PEER REVIEWED

Influence of closure on the white water dissolved solids and the physical properties of recycled linerboard

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ABSTRACT

The effect of closing the white water system on the physical properties of linerboard produced from recycled fiber under acid rosin sizing conditions was investigated. The closing of the system was simulated in a Formette Dynamique and with a British handsheet mold.

The tensile index showed a slight decrease for the British mold handsheets as the white water system closure was simulated by successive recycling of the white water. Zero-span tensile strength, ring crush, tear, and sizing were not affected significantly. Inorganic materials showed an increase in concentration in the white water with closure and recycling. Therefore, at high levels of closure (above about 70%), the continuous addition of alum in this papermaking system should be limited to the level of aluminum ion adsorption capacity of the fiber. However, inorganic buildup cannot be avoided for sodium, calcium, chloride, and sulfate because they are not removed well with the fiber but are continuously added with the stock, starch, rosin, and alum. No steady state was reached for these inorganics at high closure levels. Therefore, precipitation may eventually occur (likely involving low-solubility elements such as calcium), and interference with the physical chemistry of the papermaking system can be expected.

Application:

The influence of white water system closure on the properties of recycled linerboard and the concentrations of inorganics in white water are discussed.

THE CONSUMPTION OF secondary fiber has increased considerably over time. On average, one-third of the world's fiber needs for paper production are supplied by recycling (1). One of the largest secondary fiber consumers is the packaging sector, where mills that produce recycled linerboard and corrugated medium play an important role.

In the last 20 years, great efforts have been made to reduce water pollution by paper mills *(2)*. One way to achieve this is to install effluent treatment, which requires significant capital investment. Another approach is to close the white water system of the mill. Mills must then reuse the water that was previously going from the paper machine to effluent treatment. In this way, points where fresh water is consumed, such as wire showers, felt showers, roll showers, water gland seals, and dilution points in the stock preparation system, are changed to use white water *(3)*. Most of the time, the white water is cleaned of suspended particles by passing it through a saveall or clarification system. The dissolved material, however, is almost completely recycled to the paper machine.

Thus, three factors control the extent to which white water recycling can be practiced *(4):* thermal energy buildup, suspended solids buildup, and dissolved solids buildup.

The temperature increase in the white water occurs when less cool fresh water is used and less warm white water is discharged *(5)*. This temperature rise often results in more benefits than problems. It improves the drainage rate of the web in the forming sections and in the press section. Because of the great amount of heat transfer area, such as pipes and reservoir surfaces, the temperature of the white water system reaches a new equilibrium point and stabilizes, often without further problems.

Paper-machine white water, whether it is recycled or not, contains a variety of soluble salts and organic materials. Some of these are introduced via the freshwater supply, although the majority originate from the pulp or recovered paper used, or are chemicals deliberately added to the system *(6)*.

The water in a paper-machine system therefore contains a variety of dissolved materials. The main species are hemicelluloses, lignin derivatives, starches, sizing agents, defoamers, dyes, surfactants, slimicides, and synthetic polymers. This list is not comprehensive, and the dissolved materials will vary greatly in concentration and in the species present from machine to machine. However, with increased closure of water systems, there will be an increasing amount of dissolved substances in the white water *(6)*. The net effects of closure on process water are increases in ionic concentration, concentration of dissolved organic substances, temperature, and levels of suspended solids (fines/fillers) *(2, 6, 7)*.

The increase of ionic concentration may influence the strength properties of the resultant paper *(6)*, adsorption of additives, the mechanisms of retention, the total acidity/aluminum ion concentration (sizing), the microbiological environ-

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Closure	Recycle	Aluminum in water, mg/L	Sulfur in water, mg/L	Sodium in water, mg/L	Chloride in water, mg/L	TOC in water, mg/L	pH in water	Conductivity in water, mmho
Start run	-	0.1	7.7	3.8	1.0	106.0	5.3	0.10
73%	1	4.0	27.0	7.7	2.1	78.0	4.7	0.24
closure	2	7.1	38.0	10.0	3.1	71.5	4.6	0.32
	3	9.4	47.0	13.0	3.8	112.0	4.6	0.38
	4	11.0	52.0	14.0	4.3	118.0	4.5	0.41
	5	12.0	59.0	15.0	4.7	97.5	4.5	0.44
	6	13.0	58.0	16.0	5.1	99.0	4.5	0.47
Start run	-	0.1	6.9	3.6	0.6	52.5	5.5	0.09
87%	1	2.0	23.0	7.7	2.6	64.5	4.8	0.23
closure	2	3.0	25.0	7.9	2.6	44.5	4.7	0.25
	3	8.0	54.0	15.0	4.4	116.5	4.6	0.43
	4	11.0	62.0	17.0	4.6	95.0	4.6	0.48
	5	15.0	75.0	20.0	5.2	130.5	4.6	0.55
	6	17.0	78.0	20.0	5.8	188.0	4.6	0.59
Start run	-	0.2	7.5	4.1	0.8	39.5	5.7	0.15
100%	1	4.1	25.6	8.1	3.1	-	5.0	0.25
closure	2	-	-	-	-	-	-	-
	3	15.7	62.3	16.1	5.4	94.0	4.7	0.48
	4	-	-	-	-	-	-	-
	5	24.3	93.2	23.8	8.6	142.5	4.5	0.65
	6	28.8	108.0	27.2	7.5	213.0	4.5	0.72

I. Aluminum, sulfur, sodium, and chloride concentration in white water for 73%, 87%, and 100% level of closure (Formette Dynamique handsheets). TOC, pH, and conductivity are also shown.

ment, and corrosion.

Reported effects of system closure *(8)* show that positive and negative effects have been observed when the white water system of a paper mill is closed. Each mill situation has to be considered as a unique case, and the effect of closing the white water system in a particular mill cannot be applied directly to other mills. We have chosen to investigate white water recycling under controlled laboratory conditions using stock from a recycled linerboard mill. The results allow predictions of the magnitude and impact of dissolved solids buildup.

OBJECTIVES

We have investigated the effect of the dissolved materials on the physical properties of recycled linerboard when white water system closure is implemented. The objectives were:

- To determine the increase of organic and inorganic dissolved solids in a white water system for producing recycled linerboard under acid sizing at different degrees of closure. The behavior of pH, inorganics, and total organic carbon was investigated.
- To determine how much the physical properties of this linerboard are affected by the increase of dissolved solids at different levels of white water system closure. Tensile, ring crush, tear, zero-span tensile, and Cobb number were monitored.

EXPERIMENTAL

Level of closure and stock used

The level of closure for each handsheet formed was defined as:

$$LC = [V_{ww} / (V_{fw} + V_{ww})] \times 100 \quad (1)$$

where

LC = level of closure, %

V_{ww} = volume of white water, L

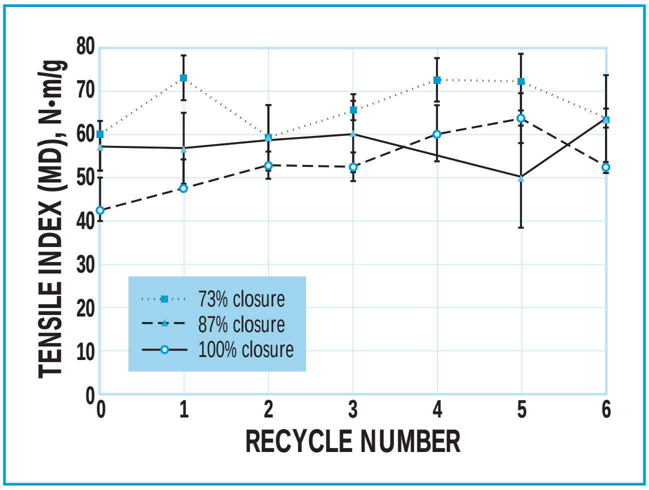
V_{fw} = volume of fresh water, L.

The research simulated the closing of a white water system to produce 205-g/m^2 linerboard from recycled fiber. The stock is described as follows.

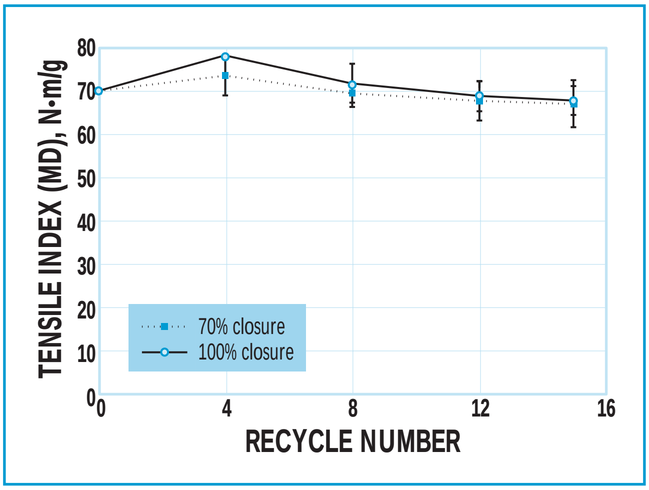
Formette Dynamique handsheets

Recycling was simulated by forming handsheets in the Formette Dynamique and reusing the white water for the next handsheet. This was repeated six times for each level of closure. During the recycling of the white water, the levels of organic and inorganic dissolved solids were determined in each cycle. Conductivity and pH were monitored. The levels of closure (LC) (Eq. 1) of the white water system for the Formette handsheets were 73%, 87%, and 100%.

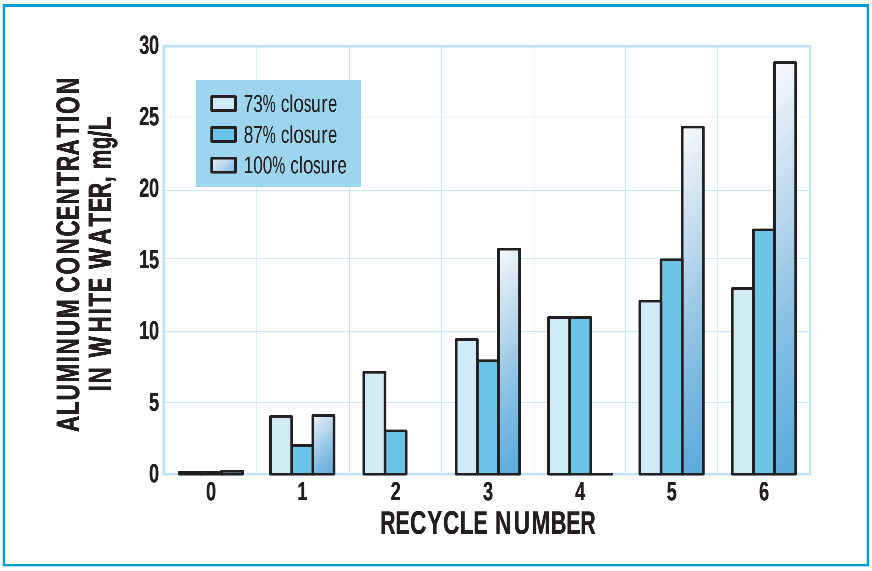
Chemical addition. The chemicals were added to the furnish in the same amounts that they are used in the recycling mill where the stock originated (40 kg aluminum sulfate/ovendry (o.d.) ton of fiber, 12 kg



1. Tensile index (MD) for 73%, 87%, and 100% closure (Formette Dynamique handsheets). No conclusive trend is seen.



2. Tensile index for 70% and 100% closure (British mold handsheets). No starch was added. A slight decrease is seen.



3. White water aluminum content for 73, 87, and 100% closure (Formette Dynamique handsheets). A trend to level off is only seen at 73% closure.

cationic starch/o.d. ton, and 6 kg rosin soap/o.d. ton). The water used to prepare the chemicals was deionized. Chemicals were added for each new handsheet. The first handsheet was formed without chemical addition to determine the properties of the stock.

Stock, stock preparation, and handsheet formation. The fiber was received from a 100% recycled linerboard paper mill that uses 80% old corrugated containers (OCC), 10% sack paper, and 10% boxboard. The stock in this mill is cleaned by pulping, high-density cleaners, coarse screening, forward cleaners, reverse cleaners, thickening, and fractionation. The long-fiber fraction of the stock had 3.54% consistency and a freeness of 450 mL CSF; the short-fiber fraction had 3.64% consistency and a freeness of 385 mL CSF.

The procedure to produce the handsheets with a basis weight of 205 g/m^2 in the Formette Dynamique was as follows:

1. Suspensions of 0.2% consistency (11 L) containing 22 g o.d. long fiber and a suspension of 0.2% consistency (7 L) containing 7 g o.d. fiber were prepared. One liter of each suspension was taken for analysis. The water used to form the water seal in the Formette Dynamique was tap water (municipal water, 21.5 mg/L hardness as $CaCO_3$).
2. The rosin soap was added first, followed by the aluminum sulfate and finally the cationic starch (5 min between the additions).
3. The handsheets were formed by first adding 5 L of long-fiber suspension, then 6 L of short-fiber suspension, and finally the last 5 L of long-fiber suspension. The drainage of the Formette Dynamique was collected to be used for the formation of the next handsheet. One liter of white water was taken for analysis after each handsheet formation.
4. The first handsheet (start run) was always made without chemi-

cal addition and with deionized water to evaluate the as-received properties of the stock.

5. For the 73% level of closure, 16 L of stock were fed into the Formette Dynamique for the production of each of the seven handsheets. Six liters of fresh water entered the Formette Dynamique for the water seal ring of the wire. The average total drainage was 22 L/handsheet [level of closure (LC) was 73%].
6. Similarly, during the 87% closure run, 3.5 L of white water plus 3 L of fresh water were used to form the water seal ring in the Formette Dynamique. During the 100% totally closed run, 6.5 L of white water were used to form the water seal ring.

The handsheets were pressed at 2000 psig for 2 min and finally at 15,000 psig for 5 min. After pressing, the handsheets were dried at 20 psig steam pressure for 3 min (each side).

British mold handsheets

To check the results obtained from the Formette Dynamique, recycling was also simulated using standard 3-g British mold handsheets (150 g/m^2, TAPPI Test Method T 205). Here, the first handsheet was produced without chemicals; the following 15 recycles were then performed with rosin soap and aluminum sulfate addition at the same level that was used for the Formette Dynamique. No starch was added. Two levels of closure were used (70% and 100%). For the 70% level of closure, 70% of the white water from the previous recycle was used for the next handsheet, and the remaining 30% was fresh water. For the 100% closure level, all the white water from the previous recycle was used for the next handsheet. The fiber used was the same long fiber as for the Formette Dynamique.

Closure	Recycle	Ring crush index, N·m/g	Zero-span tensile strength index, N·m/g
Start run	-	8.4	657.8
70%	2	10.0	657.6
closure	6	10.3	649.9
	10	11.0	662.2
	13	10.6	645.8
Start run	-	8.4	657.8
100%	2	11.2	653.5
closure	6	11.7	660.4
	10	11.8	636.9
	13	11.2	662.2

II. Ring crush index and zero-span tensile strength index for British mold handsheets at 70% and 100% level of closure (the averages of five measurements per handsheet are shown)

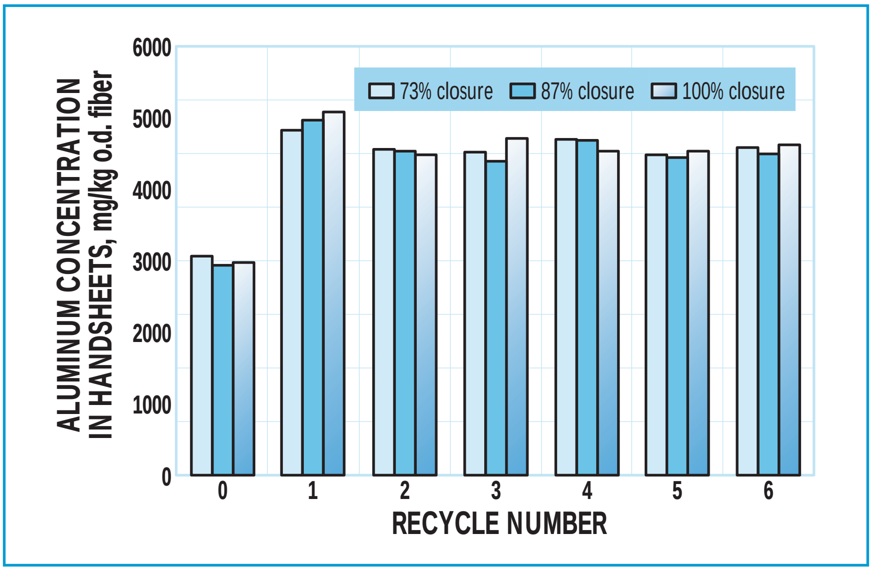
Closure	Recycle	Aluminum in paper, mg/kg	Sulfur in paper, mg/kg	Sodium in paper, mg/kg	Chloride in paper, mg/kg
Start run	-	3080	1102	357	74.3
73%	1	4850	1310	266	68.6
closure	2	4570	1300	240	68.4
	3	4530	1300	259	63.6
	4	4710	1370	248	75.0
	5	4480	1330	243	66.5
	6	4580	1370	267	86.2
Start run	-	2950	1060	333	68.7
87%	1	4980	1320	246	70.6
closure	2	4550	1280	239	46.8
	3	4410	1310	260	55.5
	4	4700	1380	241	61.1
	5	4450	1360	248	44.2
	6	4500	1370	263	63.1
Start run	-	2990	1090	286	58.1
100%	1	5100	1370	230	50.5
closure	2	4500	1360	237	53.0
	3	4720	1410	236	53.8
	4	4550	1400	245	55.4
	5	4540	1430	250	59.6
	6	4622	1460	248	92.0

III. Aluminum, sulfur, sodium, and chloride content of Formette Dynamique handsheets at 73%, 87%, and 100% level of closure (Basis: ovendry fiber)

Analytical procedures for ICP and CIE

White water samples for inductively coupled plasma (ICP) emission spectroscopy were filtered (0.45-µm filter), acidified, and then analyzed. The handsheet samples were oven dried, digested in acid and hydrogen peroxide, filtered (0.45-µm filter), and then analyzed. A four-point calibration curve was used. All injections were made in triplicate. Internal standards were used to compensate for small changes in the instrument performance.

White water samples for capillary ion electrophoresis (CIE) were filtered (0.45-µm filter) before analysis. Handsheet samples were oven dried



4. Aluminum content in Formette Dynamique handsheets for 73%, 87%, and 100% closure. After the start run (no chemicals added), the concentration levels off (maximum level of aluminum purge with the sheet is reached).

and then extracted for 2 hours under sonication followed by 2 days by soaking. Extracts were filtered before analysis (0.45-µm filter). A five-point calibration was used. Quality control measures included duplicate and spiked samples, and midrange calibration verification every 10 samples and at the end of the run.

RESULTS AND DISCUSSION

The Formette Dynamique handsheets and British mold handsheets were evaluated for ring crush, tear, tensile, zero-span tensile, and Cobb number. The measurements were made at standard conditions using the following TAPPI Test Methods:

- TAPPI T 402 for standard conditioning as required for the test procedures
- TAPPI T 494 for tensile
- TAPPI T 822 for ring crush
- TAPPI T 414 for tear
- TAPPI T 441 for sizing.

Each property measurement was indexed dividing by the basis weight of the handsheet to compare results from different recycles.

The white water drainage after each handsheet formation was evaluated for pH and conductivity (**Table I**). The pH decreased slightly during the recycling runs, while the conductivity increased due to the increase in inorganic ion concentration, as shown later in this paper.

Quantities of aluminum, sulfur, and sodium were determined by inductively coupled plasma (ICP) emission spectroscopy. Dissolved chloride was determined by capillary ion electrophoresis (CIE). The organic white water concentration was monitored after each recycle with the total organic carbon (TOC) test.

Mechanical and physical properties of handsheets

The evaluation of the tensile index for the Formette Dynamique handsheets at 73%, 87%, and 100% closure showed that this property was not affected significantly as the number of recycles increased (**Fig. 1**). Note that the start-run handsheet was formed without chemical addition (see procedure for Formette handsheets). The tensile index for the British mold handsheets showed a slight decrease as the number of recycles increased (**Fig. 2**).

A possible explanation is that the tensile index for the Formette Dynamique handsheets leveled off due to the successive starch additions. The tensile index represents mainly the fiber-to-fiber bond, and the successive addition of starch continues to strengthen this bond to a similar level for each handsheet *(9)*. On the other hand, in the British mold handsheets, there was no starch addition. For the British mold handsheets, the increasing concentration of ions in the white water during recycling (see the following) most likely reduced the swelling capacity of the fibers somewhat, which in turn is known to reduce the relative strength of the bonds between fibers *(8)*. This may then be detected as a decrease in the tensile index. In summary, the tensile index is at most slightly deceased through white water recycling, even if no starch is added.

The zero-span tensile strength index for both types of handsheets and for different levels of closure showed no change (see the data for British mold handsheets in **Table II**). The zero-span tensile strength is thought to measure mainly the individual fiber strength rather than the fiber bond strength *(10)*. If this view is adopted, the recycling of water appears not to affect the strength of individual fibers.

Other properties, such as tear and ring crush, showed no significant deterioration as the number of recycles and the level of closure increased for the Formette Dynamique and the British mold handsheets. The ring crush data for the British mold handsheets is shown in Table II as an example. No starch was added when these handsheets were produced. Averaging the tear index for the Formette Dynamique handsheets (averaging all three closure levels and all handsheets analyzed) results in a value of 7.61 mN·m²/g for the machine direction and 12.85 mN·m²/g for the cross direction (standard deviation=1.12 and 1.46 mN·m²/g, respectively). Tear is a property that depends on fiber characteristics such as length and coarseness, and as expected, is not significantly affected by closing of the water system *(11)*. Ring crush not only depends on fiber-to-fiber bond strength but also on structural characteristics of the paper, such as the thickness and rush/drag ratio *(12)*. These characteristics are not directly affected by the increased presence of dissolved solids during formation of the sheet.

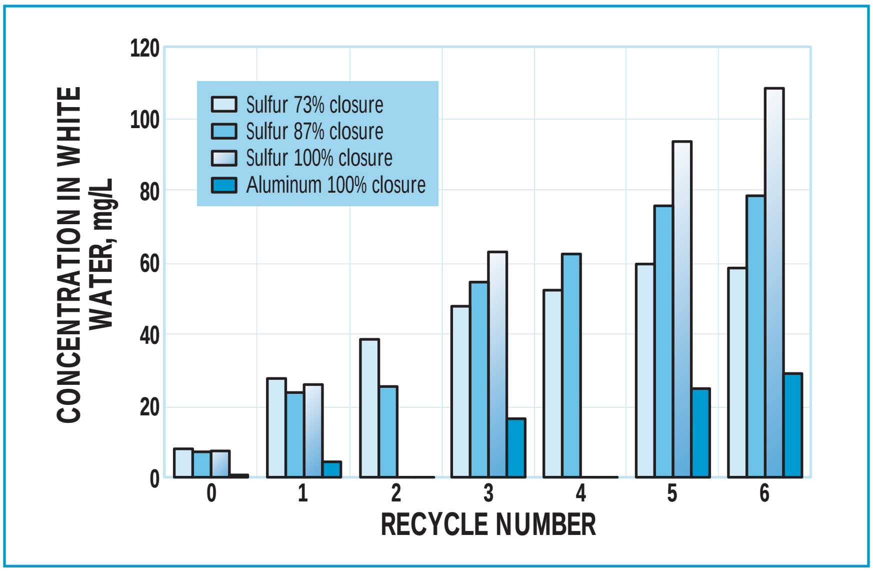
The sizing of the paper (Cobb number, 2 min) was not affected by increasing the number of recycles and by increasing the level of closure. The sizing value was fairly constant at 20–25 g water/m² from recycle 1 to 6 for Formette Dynamique handsheets at all three closure levels.

Dissolved inorganic and organic material in the white water

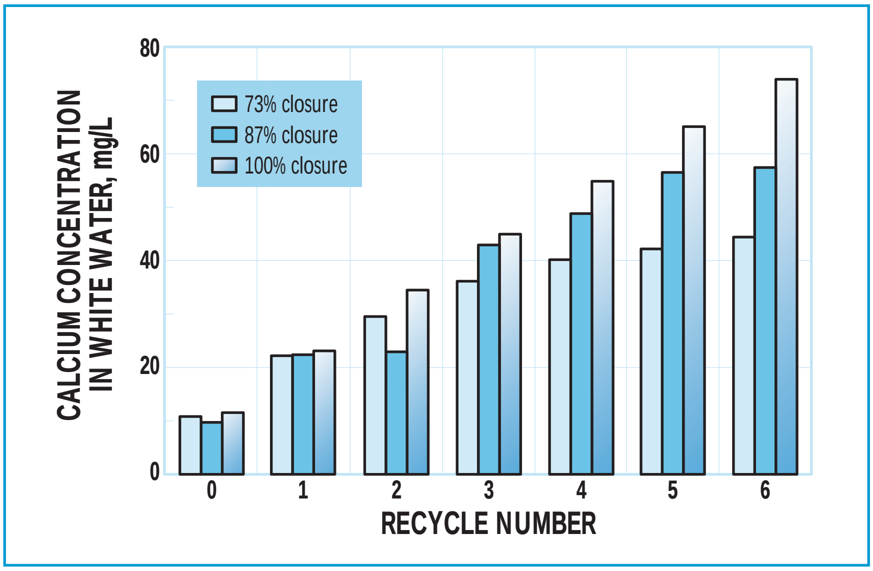
Formette Dynamique handsheets. The pH range during the production of Formette Dynamique handsheets with addition of aluminum sulfate (recycle 1 to 6, Table I) was 4.5–5.0. In this range of pH, aluminum sulfate dissociates, and the predominant species is Al^{+3}. Having the aluminum in the form of Al^{+3} explains the fairly constant value of the Cobb number, because at this pH range, the alum resinate precipitate can form and produce good size retention *(13)*.

Figure 3 shows a steady increase of the aluminum concentration in the white water. The aluminum content of the final paper is approximately constant after recycle 1 (**Fig. 4**). The start run shows the aluminum content coming in with the stock before the addition of any chemicals. When aluminum sulfate is successively added to the fiber in recycle 1 through 6, the fiber will adsorb a limited amount of aluminum, in this case 4500–4700 mg aluminum/kg of paper. This matches values from the literature fairly well *(14)*. The additional aluminum, which is coming in with the added aluminum sulfate and with the recycle water, remains in the white water. This steadily increases the white water aluminum content, with the sharpest risk at the highest level of closure.

The increase of sulfur (Table I) in the white water is due to the successive additions of aluminum sulfate. Some sulfate will go to the fiber with the alum rosin precipitate *(15)*. However, it is clear from **Fig. 5** that the increase of sulfur in the white water proceeds more rapidly than the increase of aluminum, because aluminum is purged much more efficiently with the sheet. This is also evi-



5. Sulfur concentration increase in the white water of Formette Dynamique handsheets at 73%, 87%, and 100% closure. Aluminum concentration at 100% closure is shown for comparison.



6. White water calcium content at 73%, 87%, and 100% closure (Formette Dynamique handsheets). At 100% closure, no trend to level off is seen.

dent from the difference between the aluminum content of the sheet from the start run vs. the sheet of recycle 1 at 100% recycle (**Table III**), because this difference equals roughly the purge capacity of each sheet.

Sodium ions dissociate from rosin soap when added to the pulp suspension. Some ions will attach to the fiber, but most will stay in solution. Table III shows a higher content of sodium for the incoming fiber compared to recycle 1. After the start run, there is a drop in the content of sodium in the final paper from recycle 1 to 6 (about 230–270 mg sodium/kg of paper). This drop in the sodium content in the final paper is probably due to aluminum ions displacing sodium ions from the fiber due to their higher charge density *(6)*. Therefore, the fibers will adsorb a reduced amount of sodium ions. The remaining sodium ions coming in with new rosin soap and the recycle water will increase the sodium content of the white water as the number of recycles and level of closure increase (see Table I).

The chloride in the white water stems mainly from the dissociation of chloride from the cationic substitution groups in the starch. The chloride content in the white water also shows an increase as the closure increases and the number of recycles increases (Table I). A limited amount of chloride anions is adsorbed on the fiber, as shown in Table III, and additional chloride coming with the starch will build up in the white water (Table I).

Calcium comes in with the fiber, with fillers in the paper, and with residual calcium in the recycled paper (cement bags in the recycle stream for this mill). The white water content of calcium for 73% LC for Formette Dynamique handsheets levels off at 40–44 mg/L after recycle 4. For the 87% and 100% LC, the calcium content in the white water increased steadily (**Fig. 6**). The buildup of calcium content in the white water can be rationalized because fibers will adsorb aluminum cations preferentially over calcium ions *(14)*.

The concentration of organics measured as the total organic carbon (TOC) content in the Formette Dynamique white water was relatively constant for the 73% level of closure, but it shows an increase for the 87% and 100% levels of closure as the number of recycles increases (Table I). The TOC content is associated with colloidal and soluble materials (starch and rosin) in the white water, fibers, and fiber fines. As the level of recycling increases, the TOC content rises. Some scatter in the data may stem from particulate matter (fines).

British mold handsheets. The content of aluminum, sulfur, and sodium in the white water of the British mold handsheets for the 100% level of closure increased steadily with recycling. The absolute concentrations are lower than for the Formette handsheets, because the consistency was lower for British mold handsheets. For the 70% level of closure, the content of aluminum, sulfur, and sodium in the white water reaches an approximately constant value as the number of recycles increases. The aluminum content is shown in **Fig. 7. Figure 8** shows the sodium, sulfur, and chloride content for the white water at 70% and 100% recycle. At 70% closure, the system still has a relatively large purge of the white water. This allows the concentrations to reach a steady state with an equilibrium between addition, purge with water, and purge with the sheet. However, at 100% closure, the buildup of aluminum and sulfur is clear.

Because starch and the associated chloride were not added to the British mold handsheets, the chloride content in the white water was approximately constant through the 15 recycles for the 70% and 100% level of closure (Fig. 8).

CONCLUSIONS

This particular recycle fiber and papermaking system reaches a maximum adsorption capacity of aluminum, sulfur, sodium, and chloride on the fibers when the handsheets are formed, as shown in Table III. This means that the sheet quickly reaches the limit as a “purge” for inorganics, and any further addition will lead to a buildup in the white water.

Correspondingly, the results show a steady increase in the content of dissolved inorganic species in the white water as the level of closure and number of recycles increase. Inorganics are introduced deliberately (aluminum) with other added chemicals (chloride with cationic starch, sodium with rosin, and sulfate with alum) or with the stock (calcium). Minimizing the addition of chemicals can solve the buildup problem only for aluminum, since purge (with the fiber) and controlled addition can potentially be balanced. Other inorganics that do not associate strongly with the fiber will steadily build up at high closure levels. This cannot be avoided because starch and rosin have to be added to the system continuously to maintain strength and sizing, but virtually only the organic part of these materials leaves with the sheet.

The sizing and the physical properties (ring crush, tear, and zero-span tensile) appeared not to be significantly affected as the white water system was closed and the number of recycles increased. Only a slight decrease in the tensile index of the British mold handsheets (no starch added) was found.

At high closure levels (70%–75% and above), a buildup of dissolved inorganics and organics occurs, without any sign of reaching equilibrium at 100% closure during the number of recycles tested here. The aluminum buildup could probably be controlled by balancing addition and purge with the sheet. This is not possible for other inorganics introduced with starch, rosin, and the recycle stock. Ions with low solubility, such as calcium, can then cause precipitation problems if the sheet properties do not first deteriorate to unacceptable levels as high ionic strengths are reached. For a tightly closed system, a selective purge for dissolved inorganics from the white water is clearly needed. TJ

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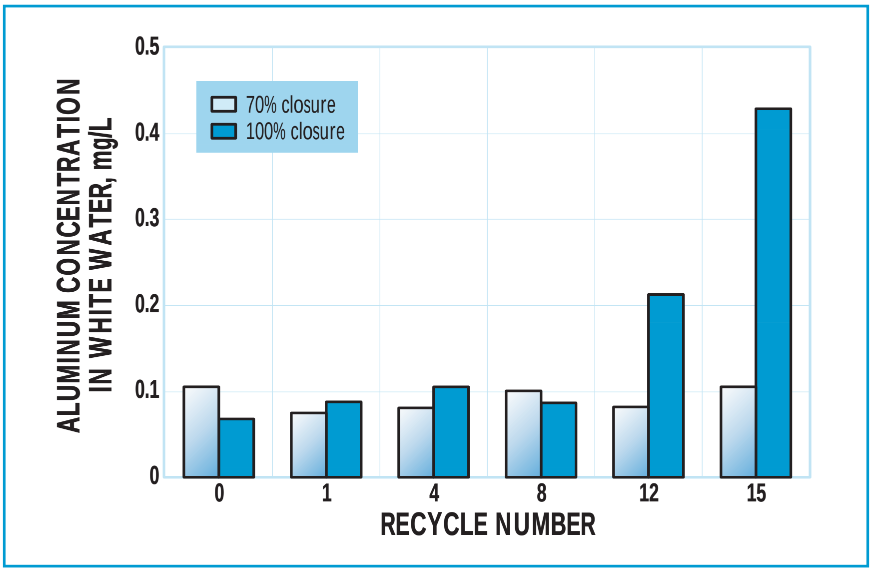
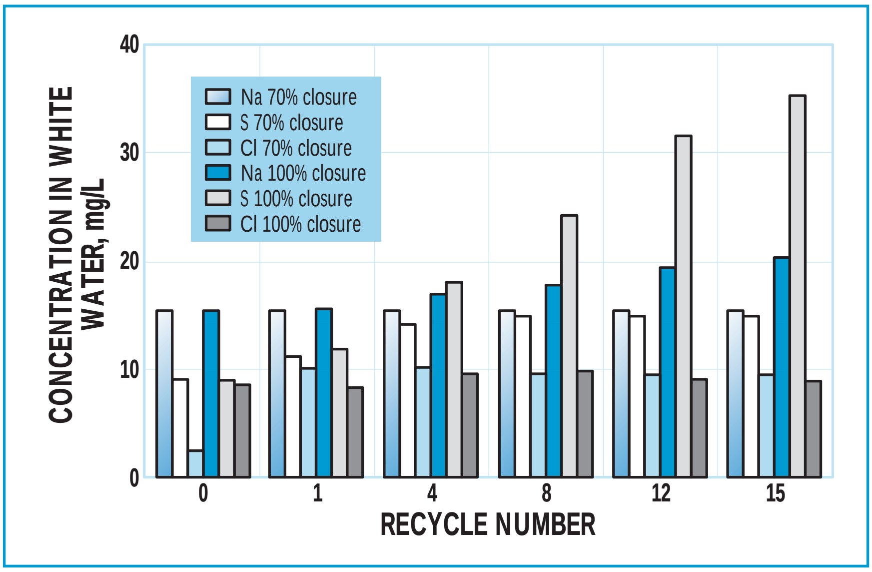


7. White water aluminum content for 70% and 100% closure (British mold handsheets). Buildup at 100% closure is evident.



8. White water sodium, sulfur, and chloride content for 70% and 100% closure (British mold handsheets). Sodium and sulfur buildup at 100% closure is evident.

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