Effects of salinity (Na_2SO_4) on performance of papermaking additives for fine-particle retention, dewatering, and flocculation

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ABSTRACT: Laboratory experiments with bleached kraft furnish were carried out to quantify the effects of major differences in electrical conductivity of papermaking process water (due to the addition of sodium sulfate) on the performance of various papermaking additives. Batches of refined pulp were prepared with conductivity levels of 168 (tap water), 1000, and 10,000 µS/cm. The absolute values of the calculated zeta potential, in various cases, were shown to decrease with increasing logarithm of electrical conductivity. The performance of retention aid systems, including cationic polyacrylamide (cPAM), were not adversely affected by increased salinity, even up to an electrical conductivity level of 10,000 µS/cm. In fact, treatment involving sequential addition of cPAM and colloidal silica showed superior retention of mineral filler at the highest conductivity level. Likewise, combinations of papermaking additives that promote the dewatering of paper continued to perform well in furnish prepared with increasing salinity. The ability of various chemical systems to induce flocculation among papermaking fibers decreased moderately at the highest level of salinity considered.

Application: The experimental results help to provide assurance that certain conventional papermaking additives may continue to perform well, even at electrical conductivity levels near to those associated with paper mills that recycle water so intensively that they have zero liquid effluent.

The average amount of fresh water utilized in typical papermaking operations has gradually been reduced over the years. For instance, Göttsching [1] reported a decrease of fresh water usage in German paper mills from about 100 m^2/metric tons in 1950 to about 15 m^2/metric tons in 1993. Money can often be saved by purchasing and treating less fresh water, saving the cost of heating that water up to the operating temperature of a paper machine and reducing the amount of wastewater that needs to be treated after the process. The reductions in fresh water usage, especially in separate paper machine systems without an adjacent pulp mill, have been achieved by recirculating more of the process water for dilution of incoming pulp, in addition to shower applications [2,3]. Some paper mills making 100% recycled paperboard products have even operated with zero wastewater volume in order to maximize savings related to water usage [4,5].

One of the major consequences of increased recirculation of process water in a paper mill is an increase in dissolved ions, which is most easily detected by measuring the electrical conductivity [4,6]. Aldrich and Janes [2] studied multi-day trials in which a pilot paper machine (30-in. trim) was run continuously with no liquid discharge. The electrical conductivity gradually rose from 736 to 1014 µS/cm. Alexander and Dobbins [7] developed mathematical relationships to predict rises in ionic content of paper mill process water, depending on the extent of recirculation. Such work has allowed papermakers to estimate the consequences of their decisions regarding the usage levels of fresh water.

It has been shown that high levels of ions in the paper machine process water can interfere with the effectiveness of wet-end additives such as retention aids [8-13]. For example, it has been reported that partial closure of a paper machine process water system will hurt hydrophobic sizing, in addition to reducing first-pass retention [8]. Lewis and Bowman [12] found that paper strength was adversely affected by running a paper machine with no liquid discharge for five days. Rousseau and Doiron [14] reported that suitable quality paperboard still could be produced on a commercial paper machine with zero liquid discharge, though it was necessary to increase the dosages of some chemical additives. Springer [15] noted that reductions in process water usage on paper machines can lead to such problems as scale deposition, corrosion of stainless steel, foaming, slime growth, sizing, and color problems. Pruszynski and Jakubowski [13] showed that whereas multivalent anions such as phosphate and silicate adversely affected

the performance of cationic polyacrylamide (cPAM) retention aid alone, those ions did not hurt the performance of systems based on sequential addition of a high-charge cationic polymer and then cPAM. More recently, Pruszynski et al. [16] have reviewed specific ways in which increased levels of ions in a paper machine furnish can interfere with the action of papermaking additives. It is important to note that increased recirculation can be expected to increase concentrations of a variety of soluble substances, in addition to inorganic ions. For instance, elevated levels of dissolved and colloidal substances have been reported for some paper mills where there is a level of water recirculation [17,18]. Such effects are not considered in the present study.

One of the mechanisms by which increased levels of ions in paper machine process water can be expected to affect the efficiency of chemicals additives is by decreasing the thickness of the electrical double layers at solid surfaces [19]. With increasing ionic strength (which is a measure of ion concentration), dissolved polyelectrolytes such as polyacrylamide-type retention aids become less extended in conformation, i.e., they have a lower average radius of gyration in the solution [20]. As a result, they will be less able to bridge the spaces between solid surfaces in a suspension of fibers and fine materials.

Tolerance of different levels of salinity (Na_2SO_4) in paper machine systems may depend on the grade of paper being produced. For instance, some of the highest levels of electrical conductivity have been reported in certain unbleached recycled paperboard grades [4]. The production of such grades is not highly dependent on the performance of retention aids or functional additives. By contrast, retention aids and various functional additives will be important when manufacturing lower basis weight products, including printing papers or high-gloss supercalendered products.

Though the issues described in the preceding information have been discussed in many of the articles already cited, there have been relatively few studies in which effects of ion concentration have been tested directly, rather than studying the consequences of recirculation and reduced fresh water usage [8,13]. Only certain papermaking additives and outcomes were considered in the work cited in previous paragraphs, with most studies only indicating a few characteristic trends, such as decreased effectiveness of retention aid polymers [8]. The present work compared effects related to retention, drainage rates, and flocculation levels in matched refined bleached kraft fiber suspensions under three widely different levels of sodium sulfate addition. One of the conditions represented "soft tap water," as present in Raleigh, NC, USA. Another represented an intermediate level of sodium sulfate addition to achieve an electrical conductivity of 1000 µS/cm, which is on the low end of typical papermaking practices for commodity grades of paper. The third batch was with sufficient sodium sulfate to reach 10,000 µS/cm, which can be regarded as approaching the range of conductivity in some paper machine systems where there is no liquid effluent [4]. A novel aspect of the work was that salinity alone was varied while other parameters were held constant.

Pulp Batch	I	II	III
Conductivity (µS/cm)	168	1000	10,000
pH	7.0	7.5	7.7

1. Effect of sodium sulfate addition on the zeta potential of bleach kraft fibers (default furnish) and after addition of either 1% sodium polyacrylate or 5% TEMPO-oxidized NFC (TONFC) on a dry basis.

EXPERIMENTAL

Fiber sources and pulp preparation

Bleach kraft fiber, in dry-lap sheets, was acquired from a regional mill. All pulp used was prepared with a 75:25 ratio of hardwood and softwood kraft pulp. The pulp was refined using a laboratory Hollander beater. The "brushing mode" (with no additional force applied) was used for about the first 5 min so that no flakes were apparent in the mixture. Then the standard load, 1 kg, was applied and refining was continued until the Canadian Standard Freeness (CSF) reached 450 mL. Tap water was used to dilute the pulp slightly below the target volume. Pulp batch 1 had no added electrolyte and contained a baseline conductivity of 168 µS/cm using a conductivity probe inserted into the stock with agitation. For batches 2 and 3, sodium sulfate (Na_2SO_4) at about 5% solids was added incrementally until the conductivity reached 1000 and 10000 µS/cm, as shown in **Table I**. The total volume was then adjusted to achieve a 0.5% consistency.

Chemical preparation

The chemicals used in these experiments included the following:

- Cationic polyacrylamide (cPAM): Accurac 90 (American Cyanamid; Wayne, NJ, USA), 10% cationic content, very high mass
- Anionic polyacrylamide (aPAM): AN 910 BPM (Floerger; Riceboro, GA, USA), 10% anionic content, very high mass
- Freeze-dried nanofibrillated cellulose (NFC) (University of Maine; Orono, ME, USA)
- TEMPO-oxidized NFC (TONFC): University of Maine, high negative charge
- Polyvinylamine (PVAm): Hercobond 6350 (Solenis; Wilmington, DE, USA)
- Clay: kaolinite (coating grade)
- Calcium carbonate ($CaCO_3$): Albacar precipitated scalenohedral (Specialty Minerals; Bethlehem, PA, USA)
- Colloidal silica: Fennosil 2180 (Kemira; Helsinki)

The clay was freshly dispersed in deionized water at 1% solids, followed by 60 s of swirling in an ultrasonic bath, before usage. The cPAM and aPAM retention aids were prepared on the day of the experiment by diluting 0.1 g of dry bead powder (assumed to be 100% dry solids) with deionized water in a conical flask to achieve a concentration of 0.1% solids, followed by magnetic stirring for at least an hour. The remaining chemicals were prepared by mixing 1 g (solids basis) of the concentrated or solid chemical and diluting it with tap water until a 1% solids concentration was achieved.

Retention tests

A cleaned Britt jar with a 200-mesh screen was used to evaluate the retention efficiency of fine particles. A 500 mL batch of untreated pulp was added to the jar with the pinch clamp closed. The pulp was agitated using an impeller set to 650 rpm. The desired chemical dosage was added and mixed for a set time of around 10 s. The first 50 mL of filtrate was returned to the Britt jar, and the second specimen of filtrate was then used to determine turbidity. As shown by Milliken, turbidity can be used as a convenient measure of the relative amount of non-retained fine material remaining in the filtrate after sheet formation [21]. This procedure assumes the accuracy of the Beer-Lambert relationship between optical density and concentration of suspended particles [22]. Known inaccuracies of this simplifying assumption include decreases in the extinction coefficient if and when particles of certain sizes become agglomerated. On the positive side, turbidity tests can be conducted very quickly, thereby enabling a high level of replication. By contrast, gravimetric measurements are subject to possible errors associated with taring and residual water in some of the specimens. The filtrate was placed into a vial and inverted before being placed in a calibrated turbidity meter. Ten replicate measurements were done to obtain an average reading and statistical quantities. The whole set of tests, as described, was carried out two times.

A modified method was used in the case of experiments involving the addition of clay or calcium carbonate mineral particles. In those cases, the turbidity of the filtrate, in the absence of retention aid, exceeded the range of the turbidity meter. To overcome this problem, a sample of about 10 mL of filtrate was diluted with tap water by a factor of ten. Ten replicate measurements were made using the subsample, which was not returned to the Britt jar. The final results, with units of nephelometric turbidity units (NTU), were multiplied by ten for those cases.

Dewatering tests

Dewatering tests were conducted using a modified Schopper-Riegler freeness tester. This device incorporates a large hole near the base of the cone to assess gravity-induced drainage. First, the top of the device was sealed with a spring-loaded cone before adding 1000 mL of stock into the device. After releasing the cone, the filtrate drained for a minute onto a balance. A stopwatch was used to record the mass of the filtrate at each desired time interval.

Flocculation tests

The photometric dispersion analyzer (PDA) contains a combination of a photodetector and light to study the levels of flocculation. A low-gain version from Rank Brothers (Newbury, UK) was used with both gain constants set to 1.0. Both buttons labeled “Filter” and “RMS” were activated for these studies. A beaker containing 500 mL of stock was stirred magnetically before being treated and circulated for 15 s before using a tube with an internal diameter of about 6 mm to connect the sample to the PDA. The flow of the stock suspension is circulated through the PDA and back into the sample for the photodetector to give readings.

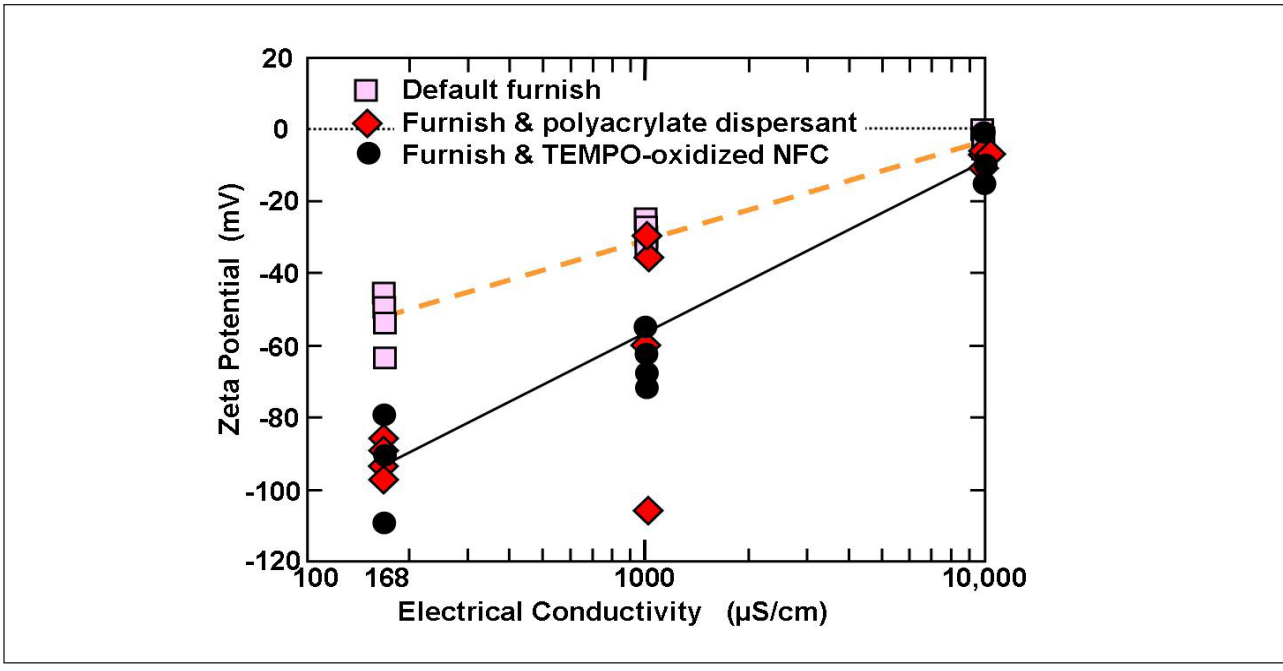
Zeta potential tests

Streaming potential testing was performed to evaluate the zeta potential of the furnish under varying conditions of electrical conductivity (adjusted by the addition of sodium sulfate). Tests were performed under three conditions (for each of the three batches of pulp having different electrical conductivity levels). The Helmholtz-Smoluchowski equation was utilized to convert the streaming potential test results to the corresponding zeta potentials, while accounting for effects of electrical conductivity and other variables such as viscosity of the solution [23,24]. Past work has shown that even after accounting for electrical conductivity, the absolute value of zeta potential can be expected to decrease with the addition of neutral salt to an aqueous system [25,26]. In addition, it has been confirmed that zeta potential values provide reliable information about ionic charges at surfaces, including a region extending about 1.5 nm from the surfaces [27]. Surface conductivity has been shown to affect the accuracy of such calculations in some cases [28,29]. Because no analysis of surface conductance was carried out in the present work, no correction for surface conductivity was made. For each of the batches of furnish, tests were carried out with (a) no further adjustment to the furnish, (b) furnish with polyacrylate dispersant (Sokalan PA 40 at the 1% level based on solids), and (c) furnish with TONFC. The TONFC was added at a 5% level based on solids.

RESULTS AND DISCUSSION

Zeta potential results

Figure 1 shows the relationship between zeta potential and electrical conductivity across these conditions. At low conductivity (~168 µS/cm), the furnish with the TONFC showed the most negative zeta potential. As conductivity increased, the zeta potential moved closer to neutral values, suggesting that the electrostatic repulsion between fibers was weakened. This effect was most noticeable in the highest conductivity condition (~10,000 µS/cm), where the dif-



1. Effect of sodium sulfate addition on the zeta potential of bleach kraft fibers (default furnish) and after addition of either 1% sodium polyacrylate or 5% TEMPO-oxidized NFC (TONFC) on a dry basis.

ferentiation between furnishes became less apparent. Further studies would be needed to find out whether there were significant effects due to likely increases in surface conductance with increasing salinity, since such increases would affect the calculated zeta potential [28,29].

The control furnish showed the lowest absolute zeta potential, while the addition of TONFC resulted in a more negative zeta potential across all conductivity levels. The furnish containing the polyacrylate dispersant also exhibited a higher absolute value of zeta potential compared to the control, though its difference was less prominent than that of NFC.

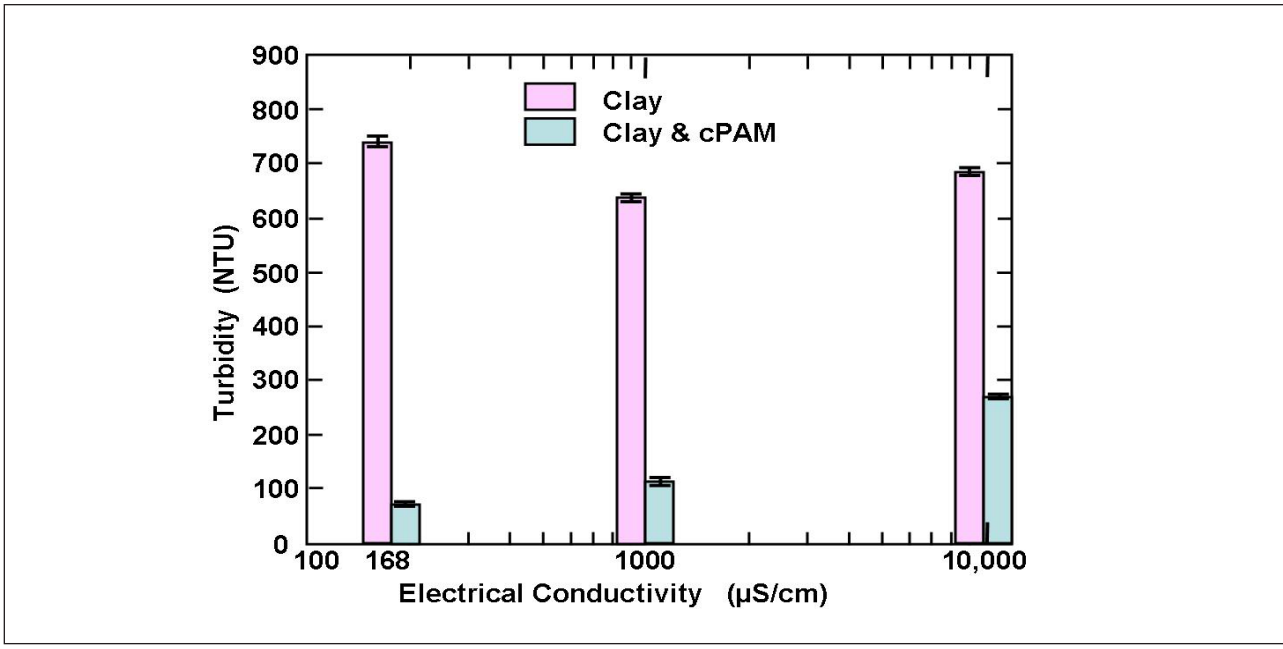
As shown in Fig. 1, a negative correlation was observed between zeta potential and electrical conductivity, but the statistical significance of these trends varied. The effects of the additives were significant at a 95% confidence level, but the impact of conductivity on zeta potential was statistically significant at the 90% confidence level. As already mentioned, these calculations were done without a correction for surface conductance.

Retention

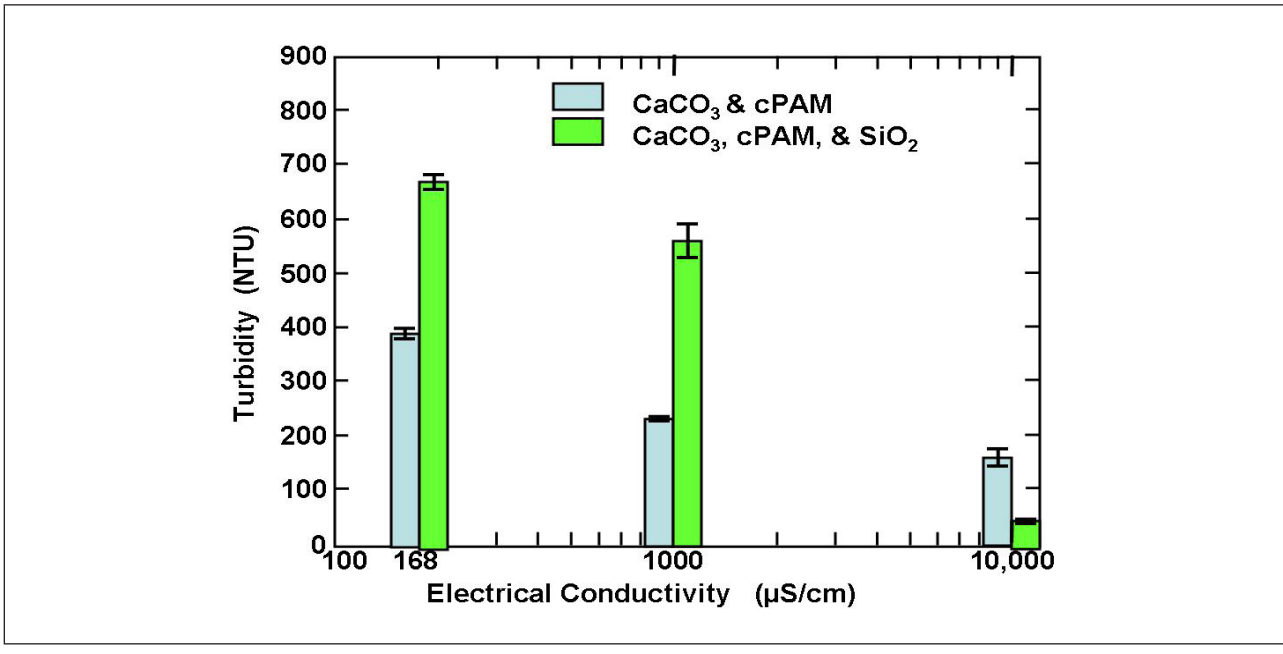
Britt jar tests were conducted to evaluate fine-particle retention across varying conductivity conditions. Each experiment involved different combinations of additives to observe how each was impacted at different salinity levels. **Figures 2–5** show the results across three levels: low conductivity (~168 µS/cm), medium conductivity (~1000 µS/cm), and high conductivity (~10,000 µS/cm).

Figure 2 compares the turbidity of filtrate results for retention tests using clay and cPAM. This includes samples with only clay and samples with clay and cPAM. Clay was added at a 5% level based on mass, and the cPAM was added at a 0.05% level based on solids. The furnish with clay and no retention aid showed consistently higher turbidity readings, indicating poor retention across all conductivity levels. With cPAM added, turbidity readings were much lower, but they increased as conductivity levels became higher, indicating a negative effect of salinity on the performance of the retention aid. The highest conductivity level had the most fines in the filtrate, showing that cPAM was least effective under those conditions.

Figure 3 shows turbidity of filtrate results for furnishes with precipitated calcium carbonate (PCC) added at a 5% level and cPAM added at a 0.1% level based on solids, with and without subsequent colloidal silica added at a 0.15% level based on solids. At low and medium conductivity, the furnish with colloidal silica had higher turbidity than the one with just PCC and cPAM, showing that retention was lower. This suggests that colloidal silica interfered with cPAM by neutralizing its cationic character, thus reducing its ability to flocculate fines and fillers. Such an effect was earlier reported by Leib et al. [30], though in that work the conductivity was not varied. However, at the highest conductivity level (10,000 µS/cm), the trend reversed, with the colloidal silica furnish showing slightly lower turbidity than the one with just cPAM and PCC, indicating improved retention. It is tentatively proposed that such results can be attributed to a sufficiently high charge density of both the silica surfaces and the cPAM segments such that they are still able to interact strongly, even at the highest salt levels considered in this work. Additional experiments would be needed to test the validity of this suggestion.

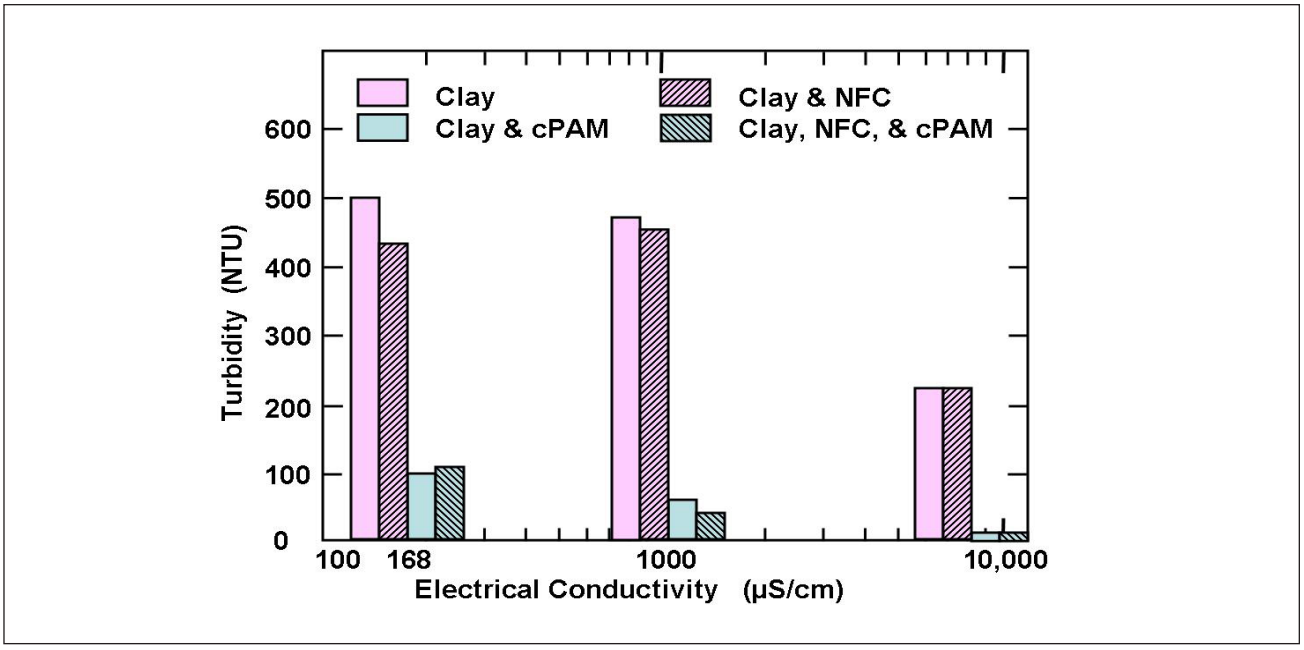


2. Effect of sodium sulfate addition on the turbidity of filtrate from a Britt Jar device with 5% clay addition to the default furnish, and the same followed by cationic polyacrylamide (cPAM) retention aid at the 0.1% level based on solids with continuous stirring.

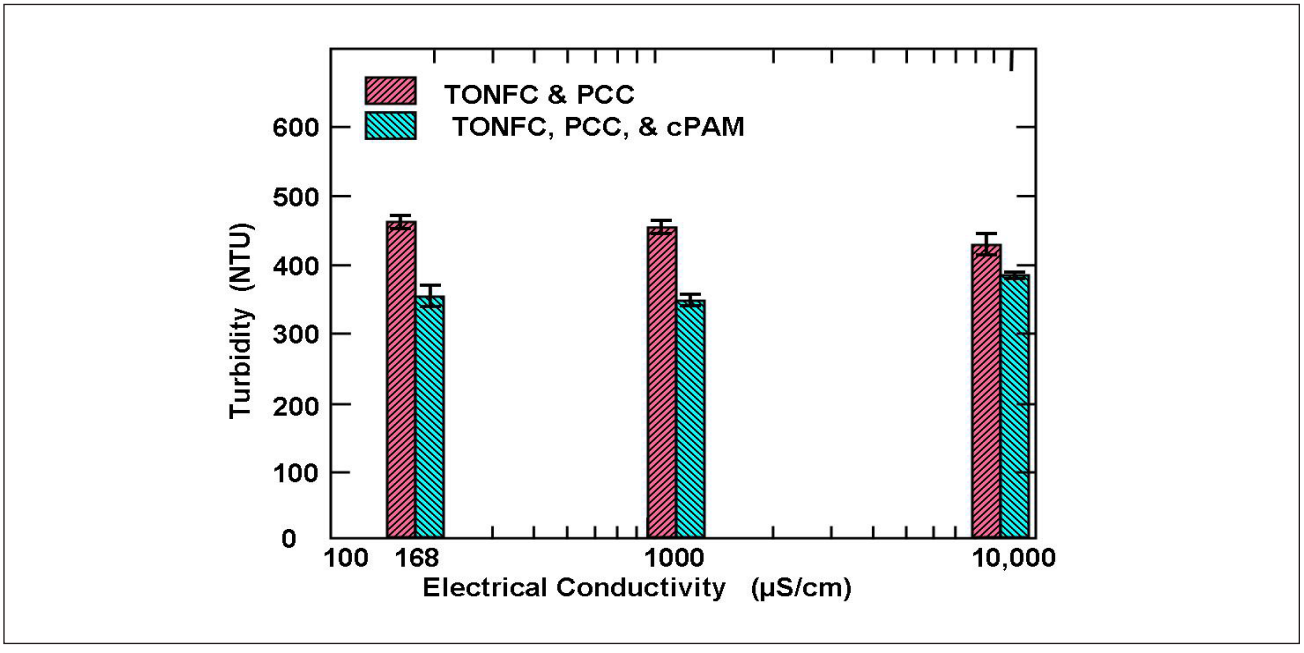


3. Effect of sodium sulfate addition on the turbidity of filtrate from a Britt Jar device with 5% calcium carbonate ($CaCO_3$) addition to the default furnish, followed by cPAM retention aid at the 0.1% level based on solids, and the same with colloidal silica (SiO_2) at the 0.15% level based on solids with continuous stirring at 650 rpm.

Figure 4 shows the effect of increasing conductivity on turbidity of the filtrate from furnishes containing clay (5% level, solids basis), NFC (5% level when present), and cPAM (0.1% level when present). As can be seen in Fig. 4, as conductivity increased, turbidity went down for most conditions, which was likely because the higher conductivity reduced repulsion between particles and helped fines attach better. The furnish with only clay had the highest turbidity across all conductivity levels, indicating the lowest retention. Adding NFC slightly lowered turbidity readings compared to clay alone, suggesting that it contributed to a degree in improving retention. However, when only cPAM was added to the clay furnish, turbidity was significantly reduced, showing that cPAM had a stronger effect on reten-



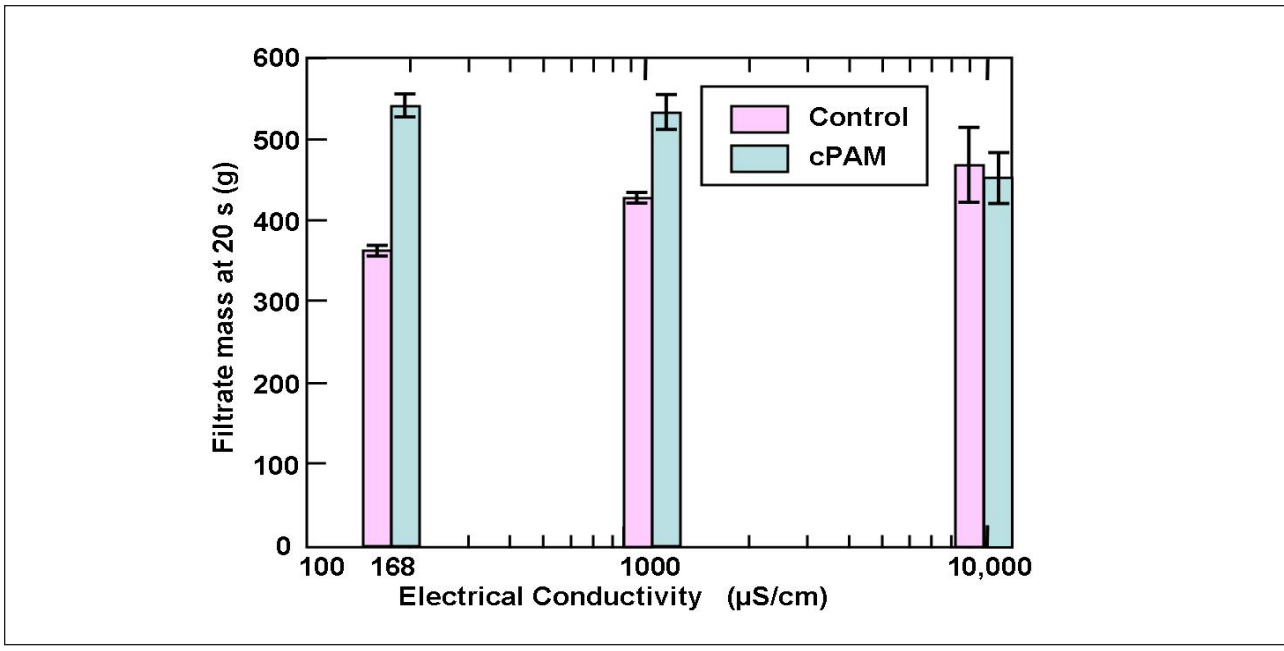
4. Effect of sodium sulfate addition on the turbidity of filtrate from a Britt Jar device with 5% clay or 5% clay with 5% default nanofibrillated cellulose (NFC), each with optional treatment with cPAM retention aid at the 0.1% level.



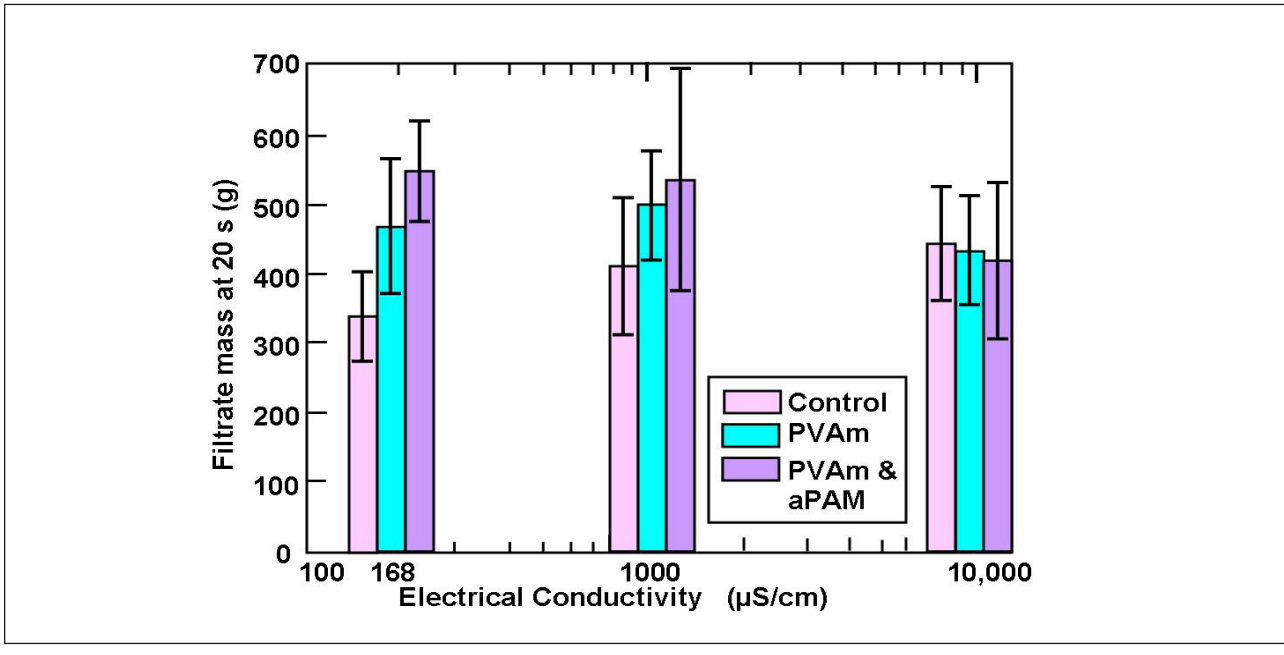
5. Effect of sodium sulfate addition on the turbidity of filtrate from a Britt Jar device with 5% $CaCO_3$ with 5% TEMPO-oxidized NFC (TONFC), with optional treatment with cPAM retention aid at the 0.1% level.

tion than NFC alone. At all conductivity levels, the furnish with cPAM and NFC yielded nearly identical turbidity results to the furnish with just cPAM, suggesting that NFC had little to no additional effect when cPAM was present. While cPAM still lowered turbidity compared to the furnish with only NFC, the gap between them got smaller, suggesting that higher conductivity reduced how much cPAM helped with retention.

In Fig. 5, the turbidity results of control samples with PCC and TONFC and samples with the optional treatment with cPAM are compared at the three different levels of conductivity. The PCC and TONFC were added at a 5% level, and the cPAM was added at a 0.1% level based on solids. The sample with cPAM had consistently lower turbidity readings, meaning better fine particle retention. However, as conductivity increased, turbidity also increased, suggest-



6. Effect of sodium sulfate addition on the mass of filtrate collected within 20 s of drainage with the default fiber furnish or with cPAM retention aid at the 0.1% level based on mass.



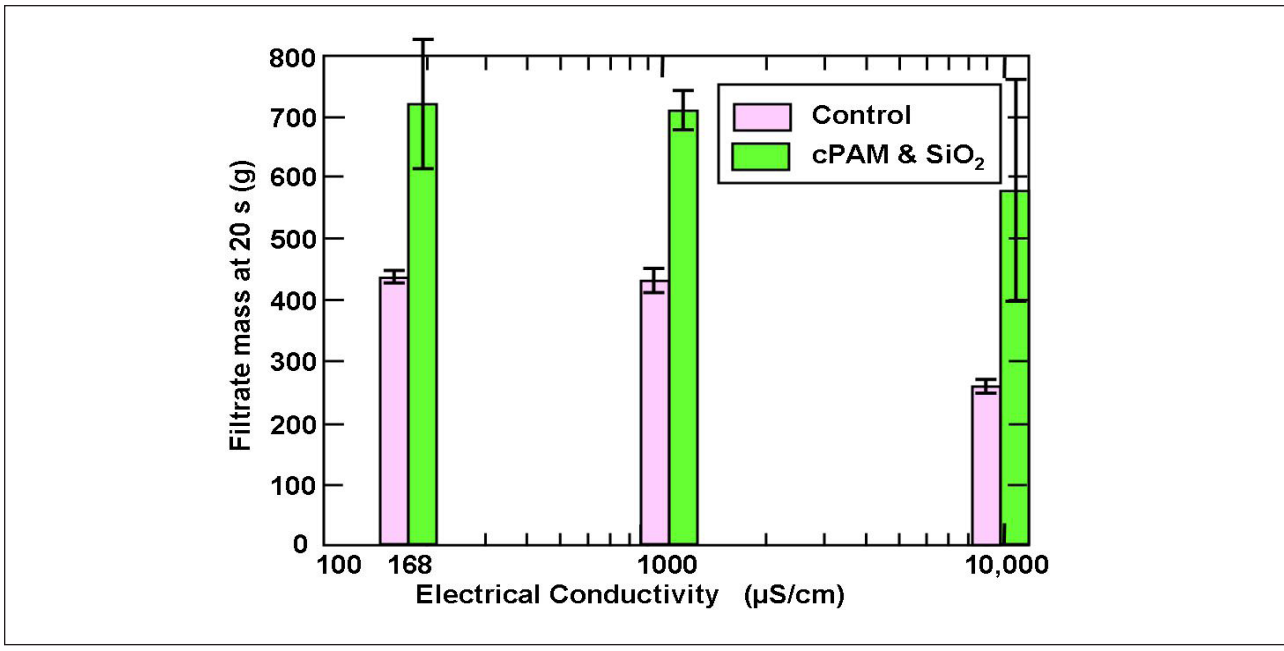
7. Effect of sodium sulfate addition on the mass of filtrate collected within 20 s of drainage with the default fiber furnish treated with polyvinylamine (PVAm) aid at the 0.2% level based on mass or the same followed by anionic PAM (aPAM) retention aid at the 0.1% level based on mass.

ing that higher conductivity interfered with cPAM's effectiveness. The sample without cPAM had much higher turbidity but gradually decreased as conductivity increased. This suggests that higher conductivity improved retention when cPAM was not present but had the opposite effect when cPAM was added. While cPAM improved retention overall, it became less effective at higher conductivity.

Dewatering rate

Dewatering tests were performed using a modified Schopper-Riegler freeness device. **Figures 6–9** show the effects of different chemical treatments and salinity levels on the amount of filtrate collected after 20 s.

Figure 6 shows the effect of conductivity on filtrate mass for the control sample and the sample treated with cPAM



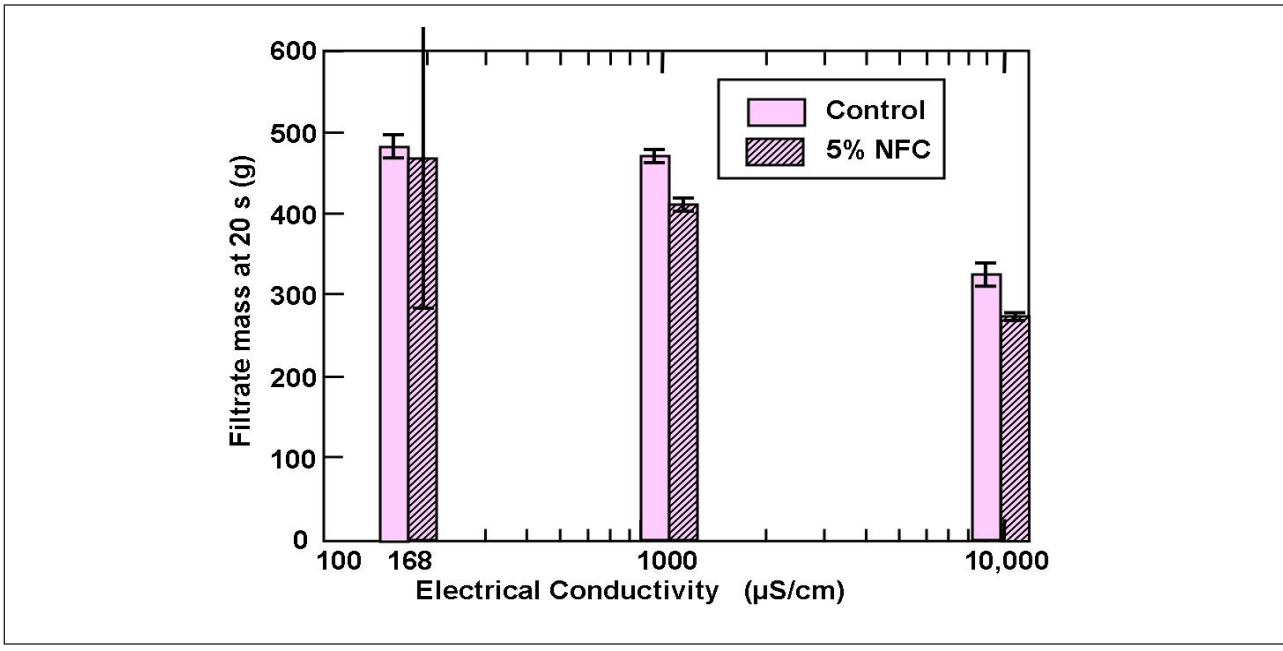
8. Effect of sodium sulfate addition on the mass of filtrate collected within 20 s of drainage of the default fiber furnish or after successive treatment with cPAM at the 0.5% level followed by SiO_2 at the 0.15% level based on mass.

at a 0.1% level based on solids. The control furnish started with a lower filtrate mass but steadily increased as conductivity increased. At the highest conductivity level, the filtrate mass of the control furnish was slightly higher than that of the cPAM-treated sample. This suggests that higher conductivity improved drainage for the control furnish. This effect is consistent with a decrease in the range of repulsive electrostatic forces with increasing salt concentration, leading to an expected increase of retention of small particles onto fiber surfaces [31]. The sample with cPAM had the highest filtrate mass at the lowest conductivity but showed a steady decrease in filtrate mass as conductivity increased. At the highest conductivity, the filtrate mass of both furnishes was nearly the same, showing that increasing conductivity reduced the dewatering benefit of cPAM. While cPAM improved drainage at low conductivity, it became less effective as conductivity increased.

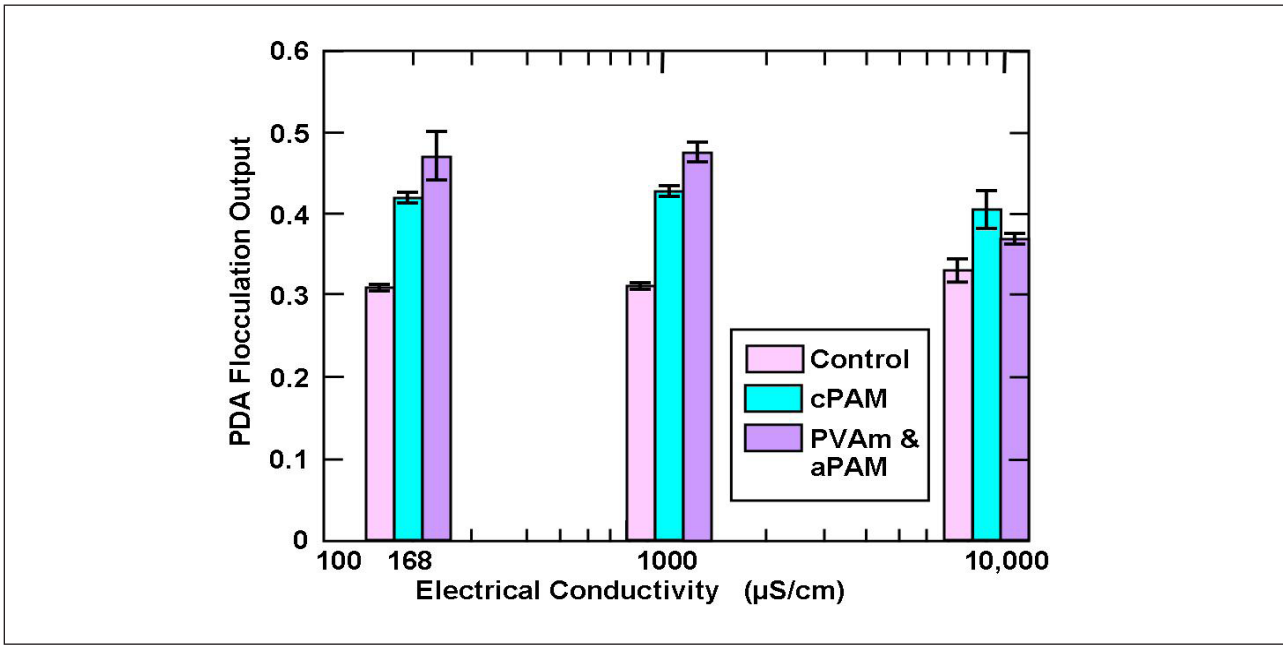
Figure 7 shows the dewatering rate of control samples, samples with only PVAm, and samples with PVAm and aPAM at three different levels of conductivity. The PVAm was added at a 0.2% level based on solids and then the aPAM was added at a 0.1% level based on solids. The furnish treated with PVAm drained faster than the control furnish at low and medium conductivity, but at the highest conductivity level, drainage dropped. A similar trend can be seen when aPAM was added after the PVAm to the furnish, as it gave the highest improvement in drainage at lower conductivity levels but showed a stronger decline at high conductivity. The control furnish, which initially had the lowest drainage, surpassed both treated furnishes at the highest conductivity. These results suggest that while PVAm and aPAM enhanced drainage under certain conditions, their effectiveness was negatively impacted in high conductivity environments.

Figure 8 compares the effect of conductivity on drainage for the control furnish and furnish treated with cPAM and colloidal silica. The cPAM was added at a 0.5% level followed by colloidal silica added at a 0.15% level based on solids. The furnish that had been treated sequentially by cPAM and colloidal silica drained significantly faster than the control furnish at all conductivity levels. The results depicted in Fig. 8 show that treatment with cPAM and colloidal silica improved drainage. However, increasing conductivity negatively impacted both furnishes, with overall drainage decreasing as conductivity increased.

Figure 9 shows the effect on drainage for the control furnish compared to furnish treated with NFC at a 5% level based on solids across varying conductivity levels in the absence of other additives. The NFC-treated furnish consistently had lower drainage than the control furnish at all conductivity levels, confirming its negative impact on dewatering, though the difference was not statistically significant for the tests carried out at 168 µS/cm. The lower dewatering at the highest level of salinity, for both the control and the 5% NFC conditions, does not appear to have been reported in previous literature for specific cases shown. However, such effects have been attributed in general to conditions favoring the blockage of drainage channels in the wet paper web [32]. It should be noted that the results tended to be inconsistent in the case of the control tests (no retention aids or other additives) in Figs. 6–9 relative to whether drainage decreased or increased with increasing salinity. These differences are tentatively attributed to differences between pulp batches or other factors related to running tests on different days.



9. Effect of sodium sulfate addition on the mass of filtrate collected within 20 s of drainage of the default fiber furnish or after addition of default NFC at the 5% level based on mass.



10. Effect of sodium sulfate addition on the level of fiber flocculation, based on photometric dispersion analyzer (PDA) output, when comparing the default furnish and the same after treatment with either cPAM at the 0.5% level of a combination of PVAm at the 0.2% level followed by aPAM at the 0.1% level.

Note that repeated dewatering results for the "control" condition were shown in Figs. 6–9. Differences in the control results can be tentatively attributed to the use of different batches of pulp, different days of experimentation, and different groups of researchers. In each case, the test conditions were being compared to control tests carried out in the same session.

Flocculation

Flocculation testing was conducted using a PDA. In **Fig. 10**, the PDA flocculation output of control samples, samples with cPAM, and samples with PVAm and aPAM are compared at three different levels of conductivity. The cPAM was added at a 0.5% level based on solids, PVAm was added at a 0.2% level based on solids, and aPAM was added

at a 0.1% level based on solids. Both treatments increased flocculation compared to the control furnish, showing their effectiveness in increasing fiber flocculation.

At the lowest conductivity, the combination of PVAm and aPAM had the highest flocculation, while cPAM also increased flocculation but to a lower degree. At mid-level conductivity (~1000 µS/cm), flocculation remained similar to the low-conductivity results for all samples, with a slight increase compared to the lowest conductivity. At the highest conductivity level, flocculation increased for the control furnish, while cPAM remained relatively stable with only a minor decrease. The PVAm and aPAM had the most noticeable drop in flocculation, suggesting they were more affected by increasing salinity levels.

Overall, both treatments increased flocculation compared to the control furnish at all conductivity levels, but PVAm and aPAM were more affected by increasing conductivity, while cPAM remained more stable.

CONCLUSIONS

Below are some conclusions based our findings:

1. Retention aid systems, such as cPAM or a sequential combination of PVAm and anionic polyacrylamide, continued to be effective with increasing levels of salinity, even up to 10,000 µS/cm of electrical conductivity. In fact, in one case (retaining $CaCO_3$ filler with sequential addition of cPAM and colloidal silica), the highest level of retention (as indicated by low filtrate turbidity) was achieved at the highest level of conductivity. These results are in conflict with earlier hypotheses that a decrease in the radius of gyration of the retention aid polymers, due to high salt levels, would hurt their performance.

2. Effects due to the presence of NFC on retention in the presence of other additives were strikingly different depending on the type of NFC. Default NFC, prepared by mechanical shearing of bleached softwood kraft pulp, did not interfere with the effects of cPAM. In contrast, the highly negatively charged version, TONFC, rendered the cPAM relatively ineffective at retaining calcium carbonate filler. Notably, the adverse effect of TONFC was apparent at all the levels of salinity tested.

3. Dewatering rates, as measured by the modified Schopper-Riegler tests, were affected in subtle ways by changes in electrical conductivity. The performance of the cPAM alone or the combination of PVAm and aPAM both exhibited minor declines in drainage at the highest level of salinity.

4. The extent of fiber flocculation was increased by either the cPAM retention aid or the combination of PVAm followed by aPAM. These effects became diminished at the highest level of salinity.

5. Further experimental work may be needed in cases where there is concern related to buildup of substances other than sodium sulfate in paper mill process water, which was the focus of this study. **TJ**

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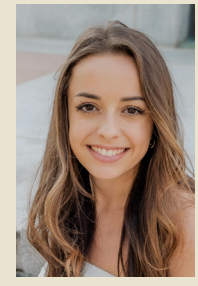
Though there is much concern about possible effects of salinity of process water on papermaking operations, few publications have dealt with this issue. The team at North Carolina State University has evaluated many effects related to papermaking additives, but most of the work has been restricted to just one intermediate level of salinity and electrical conductivity.

The most difficult aspect of this research was running a whole semester of laboratory tests, while managing not to have any evidence of cross-contamination between sub-batches of pulp with different salinity levels.

Our results showed that papermaking additives can be used to achieve retention and drainage benefits, with only minor effects of salinity, even at very high levels. These findings were surprising, as we had anticipated rather large consequences of salinity and what we found were relatively small effects for the most part.

The findings here can be regarded as "good news" for those responsible for running paper machines and achieving production targets and other goals.

A companion research paper to this one will consider the effects of different levels of water hardness in papermaking systems, and the effects on performance of papermaking additives.



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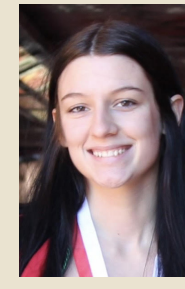
Johnson



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