ABSTRACT

Cationic polymer was applied onto fiber pads supported on brownstock vacuum drum washers in an effort to increase displacement washing efficiency. Sodium concentration, liquor conductivity, and lignin (VIS absorbance) at the feed and for pulp samples taken off the washer drum were measured as a function of polymer treatment concentration. Washing was characterized by the relative displacement ratio, RDR, defined as the displacement ratio of the treated portion of the drum divided by the displacement ratio of the control section. Displacement ratios are defined as the mass of material (sodium or lignin) removed from the pad divided by the total initial amount in the pad that is removable. In all cases, the RDR increased with the addition of polymer, thus indicating that cationic polymers improved the displacement washing efficiency. The most dramatic changes were observed with the first washer where the RDR for sodium improved from 0.815 to 0.957 by the addition of 6 g/L of cationic polymer (13 kg polymer per o.d. metric ton of pulp).

Polymer enhanced brownstock washing: mill trial

RAYMOND E. LAPPAN, ANDREW N. HRYMAK, AND ROBERT PELTON*

PULP WASHING IS A CRUCIAL UNIT operation in pulping and bleaching. High production rates must be achieved along with high washing efficiencies while using a minimum quantity of wash water. Poor brownstock washing leads to excessive black liquor and sodium carryover to the bleach plant causing unnecessary chemical consumption and effluents. On the other hand, good washing achieved by the excessive use of wash water increases the demand on the evaporators in the recovery system. Similarly, operational constraints on the bleach plant washers also penalize both poor washing or excessive water consumption.

One approach to improved pulp washing is to install new equipment. Modern drum and belt washers, operating within design capacity, can give excellent washing; however, in many older mills this approach is financially unattractive. Modern process control techniques along with good engineering practices may also improve washing. However, when these avenues are exhausted, what possibilities remain? Our research has focused on the possibility of improving displacement washing on vacuum drum washers by adding cationic polymers to shower water.

Efficient vacuum drum washer operation occurs when wash water from the shower bars completely displaces the liquor entrained in the pulp pad. In the ideal case, complete displacement occurs with a volume of wash water equal to the volume of liquor entrained in the pad. In real washers, much more wash water is used in an effort to displace all of the black liquor, although such attempts rarely result in complete liquor displacement from the pad. Poirier and Crotogino *(1)* identified pad non-uniformity in pore structure as one of the important effects limiting the efficiency of vacuum drum washers. With a non-uniform pad, there exist zones of high permeability through which the wash water easily passes. By contrast, low permeability regions of the pad are poorly washed, reflecting insufficient wash water penetration into the pad. In the extreme case, most of the wash water would pass through a small fraction of the fiber pad via high permeability zones.

Lee *(2, 3)* has proposed that washing can be enhanced by adding flow altering polymers to the wash water. He demonstrated that polyacrylamide prevented the phenomenon called viscous fingering from occurring in laboratory displacement washing experiments. His results demonstrated that nearly ideal displacement washing would be obtained with 10 ppm of high-molecular weight polyacrylamide dissolved in the wash water. Lee's technology has not been widely adopted because the polymer also reduced the water flow rates through the pad; he reported that mat drainability was reduced by a factor of 4 when polyacrylamide was used. Therefore, improved washing comes at the expense of reduced production rates.

A promising approach, invented at McMaster University, has been to add low molecular weight cationic polymers to the wash water, leading to local permeability changes, that forces the wash water to penetrate the low permeability regions and displace entrained liquor. This effect is due to the fact that positively charged synthetic polymers will form precipitates when mixed with kraft lignin, a negatively charged polymer *(4–6)*. This concept can be viable only if precipitation is selective to the high permeability parts of the pad. Initial laboratory experiments were conducted in model packed beds saturated with black liquor *(4)*. The "channel bed" consisted of uniform fine glass beads surrounding a small vertical channel of

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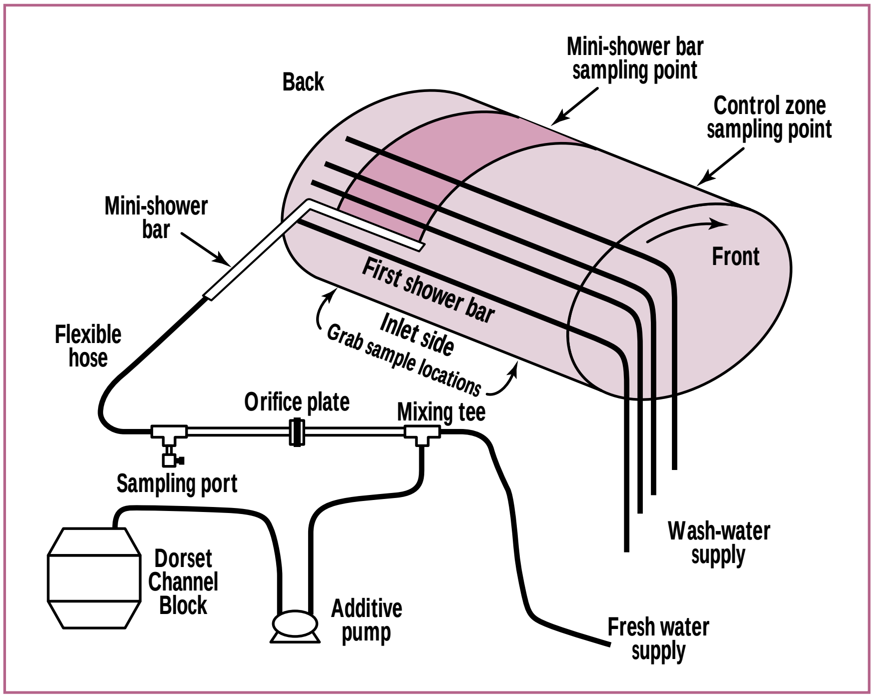
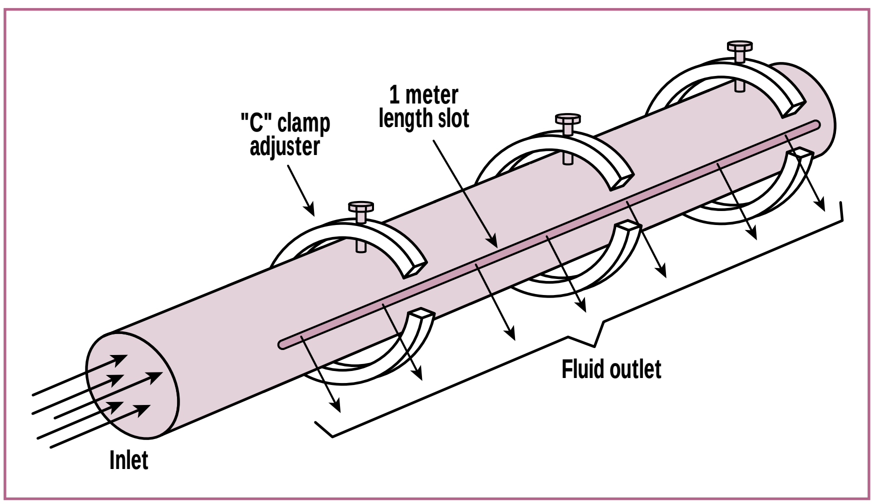


1. Rotary drum filter with mini-shower bar apparatus



2. Mini-shower bar fluid distributor

coarse glass beads. Thus, the coarse beads were a physical model for a high permeability channel through a pulp pad. In this work, it was shown that much better displacement of the liquor from glass beads occurred when cationic polymer was added to the displacement water without significant decreases in the drainage rate (less than 10%) *(7)*. Dissection of the bed after the experiment revealed black polymer/lignin precipitates exclusively in the coarse bead channel. It was speculated that only in the coarse channel were the flow rates sufficient to give the good mixing of black liquor with polymer wash water which would be required for a precipitate to form and grow.

In subsequent work, Pelton and Grosse *(8)* videotaped the formation of polymer/lignin precipitates in model channel beds. They observed that precipitation occurred initially at the interface of the high and low permeability zones. With increasing washing time, the region with precipitate grew into the coarse beads to constrict the flow in the center channel.

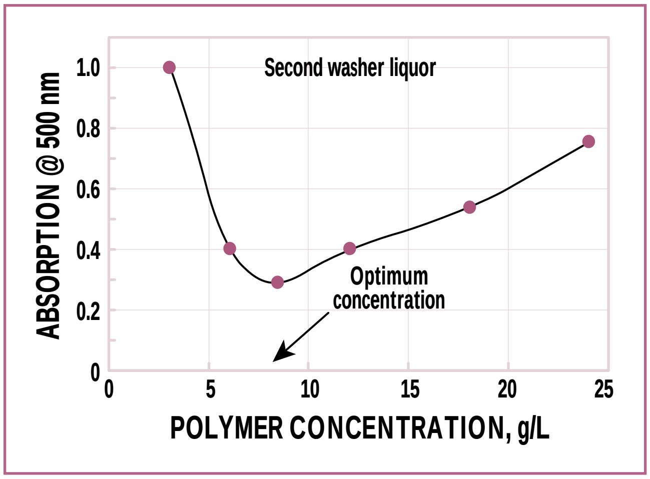
The link between model displacement washing studies in a glass-bead-channel-bed to brownstock washing is tenuous. The objectives of this work were to determine if there is any possible advantage of adding cationic polymer to the wash water of a commercial brownstock washer. In past mill work, we have experienced difficulties determining whether observed trends in washing were due to the addition of cationic polymer or simply fluctuations in the mill. In an effort to separate the effect of polymer, a 1-m-long shower bar, herein called the "mini-shower bar," was used to apply polymer to a strip of the pulp washer drum surface while the remainder of the drum was unchanged, while all but the first of the regular shower bars were still in use. The untreated portion of the washer drum (see Fig. 1) served as a control which tracked the effects of mill process changes.

EXPERIMENTAL

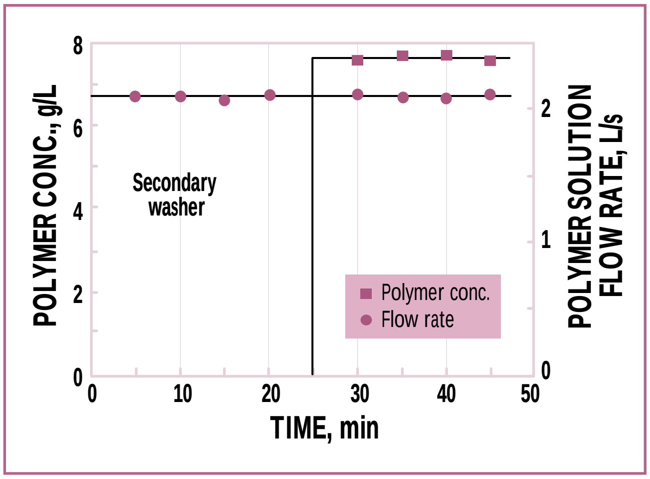
Materials and analytical methods

The cationic polymer was Dorset Channel Block®, which was supplied as a concentrate containing 50 wt. % polymer. All reported polymer concentrations are expressed as the mass of Channel Block® concentrate per unit volume.

Liquor conductivity measurements were made with Cole Parmer portable conductivity meter (Model 1481-40) fitted with a PVC-stainless steel cell. Data were collected at room temperature (approximately



3. Complete consumption test data for secondary washer test



4. Secondary washer trial flow rates and polymer concentrations in mini-shower bar wash water stream

25°C after cooling in a water bath—typically within a few hours after sample collection). Sodium concentrations were measured with a Corning combination ion selective electrode fitted to a Corning-150 pH/ion meter. Samples were cooled to room temperature and diluted with an equal volume of 0.5 *M* triethanolamine (Aldrich T5830-0) as prescribed by the electrode manufacturer. The relationship between electrode output and sodium concentration was established by calibration with 0.01 and 0.1 *M* stock NaCl solution. Results from both techniques were corrected for temperature fluctuations according to equipment manufacturers recommendation.

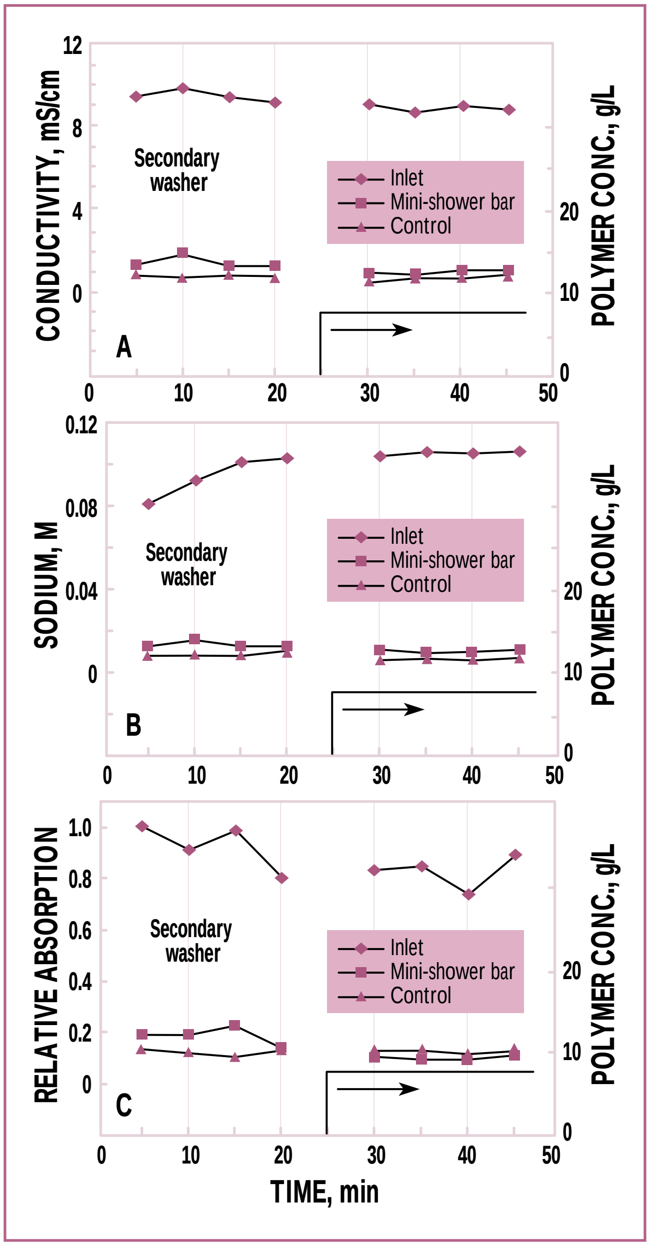
Absorbency at 500 nm was used to estimate lignin concentration in the process liquors. Samples were filtered and diluted with 0.01 *N* NaOH prior to analysis in a Spectronic-20 spectrophotometer.

Complete consumption test

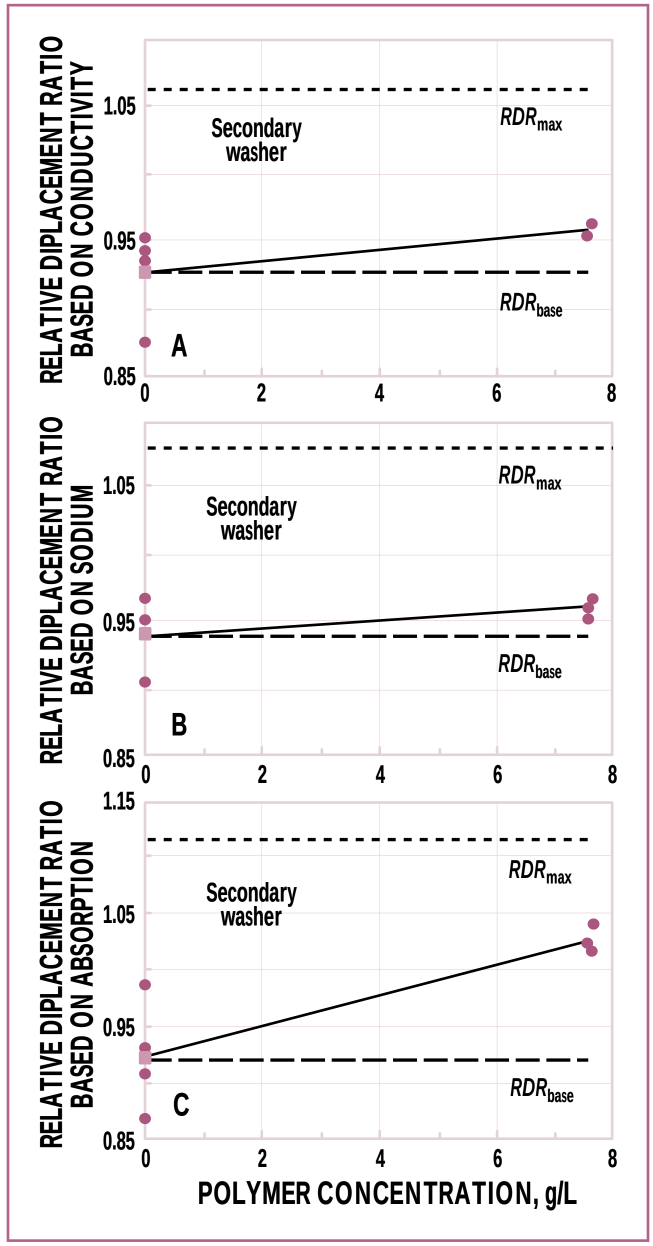
A procedure was developed to determine the polymer concentration that gives the greatest lignin removal from a black liquor sample. A vat liquor sample was cooled to room temperature and strained to remove fibers. 25 mL aliquots of liquor were dispensed into a series of vials containing 25 mL of Channel Block solutions of varying concentrations. The precipitated lignin polymer complex was allowed to settle and the supernatant was removed and filtered through a 0.45 µm Millipore filter to give a transparent solution which was analyzed by spectroscopy at 500 nm. The optimum polymer concentration for maximum precipitation corresponds to the minimum absorbency.

Mini-shower bar

Figure 2 shows a schematic drawing of the mini-shower bar which was fabricated for this research. The ancillary components and placement on a washer is illustrated in Fig. 1. The main components of this apparatus are: the polymer metering pump, the flexible water supply line with control valve, the polymer-water mixing tee, orifice plate and sampling valve, and the slotted shower bar. The metering pump (Viking Pump Model 124) and the control wash-water supply line with metering value are used to control the dosage of polymer being applied to the drum surface. Typically fresh water flow rates range from 0.5 to 3 L/s, and the maximum pump injection rate was 40 g/s. The mixing tee, 1 in. mild steel, was designed for a minimum Reynolds number of 300 in order to thoroughly mix the polymer and displacement water streams. A 316-stainless steel orifice plate, 1.895 cm orifice size with standard milled geometry (see Streeter and Wylie *(9)*) was used to measure the polymer solution flow rate. Two 76-cm long, 1-in. diameter, mild steel pipes were used to connect the orifice plate flanges to the mixing tee and to the polymer solution sampling valve, to ensure proper orifice plate operation. The final component, the slotted shower bar with slot adjustments (see Fig. 2), allowed for the uniform delivery of the diluted polymer over the drum area. This 1.5-m long shower bar, made from L-type 2-in. copper tubing, terminated with matching cap and elbow, was milled with a 1.5-mm cutter to produce a 1-m slot starting 2 cm from the terminating cap. Internal material stresses caused the slot to widen past the desired 1.5 mm width. Five brass C-clamps (see Fig. 2) enabled the gapping of the slot for even flow distribution. A 2.1-m long section of copper tubing was also used as the main support arm for the distributor as shown in Fig. 1.



5. Secondary washer trial inlet and pad entrained constituents measurements. A: Inlet and pad conductivity measurements expressed in units of milli-Siemens per cm. B: Inlet and pad sodium measurements. C: Inlet and pad relative absorbency measurements.



6. Secondary washer relative displacement ratios as function of polymer concentration. A: Relative displacement ratio as calculated from conductivity data. B: Relative displacement ratio as calculated from sodium data. C: Relative displacement ratio as calculated from absorbency data.

Placement of the mini-shower bar was facilitated by using a safety line and two mounting brackets, one bracket on the drum cover and one floor mounted bracket. The mini-shower bar was located at the back of the drum and placed between the first and second shower bar for the two trials conducted at the Prince George Pulp and Paper mill. The front of the drum being the side of the drum where the wash-water was fed into the drum showers. The reason for locating the shower bar between the first and second shower bars, and turning off the flow to the first shower bar, was to maximize contact of the polymer and the entrained black liquor. This arrangement prevents the creation of a buffer zone of water between the polymer and the lignin.

Sampling

During the trial experiments, three samples were collected simultaneously from the washer at each predetermined time period for constituent analysis. The inlet samples were a blend of two or more vat grab samples taken across the washer. This blend was then filtered to remove the fibers before any constituent analysis. Two pad exit samples, from the mini shower bar and the control zones of the drum (see Fig. 1), were collected using a wooden paddle as prescribed by the TAPPI Open Drum Washer Mat Sampling Technique and squeezed for supernatant collection for ensuing constituent analysis.

Data reduction

The method of evaluating the effectiveness of washing was to calculate the displacement ratio, *DR*, (displacement washing efficiency) which for constituent "i" is defined as:

$$DR = \text{Mass of constituent "i" removed/Mass of constituent "i" removable} \quad (1)$$

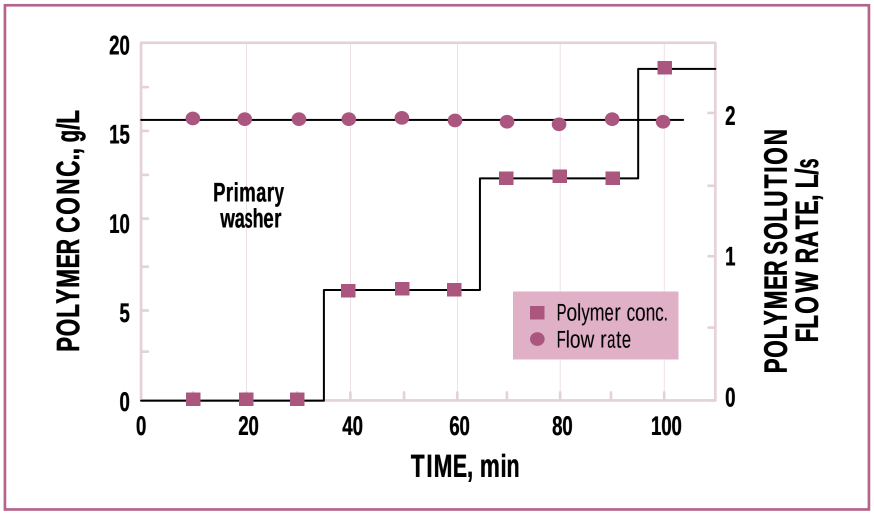
$$= (C_{\text{entrance pad}} - C_{\text{exit pad}})/(C_{\text{entrance pad}} - C_{\text{wash water}}) \quad (2)$$

where *C* is the concentration of constituent i in the vat (entering pad), exit pad, or wash water.

This definition is based on the measurement of individual constituents rather than on total dissolved solids, which is the standard definition *(10)*. Chemical additive trials on brownstock washers can be difficult to interpret because systematic changes are masked by process noise often originating from the digester's operation. To circumvent this problem, washing on the section of the drum treated with the mini-shower bar was compared with washing on the untreated (control) section of the drum so as to correct for possible process variability. Equation 1 can be divided by the displacement ratio for a control section of a drum to define the relative displacement ratio:

$$RDR = DR_{\text{treated zone}}/DR_{\text{control zone}} \quad (3)$$

RDR values were calculated for three measured quantities (i.e., conductivity, sodium, and absorption). A comparison between *RDR* base case data (i.e., water application with no dissolved polymers) to polymer addition data is thus possible because the data are corrected for any plant operation variability.



7. Primary washer trial flow rates and polymer concentrations in mini-shower bar wash water stream

	RDR_{base}	RDR_{max}
Secondary Washer		
Conductivity	0.927	1.06
Sodium	0.943	1.08
Absorption	0.923	1.11
Primary Washer		
Conductivity	0.764	1.63
Sodium	0.815	1.72
Absorption	0.801	1.19

I. Base and maximum relative displacement ratios for the primary and secondary washer

RESULTS

A preliminary laboratory study was conducted during the mill trial in order to determine the concentration of Dorset Channel Block® cationic polymer that gave the maximum amount of lignin precipitate. Liquor from the secondary washer vat at CANFOR's Prince George Pulp and Paper mill was mixed with equal volumes of varying concentrations of cationic polymer solution and the unreacted lignin concentrations were estimated by visible spectroscopy. The results, shown in Fig. 3, indicate that most of the lignin was removed from the mixture

Constituent	Control displacement ratio[a] (±s)		RDR Trend line slopes from polymer addition (L/g polymer)		Displacement ratio increase[b] ΔDR/(g/L) (x 100)	
	Primary washer	Secondary washer	Primary washer	Secondary washer	Primary washer	Secondary washer
Conductivity	0.614 ±0.048	0.945 ±0.010	1.93×10^{-2}	4.34×10^{-3}	1.18	0.410
Sodium	0.581 ±0.054	0.926 ±0.014	2.37×10^{-2}	2.72×10^{-3}	1.38	0.252
Relative absorption (inferred lignin)	0.841 ±0.042	0.899 ±0.016	9.10×10^{-3}	1.38×10^{-2}	0.77	1.24

[a] Calculation based on data collected from the control section of the drum washers.
[b] Increase in filter performance when 10 L/s of polymer is applied to drum, based on cationic polymer concentration.

II. Estimated displacement ratios (control zone), trend line slopes, and estimated washer improvement on a concentration basis for the primary and secondary washer

when the polymer concentration was 8 g polymer concentrate/L.

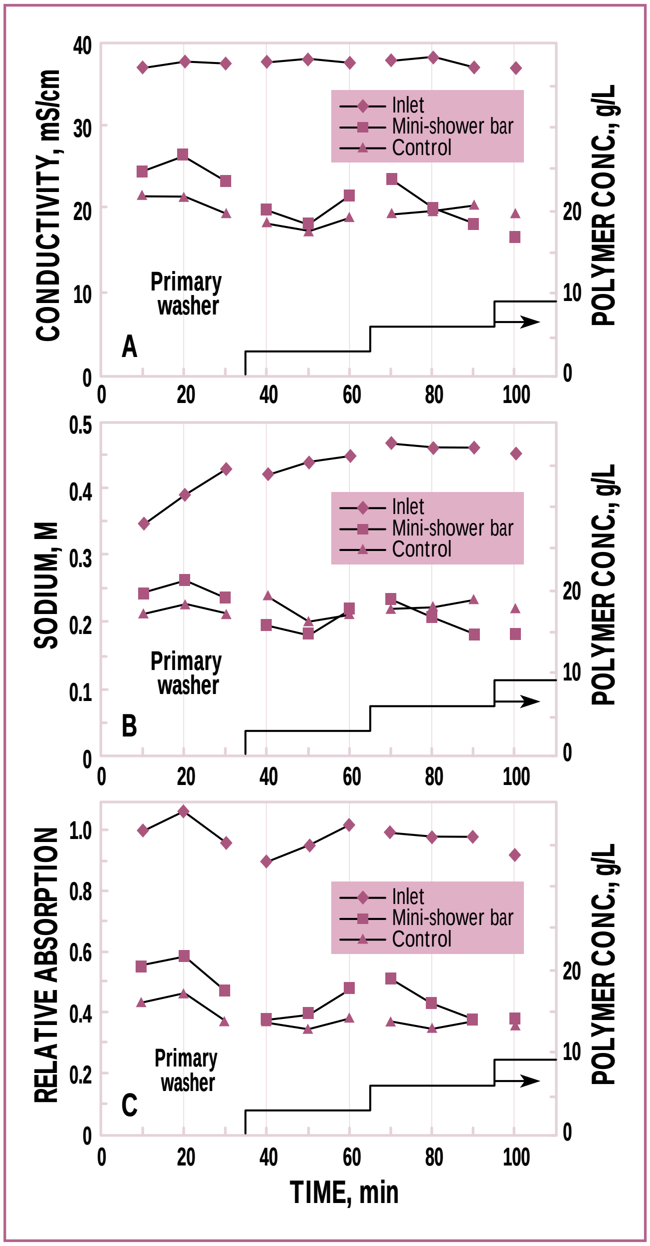
Secondary brownstock washer trial

The mini-shower bar was installed on the secondary between the existing first and second shower bar (see Fig. 1). Water flow to the first bar was stopped. The trial started with the operation of the mini-shower bar at a wash-water flow rate set for approximately 2 L/s with no polymer application (see Fig. 4). Four sets of samples were taken from the vat and the pad exit for both mini shower bar and control zones of the drum. After 25 min, the polymer pump was turned on to give a polymer concentration of 8 g polymer concentrate/L in the mini-shower bar, which is the optimum concentration. Based on the production rate and area treated, this polymer dosage corresponds to about 24 kg polymer per o.d. metric ton of pulp.

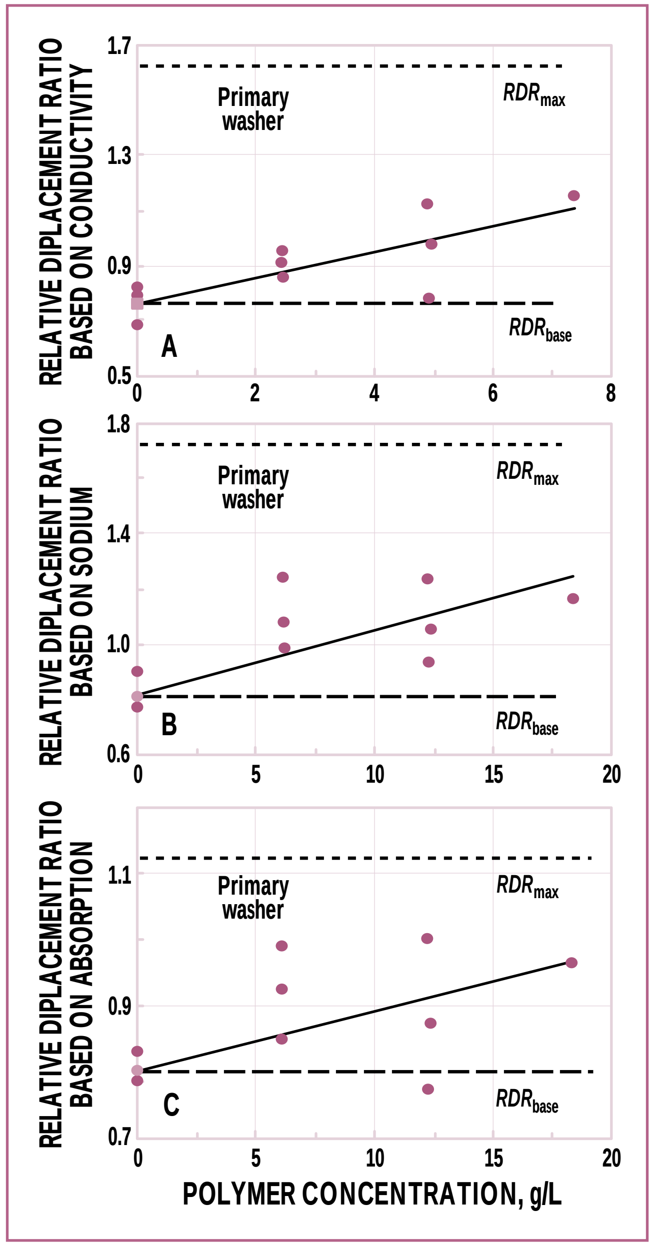
Conductivity, sodium concentration and absorption (a measure of lignin concentration) were measured for all samples and the results are shown in Figs. 5 A–C. In all cases, with and without polymer addition, the mini-shower bar treated area had higher entrained constituent concentrations than the control side of the washer. This is particularly noteworthy considering extra wash water is added with the mini-shower bar. Clearly, the front of this washer was more effective than the back where the mini-shower bar was placed even when the treated zone was washed with 18% more wash water.

Relative displacement ratios, *RDR*, were calculated from the data in Figs. 5 A–C and are plotted in Figs. 6 A–C as a function of polymer concentration. The dotted line RDR_{base} is the average value of *RDR* calculated from the four sample sets without polymer. The maximum possible *RDR* value corresponding to complete removal of the component from the pad is denoted by the RDR_{max} line. This RDR_{max} value is equal to the maximum displacement ratio of the treated area, which is equal to unity, divided by the mean value of the control's displacement ratio. Table I presents the RDR_{base} and RDR_{max} values for all three measured variables.

In all cases, as shown in Fig. 6, the washing improved by polymer addition. The apparent improvement in lignin removal was roughly two times greater than that of sodium. Lignin can be removed from the interstitial liquor of the pad by two mechanisms. The first route is that the wash water displaces liquor; this of course is the desired effect. The second is that lignin in the pad liquor may precipitate due to the cationic polymer. The fate of the polymer and lignin as a clot is expected to be temporary. Laboratory experiments by the authors show that the precipitate will dissolve when solution conditions are changed (i.e., when clots are again exposed to dilution water or bleaching solution). An estimate of the amount of lignin precipitated can be determined if one assumes that the *RDR* increase for lignin, by displacement washing, is the same as that of *RDR* for sodium. Using this assumption, an estimated 49% of the



8. Primary washer trial inlet and pad entrained constituents measurements. A: Inlet and pad conductivity measurements. B: Inlet and pad sodium measurements. C: Inlet and pad relative absorbency measurements.



9. Primary washer relative displacement ratios as function of polymer concentration. A: Relative displacement ratio as calculated from conductivity data. B: Relative displacement ratio as calculated from sodium data. C: Relative displacement ratio as calculated from absorbency data.

lignin that could be precipitated by polymer was precipitated during the trial. Justification of using sodium to track lignin removal is based on the fact that brownstock washing is a very rapid process, i.e., 10 s contact time between the washer water and the pulp. Thus contribution from diffusion processes will be minimal as opposed to longer time laboratory experiments where diffusion effects are important and lignin cannot be tracked to sodium *(11)*. Negating the above assumption, the maximum amount of lignin that could be carried with the mat was found be 17% of the total lignin input into the second washer, or 24 kg/metric ton o.d. pulp. The trend lines in each plot in Fig. 6 are based on a linear regression and forcing the line through the average *RDR* when no polymer was applied. Slope values for each trend line are presented in Table II. From all three plots, it can be concluded that cationic polymer has a positive influence on washing when applied at the optimum concentration. This increase in displacement ratio was calculated and found to range between a 0.25 and 1.25% increase in *DR* (displacement ratio increase—see Table II) per gram-per-liter of polymer applied.

The experiments on the drum washer tested two working hypotheses about the effect of the mini-washer and polymer addition. In all cases, the first shower bar was not operational in either the test or control zones. The first hypothesis is whether the additional water in the test zone (due to the mini-shower bar) can affect the washing as compared to the washing in the control zone. Results showed that the test zone, even with more shower water, had poorer washing in comparison to the control zone due to variability across the drum. As an example, using the sodium results from the secondary washer, the *DR* for the control zone was 0.926 and for the test zone the *DR* was 0.873 during water application with no polymer. The second hypothesis was whether within the test zone only, with the mini-shower bar, the addition of polymer improves washing. Results, again based on sodium from the second washer, show that the addition of polymer increases the *DR* in the treated zone from 0.873 to 0.892 when 6 g polymer concentrate/L is added. The control zone had a better wash than the test zone with no polymer; however, the addition of polymer in the test zone shows a beneficial effect.

Primary brownstock washer

A series of mini-shower bar experiments were conducted on the primary brownstock washer. The flow rate in the mini-shower bar was 2 L/s and the cationic polymer concentration in the wash water varied between 0 and 18 g/L in 3 steps (see Fig. 7). The raw data are shown in Fig. 8 A–C and the corresponding *RDR*s are given in Fig. 9 A–C. As in the secondary washer, the efficiency of the back side where the mini-shower bar was located, was lower than the front side of the drum since all the *RDR* base values were less than unity. Furthermore, the efficiency of the primary washer was much less than that of the second washer as indicated by the much greater RDR_{max} values in Fig. 9 A–C compared with those in Fig. 6 A–C.

Clearly, Channel Block addition improved washer efficiency. In all cases with polymer addition, the *RDR* values were above the RDR_{base}. Unlike the secondary washers results, lignin removal was not significantly better than sodium or electrolytes (conductivity). The washer's high efficiency in removing lignin during normal operation explains the above observation and why the RDR_{max} value in Table I is lower than the other constituent values.

The spread in *RDR* values during polymer addition at 6 and 12 g polymer/L was large. However, the same range was observed for the three independent measurements (i.e., conductivity, absorption, and sodium). Thus we conclude that the spread does not reflect experimental error but instead reflects process fluctuations. Examination of process data indicated that changes in vacuum, drum speed, and wash-water flows coincide with these *RDR* fluctuations.

DISCUSSION

The basic hypothesis behind our research is that the displacement washing of a pulp pad on a vacuum drum washer will be improved if the most open channels in the pad can be partially blocked with a small amount of precipitated lignin. Extensive laboratory results with model beds have shown that selective precipitation is possible. The mini-shower bar experiments have shown that the addition of cationic polymer to shower water improves brownstock washing which indicates that the basic hypothesis may be correct in the plant environment.

The displacement ratios on the secondary washer (see Table II) were better than those from the primary washer. Furthermore, the control data from the primary washer showed the greatest fluctuations. It is proposed that the pad was less uniform either in terms of pad thickness and/or permeability on the primary washer.

Initially, it was assumed that the optimum polymer concentration in the wash water was the concentration giving the maximum lignin precipitation when equal volumes of vat liquor and wash water were mixed. The results in Fig. 3 show that for the secondary washer the assumed optimum concentration was 8 g polymer concentrate/L. However, the lignin concentrations were much higher in the primary washer vat, and it was estimated that the maximum lignin precipitation would occur with a Channel Block concentration of 32 g polymer concentrate/L. The primary washer results were surprising because significant washing improvements were obtained at polymer concentrations of 6 g polymer concentrate/L which is one-fifth of our estimate of the required concentration. Therefore, our initial assumption about the best polymer concentrations was probably inaccurate, and further work is required to optimize the polymer concentration.

The results of this study and research program may have significant commercial implications. The total cationic polymer dosages at the lowest application rate was 13 kg/o.d. metric ton of pulp, which is not attractive considering the cost of

KEYWORDS

Bars, cationic compounds, diffusion washing, displacement ratio, lignins, showers, sodium, synthetic polymers, removal, unbleached pulps, washers.

most water-soluble polymers. However, this work is still in the preliminary stages. The amount of polymer added per metric ton of production was equal to the product of the mini-shower water flow rate times the Channel Block concentration in the mini-shower bar wash water.

Current research is directed at optimizing the balance between the shower flow rates and Channel Block concentrations to get improved washing with a minimum of polymer consumption. In addition, it must be cautioned that *DR* is not a measure of the washer's overall performance; it is a measure of the displacement efficiency only. Demonstrating an improvement in the overall washers performance would require the determination of constituent inputs (flow rates) with consistency measurements and drainage rates. Demonstrating this is thus a future goal of the authors. In summary, this work demonstrates that there is a potential to increase brownstock washer efficiency by the addition of cationic polymers to the wash water sprayed on the pad. Furthermore, there was no evidence of any other negative effects in the bleach plant or recovery cycle associated with the addition of cationic polymers to the brownstock washers.

CONCLUSIONS

The main conclusions from this work were:

1. The addition of cationic polymer to the shower bar increased displacement washing efficiencies of both the primary and secondary washers. The most dramatic effects were observed on the primary washer.
2. The mini-shower bar allowed direct comparison of treated with untreated parts of the fiber pad on the washer drum. Thus, washing improvements with chemical addition were not masked by process fluctuations.
3. Without polymer treatment, the secondary washer was more efficient than the primary one whereas both washers gave better washing on the front half of the drum than on the back. TJ

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The authors would like thank John Ball and his colleagues at CANFOR's Prince George Pulp and Paper Mill in permitting this study and for their assistance throughout the project. We are also in debt to Mike Kempe, Brian Grosse, and Jasmin Patry from McMaster University, and Mike Towers and Ron van Heek from PAPRICAN for their assistance during the trial and during trial preparation. In addition, the authors would like to acknowledge Dorset Industrial Chemicals and the Natural Science and Engineering Research Council of Canada for financial support.

Received for review July 14, 1995.

Accepted Feb. 23, 1996.

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