Effects of retention and drainage aids on paper machine drainage: a review

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Retention and drainage aids can have both positive and negative effects on the rate of dewatering on paper and board machines. The key is to know how a given product usually affects a furnish and to be able to reliably predict an additive's effect on your furnish by performing lab tests prior to a mill trial.

Although most of the materials commonly used by the paper and board industry to improve retention and drainage (**Table I**) have been available for decades, only during recent years have attempts been made to document in the published literature their effects on the drainage of stock on production machines. Usually, laboratory trials are performed prior to the introduction of these materials onto a machine, but predicting machine performance from lab trials is not always a straightforward process.

This paper was prepared as an invited contribution to a panel discussion on understanding drainage, one of the sessions at the TAPPI 1990 Papermakers Conference. The objectives were twofold:

1. Review the effects of commercially available retention and drainage aids on paper and board machine drainage
2. Examine the correlation between the results of lab and paper machine trials.

In preparing this review, we very soon discovered that there are gaps in the information published in the literature on the effects of drainage aids on machine drainage. Where these gaps exist, we have tried to supply the industry consensus on the subject. This was usually arrived at by personal experience or by discussions with technical representatives of the various companies supplying or using retention and drainage aids.

There are two main advantages of better drainage or dewatering on the paper machine: increased production rate and reduced energy consumption in the dryers. Usually mill personnel choose one of these as their objective, although sometimes it is possible to improve both. There are also a number of other possible benefits. They are usually situation specific and include:

- Better wet web strength (runnability)
- Use of slower-draining fibers
- Increased refining without production loss
- Reduced press load to maintain bulk.

I. Commonly used retention and drainage aids

PEI (polyethyleneimine)
CATPAM (cationic polyacrylamide)
ANPAM (anionic polyacrylamide)
Dual polymer systems
PEO (polyethylene oxide)
Cationic starch
Microparticle systems

There is a general consensus that paper machine dewatering occurs in four stages (**Fig. 1**). Before on-machine trials with drainage aids are carried out, the possible effects of these additives on paper machine dewatering are usually evaluated in the lab. Review of the literature on laboratory testing of drainage aids reveals that most people are using some modification of the dynamic drainage jar, originally developed by Britt and Unbehend (*1, 2*). In modified form (*3-6*), this device can measure both gravity drainage and, by applying vacuum, suction dewatering. Unfortunately, this does not cover water removal in the press section, which leaves a gap in our lab procedures for simulating machine dewatering. Some laboratories use water retention values (*7, 8*) as an indication of wet-press performance (*9, 10*). This practice has its merits, not the least of which is the simplicity of the measurement, but the relationship between press dewatering and drainage in a centrifuge is somewhat tenuous, at best.

For each of the types of retention and drainage aids listed in Table I, let's examine what has been published, or is generally accepted, regarding the effectiveness of each as a drainage aid on the paper machine. In mill trials, this is usually measured at the end of pressing, either by increased production or increased consistency. Then, for each drainage aid, we will look at the correlation of mill

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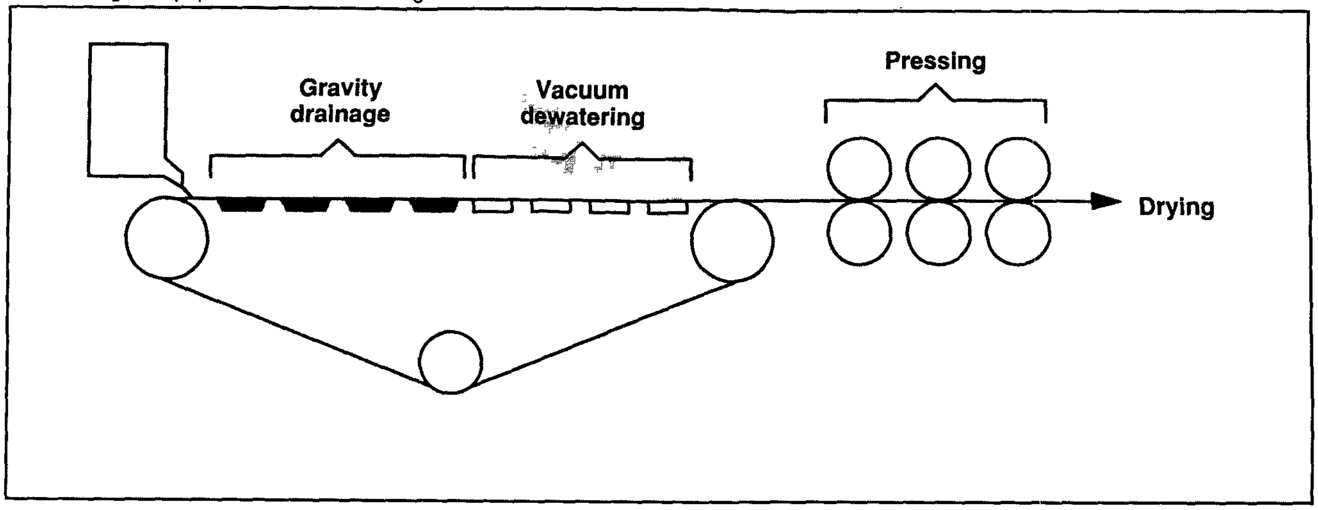
1. Four stages of paper machine dewatering



experience with lab tests, where possible. For some kinds of drainage aids, good published information correlating results from lab and mill trials is not available; in such cases, we have sometimes chosen to present lab data from the literature which illustrates certain trends that tend also to be found on production machines.

Drainage aids

Low molecular weight, high charge density, cationic polymers

The most frequently used polymers of this class are PEI and poly(DADMAC), i.e., poly(diallyldimethylammonium chloride). The consensus among manufacturers and users of this type of polymer is that it often increases machine drainage, but not in all applications.

Shown in **Table II** are results from a mill trial with PEI conducted by Linhart *et al.* (*11*) on a newsprint machine using 100% thermomechanical pulp (TMP). The addition of 0.04% PEI resulted in the consistency of the paper after the press section increasing by 0.6% during the trial and the steam consumption in the dryers decreasing by 0.09 tons/ton of paper produced. This trial certainly represented a success for PEI in newsprint from 100% TMP. However, increased drainage was not one of the reported benefits in a recent article by Westman (*12*), who gave an account of the economics for the use of PEI in a newsprint mill also using 100% TMP. One can probably surmise from this that PEI, although it is a very effective drainage aid in some furnishes, does have a drainage performance which is mill dependent.

Let's look now at some lab data for PEI as a drainage aid. In **Fig.** 2, data produced by Britt and Unbehend (*13*) show the dryness or consistency of a newsprint sheet plotted as a function of time. The second and third lines from the bottom show the gravity drainage of the furnish at two different concentrations of PEI; the bottom line shows the control experiment, without polymer. Gravity drainage increased in the presence of PEI. Higher dryness was achieved in a shorter time with polymer present, and the effect was greater at the higher concentration of PEI.

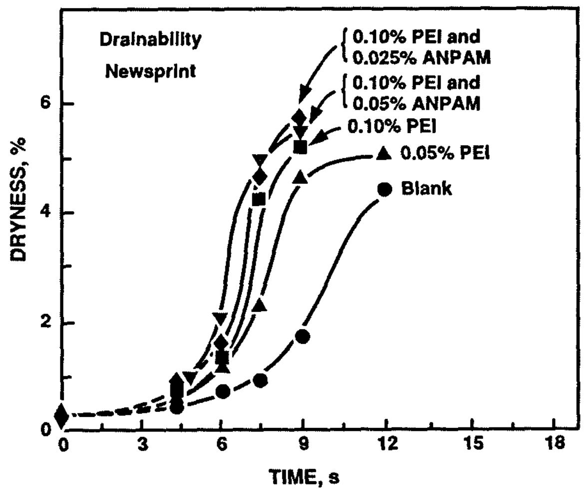
What this same study revealed for vacuum response is

II. PEI: Example of newsprint mill trial data (*11*)

	Control	*Trial*
Concentration of PEI, %	0	0.04
Machine speed, m/min	990	990
Output, tons/h	22.8	22.8
Consistency after press section, %	42.0	42.6
Steam consumption, tons/ton of paper	1.40	1.31

A 10% increase in first-pass retention was realized.

2. Lab results for effects of PEI and PEI plus ANPAM on gravity drainage using a modified dynamic drainage jar (*13*)



presented in **Fig. 3**, where dryness (i.e., consistency) is plotted as a function of time. The blank (top line) gives results with no polymer added; the second and third lines from the top give results with PEI added. Evidently, with PEI present, the stock consistencies at a given time are lower than with no polymer. This suggests that vacuum drainage is actually hampered by the presence of the polymer. So, the response of this particular furnish to the polymer is a mixed one. Gravity drainage is improved, and vacuum drainage is decreased. PEI coagulates by a patchwork or charge neutralization mechanism to give a very compact, small floc. The prevailing hypothesis maintains that this sometimes results in poorer vacuum dewatering than would be obtained, for example, with a cationic PAM, which yields larger, looser flocs that partially block the pores and permit less air channeling during the vacuum dewatering stage.

The industry consensus is that for PEI, poly (DADMAC), or any of the other low molecular weight, high charge density, cationic polymers, improved dewatering is not always evident in the lab when the modified dynamic drainage jar is used, even when improved performance is observed on the paper machine. In fact, with this kind of polymer the dynamic drainage jar also rarely predicts any increase in retention in newsprint at economical feed rates of polymer (*14*). This has been our experience with newsprint, and the people at BASF found that for their products the SchopperRiegler freeness tester gave a much better correlation between lab testing and on-machine performance (*15*). It appears that the modified dynamic drainage jar is not a consistently good predictor of the performance of this kind of polymer on a paper machine.

High molecular weight, low charge density, cationic polymers

Let's consider the high molecular weight, low charge density, cationic PAMs. Mill experience suggests that they can have small effects, both positive and negative, on drainage. Nevertheless, a small, positive influence on drainage can be significant for higher-basis-weight grades.

An example of a mill trial with CATPAM is shown in **Table III**. The data are from a cylinder board mill producing book board, as reported by Goldsberry (*16*). In the pretrial period, the basis weight was 437 g/m^2, and the machine speed registered 80 m/min. During the trial, 0.35% CATPAM was added; the basis weight increased to 471 g/m^2, and it was possible to increase machine speed by 8% to 86 m/min.

Another successful improvement in drainage during a mill trial was reported by Tarvin and Westwood for kraft linerboard (*17*). These results indicate that CATPAMs can be quite successful, especially in the higher-basis-weight grades.

An example of lab data for CATPAM is given in **Table IV**. These data were obtained by Abson *et al.* (*4*) for a 50/50 softwood kraft-hardwood sulfite furnish with clay, titanium dioxide, size, and alum. There are really two sets of results here: the first two lines with no alum present and the second two with alum. They looked at two polymers, CATPAM A and CATPAM B. With both, in the absence of alum, increases in fines retention and decreases in drainage time are evident. In the presence of alum, there is also an increase in first-pass retention of fines, but there is an increase in drainage time with CATPAM A. CATPAM B resulted in a decrease in drainage time with alum. So, for CATPAM trials in the lab, as in mill experience, we can have both positive and negative effects, depending on the specific polymer sample used and the presence of other additives.

Over the past decade, successful lab experiments with CATPAM for improved dewatering have been documented for a number of other furnishes: recycled neutral sulfite semichemical pulp (*18*), unbleached linerboard (*17, 19, 20*), kraft pulp (*16, 21*), bleached board (*16*), and fine paper (*16, 19*).

During machine trials with CATPAM, Langley *and* Litchfield (*22*) sometimes found improvements in dewatering in the wire section but a wetter sheet exiting the press section. Therefore, lab testing with a modified dynamic drainage jar, although taken as a reasonable indicator by many people of drainage and vacuum dewatering for this kind of polymer, is usually incomplete because it does not include press section performance.

Anionic polyacrylamide

ANPAMs (high molecular weight, low charge density) are sometimes employed to improve retention; however, we could find no published evidence that they work, by themselves, as drainage aids.

Lab evidence that ANPAMs are not effective in a bleached softwood/hardwood, sulfite fine paper furnish was published by Abson *et al.* (*4*). This kind of polymer is most often used in conjunction with a cationic polymer in dual-polymer systems.

Dual-polymer systems

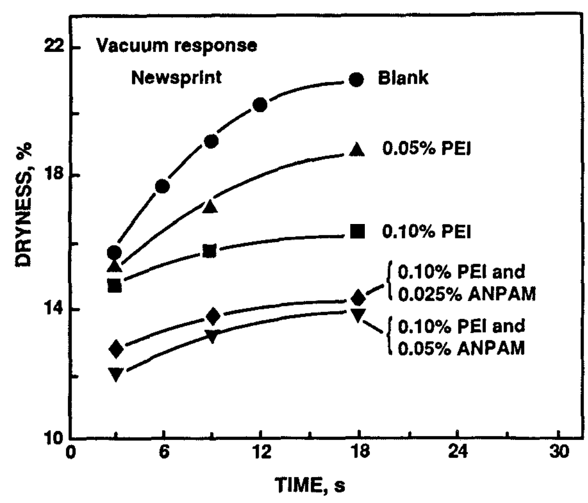
Polyethyleneimine and anionic polyacrylamide make up the classic dual-polymer system. There are, of course, many other combinations (*23*).

PEI [or poly(DADMAC)] and ANPAM have been found to promote drainage on a number of board machines, especially those using recycled paper, as reported by Kerlik and Mascarenhas (*24*). This is the system of choice in some mechanical-pulp-containing paper furnishes, especially if recycled papers are involved. We are told that drainage is improved but could find no published data. Recently, Wilharm (*25*) reported a drainage improvement on a board machine through the addition of two cationic polymers.

Two dual-polymer systems, PEI plus CATPAM and PEI plus activated bentonite plus CATPAM, have been recommended by BASF for newsprint. Lab data showing drainage improvement were published in 1986 (*26*); however, no published mill trials are available for drainage. For packaging papers, Pask and Lorz (*15*) recently documented results showing better drainage with PEI plus CATPAM.

What do the lab tests tell us about dual polymers? Let's examine data that Britt and Unbehend published in 1985 (*13*). The top two curves in Fig. 2 show gravity drainage results with the dual-polymer system PEI plus ANPAM in newsprint and at two different concentrations of ANPAM. For comparison, the lower three curves show results for the blank (no retention aid) and two concentrations of PEI. Clearly, this dual-polymer system is enabling a higher consistency to be reached in less time

3. Lab results for effects of PEI and PEI plus ANPAM on vacuum response using a modified dynamic drainage jar (*13*)



III. CATPAM: Cylinder board mill trial data (*16*)

Trial phase	*Basis weight, g/m²*	*Machine speed, m/min*
Pre-trial (8h)	437	80
Trial (6h) (0.35% CATPAM)	471	86

First-pass retention increased 8.8%.

IV. CATPAM: Example of lab data [50:50 softwood kraft-hardwood sulfite (bleached) with clay, TiO_2, 0.4% size, 1.5% alum] (*4*)

	Alum present	*Polymer*		
		None	*CATPAM A*	*CATPAM B*
Fines retention, %	No	60	74	80
Drainage time, s	No	4.7	4.4	3.0
Fines retention, %	Yes	69	79	85
Drainage time, s	Yes	4.5	6.3	3.7

than was the case for either the blank (with no polymer) or the furnish in the presence of PEI alone. So the dual-polymer system is quite effective in promoting gravity drainage in this newsprint furnish.

Nevertheless, as with PEI alone, the vacuum response of this sheet was greatly inhibited by the dual-polymer system, even more so than was the case for PEI alone. Figure 3 shows the consistency as a function of the time of vacuum dewatering, and we can see that for the dual-polymer system much lower consistencies were attained.

How can one interpret from these lab data whether or not the paper machine will benefit from dual polymers? Gravity drainage is improved, but vacuum response deteriorates, and we don't know what is going to happen in the press section. Nevertheless, lab drainage tests are usually done in preparation for a trial; obviously, a little knowledge is better than none at all.

Polyethyleneoxide

PEO is a nonionic polymer and only the very-high-molecular-weight kind is effective as a retention aid (*27*). It is of use mainly in mechanical-pulp-containing furnishes, especially newsprint (*28*) and certain groundwood specialty grades (*29*, *30*). Its effectiveness as a retention aid is often enhanced by the addition of a phenolic material (*31*). We know from personal experience and also from conversations with others who have conducted mill trials that PEO does affect drainage on the paper machine, usually positively. For example, Braun and Ehms (*29*) published mill trial data from a groundwood specialty machine that indicated about a 3% reduction in dryer steam consumption when the PEO addition rate was increased from zero to 0.2 kg/ton.

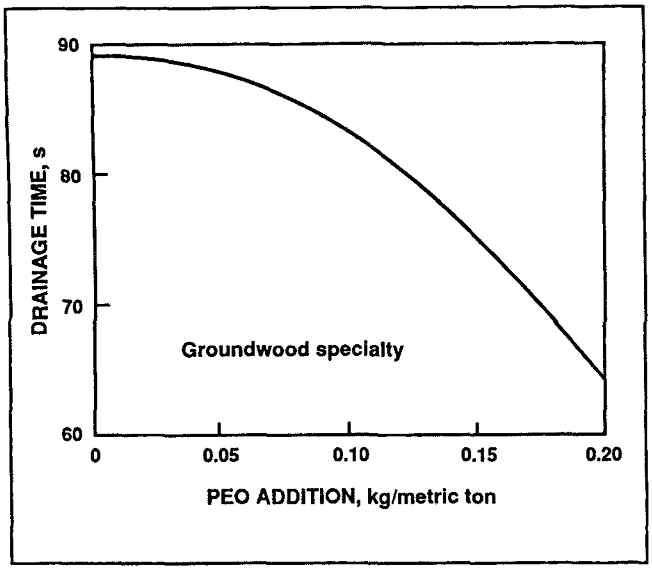
There is an indication that this improved drainage is reflected reliably in laboratory tests. The results in **Fig. 4** by Braun and Ehms (*29*) show the drainage time as a function of PEO feed rate. The samples for these lab tests were taken from the paper machine headbox during a mill trial in which the PEO concentration was increased stepwise. It clearly shows that the drainage time decreased with increasing PEO dosage.

The response of a newsprint furnish to vacuum dewatering with PEO addition was investigated by Tay (*32*); his results are shown in **Fig. 5**. Higher consistencies after vacuum dewatering were obtained as the PEO addition was increased. So the lab tests, in this case, clearly indicate what is generally observed on paper machines.

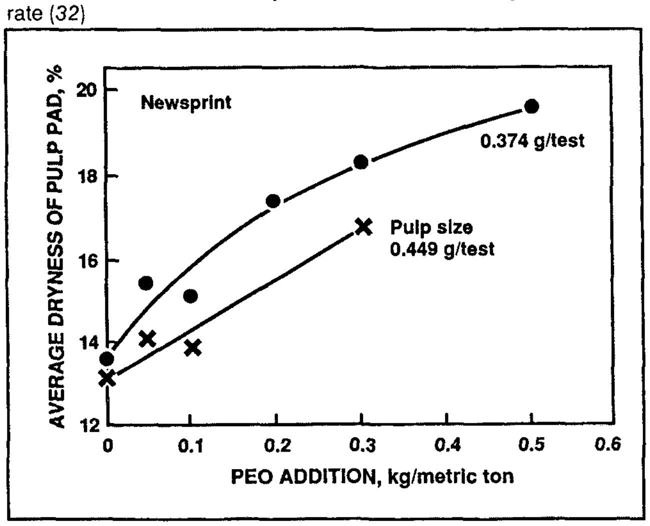
Cationic and amphoteric starches

The effects of cationic starch on drainage during machine trials have not been reported in the literature until recently, when Kearney (*33*) documented a trial with kraft board in which use of a cationic potato starch enabled a 5% increase in machine speed. He also cited a 3% increase in speed during a trial on a corrugating-medium machine. Lab work prior to each of these trials with a modified dynamic drainage jar predicted 6% and 5% increases in drainage, respectively, for the board and corrugating-

4. Drainage time vs. feed rate of PEO (29)



5. Lab results for consistency after vacuum dewatering vs. PEO feed rate (32)



medium machines. This is one of the very few cases where both the lab tests and the machine results were published. It is evident that the lab tests were fairly predictive, although the exact sizes of the increases in drainage were not accurately predicted.

The general consensus in industry on cationic starches is that they often do impart small increases in machine drainage. Kearney cautions that the nature of the cationic charge is very important in this respect (*33*).

Results from lab studies with cationic starches suggest:

1. Improved drainage and vacuum dewatering in board top liner furnish, but poorer drainage in board filler ply (*34*)
2. Improved drainage in oak kraft pulp/softwood kraft pulp furnishes (*20*)
3. Slightly poorer drainage but improved vacuum dewatering in bleached kraft hardwood/softwood furnish (*35*)
4. Improved Canadian Standard Freeness in a newsprint furnish at up to 7% starch (*36*)
5. Improved Canadian Standard Freeness in an alkaline paper furnish (*37*).

It was recently reported by McQueary (*38*) that amphoteric starch enables increases in machine speed on linerboard, bleached board, and cylinder board machines.

Microparticle systems

Microparticle systems (such as colloidal silica plus cationic starch or modified bentonite plus CATPAM) usually improve machine dewatering in neutral and alkaline systems, including fine paper, board, recycled paper, and kraft paper. This has been documented by Bunyan and Schack (*39*), who reported a 1% higher consistency after the second press of a paper machine producing a neutral-sized off-machine blade-coated paper. Moberg (*40*) reported a 3% higher consistency after pressing on a board machine. Langley and Cutts (*41*) have achieved production rate increases with the Hydrocol system (CATPAM plus a modified bentonite) in tissue, board, and lightweight coated grades. In addition, among papermakers and suppliers, there appears to be a consensus that microparticle systems are effective promoters of dewatering. On-machine effects of microparticle systems on gravity drainage and vacuum dewatering have been predicted reasonably well from lab studies with the modified dynamic drainage jar (*22*, *39*, *40*).

Conclusion

Although *retention* improvements during machine trials with retention and drainage aids are fairly widely documented in the technical literature, *drainage* performance has been much less widely reported. However, in the past few years, published information has begun to fill this gap in our knowledge.

Based on what has been published and on the shared opinions of papermakers and suppliers, the following picture is emerging:

1. Microparticle systems usually improve dewatering in alkaline paper and board manufacture.
2. PEI, poly(DADMAC), and the dual-polymer systems which include one of these as a component can improve drainage considerably, but this may be at least partially offset by a loss in vacuum dewatering. The latter appears to be very furnish dependent. Superior results have been obtained with dual polymers on some board machines.
3. CATPAM and cationic starches often give small improvements in machine drainage, especially in board and higher-basis-weight products. Drainage improvements are usually less than in no. 1 and no. 2 (above), and results are very dependent on furnish.
4. PEO usually improves drainage in newsprint manufacture.

Regarding the correlation between lab tests and machine dewatering, it is rare that both are published in the literature for the exact same furnish. In the few cases where they are reported together, the correlation for drainage and vacuum dewatering has been reasonable when using the modified dynamic drainage jar or other testers operating on a similar principle. Lab results usually can't predict the exact amount by which drainage on the machine will increase, but they appear to indicate if the increase will be zero, small, or large. Obviously, in cases where only small changes in drainage are involved, the predictive ability of the lab tests will be less reliable. In addition, lab tests are now almost universally used for screening polymers and optimizing feed rates in preparation for mill trials.

One shortcoming of the lab testing procedure as it is currently practiced is that only gravity drainage and vacuum dewatering are measured. Dewatering in the press section is therefore neither measured nor predicted. Davis, Stratton, and Chang (*42*) used the Wahren-Zotterman wet-press simulator as a lab test method for evaluating the effects of polymeric additives on press section dewatering. Other types of lab presses could also be useful.

During the preparation of this paper, we discovered many gaps in the published information on how various retention and drainage aids affect commercial machine drainage. It is evident that the amount of information published is only a small fraction of our industry's total experience. We urge readers to publish data, if it is good and relatively complete, so that paper machine performance can be properly documented. If this is not done reliably in the next few years, we'll continue to live in ignorance, which would be unfortunate. After all, most of the materials used as drainage aids have been with us for many decades.□

Literature cited

1. Britt, K. W., Tappi 56(10): 46(1973).
2. Britt, K. W. and Unbehend, J. E., Tappi 59(2): 67(1976).
3. Unbehend, J. E., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 363.
4. Abson, D., Bailey, R. M., Lenderman, C. D., Nelson, J. A., *et al.*, Tappi 63(6): 55(1980).
5. Forsberg, S. and Bengtsson, M., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 239.
6. Commercially available from Paper Research Materials, Inc., Syracuse, N.Y., and Paper Chemistry Laboratory, Inc., Carmel, N.Y.
7. Water Retention Value (WRV), TAPPI Useful Method UM 256, TAPPI PRESS, Atlanta, 1991.
8. Penniman, J., Paper Trade J. 165(10): 44(1981).
9. Yaraskavitch, I. M., Allen, L. H., and Heitner, C., J. Pulp Paper Sci. 16(3): J87(1990).
10. Busker, L. H. and Cronin, D. C., 1982 International Water Removal Symposium Preprints, Technical Section, CPPA, Montreal, p. 25.
11. Linhart, F., Auhorn, W. J., Degen, H. J., and Lorz, R., Tappi J. 70(10): 79(1987).
12. Westman, L., Grundmark, H., and Petersson, J., Nordic Pulp Paper Research J. 4(2): 113(1989).
13. Britt, K. W. and Unbehend, J. E., Tappi J. 68(4): 104(1985).
14. Pelton, R. H., Allen, L. H., and Nugent, H. M., Pulp Paper Can. 81(1): T9(1980).
15. Pask, M. D. and Lorz, R., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 247.
16. Goldsberry, H. A., 1985 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 283.
17. Tarvin, R. F. and Westwood, R. L., 1982 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 243.
18. Wegner, T. H., Springer, A. M., and Chandrasekaran, S., Tappi J. 67(4): 124(1984).
19. Scalfarotto, R. E. and Tarvin, R. F., Tappi J. 67(4): 80(1984).
20. Klungness, J. H. and Exner, M. P., Tappi 63(6): 73(1980).
21. Wegner, T. H., Tappi J. 70(7): 107(1987).
22. Langley, J. G. and Litchfield, E., 1984 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 89.
23. Allen, L. H. and Yaraskavitch, I. M., 1989 Retention and Drainage Short Course Notes, TAPPI PRESS, Atlanta, p. 59.
24. Kerlik, P. and Mascarenhas, I., Pulp Paper Can. 86(1): T12(1985).
25. Wilharm, M. T., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 223.
26. Lorz, R. H., 72nd Annual Meeting Proceedings, Technical Section, CPPA, 1986, p. B185.
27. Pelton, R. H., Allen, L. H., and Nugent, H. M., Svensk Papperstidn. 83(9): 251(1980).
28. Pelton, R. H., Tay, S. H., and Allen, L. H., J. Pulp Paper Sci. 10(1): 5(1984).
29. Braun, D. B. and Ehms, D. A., Tappi J. 67(9): 110(1984).
30. Pelton, R. H., Allen, L. H., and Nugent, H. M., Tappi J. 64(11): 89(1981).
31. Pelton, R. H., Allen, L. H., and Nugent, H. M., U.S. pat. 4313790 (Feb. 2, 1982); Canadian pat. 1137710 (Dec. 21, 1982).
32. Tay, C. H., Tappi 63(6): 63(1980).
33. Kearney, R. L., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 253.
34. Springer, A. M., Chandrasekaran, S., and Wegner, T. H., Tappi J. 67(2): 104(1984).
35. Britt, K. W. and Unbehend, J. E., Tappi 63(4): 67(1980).
36. Laleg, M., Ono, H., Barbe, M. C., Pikulik, I. I., and Seth, R. S., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 383.
37. Patton, P. P., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 151.
38. McQueary, R. T., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 137.
39. Bunyan, D. and Schack, L., Paper 204(3): 18(1985).
40. Moberg, K., 1987 Advanced Topics in Wet End Chemistry Seminar Notes, TAPPI PRESS, Atlanta, p. 7.
41. Langley, J. G. and Cutts, P. K., 1990 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 377.
42. Davis, E. ., Stratton, R. A., and Chang, N. L., J. Pulp Paper Sci. 9(3): TR68(1983).

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