Toner detachment during repulping of laser-printed office copy paper

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ABSTRACT

Specially prepared standard sheets of laser-printed office copy paper were repulped in a small laboratory pulper and in a large bench-scale pulper at consistencies of 3–9% and 6–18%, respectively. Results of both image analysis and visual microscopic examination are presented. In both sets of consistency trials, increasing consistency led to more small and fewer large toner particles. There was not, however, a corresponding change in the ratio of clean to hairy toner particles. These ratios were essentially unchanged for all size classes for the 6–18% consistency trials, although there was a significant increase in the 9% laboratory pulper trial.

Trials were also conducted at 12% consistency for three sets of conditions and compared with the baseline repulping: (a) with baseline and without added surfactant; (b) pH = 10 (baseline), pH unadjusted, and pH = 5.5; and (c) T = 40°C (baseline), T = 20°C, and T = 60°C. There was no discernible influence of surfactant and very little, if any, influence of pH. The temperature trials yielded the interesting result that lower temperature facilitated toner breakdown into smaller particles but did not produce better fiber/toner detachment; on the other hand, higher temperature facilitated fiber/toner detachment (well beyond any previous result) but did not enhance toner breakdown. These observations are discussed in terms of the brittleness of the toner at the lower temperature below its softening point compared with its leathery, tough properties at the higher temperature above its softening point.

Application:

Results suggest optimal toner breakdown is achieved at the highest practical repulping consistency, while fiber detachment from toner is little influenced by any operating conditions.

THE DEINKING AND RECYCLING OF mixed office waste (MOW) and the different grades, such as sorted white ledger, that fall into this category of the discarded paper stream have received considerable attention over the past 5–10 years. Numerous papers have appeared that discuss various aspects of the problems associated with recycling mixed office waste, including repulping *(1–3),* cleaning and screening *(4–7),* flotation *(8–14),* high-consistency dispersion *(15–19),* and process details such as the order of separation unit operations *(20–21).* By and large, these papers have been concerned with equipment and process details as opposed to fundamental research into the mechanisms that underlie and control individual unit operations. This is not to say, however, that progress has not been made in this latter area also, as in, for example, the fundamentals of flotation as applied to paper recycling or screening and cleaning technology. Still, much remains to be learned about both the basic mechanisms involved in individual deinking unit operations and the interactions of sequences of these unit operations.

This paper discusses the repulping of laser-printed office copy paper and the influence of repulping consistency on toner detachment. In another paper *(22),* we consider the high-consistency dispersion of these repulped samples and the influence of inefficient toner detachment on this unit operation. Before proceeding, however, it is instructive to first briefly consider the laser printing process.

The original toner is a thermoplastic polymer, typically a styrene-acrylate or styrene-butadiene copolymer or a polyester with a very narrow size distribution in the 8–20-µm range, depending on the type of toner. After being electrostatically attracted to the copy paper to form an image of the original, the toner is fused to the fiber web by application of heat and pressure. During the fusion step, the glass-transition temperature of the thermoplastic is greatly exceeded, and the toner particles flow together to form a homogeneous, solid mass that then reproduces the original character being copied. Equally importantly, during the fusion step, the toner mass becomes strongly attached to the fiber substrate, sometimes flowing around and beneath the fiber surface. The resulting printed copy is thus rendered very stable, especially to abrasion or casual rubbing. This feature is obviously a desirable property for the final copy to possess, but it may become a serious detriment from the recycling point of view.

We have recently discussed the question of detachment during repulping of laser-printed toner from photocopied and laser-printed office copy paper *(23–25).* During repulping, the toner masses are broken down into a wide range of particle sizes from 10–20 to several hundred microns or even larger, with large numbers of visible particles over 50–75 µm in size. Microscopic examination of the repulped toner particles has revealed that the repulping process is very inefficient in completely detaching the broken toner masses and particles from fibers, i.e., large numbers of toner particles retain fibers and are actually toner/fiber aggregates. This is especially true of particles larger than 50–100 μm in size; for particles over 250–300 μm in size, essentially 100% retain fibers, often in large numbers. We call toner particles that have retained fibers, i.e., toner/fiber aggregates, *hairy* particles, and distinguish them from *clean* particles, i.e., those that became completely detached during repulping and retain no trace of fibers.

To date we have examined repulped furnish from a variety of sources, including (a) our small laboratory repulper (65 g) at 8% consistency, (b) a large bench-scale repulper (4 lb) at 6–18% consistency, (c) the University of Maine Pulp and Paper Pilot Plant hydrapulper (90 lb) at 12% consistency, (d) two very large pilot plant trials (1000 lb) at 15% consistency, and (e) three mill samples at 17–19% consistency, including both rotor-type and drum pulpers. In all cases, we found mixtures of clean and hairy particles, with large hairy particles being abundant in all furnishes including the three mill samples *(24, 25).* Thus, we have concluded that the problem of fiber/toner detachment is a widespread one, which is common to all types of repulpers currently in use. The existence of this phenomenon is perhaps not surprising, at least in retrospect, given the strength of toner/substrate attraction and attachment imparted during fusion, and the subsequent stability and strength of the toner/fiber bond.

In this paper, the results of two studies of the influence of consistency on toner detachment during repulping are presented. This work is ongoing and we are currently investigating further the influence of temperature, pH, and type of surfactant; these studies will be the subject of a second paper.

EXPERIMENTAL PROCEDURES

Sample preparation and repulping

To compare repulping, flotation, and other recycling results, we have created a "standard" sheet of printed paper containing a pattern of about 18,000 characters and covering approximately 30% of the area. This sheet is usually printed with a single, dedicated copier or printer; in this and the next study, a Hewlett-Packard LaserJet 4 laser printer was used. All sheets were printed on SuperCopy Bright White, 8 1/2 x 11-in., 20-lb copy paper.

This repulping study consists of three parts: (a) three samples repulped in a small laboratory repulper at 3–9% consistency, (b) five samples repulped in a larger, bench-scale repulper at 6–18% consistency, and (c) samples repulped at 12% consistency under several conditions of temperature and pH, and with and without added surfactant. Details of the repulping procedures follow.

The first set of samples was prepared by repulping standard sheets in a small, cylindrical laboratory pulper (5-in.-diam. and 8-in.-high) fitted with a flat rotor. About 65 g of paper was charged with the appropriate amount of water to achieve repulping consistencies of 3%, 6%, and 9%, the upper value being the highest consistency that can be repulped satisfactorily in this pulper. Repulping conditions were as follows: temperature = 40°C at start to 45–47°C at finish; pH = 10, adjusted with NaOH; surfactant = 0.2% (based on dry paper weight) High Point DI-2000, a nonionic type; time = 30 min; and rotor speed = 1000 rpm.

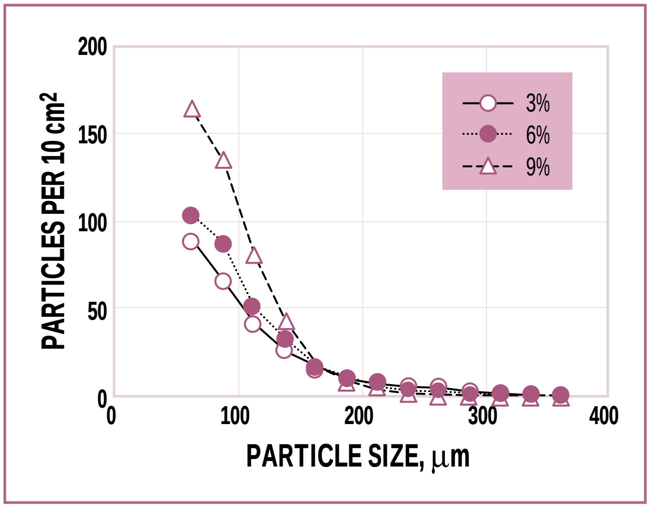
The second set of samples was prepared using a Formax 1800H laboratory pulper (Adirondack Machine Corp., Glens Falls, NY). About 2000 g of paper (1500 g for the 6% consistency trial) was charged with the appropriate amount of water to achieve repulping consistencies of 6%, 9%, 12%, 15%, and 18%. Repulping conditions were as follows: temperature = 40°C at start to 47–48°C at finish; pH = 10, adjusted with NaOH; surfactant = 0.2% (based on dry paper weight) High Point DI-2000; time = 30 min (35 min for 6% consistency); and rotor speed = 300 rpm (6%), 240 rpm (9%), and 200 rpm (12–18%).

In the trials using the Formax pulper, it was noted that the paper was completely disintegrated within 10–15 min in all cases, except the 6%-consistency trial, which required 30–35 min. However, there was a tendency for significant numbers of "nits" to form during the latter stages of repulping. To redefiber these nits before handsheets were made or other operations such as flotation performed, the repulped furnishes were diluted to about 3% consistency and disintegrated in a TAPPI disintegrator for about 1500 revolutions. This procedure completely removed any nits, while not altering the distribution of toner particles (see "Experimental Results").

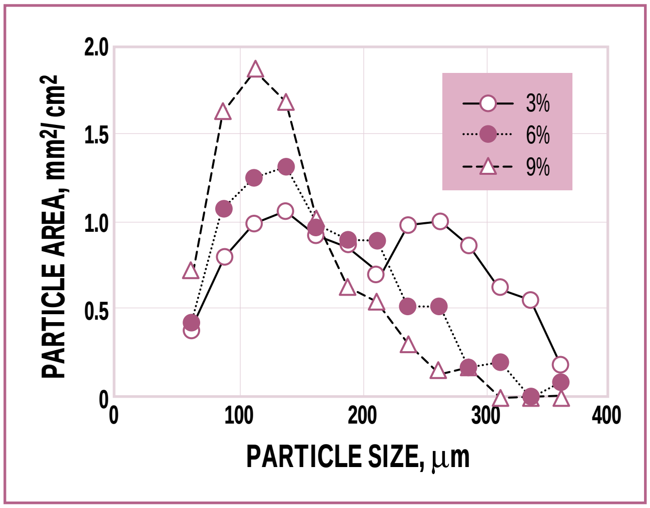
Several samples were repulped in the Formax pulper under conditions that varied from the baseline described above. A consistency of 12% was chosen for these additional trials as being representative of the 9–18% range in common use today. The repulping conditions were identical with those described above for 12% except as follows: Sample 1, no added surfactant; Sample 2, no pH adjustment (which resulted in a repulping pH of about 7.5); Sample 3, pH adjusted to 5.5 with sulfuric acid (a 20-min repulping time was used for this sample); Sample 4, repulping temperature of 20°C; and Sample 5, repulping temperature of 60°C.

Image analysis

Image analysis was done for all repulped samples using one-half-weight TAPPI handsheets. Our analy-



1. Toner particle size distribution for laboratory repulping



2. Toner particle area distribution for laboratory repulping

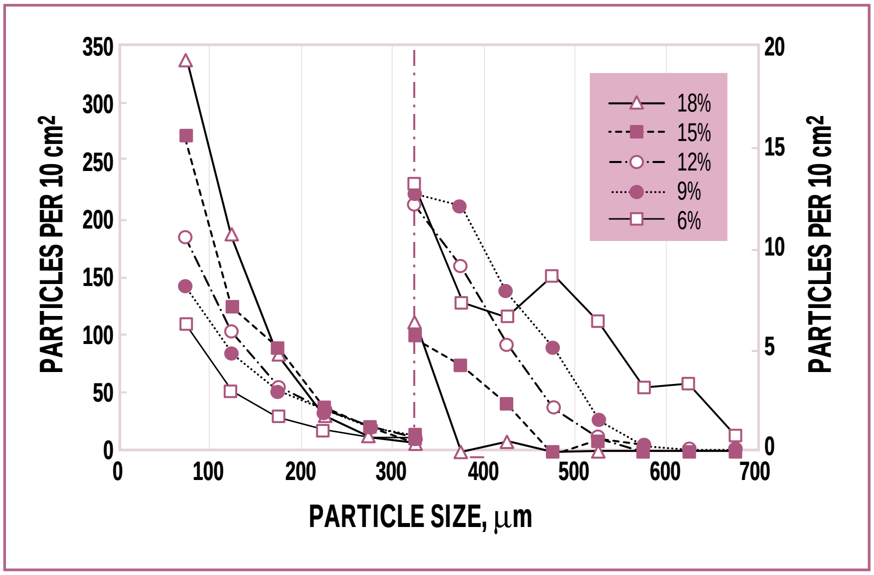
sis procedures and reasons for using these handsheets are discussed in detail in an earlier paper *(26).*

Image-analysis results were obtained over the size range of 50–700 µm in increments of 50 µm. For comparison with the microscopic examinations, these results were also lumped into the four size ranges of 100–200, 200–300, 300–420, and >420 µm.

Visual microscopic examination

All repulped furnishes were examined microscopically and classified in two ways: (a) by size: 100–200, 200–300, 300–420, or >420 µm, where these size ranges were chosen to match those used in another study involving Bauer-McNett fractions *(27, 28),* and (b) by degree of fiber attachment or "hairiness;" particles that retain no visible fibers are designated as *clean,* while those that retain fibers are designated as *hairy.*

All particles were examined in the original slurry after dilution, i.e., the particles were not dried or further treated in any other way. A binocular microscope is used at about 40X magnification. The size determination is made with a reticule installed in the microscope, and since the particle is free in an aqueous medium, this measurement may be somewhat imprecise. Further, the cutoffs at the ends of size ranges are difficult to quantify and are subject to a certain degree of arbitrariness (e.g., whether a particle close to 100 µm should be included in the 100–200-µm class or not, or whether a particle close to 420 µm in size should be placed in the 300–420 or > 420-µm class). For these reasons, a large number of particles, several hundred or more for each sample, are examined. In the results shown in the next section, we show that the reproducibility is usually satisfactory, although the microscopic examination results do not always agree closely with those obtained by image analysis.

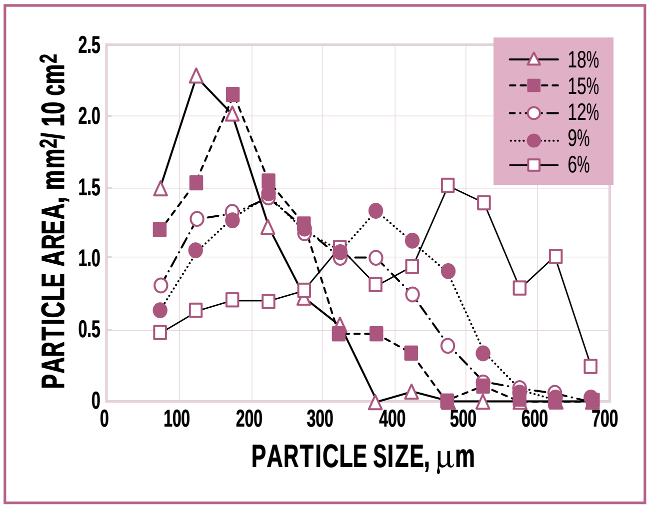


3. Toner particle size distribution curves for five bench-scale repulpings

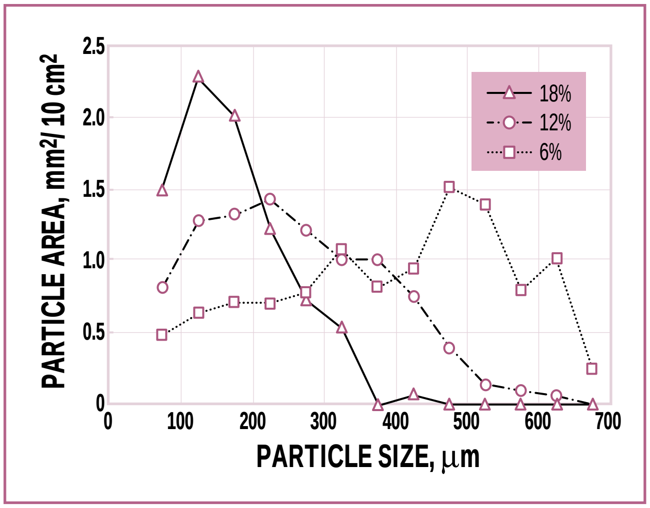
EXPERIMENTAL RESULTS

The results of the image analysis of the first set of repulped samples (3%, 6%, and 9% consistency) are shown in **Fig. 1**. In this figure, the numbers of toner particles in each 50-µm particle size bin are shown, i.e., the particle number distribution. It also is instructive to consider the amount of toner area contributed by the size ranges. This is displayed in **Fig. 2**, which shows the toner particle area as a function of particle size.

The visual microscopic examination results for the first set of sam-



4. Toner particle area distribution curves for five bench-scale repulpings



5. Simplified view of toner particle area distribution curves for three bench-scale repulpings

Repulping consistency, %	Size class, µm	IA, % total	VME % total	VME C/H
3	100–200	57	37	45/55
	200–300	22	29	12/88
	300–420	11	19	1/99
	>420	10	14	0/100
6	100–200	65	39	28/72
	200–300	23	37	13/87
	300–420	10	17	2/98
	>420	3	7	0/100
9	100–200	74	50	80/20
	200–300	21	35	48/52
	300–420	5	11	12/88
	>420	1	4	6/94

I. Comparison of image analysis (IA) and visual microscopic examination (VME) results for 3%, 6%, and 9% lab repulping. Results are the percent of total particles (% total) in a given size class and the ratio of clean to hairy particles (C/H) within that size class.

ples are summarized in **Table I**. Also shown for comparison are the image-analysis data expressed in terms of the four size classes, 100–200 through >420 µm. In this table, the IA (image analysis) and first VME (visual microscopic examination) columns represent the percentage of particles in each of the four size classes based on 100%. The second VME column gives the relative percentage of clean to hairy (C/H) particles for each size class based on 100% for that size class.

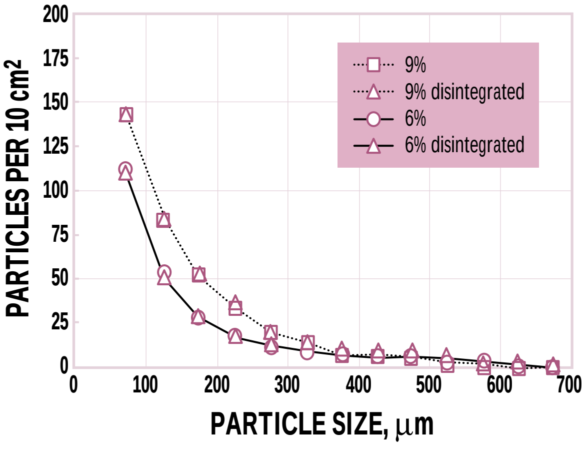
The results of the image analysis of the second set of repulped furnishes, 6–18% consistency, are shown in **Fig. 3** as the particle number distribution. This figure is split into two parts with two *y*-axes to better show the particle numbers for large particle sizes. These results are also displayed in **Fig. 4** as the toner area vs. particle size. To better see these area curves, **Fig. 5** shows an enlarged view with only three consistencies: 6%, 12%, and 18%.

The need to disintegrate nits after repulping in the Formax repulper was discussed in "Experimental procedures." We were concerned that this disintegration step might also further break up toner particles, especially larger ones. To check this, we examined the 6%- and 9%-consistency samples (which did not contain nits after repulping but did contain large numbers of large particles) both before and after disintegration. The comparison of these image-analysis results is shown in **Fig. 6**. It is seen that the 6% and 9% samples are identical, indicating that the disintegration step, although adequate to break up fiber nits, was not harsh enough to affect toner particles.

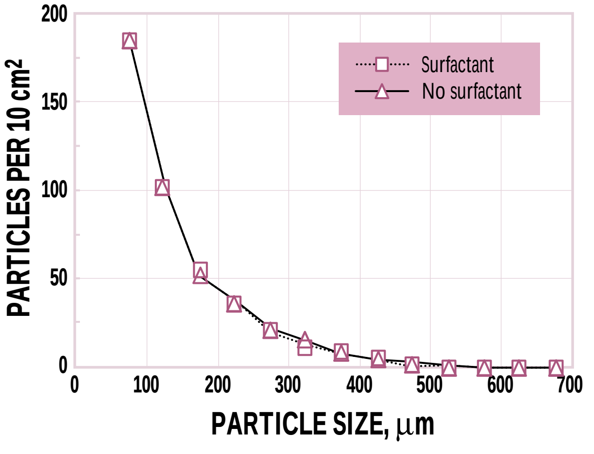
The visual microscopic examination results for the second set of samples are summarized in **Table II**. Also shown for comparison are the image-analysis data expressed in terms of the four size classes: 100–200 through >420 µm. The interpretation of this table is identical to that of Table I.

In Table II, two trials are shown for the 12%-consistency repulping. These represent separate repulpings from the same batch of printed sheets. The agreement between the two trials is seen to be excellent.

In principle, the image analysis and visual counts of particle per-



6. Toner particle size distribution curve comparisons for repulping



7. Comparison of toner particle distribution curves for 12%-consistency pulping with baseline and without surfactant

centages listed in Tables I and II should be identical; the agreement is generally quite good in Table II, although there are some discrepancies. The discrepancies that do appear probably arise for several reasons:

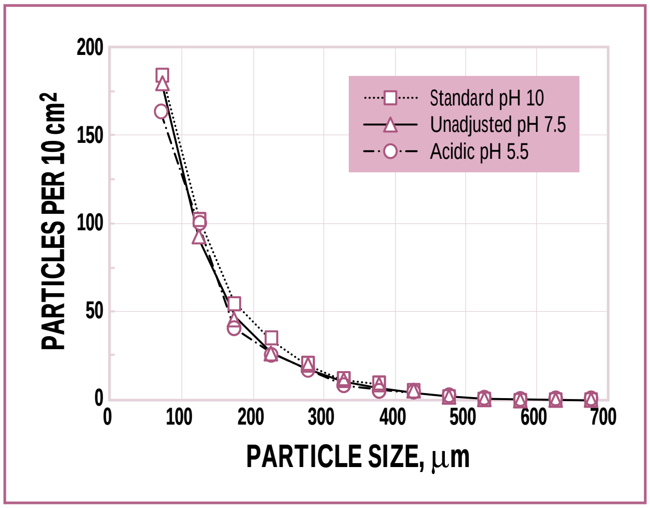
- While the image-analysis equipment makes a very sharp distinction at the limits of size classes (e.g., 199 µm vs. 201 µm), the eye cannot do this precisely or always in exactly the same way.
- The image-analysis camera tends to see a flat toner particle on the surface of a handsheet, while the aspect ratio of the particle in a slurry as seen by the observer may on average be somewhat different.
- There could be operator eye fatigue during counting.

The comparison seen in Table I is not generally as satisfactory as in Table II (or Tables III and IV, which follow). Table I is among our first visual microscopic examination of toner particles, and we feel we have since then refined our examination techniques.

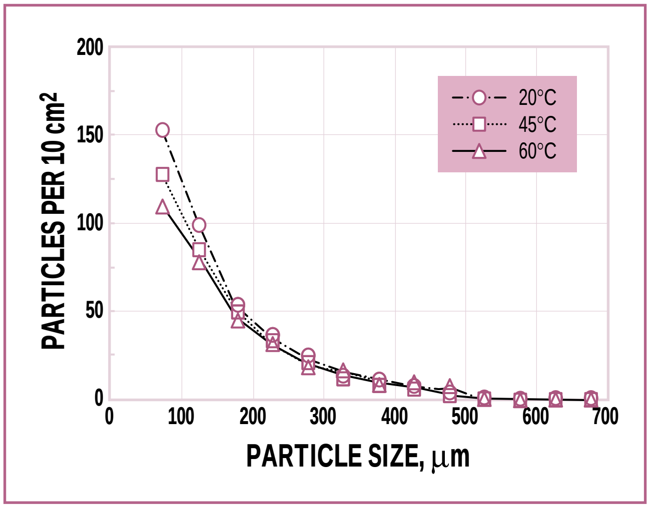
Comparisons of the image analysis results of the 12%-consistency trials are shown in **Fig. 7** (no added surfactant), **Fig. 8** (unadjusted and

Repulping consistency, %	Size class, µm	IA, % total	VME % total	VME C/H
6	100–200	50	41	39/61
	200–300	19	29	10/90
	300–420	16	15	0/100
	>420	15	15	0/100
9	100–200	59	51	49/51
	200–300	24	33	20/80
	300–420	13	11	15/85
	>420	4	5	0/100
12 (Trial 1)	100–200	64	59	52/42
	200–300	24	34	18/82
	300–420	10	6	4/96
	>420	2	2	0/100
12 (Trial 2)	100–200	65	56	58/42
	200–300	24	32	18/82
	300–420	9	7	4/96
	>420	2	5	0/100
15	100–200	75	70	56/44
	200–300	21	25	28/72
	300–420	4	4	0/100
	>420	0	1	0/100
18	100–200	84	74	51/49
	200–300	14	25	31/69
	300–420	2	1	25/75
	>420	0	0	…

II. Comparison of image analysis (IA) and visual microscopic examination (VME) results for 6% through 18% Adirondack repulping. Results are the percent of total particles (% total) in a given size class and the ratio of clean to hairy particles (C/H) within that size class.



8. Comparison of toner particle distribution curves for 12%-consistency pulping at three levels of pH: baseline (pH = 10), unadjusted (pH = 7.5), and acidic (pH = 5.5)



9. Comparison of toner particle distribution curves for 12%-consistency pulping at three temperatures: 45°C (baseline), 20°C, and 60°C

Parameter	Size class, µm	IA, % total	VME % total	VME C/H
Baseline A	100–200	65	58	55/45
	200–300	23	33	20/80
	300–420	10	6	2/98
	>420	2	3	0/100
No surfactant	100–200	62	59	56/44
	200–300	24	30	29/71
	300–420	11	7	3/97
	>420	3	4	0/100
Natural pH	100–200	66	62	54/46
	200–300	21	27	19/81
	300–420	10	7	4/96
	>420	3	3	0/100
Acidic pH	100–200	68	66	56/44
	200–300	21	29	21/79
	300–420	8	3	0/100
	>420	3	3	0/100

III. Comparison of image analysis (IA) and visual microscopic examination (VME) results for 12% Adirondack repulping with no added surfactant and at two levels of pH. Results are the percent of total particles (% total) in a given size class and the ratio of clean to hairy particles (C/H) within that size class.

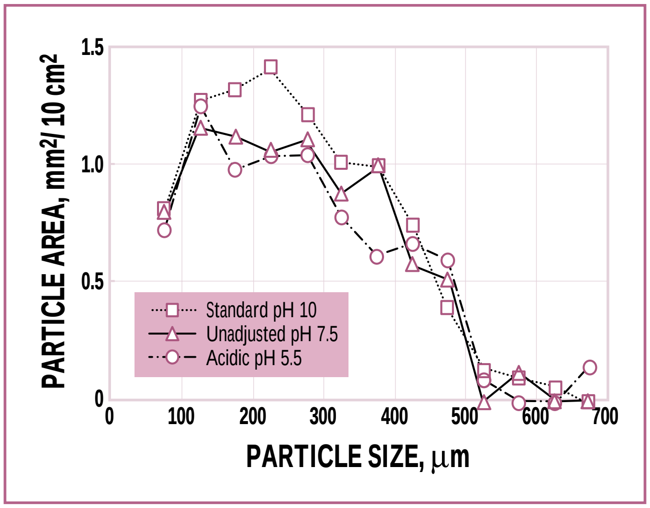
acidic pH), and **Fig. 9** (20 and 60°C). For comparison, the baseline result is also shown. Shown in **Figs. 10 and 11** are the toner area distributions curves for the pH and temperature trials.

The visual microscopic examination results for these trials are summarized, along with the image analysis data, in **Tables III and IV**. The Baseline A data shown in Table III are the average of the two 12%-consistency trials shown in Table II. The Baseline B data shown in Table IV are discussed below.

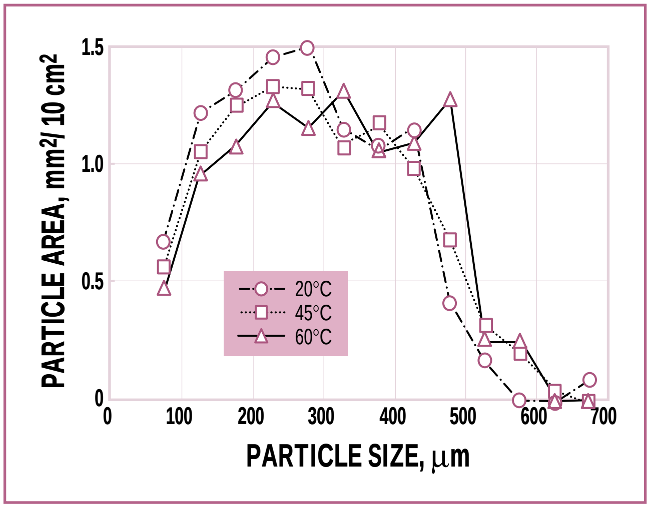
The temperature trials previously discussed involved repulping at 12% consistency and 20 and 60°C, and comparison with a 40°C, 12% baseline. The baseline data shown in Table IV and labeled "B" represent a new printing of standard sheets. The Baseline B data are averages of two repulpings of the new sheets, and although the two repulpings agreed very closely, the average Baseline B shows some differences compared with the Baseline A shown in Table III. Although we always obtain excellent agreement in the comparison of results from a given printing, on several occasions, we have experienced discrepancies in comparisons of two different printings that were repulped and otherwise treated identically. Whether these discrepancies arise because of differences in toner or copy sheet properties from month to month, or because of other reasons, is not known.

DISCUSSION AND CONCLUSIONS

Figure 1 shows a comparison of the image-analysis results of the 3%-, 6%-, and 9%-consistency trials repulped in our small laboratory pulper. It is evident from this comparison that more large and fewer small particles are produced during the lower-consistency (3%) repulping compared with the higher (9%). This trend is much more easily observed in Fig. 2, which shows a comparison of the



10. Comparison of toner area distribution curves for 12%-consistency pulping at three levels of pH: baseline (pH = 10), unadjusted (pH = 7.5), and acidic (pH = 5.5)



11. Comparison of toner area distribution curves for 12%-consistency pulping at three temperatures: 45°C (baseline), 20°C, and 60°C

toner area distribution curves. Here the 3% repulping is seen to produce a very broad and flat distribution, while the 9% displays a definite peak centered at a particle size of about 175 µm. Furthermore, there is a systematic shift in the peak location from 3% (around 150–300 µm) to 6% (about 150 µm) to 9% (125 µm).

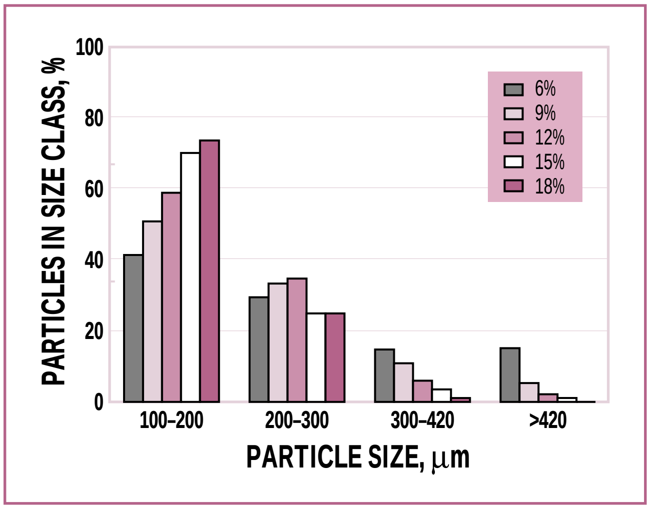
Table I summarizes both the image analysis and microscopic examination data. Visual examination reveals the same trend in toner particle size distribution as discussed in the previous paragraph. For example, particle percentages in the smallest (100–200-µm) size class increase from 37% to 50% with increasing consistency, while percentages in the two largest size classes (300–420 and >420 µm) decrease from 19% to 11% and 14% to 4%, respectively. Furthermore, Table I also shows the clean/hairy particle ratio for each size class. Three observations may be noted:

- There is a marked increase in the percentages of clean particles for the two smaller size classes (100–200 and 200–300 µm) from 45% to 80% and 12% to 48%, respectively, with increasing repulping consistency from 3% to 9%.
- The 3% repulping consistency trial appears to have been very inefficient in detaching toner.
- Virtually all toner particles greater than 300 µm in size are hairy, regardless of the repulping consistency.

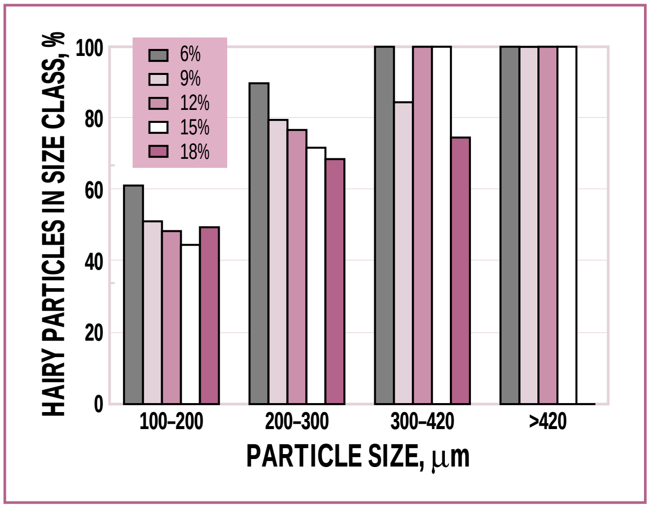
Parameter	Size class, µm	IA, % total	VME % total	VME C/H
Baseline B	100–200	60	57	66/34
	200–300	24	30	28/72
	300–420	12	7	10/90
	>420	4	5	0/100
20°C	100–200	61	57	55/45
	200–300	25	29	25/75
	300–420	11	7	0/100
	>420	3	7	0/100
60°C	100–200	57	50	74/26
	200–300	24	30	45/55
	300–420	13	11	17/83
	>420	6	8	16/84

IV. Comparison of image analysis (IA) and visual microscopic examination (VME) results for 12% Adirondack repulping at different temperatures. Results are the percent of total particles (% total) in a given size class and the ratio of clean/hairy particles (C/H) within that size class.

The second set of repulped furnishes covers a wider range of consistency variation from 6% to 18%. The image-analysis results of toner particle size distribution are shown in Fig. 3, where again a trend is seen of more small and fewer large particles with increasing repulping consistency. This trend is more clearly displayed in Figs. 4 and 5, which show the toner area distribution curves. Here a distinct maximum peak is observed for each curve, with the peak positions decreasing from about 450 µm to 375, 225, 175, and 150 µm with increasing repulping consistency of 6% to 9% through 18%, respectively. Also, the distribu-



12. Histogram of percentages of particles in four size classes for five repulping consistencies, 6–18%



13. Histogram of percent hairy particles in four size classes for five repulping consistencies, 6–18%

tions become much sharper and less broad with increasing consistency.

The microscopic examination results for the second set of samples are shown in Table II, along with the image-analysis results in size classes of 100–200 through >420 μm, for comparison. The percentage of particles in each size class is shown as a histogram in **Fig. 12**, and we observe the same trends as discussed in the previous paragraph. Furthermore, note that the 200–300-μm size class is virtually independent of repulping consistency. The clean/hairy particle ratios are also listed in Table II and shown as a histogram in **Fig. 13**. Here we observe that, with the exception of a minor drop from 6% to 9% consistency, the relative clean/hairy ratio remains essentially constant and independent of the repulping consistency. Thus, in the 100–200-μm size class, the percentage of particles almost doubles from 6% to 18% consistency, but the numbers of hairy particles must also increase proportionately. It appears that the high-consistency repulping from 12% to 18% is progressively more efficient in breaking down toner particles but not in causing fiber/toner detachment.

The next two sets of repulped samples involve a variation of two operating parameters with respect to the 12% baseline repulping (average of the two trials shown in Table II). Figure 7 shows a comparison of the image-analysis toner particle size distributions of the baseline repulping (with surfactant) with a trial with no added surfactant. The two trials yielded identical distributions as well as clean/hairy particle ratios, which are listed in Table III. This result is not surprising, as it is not clear what influence a nonionic surfactant will have on a thermoplastic toner or on the toner/fiber substrate bonding. However, this observation deserves further study, and we are currently investigating several widely used nonionic surfactants and several other surfactant types to assess the generality of the previously stated conclusion.

Figure 8 shows a comparison of the baseline repulping, with ones that were nearly neutral (unadjusted pH = 7.5) and distinctly acidic (pH = 5.5). Both Fig. 8 and Table III indicate nearly identical results of both size distributions and clean/hairy particle ratios. In Fig. 10, the particle area distribution curves are shown, and here small, *possible* differences can be discerned. For example, below particle sizes of 400 μm, the standard (pH 10) pulping yielded more small particles and the acidic pulping fewer small particles. However, these differences are very small and require further verification work.

Based on the results shown in Figs. 7 and 8 and Table III, we are inclined at this point to ascribe little, if any, influence in toner breakdown and detachment to either the presence of surfactant or pH. This suggests that the overriding repulping consideration in toner breakdown and detachment is mechanical in nature and not chemical. The toner/fiber substrate bond is a physical one and requires mechanical action such as shear or impact to be effective.

Figure 9 shows the final samples, a comparison of the baseline repulping and two repulpings at higher and lower temperatures (60 and 20°C). Here some distinct differences are observed. These differences may be seen more clearly in the toner area distribution curves shown in Fig. 11, where the 20°C curve displays fewer

KEYWORDS
Additives, bibliographies, chemical properties, consistency, fine papers, ink, lasers, particles, pH, process variables, pulping, reprographic papers, repulping, solids content, surfactants, temperature, toners, variables.

large and more small particles. Considering the statement made in the previous paragraph, operational conditions that favor changes in the physical properties of the toner thermoplastic might prove effective in subsequent toner breakdown and detachment. Since 20°C is significantly further below the glass-transition temperature of the toner (probably about 55–70°C) compared with 40°C, the toner at the lower temperature is considerably more glassy and brittle, and thus more susceptible to breakdown by mechanical forces such as shear or impact. However, the effect seen in Figs. 10 and 11 is not great.

A second, more interesting, and potentially more important difference in the three temperature trials can be seen in Table IV. The 60°C results show distinctly more clean particles, especially in the 300–420 and >420 μm size categories, with 17% and 16%. In fact, we have never before observed clean particles with sizes greater than 420 μm and rarely this many in the 300–420-μm class. We attribute this effect to the softening of the toner, which tends to weaken both physical and mechanical bonding, allowing the toner to disengage more easily from the fiber substrate. However, note that the distribution of particle sizes is unchanged from the baseline. It is interesting that lower temperature appears to enhance toner breakdown but not toner/fiber detachment; on the other hand, higher temperature facilitates detachment but not breakdown, as now the toner is less brittle and more leathery and tough.

As a final comment, we note that we examined a large number of large toner particles from the 60°C repulping for evidence of deformation or smearing on fibers. We found that 60–70% of the particles over about 300 μm in size showed some signs of edge deformation or buckling. However, no particles were globular or spherical, and there was no evidence of toner smearing on fibers. Apparently, although the toner softened during the 60°C trial and probably got somewhat above its glass-transition temperature, the temperature was not so high that the toner actually flowed. **TJ**

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