Basket cases: kraft pulps inside digesters

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Basket pulps taken from inside mill batch digesters usually come within 10% of the strength potential shown by plant pulps made from mill chips; after blowing, mill-made pulps are often 25% weaker in tear–tensile strength.

The hanging of baskets in batch digesters (Fig. 1) has a long history in the chemical pulping industry, but the record of results is largely relegated to the private files of pulp and paper companies. In fact, in the entire Abstract Bulletin of The Institute of Paper Chemistry, only one useful article on "basket cooking" is listed. Published in 1954, it contains little numerical information but does describe the technique and its possibilities (*1*).

Hanging baskets offer a means of isolating a small unit volume of a large batch digester, providing access to key results which otherwise would be impossible to obtain directly. Such results include the degree of delignification at that location, the pulp yield, and the strength of never-blown pulp. There may be questions about whether such a unit volume is truly representative of the entire contents of the digester, but there is no doubt that the basket technique subjects real mill chips to real mill cooking conditions.

We have conducted many basket experiments during the past several years and have found that the chemistry of mill cooking is generally satisfactory right to the finishing point. Unfortunately, the physics of "blowing" the cooked material from the digester to the blow tank then causes mechanical damage to the fibers.

The location and magnitude of the strength loss upon blowing softwood kraft pulp were described previously (*2–4*). As one means of measuring this phenomenon, we routinely use curves of tear strength vs. breaking length such as the hypothetical ones shown in Fig. 2. When unbleached, mill-made, softwood pulps are compared with pilot-plant reference pulps also made from a mill's chips, the mill pulps are 25% weaker, on the average, in tearing resistance at a given tensile strength.

We tested the hanging basket technique in a mill using directly steamed batch digesters to make bleachable-grade kraft softwood pulp. We found that the never-blown pulps from the baskets were only 10% weaker than the pilot-plant reference pulps (*4*). In contrast, the mill's brownstock washer pulps were at least 30% weaker than the pilot-plant pulps. A considerable amount of pulp strength was being lost just in transferring the cooked material from the digester to the blow tank.

Here, we review the results of many such basket experiments in a variety of mills. What emerges is a comprehensive picture of the physical quality of pulp inside digesters at the end of kraft cooking, and a realization that the strength loss problem demands a solution.

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Results and discussion

Using techniques reported previously (*2*), we have measured pulp strength deficiencies in kraft softwood mills ranging across Canada, most of them producing bleachable-grade pulps. Eight continuous mills and seven batch mills were surveyed. As the reference points, we used unblown pilot-plant pulps made from each mill's chips.

The tear–tensile strengths of the unbleached mill pulps varied from 65% to 85% of the potential value (Fig. 3). The strongest and weakest cases among the continuous mills were about equal to those among the batch mills. The averages were also similar, with continuous mills at 76% and batch mills at 74%. We have found a few cases in which a mill's pulp strength fell to as low as 55% of the pilot-plant reference; we have not found any cases in which it was higher than 90%.

Figure 3, then, represents the strength levels which many Canadian kraft softwood mills are achieving in their pulping operations. If all is perfect along the rest of the fiber line in the mill, this tear–tensile strength will be retained. More often, the pulp strength declines somewhat, the normal consequence of the many chemical and mechanical operations between digesters and pulp dryers or paper machines.

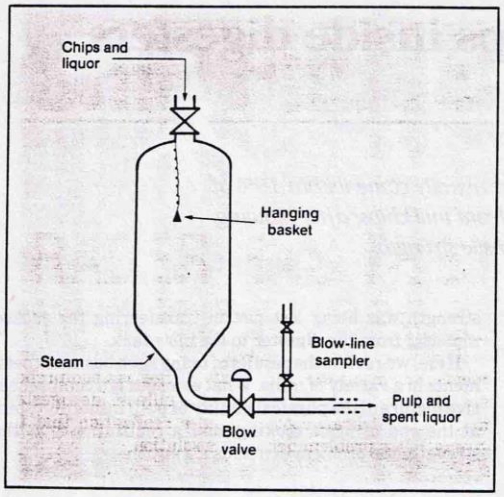
The pilot-plant cooking *always* produces pulp of higher strength from any softwood chip supply because there is no blow-line flow to damage the fibers after cooking has been completed.

There is a third level of strength, somewhere between the pilot-plant and mill levels, which represents the best a mill can do. Where is this pulp? It is inside the digester, after cooking but before blowing (*4*). How strong is it? Considerably stronger than after it has been blown from the digester.

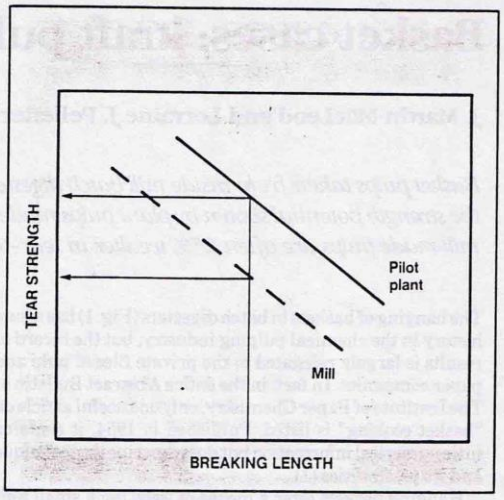
Mill 1

In work over several years in a kraft mill with directly

1. A basket hung inside a mill's batch digester provides a means to isolate a small unit volume of the total contents. Direct results can be obtained on degree of delignification, pulp yield, and the strength of never-blown pulp.



2. In comparisons of the mechanical strengths of pulps, the stronger pulp has a higher tear index at constant breaking length.



steamed batch digesters (Mill 1), we found that basket pulps averaged about 90% of the tear-tensile strength of the pilot-plant reference pulps made from the mill's chips (*4*). The pulp on the mill's brownstock washers, by comparison, averaged 68% of the strength of the reference pulps.

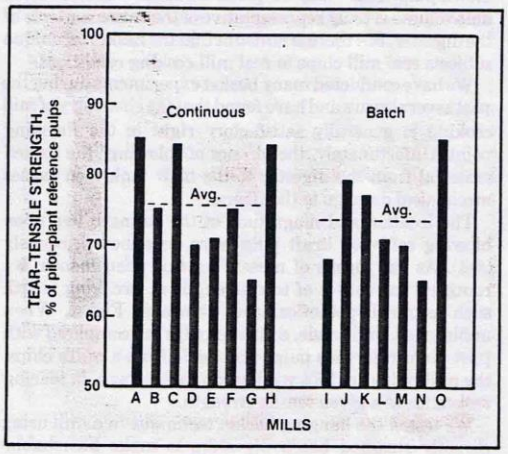
These results can be transformed to another basis if we take the philosophy that the basket pulps, not the pilot-plant pulps, serve as the best reference points. The basket pulps, after all, are the real (but never blown) products of the reactions between the mill's chips and the mill's cooking liquor.

Figure 4 illustrates the collected results of 12 basket experiments in Mill 1. In each case, the tear-tensile strength of the basket pulp was used to normalize the data of the corresponding brownstock washer pulp and the pilot-plant pulp. The brownstock washer pulps had only 73–83% of the strength of the basket pulps. Blowing alone resulted in a substantial loss of pulp strength. The pilot-plant pulps were at the 108% level; that is, they were slightly stronger than the basket pulps. The pulps from the blow-line sampler (61–74%) were weaker than the brownstock washer pulps because blow-line sampling itself damaged the fibers (*4*).

One of the remarkable aspects of Fig. 4 is that simply by knowing the tear-tensile strength of an unbleached pulp sample from this mill, one can deduce with reasonable certainty the location at which the pulp was sampled: blow-line sampler, brownstock washers, or basket.

The viscosities of these same pulp samples (after chlorite delignification) provided a further clue as to how the strength loss was occurring (Fig. 5). The viscosities ranged from 24 to 36 mPa·s, a not-unusual situation considering that sampling was done periodically over several years. The kappa numbers of these samples varied from 26 to 35. Figure 5 shows that the strength differences among the pulps sampled at the various locations were not related to

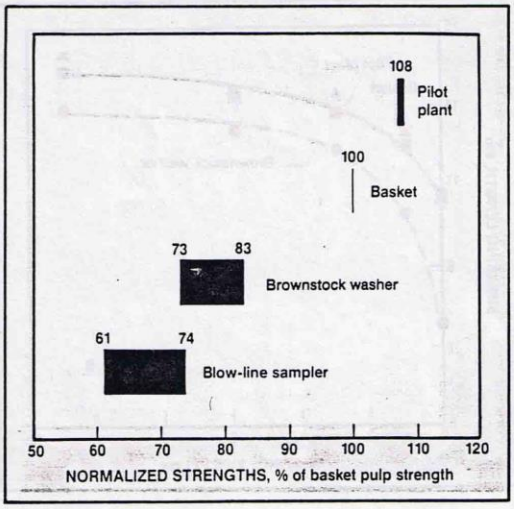
3. Mill-made kraft softwood pulps were always weaker than pilot-plant reference pulps made from the corresponding mill chips. (All of the pulps were unbleached; only one mill was not a bleachable-grade mill.)



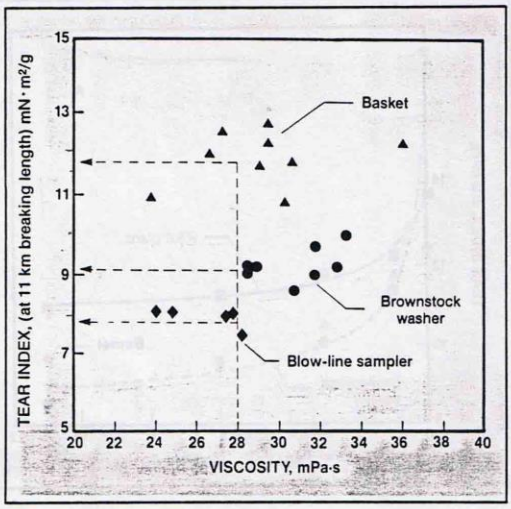
changes in pulp viscosity. Hence, the differences in the mechanical strengths of these pulps were not a consequence of chemical experience. Instead, the physical forces suffered by the fibers on their way to the sampling points produced the strength differences, after the chemistry had been completed.

Because the physical strength of unbleached pilot-plant kraft pulp varies with kappa number (*5*), we analyzed the mill data for the same effect. Figure 6 shows the tear indexes at constant breaking length vs. kappa number. Although some scatter was apparent, the three locations of sampling were again distinct. In addition, the tear-tensile

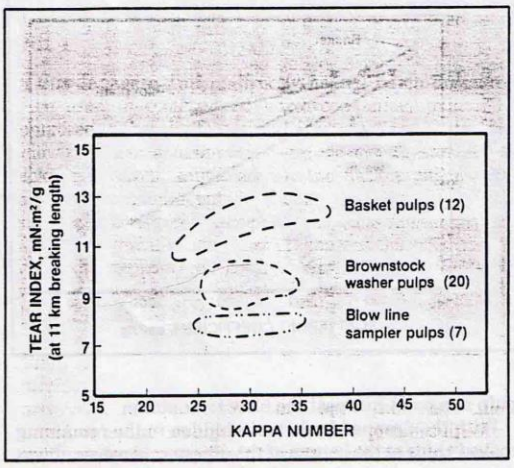
4. Normalized to the strongest mill-made pulp (i.e., from the basket), the pulps sampled at two other locations downstream from the digester were always weaker and were also different from each other. Twelve basket experiments in a single mill provided these results.



5. The viscosities of the unbleached pulps from the various sampling locations did not correlate with their tear-tensile strengths. Thus, the strength differences between the basket, washer, and blow-line pulps were based on physical, rather than chemical, experience.



6. Across a range of kappa numbers, basket pulps were always stronger than washer pulps, which in turn were stronger than blow-line pulps.



strengths of the basket pulps declined as their kappa numbers decreased. The strengths of the brownstock washer pulps and the blow-line pulps showed little variation across their kappa number ranges. In an earlier report (*5*), we demonstrated that only at kappa numbers below approximately 25 or above approximately 40 did strength drop appreciably in pilot-scale kraft pulps from spruce.

Mill 2

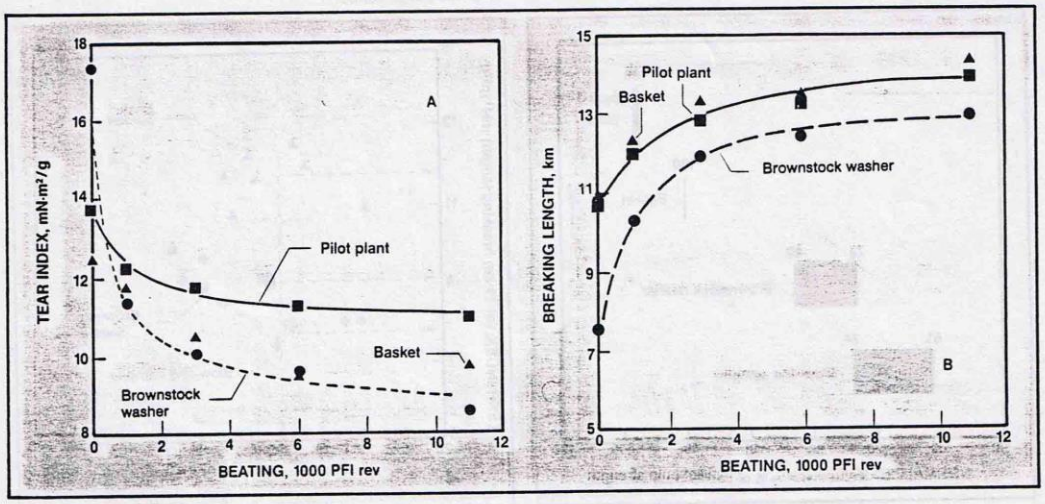
The foregoing results were all obtained in Mill 1, which was running on a chip furnish of spruce and balsam fir. To broaden the scope of the basket experiments, we conducted similar work on a contract basis in Mill 2, a mill cooking western red cedar in indirectly heated batch digesters. The experimental procedures were like those reported earlier (*4*): baskets were hung at mid-height in a 173-m^3 digester during otherwise normal pulping operations, and the basket pulps were compared with the corresponding mill and pilot-plant pulps made from the mill's chips. No blow-line sampler was available.

Using plots of tear strength vs. breaking length for the primary comparisons of pulp strength, we found that Mill 2's unbleached pulps averaged 76% of the strength of the pilot-plant pulps. The basket pulps, however, were at the 91% strength level. As in Mill 1, the conclusion was obvious: a large pulp strength loss was incurred as the cooked chips were blown from the digester to the blow tank. Two further conclusions were now apparent. First, fiber damage during blowing was due to the equipment and process, not to the softwood species. Second, the never-blown basket pulps were equally strong inside the directly steamed digester of Mill 1 and the indirectly steamed digester of Mill 2.

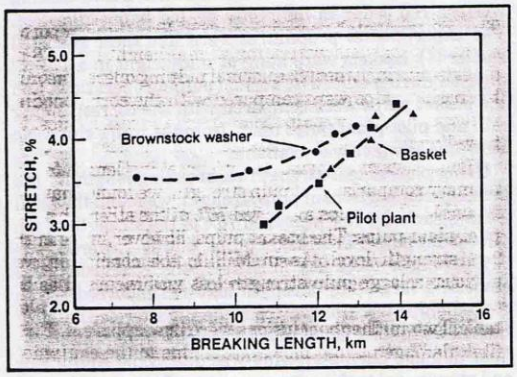
To separate tearing resistance from tensile strength, we plotted these individual properties of the cedar pulps against progressive beating in a PFI mill (Figs. 7A and 7B). In Elmendorf tear strength, the unbleached mill pulp appeared to start at a comparatively high level, but with minimal beating (approx. 500 revolutions) it fell below the strength of the pilot-plant pulp and finished with a deficit of about 15%. The basket pulp was intermediate in performance. In breaking length, the unbeaten pilot-plant pulps and basket pulps were about 10% stronger than the mill pulp. This difference remained constant across the entire beating range.

Our pulp strength comparisons are by no means limited to tear-tensile relationships (*2*). Figures 8 and 9, for

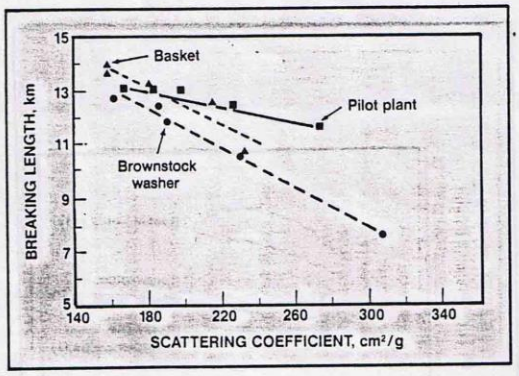
7. When tear and breaking length values were plotted separately against PFI revolutions, the blown mill pulp was weaker than the pilot-plant pulp in tear strength (**A**) and in tensile strength (**B**). The basket pulp was weaker than the pilot-plant pulp in tear strength but similar in tensile strength.



8. Before beating, the brownstock washer pulp had more stretch than the unblown pulps; the difference decreased as the pulps were beaten.



9. At a given scattering coefficient, blown mill pulp had lower tensile strength than unblown basket pulp or pilot-plant pulp. The greater the extent of beating, the narrower the gap became.



example, illustrate other data. The blown pulp of Mill 2 had higher stretch values than the basket pulps and pilot-plant pulps, and it had poorer tensile strength at any given level of light scattering (or degree of bonding).

Mill 3

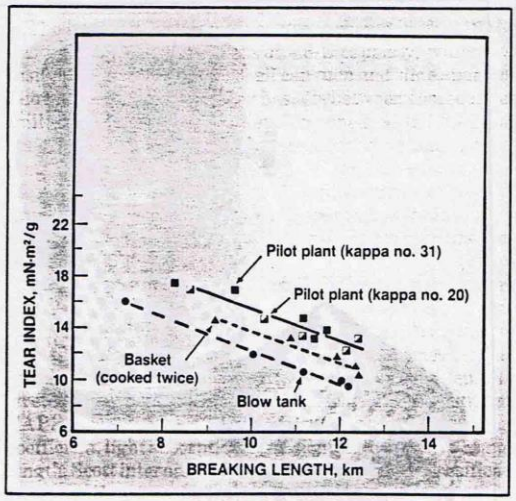
This kraft mill uses indirectly heated batch digesters to convert mixed-species softwoods into bleachable-grade pulp. We conducted only one basket experiment there, and it was not totally successful—the basket fell from its hanging point during chip filling! There was no choice but to finish filling the digester and cook the contents in a normal fashion. At the end of cooking, a conventional blow was attempted, and more than 80% of the cooked material was indeed blown from the vessel. We sampled this blown pulp at a point just past the blow tank pump.

With the dropped basket still hidden in the remaining cooked chips at the bottom of the digester, however, it was necessary to do another cook, this time with the digester only one-quarter full. At the completion of this second cook, the digester blew cleanly, and the basket was fished out of the bottom of the vessel. When its twice-cooked pulp was processed and tested, some rather remarkable results were obtained.

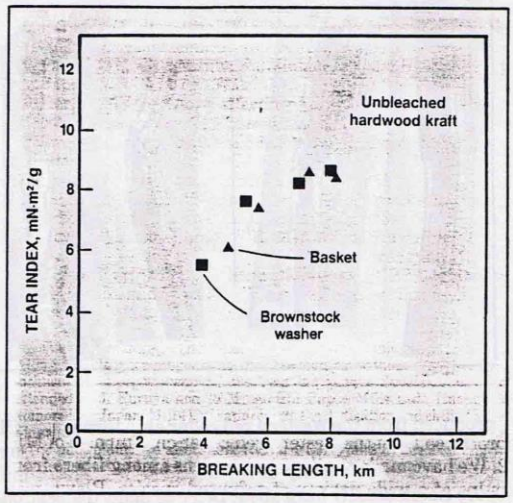
As expected, the basket pulp's kappa number (20.5) and viscosity (20.5 mPa·s) were considerably lower than normal. Nevertheless, the tear-tensile strength of the basket pulp was 89% of that of the pilot-plant pulp, whereas the blow tank pulp was at the 79% level (Fig. 10).

Was this just a random result? Experimentally, yes. But the fact that twice-cooked never-blown pulp was still

10. Twice-cooked basket pulp was weaker than either conventional (kappa no. 31) or deliberately overcooked (kappa no. 20) pilot-plant pulps, but it remained stronger than once-cooked pulp from the blow tank. (For convenience in this case, blown pulp was sampled just past the blow tank rather than at the washers).



11. Basket and brownstock washer pulps were found to be equivalent in strength in this Japanese kraft mill. In contrast to softwoods, fully cooked chips from short-fibered hardwoods are not damaged during blowing.



within 11% of its strength potential fits with all the other basket results: fully cooked pulp inside digesters is close to the strongest it can be in conventional kraft cooking, and blowing weakens it by a significant amount.

Mill 4

In this Japanese mill, indirectly heated batch digesters were used to cook mixed hardwood chips, primarily composed of beech. Two small baskets were hung, one below the other, at about mid-height in the digester. After cooking to about kappa no. 17, the basket pulps were individually disintegrated, washed, and tested. Corresponding brownstock washer pulp served as the reference.

The tear-tensile data (Fig. 11) showed that the basket and washer pulps were alike. This similarity was also valid over a range of other physical properties. In other words, blowing produced no change in this case.

Although different from the results in the softwood mills, the outcome of the hardwood experiments was anticipated. We had already found that in Canadian hardwood kraft mills processing short-fibered species, there was no strength gap between blown mill pulps and their unblown pilot-plant counterparts (*2*). The basket experiments in Mill 4 simply confirmed that pulp strength was the same before and after blowing fully cooked hardwood chips.

Other basket cases

More recently, we have done basket experiments in a kraft linerboard basestock operation and also at a sulfite bleachable-grade mill. Results are not yet available from these studies, but the experimental work was designed to broaden the scope of our studies beyond batch kraft mills making only bleachable-grade pulps.

The implications of this basket work are not confined to the batch digester mills in which the work was performed. Never-blown pulp from the worst location inside a directly steamed batch digester (*4*) or that from a twice-cooked basket is considerably stronger than blown mill pulp; unblown pulp inside a continuous digester should be at least as good as basket pulp.

In fact, this was the focus of work three decades ago (*6*), which showed that pulp removed from a continuous digester via a specially designed sampling device had tear-tensile strength equal to that of its corresponding laboratory reference pulp. Thus, the information obtained from basket experiments in batch digesters also has meaning in continuous digester operations.

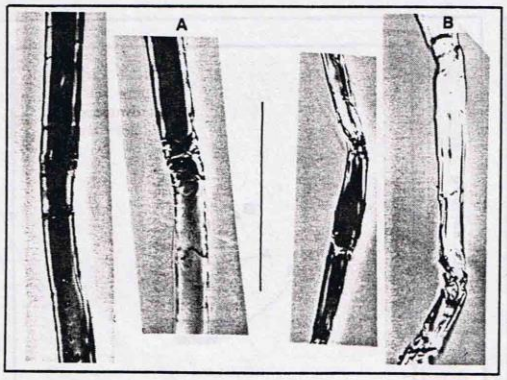
Fiber morphology

To gain further insight into the effects of blow-line flow on the fibers themselves, we examined the unbeaten fibers in a polarized light microscope. We looked at fibers from pilot-plant pulps, basket pulps, and blown mill pulps. Various wood species were represented among the samples, which were collected at mills across Canada.

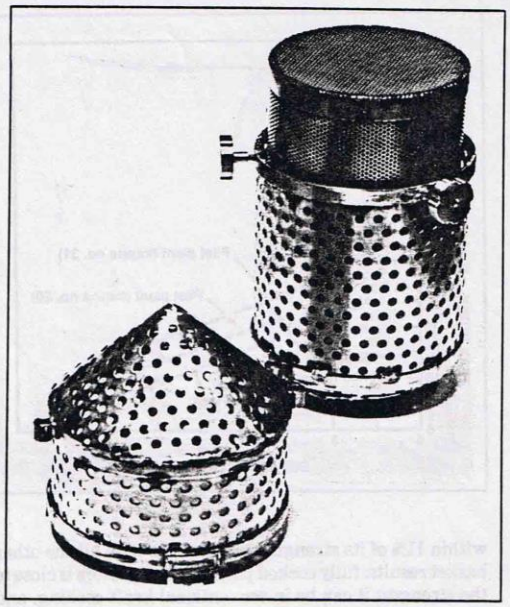
Figure 12 illustrates the general observations we made. The fibers from the pilot-plant pulp are relatively straight and have frequent dislocations along their lengths. These dislocations are not gross defects, and they cause no changes in the direction of the fiber axis. Fibers from the blown mill pulp have been stressed much more severely. They often exhibit gross defects, some of which are accompanied by significant changes in fiber axis. As the photographic insets show, the most severe defects in the blown fiber are characterized by a dramatic narrowing of the fiber and considerable cell wall damage. Such dislocations could easily become failure points in paper webs made from them, as suggested by Forgacs (*7*) and by Page *et al.* (*8*).

The fibers in Fig. 12 are latewood fibers in pulps

12. Unblown pilot-plant fibers (**A**) are characterized by relatively mild cell wall dislocations. Blown mill fibers (**B**) have more frequent dislocations, some of which are much more severe. Points of cell wall collapse (**B**) are typical of blown fibers, but are not found in the fibers from basket or pilot-plant pulps.



13. The design of this hanging basket allows for quick changes of the two inner baskets that contain the chips. The overall volume is about 15 L.



produced from the western red cedar chip furnish of Mill 2. We have made similar observations among fibers from pulps of a wide variety of softwood species. Blown mill pulp fibers usually have about twice as many dislocations as the fibers in unblown pulps. Up to half of the severe dislocations in the blown fibers exhibit collapse of the cell wall (Fig. 12A). The feature is frequently observed in fibers from blown mill pulps but is not found in unblown fibers.

Although these observations are purely descriptive, they demonstrate the effect of blow-line flow conditions and suggest why mill-made fibers are inferior in physical performance once they are made into paper.

Blow-line flow

If blow-line flow damages fibers so severely, what can we do about it? While it is necessary to transport the cooked material from the digester to the (unpressurized) fiber line of the mill, what changes might decrease or eliminate the incidence of fiber damage?

Temperature of discharge, alone, is probably not the controlling factor in either batch operations or continuous ones (*9*). It may help to have a lower temperature of discharge from a continuous digester (*6, 10*) or a batch digester (*11*). But even at discharge temperatures below 100°C, as in almost all of the continuous digester cases in Fig. 3, we still find that mill-made pulps are weaker than their pilot-plant counterparts.

The change in pressure from that inside a digester to atmospheric pressure at a blow tank or a diffusion washer is not the sole explanation either. Batch digesters are discharged at lower internal pressure than are continuous digesters, but this difference does not result in uniformly stronger batch pulps.

Although there may be some critical factors among the many involved in blow-line flow, the state of knowledge in describing fiber and fluid flow at such extreme conditions is not sufficiently advanced to identify them. The geometry of the blowing system may be important, but it doesn't provide the complete answer either (*12*). The accelerative effect of a blow valve or flow control valve, usually the smallest constriction in a blow line, can be substantial, as we have found by doing material and energy balances around a well-defined system comprising a digester, a blow line, and a blow tank. Yet such calculations are replete with assumptions about the exact consistency of the fiber suspension, the flashing of steam, frictional behavior of pulp suspensions in black liquor at high temperature, and so forth.

To solve the problem of fiber damage during blowing, we should first understand exactly which factors (including interactive ones) are important. This is an objective in our on-going work.

Conclusions

Never-blown "basket" pulps from kraft batch digesters processing softwoods are considerably stronger than the corresponding pulps blown from these digesters. This generality holds true across a range of softwood species and is not affected by whether the digester is heated directly or indirectly.

The pulp inside many continuous digesters is probably also much stronger than the pulp which reaches the washers. The chemistry of cooking is generally satisfactory, but the physics of blowing is not. The strength loss problem caused by blowing will be solved only by finding an appropriate means to transport cooked material out of digesters at the end of kraft pulping.

Experimental equipment and procedures

The chip and pulp sampling techniques used in this work

were described elsewhere (*2, 4, 13*) and are also available from the authors as an electronic storyboard disk which runs on IBM and compatible microcomputers. The specific procedure for basket experiments in mill digesters is given elsewhere (*4*).

The hanging basket we now use is shown in Fig. 13. It has two inner baskets, each of 4.6-L capacity, which fit inside the outer shell. The shell can turn and slide apart to allow quick changes of inner baskets between consecutive mill cooks. The inner baskets are lined with 100-mesh stainless steel wire. The entire assembly, when loaded with chips to be cooked, is suspended in the digester from a high-tensile stainless steel cable which runs completely around the shell through cable guides welded to it.

Pulp samples were chlorite-delignified before viscosities were measured.

Beating was done in a PFI mill. Unbeaten and beaten pulps were made into standard handsheets and tested according to CPPA-Technical Section or TAPPI methods. These tests included: Canadian Standard Freeness, basis weight, bulk, tear index, burst index, breaking length, stretch, toughness index, MIT double folds, ISO brightness, TAPPI opacity (10-FMY/C), porosity, light scattering coefficient, light absorption coefficient, zero-span breaking length, Scott internal bond, Bauer-McNett fiber classification, and fiber length determination (Kajaani FS-100).

Literature cited

1. Blume, W.M., Tappi 37(12): 145A(1954).
2. MacLeod, J.M., Pulp Paper Can., 88(9): 103(1987).
3. MacLeod, J.M., Tappi J. 70(7): 135(1987).
4. MacLeod, J.M., Cyr, M., Embley, D., and Savage, P., J. Pulp Paper Sci., 13(3): J87(1987).
5. MacLeod, J.M., Pulp Paper Can. 81(12): 128(1980).
6. Annergren, G.E., Ohrn, O.E., and Rydholm, S.A., Svensk Papperstid. 66(4): 110(1963).
7. Forgacs, O., Structural Weaknesses in Softwood Pulp Tracheids, Paprican Technical Report 216, Dec. 1960.
8. Page, D.H., El-Hosseiny, F., Winkler, K., and Bain, R., Pulp Paper Can. 73(8): 72(1972).
9. Horng, A.J., Factors affecting pulp quality from Kamyr continuous digesters, Proceedings of the 1985 Spring Conference, CPPA-Technical Section Pacific Coast and Western Branches, Harrison Hot Springs, B.C.
10. Knutsson, T. and Stockman, L., Tappi 41(11): 704(1958).
11. Sainiemi, J. and Hiljanen, S., 1986 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 643.
12. Horng, A.J. and Forde, W.E. Method used to define performance efficiency of mill digesters for pulp strength retention, Proceedings of the 1984 Spring Conference, CPPA-Technical Section Pacific Coast and Western Branches, Jasper, Alta.
13. MacLeod, J.M., Pulp Paper Can. 87(1): 76(1986).

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