Cold Water Effects on Enhanced Coagulation of High DOC, Low Turbidity Water

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Prairie farm reservoirs are usually low in turbidity and contain high concentrations of dissolved organic carbon (DOC). Some are treated with aluminum sulfate in late fall when the water drops below 3°C, often with poor turbidity reduction results. Jar tests using aluminum sulfate were conducted to study the effect of water temperature on enhanced coagulation of a typical high DOC prairie water. Jar tests showed that temperature affects turbidity, particle counts and total residual aluminum but does not affect DOC, UV254 absorbance and colour reduction. Turbidity of the treated water increased consistently as the temperature decreased. Particle counts in the 1 to 10 µm range were reduced by two logs at 20°C but only by one log at 1.5°C indicating inferior oocyst removal at low temperatures. Bentonite addition at 1.5°C did not affect the treated water particle counts but because the bentonite increased the raw water particle count, the reduction of the particles could be increased by one log. Coagulant demand for the water tested without pH adjustment is one to two mg Al per mg of DOC at all temperatures tested. The optimum pH for all temperatures was about 6.0 for DOC removal and about 6.5 for turbidity removal based on a dosage increment of 0.5 pH units. UV254 absorbance is well suited to predict optimum aluminum sulfate dosage for DOC removal.

Key words: coagulation, cold water, turbidity, dissolved organic carbon, aluminum sulfate

Introduction

Background

Canadian prairie farm reservoir water is generally low in turbidity but high in unfilterable organic carbon which is often referred to as dissolved organic carbon (DOC). The high concentration of organic matter usually imparts significant colour and taste and odour on the water, and demands high coagulant and disinfectant dosages. Coagulation is a recommended treatment to remove suspended particles and DOC on the prairie farm reservoirs.

To improve the water quality on the farm, the farmer often pumps water from a large reservoir into a smaller coagulation reservoir twice per year; the farmer treats the water with aluminum sulfate in early spring.
and late fall. The water temperature is often below 3°C and coagulation results are often poor in turbidity reduction.

Poor results from cold water coagulation have been documented (Morris and Knocke 1984; Haarhoff and Cleasby 1988; Knocke et al. 1986; Exall and VanLoon 2000). These authors reported that cold water effects were only noticed when the temperature dropped below 4 or 5°C. The most noticeable effect was the significant rise in treated water turbidity.

This paper attempts to summarize the research conducted on the effect of cold water on aluminum sulfate coagulation for typical Canadian prairie farm reservoirs. The success of coagulation is generally determined by a lowering of turbidity, particle counts, DOC, colour, UV$_{254}$ absorbance, SUVA, zeta potential and aluminum residual.

**Turbidity**

Turbidity has historically been a standard to determine the effectiveness of coagulation. It is easily measured, commonly understood and the instruments are inexpensive and robust. Recently, the fine tuning of turbidity removal has been achieved using particle counters, but turbidity measurement is still important.

Cold water significantly impacts turbidity removal. Slower aluminum polymerization and more viscous water are quoted as the primary drivers for poor coagulation results. The slower aluminum polymerization results in lighter and smaller flocs (Edzwald 1999). The increased viscosity results in poorer mixing velocity gradients and slower particle settling (Dempsey 1985; Matsui et al. 1998; Viraraghavan and Mathavan 1988). Low turbidity water has been found to compound the problem but sufficient calcium and alkalinity in the raw water seems to improve turbidity removal (Childress et al. 1999; Tseng et al. 2000)

**Particle Counts**

Particles in the water may be mineral or organic. Organic particles consist of viruses, bacteria, protozoan cysts (oocysts) and algae. These particles are stable in the water or have a very low settling rate. The particle stability is thought to be based on electrostatic repulsive interactions, hydrophilic effects or steric effects (Edzwald 1993). Coagulation using aluminum sulfate and other coagulants are known to destabilize the particles and cause flocculation and settling.

Particle counters are becoming common in water treatment plants. Particle counts provide detailed information on particle size and particle removal. Particle counts in the range of one to ten microns can also be used as a surrogate measure of the removal of oocysts such as *Cryptosporidium* and *Giardia* (Matsui et al. 1998)

**DOC and Colour Removal**

Organic matter has recently become more important in the water treatment industry. It causes taste and odour problems, increases coagu-
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and disinfectant demand, and is a substrate for bacterial growth in distribution systems. Health problems associated with disinfection by-products from chlorination such as trihalomethanes (THMs) have also elevated the importance placed on the removal of organic matter.

DOC and colour removal are not as sensitive to temperature as turbidity removal. Slight reductions of DOC and colour removal were found at lower temperatures by some researchers; other researchers found no impact of cold water on DOC reduction (Knocke et al. 1986; Randtke 1988; Hansen and Cleasby 1990).

UV$_{254}$ Absorbance

UV absorption to measure humic substances was started in Europe and was adopted in North America in the early 1980s. It can be measured rapidly, easily and inexpensively. Measuring the UV absorption at a wavelength of 254 nm gives an indication of the fractionation profile of the water. It is an excellent surrogate parameter for DOC and THM formation potential (Edzwald et al. 1985). The UV$_{254}$ wavelength is absorbed by aromatic, hydrophobic organic compounds but is not absorbed by simple aliphatic acids, alcohols and sugars. UV$_{254}$ absorbance values for the Prairies are generally around 0.2/cm but for very high DOC water, these values may be as high as 0.8/cm.

SUVA, the index of aromaticity, is defined as the ratio of UV$_{254}$ absorbance per metre to the concentration of DOC in mg/L (Edzwald and Van Benschoten 1990). Experience with numerous surface waters has shown that a SUVA of 2 indicates a non-humic water and a SUVA of greater than 6 indicates a humic-rich water (Edzwald and Van Benschoten 1990). SUVA values on the Prairies are generally about 2 to 4 suggesting a low humic water according to these findings. A humic-rich water will show greater DOC removal following coagulation than a non-humic water. During coagulation, the UV$_{254}$ absorbance value drops faster and further than the DOC concentration as the humic compounds are preferentially removed and SUVA values drop accordingly. Following successful enhanced coagulation, a SUVA of 1 to 2 is common.

Zeta Potential

Zeta potential indicates the suspended particle charge. Most organic and clay particles are negatively charged, but coagulation neutralizes this charge. Hardness in the water also affects the charge and usually makes coagulation more effective. As the pH of the water decreases, the DOC charge weakens, therefore requiring less chemical to neutralize the charge.

Van Benschoten and Edzwald (1990) have proposed that the charge required to neutralize organic matter and turbidity in water can be approximated based on the negative charge of the particles. Charge neutralization requires between 0.5 and 1.0 mg of aluminum per mg of DOC. The lower end of the range is for a pH of 5.5 and the higher end of the range is for a pH of 7.0. In comparison, turbidity has a significantly lower coagulant demand and a water with a turbidity of about 10 NTU
(20 mg/L of clay) will contribute a similar coagulant demand to approximately 1 mg of DOC (Edzwald 1999).

Aluminum Residual

Residual aluminum in the water following coagulation is to be minimized as it has been suggested to cause neurological diseases such as Alzheimer’s Disease. Cold water has a lower solubility of aluminum than warm water. Although dissolved aluminum can be easily predicted for given conditions, the particulate aluminum is related to the amount of suspended floc or turbidity therefore particulate aluminum is expected to correspond to the amount of suspended floc (Srinivasan et al. 1998).

Alkalinity

Alkalinity is a measure of the buffering capacity of the water and is reported in terms of CaCO₃. For optimum coagulation, high alkalinity water usually requires either a pH modification or excessive amounts of coagulant. Low alkalinity water (less than 30 mg/L) has been found to affect treated water turbidity because of insufficient solids during coagulation (Tseng et al. 2000). In the prairie reservoirs, there is a trend that as the DOC increases, the alkalinity also increases.

Materials and Methods

Coagulant

Liquid aluminum sulfate was diluted with distilled water to a five percent solution. The coagulant was measured using syringes and injected into the coagulation beakers.

Water

The primary water used for the research was from the Schemenaur Reservoir (Schem) A, collected in June and considered a typical prairie water with low turbidity and high DOC. Schem B and Schem C were from the same source as Schem A but were collected in September. Schem C water was different from Schem B water in that it had very high turbidity because of disruption of the sediment during sampling. Schem B and Schem C water are referenced because bentonite was added to Schem B and compared to high turbidity Schem C water.

The Ferguson Reservoir (Ferg) water was very high in DOC, turbidity and hardness. The Multi-Pork Reservoir (MP) water was referenced to better understand the full range of waters requiring treatment (Table 1).

The water was stored in a refrigerator at 4°C for up to three months. The jar tests at the various temperatures were repeated after three months to ensure the properties of the water and jar testing results had not changed significantly.
Jar tests and analysis

Jar tests were completed for various dosages of aluminum sulfate at 20, 10, 5 and 1.5°C. The water was cooled using an insulated bath and a YK230 Lauda Brinkmann circulating cooler. One litre of water was added to the two-litre square beakers and a Phipps and Bird six-paddle stirrer was used for mixing. One beaker was used as a control and the other five beakers received various dosages of coagulant. Following addition of the coagulant, the water was mixed 30 seconds at 100 rpm, 30 minutes at 20 rpm and allowed to settle for 30 minutes. Following settling, samples were drawn from a sampling tap located 50 mm above the bottom of the beaker. The samples were then tested for pH, electrophoresis mobility (zeta potential), turbidity, particle count and alkalinity. A sample of the unfiltered samples was preserved with nitric acid for total aluminum testing. The samples were filtered and tested for UV\textsubscript{254} absorbance and true colour. A filtered sample was also preserved with nitric acid for dissolved or unfilterable aluminum testing, and a filtered sample was preserved with sulfuric acid and submitted to a private lab for DOC testing.

Zeta potential was measured using a ZM-77 Zeta Meter, turbidity was measured using Palintest Micro 900 turbidimeter and pH was tested using the Hanna HI 9025 Micro pH meter. Particle counts were measured using the PC 2000 Spectrex Laser Particle Counter interfaced with a computer and Supercount software measuring 1 to 128 µm-sized particles. Alkalinity was measured using the HCl titration method according to the American Public Health Association (1998) standard methods for the

<table>
<thead>
<tr>
<th>Source</th>
<th>pH</th>
<th>Turbidity (NTU)</th>
<th>DOC (mg/L)</th>
<th>Alkalinity (mg/L as CaCO\textsubscript{3})</th>
<th>UVA\textsubscript{254} (cm\textsuperscript{-1})</th>
<th>Colour (count/mL)</th>
<th>Particle count (count/mL)</th>
</tr>
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<tr>
<td>Schem A\textsuperscript{a}</td>
<td>8.6</td>
<td>0.6</td>
<td>10.5</td>
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<td>11.5</td>
<td>110</td>
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<td>16</td>
<td>70,000</td>
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<tr>
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<td>110</td>
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<td>36.5</td>
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<td>70</td>
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<td>0.7</td>
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<td>180</td>
<td>0.17</td>
<td>14.5</td>
<td>N/A\textsuperscript{f}</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Water from Schemenaur Reservoir collected in June 2000.
\textsuperscript{b} Water from Schemenaur Reservoir collected in September 2000.
\textsuperscript{c} Water from Schemenaur Reservoir collected in September, high turbidity from sediment disruption.
\textsuperscript{d} Water from Ferguson Reservoir collected in December 2000 through ice.
\textsuperscript{e} Water from Multi-Pork Reservoir collected in spring 2000.
\textsuperscript{f} Data not available.
examination of water and wastewater. Filtering was completed using 0.45-micron glass fibre filters, the UV$_{254}$ absorbance was measured at 254 nm wavelength using the 1000 E Pharmacia Biotech Ultraspec UV/Visible Spectrophotometer with a quartz crystal cuvet, and the colour was measured at 340 nm wavelength also using the 1000 E Pharmacia Spectrophotometer. The aluminum was measured using the Spectra AA Graphite Furnace and the DOC was measured using a Technicon Autoanalyzer with automated persulfate-UV digestion.

Results and Discussion

General

The tests completed used aluminum sulfate to lower the pH at increments of about 0.5 pH units. Reference to optimum dosage, pH and removal is based on this approach. Adjustment of the pH with acid prior to coagulation and a smaller pH increment would provide some fine tuning of the process but is beyond the scope of this paper. Variation of the mixing intensity to compensate for the increased viscosity of cold water is also a factor that may affect results. Additional research is needed to identify the impact of these factors on coagulation results.

Turbidity and Particle Counts

The turbidity of the treated water was affected by the water temperature. Typical turbidity results for various temperatures are shown in Fig. 1. The optimum coagulant dose for turbidity removal at all temperatures

![Fig 1. Turbidity for various aluminum sulfate dosages and temperatures — Schem A water.](image-url)
was at about pH 6.5 based on an interval of dosing of 0.5 pH units. This is consistent with findings of other researchers (Pernitsky and Edzwald 1999). A smaller pH interval between pH 6 and 7 would refine the optimum dose but this is outside the scope of the research.

At dosages of 10 to 16 mg Al/L, the turbidity increased consistently as the temperature decreased. This was also reflected by the particle counts for particles less than 10 microns shown in Fig. 2. Particle counts at 16 mg Al/L were reduced by about 2 logs at 20°C but only 1 log at 1.5°C. These results indicate that the oocyst removal is likely significantly less at the lower temperature, as particle counts for one to ten microns can be used as a surrogate measure for oocyst removal.

At aluminum sulfate dosages greater than optimum, the particle counts increased for all temperatures but the relative difference between water temperatures of 20 and 1.5°C remained at about one log. At a low coagulant dose of 6 mg Al/L or about one-half of optimum, the turbidity was higher at 20°C than at 1.5°C. This peculiarity was replicated in the second set of jar tests and an explanation is not apparent.

Schem B water at 1.5°C was also spiked with bentonite to evaluate the benefit of higher turbidity at low temperatures. The treated water turbidity was compared to the high turbidity Schem C water and also to Schem A water (Fig. 3). At the optimum coagulant dosage, the treated water turbidity and particle counts were similar between the spiked and unspiked raw waters for the entire range of coagulant dosages. Researchers have found that low turbidity raw water affects turbidity removal at low temperatures (Morris and Knocke 1984). This may be because there were insufficient solids during coagulation for optimum turbidity reduction.

![Figure 2](image-url)

**Fig 2.** Particle count (1 to 10 µm) for various aluminum sulfate dosages and temperatures — Schem A water.
The results shown in Fig. 3 indicate that this water does not respond accordingly as there is little difference in treated water turbidity between high and low turbidity raw water. Researchers have also found that low alkalinity in the raw water can limit turbidity removal because of insufficient solids during coagulation (Tseng et al. 2000; Randtke 1988). It is speculated that the adequate alkalinity of the source water (100 mg/L as CaCO₃) may have provided sufficient solids during coagulation, therefore reducing the benefit of increasing the raw water turbidity.

Schem B water at 1.5°C was also spiked with 0, 10, 30, 60, 120 and 240 mg/L of bentonite, then treated with a constant coagulant dosage of 12.8 mg Al/L. Both turbidity and particle count results varied less than 10 percent between treatments. The beaker with the addition of 240 mg/L of bentonite showed particle counts sized less than 10 microns before and after coagulation of 1,700,000 and 3100 counts/mL or a particle removal of 2.7 logs compared to a 1.5 log removal for the beaker without bentonite addition. This indicates that the addition of bentonite may improve the removal of the suspended oocyst population.

**Zeta Potential**

Zeta potential or particle charge was measured at the various temperatures to compare the charge neutralization at different temperatures. There was insignificant differences in charge neutralization with changes in temperature (Fig. 4). There was a general trend of reduced charge with an increase in dosage. The optimum dose of 10 to 16 mg Al/L had a zeta potential of –15 mv. This is higher than expected, as most research indi-
cates an optimum zeta potential of zero or slightly positive of zero. The dosage required to attain zero zeta potential is about double of the optimum dose and is regarded as excessive.

**DOC**

DOC removal for a treatment pH of 6.0 varied between 60 and 70 percent (Fig. 5). The optimum dose for DOC removal was slightly greater than for optimum turbidity removal. DOC removal diminished as the pH dropped below 6 (16 mg Al/L dosage). An optimum pH of 6.0 for DOC removal is consistent with the findings of other researchers (Pernitsky and Edzwald 1999).

Temperature did not affect the DOC removal significantly, but there appeared to be slightly better removal at 20°C than at the lower temperatures. This was replicated in the second set of jar tests. In both runs, the raw water DOC concentration was slightly lower for 20°C than for the other runs at lower temperatures, a peculiarity that cannot be explained. The optimum dosage for DOC removal (16 mg Al/L) did not vary with temperature changes.

The dosage used for treating farm reservoirs is usually based on achieving a post-coagulation pH of 6.0 to 6.5. This pH ensures good removal of DOC with close to optimum turbidity removal. The dosages required are often considered excessive from a turbidity reduction standpoint; they are generally in the range of 1 to 2 mg Al per mg DOC (Fig. 6). This is higher than the range suggested by Van Benschoten and Edzwald (1990) and those found by Exall and VanLoon (2000), but they are less than

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Fig 4. Zeta potential for various aluminum sulfate dosages and temperatures — Schem A water.
Fig 5. DOC for various aluminum sulfate dosages and temperatures — Schem A water.

the 2.1 mg Al per mg DOC found by Tseng et al. (2000). Acidification was not used in any of the jar tests but may be advantageous for waters requiring more than 1.0 mg Al per mg DOC as suggested by Edzwald (1993).

The water from the prairie reservoirs is interesting in that the alkalinity usually increases as the DOC increases (Fig. 7). This facilitates the

Fig 6. DOC versus optimum dosage for various prairie waters.
increased buffering required for higher DOC water, and in most cases, the aluminum sulfate dosage required to drop the pH of the water to 6 is close to 1.5 mg Al per mg DOC. Van Benschoten and Edzwald (1990) found that at coagulant dosages greater than one mg Al per mg DOC, there was a much larger pH band of high DOC removal (80%) than at 0.5 mg Al per mg DOC. At one mg Al per mg DOC the pH range of high DOC removal was 3.0 pH units (5.8 to 7.8) but at 0.5 mg Al per mg DOC, the pH range for high DOC removal was only 0.3 pH units (5.2 to 5.5). The research used pH-adjusted de-ionized water spiked with fulvic acid.

**UV\textsubscript{254} Absorbance**

Colour removal and UV\textsubscript{254} absorbance for various dosages and temperatures are shown in Fig. 8 and 9. As with DOC, temperature did not affect either UV\textsubscript{254} absorbance or colour reduction. Of interest is the high correlation ($r^2 = 0.95$ to 0.97) between UV\textsubscript{254} reduction and DOC reduction (Fig. 10). Although each water type has a different regression line, the optimum UV\textsubscript{254} reduction corresponded directly to the optimum DOC reduction. DOC measurement is difficult but UV\textsubscript{254} absorbance is easy and inexpensive. The optimum dose for DOC removal can be determined by measuring UV\textsubscript{254} absorbance.

Edzwald et al. (1985) suggested that the regression lines for UV\textsubscript{254} absorbance versus the DOC concentration would not go through zero because there is a fraction of DOC not absorbed at 254 nm. Most waters tested followed Edzwald’s suggestion but the MP water is close to extending to the zero-zero coordinate. In general, there seems to be a strong

![Fig 7. DOC versus alkalinity for various prairie waters.](image-url)
trend correlating UV$_{254}$ absorbance to the DOC concentration. Additional research is needed to evaluate the potential of estimating DOC concentrations based on UV$_{254}$ absorbance readings.

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Fig 8. True colour for various aluminum sulfate dosages and temperatures — Schem A water.

Fig 9. UV$_{254}$ absorbance for various aluminum sulfate dosages and temperatures — Schem A water.
SUVA

As expected, SUVA is not affected by temperature because it is a ratio of UV$_{254}$ absorbance to DOC (Fig. 11). The SUVA value for the raw Schem water was about three which is considered only mildly humic. DOC removals of 60 to 70 percent are high for a SUVA value on the bottom of the SUVA scale of raw water that ranges from two to six (Edzwald and Van Benschoten 1990).

Aluminum

Dissolved aluminum residual (unfilterable) did not show significant differences between temperatures (Fig. 12). Lower residual dissolved aluminum was expected for lower temperature water but not found (Edzwald 1999). As expected, a drop in pH below six caused the aluminum to spike upward.

Total aluminum residual showed a trend similar to turbidity, but the difference between temperatures was not as dramatic (Fig. 13). At a high dosage, the aluminum spiked up, especially for the 1.5 and 5°C temperatures. This indicates that the major cause of the turbidity was suspended floc as suggested by Srinivasan et al. (1998). The total aluminum in the water minus the dissolved aluminum following settling as a percent of the added aluminum gives an indication of what percent of the developed floc settled out in the 30-minute time period. Figure 14 shows that a high percentage of the floc has settled out. At optimum dosages, less than two percent of the aluminum introduced as aluminum sulfate remained sus-

![Graph](image-url)

Fig 10. UV$_{254}$ absorbance versus DOC for various prairie waters.
suspended in the water. This shows that almost all of the introduced aluminum forms a settleable floc and this floc settles out rapidly.

The high turbidity of the treated cold water was expected to affect the treated water DOC concentration because some of the DOC would be complexed with the remaining suspended floc. This was not found, even

Fig 11. SUVA for various aluminum sulfate dosages and temperatures.

Fig 12. Dissolved aluminum for various aluminum sulfate dosages and temperatures — Schem A water.
with the large increase in turbidity for cold water and high dosages; however, one must consider that a change in unsettled floc from two percent to 14 percent represents an increase in total suspended solids in the treated water of about sevenfold but only a difference in DOC removal of about seven percent, assuming a 60 percent DOC removal. We speculate

Fig 13. Total aluminum for various aluminum sulfate dosages and temperatures — Schem A water.

Fig 14. Percent of unsettled floc for various aluminum sulfate dosages and temperatures — Schem A water.
that this may be a large factor in explaining why turbidity and particle counts are severely affected by cold water but DOC removal is not noticeably affected.

Conclusions

Temperature affects turbidity and particle counts during coagulation. Temperature has an insignificant effect on the reduction of zeta potential, DOC, UV$_{254}$ and colour. The reduction of particles for 20°C water was about two logs, but at 1.5°C this dropped to about one log. This implies reduced oocyst removal for colder temperatures. Addition of bentonite did not reduce the treated water turbidity but did increase the change in particle count between raw and treated water. The addition of bentonite to cold water increased particle removal up to one log and this may aid in oocyst removal.

The coagulant demand is based on the DOC in the raw water. In the prairie reservoirs, the coagulant demand without pH adjustment for optimum DOC removal is in the range of one to two mg Al per mg of DOC and as the DOC increases, the alkalinity also tends to increase. This increase in alkalinity provides additional buffer for the additional aluminum sulfate required for high DOC water. In general, the reduction of water to pH 6 results in approximately 1.5 mg Al/ mg DOC, which may be a little higher than necessary. Acidification of the water could reduce coagulant demand for the waters examined.

For prairie reservoirs, the optimum pH for treatment is between 6 and 6.5. The optimum pH for turbidity removal is about 6.5 and for DOC removal is about 6.0 based on the research with pH increments of 0.5 units. With the high concentrations of DOC in the prairie waters, a treatment pH closer to 6.0 is recommended.

UV$_{254}$ absorbance seems well-suited to predict optimum aluminum sulfate dosage based on DOC removal at any temperature. It is inexpensive and easy to use. UV$_{254}$ absorbance can be used to give an estimate of the raw water DOC concentration.

SUVA values were low for the Schem water, but the DOC removal varied between 60 and 70 percent. This level of removal is exceptional for a water that is low in humic substances.

The research used aluminum sulfate to lower the pH at increments of about 0.5 pH units. Mixing intensity was not varied to compensate for the increased viscosity of cold water. Additional research is needed to identify the impact of these factors on coagulation results.

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References


