DEINKING OF LASER-PRINTED STOCK USING CHEMICAL DENSIFICATION AND FORWARD CLEANING

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ABSTRACT

Mixed office waste is receiving considerable interest as a source of recycled fiber, particularly in printing and writing grades. The major problem in using mixed office waste (and the reason why it is currently underutilized) is that it contains from 50 to 80% non-impact printed material (commonly referred to as "laser" or "xerographic") which is difficult to deink. The current approach to deinking this furnish involves mechanical dispersion followed by mechanical removal and requires significant capital investment.

A new process for deinking non-impact printed waste has been developed. The process involves chemically enhanced densification of the toner particles to facilitate their removal by forward cleaning. Using this technology, a stock preparation/deinking system can provide clean pulp at substantially reduced capital investment.

This paper discusses the development of the chemical technology, the physical and chemical mechanisms by which densification is achieved, and key cleaning operating parameters. The results of 12 production-scale trials are reviewed. Ink removal efficiencies of 95-97% are demonstrated to be practical with the proper chemistry and correctly designed and balanced forward cleaning systems.

KEYWORDS

Deinking, Laser print, Xerographic print, Non-impact printing, Mixed office waste, Particle densification, Particle size, Forward cleaning

INTRODUCTION

The use of mixed office waste as a source of recycled fiber for printing and writing grades is receiving considerable interest and with good reason. The economic benefits associated with office waste include a lower cost source of chemical fiber and classification as postconsumer.[1] Additionally, the availability of this furnish will increase as recovery is expected to triple through 1995.[2] The environmental benefit of using office waste is a reduction of waste going to the landfills. Currently, office waste is a larger contributor to municipal solid waste than either ONP or OCC and is expected to surpass the solid waste load of the two combined by 1995.[3]

Deinkability of Mixed Office Waste

The major problem in using mixed office waste (and the reason why it is currently underutilized) is that it contains a high percentage of difficult-to-deink non-impact printed material.[4] Non-impact printing is an electrophotographic process (Figure 1) that uses a dry toner rather than ink. During the process, heat or the combination of heat and pressure is applied which causes the toner particles to fuse to the paper surface and one another. Although generally referred to as "laser print", the electrophotographic printing process is used in xerographic copy machines as well as high speed laser printers.

Toner may be removed from a fiber surface by repulping of the furnish under alkaline conditions. However, the separated particles are flat, plate-like, and of varying size,

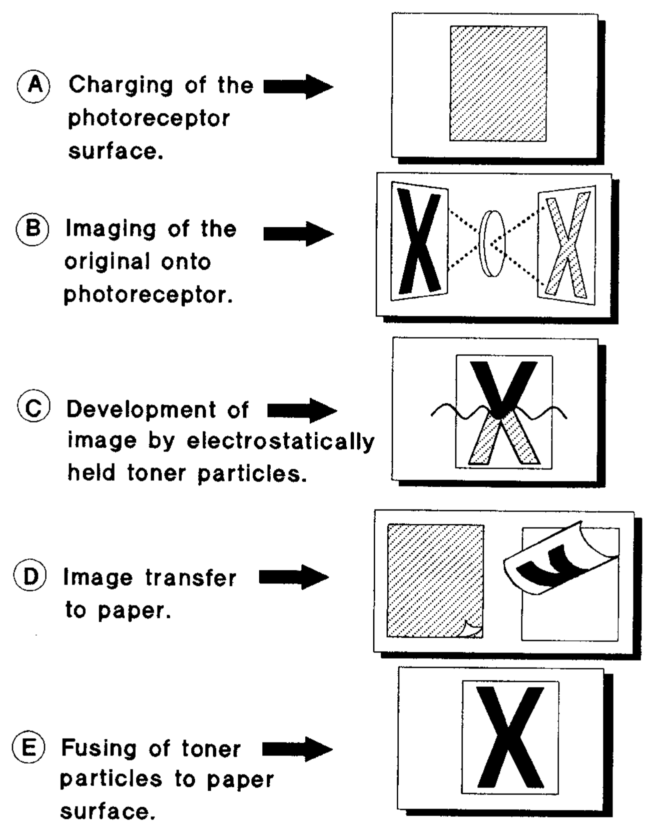


Figure 1: Steps in Electrophotographic Printing Process

and have a density close to that of water. This type of particle is not readily removed by conventional mechanical means such as screening, cleaning, flotation, or washing.[5] Consequently, the furnish can be used only at very low levels (1-2%) in printing and writing grades or in grades such as boxboard, where dirt in the final product is less of a concern.[6]

Current Approaches to Improving Deinkability

The more common approach to improving the deinked quality of non-impact printed material involves mechanical dispersion of the toner particles followed by mechanical removal. Figure 2 shows the recommended process for this approach.[7] Essentially, the system consists of two lines of conventional deinking equipment connected by a dispersion unit. The first line of equipment is designed to remove the conventional impact inks that are present in the office waste. The dispersion unit is expected to break up the remaining laser toner particles into a size that can be removed by the second line of deinking equipment. This approach requires significant capital investment.

A chemical approach has been described that requires the use of two proprietary formulations. The first product is intended to lower the glass transition temperature of the thermosetting resins contained in the toner particles. The second product is intended to act as a seed or collector, which causes the formation of large (2-4 mm) particles for subsequent removal by pressure screens.[8] The reported disadvantage of this approach is that consistently high percentages of laser ink are required in the furnish.[5]

Development of a New Deinking Process

A research program was initiated to investigate alternative means of improving the deinked quality of mixed office waste. Early in the investigation it was determined that the deinking technology must be able to:

- chemically modify the toner particles to facilitate their removal by mechanical means
- be effective for all non-impact printed material regardless of toner type
- function at low as well as high percentages of toner content in the furnish
- be independent of and not affected by water chemistry
- minimize equipment (capital) requirements

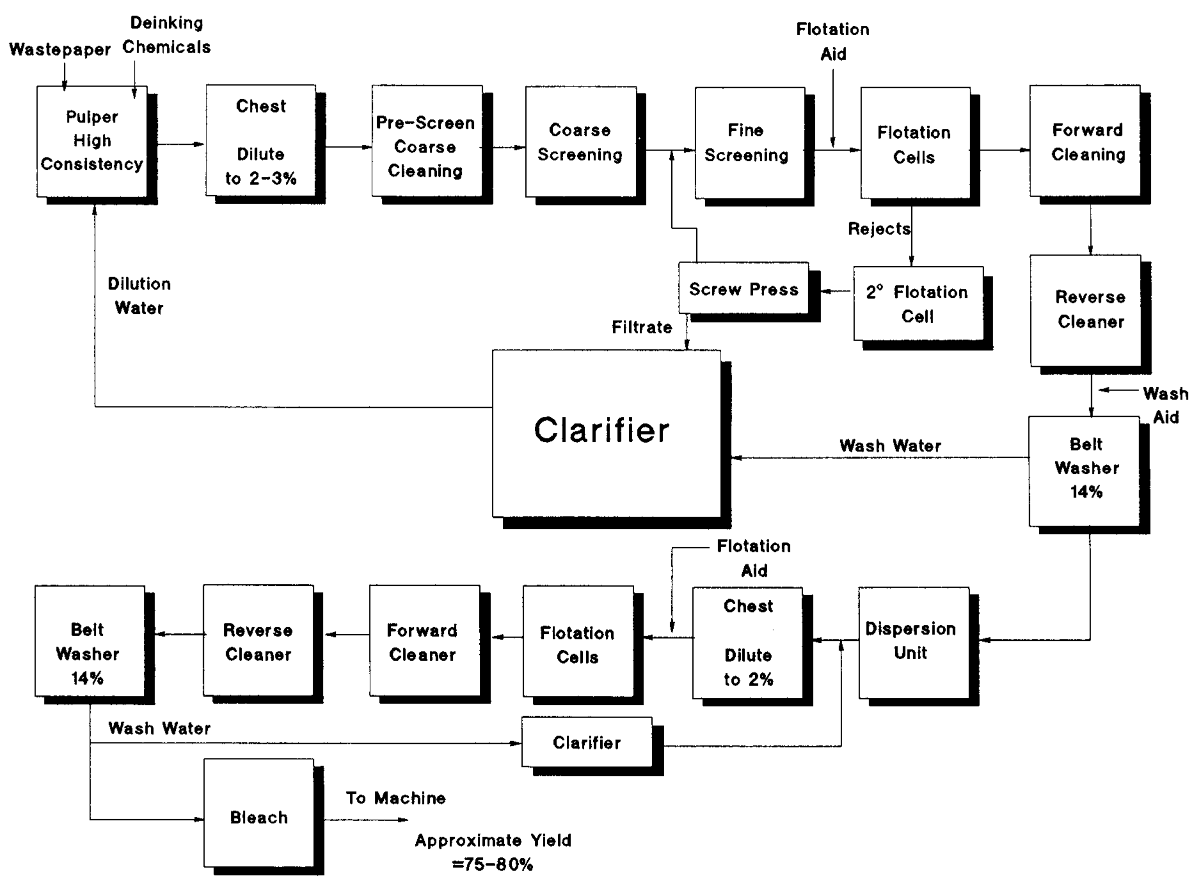


Figure 2: Existing Process for Deinking Mixed Office Waste

The experimental program undertaken to develop this technology involved characterizing toner types in terms of physical and chemical behavior, identifying the changes in surface chemistry necessary to modify the toner particles, selecting the most effective means of mechanical removal, determining the effect of process variables on removal and screening a wide variety of non-impact printed furnishes. The laboratory and pilot-scale results were confirmed on commercial-scale equipment at production facilities.

LABORATORY EVALUATIONS

Toner Characterization

The actual composition of toner is proprietary to the particular manufacturer and has been formulated for optimum performance in the equipment with which it is used. However, most toners contain the following general components:[9]

- ***Pigment***. The pigment is usually carbon black, although colored toners are also used.

- ***Base binder resin***. The base binder resin is responsible for fusing the toner particles and is selected based on the type of fuser used in the equipment. This resin is usually a blend of monomers and may be styrene acrylates, polyesters, or epoxy type resins.

- ***Modifier resin***. The modifier resin is usually a natural material such as abietic acid or rosin. It is used to enhance the strength of the toner/paper interface so that the toner will go with the paper rather than stay with the fuser roll.

- ***Charge control agents***. Charge control agents provide the toner particle with the electrostatic charge necessary for development. With equipment that uses magnetic charge development, the toner will contain iron oxide at a level as high as 50% by weight.

The physical and chemical behavior of toner from different types of electrophotographic equipment was evaluated in the laboratory. While this represented a large number of different toner types containing very different binder resins, it was found that they shared some characteristics. All of the toners softened and became tacky in the temperature range of 140 to 150 °F and they were considerably more hydrophobic (as measured by contact angle) than cellulose. The contact angle of cellulose, compared to several of the tested toners, is shown in Figure 3.

Modifying the Toner Surface Chemistry

Hydrophobic or "water-hating" particles suspended in the water phase have a strong attraction to each other as they try to satisfy their solubility (get out of the water phase). Once in contact, hydrophobic particles seek to minimize their free surface energy.

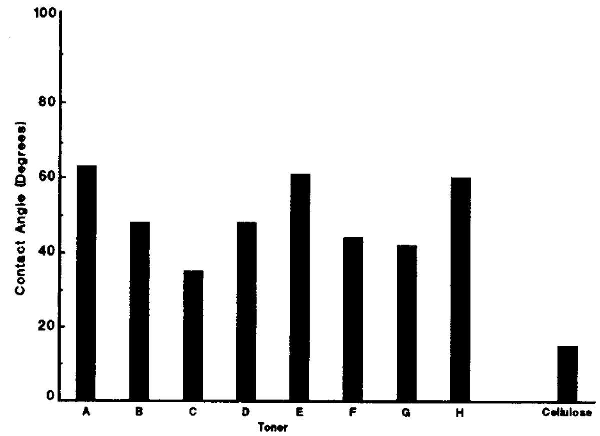


Figure 3: The Hydrophobicity (Contact Angle) of Cellulose as Compared to Several Toners

It was felt that an increase in the hydrophobic character of the toner particles would increase the attraction of the particles for one another. Under the influence of temperature and shear in the pulper, the decrease in particle surface area and volume would lead to denser, more spherical particles. These chemically modified (or densified) particles could then be removed using forward cleaning.

Surfactants adsorb onto and modify the surface properties of solid/gas, solid/liquid, and liquid/air interfaces. Combinations of a wide variety of these materials were evaluated for their ability to adsorb at the solid/liquid interface and increase the hydrophobicity of the toner particles. An example of the data is shown in Figure 4. With chemical treatment there was a significant increase

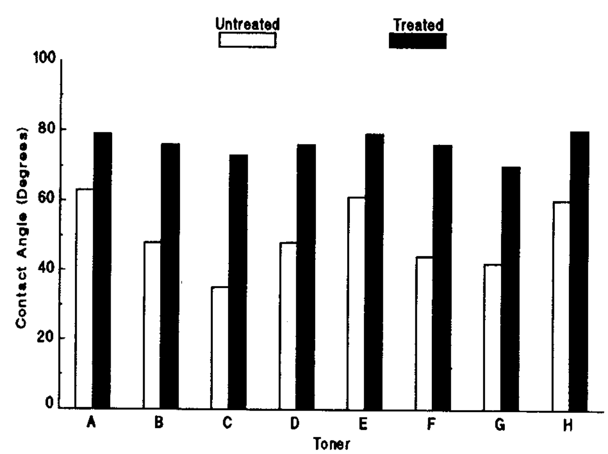


Figure 4: The Effect of Chemical Treatment on Toner Particle Hydrophobicity

in the contact angle or hydrophobicity of the different toner types tested.

In order to determine the effect of chemical treatment on particle density, a laboratory method was developed for measuring the density of individual particles. The method involves dropping a particle of known radius (measured using image analysis) through a column containing a solution of known viscosity. The terminal velocity of the particle is measured and an application of Stoke's law used to calculate density. Particles whose densities are lower than that of the solution are measured according to their terminal velocity as as they move up through the column.

This method made it possible to develop a density distribution of the toner particles with and without chemical treatment. As shown in Figure 5, there was a significant increase in particle density with chemical treatment. The treated particles had an average density greater that 1 g/cm³, which would facilitate their removal by forward cleaning.

"Pedigree" Furnish Testing

The ability to chemically modify and densify the toner particles had to be confirmed using actual furnish. Because it was also necessary to confirm that the chemical treatment was effective on all toner types, representative furnish samples were collected from a wide variety of electrophotographic equipment.

Each "pedigree" furnish was repulped in the laboratory pulper at 150 °F for 45 min with a 20 lb/T chemical treatment. Following pulping, a representative sample of particles was removed from the pulp slurry. The density of the individual particles was measured. As shown in Figures 6 and 7, there was a particle density increase with each of the furnishes tested. It is important to note that control (no chemical treatment) pulpers were run for each "pedigree" furnish. In each case, without chemical treatment the average particle density was less than 1 g/cm³.

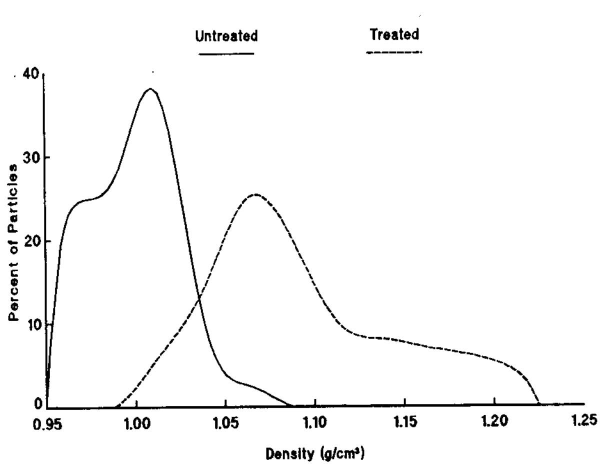


Figure 5: The Effect of Chemical Treatment on Toner Particle Density

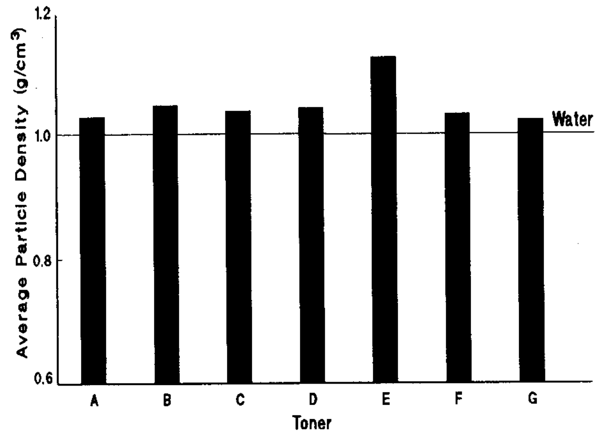


Figure 6: Pedigree Furnish Testing - The Effect of Chemical Treatment on Xerographic Toner Particle Density

Varying the Percentage of Non-Impact Printed Material

Due to the variable nature of office waste, it was necessary to confirm that the chemical treatment was effective even when the furnish contained low levels of non-impact printed material. For this study, conventional impact printed waste was blended with laser print at known ratios.

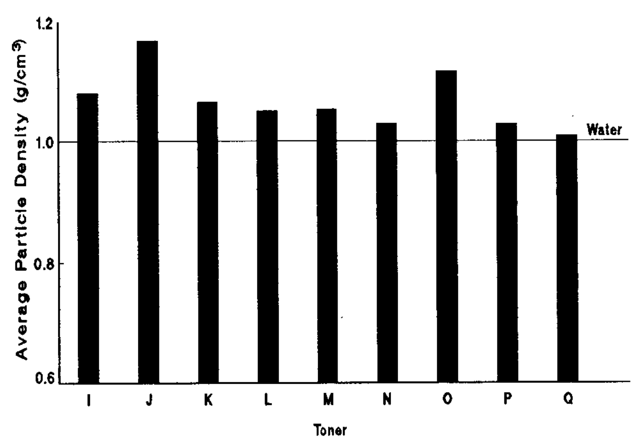


Figure 7: Pedigree Furnish Testing - The Effect of Chemical Treatment on Laser Print Toner Particle Density

Laser and impact-CPO were blended in the laboratory pulper at levels from 5% to 100% laser content. Chemical treatment and pulping conditions were held constant. The resulting mean particle sizes and densities are displayed in Figure 8. Reducing the laser-printed percentage in the pulper to 5% did not significantly reduce the mean particle density. There was a modest decrease in mean particle size. The resulting particles, independent of laser content, were of sufficient density and size to be efficiently removed by forward cleaning.

Effect of Water Chemistry on Density Development

A study was conducted to confirm that the chemical modification or densification of the toner particles was not dependent on or affected by the system water chemistry. Several pulper dilution water samples, supplied by mills, were used to repulp chemically treated mixed office furnish in the laboratory. Particles from these pulpers were compared with particles obtained when the same furnish was treated and repulped with fresh water.

The results indicated that the densification process was insensitive to changes in white water chemistry. White water solids contents of up to 0.8% consistency had no significant effect on densification. Ash (various carbonates and silicates) comprising up to 61% of the total solids caused no interference. Extractable organic constituents (up to 0.9%) that were present included fatty acids, ethoxylates, lignosulfonates, hydrocarbons, and a variety of other compounds. None of these constituents caused significant interference with the densification process.

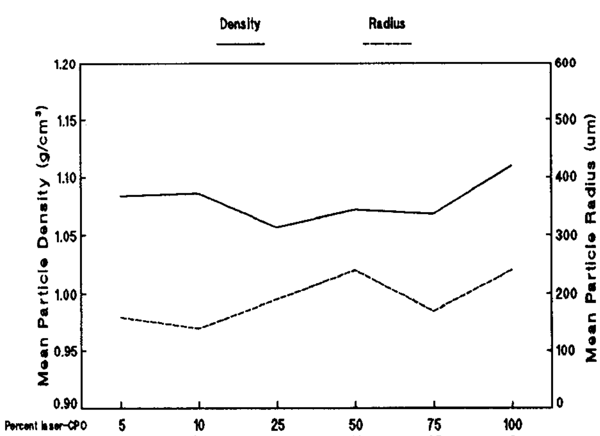


Figure 8: Varying the Percentage of Non-impact Printed Material Effect on Toner Particle Density and Size

PILOT-SCALE FORWARD CLEANING STUDIES

Experimental

Pilot Cleaning System. A forward cleaning system was set up to conduct replicated experiments using different furnishes, pulping conditions, chemical treatments, and cleaner process conditions. The pilot system was designed around a commercial 4-in. diameter centrifugal cleaner cone. The cleaner was fed from a 50-gal tank with a 7.5 Hp centrifugal pump. Feed and accepts pressures were adjusted by means of hand valves. Stock could be recirculated to the feed tank during start-up or directed to accepts and reject tanks for sampling. The size of the equipment allowed batch runs of 1-2 min in length.

Pulping Conditions. Mixed office waste furnishes were obtained from several waste paper brokers. Repulping was performed using the laboratory hydropulper (2-lb capacity) under the following range of conditions:

- temperature: 140-150 °F
- pH: 7-11
- time: 15-45 min
- chemical treatment: 10-20 lb

Particle Density Measurement. Forward centrifugal cleaning is a separation process in which the denser, lower specific surface area material is selectively fractionated into the rejects. To study the ability of the cleaner to remove treated laser particles, the method described previously was used to measure the density of particles in the feed stock.

Particle Size Analysis and Dirt Count Measurement. Several measurement techniques, using a Brinkmann Particle Size Analyzer outfitted with a video camera, were developed to quantify the changes in laser particle characteristics that occurred with chemical treatment. Methods were developed for measuring the particle size distributions of discrete particles removed from the pulp and particles imbedded in handsheets.

Particle size analysis was also used to quantify the removal efficiency of treated laser particles during forward cleaning. The Brinkmann measurement technique for handsheets was modified to provide a total dirt area which could be expressed as a dirt count in parts per million.

The Brinkmann Dirt Count values are significantly higher than manually performed TAPPI Dirt Counts because the measurement is done at 11x magnification and includes particles of 0.005 mm² and greater. The TAPPI Dirt Count excludes particles smaller than 0.04 mm². However, a strong correlation was found to exist between Brinkmann Dirt Counts and those manually performed using TAPPI

Method T437. Using this correlation, it was possible to convert the Brinkmann Dirt Counts to the more generally accepted TAPPI Dirt Count.

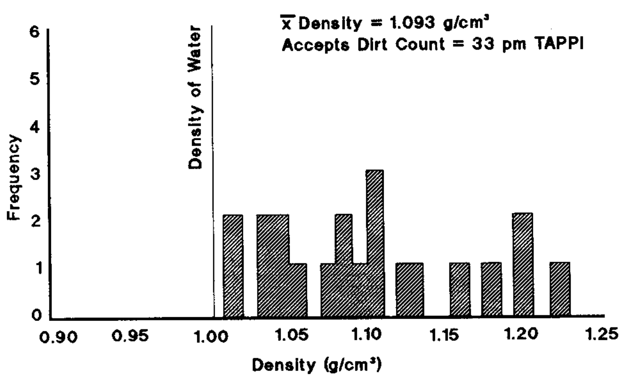
Results

Effect of Particle Density. Particle density measurements of cleaner feed stocks showed that the untreated, smaller, flake-like laser particles had densities slightly less than 1 g/cm³. The treated laser particles were larger with a spherical or granular shape but, more importantly, had densities >1 g/cm³. This subtle shift in the particle density distribution significantly increased the removal of the laser particles through forward cleaning.

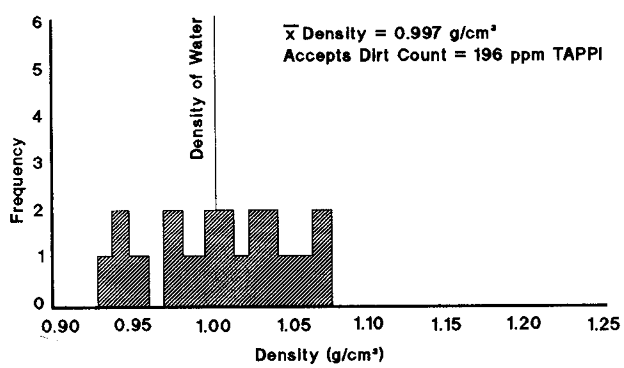
Figure 9 is an example of the effect of particle density on removal efficiency. Pulping conditions (i.e., chemical treatment) were adjusted to produce cleaner feed stocks with similar dirt counts but with two different particle density distributions. The feed stock used in Run A had a particle density distribution >1 g/cm³ (mean of 1.093 g/cm³). With one pass across the cleaner, the accepts TAPPI Dirt Count was 33 ppm. The feed stock in Run B had a mean particle density of 0.997 g/cm³. Under identical cleaning conditions, the accepts TAPPI Dirt Count was 196 ppm. The absolute difference between the two distributions is small (mean of 1.093 vs. 0.997 g/cm³) but because it is so close to 1 g/cm³; the relative difference is extremely important.

Effect of Particle Size. This study also showed that particle size development was of secondary importance to density development. Figure 10 shows the particle radius histograms for the two cleaner feed stocks described above. Run B clearly had larger particles (mean radius of 810 μm) but had a poorer removal efficiency than Run A (mean radius of 379 μm). Although some size development and attainment of a spherical or granular shape was important, the mechanism that permitted efficient particle removal by forward cleaning was the subtle increase in particle density that occurred as a result of chemical treatment.

Effect of Cleaning Process Variables. Cleaning process variables, such as pH, temperature, pressure drop, and feed consistency, were studied for their effect on treated laser particle removal efficiency. Feed consistency had a significant effect on accepts pulp cleanliness. As shown in Figure 11, a decrease in the feed consistency from 0.8% to 0.4% improved the accepts TAPPI Dirt

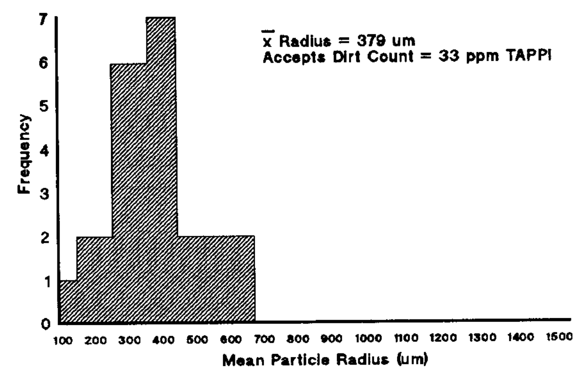


Run A – Cleaner Feed Density Histogram

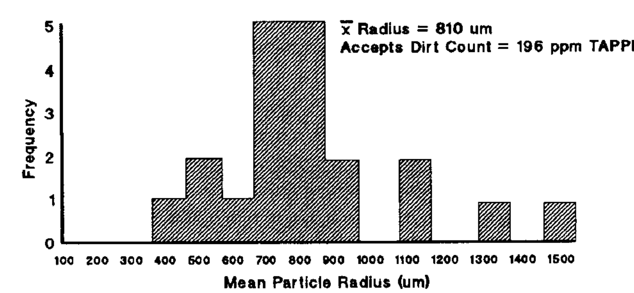


Run B – Cleaner Feed Density Histogram

Figure 9: Effect of Treated Particle Density on Forward Cleaning Removal Efficiency



Run A – Cleaner Feed Particle Size Histogram



Run B – Cleaner Feed Particle Size Histogram

Figure 10: Effect of Treated Particle Size on Forward Cleaning Removal Efficiency

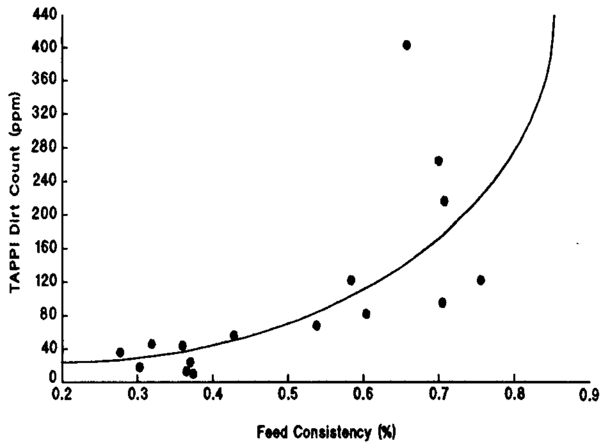


Figure 11: Effect of Feed Consistency on Cleaner Removal Efficiency

Count from 340 to 40 ppm with one pass across the cleaner. The importance of this effect was also evident in commercial scale equipment.

PRODUCTION-SCALE FIELD TRIALS

Trial Conditions

A series of production-scale trials were begun in April, 1991 to investigate the effects of:

- cleaner types (different diameters, standard vs. low reject rate tips)
- configurations (single vs. series primary, varying feed consistencies)
- furnish (varying non-impact ink content, mixed office waste, laser CPO)

The pulping conditions used during these trials were as follows:

- temperature: 145-155 °F
- pH: 11.0
- time: 30-60 min
- chemical treatment: 20 lb/Ton

Results

The results of these trials are summarized in Table 1. Trials A, D, G, and H were conducted at production facilities. Trials B, C, E-F, and I-L were performed with production-scale pilot equipment. The average percent dirt reduction for each trial is presented in Figure 12. The cleaner accepts TAPPI Dirt Count is presented in Figure 13.

Effect of Cleaner Type. Three-inch diameter cleaners were able to provide higher treated laser particle removal

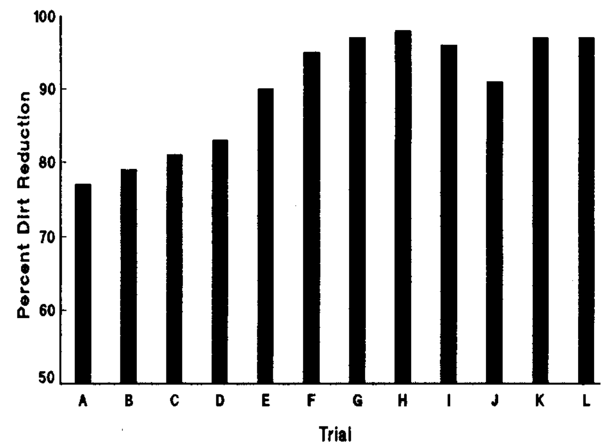


Figure 12: Field Trial Results: Dirt Reduction by Forward Cleaning

efficiencies than 6-in. diameter cleaners (Trial I vs. A and Series Trial H vs. G). The ink removal performance of 4-in. cleaners (Trial E) was also better than that of 6-in. cleaners (Trial A).

Low reject rate tips are used to limit the number of cascading stages, capital costs, and power consumption. Their effect on laser particle removal was evaluated in Trials B and C. The performance of these types of cleaners (averaging 80% dirt removal for a single pass) was inferior to similar size cleaners with standard tips (91% removal in Trial J). Low reject rate systems are suitable for many recycling and stock preparation applications. However, in this case, the very high debris loading in the feed overwhelms the cleaner's ability to remove it.

Effect of Cleaner Configuration. Series primary cleaning (two passes through primary cleaners) was generally required with pulp of high non-impact ink content. This ensured that accepts with consistently low dirt counts were produced (Series Trials F-H, K, L). In the best case,

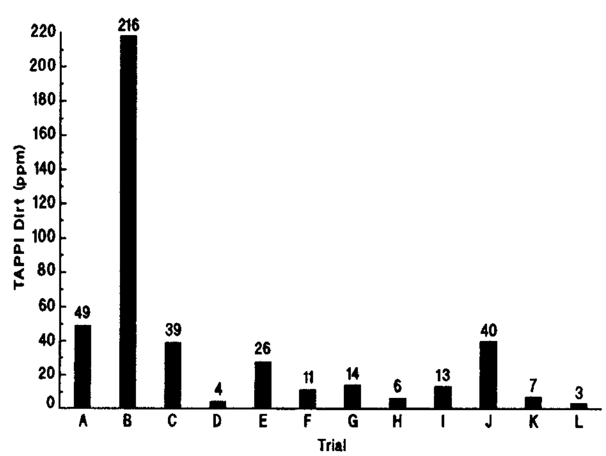


Figure 13: Field Trial Results: Cleaner Accepts TAPPI Dirt Count

TABLE 1: Summary of Laser Deinking Field Trials

Trial	Date (1991)	Furnish to Cleaner	Series/Single Primary	Cleaner Diameter (in.)	Configuration Type Standard/LRR	Primary Feed Consistency(%)	Feed Dirt (ppm Brink)	Accept Dirt (ppm Brink)	Brink Dirt Reduction (%)	Accept TAPPI Dirt Estimate (ppm)
A	April	40% Laser-CPO	Single	6	Standard	0.46	2647	611	77	49
B	May	100% MOW* (75% non-impact)	Single	3	Low Reject Rate	0.70	5770	1776	79	216
C	May	100% Laser-CPO	Single	3	Low Reject Rate	0.70	2650	512	81	39
D	May	10% Laser 90% Impact	Single	6	Standard	1.6	552	95	83	4
E	June	50% Laser-CPO/ 50% Impact	Single	4	Standard	0.45	3990	386	90	26
F	June	50% Laser-CPO/ 50% Impact	Series	4-4	Standard	0.45	3990	210	95	11
G	June	100% Laser Waste	Series	6-6	Standard	0.50	7310	243	97	14
H	June	100% Laser Waste	Series	6-3	Standard	0.50	7310	131	98	6
I	July	100% MOW* (75% non-impact)	Single	3	Standard	0.50	6500	229	96	13
J	July	100% MOW* (75% non-impact)	Single	3	Standard	0.75	5539	520	91	40
K	July	100% MOW* (75% non-impact)	Series	3	Standard	0.75	5539	153	97	7
L	July	50% MOW* 50% Impact-CPO	Series	3	Standard	0.75	3360	89	97	3

*Mixed Office Waste

Trial L, pulp with a TAPPI Dirt Count of 3 ppm was produced from a blend of 50% treated mixed office wastes and 50% untreated impact-CPO. TAPPI Dirt Counts of 6-7 ppm were achieved from 100% laser (Trial H) and 100% mixed office waste (Trial K).

As observed in the laboratory evaluations, a reduction in the cleaner feed consistency reduced the accepts dirt count. One pass of cleaning at 0.5% feed (Trial I) had better removal efficiency (96% vs. 91% dirt reduction) than one pass of cleaning through the same system at 0.75% consistency (Trial J). A second series pass at 0.75% had to be added (Trial K) to lower the dirt count below that achieved with one pass at 0.5% consistency.

Effect of Furnish Composition. The amount of non-impact printed waste in the trial furnishes ranged from 10 to 100%. As shown in Figure 14, a strong correlation existed between the dirt content of the cleaner feed and the level of non-impact printed material in the furnish. However, even at low levels of laser in the furnish, sufficient particle density was developed to achieve efficient removal of the particles. Mills with equipment constraints (i.e., Trial D) can alter the dirt content of their pulp by adjusting the percentage of chemically-treated laser pulp prior to cleaning. Pulp blending should be performed after the pulper.

RECOMMENDED LASER DEINKING PROCESS DESIGN

Traditionally, centrifugal cleaners have been relied upon to remove relatively modest concentrations of debris (contaminants, tramp material, etc.) from the stock.

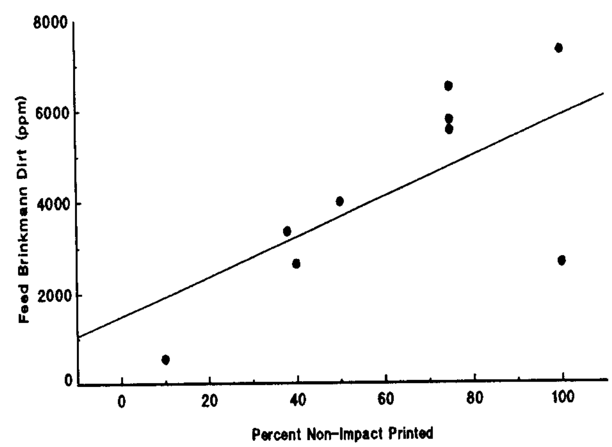


Figure 14: Effect of Non-Impact Print Content on Feedstock Dirt Count

With chemical densification of laser toner particles, the role of the forward cleaner is being re-defined to that of a primary "deinking" unit. During the trials described above, extremely high concentrations of material (densified toner) were intentionally introduced to the forward cleaner and effectively removed. The pulp produced was of sufficient cleanliness and brightness (normally 80+ TAPPI without bleaching) to be used in printing and writing grades.

Based on these experiences, a recommended laser deinking process design is presented in Figure 15. The key points of the system include:

- Pulping–20 lb/Ton chemical treatment, pH 11, 145-155 °F and 30-45 min batch time.
- Series primary forward cleaning–two stages of primary cleaning, 3-in. diameter standard cones, feed consistency 0.5%. Series primary cleaning is necessary when a high laser-ink content is in the waste furnish. It ensures that the pulp cleanliness is suitable for fine paper manufacturing.
- Screens and through-flow cleaners–for removal of contaminants, not laser ink.
- Single-stage washing and water clarification–for removal of easily dispersible impact inks from the mixed furnish.

This process is considerably less complex and less capital-intensive than those currently proposed for removal of non-impact printing ink.

CONCLUSION

A new process developed for deinking mixed office waste involves chemical densification of laser toner particles and subsequent removal using forward cleaning. The increase in particle density and its effect on cleaning efficiency was documented in laboratory and pilot-scale studies and confirmed in 12 production-scale trials.

To date, the chemical treatment has been effective regardless of toner type, laser content in the furnish, and system water chemistry. With two passes of primary forward cleaning, the cleanliness of the accepts was acceptable for use in printing and writing grades.

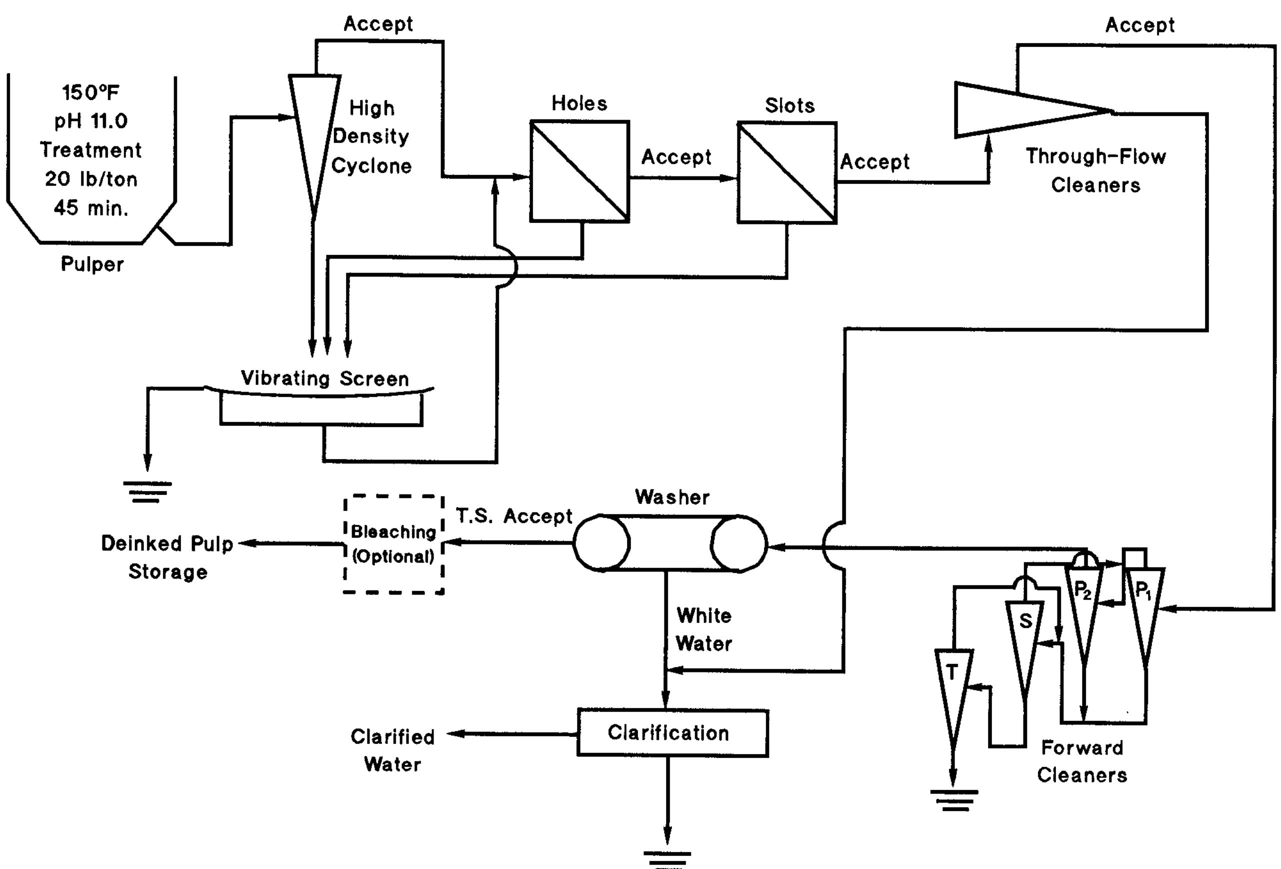


Figure 15: Proposed Laser Deinking Process Flow Diagram

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