High-shear laboratory beating and fiber-quality testing offer new insights into pulp evaluation

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ABSTRACT: The conventional laboratory method of beating pulp samples in a PFI mill subjects the pulps to much milder shear conditions than exist in a commercial refiner. The results presented in this report suggest that a high-shear laboratory beater—the Kady mill—may prove helpful in assessing the likely performance of pulps in commercial systems.

KEYWORDS: Beating, evaluation, fibers, PFI mills, pulps, quality, refining, test methods.

Mills conventionally evaluate pulp by examining changes in the physical properties (tensile strength, tear index, burst strength) of laboratory handsheets produced from pulps beaten for different periods of time in a PFI mill. This is a time-honored procedure, but how well does the response of laboratory handsheets to PFI-mill beating predict the relative response of pulps to commercial refining and papermaking? An alternative laboratory method—Pulmac fiber-quality testing—brings new perspectives to this question.

Laboratory beating vs. commercial refining

In a previous paper,* the tensile strength (breaking length, measured in kilometers) and tear index (measured in milliNewton·square meters per gram) of conventionally prepared PFI handsheets were assessed in relation to the Pulmac fiber-quality numbers obtained from the same handsheets. The characteristic responses of the fiber-quality numbers to laboratory beating in a PFI mill are reproduced in **Fig. 1** for three bleached-kraft softwood pulps. The fiber-quality numbers are defined in **Table I**.

Commercial refining is readily characterized in respect to its effect on fiber-quality numbers simply by comparing the refined pulp with the unrefined pulp, i.e., the starting point (unbeaten) with the end point (after refining). An appropriate means of comparing commercial data with laboratory beating is to examine the percentage change in the FS and L numbers as a function of the percentage change in the B number. The laboratory PFI-mill data in Fig. 1 have been reframed in this manner in **Figs. 2 and 3**, which shows the changes in FS number and L number, respectively. Results from a number of unconnected refiner studies are superimposed on these graphs, with shaded squares representing northern bleached-kraft softwood pulps and plain squares representing southern bleached-kraft softwood pulps.

Clearly, commercial refining at the same percentage increase in the B number yields pulps that show quite different FS and L responses for a wide range of different softwood pulps at different commercial locations. Commercial refining of northern bleached-kraft softwood pulps typically did not produce the net increase in either the FS or L numbers that was characteristically achieved by PFI-mill treatment. Southern bleached-kraft pulps acted similarly, although the changes in the L number induced by commercial refining did not differ quite so dramatically from the PFI-mill results.

These results raise two important questions. Why do pulp fibers respond so differently to commercial

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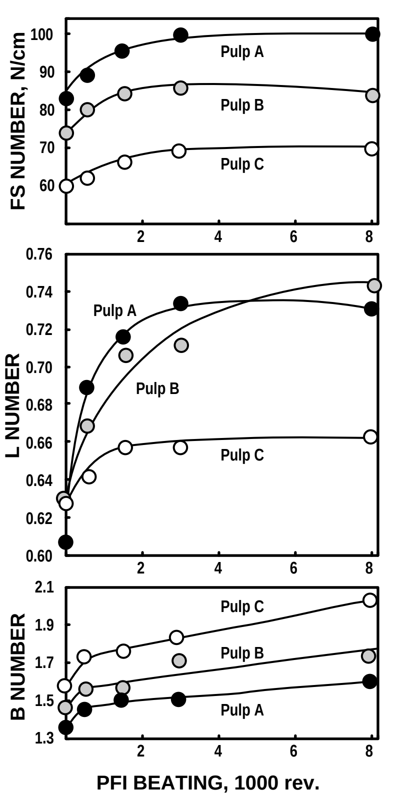
*Cowan, W. F., *Tappi J.* 78(1): 101(1995).

1. FS, L, and B numbers as a function of PFI beating for three bleached-kraft softwood pulps. Pulps A and B are northern species; Pulp C is a southern species.



I. Definitions of fiber-quality numbers

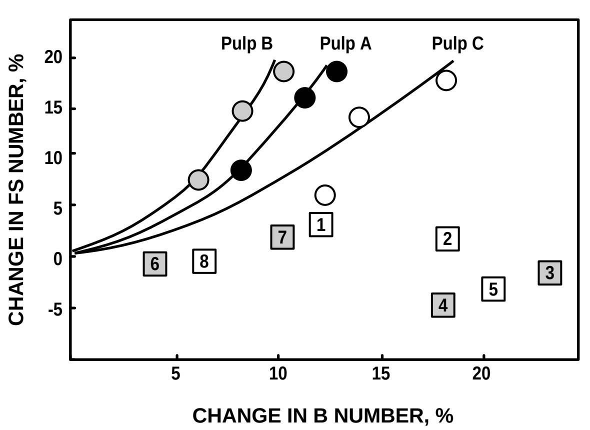
FS number (fiber strength)	Wet zero-span tensile strength corrected to 60 g/m², N/cm
L number (fiber length)	Ratio of wet 0.4-mm-span strength to wet zero-span strength
B number (fiber bonding)	Ratio of dry to wet 0.4-mm-span tensile strength

II. Changes in FS and L numbers (relative to unbeaten pulp) after 100% beating energy*

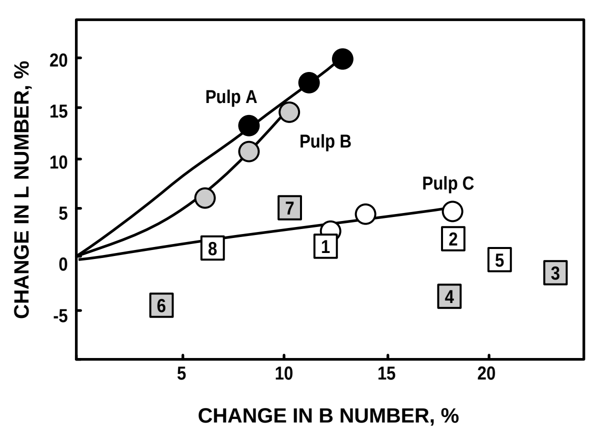
		Kady mill	
	PFI mill	*Low shear*	*High shear*
FS number			
Pulp A (northern softwood)	12.0%	9.0%	0.0%
Pulp B (northern softwood)	7.0%	10.0%	–4.0%
Pulp C (southern softwood)	14.0%	7.5%	–6.5%
L number			
Pulp A (northern softwood)	12.5%	12.5%	13.0%
Pulp B (northern softwood)	13.0%	7.0%	7.0%
Pulp C (southern softwood)	2.5%	2.5%	–6.0%

* 100% beating energy represents about 1 hour in the PFI mill and 8 min in the Kady mill

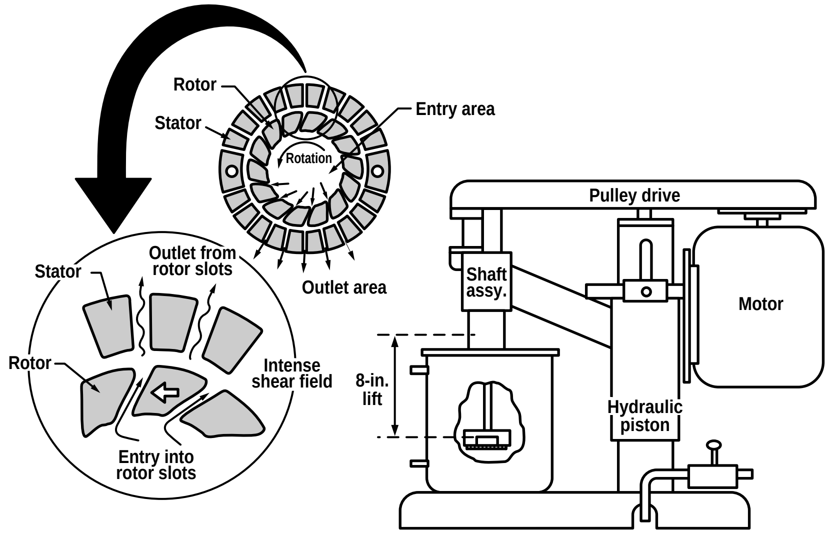
2. FS-number response for PFI laboratory beating (Pulps A, B, C) and commercial refining (squares 1–8) of bleached-kraft softwood pulps. Northern species: shaded squares and Pulps A and B; southern species: plain squares and Pulp C.



3. L-number response for PFI laboratory beating (Pulps A, B, C) and commercial refining (squares 1–8) of bleached-kraft softwood pulps. Northern species: shaded squares and Pulps A and B; southern species: plain squares and Pulp C.



4. Kady-mill laboratory beater



refining compared with PFI laboratory beating? What significance might this have in respect to using PFI-handsheet data to predict commercial performance?

The Kady-mill beater

One obvious difference between commercial refining and laboratory beating in a PFI mill is the much greater energy input to the commercial refiner. Consequently, the shear stresses applied by the commercial refiner are also much higher. Our work with a new type of laboratory beater, the Pulmac Kady-mill beater, gave us the opportunity to explore the significance of shear stress in determining fiber behavior during beating.

The Kady-mill beater is a modification of a dispersion unit that is conventionally used to disperse pigments and particles in the paint, coatings, and food industries. The Kady mill produces very high shear rates with a high-speed rotor, which pumps material across a narrow gap and through channels in a surrounding stator, as illustrated in **Fig. 4**. The rotor is easily changed, and the gap between rotor and stator can be varied by using rotors of different diameters, thus allowing the intensity of the shear field to be altered over a wide range.

Pulps in the Kady mill are beaten at relatively low consistencies (ca. 0.5%) for periods up to 10 min. The resulting pulps are processed through the PQ system to characterize fiber FS, L, and B numbers. Two different rotors are typically used to observe the effect of a moderate shear treatment (shear gap of 3.18 mm) and a very high shear treatment (shear gap of 0.45 mm). The high shear intensity is approximately 10 times that of the low shear value.

Characteristic Kady-mill profiles and their meaning

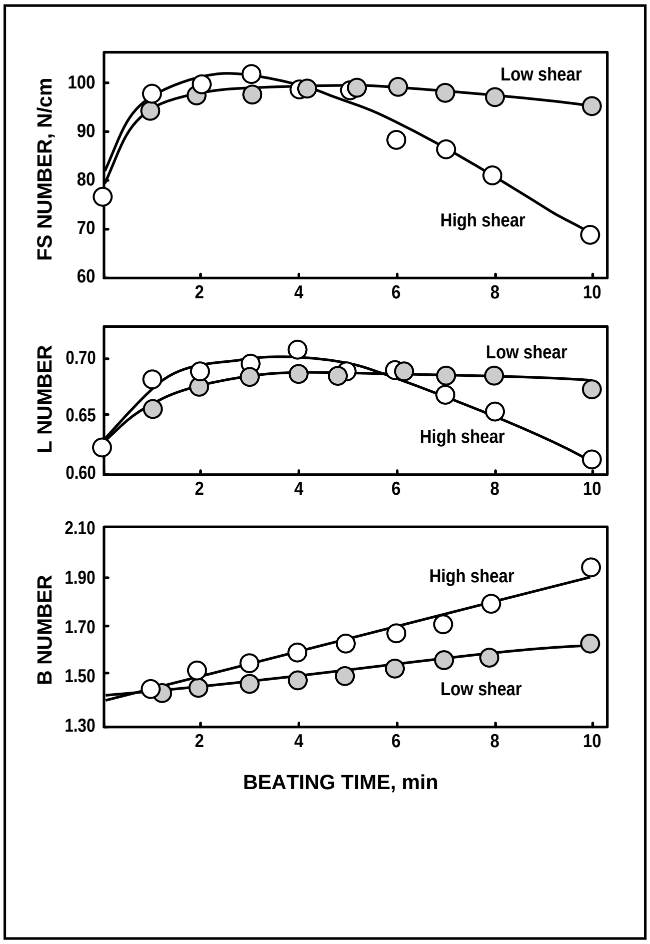
A typical Kady-mill fiber-quality profile for a bleached-kraft softwood pulp is shown in **Fig. 5**. The pulp's response to low- and high-shear Kady-mill treatment is markedly different. The low-shear profiles resemble the PFI-mill profiles shown in Fig. 1. In contrast, the high-shear treatment produced a rapid rise in the FS and L values, followed by a marked decline in both parameters.

The explanation for this decline is that, at some point, high-shear treatment begins to break fibrils away from the parent fibers, producing fines, which causes the FS number to decline. (The wet zero-span test cannot clamp fines, so the test value declines in direct proportion to the increase in fines content.) High-shear treatment also causes fiber fracture, as evidenced by a decline in the L number. The B number for high-shear treatment also shows a linear increase with beating, but the slope of the line is greater, reflecting the higher B number required to bond increasing quantities of fines and shortened fibers.

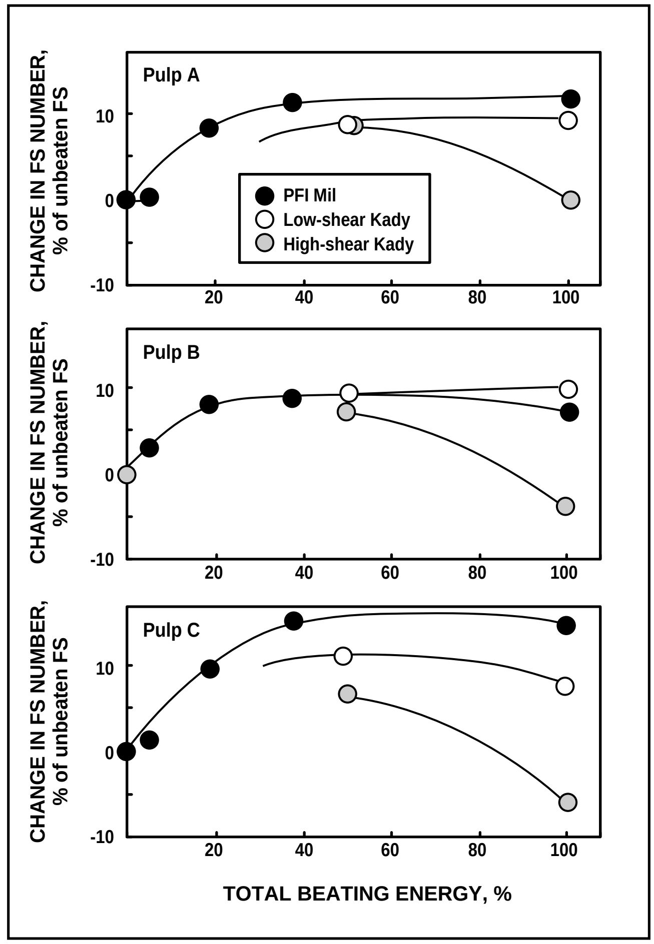
High-shear Kady-mill beating thus reveals beating/refining as a competition between the beneficial effects of fiber swelling and the deleterious effects of fiber breakdown. Fiber swelling increases the load-bearing capability of the fiber (increases the FS number) and promotes dekinking and decurling, thus enhancing its effective length (increases the L number). Fiber breakdown produces fines (reducing the FS number) and induces fiber fracture (reducing the L number).

This picture of the beating process explains the FS and L response of the commercially refined pulps, as illustrated in Figs. 2 and 3. The fact

5. FS, L, and B numbers as functions of beating time in a Kady mill at high and low shear for a bleached-kraft softwood pulp



6. Effect of PFI- and Kady-mill beating on FS number for three bleached-kraft softwood pulps. Beating energy of 100% represents about 1 hour (8000 revs) in a PFI mill and 8 min in the Kady mill.



that they typically lie well below the levels observed for PFI-mill treatment suggests the importance of fiber breakdown in commercial refiners. It also suggests that an important quality characteristic of a commercial pulp might well be its resistance to fiber breakdown.

Comparison of PFI- and Kady-mill treatment of the same pulps

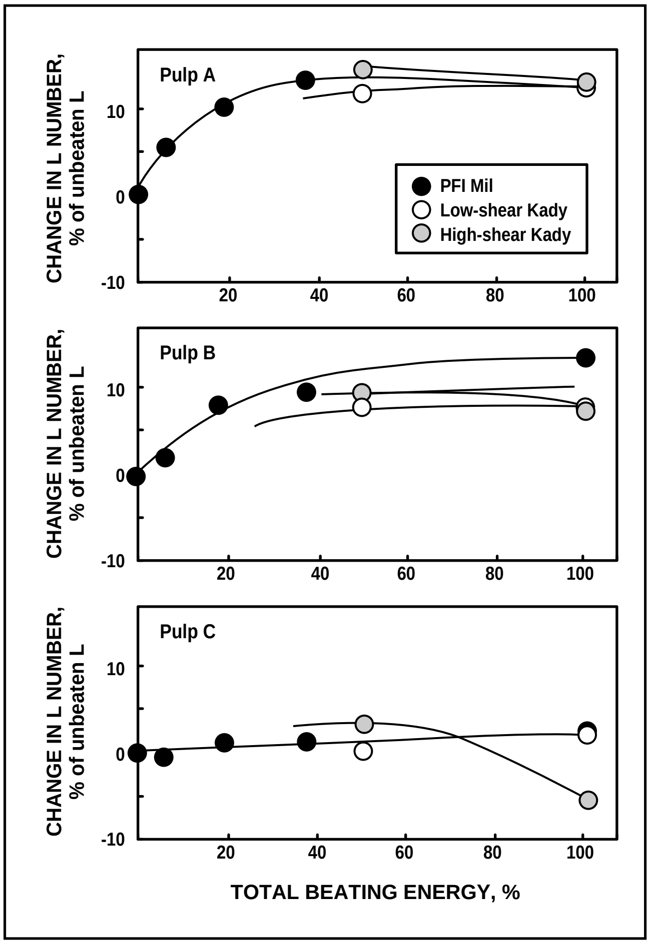
The three bleached-kraft softwood pulps whose PFI fiber-quality numbers are reported in Fig. 1 were also tested in the Kady mill. The comparative profiles for the FS, L, and B numbers are shown in **Figs. 6–8**, respectively, with the fiber-quality parameters expressed in terms of their relative change from zero beating. The results are shown in relation to beating time, expressed as a percent of the maximum beating time. In the case of the PFI-mill data, this was 8000 revs (approximately 1 hour). For the Kady mill, it was 8 min.

Table II shows the changes in FS and L numbers after 100% beating energy compared with the FS and L numbers of the unbeaten pulps. The changes in the FS value for high-shear Kady-mill treatment are zero or negative, indicative of fiber breakdown. The results at high shear are in contrast to the substantially positive values for both PFI-mill treatment and low-shear Kady-mill treatment. The extent of this fiber breakdown under high-shear Kady-mill treatment differs for the three pulps, indicating that they probably differ in respect to their resistance to fiber breakdown.

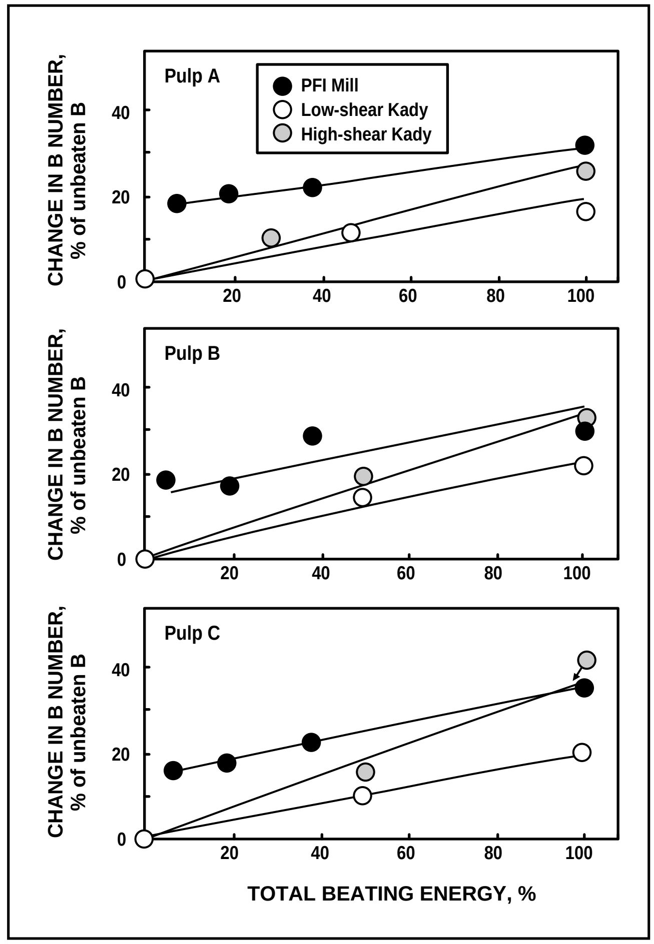
The L-number profiles (Fig. 7) do not show as sharp a distinction between the high- and low-shear beating processes, but they too reflect differences among pulps subjected to high-shear beating. Indeed, the L-number results in Table II mirror the FS results, which suggest that Pulp A is the most resistant to fiber breakdown, while Pulp C is the least resistant.

The B-number profiles (Fig. 8) indicate that the PFI-mill and the low-shear Kady-mill pulps exhibit about the same slope for the linear growth in B number, while the high-shear Kady-mill pulps show a

7. Effect of PFI- and Kady-mill beating on L number for three bleached-kraft softwood pulps. Beating energy of 100% represents about 1 hour (8000 revs) in a PFI mill and 8 min in the Kady mill.



8. Effect of PFI- and Kady-mill beating on B number for three bleached-kraft softwood pulps. Beating energy of 100% represents about 1 hour (8000 revs) in a PFI mill and 8 min in the Kady mill.



greater slope. The increase in slope reflects the increase in B number as pulp fibers break down. The upward displacement of the PFI B-number profile relative to the Kady-mill profile reflects a particularly low B number for the unbeaten PFI pulp. The fiber-quality numbers for unbeaten pulps are very sensitive to the slurrying procedure. The PQ system standard (a 25-s, low-consistency, low-speed treatment in a modified Waring blender) differs from the normal TAPPI test method, which may account for the observed displacement.

Conclusion

Using Pulmac fiber-quality numbers as a benchmark, it is apparent that the relatively mild conditions in a laboratory PFI mill do not reflect what happens in commercial refiners. Fiber-quality results for pulps treated in a high-shear laboratory beater (Kady mill) suggest that the discrepancy between PFI results and commercial results is a consequence of fiber breakdown. It is posited that some degree of fiber breakdown is the norm when pulps are subjected to the harsh conditions of commercial refining. Further, the data presented in this study imply that different pulps exhibit different breakdown tendencies.

These results illustrate why PFI-handsheet data provide only a rough guide in assessing pulp performance. Previous work* demonstrated that the three Pulmac fiber-quality parameters (FS, L, B) provide a useful measure of pulp properties. The present work suggests that evaluation of pulp performance with Pulmac fiber-quality parameters in conjunction with the high-shear capability of the Kady laboratory mill provides a better view of pulp quality than the current laboratory procedures.

Future work will determine whether the proposed system improves the precision of predicting pulp performance in a commercial setting. TJ

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