

## Coagulation optimisation for NOM removal by direct filtration in clay aggregate filters

Torgeir Saltnes, Bjørnar Eikebrokk and Hallvard Ødegaard

### ABSTRACT

Optimisation of the coagulation step in a coagulation/direct filtration process in which filtration takes place in a lightweight expanded clay aggregates (Filtralite) filter is investigated. The water is high in NOM but low in turbidity, a situation frequently found in Norwegian lake water. Experimental studies in a pilot-scale direct filtration plant compare filtration efficiencies for different coagulants and coagulation conditions. Type of coagulant and coagulant dose are optimised as well as the pH of coagulation for four different coagulants. It is demonstrated that the biopolymer chitosan is a very interesting alternative coagulant in this particular process situation. Also poly-aluminium chloride (PAX) is superior to the traditional metal-salts, aluminium sulphate (ALG) and ferric chloride sulphate (JKL) in terms of turbidity and residual metal. Coagulation with ALG and JKL results in a certain floc-particle (turbidity) 'leakage' from the clay aggregate filter, while such 'leakage' is not equally evident when PAX and chitosan are used for coagulation.

**Key words** | chitosan, coagulation, direct filtration, expanded clay aggregates, humic substances

**Torgeir Saltnes** (corresponding author)  
NTNU-Norwegian University of Science and Technology,  
Dept. of Hydraulic and Environmental Engineering,  
N-7491 Trondheim,  
Norway  
Fax: +47 73 59 12 98  
E-mail: [torgeir.saltnes@bygg.ntnu.no](mailto:torgeir.saltnes@bygg.ntnu.no)  
and  
Optiroc AS,  
PO Box 216 Alnabru,  
N-0614 Oslo,  
Norway

**Hallvard Ødegaard**  
NTNU-Norwegian University of Science and Technology,  
Dept. of Hydraulic and Environmental Engineering,  
N-7491 Trondheim,  
Norway

**Bjørnar Eikebrokk**  
SINTEF Civil and Environmental Engineering,  
Dept. Water and Wastewater,  
N-7465 Trondheim,  
Norway

### INTRODUCTION

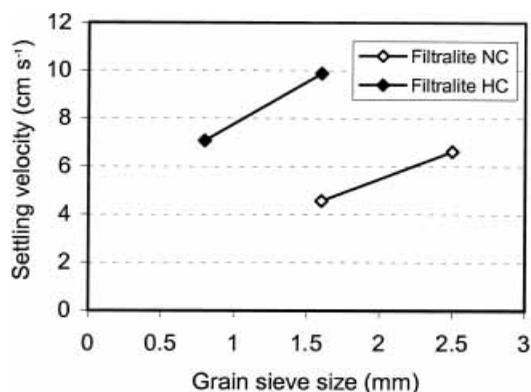
The removal of humic substances is a major challenge in water treatment in Norway as well as in many other parts of the world. When (in humic water) the coagulation process is optimised with respect to turbidity removal, a treated water high in dissolved organic matter may result, with the risk of forming disinfection by-products (DBPs). In the USA so-called 'enhanced coagulation' with pH and coagulant control is recommended for the optimisation of humic substances removal. Nevertheless, turbidity is still a very important process control parameter and an indicator of pathogens (i.e. *Giardia* and *Cryptosporidium*) removal efficiency.

The raw water in Norway is quite often surface water with low turbidity and relatively high colour levels (Ødegaard *et al.* 1999). Temperature varies with season and is normally between 2 and 15°C. A traditional coagulation/direct filtration treatment plant involves pH control, coagulation (usually with a metal-salt), filtration,

disinfection and pH-, alkalinity- and calcium-adjustment (corrosion control).

Coagulation by metal-salts (i.e. aluminium sulphate) in a conventional dual media anthracite/sand filter optimised for humic substances removal, may result in short filter runs if the dose required is high and so also the suspended solids production. In order to increase water production capacity there is a need for improvement of the traditional filter systems. Increased filter run times can be achieved by increasing the deposit storage capacity in the filter.

Residual metal in treated water usually determines the minimum coagulant dose requirements for coagulation of low-turbidity, humic waters (Eikebrokk 1999). The solubility of the metal is dependent on pH, temperature and content of organic substances as well as other dissolved compounds. The strength and size of the hydroxide precipitate (or hydroxide-humic precipitate) has an



**Figure 1** | Settling velocity of Filtralite filter grains as a function of grain size for the two different densities used.

important effect on the filterability of the flocs, and can lead to increased residual metal in the filtrate. Metal-containing deposits and residual metal in treated water are therefore the main technical and economic challenges for many water works. If a cationic, biodegradable polymer (i.e. chitosan) could be used, the problems connected to residual metal in treated water and disposal of metal-containing sludge would be eliminated.

## EXPANDED CLAY AGGREGATE FILTERS

The experiments reported here were primarily carried out in order to optimise the coagulation process for filtration in an expanded clay aggregate filter (Filtralite filter). The clay aggregates are made from the burning of clay at about 1,200°C, followed by crushing and sieving to the desired size fraction. The aggregates can be produced with an inverse relationship between size and density, and this make them ideal for coarse-to-fine down-flow filters. Down-flow filters that are regularly backwashed, should ideally have a decreasing grain size and an increasing grain density in the direction of flow. Settling velocity tests as described by Ives (1990) for the filter grains were performed on two types of Filtralite grains with different densities. These tests showed which size fractions of grains would combine successfully and prevent intermixing of the two filter layers. As demonstrated in Figure 1

there is no overlapping in settling velocities for the two filter grain qualities.

The filter grains used were coarser than in a conventional water treatment filter for this type of application. The idea behind this was to increase the deposit storage capacity in the filter bed. According to filtration theory, however, small particles are more effectively removed in a filter with small grain sizes. An increase in grain size can be compensated for, to some extent, by increasing the depth of the filter layer (Ives and Sholji 1965; Moran *et al.* 1993). On the basis of this theory and by comparing with the filter bed used by Eikebrokk (1999) for the same application, a Filtralite filter bed was designed. Total filter depth was chosen to be the same as for the reference filter in order to see if it was possible to compensate for larger grain sizes by modifying the pre-treatment, without increasing the depth of the filter bed. However, the bottom layer depth was slightly increased to optimise the filter bed within the mentioned limits. Head loss distribution plots were also used to optimise the design of the filter, but the results are not included in this paper. The Filtralite filter had a top layer of 47 cm and grains with a wet particle density of about 1,200 kg m<sup>-3</sup> and size 1.6–2.5 mm (Filtralite NC, normal density, crushed), while the bottom layer had a depth of 47 cm with grains of a wet particle density of about 1,800 kg m<sup>-3</sup> and size 0.8–1.6 mm (Filtralite HC, high density, crushed).

## EXPERIMENTAL

The experiments were performed in a pilot-scale coagulation-direct filtration pilot plant with two filter columns as illustrated in Figure 2. One of the filter columns contained the Filtralite filter and the other a traditional anthracite/sand filter. The comparison between the two filters will be dealt with in another paper. The purpose of the experiments presented here was to identify the optimum coagulation conditions in terms of dose and pH for four different coagulants in the Filtralite filter.

A humic-concentrate (regenerant from an anion-exchange plant for humics removal) was added to tap

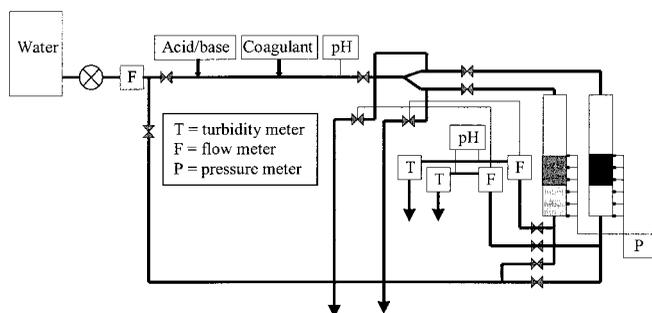


Figure 2 | The coagulation-direct filtration pilot plant.

water at a dose of about 0.06 volume % in order to prepare the raw water with a colour level of  $50 \text{ mg Pt. l}^{-1}$  and an organic carbon content of about  $5.5 \text{ mg l}^{-1}$  (TOC). Experiments were also performed with a raw water colour of about  $15 \text{ mg Pt. l}^{-1}$  and an organic carbon content of about  $2.5 \text{ mg l}^{-1}$  (TOC). Both the raw waters used had a turbidity  $<0.3 \text{ NTU}$ . Raw water temperature for the experiments varied between 5 and  $12^\circ\text{C}$ .

Hydrochloric acid was added for pH control and the coagulant was mixed in-pipe at a head loss of about 0.2 m. A much greater flow of water was coagulated ( $10 \text{ l min}^{-1}$ ) than supplied to the filters in order to get an accurate dose. After coagulation the flow was split and led to each of the two filter columns. The internal diameter of the filter columns was 123 mm, and the flow rate for all of the experiments was  $7.5 \text{ m h}^{-1}$  ( $1.5 \text{ l min}^{-1}$ ). The water flow was automatically controlled by use of a flow meter and a controller for each filter.

Four different coagulants were tested, aluminium sulphate (ALG), ferric chloride sulphate (JKL), pre-polymerised aluminium (PAX, with  $[\text{OH}/\text{Al}] = 1.05$  and 9.02 wt-% Al) and the cationic biopolymer chitosan (CHI, with a deacetylation degree of 93%), at different doses and pH levels. The doses and pH ranges were selected on the basis of experiments performed earlier (Eikebrokk 1999) in a dual media anthracite/sand filter on the same types of raw waters.

Table 1 shows the conditions under which the experiments were run. Flow rate, turbidity (Hach Company, model 1720D) and pH in and out of the filters as well as head-loss and head-loss distribution in the two filters were

measured on-line, displayed and stored. Samples of raw water and filtered water were taken for each run at a time when a stable turbidity was obtained (after about 2 hours) and analysed for pH, turbidity, true colour, total organic carbon (TOC as non-purgeable organic carbon, NPOC) and total metal residual (Al and Fe based coagulants). Samples of coagulated water were analysed for suspended solids, zeta-potential (Coulter Delsa L140 Se) and particle size (Coulter LS 230) (RW 50 only).

## RESULTS AND DISCUSSION

Optimum pH and dose conditions for the four coagulants were evaluated on the basis of treated water turbidity and residual metal as well as colour and TOC removal. Zeta potential and particle size measurements in coagulated water were used in order to evaluate the reason for the differences in performance. The coagulation conditions (dose and pH) selected as the optimum ones are listed in Table 2 for the four different coagulants. As demonstrated, the optimum pH generally decreases when the TOC in the raw water (and the coagulant doses) increase.

### Effect of pH

Figure 3 shows the results obtained in the Filtralite filter at 'optimum dosage' as a function of pH for the different coagulants. The 'optimum dosage' indicated in the figure was determined as a compromise between the filtrate turbidity and residual metal as well as the removal of TOC and colour. For the raw water RW 50, the optimum dosages were  $3.0 \text{ mg Al l}^{-1}$ ,  $7.0 \text{ mg Fe l}^{-1}$ ,  $2.5 \text{ mg Al l}^{-1}$  and  $4 \text{ mg l}^{-1}$  for ALG, JKL, PAX and CHI respectively.

From the graphs in Figure 3 it can be seen that the metal-salts (ALG and JKL) remove a higher fraction of colour and TOC than do the polymerised coagulants. JKL removes more than 90% of the colour and about 80% of the TOC and, compared with ALG, it gives a lower effluent turbidity over a wider range of pH. The wide pH range for effective coagulation with JKL can be seen in connection with the solubility of Fe(III) salts. The residual iron

**Table 1** | Experimental conditions for dose and pH optimisation (75 runs in total). Doses in mg l<sup>-1</sup> as Me or CHI, pH varied within the given range

Raw water 15 mg Pt. l <sup>-1</sup> (RW 15)								Raw water 50 mg Pt. l <sup>-1</sup> (RW 50)							
ALG		JKL		PAX		CHI		ALG		JKL		PAX		CHI	
Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH
0.6	5.3	1.5	3.9	0.4	5.6	1.0	5.1	2.3	5.0	5.5	4.2	1.9	5.2	3.0	4.7
1.0		2.0		0.8		1.5		3.0		7.0		2.5		4.0	
1.4	6.2	2.5	4.6	1.2	6.4	2.0	6.3	3.7	6.1	8.5	5.8	3.1	6.2	5.0	6.5

**Table 2** | Optimum coagulation conditions (in terms of dose and pH) selected for the two raw waters and the four coagulants used

Raw water 15 mg Pt. l <sup>-1</sup> (RW 15)								Raw water 50 mg Pt. l <sup>-1</sup> (RW 50)							
ALG		JKL		PAX		CHI		ALG		JKL		PAX		CHI	
Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH	Dose mg l <sup>-1</sup>	pH
1.0	6.2	2.0	4.6	0.8	6.0	1.5	6.0	3.0	5.7	7.0	5.2	2.5	5.8	4.0	5.0

graph shows that most iron is removed at a pH where the lowest filtered turbidity is obtained.

The rapidly increasing turbidity for ALG when increasing pH up to about 6 is caused by an increasing hydroxide precipitation, which has its optimum at about pH 6.5 (minimum solubility of aluminium hydroxide). This extra hydroxide precipitation has a negative effect on filter effluent turbidity. The pH increase does not decrease the removal of colour and TOC to any great extent, however. This supports the hypothesis that the poor turbidity removal is due to excessive formation of weak hydroxide-humic substance precipitates that lead to broken floc particles in the filter pores, rapidly penetrating the filter bed.

When coagulating with the pre-polymerised PAX the filtered turbidity is considerably lower than with ALG. This is probably due to the fact that the polymer-humic precipitates are stronger and more resistant to shear in the filter pores. Van Benschoten and Edzwald studied the formation of hydrolysis products from aluminium sulphate and polyaluminium chloride coagulation and

found that for the latter about 90% of the Al was in polymerised form (Edzwald and Benschoten 1990a). When investigating coagulation of a model suspension with kaolin clay, Gregory and Rossi (2000) found that PAX creates a larger floc size and stronger flocs than ALG. The predominant aluminium species in PAX-coagulants is the highly charged  $Al_{13}O_4(OH)_{24}^{7+}$  (Gregory and Rossi 2000). High charge for the hydrolyses product, allowing stronger electrostatic bonding with the humic substances, is one of the reasons for the good turbidity removal that is experienced with PAX. PAX coagulation results, however, in a high residual aluminium at pH 5.2 due to the solubility of the precipitate.

CHI gives excellent filter effluent turbidity but the removal of colour and TOC is lower than for the other coagulants, about 80% and 40%, respectively. When coagulating with CHI one is in fact adding organic carbon. CHI contains about 60 wt% TOC, and the relatively low TOC removal could partly be caused by residual CHI in the filtrate. Rough estimates show a possible contribution

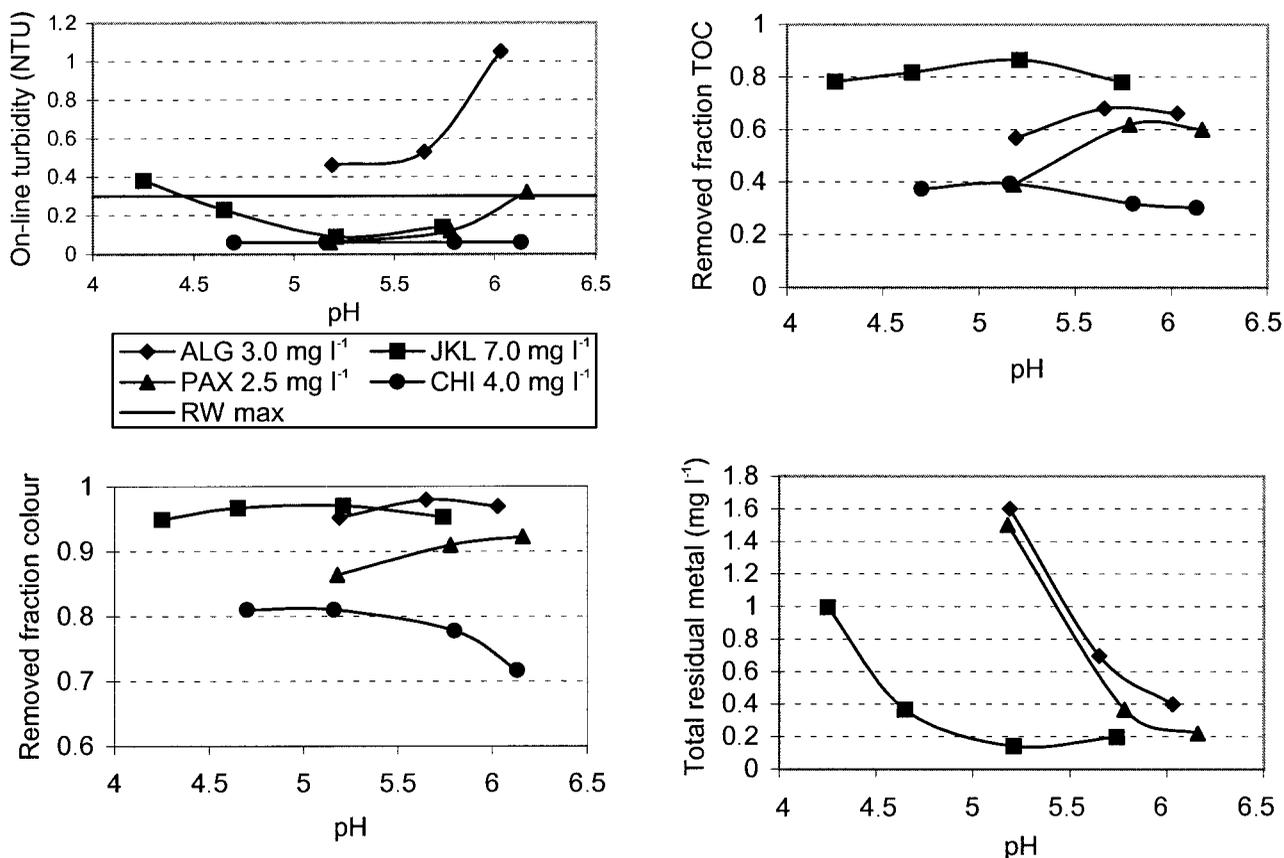


Figure 3 | Effects of coagulation pH on filtrate turbidity, removal of colour and TOC and residual metal obtained with RW 50.

of up to  $1 \text{ mg l}^{-1}$  TOC from CHI in the filtrate, at a dosage of  $4 \text{ mg l}^{-1}$ . Chitosan is a biodegradable substance and it is a risk that this leakage might lead to bacterial growth in the distribution system. There is no hydroxide precipitation and therefore CHI-coagulation does not create suspended solids in the form of hydroxide as the metal-containing chemicals do. It is demonstrated that the turbidity, colour and TOC removal is not influenced to any great extent by the change in pH from 4.7 to 6.2 for a dose of  $4.0 \text{ mg l}^{-1}$  CHI. This coagulant is not limited in pH by residual metal. This means that pH can be adjusted to the optimum value 5–5.5 without any problems, and only the cost of the pH adjustment has to be taken into consideration.

Each of the four coagulants has a relatively well-defined optimum pH range with respect to TOC removal. In general, the pH of optimum TOC and colour removal in

the filter does not differ much for the four coagulants. For the aluminium-based coagulants, the pH-range for minimum residual metal is, however, not in the same range as for minimum effluent turbidity.

### Metal residuals

In Norway the maximum residual metal allowed in treated water is as low as  $0.1 \text{ mg Me l}^{-1}$  when metal based coagulants are used. Residual metal is, therefore, the parameter that controls the coagulation conditions (pH and coagulant dose) in most cases.

Figure 4 shows the total residual metal content of the filtered water. The temperature of the water used was about  $10^\circ\text{C}$ . The solubility curves in Figure 4 are based on membrane filtered samples ( $0.2 \mu\text{m}$ ) of coagulated water from the pilot plant. For each of the two coagulants and

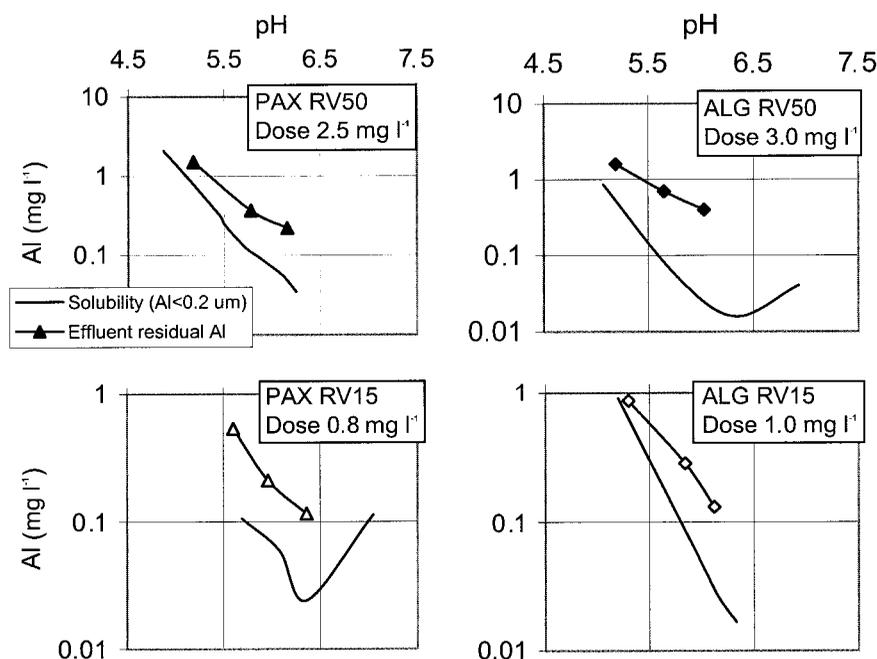


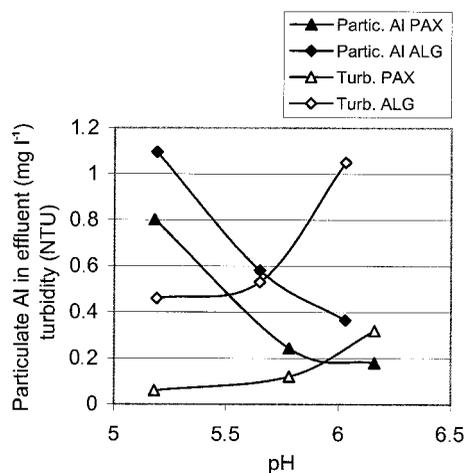
Figure 4 | Measured residual aluminium compared with the solubility of aluminium (filtered through 0.2  $\mu\text{m}$  for experiments with RW 15 and RW 50, coagulated with PAX or ALG.

the two raw waters, the samples were analysed for total aluminium after membrane filtration. As demonstrated, the solubility of Al is very high at low pH, with a minimum at about pH 6.5.

When comparing with the solubility curve, the residual aluminium is above the solubility curve for all the experiments. The solubility of aluminium is also influenced by the content of complex-forming organic matter in the water (Jekel & Heinzmann 1989; Van Benschoten & Edzwald). A large part of the Al occurs as positively charged species at pH below 5.5 and these species may easily form complexes with the negatively charged humics. The coagulation mechanism at low pH is probably dominated by charge neutralisation, as the dose added is not high enough to precipitate much aluminium hydroxide. At higher pH the increasing precipitation gives lower residual aluminium in the effluent both for PAX and ALG. The solubility of PAX is higher than for ALG for both raw waters in the actual pH range. This implies that for ALG coagulation there is more aluminium precipitated which results in an increased turbidity in the filtered water. The difference between the solubility of Al when PAX and ALG

are used as coagulants is probably caused by the different hydrolysis species formed and their characteristics.

The filterability of the flocs created with ALG and PAX is indicated by subtracting the soluble Al from the residual Al. This results in Figure 5 (for RW 50). The curves represent particulate aluminium in the effluent from the filter. This is compared with the effluent turbidity for the same experiments. It is known that metal hydroxide precipitates can be smaller than 0.2  $\mu\text{m}$  (Jekel & Heinzmann 1989), and these small colloids may to some extent penetrate the filter creating an increase in turbidity. Turbidity is also dependent on particle size with a maximum contribution from 0.2–0.3  $\mu\text{m}$  particles. Because of this, Al determined as soluble ( $< 0.2 \mu\text{m}$ ) could be causing turbidity in the filtrate. According to the particulate Al, the flocs are most filterable above pH 6 where the turbidity is at its highest. In direct filtration there is not much time between coagulation and filtration. If the kinetics of Al-precipitation is 'slow', due to cold water, for instance, the soluble part of Al before and in the filter is higher than in the effluent. If this is true, the time after coagulation and before filtration has to be increased in order to create



**Figure 5** | Residual particulate aluminium and on-line effluent turbidity for experiments with RW 50, coagulated with PAX or ALG.

more filterable flocs required for the big grain sizes in the Filtralite filter. The high value for particulate Al at low pH could also be caused by a pH difference in and out of the filter, leading to post-filter precipitation. Both the particulate Al curve and the turbidity curve indicate that the filterability of PAX flocs is better than that of ALG flocs.

The filterability of the Al-flocs is not good enough in the Filtralite filter to comply with the Norwegian standards for residual aluminium ( $0.1 \text{ mg l}^{-1}$  when metal-based coagulants are used). With ALG, the turbidity limit ( $<0.3 \text{ NTU}$ ) is also exceeded. Therefore, coagulation with chitosan, which does not create any problem with residual metal, is particularly interesting for this coarse grained filter bed.

### Effect of dose

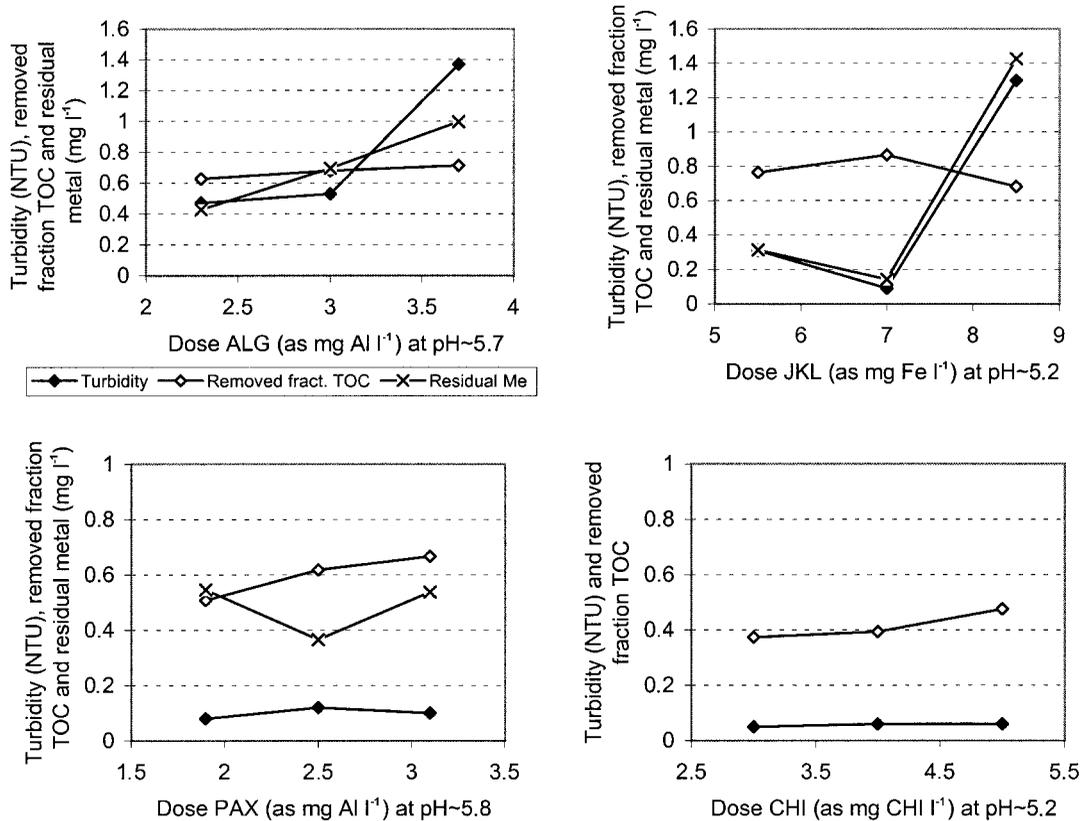
At the optimum pH for each coagulant three dose levels were selected in order to describe the effect of dose on the quality of the filtered water. The parameters chosen in order to evaluate the results were zeta-potential of coagulated water, on-line turbidity of filtered water, TOC removal and residual metal in the filtrate. Particle size distributions for coagulated water with RW 50 were also determined. In several instances, however, the coagulated water contained too few particles to get any significant

measurement, and the results did not show any systematic trends. Consequently they are not discussed in this paper.

In Figures 6 and 7 the results for the four different coagulants are presented. As shown in Figure 7, the particles made from ALG coagulation go through the expected stages of destabilisation and restabilisation as the dose increases. According to the solubility of aluminium hydroxide, the pH and the doses, different amounts of hydroxide are formed. Al- and Fe-hydroxide have a zero point of charge pH of 8–8.5. At the pH levels used in Figures 6 and 7, the metal hydroxide is positively charged. At low dosages the positively charged microcrystalline aluminium hydroxides adsorb humics, and some of the humics are probably baked into the hydroxides during precipitation. There is an excess of negatively charged humics and not enough hydroxide to obtain destabilisation. When the dosage is increased to  $3.0 \text{ mg Al l}^{-1}$  the surface area of the precipitate increases and humics adsorbed on the surfaces equal the amount needed to stabilise the particles. Increasing the dosage even more leads to restabilisation of the particles caused by an excess of hydroxide precipitate. When the increasing dose reaches the point of charge neutralisation of the suspension, it starts to flocculate. The flocs created with the humic substances in the water are probably weak and easily broken by shear in the filter pores. This leads to a dramatic increase in the filter effluent turbidity.

The increasing dose does not have the same effect on the removal of organic carbon. The reason for this might be that the flocs created in the high dosage region do not contain as much humic material as a result of the excess of hydroxide surface area. In other words, a part of the flocs that are broken, creating turbidity in the filter effluent, are hydroxide precipitates 'without' humics adsorbed on them.

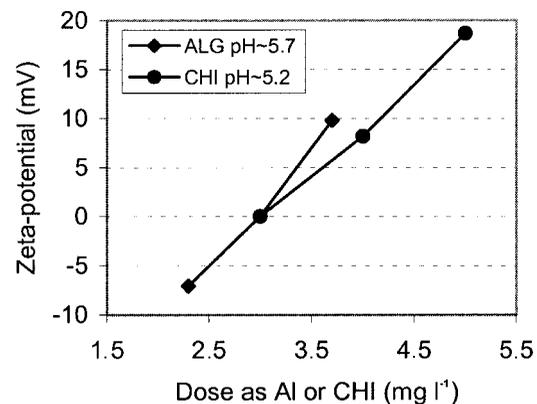
Looking at the results for CHI in Figure 6, not much is lost with respect to removal efficiency by decreasing the dose. The polymer-humic substances flocs created are stronger and more able to resist shear in the filter pores. In Figure 7 the positive zeta-potentials for CHI indicate 'over-dosing'. This does not influence the effluent turbidity in the same way as for ALG coagulation, because there is no hydroxide precipitation and therefore less suspended solids in the influent. Considering the high price of CHI,



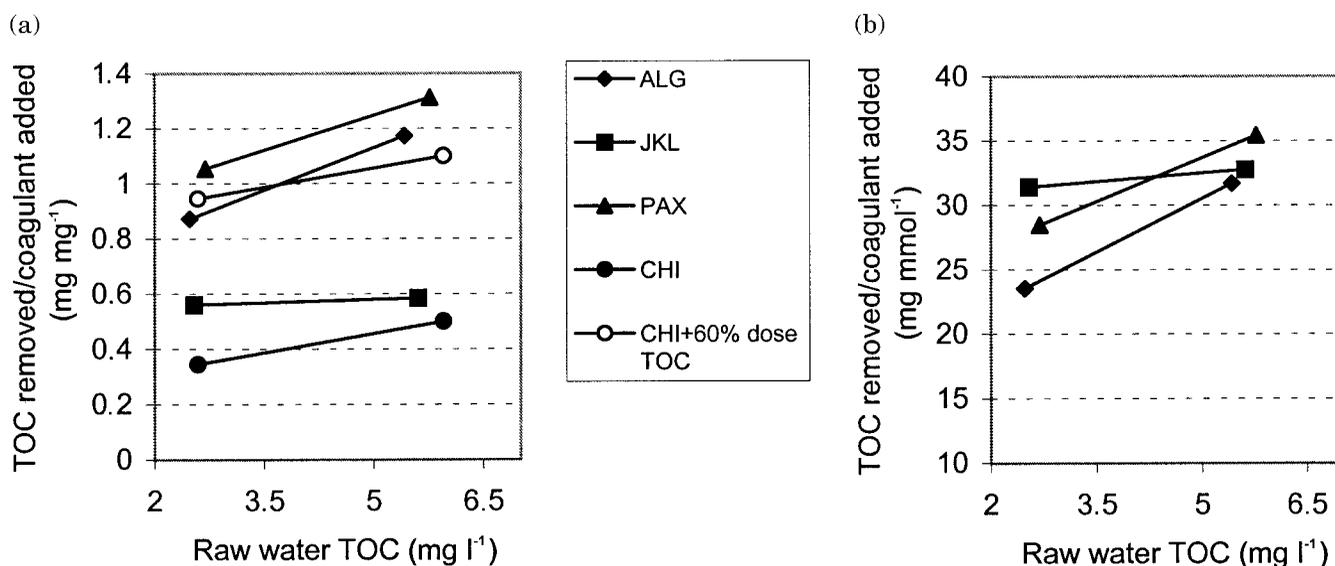
**Figure 6** | Effect of dose on on-line turbidity, residual metal and TOC removal for the Filtralite filter. Raw water of colour 50 mg Pt l<sup>-1</sup> (RW 50) was coagulated at pH values of 5.7, 5.2, 5.8 and 5.2 for ALG, JKL, PAX and CHI, respectively.

one could probably decrease the dose even further and still get a reasonably good removal of TOC.

Figure 6 demonstrates that the residual aluminium concentration is increasing with increasing ALG-dose. Again this proves that it is difficult to deposit the hydroxide-humic substance flocs (or broken flocs) in the Filtralite filter. By studying breakthrough and head loss curves of many contact filtration experiments, Rebhun (1990) found that detachment of the aluminium-humic substance flocs was extremely high due to the weak structure of the flocs. In conventional filters, the residual metal content is often higher for low doses than for higher doses (Eikebrokk 1999). The reason that this is not observed in the Filtralite filter is probably that the range of doses used was relatively narrow, and that more precipitate goes through this filter than a filter with smaller filter grains.



**Figure 7** | Effect of dose on zeta-potential for coagulated water. Raw water of colour 50 was coagulated at optimum pH 5.7 and 5.2 for ALG and CHI, respectively.



**Figure 8** | Specific TOC removal as a function of raw water TOC. (a) TOC removed/coagulant added (mg TOC per mg Me or CHI); (b) TOC removed per mmol coagulant.

Jekel and Heinzmann (1989) stated that if residual aluminium is higher than predicted for the given pH value, there might be an insufficient removal of colloidal precipitation products and the effluent turbidity should then be higher than about 0.1–0.15 NTU. In the case of JKL-coagulation the residual iron follows the trend of the turbidity, and they are both satisfactory at the optimum dosage. It is clear from the results for JKL that increased turbidity in the effluent when the dose is increased, is precipitated iron penetrating the filter. As a result of this the removal of TOC is reduced. The effluent turbidity is low for all the PAX doses used. The residual aluminium concentration in the PAX experiments is relatively high even though the turbidity is low. This is probably due to post precipitation caused by a pH change through the filter. If PAX is to be used with the Filtralite filter, the pH of coagulation has to be increased to more than 6 in order to comply with the residual metal standard.

### Effect of organic matter in the raw water

The experiments were performed on two raw waters with different levels of organic matter: RW 15 with a TOC of

about 2.5 mg l<sup>-1</sup> and RW 50 with a TOC of about 5.5 mg l<sup>-1</sup>. A fraction of the TOC is not caused by colour-causing carbon. Figure 3 shows that in the case of JKL-coagulation, it is possible to remove almost all of the colour (98%) but only about 85% of the TOC for RW 50. In Figure 8 all the experimental results for each of the coagulants are averaged and plotted as specific TOC removal (removed TOC/dose added) as a function of raw water TOC.

Figure 8 demonstrates that less coagulant is needed for a given TOC-removal when raw water TOC is high. This may indicate that the humic substances in RW 50 are easier to coagulate. Edzwald and Tobiasson (1999) use SUVA as an indicator for the nature of humic substances and the effectiveness of coagulation. SUVA is the specific UV absorbance as UV (254 nm) per unit DOC (mg l<sup>-1</sup>). For SUVA values greater than 4, it is considered that the humics are dominated by high molecular weight compounds and that they control the coagulation that gives a good TOC (and DOC) removal. SUVA values from 2 to 4 indicate lower MW humics and less TOC removal by coagulation. The SUVA values for the two raw waters used in these experiments were 3.7 and 4.9 for RW 15 and RW 50, respectively (Eikebrokk 1999).

When using JKL the influence of raw water TOC on TOC removal is not very strong. Coagulation with iron-salt seems to be less influenced by the SUVA relationship (the nature of the humic substances). The low values for  $\text{TOC}_{\text{removed}}$  in the case of JKL-coagulation (Figure 8a) are caused by the high molecular weight of iron compared with aluminium. When considering TOC removal per mmol coagulant, however, JKL is more effective than ALG (Figure 8b).

When coagulating with CHI one is adding TOC to the water which influences the removal of CHI in the filter bed. CHI contains about 60 wt% of TOC. Taking this into consideration by adding the CHI-TOC to that of the raw water, it is demonstrated in Figure 8a that organic matter is effectively removed with CHI by the filter.

## CONCLUSIONS

1. The experiments have shown that the combination of the relatively coarse Filtralite filter and chitosan as coagulant is a very interesting alternative to the traditional coagulation/direct filtration scheme (dual-media filter with metal coagulant). When using chitosan as coagulant the Filtralite filter produced a low turbidity water and residual metal is of no concern for this coagulant.
2. Of the metal-based coagulants, the best overall results were obtained with the poly-aluminium chloride (PAX)-coagulant.
3. The widely used aluminium sulphate (ALG) does not produce satisfactory water quality in the coarse Filtralite filter. It is not possible to combine good turbidity removal with low residual aluminium in the effluent. The filterability of the flocs is not satisfactory.
4. A removal rate of 80% colour and 40% TOC (for a raw water with a TOC of about  $5.5 \text{ mg l}^{-1}$ ) was achieved with chitosan as coagulant. For raw water with a colour of  $15 \text{ mg Pt. l}^{-1}$  the removed fraction of colour and TOC obtained is less than for a more coloured raw water.
5. Taking into account that chitosan is a biodegradable biopolymer (made from waste shrimp and crab shells) and that it produces less and metal-free sludge, it is a very interesting coagulant even though the price is relatively high.
6. The optimum dosage and pH for coagulation for metal-based coagulants are often controlled by the residual metal content of the effluent. When PAX is used in combination with the Filtralite filter, the pH has to be increased to above 6 in order to comply with the residual metal standard.

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