RECYCLING, PAPER

1. Introduction

Paper recycling mills encompass a range of unit operations. The choice and sequence of these operations are determined by the types of recovered paper being processed; the types of paper products produced; availability of process water; economic considerations; and environmental considerations.

There are a wide variety of recovered paper types (Table 1) and grades within each type (1). The types of recovered paper being processed determine the contaminants that must be removed. The types of paper products being produced determine the degree to which these contaminants are removed. Contaminants include ink, adhesives and glue, rosin, wax, starches and gums, coatings, paper fillers, styrofoam, and plastic from bags and tape. Adhesives, glue, and waxes are grouped together and called "stickies" (2,3).

Important unit operations in these mills include pulping; high density cleaning; screening; forward cleaning; reverse cleaning; washing; flotation; dispersion and kneading; bleaching; water treatment; and sludge handling.

These operations are designed to remove contaminants from the pulp. The effectiveness of these separation operations is determined by contaminant particle size, geometry, density, and surface chemistry. This is illustrated in Fig. 1 for ink particles (4). The unit operations most effective for various types of other contaminants (2) are summarized in Table 2. Correct choice of process chemicals can improve the effectiveness of some of the unit operations listed in Fig. 1 and Table 2.

Representative sequences of unit operations are presented in Fig. 2 for a wash deinking mill processing old newspapers to make newsprint; a modern mill processing mixed office papers to produce printing and writing paper; a flotation-wash mill processing a mixture of old newspapers and old magazines to make newsprint; a mill processing old paper to make tissue products; and a mill recycling old corrugated containers. Most recovered office paper is consumed by tissue mills and boxboard mills or exported and not used to produce new office paper (5).

2. Contaminants

Inefficient removal of ink can cause low recycled paper brightness and the appearance of visible specks on recycled paper sheets. Stickies can also be visible on the sheet. However, they can cause additional problems as well. Stickies can interfere with efficient paper machine operation by sticking to wires, felts, uhle boxes, and dryer cans. This plugging can reduce paper machine drainage rates forcing mill operators to run machines at lower speeds thus reducing paper production. Periodically shutting down the mill to clean felts also reduces the level of stickies in the finished paper. Stickies remaining in the paper can cause it to adhere to itself when taken up on a paper roll. This results in tears and pressroom breaks interfering with printing operations. While stickies surfaces may be detackified using talc or copolymers of acrylic acid and maleic acid (6), stickies removal from the pulp remains very important. Removal of both ink and stickies will be reviewed below in the discussion of the various unit operations used in paper recycling mills.

3. Pulping

The first of these unit operations is pulping. Pulping disintegrates paper into individual fibers dispersed in water. It may be a batch or continuous process. Added chemicals combined with the mechanical forces of agitation promote ink detachment from fibers (Fig. 3) and adjust the dispersed ink particle size. Newsprint deinking mills commonly use continuous pulping. Most mills producing tissue products or printing and writing paper from deinked pulp use batch pulping.

Low consistency pulping (3–6% solids) is common in newsprint and many tissue mills. Medium (6–12%) and high consistency pulping (12–18% solids) is common in mills deinking office papers. Pulping temperature is typically 40–55°C. The pH is usually 9.0–10.5. Process time ranges from 4 to 60 min.

Both mechanical and chemical action promote ink detachment from cellulose fibers during pulping. Mechanical action includes interfiber abrasion and fiber flexing and bending. Chemical action includes fiber swelling and surfactant-promoted ink particle emulsification and solubilization.

Fiber swelling is promoted by high pH. For this purpose, sodium hydroxide is often added to the pulper. As much as 3% (based on dry paper weight) may be used (7). However, more typical dosages are 0.8–1.5%. Newsprint and magazines are commonly pulped at pH 8–10. In office paper deinking, pulper pH is sometimes as high as 10–11, but may be as low as 7–8. There has been increased interest in neutral pH deinking, which is said to significantly reduce chemical costs by U.S.$2–5 per ton due to the elimination of caustic, hydrogen peroxide, chelating agent, biocide and some or all of the sodium silicate used in the pulper. Hydrogen sulfite has been added to the pulper to compensate for the low pulp brightness produced in neutral pH pulping.

High pH can promote yellowing of lignin-containing pulps (usually groundwood or thermomechanical pulp). To minimize this, a bleaching agent, usually hydrogen peroxide, is often added to the pulper. Hydrogen peroxide treatment levels up to 2% of the dry paper weight are used (7). Chelants are added to retard hydrogen peroxide decomposition promoted by multivalent metal ions present in the process water. The most commonly used are sodium silicate, ethylenediaminetetraacetic acid (EDTA) and diethylenepentaminetetraacetic acid (DPTA). Both EDTA and DTPA dosage levels are ~0.15–0.4% relative to dry paper weight. Sodium silicate, which also may be used to control pH, is used at dosages of 1.0–3.0% based on dry paper weight (7).

Surfactants are added to the pulper to promote ink particle detachment from fibers and dispersion of detached ink in the process water. Dosages are 0.25–1.5% relative to dry paper weight (7). Mechanisms of ink removal are similar to those proposed for liquid soil removal from fabrics (8). Toner inks are thought to behave similarly to solid soils (8,9).

Some researchers have proposed using enzymes to promote deinking, particularly of xerographic and toner-printed paper (10,11). The enzyme is thought to function by detaching ink-containing fibrils from cellulose fibers during pulping. A high ratio of beta-glucosidase activity to filter paper units (FPU) is thought to be required (12).

Surfactants also can provide some control over the particle size of detached ink. The effectiveness of different deinking unit operations in separating dispersed ink from cellulose fibers varies with ink particle size (Fig. 1). In deinking office paper containing toner ink printed paper, some deinking agents promote aggregation of dispersed ink into three-dimensional (3D) ink particles (13–16). These are more easily removed by fine screens and some types of cleaners than the two-dimensional (2D) toner ink flakes usually formed during pulping. Thus, deinking process engineering can determine the type of surfactant used in the pulper.

Ink particle redeposition on cellulose fibers can reduce deinked paper brightness. Should larger ink particles redeposit on fibers, visible ink specks may result. Sodium silicate is often added to the pulper to act as a dispersant and to reduce this redeposition (8,17). Up to 5% (based on dry paper weight) may be used (7). Redeposition appears most severe with flexographic newsprint ink because of the very small particle size of the dispersed ink (17). These very small water-based ink particles are not difficult to detach from cellulose. However, they redeposit on fibers readily (18). Use of laundering antiredeposition agents, such as carboxymethyl cellulose and sodium poly (acrylate), can increase deinked sheet brightness (19). Presumably, these chemicals function by reducing dispersed flexographic ink particle redeposition onto cellulose. Removal of ink particles from process water during water clarification for recycle is also important.

The use of mixtures of sodium sulfite and sodium carbonate $>$ pH 7.5 has been reported to provide improved deinking results (20).

Mild pulping conditions preserve stickies as relatively large particles permitting their later removal by screens and mechanical cleaners. For example, wax is a common contaminant in mills recycling old corrugated containers. Pulping $< 50^{\circ}$C helps prevent wax from melting. This makes the wax easier to remove using fine screens and mechanical cleaners.

Another technique to reduce the problems caused by stickies is to use additives to reduce the tackiness of these particles. This prevents their later reagglomeration and attachment to paper machine surfaces. These additives are usually added to the pulper. The most common is talc (21) usually added to the pulper in repulpable bags. Emulsified talc is also sometimes added to the pulp just before the pulp encounters high shear. Organic polymers (22), such as a polyvinylpyrrolidinone copolymer (23) have also been reported to reduce the tackiness of stickies.

Dispersants have been added to the pulper to maintain stickies is a colloidal state. The small particle size reduces the problems stickies cause on the paper machine and in the paper products. Among the chemicals that have used are fatty alcohol ethoxylates, alkylphenol ethoxylates, lignosulfonates, and napthalene sulfonates (22).

4. High Density Cleaning and Screening

High density cleaning is usually the first step after pulping (24). These cleaners remove high and medium density large particles: rocks and dirt, nuts, bolts, nails, paper clips, and other objects often found in wastepaper. Centrifugal forces separate the less dense cellulose fibers from these heavy objects. Large objects also are removed using a perforated plate called a pulper detrasher.

Screening usually follows high density cleaning (25,26). Screening removes relatively large ink (Fig. 1) and (usually low density) contaminants from the pulp slurry. Coarse screens are fitted with holes, which permit the passage of cellulose fibers and liquids while holding back large particles. Hole size ranges from 6 to 20 mm (27). Fine screens are fitted with slits as small as 0.15–0.30 mm in width. These separate smaller (down to $\sim 250\,\mu$) contaminant particles and toner ink particles from the pulp. These contaminants include unpulped paper, plastic, and large adhesive particles from envelopes and labels. Fine screening also can remove some large toner ink particles. Careful design of the rotor in these screens can minimize the build-up of a mat of fiber reducing operating rates and separation efficiency.

5. Washing

Washing is used to remove dispersed ink particles from the pulp slurry (28). This process is comparable to home laundering in many ways. The surfactant is added to the pulper at a dosage level of 0.25–1.5% relative to dry paper weight. Strong dispersants such as alcohol ethoxylates and alkylphenol ethoxylates perform well in wash deinking. These surfactants promote ink particle dispersion by increasing the hydrophilic nature of the ink particles on which they adsorb. Washing is most effective in removing small, dispersed ink particles such as letterpress, offset, and flexographic newsprint inks. It is less effective on large, poorly dispersed ink particles such as toner inks from photocopiers and laser printers and ultraviolet (uv)- and heat-set inks.

The optimum surfactant hydrophilic:lipophilic balance (HLB) for wash deinking is dependent on ink composition. Surfactants with a HLB of about 14.5 provide the highest deinked newsprint brightness (29). The optimum deinking surfactant HLB for ledger inks is 13–14 while that for toner inks is 10–11 (30).

Water removed from the pulp slurry during washing passes through a mat of paper fibers. As more water is removed from the pulp, the pulp consistency at the washer discharge increases. Commercial washers can be classified on the basis of their discharge pulp consistency (28): low consistency - up to 8% consistency (sidehill screens and gravity deckers); intermediate consistency (8–15% consistency) (high speed belt washers, inclined screw extractors, and vacuum filters); high consistency (>15%) (screw presses and belt presses). Cellulose fiber loss is a function of washer design and pulp discharge consistency (28).

Typical papers processed using wash deinking are 100% old newspaper and sorted office paper from which toner ink-printed paper has been removed.

The effluent from washers is heavily laden with ink, mineral coating and filler particles, and small cellulose fibers. As a result, it can be difficult to clarify (see below).

6. Flotation

Flotation is used alone or in combination with washing and cleaning to deink office paper and mixtures of old newsprint and old magazines (31). An effective flotation process must fulfill four functions:

1. Efficiently entrain air. Air bubble diameter is $\sim 1000\,\mu$. Typically air bubbles occupy 25–60% of the flotation cell volume. Increasing the air/liquid ratio in the flotation cell is said to improve ink removal efficiency (32).
2. Ink must attach to air bubbles (Fig. 4). This is primarily a function of surfactant chemistry. Air bubbles must have sufficient residence time in the cell for ink attachment to occur.
3. Minimal trapping of cellulose fibers in the froth layer. This depends on both cell design and surfactant chemistry.
4. Separate the froth layer from the pulp slurry before too many air bubbles collapse and return ink particles to the pulp slurry.

Pulp slurry consistency during flotation is typically 0.7–1.2%. Air enters the pulp slurry as bubbles. Surfactants adsorbed on ink particles render them hydrophobic promoting adsorption onto air bubbles (Fig. 4). Thus, optimum HLB values are significantly lower for flotation deinking surfactants than for wash deinking surfactants. Flotation deinking surfactants are added either to the pulper or immediately before flotation. Adsorbed ink and mineral coating and filler particles rise with the bubbles to the top of the flotation cell. These solids plus small cellulose particles are trapped in the foam layer. The surfactant stabilizes the foam long enough for it to be removed before many bubbles collapse and return ink to the pulp slurry.

Early flotation deinking surfactants were fatty acids. Fatty acids are often referred to as collectors. They require calcium ions to function. A minimum water hardness of $\sim$90 ppm (as calcium carbonate) is needed (1). The calcium salt can be generated *in situ*, usually by addition of a soluble Ca^{2+} salt, such as calcium chloride. Process water naturally containing high levels of hardness ions may not require addition of a calcium salt. Calcium carbonate filler particles in magazine paper can also serve as a calcium source. Fatty acids are added just before flotation at dosage levels up to 1.0% based on dry paper weight. This is two to five times that of more recently developed flotation deinking surfactants.

More recently developed flotation deinking surfactants are proprietary alkoxylates of fatty alcohols or fatty acids containing both ethoxy (EO) and propoxy (PO) units (33–35). Patents suggest the optimum products are synthesized by adding an $\sim$2 : 1 by weight mixture of EO and PO to an alcohol or carboxylic acid substrate such as stearic acid (36,37). However, the situation is complex as EO/PO ratios ranging from 1 : 2 to 4 : 1 have been claimed in the patent literature to be effective deinking agents (38,39). Alkoxylates in which the EO and PO are added separately to form two or more blocks can also be used (40). Hydrophobe chain lengths typically are 12–18 carbon atoms. Lanolin alcohol and fatty acid alkoxylates have also been used (41). Deinking efficiency of branched and twin-tailed hydrophobe alkoxylates is said to be superior to single-chain hydrophobe alkoxylate surfactants (33,42). Another formulation contains a mixture of two alkoxylates with different cloud points plus a polyester of a cyclic aliphatic diacids (43). These surfactants are often formulated with fatty acids. Ethylene oxide-propylene oxide copolymers are also used in flotation deinking operations (44).

Excessive foaming results in undesirably high fiber yield loss during flotation. While proper choice of flotation agent can reduce this, the use of sorbitan fatty esters and other chemicals to control foaming has been reported (45). Sodium silicate wetting, emulsifying, penetrating, and other surface-active properties do not appear to impact ink removal efficiency in flotation (37).

Flotation can also remove some of the paper filler and coating particles dispersed in the pulp. Addition of certain cationic organic polymers and acid salts of amine compounds improves the removal efficiency of these particles during flotation (46). Flotation of pulp made from wax-coated corrugated boxes to remove wax has also been reported (47).

7. Mechanical Cleaning

A cleaner is a hydrocylone device utilizing fluid pressure to create rotational fluid motion (24). Pulp is introduced tangentially near the top of the cleaner. Contaminants denser than water such as chemically treated toner inks and sand migrate toward the outer wall of the cleaner and exit in a separate (reject) stream. For most forward cleaners, optimal ink removal efficiency is obtained at a pulp consistency of 0.2–0.3%. Most forward cleaners' deinking efficiency declines at pulp feed consistencies $>0.4\%$. However, a cleaner said to be efficient at 1.2% pulp consistency has been reported (48).

To reduce fiber yield loss, the rejects stream from a multistage array of forward cleaners has been field to a flotation cell and the flotation cell accepts been fed to a second bank of centrifugal cleaners (49). Reverse cleaners operate on the same principles as forward cleaners (24). Contaminants less dense than water migrate toward the center of the cleaner and exit as a separate (reject) stream from the pulp slurry. Reverse cleaners are used to remove adhesive and plastic particles as well as paper filler particles and low density particles formed from paper coatings. Cleaners are most efficient on relatively large particles, 80–300 μ in diameter (Fig. 1). Flat toner ink particles can fragment during processing. So it is probably best to locate mechanical cleaners early in the sequence of office paper deinking unit operations (50).

Forward and reverse cleaning are considered to be purely mechanical processes. However, use of certain deinking agents can facilitate removal of toner inks using forward cleaners by increasing ink particle size and/or density in the pulper (16). Proprietary surfactants have been found to promote the formation of 3D dispersed toner particles (13). These have a higher apparent density than the flat ink flakes usually formed during pulping. The 3D character thus facilitates ink removal in forward cleaners (13,51).

8. Dispersion and Kneading

Dispersion and kneading are mechanical processes designed to reduce dispersed ink particle size through fiber–ink abrasion processes (52,53). Fiber–fiber abrasion can detach additional ink from fibers. Dispersion is performed at elevated temperatures above the softening point of toner inks (~65°C), uv-cured inks (85–120°C), and adhesive particles (85–110°C). Particle softening can aid in reducing particle size. Kneading may be performed at ambient temperature. Both processes are performed at high consistency, up to 30% by weight cellulose fiber (54). This particle size reduction reduces the number of visible ink particles.

Dispersion and kneading are often used for pulp containing toner inks since these inks tend to form large particles during pulping. Dispersion and kneading reduce toner ink particle size below the visible range. With pulp made from old newsprint and magazines, dispersion is sometimes used after flotation and washing to improve optical homogeneity of paper made from the deinked pulp.

Washing and/or flotation are often performed after dispersion or kneading to remove the small ink particles formed in these processes. This removal significantly increases deinked pulp brightness (54). Flotation can also further reduce the number of visible ink particles.

Dispersion at temperatures of 90–110°C is a common final step in European mills processing wax-coated old corrugated containers. Dispersion temperatures < 90°C are reported to reduce wax particle size to improve pulp drainage properties on paper machines while improving paper strength (55). Dispersion has been used to reduce hot melt adhesive, plastic coating, and asphalt particle size. These low-density particles can then be removed from the pulp by flotation (56).

9. Agglomeration

Agglomeration agents are sometimes used to promote aggregation of toner-based inks with conventional inks and other contaminants. Among the agents used to promote this aggregation are detergent range alcohols and low mole alcohol ethoxylates. Fine screening, centrifugal cleaning or flotation is then used to remove the large, aggregated ink particles. To improve agglomerated particle separation in forward cleaners, densifying agents have been added. When the densifying agent is magnetic, magnetic removal may be employed to remove the ink and contaminants (57).

A novel technique recorded in the patent literature (58) involves photocopying using paper containing a removable modified silicone oil and curable silicone compound coating on which the toner inks are deposited. Removing of the coating provides a sheet of paper suitable for reuse.

10. Bleaching

Bleaching has a long history since it was first developed for bleaching cellulose fibers prepared directly from wood (59). In paper recycling, bleaching agents are used both during pulping and in separate bleaching operations performed after removal of inks and other contaminants from the pulp (59,60). Bleaching during pulping to retard fiber darkening at high pH is discussed above.

Bleaching as a separate operation whitens fibers and removes the coloring effect of dyes. As practiced in paper mills, bleaching is a multistage operation using different bleaching agents in each stage. There are two types of bleaching: oxidative and reductive. Oxidative bleaching cleaves carbon–carbon double bonds thus destroying chromophores. Reductive bleaching reduces carbon–carbon double bonds to single bonds. The loss of extended conjugation in the chromophore leads to loss of color.

Common oxidative bleaches are hydrogen peroxide; sodium hypochlorite; chlorine dioxide; oxygen; and ozone. Although it is a very cost-effective bleaching agent, sodium hypochlorite is not used extensively to whiten deinked pulp due to environmental concerns. Reductive bleaches include sodium hydrosulfite and formamidine sulfinic acid (FAS). Oxygen gas in combination with an alkaline agent such as sodium hydroxide has been reported to reduce the tackiness of stickies (61).

Catalase enzymes commonly found in paper recycling process streams are known to decompose peroxide bleaches, such as hydrogen peroxide. Aldehyde group donors, such as methylolhydantoin have been found to reduce this undesirable decomposition enabling less peroxide to be used in attaining a given pulp brightness (62).

11. Refining and Fractionation

Refining and fractionation are processes used to alter and select cellulose properties so the final sheet has the desired properties (63). Properties of recycled fibers differ from those of fibers prepared directly from wood. Recovered chemical fibers have lower freeness (an apparent viscosity leading to different water drainage characteristics on paper machines); increased apparent density; lower sheet strength (burst, tensile, etc); increased sheet opacity; inferior fiber:fiber bonding properties; lower fiber swelling; lower fiber flexibility; lower water retention; reduced fiber fibrillation; and much lower internal fiber delamination.

Refining is used to develop the desired pulp drainage properties and control the following sheet properties: bulk and density; strength; surface smoothness; porosity; and printing characteristics. Fractionation separates fines and short, weak cellulose fibers from longer, stronger cellulose fibers (64). Its primary application is in processing old corrugated containers into new packaging products but it has also been recommended for recycling of office paper and mixed waste paper (65). With higher paper recycling rates, fiber fractionation is of increased interest to produce recycled pulp having adequate strength.

12. Water Clarification

Process water that needs to be clarified comes from several different sources in the recycling mill: rejects from screens and mechanical cleaners; rejects from washers, thickeners, and flotation cells; water that drains from the pulp as it is converted into paper on the paper machine (white water); and water from felt washers. These waters contain different dissolved chemicals and suspended solids and often are processed separately.

Mills have three major options in handling their process water. The first is to discharge the water to a municipal treatment facility. The second is to use sedimentation tanks to allow solids to settle out of the liquid. The third is dissolved air flotation. Dissolved air flotation is faster than settling and the water loses less heat before being returned to mill operations. The sludge removed from the dissolved air flotation unit is higher in consistency than sludge from settling tanks.

Water from screens, cleaners, washers, thickeners, and flotation cells contain relatively high levels of ink. These waters also contain valuable chemicals: sodium hydroxide and surfactants. Recycling this water for reuse in the mill can save up to 10% in chemical costs.

Customarily, combinations of cationic and anionic flocculants are used in deinking process water clarification. Typically, a low molecular weight cationic polymer is first added to neutralize negative charge on suspended solids. For economic reasons, the polymer is typically an ammonium salt. Then a high molecular weight anionic polymer is added to flocculate the suspended solids. This is usually a copolymer of acrylamide or a chemically modified polyacrylamide. The nature of the deinking surfactant can have a major effect on the efficiency of flocculants in clarifying deinking process water (16).

Inorganic chemicals may also be used. Bentonite may be used as a flocculant in combination with polymer treatment. Alum, once a common coagulant, is less used now because its concentration can build up in recycle water. Alum often binds ink to fibers and increases the difficulty of deinking.

Removal of the very small flexographic ink particles in process water is difficult. Ultrafiltration has been proposed for removing these very small dispersed ink particles (66).

13. Rejects and Sludge Handling

Sludge from water clarification contains: water; inks and solid pigments; dispersed adhesive particles; small plastic particles, wax; short cellulose fibers; paper filler and coating particles; and large solid materials: rocks, dirt, wire, ceramics, etc. Efficient dewatering minimizes sludge volumes sent to landfills thus reducing hauling costs and tipping fees. Efficient sludge dewatering also increases the efficiency of heat utilization during incineration. Inclined screw thickeners are often used to thicken the rejects from dissolved air flotation clarifiers. Reciprocating piston presses are also used. Polymers are often used to improve drainage across a sludge press thus increasing the consistency of the final sludge. Sludge applications under investigation include use in bricks and as a fertilizer spray on fields and roadsides.

14. Economic Aspects

Worldwide use of recycled paper is expected to increase from nearly 75 million tons in 1988 to 130 million tons in 2001 (67). Paper recycling continues to grow worldwide, particularly in Europe and the Pacific Rim. Paper recycling rates in ten leading paper-producing countries in 1997 are summarized in Table 3 (68).

In the United Kingdom, where the paper recycling rate has historically lagged that of other European nations, it increased to 57% in 2004 (69).

According to the American Forest & Paper Association (AF&PA), Washington, D.C., more than one-half (50.3%) of the paper consumed in the United States during 2003, or 49.3 million tons, was recovered for recycling (70). This is an increase of 69% since 1990, when 33.5% of the paper consumed in the United States was recycled. The grade of paper offering the greatest opportunity to substantially increase U.S. recovery rates is printing and writing paper. Only 16% of postconsumer printing and writing paper was recovered in 2000 (5).

In Japan, the paper recycling rate increased to 71.2% in December 2004 (71). Of the 32.3 million metric tons of paper in 2004 consumed in 2004, 18.5 million metric tons were produced from paper recovered domestically while another 3.0 million metric tons of recovered paper were imported for processing in Japanese paper mills. Current Canadian consumption of recovered paper is about 4 million metric tons per year, much of it imported from the United States.

Global growth of paper recycling will significantly increase demand for surfactants, bleaching agents, complexing agents, and other chemicals used in paper recycling. Deinking chemical demand has been estimated at ~294 million lb in (72). These chemicals include surfactants, fatty acids, silicates, sodium hydroxide, and others (73). Increases in paper recycling and changes in bleaching technology are cited as the reasons EDTA chelating agent use is expected to increase 3–5% annually (73). Defoamer use is also increasing due to the growth in paper recycling (73).

Recycled paper contains more fines, short fibers, and anionic trash. This will increase demand for process chemicals such as drainage aids and both wet and dry strength resins (53).

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Table 1. **Recovered Paper Sources**

Source	Abbreviation	Recycled paper products
	Postconsumer	
old corrugated containers	OCC	linerboard, boxboard, corrugating medium, tissue, paper towels
linerboard (cardboard boxes)	DLK	linerboard, boxboard, corrugating medium
old newspapers	ONP	newsprint, boxboard, tissue, paper towels
old magazines	OMG	magazine newsprint, tissue, towels
computer printouts	CPO	printing and writing paper, tissue, paper towels
ledger		printing and writing paper, boxboard, tissue, towels
mixed office paper	OWP or MOW	printing and writing paper
	Preconsumer[a]	
boxboard cuttings		linerboard, boxboard
envelope cuttings		envelopes, tissue, paper towels
printer trims		depends on original paper type

[a]Commercial–industrial–converter material.

Table 2. **Unit Operations for Removal of Various Contaminants from Recovered Paper**[a]

Contaminant	Particle size	Specific gravity	Unit operation
metal bolts, screws, wire, staples, paper clips, sand, dirt, glass	very large	usually >1.0	perforated plate in pulper covering exit flow line, coarse screens
wood chips, string, nylon mesh, rags, kraft shipping and wrapping paper, laminated paper, sealing tape, cellophane from envelope windows, polyethylene-coated board, miscellaneous plastics from styrofoam cups, packaging, etc	medium large	usually <1.0	coarse screens, fine screens
wood shives, flakes from paper coatings[b]	medium small	usually <1.0	fine screens, forward cleaners
paper fillers,[c] mineral waxes, some hot-melt adhesives, high viscosity adhesives[d]	small	>1.0	forward cleaners, washing, flotation, mechanical dispersion
low and medium viscosity adhesives[e]	small	<1.0	reverse cleaners, washing, flotation

[a]Ref. 2.
[b]1.5–5.0 mm^2 area.
[c]For example, clays or titanium dioxide.
[d]For example, asphalt.
[e]For example, hot melts, waxes, and natural or synthetic resins.

Table 3. **Paper Recycling Rates**

Country	Recycling rate, %
World	43
Germany	72
South Korea	66
Sweden	55
Japan	53
Canada	47
United States	46
France	41
Finland	35
Italy	31
China	27

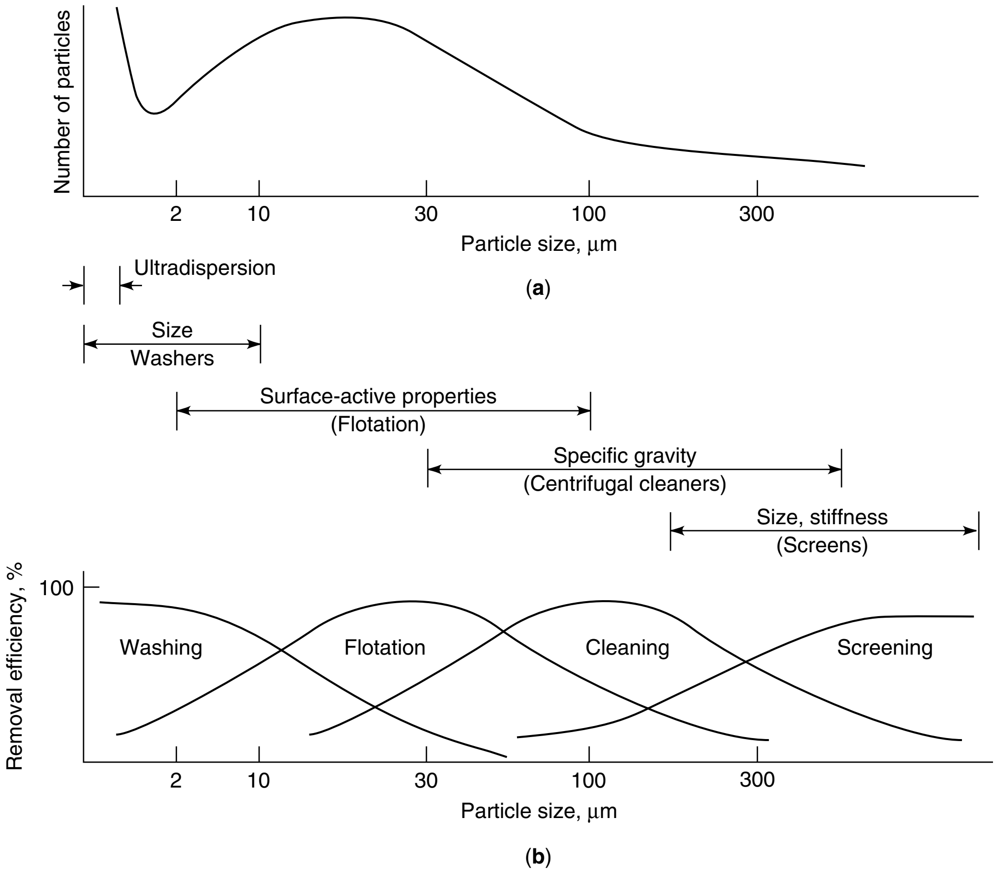

Fig. 1. Ink removal effectiveness of unit operations as a function of ink particle size: (**a**) particle size distribution in pulper; (**b**) unit removal efficiency (4).

Newsprint wash deinking mill	Office paper deinking mill	Newsprint/magazine deinking mill	Tissue mill	Old corrugated container mill
Pulper HD cleaner Coarse screens Fine screens Forward cleaners Reverse cleaners Washer Bleach tower	Pulper HD cleaner Coarse screens Fine screens Thickener Kneader Flotation cells Reverse cleaners Forward cleaners Washer Bleach tower	Pulper HD cleaner Coarse screens Flotation cells Forward cleaners Reverse cleaners Washer Thickener Dispersion unit Flotation cells Reverse cleaners Washer Bleach tower	Pulper HD cleaner Coarse screens Optional flotation cells Reverse cleaners Forward cleaners Washer Bleaching	Pulper HD cleaner Coarse screens Dilution Forward cleaners Reverse cleaners Fractionation Thickener Dispersion unit

Fig. 2. Simplified process designs of paper recycling mills (HD = high density).

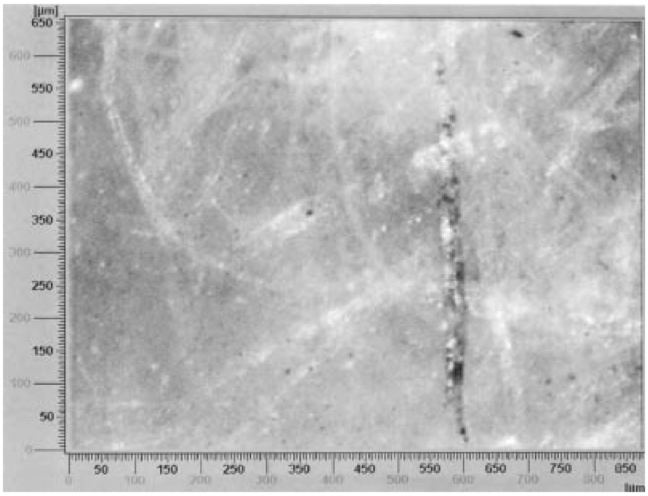

Fig. 3. Cellulose fiber during office paper pulping, which still contains attached ink. (Courtesy: John K. Borchardt, Southhaven Communications.)

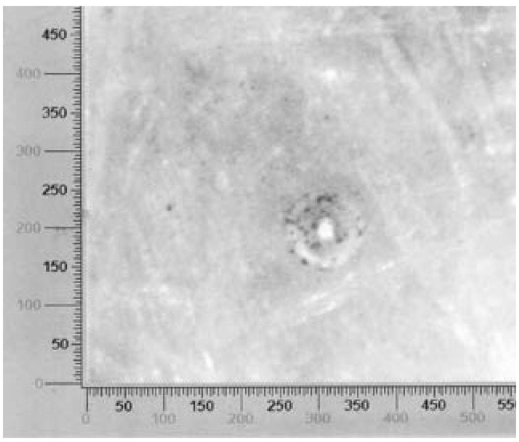

Fig. 4. Air bubble in flotation cell containing attached ink particles. (Courtesy: John K. Borchardt, Southhaven Communications.)