

Fiber and toner detachment during repulping of mixed office waste containing photocopied and laser-printed paper

DONNA A. JOHNSON AND EDWARD V. THOMPSON

Hairy toner particles confound mixed office waste repulping and flotation.

Toner “inks” are widely used in office photocopiers and laser printers, and their use appears to be increasing as newer high-speed copiers and high-resolution printers come on the market. Toners are comprised principally of a thermoplastic polymer, either styrene-butadiene copolymer, acrylic polymer, or polyester, with added carbon black or a colored pigment, and sometimes iron oxide (magnetite) to render the toner magnetic. The original toner particles are typically about 20 microns in size for most machines, or 10 microns or less for high-resolution printers. During the copying process, the toner particles are laid down electrostatically on a paper sheet to form the desired characters. The paper sheet and toner are then subjected to elevated temperature and moderate pressure. Since the toner is a thermoplastic, the particles fuse under the influence of heat and pressure to form a continuous toner mass. The heat and pressure also act to strongly adhere the fused toner character to the paper sheet. The final copied or printed characters on the copy paper are rendered very stable, especially to physical abrasion and rubbing. The extreme tenacity with which the fused toner characters adhere to the paper substrate is obviously a desirable quality for the final copied sheet to possess. However, this very quality becomes a serious detriment if these copied sheets are subsequently to be recycled.

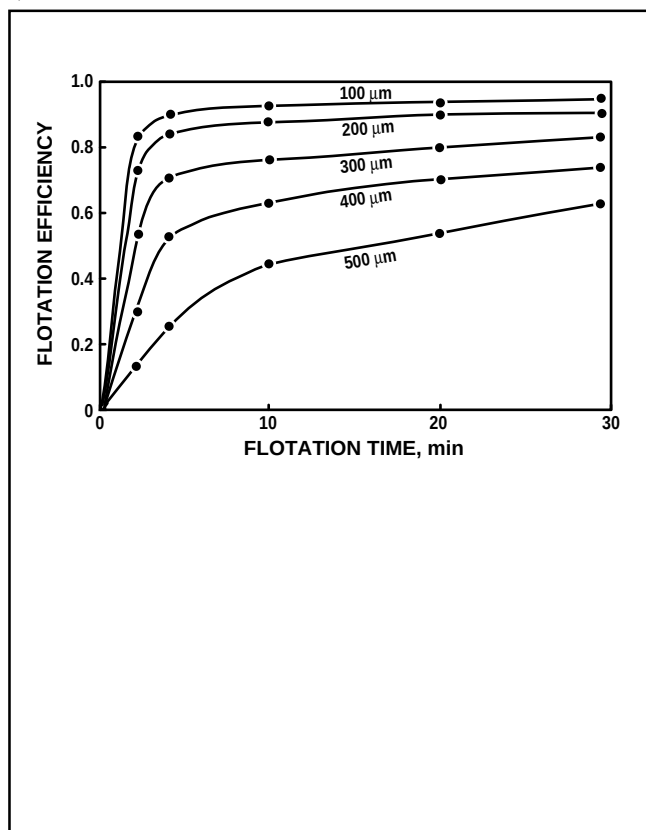
The process of recycling paper consists basically of two steps: first, the wood fibers that form the sheet web must be detached and separated not only from each other but also from all other substances on the sheet, including the so-called contaminants such as toner inks adhesive-based “stickies,” and latex-based coatings; second, the wood fibers must be separated from the contaminant particles into a pure stream so they can then be reused to make paper. It is perhaps ironic that the thermoplastic toners, so carefully engineered for photocopy and laser printer use and so integral and necessary a part of the final printed product, become contaminants during the recycling process.

The first step in the recycling process, the disintegration of the paper sheet, is a repulping process and is typically accomplished at high consistency using either a conically-shaped rotor or a rotating drum. The second step, the separation of the wood fibers from the contaminant particles, is accomplished using a number of unit operations including washing, flotation, cleaning, and screening. Good success has been achieved in recycling many grades of recovered paper including old newspapers, magazines, and old corrugated containers, but serious problems have been encountered in dealing with other grades, especially flexographically printed newsprint and the so-called mixed office waste stream. For the toner contaminant particles found in mixed office waste, flotation is believed to represent the best separation process, although there are many problems to overcome. In this article, we will describe a recently discovered phenomenon which appears to shed light on a major problem in the recycling of toner printed recovered paper and explains why flotation of toner particles is so difficult and inefficient.

How do toners repulp and float?

In two recent papers (1, 2), we have discussed the repulping of carefully standardized sheets of copy paper printed with specific photocopiers and laser printers, each with its specific type of toner. Although it is well known that printed toner characters break up during repulping into a broad distribution of particle sizes, the differences we observed between different toners and different printers were very striking. In related studies (3–7), we have investigated the rate of toner removal by flotation in both pilot plant and laboratory trials, being particularly interested in the influence of particle size on flotation efficiency. A typical result is shown in Fig. 1, where a very dramatic effect of particle size is seen. Although it is again well known that larger particle sizes are harder to float, these results begin to quantify the magnitude of the effect in a systematic way.

1. Flotation efficiency (fraction particles floated to those originally present) vs. time (2, 4, 10, 20, and 30 min) for five particle sizes as determined by image analysis. From a repulping and flotation trial of laser printed standard sheets in the University of Maine pilot plant (1, 2).



2. Microscopic examination for the presence of fiber-retaining (hairy) particles of a flotation feed sample after repulping. Numbers are percentages of total particles counted.

LEVEL OF ATTACHMENT	SIZE, μm			
	100-200	200-400	>400	
Clean (C)	28	7	0	35
Moderately hairy (M)	22	25	7	54
Very hairy (V)	2	6	3	11
	52	38	10	

Paralleling the experimental work described above, we have also been developing three theoretical models (8, 9) including a statistical, global model for predicting flotation efficiency (4–6). As part of the development of this global model, at one point we attempted to fit experimental rate data, such as that shown in Fig. 1, to the global model parameters (bubble–particle capture radius (4) and air bubble rate). In so doing, we were surprised to find that for any given, *single* particle size, a single value of the capture radius parameter yielded a completely inadequate fit, whereas two assigned values of capture radiuses yielded an excellent fit. This suggested to us that, for any given particle size, there appeared to be two kinds of particles, one kind that could be floated much more rapidly and efficiently than the other kind (5). This finding appeared to us to have important implications in toner particle flotation, and the search for an explanation to fit our two-particle hypothesis is described below.

Hairy particles?

In searching for a possible rationalization for our idea that a repulped feed stock consists of two kinds of particles, one kind more easily floatable than the other, we began examining toner particles microscopically. Almost immediately, it became ap-

parent that many toner particles, especially large ones, retained attached fibers after repulping. This is probably not surprising as the manufacturers of toners and printing machines have tried to produce a system in which the fused toner characters are strongly adhered to the paper substrate and not easily removed. Nevertheless, we now hypothesized that there did, indeed, exist two kinds of particles: those that detach cleanly from the paper fibers during the repulping process, which we denote “clean” particles, and those that do not detach cleanly and retain attached fibers, which we call “hairy” particles. Typically, a large percentage of toner particles over 100 microns in size are hairy, with virtually all over about 250 microns being hairy: particles under 100 microns in size tend to be clean, although small particles often are part of more complex tangles of fibers and particles (as will be illustrated a little later).

In our microscopic examination of toner particles, we typically classify the particles in two ways, by size (either three or four size categories) and by degree of hairiness. An example of such a classification is shown in Fig. 2. In this study, our standard sheet of characters was printed with a Hewlett Packard LaserJet III laser printer and repulped in a laboratory repulper at 8% consistency under standard operating conditions (5). The particles are examined in the original repulped slurry and never dried or altered in any way. A total of about 900 particles

3. Microscopic examination for the presence of fiber retaining (hairy) particles of a flotation feed sample after repulping and the floating accepts and rejects after two time intervals. Numbers are percentages of total particles counted.

Feed					10-s Accepts					60-s Accepts				
SIZE, μm					100–200 200–400 >400					100–200 200–400 >400				
Clean (C)	28	7	0	35	(C)	12	3	0	15	(C)	7	4	0	11
Moderately hairy (M)	22	25	7	54	(M)	17	33	13	63	(M)	16	20	8	44
Very hairy (V)	2	6	3	11	(V)	7	10	5	22	(V)	11	25	9	45
	52	38	10			36	46	18			34	49	17	
					0–10-s Rejects					30–60-s Rejects				
					100–200 200–400 >400					100–200 200–400 >400				
					(C)	53	10	2	65	(C)	12	2	0	14
					(M)	24	8	3	35	(M)	14	24	11	49
					(V)	0	0	0	0	(V)	10	18	9	37
						77	18	5			37	43	20	

were examined to establish Fig. 2, and while it might be argued the examination is subjective, the reproducibility of repeat countings is actually quite good. It is seen that a total of 35% of the toner particles over 100 microns in size are clean, while the remaining 65% are hairy, 54% being moderately hairy (one or two retained fibers) and 11% very hairy (three or more retained fibers). We note that only 7% of the particles over 200 microns are clean, and none over 400 microns in size.

Do hairy particles float?

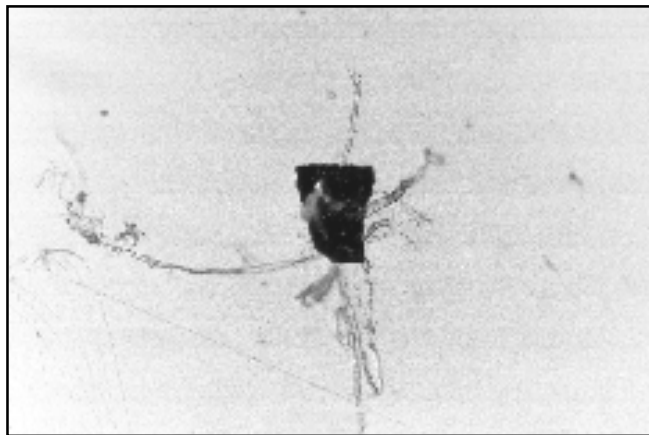
The flotation of polymeric contaminants, such as toner particles, works well if the particles are or can be made sufficiently hydrophobic to become attached to air bubbles and floated out in the froth phase (the so-called “rejects”), while the more hydrophilic cellulose wood fibers remain in the aqueous slurry phase (the “accepts”). The presence of hairy particles in flotation feed stock has, therefore, important implications. It is easy to imagine, for example, that the presence of retained fibers on a toner particle might render the particle more hydrophilic and, therefore, less floatable. Further, the presence of dangling fibers might also tend to mechanically impede the approach and attachment of a particle to an air bubble.

The repulped feed stock shown in Fig. 2 was floated in a laboratory Denver flotation machine, and the results of microscopic examination of accepts and rejects samples taken over two time intervals are shown in Fig. 3. (The feed is again shown for comparison.) While the feed contained 35% clean particles, the 0–10-second rejects sample contained 65%, a very large increase. Also, this rejects sample contained only 35% moderately hairy particles, compared to 54% in the feed, and no very hairy particles. On the other hand, the 10-second accepts sample contained only 15% clean particles, and this dropped to 11% at 60 seconds. Concurrently, hairy particles were being concentrated in the accepts, 85% after 10 seconds and 89% after 60 seconds.

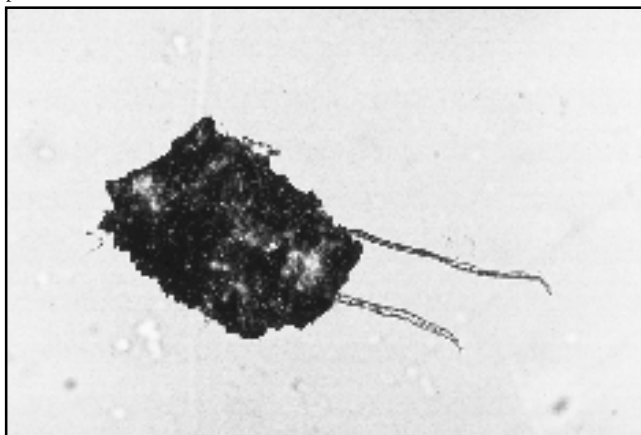
Our expectation that hairy particles are less floatable, compared to clean particles, appears to be borne out by the results shown in Fig. 3, and we have other examples with similar results that could be cited. Further, these results seem to corroborate our hypothesis concerning the use of two capture radii in fitting experimental laboratory and pilot-plant flotation rate data to the global mode. We associate the larger capture radius with the clean, more easily floatable particles and the smaller capture radius with the hairy, less easily or nonfloatable particles.

Recycling

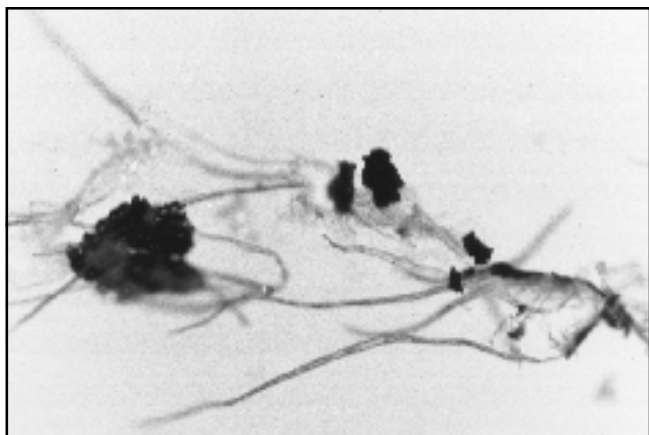
4. Hairy particle from Mill A production sample. Longest particle dimension, 250 microns; longest fiber length, about 700 microns.



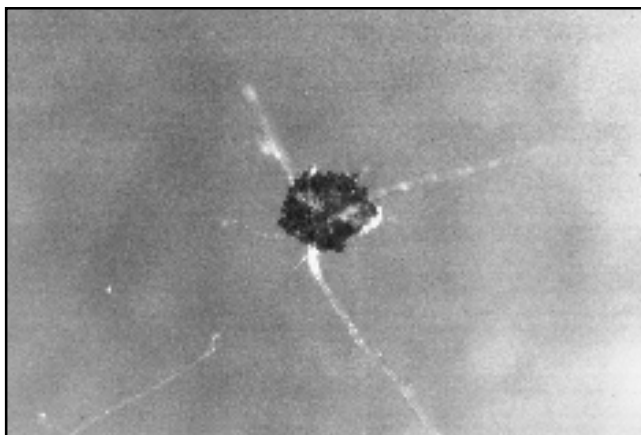
5. Hairy particle from Mill B production sample. Longest particle dimension, 600 microns. Note the fibers crossing over the particle surface. The texture and size of the particle suggest it came from a laser printer.



6. Entangled fiber and toner mass from Mill B production sample. Large particle (left) dimension, about 300 microns; smallest particle (right center) dimension, about 20–30 microns.



7. Hairy particle from large-scale pilot-plant trial using sorted white ledger, PP/SWL. Largest dimension, 250 microns. Note the fibers crossing over the particle surface and the one partially embedded in the lower left.



Are they in the mill?

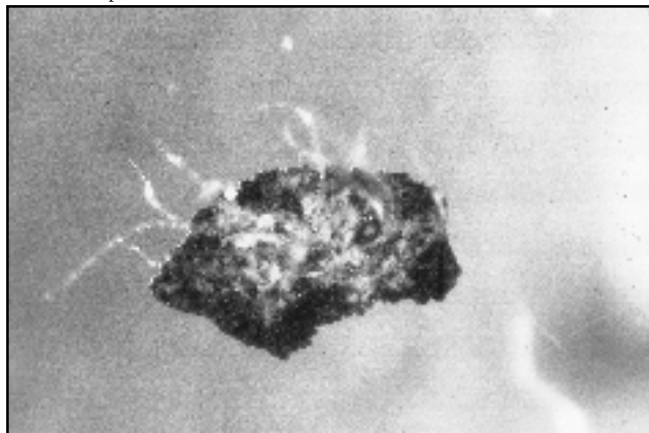
Until recently all of our microscopic examinations of toner particles have been from repulped samples produced by either laboratory repulpers (Dynapulper at 3% consistency or our home-made lab repulper at 8% consistency) or our pilot-plant Hydrapulper (rotor-type at a medium-high consistency of 12–13%). We have found hairy particles after repulping with all of these repulpers and for every furnish containing toner inks we have tried. Nevertheless, we have been concerned as to whether the occurrence of hairy particles is a widespread phenomenon found in large pilot-plant and mill situations or whether they are merely an artifact of our lab and plant repulpers.

To begin to answer this question, we have examined two mill samples. Both involved state-of-the-art high-consistency (17–18%) pulpers but of two very different design types. We will denote these mill samples as Mill A and Mill B. We further conducted a large-scale pilot-plant trial at a major, well known installation. The pilot-plant work included two trials at 15–

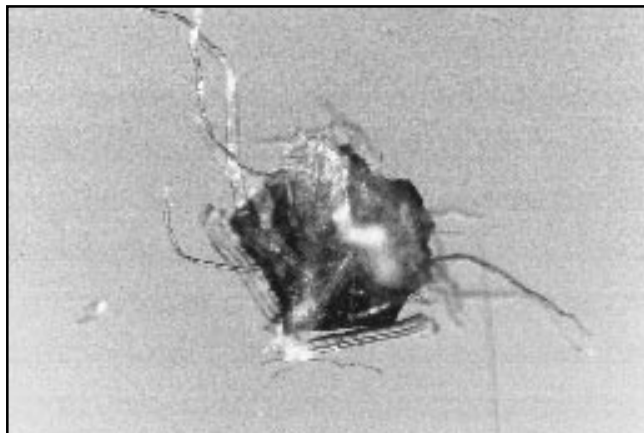
16% consistency using a rotor-type repulper. In each case, we repulped 1000 lb of paper; the first trial involved our standard printed sheets, including 30% Hewlett Packard LaserJet III and 30% Hewlett Packard LaserJet 4 laser printed copy paper and 40% offset ink printed paper; the second trial used a sorted white letter grade supplied by a broker. We denote the first trial PP/STD and the second PP/SWL. For comparison, we also include a sample of Hewlett/Packard LaserJet 4 standard printed sheets repulped in our University of Maine pilot-plant hydrapulper, which we denote UMO/STD.

The series of eight photographs shown in Figures 2 and 4–11 show typical hairy particles from the five types of samples described above. The particles were photographed in the original repulped fiber slurry after dilution and were never dried or otherwise altered. All five samples were found to yield a large number and wide range of both moderately and very hairy particles, and, although we have not yet performed detailed microscopic counting, all appear to yield more or less compa-

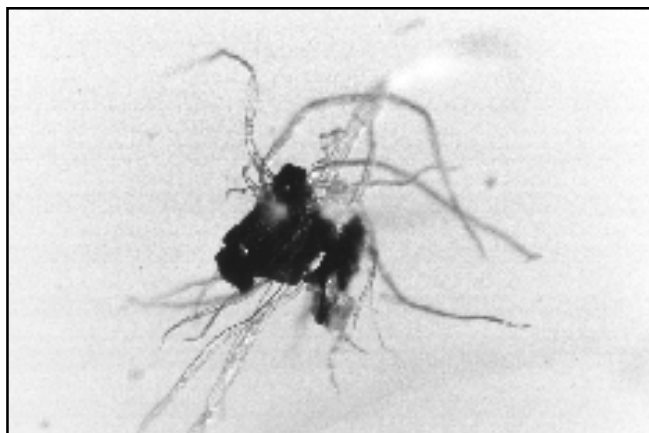
8. Hairy particle from large scale pilot plant trial using standard, laser printed sheets, PP/STD. Largest dimension, about 800 microns. Extremely large and very hairy particle, probably from the Hewlett Packard LaserJet III printer.



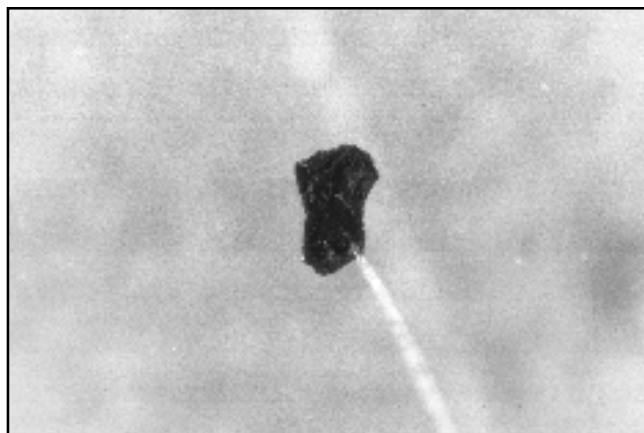
9. Hairy particle from PP/STD. Largest dimension, about 500 microns. Note the kinked fibers at the bottom and lower left.



10. Cluster of two (or three?) hairy particles from small-scale pilot-plant trial, UMO/STD. Largest dimension of large (left) particle, about 250 microns.



11. Hairy particle with a single fiber from UMO/STD



erable numbers of clean to moderately hairy to very hairy particles.

The hairy truth?

The photographs shown in Fig. 4 (Mill A) and Figs. 5 and 6 (Mill B) are typical of both mill samples. Very hairy particles like Fig. 5 are plentiful, and the entangled fiber-particle mass seen in Fig. 6 is relatively common, although more so in the Mill B sample. The large particle shown in Fig. 5 is of interest in that the dangling fibers can be traced across the surface of the toner.

The particle shown in Fig. 7 from PP/SWL is similar to that shown in Fig. 5 in that the dangling fibers can be traced across the toner surface. This example has the added interesting feature that the fiber, which enters the particle at about 2 o'clock and emerges at about 7 o'clock, is partially embedded in the toner itself over the left-hand side of the particle.

The two particles shown in Figs. 8 and 9 from the large-scale pilot-plant trial PP/STD are very large, being about 750 and 500 microns across, respectively. These particles were produced from sheets printed with either a Hewlett Packard LaserJet III or 4 laser printer, both of which we have found to repulp into a very broad distribution of particle sizes, including some very large particles (1). These very large particles are always extremely hairy.

The final two photographs, Figs. 10 and 11 (from our pilot plant, UMO/STD) show two extremes: a very hairy particle (Figure 10) and a particle with a single, although rather long, fiber (Figure 11). We also see a complete range of intermediate degrees of hairiness from our pilot-plant pulper.

What next?

The results of our examination of large-scale pilot-plant trial samples and two mill production samples appear to confirm

the existence of large numbers of repulped toner particles in sizes of about 100 microns or larger with undetached wood fibers, what we have called "hairy" particles, in every repulping setting from lab to mill. A key question that now follows is "What is the fate of these hairy particles as they proceed through subsequent unit operations after the repulper?" We need to look at the effects of deflaking or high-consistency dispersion, for example, on the attached fibers. Do the dangling ends break off, or are the entangled masses broken up, and if so, what is the final state of the particles and how much, if any, fiber do they now retain? Further, in what condition do the particles arrive at the flotation cell, and what is the efficiency of removal of the remaining hairy particles?

These are all questions we are presently investigating using both our controlled standard printed sheets and mill samples obtained from various points along the production process. We hope the answers to these questions will lead to a better understanding of the underlying mechanisms controlling laser toner deinking and help in designing unit operations more efficient in toner particle removal. ■

Literature cited

1. Vidotti, R. M., Johnson, D. A., and Thompson, E. V., *Progress in Paper Recycling* 2(4): 30(1993).
2. Vidotti, R. M., Johnson, D. A., and Thompson, E. V., *Progress in Paper Recycling* 3(3): 39(1994).
3. Vidotti, R. M., Johnson, D. A., and Thompson, E. V., *TAPPI 1992 Pulping Conference Proceedings*, TAPPI PRESS, Atlanta, p. 643.
4. Pan, R., Paulsen, F. G., Johnson, D. A., et al., *TAPPI 1993 Pulping Conference Proceedings*, TAPPI PRESS, Atlanta, p. 1155.
5. Pan, R., Paulsen, F. G., Kocer, H., et al., *TAPPI 1994 Recycling Symposium Notes*, TAPPI PRESS, Atlanta, p. 291.
6. Pan, R., Paulsen, F. G., Johnson, D. A., et al., "A Statistical, Engineering Model of Flotation: Model Predictions of Flotation Efficiency, and Confirming Experimental Studies," in *6th PTS Deinking Symposium Notes* (H. Grossmann and H. L. Baumgarten, Eds.), PTS Verlag, Munich, 1994.
7. Pan, R., Paulsen, F. G., Kocer, H., et al., *TAPPI 1994 Pulping Conference Proceedings*, TAPPI PRESS, Atlanta, p.1291.
8. Pan, R., Bousfield, D. W., and Thompson, E. V., *TAPPI 1992 Pulping Conference Proceedings*, TAPPI PRESS, Atlanta, p. 941.
9. Paulsen, F. G., Pan, R., Bousfield, D. W., et al., *Second Research Forum on Recycling Proceedings*, Canadian Pulp and Paper Association, Montreal, p. 1, 1993.

The work described in this article was performed as part of the activities of the Cooperative Recycle Fiber Studies Program, a research program within the Department of Chemical Engineering. This program is funded by a group of industrial sponsors, and we are most grateful both for their generous financial support and to the individual corporate representatives who meet with us three times a year as an Advisory Board. The corporate sponsors are Ahlstrom Kamyr, Inc., Beloit Corp., Black Clawson Co., Champion International Corp., Cross Pointe Paper Corp., Hansol Paper Co., Shell Development Co., Sunds Defibrator AB, and Weyerhaeuser Paper Co.

Johnson is research scientist with the Cooperative Recycle Fiber Studies Program, and Thompson is Pulp and Paper Foundation research professor of chemical engineering and director, Cooperative Recycle Fiber Studies Program, Department of Chemical Engineering, University of Maine, Orono, ME 04469.