

The influence of fiber, sheet structural properties, and chemical additives on wet pressing

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ABSTRACT *The influence of fiber and sheet structural properties on wet pressing was examined using a dynamic press simulator. Two furnishes—unbleached softwood kraft and cotton linters—were used. The primary deterrent to water removal was the amount of water held by the swollen fiber. Sheet formation and fiber length had no effect on the dryness change of a wet web during a single press pulse. However, poorer sheet formation and decreasing fiber length caused the hydraulic pressure generated within the sheet to increase, indicating that dewatering became more flow controlled. Refining influenced press performance to the extent that it influenced the water-retention capability of the refined fibers and fines. The presence of fines had a greater negative influence on dewatering than fiber fibrillation. In situations where the fibers were highly swollen, the recorded hydraulic pressure was low. Dewatering in these instances may be best described as "fiber-flow limited." The observation that the extent of fiber swelling is the most important variable in first-press performance is consistent with the observation that chemical additives do not influence pressing performance unless they penetrate the fiber.*

KEYWORDS

Fibers
Pressing
Press sections
Refining
Sheet formation
Water removal
Wet pressing
Wet end
chemicals

The removal of water during the papermaking process is of primary importance to the papermaker. Water is removed in four successive zones on the paper machine (1):

1. Forming zone, from the slice to the flat boxes
2. Vacuum zone, from the flat boxes to the suction couch

3. Press section
4. Dryer section.

Water removal becomes progressively more difficult and expensive in each successive zone. Since approximately 80% of the energy consumed on the paper machine is used to remove water from the wet web in the dryer section, it is to the advantage of the papermaker to achieve greater water

removal prior to evaporative drying.

Studies of water removal on the fourdrinier wire have shown that the dewatering behavior of stock in the forming zone and in the subsequent vacuum zone are distinctly different. Britt *et al.* (1, 2) found that conditions favoring rapid drainage in the forming zone can have the opposite effect in the vacuum zone, and vice versa. They attribute these differences to

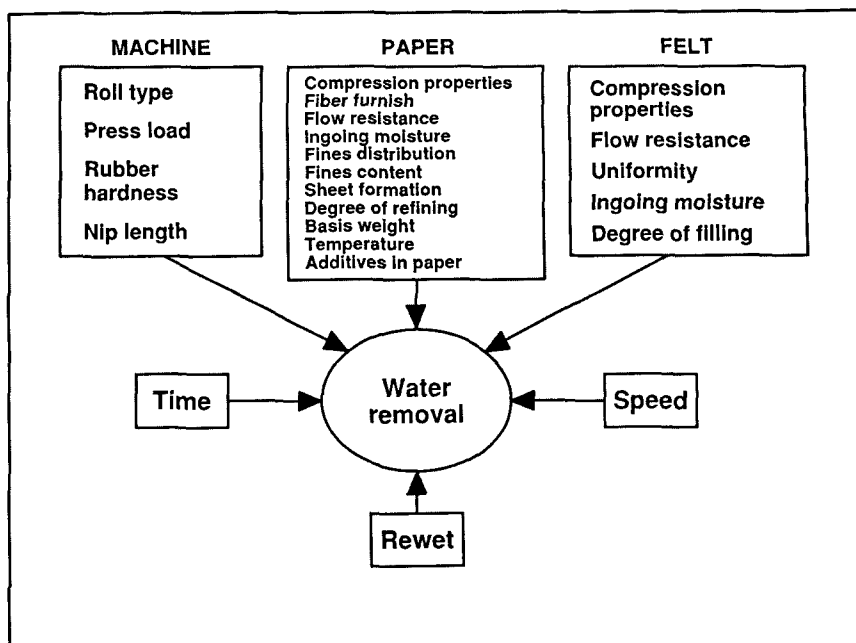
factors that affect sheet structure and consolidation, such as the type of fiber furnish, degree of refining, fines content, sheet formation, and addition of chemicals.

The effect of these factors on wet pressing had not been studied until recently. Caulfield *et al.* (3-5) investigated the effect of initial moisture content, refining, basis weight, fiber geometry, and formation on the dewatering response. They concluded that the initial moisture content of the web entering the press nip was the dominant variable influencing dewatering behavior. The other variables affected dewatering only for webs with low initial moisture contents. However, the examination of fiber geometry and sheet formation was cursory. The effects of fiber geometry on wet pressing were studied using three different wood species to represent different ultrastructures and chemical compositions, both of which would influence the water-retaining potential of the fibers. The effects of formation were studied by comparing handsheets with machine-made webs. Sheet formation, however, was not quantified.

The individual effects of the refining action—increased fines content, change in fiber-length distribution, fibrillation of fibers, and increased fiber swelling—were not taken into consideration in studies examining the influence of refining on wet pressing (3, 6, 7). While it is well documented that the outgoing dryness of the pressed sheet decreases with increasing refining, the reason for this decrease has not been established.

The work presented in this paper is a fundamental study of the influences of fiber and sheet structural properties on wet pressing. It was designed to elucidate how factors such as fiber type, fiber length, fiber fibrillation, fines content, and sheet formation affect the pressing response. The results show that, under the pressing conditions employed, the primary deterrent to water removal by pressing is the amount of water held by the fiber itself. This implies that chemical additives should not affect pressing behavior of the sheet, and the data presented are consistent with this observation. Chemical additives have an indirect influence on wet pressing, since they can affect the drainage on the machine and thus the initial moisture content of the sheet as it

1. Variables influencing press dewatering



I. Sheet formation and floc analysis*

Formation index	Total floc count	Floc area, %	Floc size, cm ²	Number of bins
2.93	82	26	0.3296	30
4.53	94	23	0.2485	24
7.78	113	24	0.2168	19
11.50	121	16	0.1322	16

*All values are for UBK pulps and represent the average of three observations. Formation was monitored with an M/K formation tester.

II. Fiber length and coarseness data for three categories of fiber length^a

Fiber fraction ^b	Arithmetic average length, mm	Length-weighted average, mm	Weight-weighted average, mm	Fines, %	Coarseness, mg/100 m
UBK 30	1.71	2.07	2.37	3.82	32
UBK 50	1.23	1.50	1.77	4.09	29
UBK 100	0.60	0.72	0.88	3.78	22

^aAll values represent the average of three observations.
^bValues in this column represent the screen mesh.

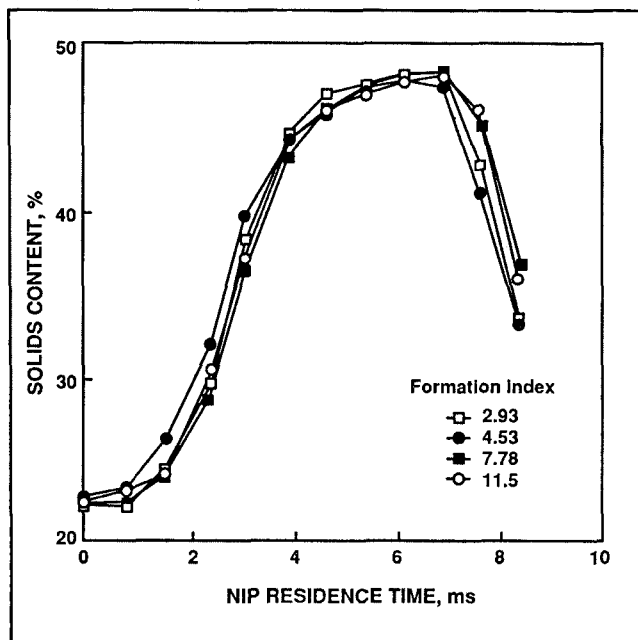
enters the press. For sheets entering the press at equal moisture contents, however, the presence of additives has no influence on the moisture content of the sheet as it leaves the press.

The overall variables that influence pressing behavior are summarized in Fig. 1. They can be broadly classed as machine variables, paper variables,

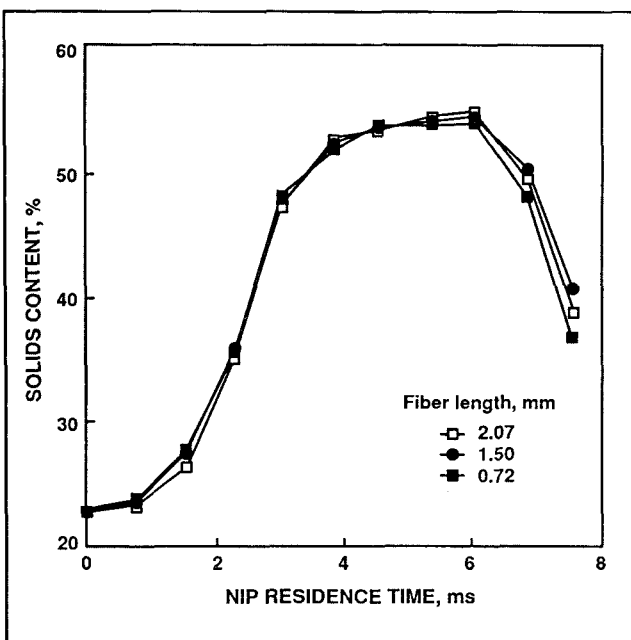
and felt variables. The machine and felt variables have received a lot of attention, while the paper variables have not been studied extensively.

This study examines the effect of fiber and sheet structural properties on water removal by wet pressing under first-press conditions. The following factors were investigated:

2. Effect of sheet formation on the pressing performance of a UBK furnish (520 mL CSF)



3. Effect of fiber length on the pressing performance of a UBK furnish



III. Applied and hydraulic pressures for three categories of fiber length (UBK fibers)*

Fiber length, mm	Applied pressure			Hydraulic pressure		
	Maximum, psi	Impulse, psi-ms	Average, psi	Maximum, psi	Impulse, psi-ms	Average, psi
2.07	528	2,047	273	28	83	11
1.50	506	2,074	277	54	138	18
0.72	531	2,035	271	106	241	32

*Nip residence time = 7.5 ms

IV. Water-retention values for three categories of fiber (UBK fibers)

Fiber length, mm	WRV, g water/g fiber
2.07	0.927
1.50	1.235
0.72	1.432

- Sheet formation
- Fiber length
- Degree of refining
- Fines content
- Fiber fibrillation
- Fiber swelling.

Two different furnishes—unbleached softwood kraft (UBK) and cotton linters—were used. The pressing process was studied using a dynamic press simulator operated under first-press conditions. A description of pressing conditions is available in the literature (8).

Sheet formation

The influence of sheet formation on wet pressing was determined using sheets formed with varying degrees of

flocculation. Table I lists the results of the formation and floc analysis for the four distinctly different formations that were obtained. The results show that as the formation index increases (indicating an improvement in formation), the average floc size decreases, along with the percentage of area covered by flocs. The total floc count is lower for poorly formed sheets, since the flocs in these sheets are larger and cover more area.

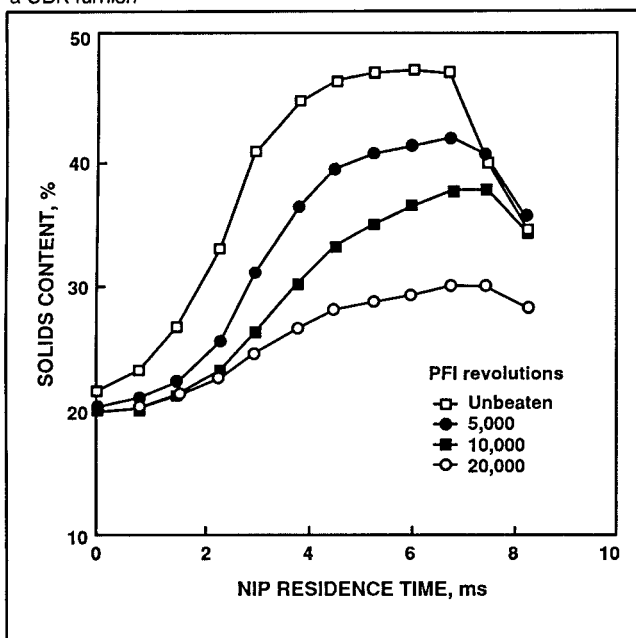
Under the first-press conditions employed in this study, formation did not affect the maximum dryness attained by the sheet as it passed through the press nip. Figure 2 shows the change in sheet dryness for the four sheet formations. It is apparent that the maximum dryness as well as the paths to the maximum dryness are the same for all four formations.

Based on these results, it appears that sheet formation has no influence on either the maximum percent dryness achieved or the dryness change within the press nip under the press conditions examined.

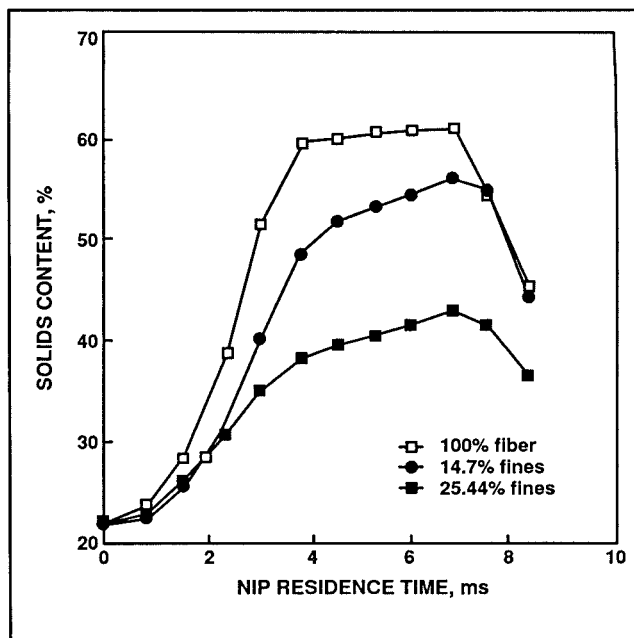
Fiber length

To study the influence of fiber length on wet pressing, UBK fibers were fractionated into three length categories using a Bauer-McNett classifier. Table II lists the data for the three fractions. Table II also lists the fiber coarseness for the three length categories, since fiber classifiers separate fibers on the basis of both length and coarseness. Because coarseness decreases with decreasing fiber length, the influence of fiber length on pressing could not be separated from the

4. Effect of refining (PFI revolutions) on the pressing performance of a UBK furnish



5. Influence of UBK fines on the press response of UBK fibers



influence of fiber coarseness.

Under the press conditions employed in this study, fiber length did not influence either the maximum dryness attained in the press or the change in the dryness of the sheets within the nip, as seen in Fig. 3. The figure also shows that the degree of expansion in the exiting portion of the nip was also the same for all three length categories.

Fiber length did have a significant impact on the hydraulic pressure generated within the sheet, however. Table III shows a substantial increase in hydraulic pressure with decreasing fiber length. Because the sheets have the same basis weight, a decrease in fiber length causes the sheet to be more consolidated. With smaller void spaces between the fibers, the flow resistance between the fibers is larger. This increase in flow resistance gives rise to an increase in hydraulic pressure, suggesting that the dewatering becomes more flow controlled as the fiber length decreases. No shift in the hydraulic pressure pulse was noted.

Water-retention value (WRV) increases with decreasing fiber length, as seen in Table IV. With the basis weight held constant, this increase in WRV is due to the increase in surface area of the shorter fibers.

The studies of formation and fiber length show that the factors affecting

V. Maximum solids content for wet-pressed UBK and cotton furnishes at four levels of refining

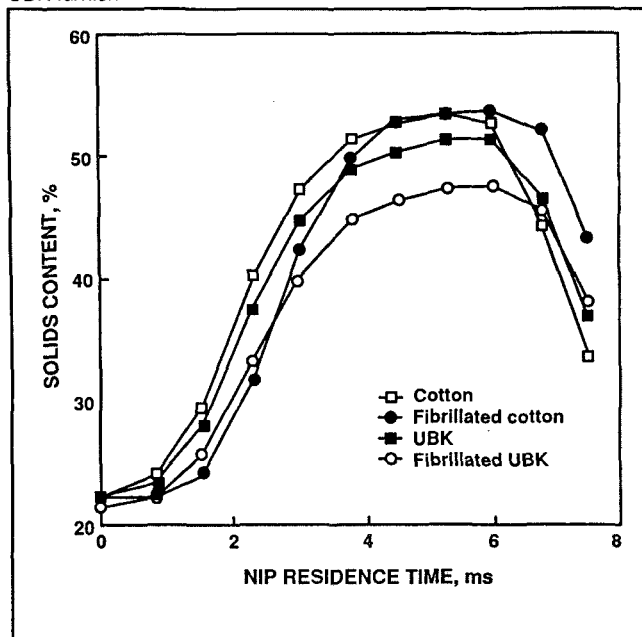
PFI revolutions	Maximum solids content, %	Standard deviation	Number of observations	Confidence interval (95%)
Unbleached kraft pulp				
Unbeaten	47.59	0.141	7	± 0.131
5,000	41.91	0.179	8	± 0.149
10,000	37.91	0.109	8	± 0.091
20,000	30.18	0.155	8	± 0.129
Cotton				
Unbeaten	58.90	0.141	8	± 0.118
5,000	58.62	0.074	8	± 0.062
10,000	58.69	0.089	7	± 0.082
20,000	57.05	0.184	6	± 0.193

the macrostructure of the sheet do not affect wet-pressing performance under the conditions used here. Changes in sheet macrostructure do influence the hydraulic pressure developed within the sheet during pressing. Macrostructural changes that reduce the void volume between the fibers cause an increase in hydraulic pressure, and dewatering in the press is increasingly controlled by flow.

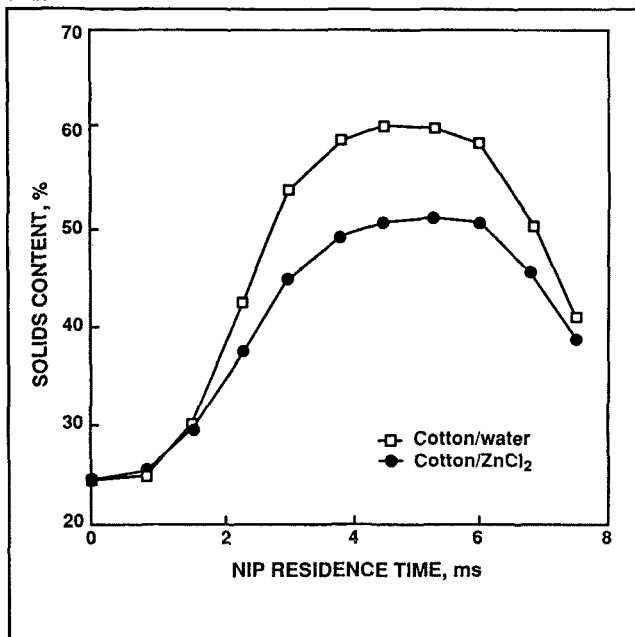
Degree of refining

Various researchers have shown that an increase in refining reduces the outgoing sheet dryness. Carlsson (6) attributes this to an increase in the flow resistance with increased refining. The increased flow resistance results in a higher hydraulic pressure and in a lower sheet dryness. Carlsson presents data showing that the hydraulic pressure not only increases

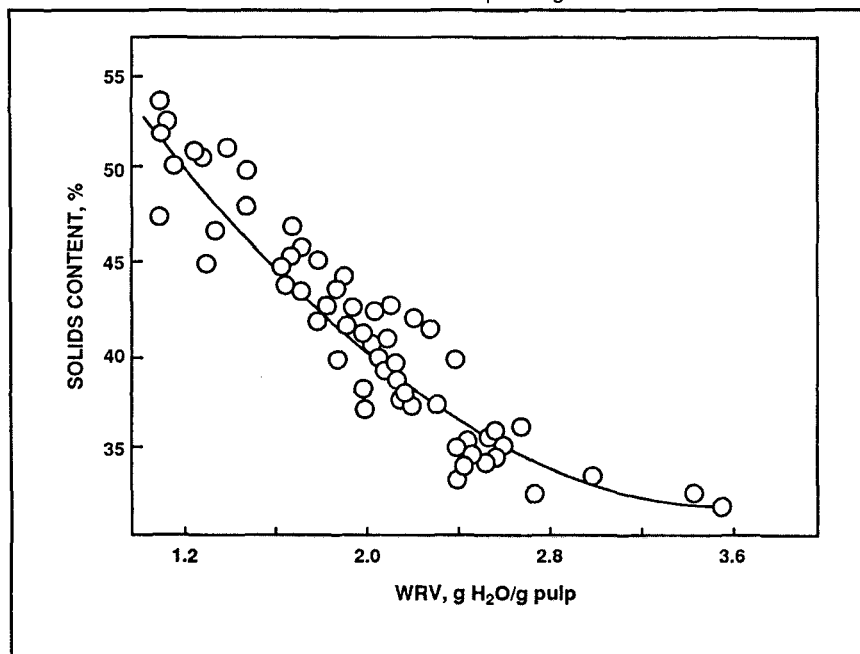
6. Effect of fibrillation on the press response of cotton furnish and UBK furnish



7. Effect of swelling agent (ZnCl_2) on the pressing response of a cotton furnish



8. Correlation of WRV and solids content after wet pressing



with refining but that the position of maximum hydraulic pressure shifts from the ingoing side of the nip toward mid nip. In addition, as refining increases, the point of maximum solids content is moved from mid nip to the expanding portion of the nip. Carlsson also points out that sheets formed from unbeaten fibers exhibit a relatively strong expansion after mid nip, whereas sheets formed from beaten fibers show little or no expansion. The data

presented in his refining study show that as the degree of refining is increased, the dewatering response is increasingly controlled by flow.

We carried out a separate refining study for our research project. UBK and cotton fibers were individually beaten in a PFI mill for 0, 5000, 10,000, and 20,000 revolutions. Figure 4 shows the results of the dryness change within the nip for the UBK. This figure clearly illustrates the

expected trend for the influence of refining on sheet dryness: the more highly refined the fibers, the lower the maximum sheet dryness. Table V shows that sheets made from unbeaten UBK pulp had a maximum dryness of 47.6%, while sheets containing fibers beaten for 20,000 revolutions achieved maximum dryness of only 30.2%, a difference of more than 17 points. Figure 4 also reveals a slight shift in the point of maximum solids content toward the end of the press pulse for the highly beaten fibers. In addition, the degree of sheet expansion (as measured by the decrease in solids content) is shown to decrease with an increase in refining. These results are in accordance with those obtained by Carlsson (6) and show that dewatering becomes more flow controlled with an increase in refining.

The magnitude of the hydraulic pressure generated between the fibers depends not only on flow resistance between the fibers but on the amount of water available for flow. In highly swollen pulps like the UBK in this study, the amount of water available for flow is small even though the flow resistance is high. The recorded hydraulic pressure will therefore be low. This means that a wet web can be flow controlled even though the hydraulic pressure measured in the transportation channels is low (6).

VI. WRV of bleached softwood kraft (250 mL CSF) treated with various retention and drainage aids

Polymer No.	Polymer description	Molecular weight	WRV, g water/g fiber			
			Chemical addition per ton of pulp			
			0	1 lb	2 lb	3 lb
1275	Strongly cationic polyamide	30,000	2.08	2.22	2.08	2.04
1290	Strongly cationic polyamide	10,000	2.30	2.02	2.06	2.08
DPP 861	Strongly cationic polyamide	300,000	2.12	1.99	2.01	1.94
1262	Strongly cationic polyacrylamide	2,000,000	2.22	2.22	2.16	2.24
1264	Moderately cationic polyacrylamide	8,000,000	2.28	2.20	2.13	2.08
Experimental PEO	Nonionic polyethylene oxide	4,000,000	2.41	2.50	2.39	2.32
Experimental PAM	Nonionic polyacrylamide	4,000,000	...	...	...	...
DPP 1013	Weakly anionic polyacrylamide	16,000,000	2.25	2.22	2.32	2.28
DPP 1014	Strongly anionic polyacrylamide	16,000,000	2.26	2.20	2.38	2.33

VII. Pressing data for newsprint/corrugated furnish treated with various retention and drainage aids*

Polymer No.	Polymer description	Basis weight, g/m ²	Pressure, psi		Dryness, %			
			Applied	Hydraulic	In	Out	Change	
							Mean	Std. dev.
1275	Strongly cationic polyamide	199	609	234	31.71	34.98	3.29	1.66
1290	Strongly cationic polyamide	201	591	354	31.99	35.73	3.73	1.353
DPP 861	Strongly cationic polyamine	207	595	258	33.07	36.48	3.41	1.513
1262	Strongly cationic polyacrylamide	203	595	276	32.39	34.75	2.36	0.555
1264	Strongly cationic polyacrylamide	200	651	339	31.53	34.95	3.29	1.390
Control		195	631	371	30.35	34.46	4.10	1.58
Experimental PEO	Nonionic polyethylene oxide	203	620	498	31.52	33.59	2.26	0.553
Experimental PAM	Nonionic polyacrylamide	189	603	168	30.53	36.34	5.63	1.56
DPP 1013	Weakly anionic polyacrylamide	196	606	443	30.47	34.62	4.14	0.652
DPP 1014	Strongly anionic polyacrylamide	192	614	394	29.95	33.96	3.61	1.587

*Furnish was 50% newsprint and 50% corrugated. Chemicals were added at a rate of 1 lb/ton on an active basis. Sheet basis weight was 200 g/m². Nip residence time was 10 ms, and applied pressure was 600 psi.

Fines content

Refining has several effects on the fiber: fiber shortening, external and internal fibrillation, internal splitting, and fines production. In this study, we attempted to isolate the effects of fines on wet pressing.

UBK fines were generated in a PFI mill and added in varying levels to a base sheet composed of UBK fibers of uniform length. Two types of fines were generated in order to determine if the nature of the fines themselves influences the pressing response. **Figure 5** illustrates the effect of UBK fines on the dryness change in the nip. The maximum dryness attained decreases with increasing fines content. There is approximately a 17-point difference in the maximum dryness for sheets with no fines and those with 25% fines. The point of maximum solids content does not appear to have shifted. However, for the sheets with no fines, the dryness change appears to level off at about 4 ms, while for the sheets with 15% and 25% fines, the dryness continues to increase for an additional 3 ms. (The point of maximum dryness for all three sheets is obtained at a nip residence time of 7 ms.) The figure also shows that the degree of sheet expansion is higher for sheets with lower fines content. These results are similar to those obtained in the refining study for the UBK.

Fiber fibrillation

To isolate the influence of fiber fibrillation (includes internal and external fibrillation and fiber splitting) on wet pressing, UBK fibers were refined in a PFI mill for 20,000 revolutions and then fractionated using a Bauer-McNett classifier. Fines-free samples of uniform length were obtained by fractionating the pulp. Unrefined samples were used as a control. The dryness change in the nip is illustrated in **Fig. 6**. The maximum solids content attained in the nip decreased 4.7 points when the UBK fibers were fibrillated by refining. This indicates that fibrillation of UBK fibers influences the dryness change in a nip.

Fiber swelling

In all the studies discussed so far, the cotton samples have shown the least influence on wet pressing. In most

cases, the water retention value of the cotton samples were lower than the UBK samples. An attempt was made to increase the swelling (and thus WRV) of the cotton fibers in order to achieve a dewatering response similar to that of UBK. Dry cotton pads were soaked in either 65% zinc chloride or distilled water for 30 min before being pressed. **Figure 7** shows that the zinc chloride treatment significantly influenced the maximum solids content achieved in the nip, with the treatment producing a 9-point decrease in the maximum dryness. This indicates that the difference between the pressing behavior of cotton and UBK is determined by the amount of water that the fibers can hold.

Correlation between maximum solids content and WRV

Busker and Cronin (9) have suggested using WRV to predict the solids content after wet pressing. **Figure 8** shows the correlation between solids content and WRV for approximately 60 furnishes having a broad spectrum of pulp type and refining (9). The WRV appears to be a good predictor of the solids content. This relationship supports the concept that the removal of water from the fiber wall is the limiting factor for attaining a high solids content after the presses.

The consistent picture that emerges is that first-press performance is influenced by the factors that affect the water-holding capacity of the individual fibers. This observation is consistent with previously generated data illustrating that chemical additives did not significantly affect simulated first-press performance (10).

Table VI shows a sample of bleached kraft pulp beaten to 250 mL CSF and treated with a wide range of retention and drainage aids commonly used in the paper industry. In no instance was the WRV of the pulp dramatically influenced by the additives. **Table VII** shows that when these same additives were applied to a furnish of 50% newsprint and 50% corrugated, no significant change in the pressing behavior was observed. It now seems obvious that the additives affected the sheet structural properties (sheet formation was usually different) but did not influence the fiber properties. Given the high

fines content of the furnish, the additives must not have appreciably influenced the amount of fines retained in the sheet, which was quite heavy (≈ 200 g/m²) and thus did an efficient job of retaining fines.

If an additive is to affect first-press performance, it must be able to penetrate the fiber structure and influence its water-holding capacity. This is consistent with the observation of Stratten (10), who postulated that high-charge-density, low-molecular-weight polymers should have the greatest effect.

Conclusion

The influence of fiber and sheet structural properties on wet pressing was examined. For the pressing conditions employed in this study, the following conclusions have been drawn:

Refining and swelling agents. Factors that increase the water-holding capacity of the fibers, such as refining and swelling agents, have a negative influence on the dryness change in the press nip. These same factors increase the hydraulic pressure generated within the sheet, indicating that dewatering is being limited by flow from the web. In webs where the fibers are highly swollen, however, the hydraulic pressure is low because of the high flow resistance in the fiber wall (6). Dewatering in this case is "fiber-flow limited."

Of the individual effects of refining, the production of fines has the greatest influence on the dewatering response. Unbleached softwood kraft (UBK) fines had a greater negative effect on the dryness change than cotton fines. This difference in behavior is due to the higher water-holding capacity of the UBK fines.

Fibrillated UBK fibers have a greater negative effect on press performance than fibrillated cotton fibers. Again, this is because UBK fibers retain more water than cotton fibers.

Sheet-structure properties. Sheet-structure properties such as formation and fiber length have no influence on the dryness change of a wet web during pressing. However, sheet structural changes that result in a decrease in the void volume between the fibers cause an increase in the hydraulic pressure generated in the sheet. As hydraulic pressure in-

creases, dewatering becomes more flow controlled.

Chemical additives. Chemical additives do not seem to influence first-press performance because they do not appear to significantly alter the water-holding capacity of the individual fibers. The only additives that can influence pressing are those that penetrate the fiber structure. □

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