfactants when such particles display high affinity toward the surfactant, which ultimately strips the surfactant molecules away from the surface (Binks et al. 2010).

Decreasing the pH of a suspension containing silica particles improved foam stability (Binks et al. 2007), by virtue of reducing their zeta potential, and as they became more hydrophobic, more of them participated at the interface. The same trend and explanation apply to increasing the salt concentration (Binks et al. 2007). For the hydrophilic polystyrene latex particles, no foam was observed until the dispersion approached the coagulation conditions with the addition of metallic salts and/or cationic surfactant which rendered the particles hydrophobic (Binks 2002). Suzuki & Maruyama (2002) studied the effect of coagulation and surfactant and protein
addition on air flotation. According to their findings, the addition of SDS surfactant or casein protein following coagulation enhanced flotation and foaming, which ultimately enhanced turbidity removal, especially for casein. Coagulated solids adsorbed readily onto the bubbles and their adsorption increased as their hydrophobicity increased. Casein produced a more hydrophobic floc, and hence gave better results than SDS. Salinity as well as surface active agents originally existing in wastewater helped improving the performance of casein. For the surfactants, salinity reduced surface tension and promoted the foaming capacity of the surfactants. It should be noted that dairy manure contains casein, which represents a high percentage of the proteins in the milk.

Flocculation coupled with air flotation was employed for oil removal from oily wastewater (Suzuki & Maruyama 2005). The addition of polyaluminum chloride coagulant helped to make the solid interface more hydrophobic, which promoted adsorption of flocs onto the air bubbles and floatation of the emulsified oil. However, further increase in the coagulant led to settling of the flocs instead of floatation. The addition of casein improved the adsorption of the flocs onto the bubbles, since casein neutralized the colloid surfaces, especially for pH range 6–8. It is worth noting that aluminum hydrolysis species carry positive charges in this pH range, while casein carries negative charges.

Finally, short chain species such as salts and sugars can also stabilize foam by reducing the hydrophobic attractive forces between the bubbles (Craig et al. 1993). Gonzenbach et al. (2006) used short chain amphiphiles, such as carboxylic acid and alkylamines, in concentrated silica and alumina suspensions (15–45% by vol.) and produced high-volume foams by mechanical frothing of the suspensions. The resulting foam was highly stable and its stability was attributed to the strong attachment of particles at the air-water interface.

**EXPERIMENTAL METHODS**

Company X’s treatment train was simulated by bench-scale batch units subjected to mixing and residence time. Contaminant concentrations were compared between the batch units and the field data in order to ensure appropriate representation of the field train.

**Investigating the source of foam and its stability**

To identify the source of foam in company X’s treatment train, experiments in the presence and absence of floculants and coagulants were performed. The first experiment aimed to investigate whether foam originates from compounds existing in the feed wastewater stream. For this experiment, air was sparged into raw wastewater without addition of coagulants or floculants. Fifty milliliters of wastewater was placed in a graduated cylinder and air at 0.19 ml/min was sparged from the bottom for 5 min. Once sparging was stopped, the time needed for the foam to disappear was recorded.

The other experiments aimed to study whether foam originates from interactions between the coagulant (alum), the cationic polymers (X4–X7) and/or a combination of both and the wastewater. For these experiments, control samples were run in distilled water. Doses of coagulant and cationic polymers similar to those typically employed by company X were used, namely 1,920 mg (4 ml) of the 48% (wt/wt) alum stock solution and 600 mg (120 ml) of the 0.5% (wt/wt) cationic polymer solution floculant per liter of the raw wastewater. Upon addition of the coagulant and/or the polymer floculant to the 50 ml distilled water, or wastewater, the samples were vigorously mixed using a vortex mixer for 2 min and, then, placed in a graduated cylinder for the air sparging step. Once sparging was stopped, foam volume was recorded with time.

**Investigating total suspended solid and total organic carbon removal**

This set of experiments aimed to evaluate the effectiveness of company X’s treatment train in removing the TSS and total organic carbon (TOC). Six milliliters 0.5% (wt/wt) cationic polymer solution and 0.2 ml of the 48% (wt/wt) alum stock solution were added to 50 ml of the raw wastewater and vigorously mixed using a vortex mixer for 1 min. The sample was then filtered using a No. 60 screen (average pore opening 250 μm). The screen was placed in the middle of a funnel and the screening time was recorded.
The TSS level of the filtrate was measured using Hach DR/890 colorimeter (Hach Company, CO, USA). After measuring the TSS level, 1 ml of the cationic polymer solution was added to the sample, followed by mixing for 1 min and then settling for 30 min. This addition simulates the addition of the second dose of flocculant as depicted in Figure 1 (location 1). After settling, a sample of the supernatant was collected from the middle of the beaker using a syringe, and the TSS level was measured. The supernatant was further filtered using a Whatman qualitative filter paper grade 2 (8 μm pore size), and TSS level of the filtrate was measured. Only the filtrate obtained from X4 flocculant, the most commonly used polymer, was assessed for its TOC content. The filtrate was analyzed for its total carbon (TC) and inorganic carbon (IC) using a total organic carbon analyzer, TOC-VE (Shimadzu Corporation, Kyoto, Japan). The TOC was obtained as the difference between TC and IC. At least three replicates were prepared for all of the samples, and the mean and the 95% confidence intervals are reported in the figures.

Addition of an antifoaming agent

Antifoaming agent was added to the raw wastewater to be treated with X4 flocculant. Different masses of antifoam A concentrate (100% active silicon polymer, Sigma Aldrich, ON, Canada) were added to 50 ml of raw wastewater to obtain a final concentration of either 25 or 50 mg/l prior to addition of any chemicals. The samples were mixed for 2 min before 6 ml X4 flocculant and 0.2 ml alum coagulant were added to the sample as practiced by company X. The samples were vigorously mixed using a vortex mixer for 2 min and then placed in a graduated cylinder for the air sparging step. Once sparging was stopped, foam volume was monitored with time as previously indicated. TSS and TOC measurements were performed according to the above procedures.

Proposed addition scheme

An addition scheme of the flocculant and coagulant resulting from this work was proposed, and was tested with X4 flocculant only. In this scheme, only the cationic polymer flocculant was added to the raw wastewater before micro-screening. Either 6 or 3 ml of 0.5% (wt/wt) X4 cationic polymer was added to 50 ml of raw wastewater. The sample was then filtered through the microscreen and the TSS level of the filtrate was measured as described above. A volume of 0.2 ml of 48% (wt/wt) alum coagulant was added to the filtrate and mixed for 1 min and left for 5 min to settle. An additional 1 ml of X4 cationic polymer was added to the sample, as typically practiced by company X, and mixed for 2 min, followed by settling for 5 min. After settling, the sample was screened using the 250 μm micro-screen and the TSS level was measured. Lastly, the sample was further filtered using a Whatman qualitative filter paper grade 2 (8 μm pore size), in order to mimic the polishing filtration step of Figure 1, and TSS and TOC content were measured. Figure 2 depicts a block diagram of the proposed addition scheme.

RESULTS AND DISCUSSION

Foaming and foam stability

Foaming and foam stability of the wastewater were tested in the presence and absence of added chemicals. Figure 3 plots the initial foam volume and its stability, expressed as time needed for foam to collapse, for treated and untreated samples with alum and/or polymer flocculants. Figure 3 suggests that the raw wastewater has only minor ability of produce foam with a maximum foam volume of 5 ml which only lasted for 2 min (using a 50 ml sample). The addition of alum slightly increased the foam volume and foam stability. This suggests that the interaction between the contaminants in the wastewater and alum may have resulted in slight activation of otherwise surface inactive species, especially knowing that the control samples containing the same dose of alum in distilled water displayed a maximum of 2 ml foam volume which disappeared within 1 min. Therefore, the less likely explanation is that alum, as a salt, is capable of stabilizing foam by reducing the hydrophobic attractive forces between the air bubbles (Craig et al. 1995).

The addition of one of the cationic polymers, X4–X7, to the wastewater did not have a significant effect on foam volume or stability. It should be noted that the control samples in distilled water displayed similar results to those...
shown in Figure 3, in the absence of alum, a maximum of 5 ml with 2 min lifetime. Possible hydrolysis of company X cationic polymers may have resulted in decrease of their foaming capabilities in a similar fashion to hydrolyzed proteins (Townsend & Nakai 1985). Hydrolyzed polymers/proteins possess higher degree of hydrophilicity, which promotes migration of the species from the interfacial region to the bulk aqueous phase.

When both cationic polymer and alum were added to the wastewater (shaded bars in Figure 3), the foam volume and stability were the highest for all of the different polymers. This increase was nevertheless more pronounced for X4 and X5. Comparison with the control samples containing the same doses of the cationic polymer and alum in distilled water, which produced a maximum foam volume of 4 ml with 2 min lifetime, reveals that interactions between
the cationic polymers, alum and the contaminants in the wastewater resulted in the formation of stable, surface active species and, hence stable foam. Binks (2002) reported that the use of metallic salts and cationic polymers increased foam stability by increasing the hydrophobicity of polystyrene latex particles and the most stable foam volume was obtained at metallic salts and cationic polymer concentrations that correspond to surface neutralization and bulk coagulation. Suzuki & Maruyama (2002) reported that flotation and foaming are enhanced by the addition of casein protein after coagulation, since flocs resulting from coagulation have a higher tendency to adsorb onto the air bubbles as a consequence of increasing their hydrophobicity.

**Addition of an antifoaming agent**

To provide a quick recipe for solving the foaming issue of the current company X treatment train, silicone polymer antifoaming agent, antifoam A concentrate, was added to the raw wastewater stream feeding into the microscreen as in Figure 1. The rest of the chemicals, i.e. flocculants and coagulants, were added per company X’s practice. Two doses were tested, 25 and 50 mg/l. Figure 4 depicts detailed results for the 50 mg/l dose. This dose completely eliminated foaming, while a dose of 25 mg/l of the antifoam restricted foam volume to a maximum of 2 ml and less than 2 min lifetime. Antifoam treatment presumably provides company X customers with a quick solution to their foaming issue with no impact on the performance of the current treatment train as reflected by the TOC and TSS levels of Figure 4.

**Proposed treatment scheme**

A new scheme was proposed, which maintains the addition of the first dose of the flocculant into the feed stream, while delaying the coagulant addition until the stream goes into the settling tank as shown in Figure 2. The second flocculant dose is still added to the settling tank, however, after 5 min following the coagulant addition.

Figure 5 compares typical TSS levels from company X field train and that of the bench-scale batch units from our laboratory. The results were deemed comparable and provided enough confidence that the bench-scale system indeed replicates the field treatment. The slight improvement on the TSS level after the microscreen can be attributed to the fact that a smaller pore size microscreen was used in the bench-scale units, 250 μm compared with 300 μm, for the field train.

The proposed addition scheme in Figure 2 resulted in 88 ± 19 mg/l TSS in the stream leaving the first microscreen (location 1, Figure 2), which represents about 65% improvement in TSS removal relative to the current scheme. Moreover, the flocs formed when only the cationic polymer

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**Figure 4** TSS and TOC levels for the current company X treatment scheme with 50 mg/l (solid gray) and without (solid black) antifoaming agent. Locations 1–3 are shown in Figure 1.
was added to the feed stream was bigger and clogging of the microscreen was less frequent. For example, it took the filtrate \(<1\) min to pass through as opposed to \(\sim 4\) min using the current company X treatment scheme. Keeping the results of foaming experiments in mind, it is evident that the complexation between the cationic polymer, alum and the contaminants, which resulted in highly stable foam and smaller floc size, was avoided in the proposed scheme.

For the clarifier unit, following company X’s current scheme (location 2, Figure 1), the resulting floc after the second cationic polymer addition was not intact and any agitation or turbulence resulted in resuspending the solids, which prevented the collection of a clear supernatant for TSS measurement. When alum was added to the clarifier in the proposed scheme, the wastewater appeared clearer. However, the floc was also not intact. Upon addition of the second polymer dose to the clarifier, 5 min after the addition and mixing of the alum, the floc promptly clustered and floated to the surface. Removal of the clustered floc was easily accomplished by the second microscreen (location 2, Figure 2). Alternatively, skimming could be used, since the clustered floc was very intact. Subsequently, the proposed treatment scheme would be more compatible with a simple skimming tank than the more sophisticated and more expensive settling tank. It is, nevertheless, recommended that many more wastewater streams be tested before a decision to make such a change can be reached. Employing the proposed scheme, the filtrate leaving the second microscreen (location 2, Figure 5) had a TSS level of \(94 \pm 28\) mg/l, which is slightly higher than the feed to the clarifier (location 1, Figure 5). Although one might think that part of the clustered floc may have passed through the microscreen, as will be shown later, addition of alum in the clarifier resulted in converting a significant amount of dissolved solids to suspended ones. The newly formed suspended solids might not have been incorporated into the clusters to the same extent. Nevertheless, the suspended solids which escaped the second microscreen could be easily captured in the polishing filter (location 3, Figure 2).

The current company X treatment scheme resulted in TSS level of \(130 \pm 10\) mg/l in the stream leaving the polishing filter (location 3, Figure 5). The same stream contained \(180\) mg/l TSS per field data. In the proposed treatment scheme, the TSS level of the stream leaving the polishing filter was approximately \(19 \pm 11\) mg/l (location 3, Figure 5). This speaks to the nature of the TSS resulting from the proposed sequence of addition, especially knowing that the polishing filter used in our bench-scale experiments had \(8\) \(\mu\)m pore size while the one employed by the field train has \(1–5\) \(\mu\)m pore size. Larger flocs produce lower TSS levels in the filtrate, and in the meantime, minimize the frequency of filter clogging and the frequency of backwashing.

Figure 6 shows that all of the cationic polymers employed by company X display very similar performance in terms of TSS reduction following the proposed treatment scheme.

![Figure 5](https://iwaponline.com/jwrd/article-pdf/5/3/271/377460/jwrd0050271.pdf)
Proposed scheme with 40% lower polymer dose

Keeping in mind the interaction between the cationic polymer and the RO membrane material and its impact on membrane fouling, the investigation was extended to evaluate the effect of reducing the cationic polymer dose by 40%. This reduction involved lowering the first polymer dose by 50%, while maintaining the second dose as shown in Figure 2. Only X4 polymer was used in this study. Figure 7 shows that following the proposed scheme, the TSS level for the stream leaving the first microscreen (location 1, Figure 7) was approximately 585 ± 91 mg/l, which is significantly higher than company X current treatment scheme. It is worth noting that ensuring quiescence is essential for the reproducibility of the results as the precipitate could very easily be dispersed. Nevertheless, when the stream leaving the microscreen was treated with the same alum dose in the clarifier followed
by the second polymer dose (location 2, Figures 2 and 7), the TSS level dropped to 78 ± 15 mg/l. This TSS value is significantly lower than that currently obtained by company X’s treatment scheme. Furthermore, the sludge obtained when the polymer dose was reduced to 40% was more intact than even when the full dose was added. The resultant sludge was also easily removed by skimming the surface without the need for a second microscreen.

Following the polishing filter, approximately 35 ± 24 mg/l TSS was obtained using the proposed scheme (location 3, Figure 7). The proposed scheme displays very high overall reproducibility of the TSS level in the stream leaving the polishing filter and does not seem to be affected by the ease of redispersion encountered at the first microscreen (location 1, Figure 2).

Reducing the polymer dose reduced foam volume, where the resultant foam had a maximum volume of 4 ml and disappear within 2 min. Figure 8 compares the TOC level for the stream leaving the polishing filter for company X’s current treatment train, 318 ± 17 mg/l, the proposed treatment train using the same dose, 109 ± 6 mg/l, and the proposed treatment train using 40% lower overall polymer dose, 138 ± 11 mg/l. This result, again, speaks to the many advantages that could be attained using the proposed treatment scheme with lower dose.

**CONCLUSIONS**

This study explored the foaming problem arising at the microscreen of company X’s treatment train. Foaming causes water spills from the microscreen as well as a decline in the efficiency in all the units that follow. Results show that the interaction between the added chemical, i.e. the alum coagulant and the cationic polymers, with the contaminant in the wastewater is the main cause of foaming. It is believed that an interaction between the reagents and the contaminants in the wastewater contributes to hydrophobic species that tend to adsorb onto the surface of the air bubbles leading to stable foam. The addition of antifoaming agent to the raw wastewater was very effective at preventing foam formation and did not impact TSS and TOC removal, without the need to modify the reagent addition scheme.

Another approach was proposed in this work involving addition of only the flocculant to the raw wastewater and delaying the addition of the coagulant until the clarifier. This approach significantly reduced the foam volume and stability and improved TSS and TOC removal to a large extent, which would alleviate RO membrane fouling. Moreover, using the proposed scheme, 40% lower flocculant dose was possible, while maintaining the same performance in terms of foam reduction, TSS and TOC removal. Lower cationic polymer dose is most likely to relieve the RO unit from
the frequent fouling encountered in the current treatment train of company X.

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REFERENCES


Reynolds, T. & Richards, P. 1996 Unit Operations and Processes in Environmental Engineering, 2nd edn. PWS, Boston, MA, USA.


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