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ABSTRACT

What will happen to the effectiveness of presently available retention- and drainage-aid systems in newsprint mills as we increase the degree of system closure? Will they continue to function well, or will it be necessary to develop new, more effective aids as the degree of white-water recycling increases? The performance of five different retention- and drainage-aid systems was measured at three degrees of closure in TMP (thermomechanical pulp) newsprint. The three levels of fresh water makeup used in this study were 55, 20, and 3 m^3/metric ton of pulp, representing water usage in older mills, modern mills, and a closed mill system. For the 55 and 20 m^3/metric ton cases, samples of pulps and paper machine white waters were obtained from existing TMP newsprint mills. For the 3 m^3/metric ton case, samples of white water were prepared in our system-closure pilot plant. The five retention-aid systems consisted of bentonite/anionic polyacrylamide (Organosorb/Organopol), polyethylene oxide/phenolic resin, polyethyleneimine (Polymin SKA), poly(DADMAC) (diallyldimethylammonium chloride), and chitosan. Furnishes with more highly recycled white waters had higher cationic demands. Results suggest that system closure impairs the performance of cationic polymers, while that of the nonionic flocculants was relatively unaffected or improved.

Application:

A look at how mill closure may affect the efficiency of common retention aids.

Effects of system closure on retention- and drainage-aid performance in TMP newsprint manufacture

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THE TREND TOWARD INCREASING closure of white-water systems in newsprint mills raises several questions regarding the future effectiveness of retention- and drainage-aid systems. Will the increase in cationic demand require higher feed rates of cationics? Will nonionics continue to function? Will we possibly need entirely new types of retention aids to face the new operating conditions?

We do know that system closure has considerable impact on white-water chemistry. For example, there is a buildup of negatively charged dissolved and colloidal substances (DCS) *(1–6)*. It has been recognized for some time that the anionic DCS can degrade the performance of cationic retention-aid systems *(1, 2, 7–11)*. Nonionic retention aids, on the other hand, appear to be more tolerant to the presence of DCS *(9, 10, 12–14)*. In fact, in relatively open white-water systems, there is some suggestion that the performance of polyethylene oxide (PEO) retention aids may benefit from some of the DCS *(12, 13)*.

A number of board mills are operating with closed white-water systems. These tend to be mills where a high percentage of the furnish is recycled. The main observation in such mills is that, with closure of the white-water system, the costs for retention aids increase substantially *(15–17)*. In modern TMP newsprint mills, the fresh water used for makeup on the paper machine is usually of the order of 20 m^3/metric ton of pulp. However, many older mills are operating with much higher levels of fresh water usage, up to 40–80 m^3/metric ton *(18)*.

Newsprint mills use retention and drainage aids to

- Improve fines retention
- Increase drainage on the paper machine
- Control deposits
- Improve filler retention (often from recycled paper)
- Increase sheet dryness exiting the press section
- Improve runnability
- Reduce linting and improve pressroom performance.

However, excessively high feed rates of retention aids can hinder sheet formation.

There are a variety of retention- and drainage-aid systems on the market for newsprint manufacture. These include coagulants, such as poly(DADMAC) (polydiallyldimethylammonium chloride) *(1, 2, 11)* or polyamines *(1, 2, 11)*; flocculants, such as chitosan *(19, 20)*; hybrid systems, such as Polymin SKA *(1, 2, 7–11)* (which can operate both as a cationic coagulant and as a flocculant because of its intermediate size and structure); and the nonionic combination of PEO and a phenolic resin *(9, 10, 12, 13)*. Another retention- and drainage-aid system of interest is the Organopol/Organosorb system, which involves the introduction of a bentonite clay into the furnish, followed by use of a low-charge-density, anionic, high-molecular-weight polyacrylamide just before

	Mill A	Mill B
Wood type	40% spruce 60% fir	75% spruce 25% fir
Pulp type	TMP dithionite[a]	TMP dithionite[a]
Makeup water, m^3/ton	20	55
Consistency, %	1.10	0.90
Additives[b]	None	None

[a] Dithionite content = 1 kg/metric ton pulp
[b] Retention aid, additives, or alum

I. Furnish properties

	Mill A	Mill B
pH	4.68	4.33
Freeness, mL CSF	34	41
Fines content,[a] %	67.2	54.9
Short-fiber content,[b] %	46.5	41.7
DCM extractives,[c] mg/L	860	25
TOC,[d] g/L	2.95	1.80
UV lignin, g/L	1.08	0.76
Carbohydrates, g/L	2.02	2.72
Dissolved solids, g/L	3.80	2.70
Ion analyses, mg/L		
Al	6.01	2.60
Na	353	231
K	50.1	34.5
Cu	≈0.10	≈0.12
Fe	1.27	1.27
Mn	4.89	6.49
SO_4^{2-}	359	356
$S_2O_3^{2-}$	<2.5	2.3
SO_3^{2-}	48.8	7.7
S^{2-}	N.D.[e]	N.D.[e]
Cl^-	14.3	6.10
Br^-	8.02	<1.00
PO_4^{3-}	3.68	1.30
CO_3^{2-}	47.9	15.0

[a] Pulp fraction passing through 200-mesh screen in a Bauer–McNett classifier
[b] Percent fibers < 0.2 mm as measured with a Kajaani fiber analyzer
[c] Extracted in dichloromethane
[d] Total organic carbon
[e] Not detected

II. Pulp characteristics

	Mill A	Mill B	Lab
pH	4.72	4.32	5.46
Consistency, %	0.45	0.40	0.50
Conductivity, µS/cm	1.28	1.04	2.28
Cationic demand, meq/L	9.9	8.4	11.8
DCM extractives,[a] mg/L	980	24	356
TOC,[b] g/L	1.55	1.65	4.53
UV lignin, g/L	0.98	0.76	0.98
Carbohydrates, g/L	2.53	2.45	3.66
Dissolved solids, g/L	3.91	3.10	10.90
Suspended solids, g/L	5.66	6.34	3.04
Ion analyses, mg/L			
Al	6.55	1.00	0.52
Na	341	260	583
K	48.4	33.9	52.4
Cu	≈0.10	≈0.09	0.62
Fe	1.28	1.10	7.71
Mn	4.63	6.28	20.5
SO_4^{2-}	424	345	610
$S_2O_3^{2-}$	1.7	2.1	1.5
SO_3^{2-}	57.9	7.8	13.0
S^{2-}	N.D.[c]	N.D.[c]	N.D.[c]
Cl^-	14.7	6.0	6.0
Br^-	10.41	N.D.[c]	N.D.[c]
PO_4^{3-}	5.2	1.2	N.D.[c]
CO_3^{2-}	50.0	13.0	112.0

[a] Extracted in dichloromethane
[b] Total organic carbon
[c] Not detected

III. White-water characteristics

the paper machine headbox *(21, 22)*. These systems, with the exception of chitosan, have been available for 15 years or more. More recently, a number of newer chemistries have been developed and explored *(23, 24)*.

The objective of this investigation was to determine the effects of system closure on the performances of the traditional retention and drainage aids used in newsprint manufacture. The newer retention-aid systems will be addressed in a future work.

EXPERIMENTAL

Experimental approach

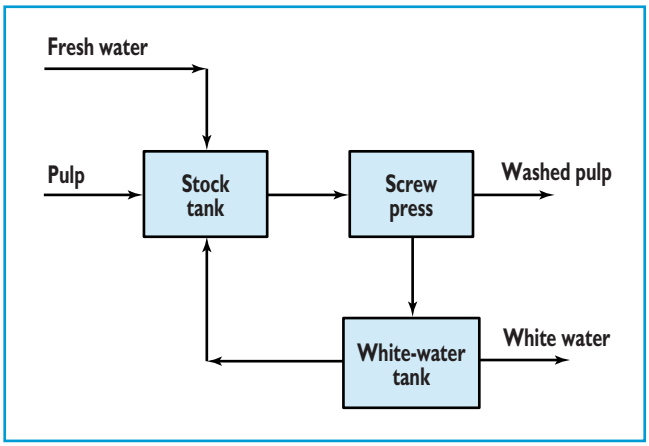
The performance of five different types of retention- and drainage-aid systems was measured in the laboratory at three levels of system closure. In this work, we have defined the degree of system closure in terms of fresh water makeup to the machine. The levels of system closure used were 55, 20, and 3 m^3 of fresh water consumption per metric ton of pulp. The latter might well represent complete closure, as this amount of water usually can be disposed of in a combustion boiler or economically treated and reused.

Pulps and white waters

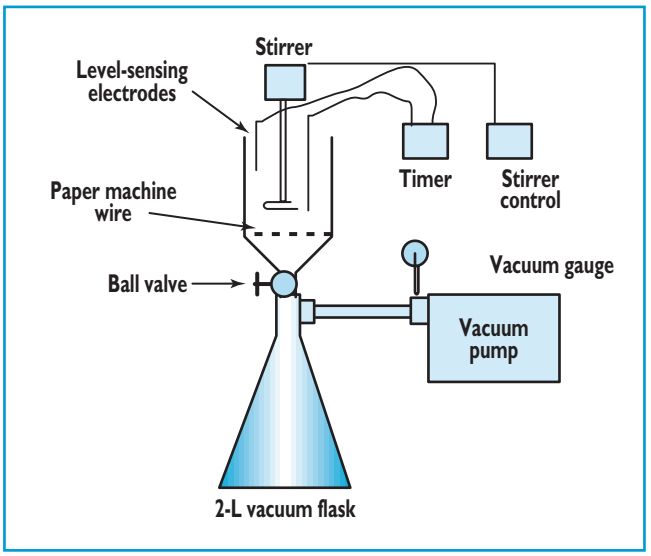
Headbox pulp and wire-pit white-water samples were taken from two integrated TMP newsprint mills located in Quebec. Furnish properties are listed in **Table I**. Mill A was a modern facility, with fresh water usage of 20 m^3/metric ton of pulp, typical of TMP newsprint mills built in the last 10 years. Mill B's fresh water usage was 55 m^3/metric ton, typical of an older facility. Retention aids were not employed in either mill.

The pulp characteristics listed in **Table II** were obtained using CPPA standard methods. Ionic concentrations were determined by ICP (inductively coupled plasma) spectroscopy and ion chromatography *(25, 26)*. Dissolved lignin and carbohydrates were determined by UV absorption at 280 nm *(27)* and the anthrone method *(28)*, respectively.

Simulated white water for a high level of closure was prepared in the laboratory by washing pulp collected from the secondary refiner discharge in Mill B. The apparatus for white-water preparation, shown in **Fig. 1**, consisted of a stock tank, screw press, white-water tank, and pumps *(29)*. It was operated in batch mode. The unwashed pulp at 30% consistency was diluted to 2% consistency with fresh water and agitated for 30 min at 60°C. The pulp suspension was then dewatered to approximately 44% consistency with the screw press, and the pressate was recycled to dilute the next batch of pulp. This cycle was repeated for 13 more batches until the desired contaminant level was attained. A small volume of fresh water was added after batch 10 to produce the desired volume of white water. Gravity clarification was used to remove the suspended solids.



1. Simulated white-water manufacture in the Paprican system-closure pilot plant



2. Modified dynamic drainage jar

The contaminant level in the paper machine white water depends on a number of factors besides the fresh water usage, including the white-water management strategy *(5)* and the choice of dewatering equipment *(30)*. Therefore, it is not possible to directly relate the contaminant level of the simulated white water to a mill closure level. The simulated white water corresponded to what might be expected in a fully integrated white-water system with fresh water added to the process at the rate of about 3 m^3/metric ton of pulp *(5)*. **Table III** shows the characteristics of the white waters at the three levels of mill closure tested in this study.

Cationic demand

The cationic demands for the furnishes were determined at pH 5 using a modified polyelectrolyte titration technique outlined by Horn *(31)* and Terayama *(32)*.

Polymer characterization

Table IV shows the properties of the retention- and drainage-aid polymers that were used in this study. Polymers were obtained from various suppliers. All polymer solutions were prepared with twice-distilled water produced in a glass distillation apparatus. Solutions were freshly prepared every day at a concentration of 1% active ingredients. The chitosan was prepared by weighing 1.0 g chitosan, wetting the chitosan with 1 mL of 50% acetic acid, and diluting to 100 mL with doubly distilled water. The PEO was prepared by adding 1.0 g PEO, wetting the PEO with 1 mL of ethanol, and diluting to 100 mL with doubly distilled water.

Determination of percent active ingredients

For coagulants and dry polymers, approximately 1.0 g of polymer solution or powder was accurately weighed into a preweighed 25 mL vial, followed by addition of 10 mL of doubly distilled water. The vials were shaken slightly, capped, and placed into an ethanol bath (–46°C) for 30 min to freeze. The vials were then freeze-dried for 48 hours and reweighed. The average percent solids was calculated from triplicate determinations.

For inverse emulsion polymers, approximately 0.5–0.7 g of emulsion polymer was accurately weighed into a preweighed 50 mL vial, followed by addition of 15 mL of hexane. The vial was shaken vigorously to dissolve the emulsion into the hexane and then left standing for 12 hours, during which the insoluble polymer fraction precipitated to the bottom of the vial. After the 12 hour standing period, 10 mL of doubly distilled water was gently added along the side of the vial. The supernatant hexane layer was carefully removed using a Pasteur pipette connected to a vacuum flask. Excess hexane was gently evaporated with dry air. The vials were capped and placed into an ethanol bath (–46°C) for 30 min to freeze and then freeze-dried for 48 hours and reweighed. The average percent solids was calculated from triplicate determinations.

Polymer charge density

Polymer charge density was determined using the same procedure that was used to measure cationic demand [i.e., a modified polyelectrolyte titration technique outlined by Horn *(31)* and Terayama *(32)*]. A 10 mL sample of polymer solution (active ingredients 0.01% w/w) was diluted to 100 mL and titrated with PVSK (polyvinylsulfate potassium) to a pink endpoint.

Kjeldahl analysis

Total nitrogen was determined using the Kjeldahl method *(33)*. Approximately 0.2 g of polymer solution, as received, was accurately weighed into a weighing dish. The polymer solution was rinsed with doubly distilled water into a distillation flask (Buchi 323), digested for 1.5–2.5 hours, and steam distilled for 4 min. The distillate was collected and titrated with 0.02*N* sulfuric acid with a phenolphthalein indicator.

Polymer	Molecular weight, kdalton	Polymer active ingredients, %	Charge density (by colloidal titration), meq/g net at pH 5	Nitrogen equivalents (by Kjeldahl analysis), meq/g net	Chemistry
Poly(DADMAC)	~200–300	46.6	5.65	6.2	Poly(diallyldimethylammonium chloride)
Polymin SKA	~500–600	24.5	5.89	10.3	Polyethyleneimine/polyamine
Chitosan	~40–500	99.5	4.97	5.4	Aminopolysaccharide
PEO	~6000–9000	99.8	0	0	Polyethylene oxide
Organopol	~2500–3500	90.9	–0.06	12.7	Polyacrylamide-sodium acrylate copolymer
Organosorb	N.A.*	91.1	0	0	Bentonite clay
Resin	N.A.*	48.4	0	0	Phenol formaldehyde resin

* Not analyzed

IV. Polymer properties

Retention and drainage measurements

First-pass retention (FPR) with mat formation (nominal basis weight 80–120 g/m^2), drainage rate, and consistency after vacuum were obtained using our modified dynamic drainage jar (DDJ) method *(34)*. All polymer concentrations are expressed as net active ingredients in the results. The modified drainage jar is illustrated in **Fig. 2**. With the exception of the phenolic resin, which was prepared at a concentration of 0.3% w/w active ingredients, all polymers were prepared at a concentration of 0.1% w/w active ingredients.

Headbox stocks representing the three levels of closure (3, 20, and 55 m^3/metric ton) were diluted with white water to ≈0.15% consistency. The dilution white waters were filtered once (Reeve Angel 202 filter paper) to remove all suspended solids. Headbox stock from Mill A (20 m^3/metric ton) was diluted with filtered white water from Mill A; headbox stock from Mill B (55 m^3/metric ton) was diluted with filtered white water from Mill B or with the filtered simulated white water (3 m^3/metric ton).

Diluted headbox stocks were poured into a beaker and heated to 60°C. The pH was adjusted to 5.2, if needed. If Organosorb or PEO chemistries were being evaluated, the bentonite or resin was added to the beaker and stirred 2 min prior to running the DDJ experiment. The Organosorb was added at a constant dosage of 0.2% based on the weight of ovendry (o.d.) pulp, and the resin was added at a dosage three times that of the PEO.

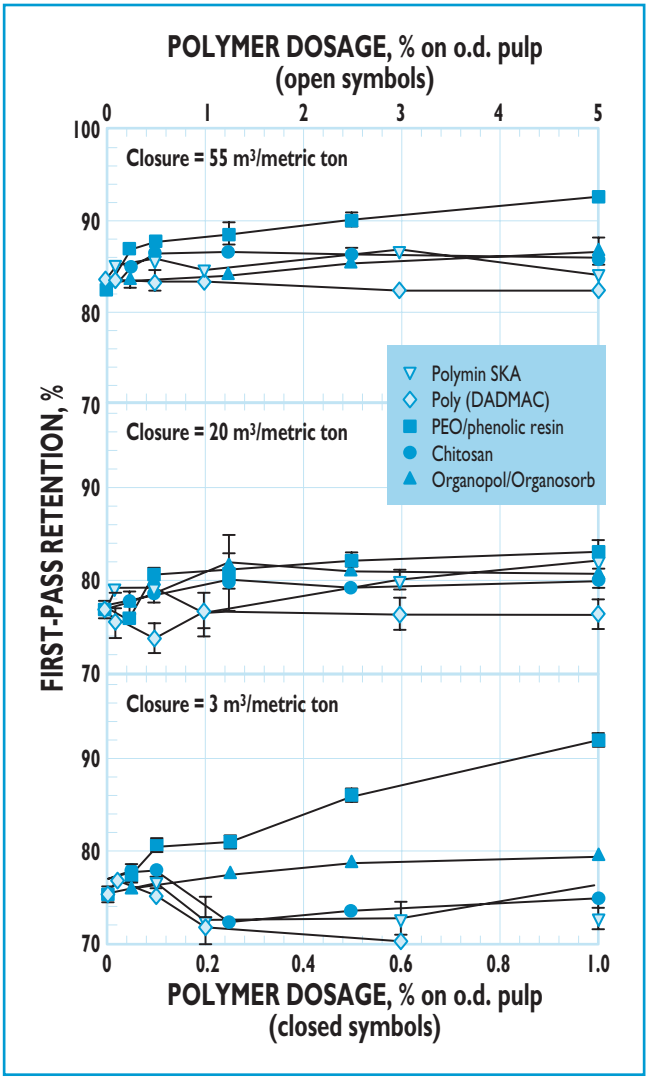
The sample was then poured into the modified DDJ. With the propeller rotating at 500 rpm, air was bubbled under the screen to keep the sample from draining into the part of the DDJ below the screen, where it would not be properly mixed. One minute after pouring the stock into the DDJ, the polymer being tested was added to the DDJ. After 1 min and 50 s, the airflow was stopped and the vacuum was applied to the vacuum flask at 20 cm Hg. At exactly 2 min, the drainage valve was opened, allowing the sample to drain. The level-sensing electrodes measured the drainage time, and when the timer had stopped, full vacuum (64 cm Hg) was applied for 40 s.

The mat was peeled off the screen and weighed. The sample was placed in a centrifuge tube equipped with a screen and centrifuged at 5000 rpm (4500 g) for 30 min (Sorvall RC-3B centrifuge with HG-4L rotor). The mat was reweighed, dried overnight in an oven at 105°C, and the dry weight was recorded *(35, 36)*. The response of the wet web to vacuum was evaluated by calculating the consistency of the mat after exposure to vacuum, and the water retention values are reported as the consistency after centrifugation *(35, 36)*.

The consistency of a 100 mL sample of the total filtrate collected during vacuum was used to calculate the first-pass retention (FPR) with mat formation. A minimum of three runs was performed for each experimental point, from which an average was calculated.

RESULTS AND DISCUSSION

It is interesting to compare the properties of the pulps and white waters from Mills A and B, since they reflect some differences resulting from the degree of system closure. Table II shows that Mill A—with its greater degree of system closure—had higher TOC (total organic carbon), dissolved lignin, and dissolved solids in its headbox pulp, as might be expected. Curiously, the concentration of carbohydrates was lower in Mill A. Other differences between Mills A and B are attributable to operating conditions. For example, at the time of sampling, Mill A was producing pulp of lower freeness, and this is reflected in the slightly higher fines and short-fiber content, as might be expected. The higher DCM (dichloromethane) extractives on pulp in Mill A was probably due mainly to wood



3. First-pass retention of fines vs. polymer dosage at three degrees of system closure (Note: abscissa scale at the bottom of the figure pertains to the closed symbols; the horizontal scale at the top is for the open symbols.)

handling rather than to differences in wood species (Table I), since both spruce and fir typically have low (1–2%) extractives contents *(37, 38)*. It is likely that the wood used in Mill B was more seasoned.

In comparing the white waters of Mills A and B (Table III), the greater degree of system closure at Mill A is reflected in the higher measured values for conductivity, cationic demand, extractives content, dissolved lignin, carbohydrates, and dissolved solids and the lower value for suspended solids. The differences between the mills are not large, but the trends definitely exist and are consistent. For the extractives content, the method described by Allen *(39)* was used for the white waters, and the CPPA standard procedure *(40)* was used for the headbox pulp after evaporation to dryness. In both cases, the solvent used was DCM. In the case of the DCM extracts, there is a large difference, but this again is probably due to the higher extractives content of the wood in Mill A and, to a lesser degree, to the lower freeness of the Mill A pulp.

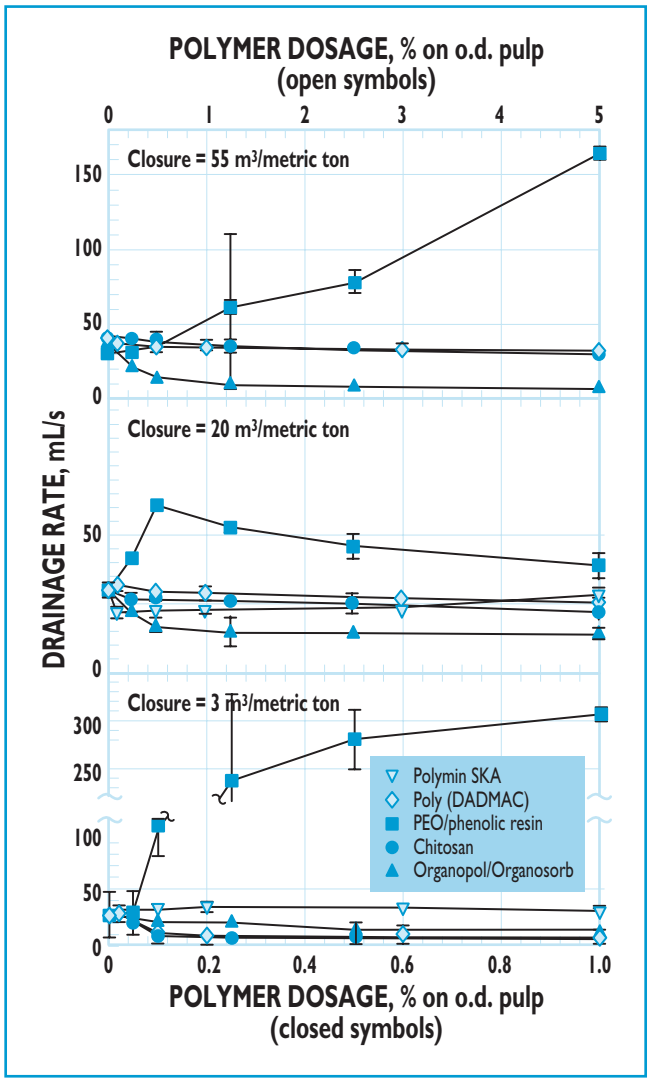
Figure 3 shows the first-pass retention of fines as a function of polymer dosage for the five retention-aid systems studied. The results encompass the three degrees of system closure: 55 m^3/metric ton (top figure), 20 m^3/metric ton (middle figure), and 3 m^3/metric ton (bottom figure). In this and subsequent figures, there are two scales for polymer dosage: the scale at the top of the figure applies to the open symbols (Polymin SKA and poly(DADMAC)) and the scale at the bottom of the figure applies to the closed symbols (PEO/phenolic resin, chitosan, and Organopol/Organosorb). Standard deviations are indicated by the error bars; in cases where there are no standard deviations evident, it is because the standard deviation is less than the size of the symbol itself.

The experiments were carried out over a range of dosages, from zero to concentrations many times higher than those used on paper machines. The high end was explored both for scientific interest and also, especially for the coagulants (open symbols), to compensate for a lack of polymer recirculation and enrichment that would occur on a paper machine.

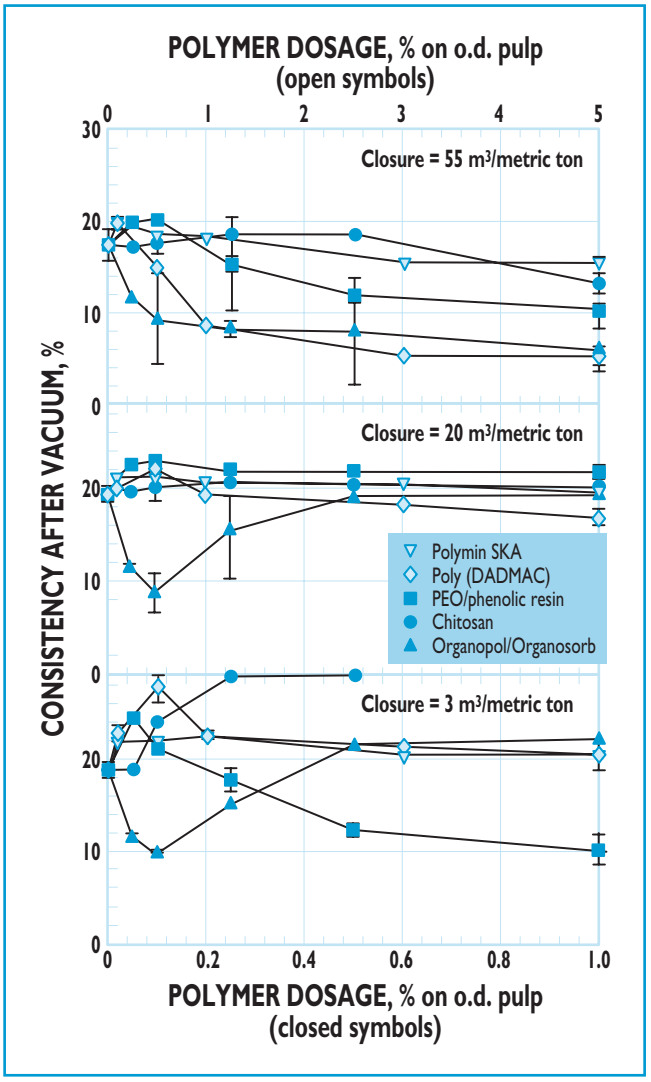
At 55 m^3/metric ton (Mill B), first-pass retention in the absence of retention aids was about 83%. In this furnish, increasing concentrations of poly(DADMAC) had little influence on retention. The other retention-aid systems had some influence, increasing it by up to 10 percentage points in the case of PEO/phenolic resin.

At 20 m^3/metric ton (Mill A), the trends are similar to those in Mill B at 55 m^3/metric ton. Polymin SKA, which often passes through a maximum in retention as feed rate is increased, did better in the more closed furnish at high concentrations, as might be expected. In the absence of retention aids, the first-pass retention was approximately 77%, and the highest increment due to retention aids was approximately six percentage points with PEO/phenolic resin.

At 3 m^3/metric ton, with a simulated white water, it is clear that the two synthetic cationic retention aids (open symbols) were not able to increase retention even at concentrations many times higher than presently used in mills. The performance of chitosan was also negatively affected. The Organopol/Organosorb system, on the other hand, showed a modest improvement in first-pass retention with increasing polymer dosage. The nonionic retention aid, PEO/phenolic resin, appears to have performed well under closed conditions, with a dramatic increase in first-pass retention from 75% at zero dosage to 92% at 1% polymer dosage.



4. Drainage rate under vacuum (20 cm Hg) vs. polymer dosage at three degrees of system closure (Note: abscissa scale at the bottom of the figure pertains to the closed symbols; the horizontal scale at the top is for the open symbols.)



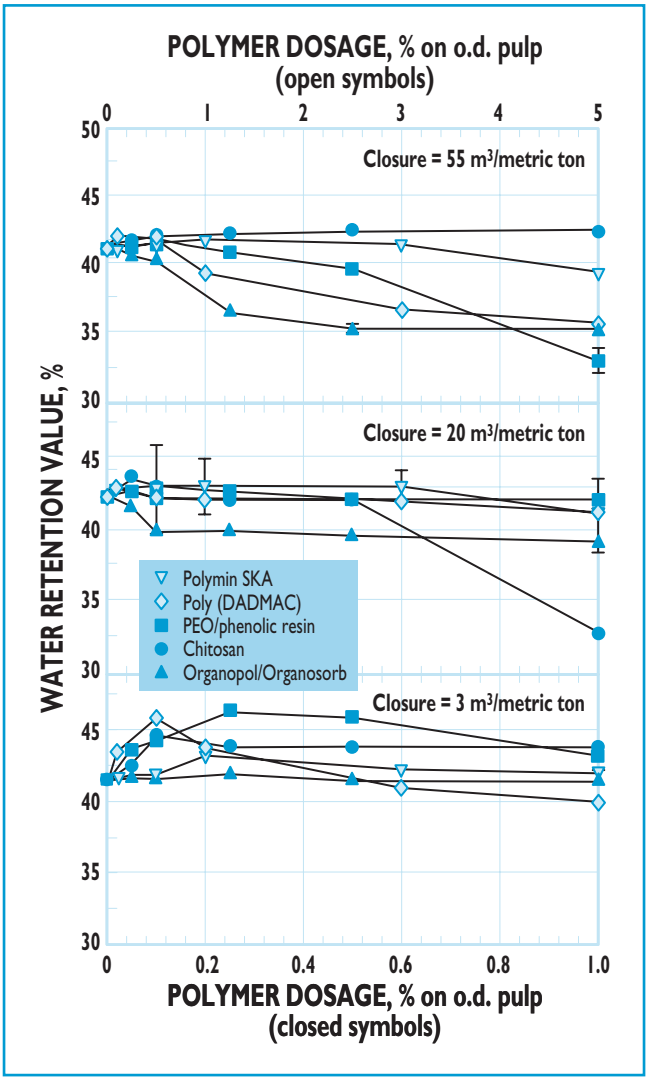
5. Consistency after vacuum dewatering (64 cm Hg) vs. polymer dosage at three levels of system closure (Note: abscissa scale at the bottom of the figure pertains to the closed symbols; the horizontal scale at the top is for the open symbols.)

It is clear from these results that, at high degrees of system closure, the FPR performance of the cationic polymers was negatively affected. Conversely, the nonionic retention-aid system, PEO/phenolic resin, excelled.

Figure 4 shows the drainage rate as a function of polymer dosage at the three levels of closure. In these particular furnishes, it is clear that the Organopol/Organosorb system had a negative effect on drainage at all degrees of closure. A consistently positive effect was observed for PEO/phenolic resin at all degrees of closure and especially at 3 m³/metric ton. The cationic coagulants were mostly ineffective.

Figure 5 shows the consistency of the mat after vacuum dewatering as a function of polymer dosage at the three levels of closure. This measurement is thought to reflect the wetness of the sheet after suction dewatering in the wire section of a paper machine. It is evident that there was considerable variation from one polymer system to another. The Organopol/Organosorb had a negative influence at low concentrations at all three levels of closure. PEO/phenolic resin showed a negative effect at 55 and 3 m³/metric ton, but only above a polymer dosage of 0.12% on o.d. pulp, which is at the high end of the range currently used on paper machines. At 20 m³/metric ton PEO/phenolic resin had a positive effect. At 3 m³/metric ton, chitosan had a positive effect.

Figure 6 shows water retention values as a function of polymer dosage at the three levels of closure. Water retention value is generally held to be an indication of stock consistency after pressing *(41)*. Higher consistencies after centrifugation in-



6. Water retention value vs. polymer dosage at three levels of system closure (Note: abscissa scale at the bottom of the figure pertains to the closed symbols; the horizontal scale at the top is for the open symbols.)

dicate a dryer sheet. It is evident from Fig. 6 that, at 55 m^3/metric ton, none of the retention-aid systems, except possibly chitosan, influenced the water retention value in a positive way. This appears also to be true at 20 m^3/metric ton, although chitosan loses its positive influence above 0.5% on o.d. pulp. At 3 m^3/metric ton, PEO/phenolic resin and chitosan had clearly positive effects on water retention value. Poly(DADMAC) at lower concentration also had a positive effect.

CONCLUSIONS

The situation for retention and drainage aids in TMP newsprint manufacture with system closure looks reassuring. It would appear that at least one of the existing technologies will continue to function well.

At a high degree of closure, such as 3 m^3/metric ton, PEO/phenolic resin proved to be the retention-aid system of choice, since it improved first-pass retention of fines, drainage rate, and water retention value. Only the consistency after suction drainage was negatively affected, but this occurred only at dosages higher than those presently used by industry. PEO has recently been shown to operate by a bridging mechanism, and the phenolic resin is thought to stiffen the bridge to make it more effective *(42)*. Some of the dissolved polymeric materials in mechanical pulps may also aid in this reinforcement. In the future, for PEO to be even more effective, the current challenges are the manufacture of higher-molecular-weight PEO and the development of better phenolic cofactors.

The results have confirmed that, with increasing system closure, the increase in cationic demand tends to reduce the performance of cationic polymers in TMP newsprint. It is possible that our testing procedures discriminated against the effectiveness of cationic polymers. On an industrial scale, more cationic polymer is added with each pass of the white water over the paper machine, and some cationics do continue to be effective after recirculation. Thus, they may have a more positive effect on paper machines than our lab tests predicted. On the other hand, we did attempt to compensate for this by going to dosages 15–20 times those normally used in mills. The cationic polymers with higher charge densities that are now being developed by suppliers may provide better performance than the conventional cationic systems used in this study. This is a subject of ongoing research in our laboratory. **TJ**

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LITERATURE CITED

1. Linhart, F., Auhorn, W. J., Degen, H. J., *et al.*, *Tappi J.* 70(10): 79(1987).
2. Springer, A., Boylaw, J., and McMahon, W., *Southern Pulp Paper Mfr.* 47(3): 21(1984).
3. Webb, L., *Pulp Paper Intern.* 37(1): 44(1995).
4. Springer, A., Dullforce, J. P., and Wegner, T. H., *Tappi J.* 69(4): 106(1986).
5. Wearing, J. T., Huang, S., Piggott, A., *et al.*, *Pulp Paper Can.* 86(5): T139(1985).
6. Kotila, P. S. and Estes, T., *Progr. Paper Recycling* 3(4): 42(1994).
7. Alince, B., *Paperi Puu* 69(3): 230(1987).
8. Rahman, L., *Tappi J.* 70(10): 105(1987).
9. Rahman, L. and Tay, C. H., *Tappi J.* 69(4): 100(1986).
10. Lueng, P. S. and Goddard, E. D., *Tappi J.* 70(7): 115(1987).
11. Sundberg, K., Thornton, J., Ekman, R., *et al.*, *Nordic Pulp Paper Res. J.* 9(2): 125(1994).
12. Pelton, R. H., Allen, L. H., and Nugent, H. M., *Svensk Papperstid.* 83(9): 251(1980).
13. Pelton, R. H., Tay, C. H., and Allen, L. H., *J. Pulp Paper Sci.* 10(1): J5(1985).
14. van de Ven, T. G. M., *1996 International Paper and Coating Chemistry Symposium Preprints*, CPPA Technical Section, Montreal, p. 13.
15. Patel, J. C., *Am. Papermaker* 58(1): 36(1995).
16. *PIMA Mag.* 74(10): 30(1992).
17. Pietschker, D. A., Ormerod, D. L., and Brown, C. R., *Pulp Paper* 67(4): 55(1993).
18. Francis, D. W., Reside, D. A., and Wearing, J. T., *Pulp Paper Can.* 99(12): 134(1998).
19. Laleg, M. and Pikulik, I. I., *Nordic Pulp Paper Res. J.* 7(4): 174(1992).
20. Laleg, M. and Pikulik, I. I., *Nordic Pulp Paper Res. J.* 6(3): 99(1991).
21. Kettunen, K., *Paperi Puu* 78(5): 265(1996).
22. Litchfield, E., *Japan. J. Paper Technol.* 7(7): 5(1990).
23. Huining, X., Pelton, R., and Hamielec, A., *TAPPI J.* 79(4): 129(1996).
24. Le Roux, R., Armstrong, J. R., Lin, J. F., *et al.*, *81st CPPA Annual Meeting Preprints*, Book A, CPPA Technical Section, Montreal, p. 243, 1995.
25. Douek, M., Sullivan, J., and Ing, J., *J. Wood Chem. Technol.* 13(3): 439(1993).
26. Guo, X-Y. and Douek, M., *J. Pulp Paper Sci.* 22(11): J431(1996).
27. TAPPI Useful Method UM-280.
28. Morris, D. I., *Science* 107: 254(1984).
29. Francis, D. W. and Ouchi, M. D., *PIRA International Wet End Conference Proceedings and COST Workshop*, PIRA, Leatherhead, U.K., 1997.
30. Francis, D. W., private communication.
31. Horn, D., *Progr. Colloid Polymer Sci.* 65: 251(1978).
32. Terayama, H., *J. Polymer Sci.* 8(2): 243(1952).
33. American Public Health Association, *Standard Methods for the Examination of Water and Wastewater*, 15th edn., Method 420a, APHA, Washington, DC, 1981.
34. Yaraskavitch, I. M., Allen, L. H., and Heitner, C., *J. Pulp Paper Sci.* 16(3): J87(1990).
35. Tappi Useful Method UM-256.
36. Scallan, A. M. and Carles, J. E., *Svensk Papperstid.* 75: 699(1972).
37. Nugent, H. M., Allen, L. H., and Bolker, H. I., *CPPA Trans. Tech. Sect.* 3(4): TR103(1977).
38. Mutton, D. B., in *Wood Extractives and Their Significance to the Pulp and Paper Industries* (W. E. Hillis, Ed.), Chap. 10, Academic Press, New York, 1962, p. 333.
39. Allen, L. H., *Tappi J.* 71(1): 61(1988).
40. CPPA Standards G13 and G20, "Standard Procedure for Extractives in Wood and Pulp," 1993.
41. LeBel, R., Nobleza, G., and Paquet, R., *CPPA 64th Annual Meeting Preprints*, Book B, CPPA Technical Section, Montreal, p. 167, 1978.
42. van de Ven, T. G. M. and Alince, B., *J. Pulp Paper Sci.* 22(7): J257(1996).