Effect of pulping conditions on stickies behavior in office waste deinking systems

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ABSTRACT: Office recovered paper (ORP) as a fiber source for printing and writing grades can be limited by its high content of nonimpact or "laser print" inks. Chemical aggregation and densification of nonimpact inks are one option for deinking ORP. ORP containing stickie contaminants was deinked under "mild" and "harsh" pulping conditions. Contaminants were removed using cleaning and screening. The same furnish was also deinked using the chemistry and "harsh" pulping conditions, required for aggregation and densification of nonimpact inks. The effects on the size of stickies, efficiency of stickies removal by cleaning and screening, and the nature of the stickies in the finished stock were investigated. Under the pulping chemistry and conditions required for aggregation and densification of nonimpact inks, most stickies are associated with the ink in the pulper. The combined particles were separable from the fiber by mechanical systems, particularly by forward cleaning. These contaminants were less prone to deposition than stickies formed without chemical treatment. The deposition potential of the chemically treated contaminants was no greater than stickies formed under mild pulping conditions without chemical treatment.

KEYWORDS: Agglomeration, cleaning, deinking, densification, ink, screening, stickies, waste papers.

According to the National Office Paper Recycling Project, 5.1 million tons of office recovered paper (ORP) could potentially be recovered from the waste stream in 1995. This would represent greater than a threefold increase from the amount recovered in 1990 *(1)*. In the past, the high percentage of nonimpact or "laser-printed" paper and other contaminants contained in ORP has limited its use to recycled paperboard and construction products *(2)*. The problems associated with deinking laser-printed paper with traditional chemistries and equipment were reviewed by Carr *(3)*.

Chemical aggregation and densification technology *(4)* is one option for deinking ORP containing laser-printed inks, allowing its use in printing and writing grades. This technology involves pulping and chemically treating the recovered paper at temperatures of 145–155°F (63–68°C) at a pH of 11. Removal of the densified laser toner from the fiber is accomplished using forward cleaning.

In addition to laser-printed papers, ORP is typically contaminated with adhesive labels, tapes, binders, and self-sealants. These contaminants cause a variety of stickies problems on the paper machine and in the finished paper. A thorough review of the chemical nature of stickies and the problems they cause in papermaking was prepared by Moreland *(5)*.

The problems stickies generate on the paper machine and in the finished paper are largely related to the particle size. High shear force and elevated temperature in the pulper (which are believed to disintegrate stickies) have been avoided to keep the stickies large *(6)*. Large stickies are defined as those that are

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removable by mechanical means, such as screening and cleaning *(7)*.

Small stickies, which can pass through cleaning and screening equipment, are a problem because they tend to aggregate. These stickies can deposit onto the paper machine, attract more stickies, and subsequently form large deposits. Stickies can also accumulate in the closed white water systems of paper machines and deinking plants. These stickies can also associate and form deposits *(8)*.

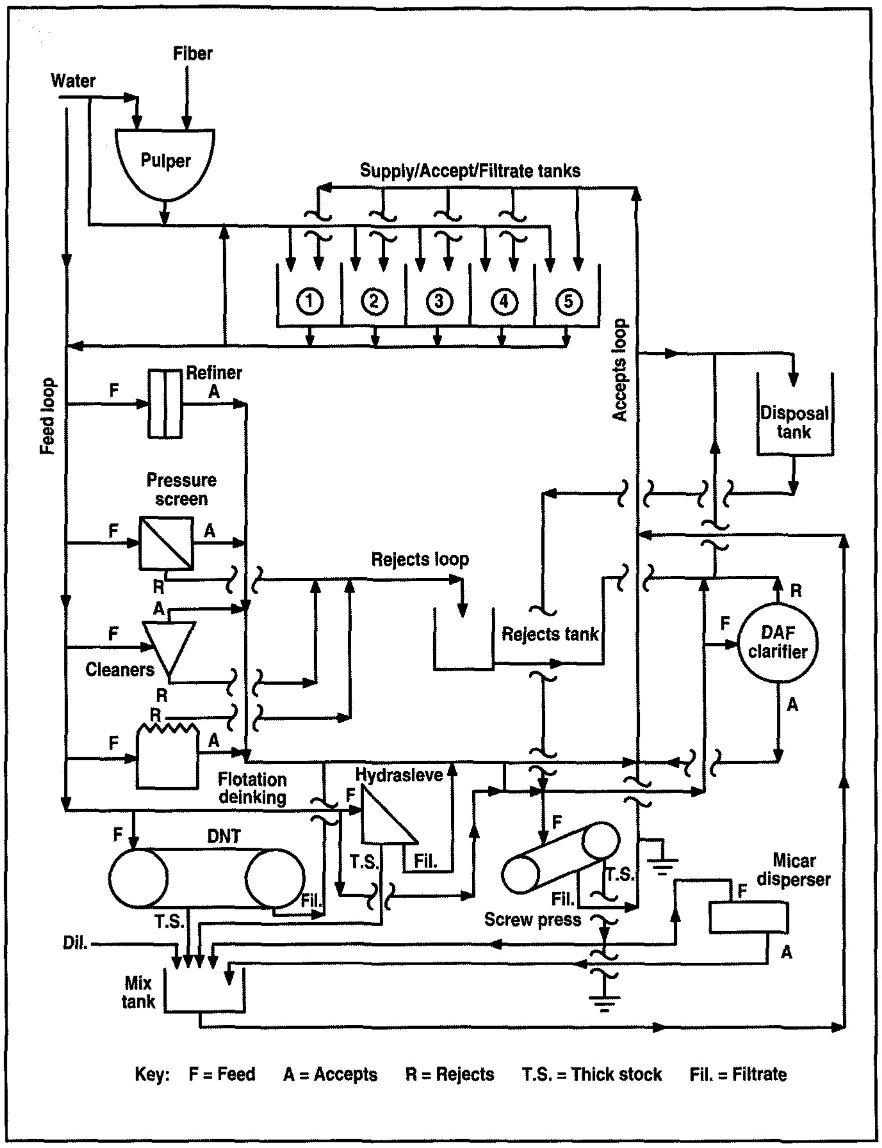
Removing laser print from ORP can be accomplished using chemical densification and aggregation technology. However, understanding the behavior of the stickies present in the furnish is important to successfully use this technology. This study was conducted to investigate the nature of stickies present throughout the ORP deinking process.

Objectives

The fate of stickies in office waste deinking systems was assessed under different pilot pulping conditions. This experiment was designed to address the following:

- What happens to stickies in the pulper under different pulping conditions? Do they disperse, aggregate, associate with ink, or remain discrete stickies particles?
- How effective are conventional mechanical separation processes at removing the stickies from the stock after repulping? What are the removal efficiencies of fine-slotted screening, forward cleaning, and through-flow cleaning for the stickies formed by the different pulping conditions above?
- What is the nature of the stickies remaining with the finished pulp after the mechanical separation processes? Does the deposition potential of these particles depend on their formation under the different pulping conditions above?

1. Simplified process flow diagram



Pilot simulation and general procedure

Pilot capabilities

A pilot-scale experiment was run in a multipurpose stock preparation and recycling pilot facility. This facility permitted evaluation of the effects of process chemistry on a wide variety of pulp and paper mill processes. A simplified process flow diagram outlining the mechanical capabilities of the plant is shown in **Fig. 1**.

Furnish and stickies addition

The pilot experiment consisted of three independent runs, each using sorted white ledger office recovered paper (PS-40) as furnish. The paper bales used for the experiments had a high laser-printed content (70–80%) and contained essentially no colored (dyed) sheets, unbleached fiber, or groundwood.

Stickies-forming adhesives were intentionally added to each run to keep the stickies concentration constant. A dose of 0.025% adhesive, a mixture of contact adhesive and hot-melt glue, on AD fiber was applied directly to the ORP stock prior to pulping. The contact adhesive was a combination of Avery-Dennison self-adhesive labels and 3M brown strap-

I. Pulping conditions

Case	Temperature	pH	Laser deinking chemistry	Comments
1	120°F (50°C)	8.4	No	"Mild" conditions usually sufficient to defiber ledger grades; not recommended for laser deinking
2	150°F (65°C)	11.0 (w/NaOH)	No	"Harsh" conditions with no laser deinking chemical
3	150°F (65°C)	11.0 (w/NaOH)	1% on ad fiber (20 lb/ton)	"Harsh" conditions with laser deinking chemical

ping tape. Both are primarily rubber-based, pressure-sensitive adhesives. The hot-melt glue was an ethylene vinyl acetate with a melting point of 78°C.

Pulping procedures

Pulping occurred in a 4-ft- (1.2-m-) diam. Black Clawson Hydrapulper, and a 170-lb (77-kg) batch of AD fiber was used for each run. The stock, diluted with city water to achieve a 5% consistency, was agitated with a 2-ft- (0.6-m-) diam. low-consistency rotor at 450 rpm for 45 min. The repulped stock was then extracted through a plate with 0.625-in. (1.6-cm) holes. The three runs, identical in every aspect except for the pulping conditions, are outlined in **Table I.**

Stock preparation

Figure 2, a flow diagram of the pilot trial plan, contains data on pertinent process setpoints. The extracted stock was dumped into a stainless steel tank. This tank was then agitated and had closed-loop temperature control via direct steam injection. The stock was diluted to a 2.0% consistency with city water; a diluted stock temperature of 120°F (50°C) was maintained for all separation processes.

The stock for each run was coarse screened to remove unpulped fiber bundles and large contaminants such as staples, plastics, and adhesive backings. Large debris remaining in the stock could influence analysis of the results, and coarse screening was not expected to remove significant quantities of ink or problematic stickies. The equipment for coarse screening was a Voith Mini-Sorter Size "O" pressure screen, operated with a 0.062-in. (1.6-mm) contoured hole basket. The pressure drop across the screen basket was undetectable as the flow rate was well below screen capacity.

After coarse screening, the stock was split into three parallel flows to determine the separation efficiencies of the individual unit processes. All stock was stored, agitated, and heated in stainless steel tanks. A parallel-flow design was chosen to compare the stickies removal efficiency of each process rather than that of their combined performance as a series system. Each piece of equipment was operated at the consistency previously identified as optimal.

Stickies separation processes

A portion of the coarse-screen accepts was diluted and screened; fine-slotted screening was performed with the Voith Mini-Sorter. This time a 0.006-in. (0.15-mm) slotted profile basket was used, and the mean passing velocity across the screen basket was approximately 0.7 m/s. Any pressure drop across this screen was undetectable, as with the coarse screening.

Another portion of the coarse-screen accepts was diluted and through-flow cleaned using a Black Clawson X-Clone. A single 3-in.- (76-mm-) diam. cone was used to process the stock. The remaining coarse-screen accepts were diluted and forward cleaned. Forward cleaning was performed using a Hymac HY80X centrifugal forward cleaner cone, and a single 3.1-in. (80-mm) cone was used to process the stock.

Composite samples were taken from the pulper in addition to the feed, accepts, and rejects of each separation process. Each run was completed and the system was thoroughly flushed before the next pulper batch was started.

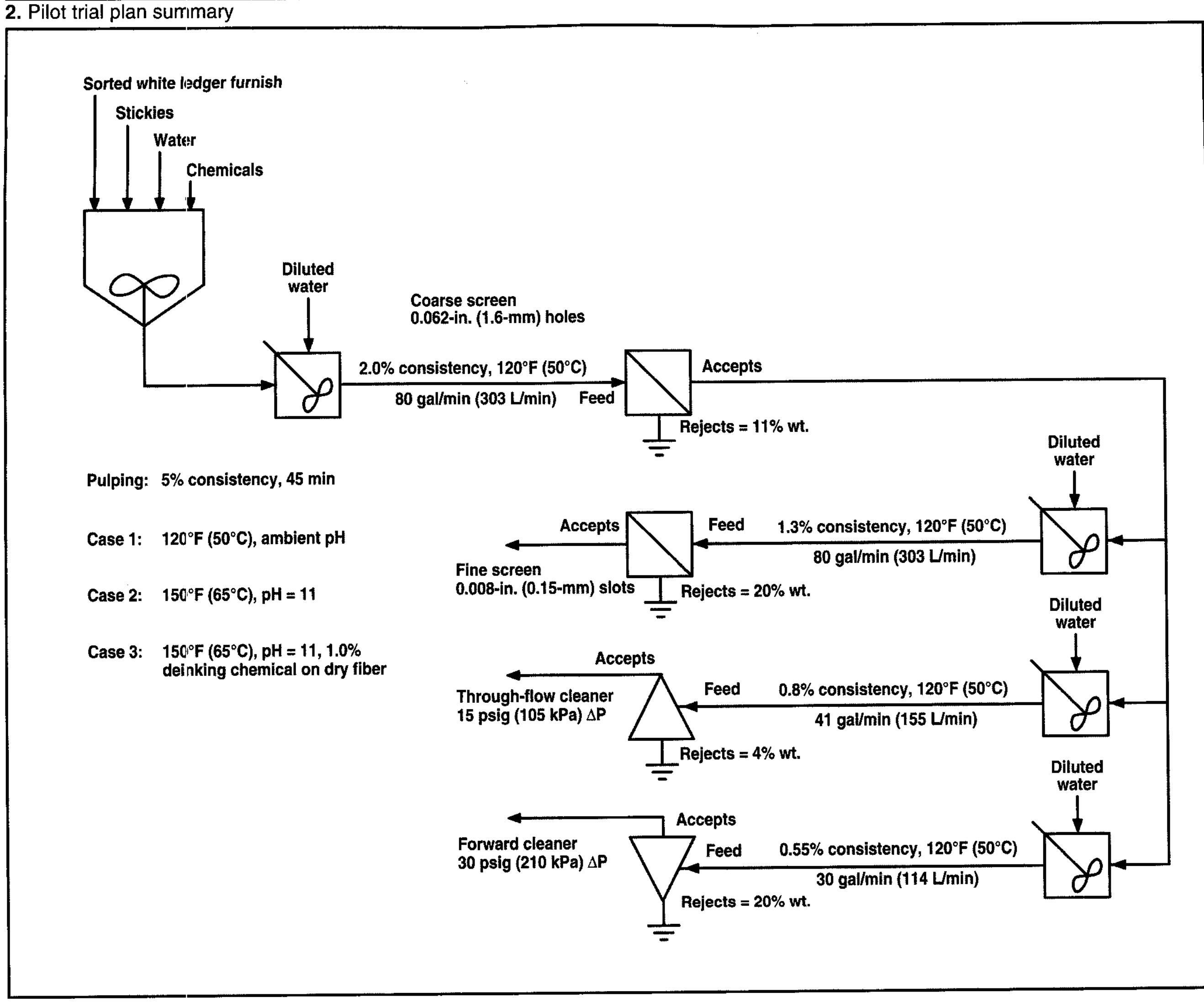
Fate of stickies in the pulper

Macroscopic contaminants

Experimental. Macroscopic ink and stickie-ink "combined" contaminants were quantitatively measured using the ASA-2000 Automatic Sheet Analyzer *(9)*. This system measures dirt and foreign particles in finished paper, board, and handsheets. We could not differentiate between the two contaminant types. The stickie-ink aggregates took on a gray-black appearance due to the inclusion of laser inks. Once the combined level of macroscopic ink and stickie-ink contaminants was determined, efforts were made to quantify the level of ink-free macroscopic stickies in the furnish.

The level of ink-free macroscopic stickies for each pulping condition was determined by staining the

2. Pilot trial plan summary



sheets with black ink *(10)*. This staining method permitted absorption of the ink by the hydrophilic fibers, while the hydrophobic stickie contaminants did not absorb the ink. Each pulper sheet was immersed in Higgins ink for 30 seconds, pressed between blotters to remove excess ink, and air-dried overnight. Quantitative sheet analyses were performed using the ASA-2000 Automatic Sheet Analyzer and reverse mode imaging (viewing light contaminant particles on a black background). A direct comparison of macroscopic contaminant levels for each pulping condition was made, and macroscopic contaminants were specified as those that measured greater than 160 μm in diameter.

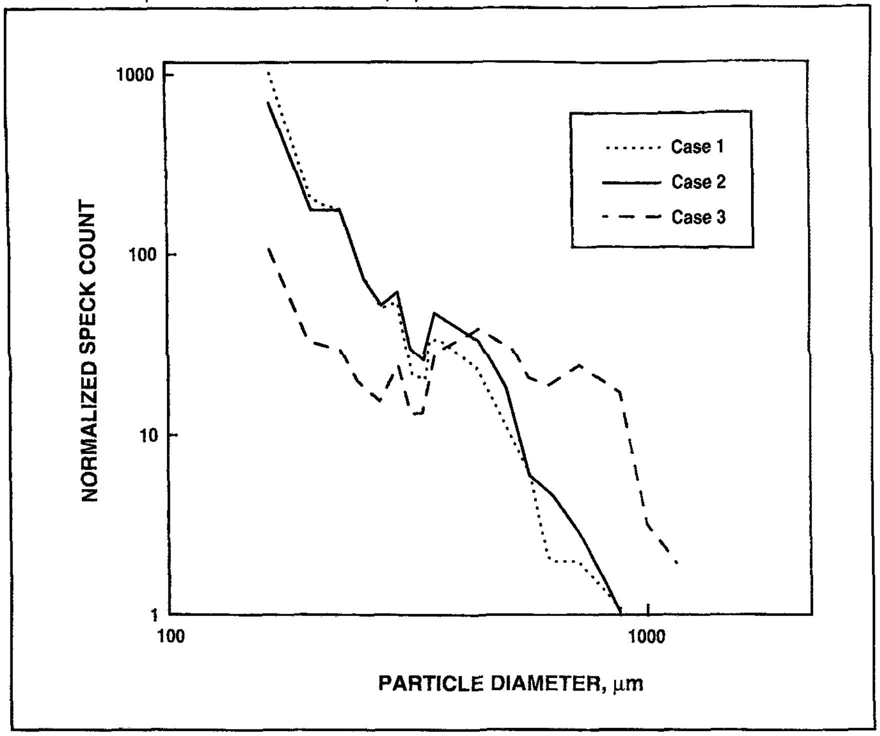
Results. Figure 3 shows the particle size distribution of inks and stickie-ink combination contaminants in the pulper stock under the three pulping conditions. Contrary to expectations, harsh pulping conditions (Cases 2 and 3) did not produce a greater number of small particles (< 200 μm) compared to Case 1 (mild pulping conditions).

Chemical treatment under harsh pulping conditions (Case 3) greatly increased the size of the aggregates, thereby reducing the number of particles detected. It was clear that, in the presence of the laser-deinking chemical, inks and stickie-ink contaminants tended to aggregate rather than disperse under the harsh pulping conditions of Case 3. Typical ink aggregates and stickie-ink combination contaminants in the macroscopic size range are displayed in **Figs.** 4 **and** 5, respectively.

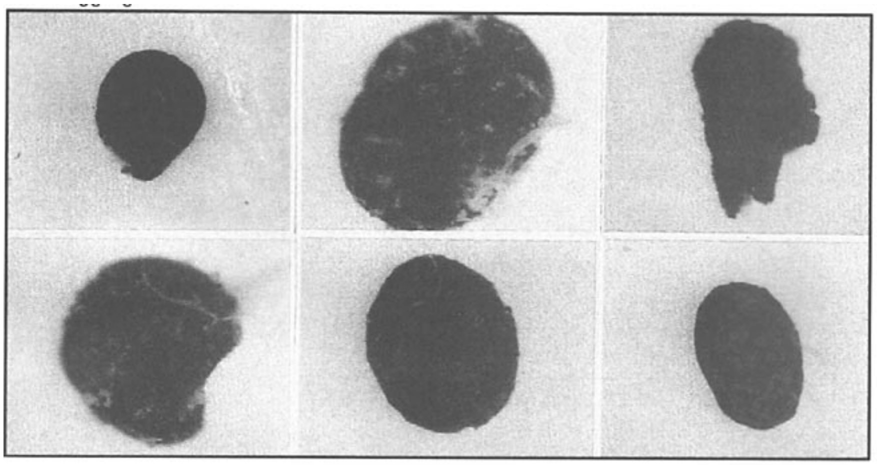
The particle size distribution of aggregates in the coarse-screen accepts (**Fig.** 6) was similar to that in the pulper stock for each pulping condition. This was expected, as the coarse screen is primarily designed to remove large pieces of tape, labels, and unpulped fiber bundles; it does not remove significant quantities of ink and stickie-ink contaminants.

Staining showed very few macroscopic ink-free stickies in the pulper

3. Normalized particle size distribution: pulper stock



4. Ink aggregates



stock in all cases. The coarse-screen accepts were also dyed, and no macroscopic ink-free stickies were identified. These observations confirmed that few "free" macroscopic stickies existed after repulping. Nearly all stickies existed after repulping, and most stickies in the macroscopic size range are associated with the laser inks.

Microscopic contaminants

Experimental. As discussed earlier, the harsh pulping conditions with chemical treatment enhanced aggregation of inks and stickie-ink contaminants. As a greater number of stickies were associated with inks, fewer dispersed (ink-free) stickies should remain in the pulper stock. To prove this hypothesis, the microscopic fluorescence test method was used to quantify the level of dispersed colloidal stickie particles in the furnish.

Fluorescence-reflected light illumination is a method used to study material that can be made to fluoresce, either in its natural form or when treated with chemicals capable of fluorescing *(11)*. Compounds that fluoresce in their natural form (autofluorescence) generally contain alternating single and double bonds between the atoms or contain aromatic rings. The stickie contaminants used for this study (commercial hot melts and contact adhesives) autofluoresced.

For video imaging and recording, a photo-eyepiece and a parafocalizing adapter connected the video camera to the microscope. The image on the video screen was interfaced with an image analysis program. This allowed collecting multiple fields of fluorescent particles across the handsheet. The software only detected fluorescent stickie particles and not the laser inks present on each sheet. To collect statistically reproducible data, 40 fields were counted on each sheet; the data were analyzed using Lotus software. The total number of particles, mean diameter, and total contaminant area were reported.

Results. The number of microscopic ink-free stickies was 47% lower for Case 2 (harsh pulping conditions with no chemical treatment) and 54% lower for Case 3 (harsh pulping conditions with chemical treatment) when compared to the mild pulping conditions of Case 1 (**Fig.** 7).

For the coarse-screen accepts, the number of microscopic stickies for Cases 2 and 3 was lower than for Case 1 (**Fig.** 8). Relative percentages shifted in the coarse-screen samples due to the lower counts seen in Case 1. Fewer ink-free microscopic stickie particles in the Case 2 and Case 3 samples were a result of the stickie contaminants' association with laser ink under harsh pulping conditions.

Effect of separation processes on stickie removal efficiency

Macroscopic contaminants

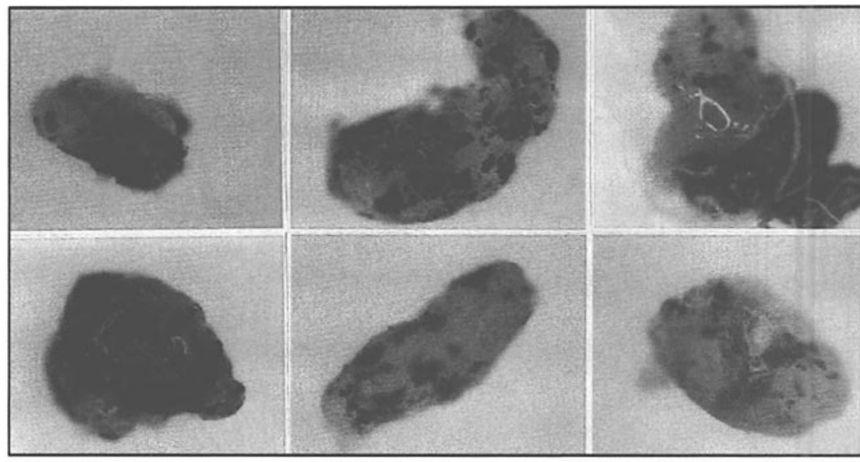
Experimental. The ASA-2000 sheet analyzer was used to determine any change in macroscopic contaminant level (both ink and stickie-ink aggregates) across each mechanical removal process. Using the coarse-screen accepts as the "universal feed" for each pulping condition, percent contaminant removal efficiency was calculated based on the change in total contaminant area across each mechanical process.

Results. The efficiency of mechanical separation processes at removing the ink and stickie-ink aggregates from the stock is presented in **Fig. 9**. The forward cleaner provided the most efficient removal regardless of pulping conditions, and fine screening appeared to be more effective than through-flow cleaning. In all cases, the performance of the through-flow cleaner was marginal in removing contaminants. Generally, contaminant removal efficiency increased from mild to harsh pulping conditions and increased further with laser-deinking chemical treatment.

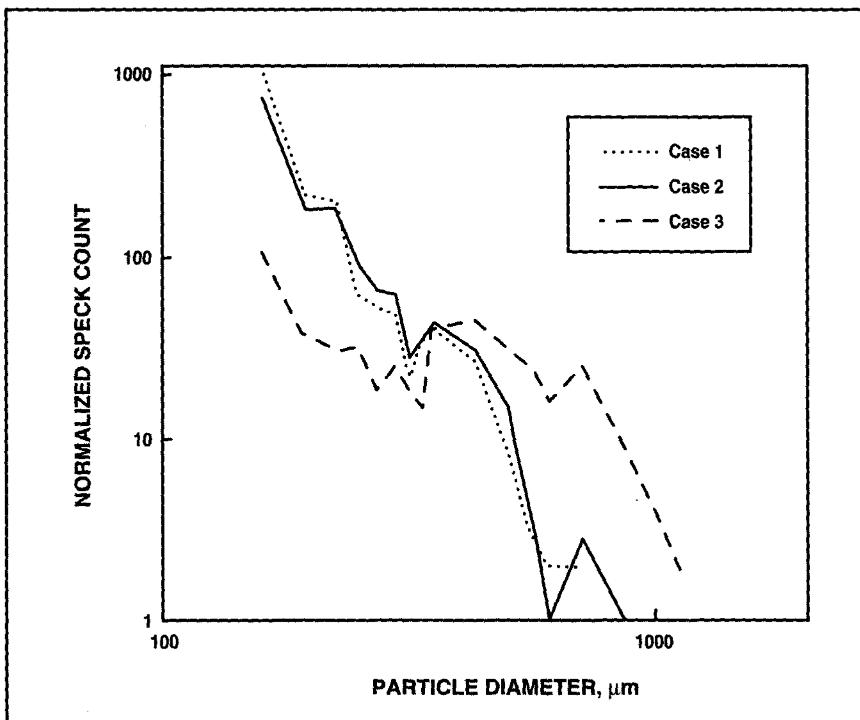
As seen in Figs. 3 and 6, the diameter of the aggregate particles was significantly larger in Case 3. This diameter increase should make fine screening more efficient. Screening efficiencies were 23%, 33%, and 63% for Cases 1, 2, and 3, respectively (Fig. 9).

The ink and stickie-ink contaminants that were not chemically treated had an average density of about 1.03 g/cm^3. A slight increase in particle density with chemical treatment was observed, with the average density being approximately 1.05 g/cm^3. In addition to the density increase, a development of spherical-shaped aggregates was noticed when pulping under Case 3 conditions. The subtle increase in aggregate density combined with larger size development and attainment of a spherical or granular shape resulted in improved contaminant removal by forward cleaning. The forward cleaner efficiency increased from 46% in Case 1 (mild pulping conditions) to 81% in Case 2 (harsh pulping conditions) and was 98% in Case 3 (harsh pulping conditions with chemical treatment).

5. Stickie-ink combination contaminants



6. Normalized particle size distribution: coarse-screen accepts

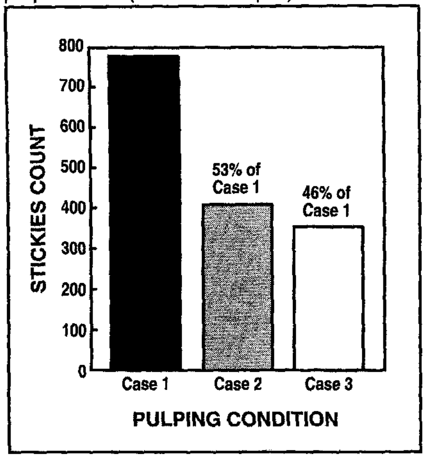


Microscopic contaminants

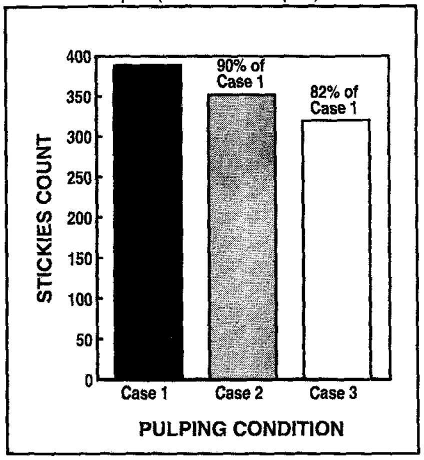
Experimental. Fluorescence-reflected light illumination was used to determine the effect of the mechanical separation processes on the removal of microscopic stickie contaminants. For each pulping condition, the universal feed (coarse-screen accepts) was compared to each mechanical separation process, and percent removal efficiency was calculated based on stickie contaminant count.

Results. Measurements showed that the mechanical separation processes were effective in removing

7. Counts of microscopic stickies in the pulper stock (diam. < 160 μm)



8. Counts of microscopic stickies in coarse-screen accepts (diam. < 160 μm)



microscopic stickies in certain cases (**Fig. 10**). However, the removal efficiency was lower than that seen for macroscopic aggregates. One possible explanation is that some microscopic stickie particles were loosely associated with macroscopic aggregates due to their hydrophobic nature.

With the exception of the Case 2 fine-screening process, the trends for mechanical removal of microscopic stickies were the same as those for macroscopic contaminant removal. The forward cleaner provided the highest removal efficiency in each case, with Case 3 showing the highest level of removal efficiency. A "negative" percent removal indicated the counts in the accepts were higher than those of the feed (Fig. 10). This implied that the particles were broken up under high shear force (e.g., with a fine screen). The slightly negative removal efficiency for the through-flow cleaning in Case 1 was probably due to experimental error.

Compared to the pulper sample, a dramatic increase in stickies count for the fine-screen accepts in Case 2 was observed. This indicated the stickies and stickie-ink contaminants were loosely associated and could not withstand high shear stress. This phenomenon supports the general opinion that harsh pulping conditions may result in stickie problems on the paper machine (e.g., difficulty in mechanical removal and later reaggregation). In contrast, this phenomenon did not occur in Case 3. Chemical treatment rendered strong bonding of the aggregates, allowing them to remain intact during fine screening and significantly improving mechanical separation efficiency.

Figure 11 shows the correlation between microscopic stickies removal and macroscopic contaminant removal. Note that data from the Case 2 fine-screen accepts were not used for the correlation due to the breakup of contaminants. A linear relationship for all other conditions was clearly shown. It was evident that mechanical processes, which removed significant amounts of the macroscopic contaminants, also removed substantial amounts of microscopic stickies.

Based on these macroscopic and microscopic studies, a solid conclusion can be drawn: Harsh pulping conditions with chemical treatment enhanced ink and stickie-ink aggregation. This, in turn, improved mechanical separation efficiency. In commercial processes, cleaning and screening are performed in series rather than in parallel. As a result, the compounding higher removal efficiencies would reduce the number of stickies reaching the paper machine. This is essential for maintaining machine efficiency and final product quality.

Nature of stickies remaining with pulp

Experimental

The Stickies Deposition Test *(12)* was used to measure the amount of active stickies that tend to deposit onto hydrophobic surfaces such as wires and felts. The deposition tendency of contaminants can be affected by their hydrophobicity, tackiness, softness, size, and shape.

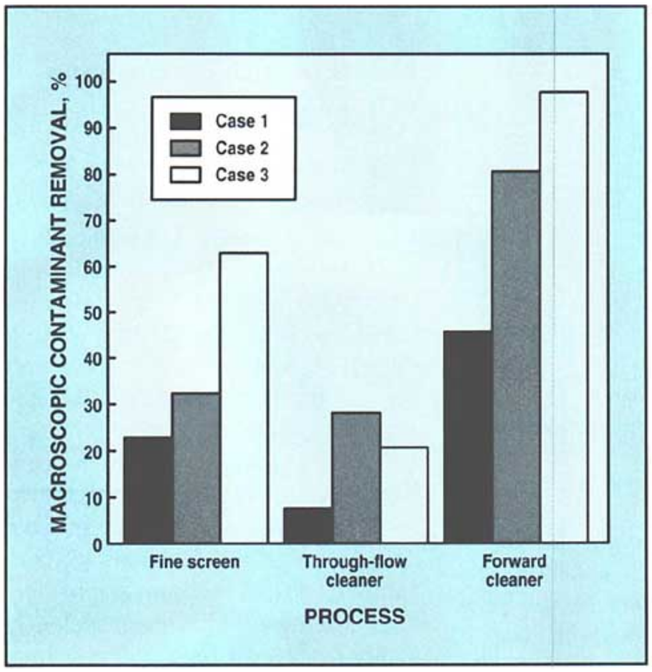
Recovered paper used in the converting process is defibered, allowing the release of adhesives from the paper surface. Those stickie contaminants that are considered "active" are those which are sufficiently tacky to deposit on paper machine surfaces. The Stickies Deposition Test quantified the level of "active" stickies in a given sample. A lower level deposited onto the polypropylene packing foam surface indicated a lower probability of deposition on the machine.

Three replicates were performed for each pulper and forward cleaner accept case. This test compared the deposition tendency of the stock sample containing the highest contamination level (pulper) to that expected to contain the lowest contamination level (forward cleaner accepts).

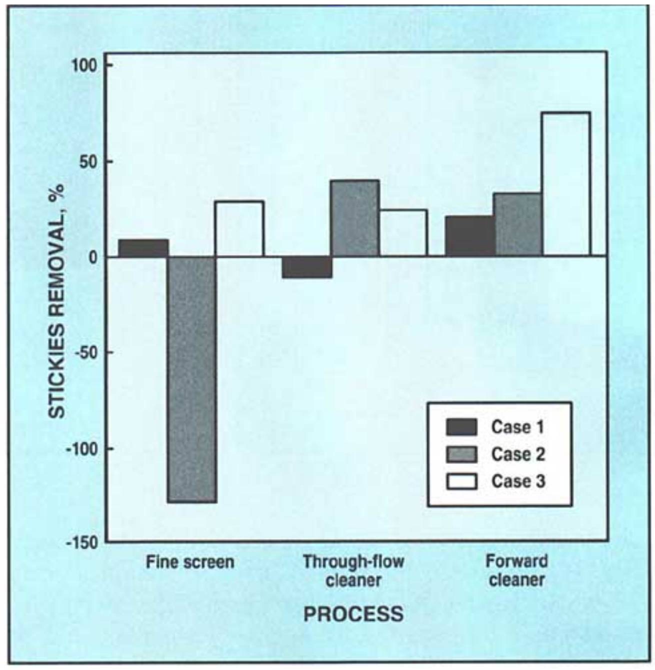
Results

We believed that harsh pulping conditions and chemical treatment had an impact on stickie characteristics. **Figure 12** shows active contaminant content (expressed in grams per metric ton) in the forward cleaner accepts. The "active" contaminant level in Case 2 was the highest of the three pulping conditions (460 vs. 260–290 g/metric ton). This provided some evidence that contaminants generated in Case 1 (mild pulping conditions) and Case 3 (harsh conditions with chemical treatment) had less tendency to deposit onto paper

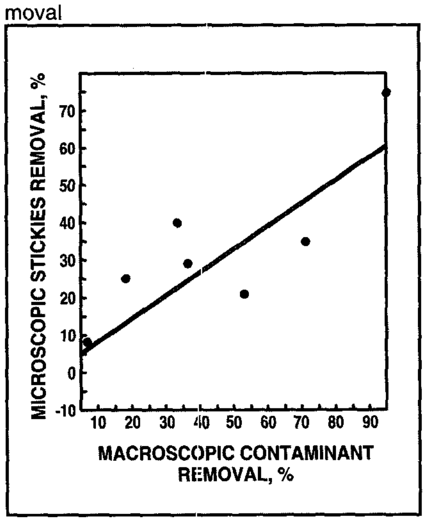
9. Efficiency of macroscopic contaminant removal by different mechanical cleaning processes (diam. > 160 μm)



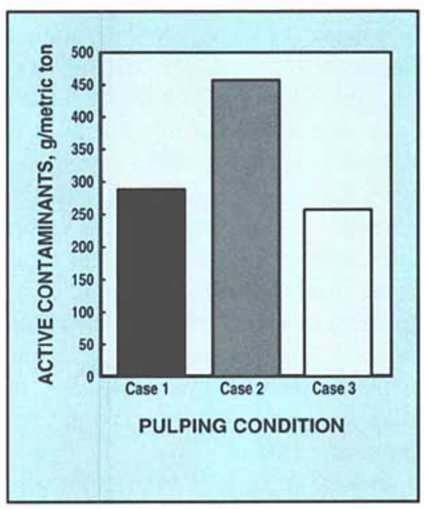
10. Efficiency of microscopic stickies removal by different mechanical cleaning processes (diam. > 160 μm)



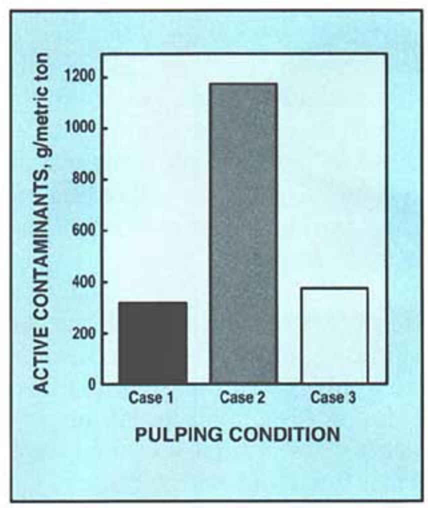
11. Correlation between microscopic stickies removal and macroscopic contaminant removal



12. Active contaminants in forward cleaner accepts



13. Active contaminants in the pulper stock



machine surfaces than those generated under harsh conditions with no chemical treatment.

One could argue that the lower "active" contaminant content in Case 3 was due to the small amount of stickies that remained after forward cleaning. As a result, the Stickies Deposition Test was repeated using the pulper stocks, representing the highest level of active contaminant content for all cases. Similar trends were again evident (**Fig. 13**). Chemical treatment of stickie contaminants under harsh pulping conditions in the presence of laser inks did not increase deposition potential when compared to contaminants generated under industry-accepted mild pulping conditions.

Conclusions

It has been demonstrated that ORP can be deinked under harsh pulping conditions, using appropriate chemistry, without an increase in stickies loading to the paper machine. The following conclusions were drawn from this experiment:

- Microscopic studies showed that fewer discrete stickies existed in the pulper stock in Case 3 (harsh pulping with chemical) than in Case 1 (mild pulping with no chemical) or in Case 2 (harsh pulping with no chemical). Macroscopic studies showed few discrete ink-free stickies in any case.

- Harsh pulping conditions without chemical treatment (Case 2) slightly enhanced the association of ink and stickie-ink contaminants. However, the contaminants possessed a loosely packed structure that broke up under high shear stress (fine screening).
- Harsh pulping conditions with chemical treatment (Case 3) dramatically enhanced the aggregation of ink and stickie-ink contaminants. These aggregates had higher density, larger size, and stronger bonding characteristics (particle integrity) than those particles seen in Case 2.
- Chemical treatment (Case 3) significantly improved macroscopic and microscopic contaminant removal during forward cleaning.
- Under the test conditions, forward cleaning was the most efficient removal process. Fine-screening efficiency improved only with the combination of increased particle size and improved aggregate bonding seen in Case 3. Through-flow cleaning provided only marginal contaminant removal for all cases.
- Microscopic dispersed stickies removal efficiency exhibited a strong correlation with macroscopic contaminant removal efficiency.
- The dispersed stickies concentration remaining with the pulp after mechanical separation processes was significantly lower with chemical treatment in the pulper than without chemical treatment.
- Contaminants from Cases 1 and 3 were less prone to deposition than those from Case 2. Laser-deinking chemical treatment did not increase contaminant deposition potential. TJ

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