P

PACKAGING, RECYCLING AND PRINTING

Contents

Paper Recycling Science and Technology

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Introduction

The principal raw material used in making paper, cellulose fiber, is derived chiefly from the wood of trees, although other plant residues such as rice straw, kenaf, and bagasse are also potential sources of fiber. Several pulping processes ranging from mechanical, chemimechanical, to chemical, are used to separate fibers in wood to produce virgin pulp (*see* **Pulping**: Chemical Pulping; Mechanical Pulping). Important hardwood species include aspen, oak, maple, and eucalyptus, while softwood types include species of pine, spruce, fir, and larch. If the fiber is not severely contaminated or has not deteriorated during its use in the paper or board product, it can be reused again as secondary or recycled fiber.

During the paper-recycling process, cellulose fibers are separated from recovered (waste) papers and reused to manufacture new products. In 2001, the US supply (= production + import − export) of pulp and paper was estimated to be 98 million tons, of which 47 million tons, or 48% of the total, was recovered (**Table 1**). The amount of paper land-filled decreased from 40.6 million tons in 2000 to 36 million tons in 2001. As shown in **Table 2**, the world production of paper and paperboard decreased from about 324 million tons in 2000 to 318 million tons in 2001, whereas paper recovery increased from 45.3% in 2000 to 45.9% in 2001. (Note that **Table 1** includes paper and board recovered for paper-making as well as for other uses, while **Table 2** includes paper recovered primarily for paper-making.)

Paper mills have many choices for the selection of raw material. Virgin sources include many species of softwoods and hardwoods while secondary sources include various grades of recovered papers. There are more than 50 grades of recovered papers. Four widely used recovered paper grades are described in the next section. The choice of raw material, virgin and/or secondary, will depend on many factors, such as geographic location of the mill, product manufactured, and economics.

Once the right paper grade has been selected, the next task of the mill is to separate fibers and contaminants like paper clips, staples, inks, and

Table 1 Paper and paperboard recovery in the USA

Year	*Supply (000 tons)*	*Recovered (000 tons)*	*Recovery rate (%)*
1990	86 796	29 112	33.5
1991	85 071	31 201	36.7
1992	88 273	33 954	38.5
1993	91 538	35 460	38.7
1994	95 718	39 691	41.5
1995	96 036	42 189	43.9
1996	94 495	43 076	45.6
1997	99 542	43 989	44.2
1998	101 139	45 076	44.6
1999	105 557	46 818	44.4
2000	103 192	47 311	45.8
2001	97 911	47 252	48.3

‘Supply’ includes consumption of all paper, corrugated and paperboard, including construction paper and board.
Supply = production + import − export.
‘Recovery rate’ is the ratio of total paper, corrugated and paperboard recovered (for paper-making and other uses) to supply.
Reproduced with permission from American Forest & Paper Association (AF&PA) (2002) *Recovered Paper Statistical Highlights*. Washington, DC: AF&PA. Available online at: www.afandpa.org.

Table 2 World paper and paperboard production and recovery (all figures (except percentages) in thousand tons)

	Total production		*Paper recovered*		*Paper recovered (%)*	
	2000	*2001*	*2000*	*2001*	*2000*	*2001*
Europe	100 066	98 255	44 775	45 434	44.7	46.2
Asia	95 797	97 661	45 706	44 998	47.7	46.1
Australasia	3526	3494	1807	1981	51.2	56.7
North America	106 603	100 433	46 702	45 589	43.8	45.4
Latin America	14 789	14 855	6558	6625	44.3	44.6
Africa	3200	3449	1238	1289	38.7	37.4
Total	323 981	318 147	146 786	145 916	45.3	45.9

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adhesives. Unit processes like pulping, screening, cleaning, flotation, and washing are used to remove contaminants from the pulp. One of the contaminants that poses a serious challenge to paper recycling arises from adhesives, glues, and binders used in inks and coatings. Strategies to handle stickies are presented, followed by a brief presentation of the changes in paper properties due to recycling.

Paper Grades

The Paper Stock Institute of the Institute of Scrap Recycling Industries (ISRI) publishes a list of more than 50 recovered paper grades. Each grade has its own characteristics related to fiber species, the original pulping process, brightness, contaminant content, and degree of converting. In general these grades can be segregated into four main categories:

1. Corrugated or boxboard.
2. Newspapers.
3. High grades.
4. Mixed papers.

The recycling process changes the properties of the fiber so that it performs differently compared to virgin fiber. Additives, coatings, and inks used to increase the value and performance of the paper or board product can cause problems during the recycling process and must be removed during the recycling operations. The value of the recovered paper or board is a function of how difficult it will be to defiber, the degree of contamination, and the requirements to restore the fiber characteristics necessary to produce paper meeting the required specifications.

Corrugated Containers

Approximately one-half of the paper recovered in the USA in 2001 was old corrugated container (OCC). Corrugated includes corrugated boxes, kraft grocery bags, multiwall shipping sacks, and similar unbleached containers. The American Forest and Paper Association has estimated that, in 2001, 75% of the OCC was recovered in the USA. The chief source of OCC is from grocery stores and retail businesses, with an increasing quantity coming from individual households and small businesses. Most of the OCC is recycled into linerboard, corrugating medium, and containerboard. A typical OCC system is shown in **Figure 1**. Some of the unit processes shown in **Figure 1** are described in the next section.

OCC quality varies depending on the source. In the USA, a large percentage of corrugated containers have virgin fiber, usually unbleached softwood kraft, in the liner. Softwood kraft fibers are desirable due to their strength properties. In the USA, liner containing up to 20% recycled fiber is still classified as virgin. When a high proportion of recycled fiber is used, the liner may be termed test, jute, or bogus liner. The use of recycled fibers in the production of liner grades does not permit the stringent control of the fiber types as in the virgin grade. Since there are differences in the distribution of long and short fibers in recycled grades, the characteristics such as strength properties seldom match those of the virgin grade.

A requirement of fibers used in corrugating medium is stiffness, which gives the medium its crush resistance. Virgin medium is usually produced from hardwood fibers pulped by one of several processes, including neutral sulfite semichemical and alkali carbonate process (*see* **Pulping**: Chemical Pulping). Recycled medium may contain OCC, old magazines, and mixed papers.

Recovered OCC is used in the manufacture of solid folding boxboard. The application of fractionating permits the separation of the recycled pulp into a long and a short fiber fraction, each of which can be directed to the desired end use. Short fibers, which tend to be stiffer, are used in the top ply to provide good printing characteristics. The longer fibers, which provide better strength and runnability, may be used in the filler plies.

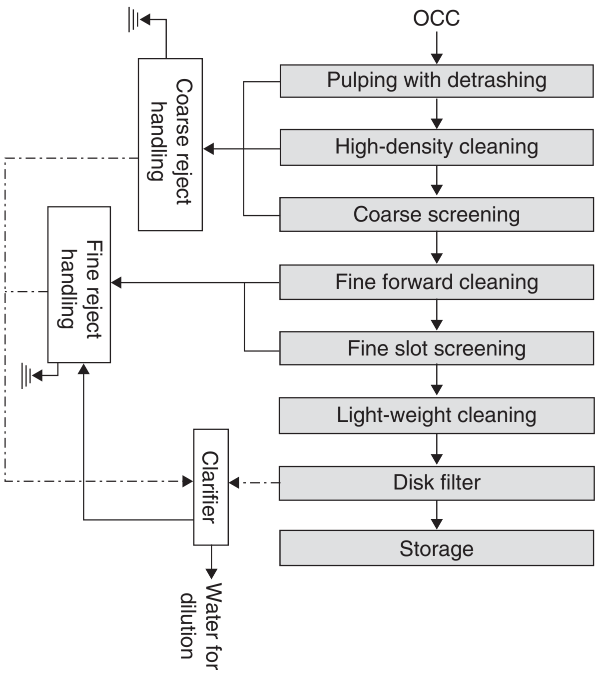

Figure 1 Recycling system for old corrugated container (OCC) to linerboard.
Notes

1. High-density cleaning corresponds to cleaning in large-diameter (30–75 cm) hydrocyclones, usually at consistency of 3–4%.
2. Cleaning in hydrocyclone to remove contaminants with density greater than that of water is termed heavy-weight cleaning or forward cleaning.
3. Cleaning in hydrocyclone to remove contaminants with density less than that of water is termed light-weight cleaning.
4. Disk filter is used as a thickening device.
5. Dissolved-air flotation (DAF) is generally used here for water clarification.

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Other uses for OCC include use in absorbent grades such as industrial toweling and in packaging papers such as grocery bags and industrial wrappers.

Newspapers

This category includes old newspapers (ONP) collected from residences, offices, and other sources. In the USA, approximately 78% of the newspapers printed are now being recovered. In 2001, 9 million tonnes of ONP were recovered, or nearly twice the recovery rate in 1989. About 60% of all ONP recovered is recycled domestically to manufacture newsprint or recycled paperboard. In paperboard, ONP serves as filler.

ONP has a high percentage of mechanical fiber, which includes groundwood and thermomechanical pulp. Chemical fiber such as kraft may comprise up to 30% by weight and is added to improve the strength properties of the paper. Other constituents may include additives such as starch, inorganic fillers, and dyes for color control. Inorganic filler content (ash) may range from 3 to 12% by weight. Newspapers are printed by letterpress, offset, and flexographic processes. Ink content in printed newspapers comprises 1–2% by weight.

When recycled to produce newsprint, ONP is processed through a sequence of deinking steps. While there are several variations in the deinking process, the common unit processes consist of:

- pulping (and detrashing)
- washing (and thickening)
- screening
- dispersion
- cleaning
- bleaching
- flotation deinking
- water clarification.

A typical deinking system is shown in **Figure 2**.

Deinking technology for recycling ONP is well established; however, there have been distinct differences in the approaches developed in Europe and Asia compared to North America. Dispersed-air flotation deinking was traditionally applied in Europe and Asia, whereas in North America washing was the primary deinking process. In recent years, flotation deinking has gained acceptance in North America, where it is commonly used in combination with washing.

In mills deinking with flotation, ONP is commonly blended in a 70 : 30 ratio with old magazines (OMG). The presence of OMG in the furnish aids in flotation due to the high filler content (clay and/or calcium carbonate) which may stabilize the foam. OMG also enhances product brightness and strength due to the presence of bleached chemical fibers. Deinking chemicals such as fatty acid soap, sodium silicate, chelants, and caustic are added to the pulp to aid in ink detergency. Soap promotes ink particle attachment to air bubbles by making the ink more hydrophobic and it promotes a stable foam, allowing the flotated ink to be removed from the process before the bubble breaks.

High Grades

These grades are usually processed by a deinking operation. High grades are primarily printed and unprinted white papers collected from converting

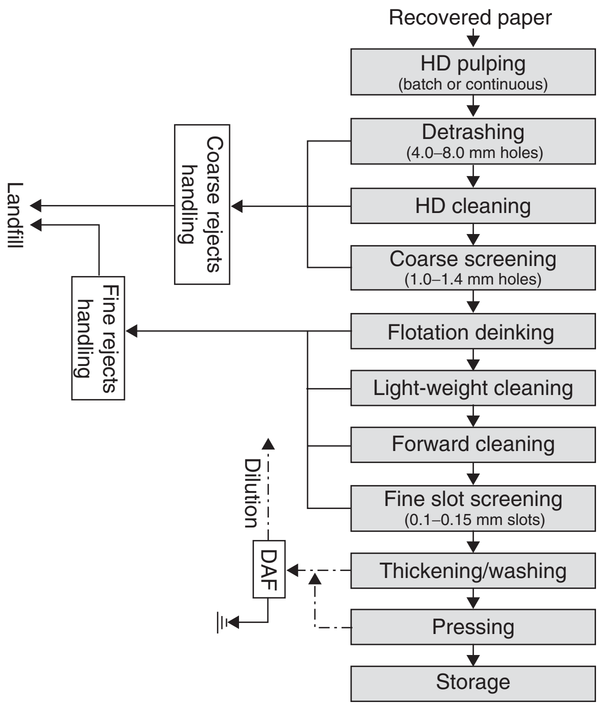

Figure 2 Flow diagram for old newspaper deinking system. *Notes*:

1. HD (high-density) pulping stands for pulping at solids concentration (consistency) of 12–18%.
2. HD cleaning corresponds to cleaning in large-diameter (30–75 cm) hydrocyclones, usually at a consistency of 3–4%.
3. Cleaning in hydrocyclone to remove contaminants with density less than that of water is termed light-weight cleaning.
4. Cleaning in hydrocyclone to remove contaminants with density greater than that of water is termed heavy-weight cleaning or forward cleaning.
5. DFA stands for dissolved-air flotation. DAF is used here for water clarification.

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operations, printing plants, and offices. These grades are versatile raw materials and have been recycled to make a range of products, from tissue to recycled paperboard to printing and writing papers. Demand for some grades is high, for example pulp substitutes; however, the potential for growth of some high grades is limited since virtually all sources have been exploited. Additional supplies of mixed and sorted office papers will be generated through expanded office paper recovery programs.

Mixed Papers

Unlike the preceding categories, mixed paper grades are not segregated. The category mixed papers is comprised of several types of papers commingled together. As a result, the fiber is more heterogeneous, filler content is variable, and contamination levels are higher. However, demand for mixed papers is increasing as the more valuable grades reach the limit of recovery, and as recycling technology advances. Mixed papers are generally substituted for other grades such as ONP and OCC in container-board. Mixed papers are generally collected from homes and offices.

Recycling Unit Processes

The recycling of recovered paper involves several unit processes that separate the paper-making fibers from contaminants which may detract from the appearance or strength properties of the final product. Contaminants include sand, staples, wood, inks, plastics, adhesives, coatings, and inorganic fillers. The number and sophistication of the unit processes increase as the requirements for cleanliness and brightness in the final product increase.

Pulping

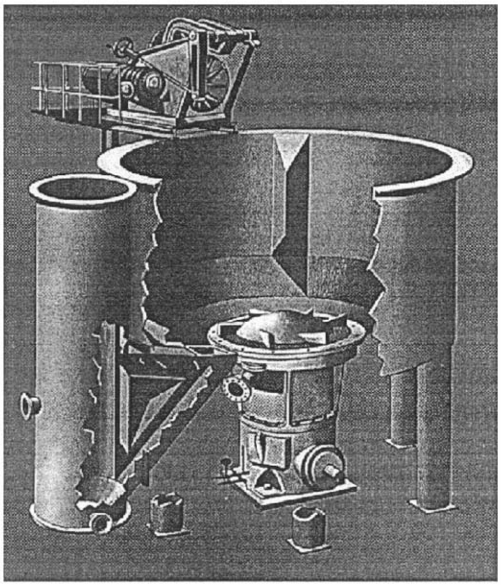
The primary purpose of pulping is to defiber the paper into its constituent fibers without significantly degrading contaminants. Important parameters in pulping include stock consistency, temperature, pulping intensity, pH, and pulper configuration. Progress has been made in understanding and modeling pulping and ink detachment.

Pulping is accomplished through three basic mechanisms:

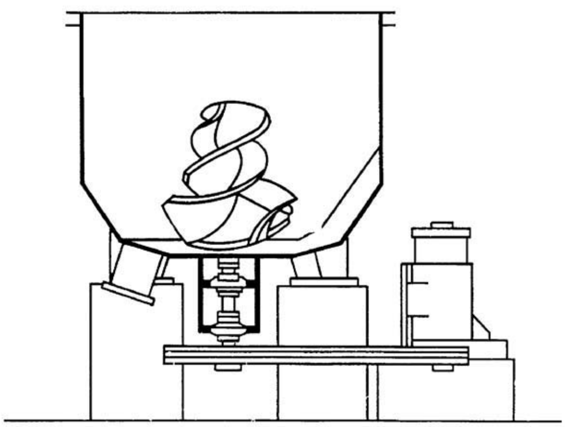
1. Wetting the paper to the desired consistency.
2. Circulation either to return the material to a high shear zone or to promote fiber-to-fiber friction.
3. Attrition, by which flakes are torn apart in a high shear zone.

Pulpers are characterized by their operating mode, whether batch or continuous, geometry, rotor type, operating consistency, and accessories. They can be broadly classified as either vat-type or drum-type. A typical vat-type pulper is shown in **Figure 3a**. This pulper consists of a vat or tub in which the stock is mixed by a rotor positioned at the bottom or side of the tub. The type of rotor used is dependent upon the consistency requirements, operating mode, and fiber type. Helical rotors, which resemble a large screw (**Figure 3b**), operate at high consistency and promote fiber-to-fiber friction through radial motion. Attrition rotors, used in low-consistency pulpers, have blades that maximize turbulence and shear.

The drum-type pulper consists of a rotating vessel through which the recovered paper tumbles and is



(a)



(b)

Figure 3 (a) Side cut-away of a vertical pulper. (b) Helical rotor pulper. Reproduced with permission from Silveri L and Wagner MM (1998) The pulper/detrasher module in the recycle system. In: Doshi MR and Dyer JM (eds) *Paper Recycling Challenge*, vol. III, *Process Technology*. Appleton, WI: Doshi & Associates, Inc.

defibered as it is transported along the length of the drum. Drum pulpers operate at high consistency (15–20%) and are used for treating low-strength materials such as newspapers which defiber easily. A schematic of a drum pulper is shown in **Figure 4**. Recently, variations in the design of drum pulper have been introduced. Applications of drum pulpers have been extended to other paper grades such as office papers and OCC.

Many modern pulpers are fitted with ancillary equipment that removes trash and contaminants before they are broken down into small pieces. This equipment includes the ragger to remove wires and rope-like contaminants, junk tower, for larger trash, and the secondary pulper. The secondary pulper, or detrasher, which receives a small side stream from the main pulper, consists of a dual-chamber device in which the rejects chamber and the accepts chamber are separated by an extraction grate, a perforated plate. The rotor wipes the extraction plate to keep it free of contaminant build-up during the passage of accepted fiber.

Pulpers are operated in one of two modes: batch or continuous. In batch pulping, paper stock, water, steam, and chemicals, if necessary, are charged to the pulper and the entire mixture is processed for a set amount of time before it is dumped to a receiving chest. Batch pulping is more commonly used in deinking where high consistency is desired and when the residence time in the pulper must be controlled to ensure sufficient detachment of ink from the fibers.

Continuous pulpers are fed with recovered paper and water on a continuous basis while defibered materials pass out of the pulper through an extraction plate. The residence time of the material in the pulper is a function of the feed rate, size of the pulper tub, and the opening size of the holes in the extraction plate. Generally operating at 4–8% consistency, this mode of pulping is used where high production is desired and is commonly used in OCC processing systems.

Screening

Screens are able to separate a multicomponent flow into two fractions on the basis of differences in morphology or shape. Screening is the most common separation process used in recycled fiber systems. While screening is most commonly associated with the separation of contaminants from fiber, several applications are based on screening or barrier separation technology:

1. Contaminant screening.
2. Fractionation.
3. Washing.
4. Dewatering.

Contaminant screening The object of contaminant screening is to remove nonfibrous contaminants while minimizing the loss of fiber. Pressure screens are the most commonly used devices for this purpose, although some gravity screens are operating in tailing systems. The pressure screen consists of a cylinder with either perforated holes or fine slots: it is attended by a rotating hydrofoil or other rotating element providing alternating pressure or vacuum pulses to the screening surface to keep it from plugging or blinding with debris or fiber. The materials that pass through the screen openings, considered accepts, are sent forward in the system,

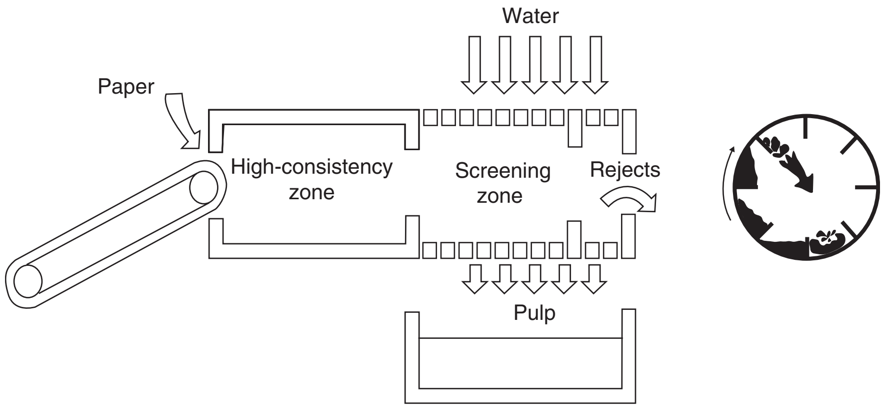


Figure 4 Drum pulper. Reproduced with permission from Silveri L and Wagner MM (1998) The pulper/detrasher module in the recycle system. In: Doshi MR and Dyer JM (eds) *Paper Recycling Challenge*, vol. III, *Process Technology*. Appleton, WI: Doshi & Associates, Inc.

while the materials that are blocked at the openings are rejected and are either reprocessed in another area of the system or discarded. Coarse screens, generally positioned early in the system, process relatively contaminated stock and have perforated cylinders. Perforations are usually 1.38 mm (0.055 in.) or larger. Fine screens, with slotted cylinders, are positioned after coarse screens where they are more effective in removing small contaminants. The slot opening width of fine screens ranges from 0.10 to 0.60 mm (0.004–0.024 in.).

Fractionation Fractionating screens separate the stock into a long fiber fraction and a short fiber fraction. These devices normally use holes in the range 1.3–2.0 mm and operate in the consistency range 2–4%.

Washing When used for washing pulp, a fabric is used to retain fibers while allowing the fines, fillers, and ink to pass with water through the fabric. Traditionally, sidehill screens and deckers were used. During the last 15 years more aggressive washers, which minimize the formation of a mat on the fabric, have been developed.

Dewatering The function of dewatering screens is to maximize the removal of water from stock while minimizing the loss of solids. Disk filters are used for low-consistency applications, while belt presses, screw presses, and twin wire presses are used at high consistency.

Cleaning

Cleaners or hydrocyclones remove contaminants from pulp based on the density difference between the contaminant and water. These devices consist of a conical or cylindrical–conical pressure vessel into which pulp is fed tangentially at the large-diameter end (**Figure 5**). During passage through the cleaner the pulp develops a vortex flow pattern, similar to that of a cyclone. The flow rotates around the central axis as it passes away from the inlet and toward the apex, or underflow opening, along the inside of the cleaner wall. The rotational flow velocity accelerates as the diameter of the cone decreases. Near the apex end the small-diameter opening prevents the discharge of most of the flow which instead rotates in an inner vortex at the core of the cleaner. The flow at the inner core flows away from the apex opening until it discharges through the vortex finder, located at the large-diameter end in the center of the cleaner. The higher-density material, having been concentrated at the wall of the cleaner due to centrifugal force, is discharged at the apex of the cone.

Cleaners are classified as high-, medium-, or low-density depending upon the density and size of the contaminants being removed. A high-density cleaner, with diameter ranging from 15 to 50 cm (6–20 in.) is used to remove tramp metal, paper clips, and staples and is usually positioned immediately following the pulper. As the cleaner diameter decreases, its efficiency in removing small-sized contaminants increases. For practical and economic reasons, the 75-mm (3-in.) diameter cyclone is generally the smallest cleaner used in the paper industry.

Reverse cleaners and throughflow cleaners are designed to remove light-weight contaminants such as wax, polystyrene, and stickies. Reverse cleaners are so named because the accepts stream is collected at the cleaner apex while the rejects exit at the overflow. In the throughflow cleaner, accepts and rejects exit at the same end of the cleaner, with accepts near the cleaner wall separated from the rejects by a central tube near the core of the cleaner.

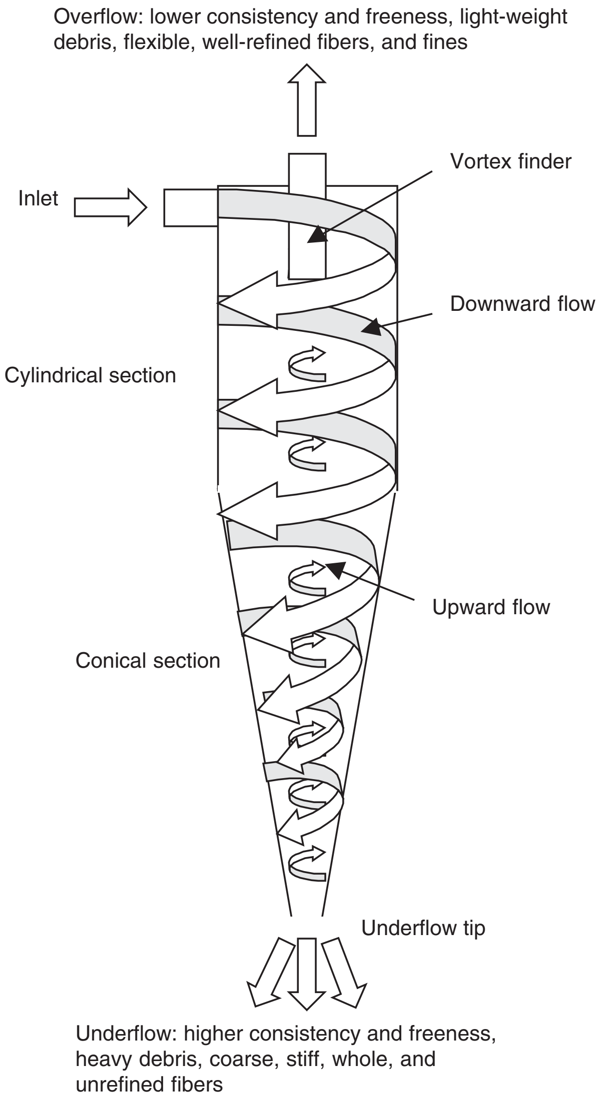


Figure 5 Parts of a hydrocyclone, major flow patterns, and separation trends.

Continuous centrifuges used in the 1920s and 1930s to remove sand from pulp were discontinued after the development of hydrocyclones. A recently designed cleaner, the Gyroclean, developed by Centre Technique du Papier, Grenoble, France, consists of a cylinder that rotates at 1200–1500 rpm. The combination of relatively long residence time and high centrifugal force allows light-weight contaminants sufficient time to migrate to the core of the cleaner where they are rejected through the center vortex discharge.

Deinking

In grades that are destined to be recycled into printing and writing grades, tissue, etc., deinking is applied to remove ink from the pulp. The deinking process begins in the pulper where fiber-to-fiber rubbing and added chemicals for detergency detach ink from the fiber surface. Processes present in the system for removing ink from pulp include cleaners, washers, froth flotation, and, to a certain extent, screens. Kneaders and dispersers are used to disintegrate residual ink into smaller particles too small to be seen by the naked eye. Kneaders and dispersers also assist in the detachment of inks and other contaminants from fibers.

Deinking chemistry The goal of deinking is to provide the conditions in the pulper that will advance the detachment of ink from fiber, and then, in subsequent equipment, separate the detached ink from the pulp. Chemicals are commonly used to enhance deinking. Sodium hydroxide is used to adjust pH. Surfactants affect detergency and dispersed ink particle size, critical for effective ink removal in the processes following pulping. In the pulper, the mechanisms of ink detachment include:

- surfactant-promoted solubilization of ink into the aqueous pulping medium
- surfactant-promoted wettability alteration of cellulose surfaces promoting ink detachment and emulsification
- cellulose fiber swelling, promoted by high pH, to enhance ink detachment from fiber
- fiber-to-fiber rubbing promoted by mechanical agitation.

Inks differ in surface chemistry and composition. As a consequence, the selection of chemistry and removal processes must focus on the type of ink that is encountered in the particular recovered paper grade. The role of the surfactant used for wash deinking is to create hydrophilic, dispersed ink particles. Flotation deinking surfactant must make the detached ink particles more hydrophobic so that they attach to air bubbles, and the surfactant must produce sufficient air bubble stability so that the froth can be removed from the pulp. Sometimes a dispersant like sodium silicate may be necessary to stabilize detached ink particles and avoid redeposition back on to fibers.

Washing Washing is effective for removing dispersed ink, fines, and filler particles of less than 15 μm. Washing devices function in a manner similar to a laundry process whereby finely dispersed particles are transported away from the pulp with the filtrate as the pulp thickens on a mesh or wire. The formation of a fiber mat during washing can reduce the removal efficiency of fine particles, therefore highly turbulent washers tend to be more efficient, but at the sacrifice of lower yields, i.e., greater fines and/or fiber losses.

Dispersed-air flotation Originating in the mining industry for enrichment of ores, the flotation process developed in Europe for deinking has gained importance in North America. In this process, hydrophobic particles such as ink and small contaminants attach to air bubbles injected into the pulp and get carried upward to the froth while fibers remain in the bulk. The particles are separated from the pulp by removing the froth from the surface of the pulp. Surfactants are commonly used to enhance the hydrophobicity of the particles and to improve the stability of the froth. The optimum consistency range of froth flotation is 0.6–1.0%, and particles in the size range 25–300 μm can be removed by the process. Several factors influence the effectiveness of flotation units in removing ink particles from pulp. These include water hardness, temperature, ink particle size, ink particle chemistry, air bubble diameter, hydraulic flow patterns, air-to-stock ratio, and the froth removal system.

Kneading and dispersion Kneading and dispersion devices mechanically treat the pulp to reduce visible particles such as ink to subvisible sizes. In disk dispersion, pulp at high consistency is forced between two parallel disks, one stationary, and one rotating at 1200–1800 rpm. The disks are separated by an adjustable, narrow gap. Under the conditions of high shear and friction within the zone between the disks, ink and contaminant particles are reduced in size.

Kneading, also referred to as low speed dispersion, imparts relatively longer mechanical treatment to the pulp with a moderate shearing effect. In principle, the kneader consists of a shaft, to which are affixed several rows of fingers, slowly turning within a stator wall on which other fingers are attached. Pulp is fed by a screw conveyor into the narrow passage between the rotating shaft and stator where it is subjected to rubbing action. A discharge door controls the pressure on the pulp and the volume of pulp in the device. Double-shaft kneaders have two counterrotating shafts, turning at different rates.

Dispersers have been used to mix bleaching chemicals into the pulp. Located near the end of the process, dispersers can disintegrate the remaining contaminants which are then removed from the pulp by a postdispersion screening, cleaning, flotation, and/or washing steps.

Bleaching

The reasons for bleaching recycled fibers include color stripping, delignification, and brightening of fibers. In oxidative bleaching, agents such as hypochlorite, hydrogen peroxide, oxygen, and ozone are used. Reductive bleaching compounds include sodium hydrosulfite and formamidine sulfinic acid (FAS). Recovered paper pulps may contain chemical pulp, mechanical pulp, and dyes, each of which requires a specific bleaching approach for maximum effectiveness.

Bleaching mechanisms The bleaching agents can be categorized as nondegrading reagents and degrading agents. The nondegrading reagents such as hydrogen peroxide reduce color bodies (chromophores) in pulp by oxidizing carbonyl groups, while FAS and hydrosulfite reduce the quinone structures. These chemicals are useful in bleaching wood-containing grades since they do not react with lignin.

The degrading agents, which include oxygen, ozone, and the chlorine-containing compounds such as hypochlorite, are used primarily for bleaching chemical pulps and act by destroying the phenolic groups and the carbon–carbon double bonds. In recycled pulps containing higher amounts of mechanical fibers, the degrading agents tend to reduce the yield and yellow the pulp due to the fragmentation and/or modification of the lignin.

Dyes pose a special problem since, with the exception of ozone, no single bleaching agent is effective in destroying the broad range of dyes found in recovered papers. In general, direct dyes that contain conjugated nitrogen–nitrogen double bonds are readily decolorized by hydrogen peroxide and the reducing agents. Basic dyes, which contain conjugated carbon–carbon double bonds in aromatic compounds, are more prone to degradation by strong oxidizing agents. High temperature (above 100°C) peroxide bleaching seems to be effective in bleaching office papers.

Microbial enzymes such as xylanases and ligninases can improve lignin and chromophore removal, thereby facilitating bleaching in subsequent processes. When followed by peroxide bleaching, enzyme-pretreated pulps show a higher level of brightness and cleanliness than conventionally deinked pulps.

Bleach application methods Three main application points for bleaching agents include the pulper, bleach tower, and disperger/kneader. Hydrogen peroxide is commonly used with chelants and/or sodium silicate directly in the pulper to increase the brightness of mechanical grades such as ONP/OMG. In bleach towers, bleaching chemicals are mixed with pulp and the mixture is allowed to remain for an extended time period, usually 0.5–1.5 h. This longer residence time permits the completion of the bleaching reaction. Dispersers and kneaders are used in bleaching since they commonly operate at elevated temperatures which drive the bleaching reaction, and they promote excellent mixing of the chemical with the pulp. Following the disperser or kneader there may be a chest in which the bleaching reaction is allowed to proceed.

Commonly, bleaching sequences comprised of two or more bleach stages, each using a different bleaching reagent, may be used to maximize the brightness increase and color removal from the recovered fiber. For example, an oxidative stage using hydrogen peroxide bleaching may be followed by a reductive stage using sodium hydrosulfite.

Water Clarification

Considerable quantities of water are used for dilution, conveying, and washing during the processing of recovered fiber. Processes that enable the reuse of water are important from an environmental and financial standpoint. Water clarification is the unit operation which removes the bulk of suspended solids and the small amount of dissolved solids from the water, thus making it possible to reuse it in the system. By reusing clarified process water both the volume of effluent discharged to the wastewater treatment plant and the amount of incoming fresh water that must be treated are reduced. For example, a deinking stock preparation system will require 11–30 m^3 (3000–8000 gallons) of water per ton of production.

Clarification processes are usually attended by a chemical conditioning program. Flocculation and/or coagulation chemicals and polymers are used to aggregate solids in water, thus making the particle size larger.

Several techniques for clarifying process water are practiced. Some of these include sedimentation, dissolved-air flotation (DAF), and filtration. In the sedimentation process, process water is held in a clarifier tank at quiescent conditions for an extended time period. Solids separate from the liquid due to differences in density, interfacial tension, degree of hydrophobicity, or a combination of these factors. The net result is for the solids either to sink to the bottom or float to the top of the clarifier where they are removed.

In the DAF process, very fine air bubbles are introduced into the clarifier to provide buoyancy to the solids. Prior to introduction into the clarifier, a small portion of clarified water is pressurized and semisaturated with air. When this water is released into the clarifier, the dissolved air leaves solution and forms very small bubbles (0.01–0.1 mm diameter) which attach to the flocculated solids. The solids containing air bubbles become buoyant and are carried to the surface of the clarifier where they are skimmed from the tank. In a subsequent process, the solids, or sludge, is dewatered for disposal. DAF has the advantage of requiring low residence time (3–8 min) compared to sedimentation clarifier and it is able to separate solids with a fairly broad range of specific gravities.

Filtration technology includes drum filters, which remove larger suspended solids such as fibers and fiber fines, and membrane filtration, including reverse osmosis, nanofiltration, and ultrafiltration. Ultrafiltration, effective on particles down to 0.005–0.13 μm diameter, is being considered for the removal of flexographic inks from ONP deinking process water. Due to high energy, maintenance, and capital costs, ultrafiltration is not widely used in the paper industry at this time.

Stickies

Contamination from adhesives, called stickies by paper-makers because they adhere to paper machine felts and wires and cause operating problems and product quality defects, are a major problem during both the processing of recovered paper and paper-making operations. Stickies are the undesirable recovered paper components that originate from pitch, ink, plastic films, converting aids, coatings, and adhesives. Adhesives are either hot melts, commonly used in book-binding and case sealing, or pressure sensitives, used in labels and tapes.

Stickies have been classified based on their behavior and size. The reason for categorizing stickies is because methods for removing the different types are different, and the strategies for minimizing their impact on paper-making are different. The size-based classification divides stickies into the two groups macro and micro. Macro stickies are those which are separated when pulp is processed through a laboratory slotted screen (>100 μm), while micro stickies are those which are able to pass through the slots of the screen (<100 μm). Based on behavioral characteristics, stickies are divided into two classes, primary and secondary. Primary stickies result from the disintegration of adhesives during pulping and subsequent stock preparation. Secondary stickies are derived via a two-step sequence: (1) formation of soluble and/or colloidal materials during pulping, and (2) destabilization of the pulp suspension either by the addition of cationic polyelectrolytes, pH, and/or temperature shock, or other means which decrease solubility, causing soluble or colloid substances to precipitate.

Strategies to control stickies during the recycling process include: (1) selecting recovered paper with lower concentrations of stickies and monitoring quality; (2) keeping pulping conditions mild in order to minimize degradation of adhesives; and (3) use of slotted screens, flotation cells, and reverse cleaners to remove macro stickies. Methods used to control dispersed and colloidal stickies include pacification by the addition of talc, cationic polymers, enzymes, and dispersants. These substances affect the surface of stickies by binding to them or modifying the tackiness. Dispersed stickies may be removed from pulp during washing; however, effective clarification of washer filtrate is essential to prevent the build-up of stickies in the process water system.

US Postal Service initiated a project at Forest Products Laboratory, Madison, Wisconsin, with the goal of implementing recycled compatible pressure-sensitive adhesives to postage stamps. Many articles resulting from this project were presented at the TAPPI Recycling Symposium in 2002.

The Effect of Recycling on Paper Properties

The suitability of fibers for recycling is a function of the origins and past treatments to which the paper product has been subjected. The manner in which the wood was pulped, the paper-making process, the printing and converting method, the consumption and collection history, and the manner in which the paper will be recycled all affect the quality of the recycled fiber.

Refined chemical pulps behave differently from mechanical pulps upon recycling. When pressed and dried, the lumen and fibrils of chemical pulps collapse. During the rewetting in recycling, the degree of fiber swelling and fibrillation decreases due to a phenomenon referred to as hornification. Because the recycled chemical fibers are less flexible, physical properties that rely on bonding such as tensile, burst, and density decrease while tear and stiffness increase (**Figure 6**). The opposite effect is seen for recycled mechanical fibers which, due to the presence of lignin that minimizes the hornification in the fiber wall, become more flexible and may show small increases in tensile strength and density.

Several strategies are available for increasing the potential of recycled fibers for paper-making. Refining can be applied to improve fiber bonding through the reswelling of the fiber wall. However, refining recycled fibers tends to shorten the fiber length and produces fines that decrease the pulp's drainage rate. Cationic starch is added at the wet end of the paper machine to improve the bonding strength. Sodium hydroxide is used during repulping to promote fiber swelling which helps to reverse hornification. Through fractionating screens, two fiber fractions, one longer fiber and one shorter, are used in separate grades or in different plies of the same paper.

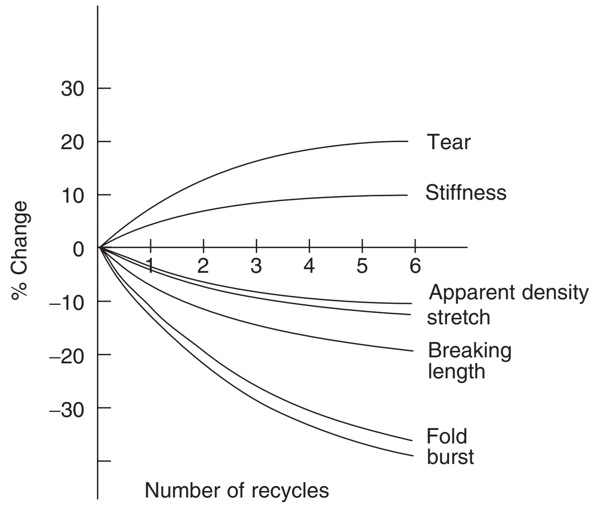


Figure 6 The general effect of recycling on the properties of paper made from refined chemical pulps. Reproduced with permission from McKee RC (1971) *Paper Trade Journal* 155(21): 34.

Summary

During the recycling process, fibers are separated from recovered paper and reused in the manufacture of new products. The practice of recycling paper is expected to grow as the worldwide demand for fiber increases. The percentage of recovered paper used worldwide in the production of paper and paperboard increased from 45.3% in 2000 to 45.9% in 2001.

Recycled fiber processing begins with pulping, during which the recovered paper is defibered. In subsequent steps, which include cleaning and screening, contaminants are removed. Depending upon the final product requirements, flotation and washing may be used to remove ink from the pulp. Bleaching is applied to remove color and increase the brightness of the fibers.

The use of recycled fibers in making paper and board poses an interesting challenge from the perspective of overall economics, removal of contaminants, and strength properties of the recycled product.

Acknowledgment

This chapter is an updated version of an original article published in *Encyclopedia of Materials:*

See also: **Papermaking**: Overview; Paper Raw Materials and Technology; The History of Paper and Papermaking; World Paper Industry Overview. **Pulping**: Bleaching of Pulp; Chemical Pulping; Environmental Control; Mechanical Pulping.

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Printing

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Introduction

Printing has been called the single most significant technical development of human history. Prior to the invention of printing, virtually all communication was verbal. It was difficult to communicate to a large number of people. Printing provided the ability to record ideas in a manner that can be passed through generations. Paper is still the most utilized substrate for printing.

As early as 35 000 BC, people were drawing messages on cave walls. Pictographs were used to represent real objects. Pictographs evolved to ideographs, which were developed by the Phoenicians. By 900 BC, the Phoenicians had also assigned sounds to the symbols.