DE-INKING OF WASTE PAPER: FLOTATION

C. Jiang and J. Ma, Enzymatic Deinking Technologies, Norcross, GA, USA

Introduction

The earliest work on utilization of froth flotation for de-inking of wastepapers dates back to the 1930s. The first flotation de-inking patent was filed by Hines in 1933. However, it was not until 1952 that the first commercial flotation de-inking system was installed at a paper mill in the USA, and the first European installation was at a tissue mill in Greece in 1959. Up to 1970, the growth of flotation de-inking technology was relatively slow. However, in the past 20 years, the market has grown extremely rapidly. The worldwide flotation capacity for de-inking of wastepapers has increased from 0.2 million tons in 1965 to about 25 million tons in 1995.

De-inking is a separation process to remove inks and other nonfibrous contaminants from wastepapers. Different types of units are required to separate inks from fibres, and this mainly includes washing, flotation, cleaning and screening. The selection and operation of these units are based on the types of wastepapers and the requirements of the finished de-inked pulp. Wastepaper is commonly grouped into five categories, which include mixed paper, old newspapers, old corrugated containers, pulp substitutes and high grade de-inked. **Table 1** shows a typical wastepaper classification and the finished products obtained from different kinds of wastepapers.

De-inking is a two-stage process which involves dislodging the ink and nonfibrous contaminants from the fibre surface and removing them by washing, flotation, cleaning and screening. Common contaminants include ink, staples, paper clips, sand, plastics and stickies. The most important and widely used de-inking process to date is the froth flotation process. This process removes the widest range of ink particles from wastepapers. Flotation alone or in combination with other processes can remove almost all types of ink particles and other contaminants from the slurry of wastepaper.

Flotation Process and Equipment

Flotation Process

Pulping The first step in de-inking wastepaper is pulping. Because of the nature of the chemicals and equipment used to pulp wastepaper, the pulping process is analogous to sulfite 'cooking'. Chemicals, together with heat and mechanical energy, are used to detach the ink particles and other contaminants from the fibres in a pulper. Pulping can be either a batch or continuous process. Newsprint mills typically use continuous pulping at a consistency of 4–8%. Other mills usually use batch pulping at a higher consistency of 8–18%.

Flotation Flotation de-inking is a selective separation process that utilizes the difference of surface physicochemical properties between the ink and fibre. Flotation chemicals are fed to the wastepaper slurry to render the ink particles selectively more hydrophobic and hence to increase the floatability. When the air bubbles are sparged into the flotation cell containing the wastepaper slurry, the ink particles get at-

Table 1 Typical wastepapers and their classification

Category	*Compositions and abbreviations*	*Finished products*
Old newspapers	Old newspapers (ONP), white blank newspapers	Newsprint, boxboard, tissue, paper towels
Old corrugated containers	Old corrugated containers (OCC), double linerboard kraft corrugated clippings (DLK)	Linerboard, boxboard, corrugating medium, kraft towels
Mixed paper	Mixed office waste (MOW), old magazines (OMG), sorted ledgers, computer printout (CPO), manifold white ledger (MWL), sorted office waste (SOW)	Printing and writing paper, paperboard, tissue, paper towels, magazine newsprint
Pulp substitutes	Unprinted paper and board, boxboard cuttings, printer trims, envelope cuttings	Fine paper, tissue, envelopes
High grade de-inked		Fine paper, tissue, printing and writing papers

tached to the air bubbles due to their relatively high hydrophobicity and are floated to the surface of suspension, and the hydrophilic fibres remain in the water phase.

Flotation De-Inking System

Flotation is traditionally the standard European de-inking system for old newspapers. The stocks or wastepaper slurry after pulping generally go through a soaking stage in a dump chest to swell the fibres and to improve ink detachment from the fibre.

The stock is subsequently aerated at 0.7–1.5% consistency in a series of flotation cells. Typically, six to 10 flotation cells in series (primary flotation) are required for efficient ink removal. The froth from primary flotation is subsequently cleaned in a secondary or recovery stage (usually two cells) to further recover food fibres and to decrease fibre loss. A typical and representative example of a flotation system is illustrated in **Figure 1**.

Most technical advances made during the past 10 years involved utilization of a combination of flotation and washing stages to remove inks from the more complex wastepaper. The concept of the post-flotation system is to add a disperger or kneader between two standard flotation stages. The dispersion or kneading stage further helps the detachment and size reduction of ink and other nonfibrous particles, and hence improves the overall flotation performance.

Evolution of Flotation Cells

Froth flotation is the most widely used separation process in modern paper mills. During the last 10 years, the development of flotation de-inking cells has been pursued more aggressively than the technologies of any other segment of the pulp and paper industry.

Initially, Denver flotation cells used in the mineral industry were installed in paper mills. These cells are open, rectangular vats, with mechanical removal of flotation froth by a rotating paddle and mechanical mixing of air and pulp suspension at the bottom. However, these cells are not currently in use.

Although the development of flotation cells for de-inking was less dramatic in the early years, there have been many changes in cell design in the last two decades. **Table 2** lists the historical development of flotation de-inking cells.

The major driving forces of the evolution of modern flotation cells are the reduction in energy and water consumption, lower footprint space and an increase in efficiency and capacity. Although many changes in flotation cell design have been made, the improvements in flotation de-inking performance are not always obvious. More recently, because of the great advances in printing, coating and modification of paper by converters to impart special properties, flotation de-inking has evolved from removing ink particles only to removing an ever-increasing variety

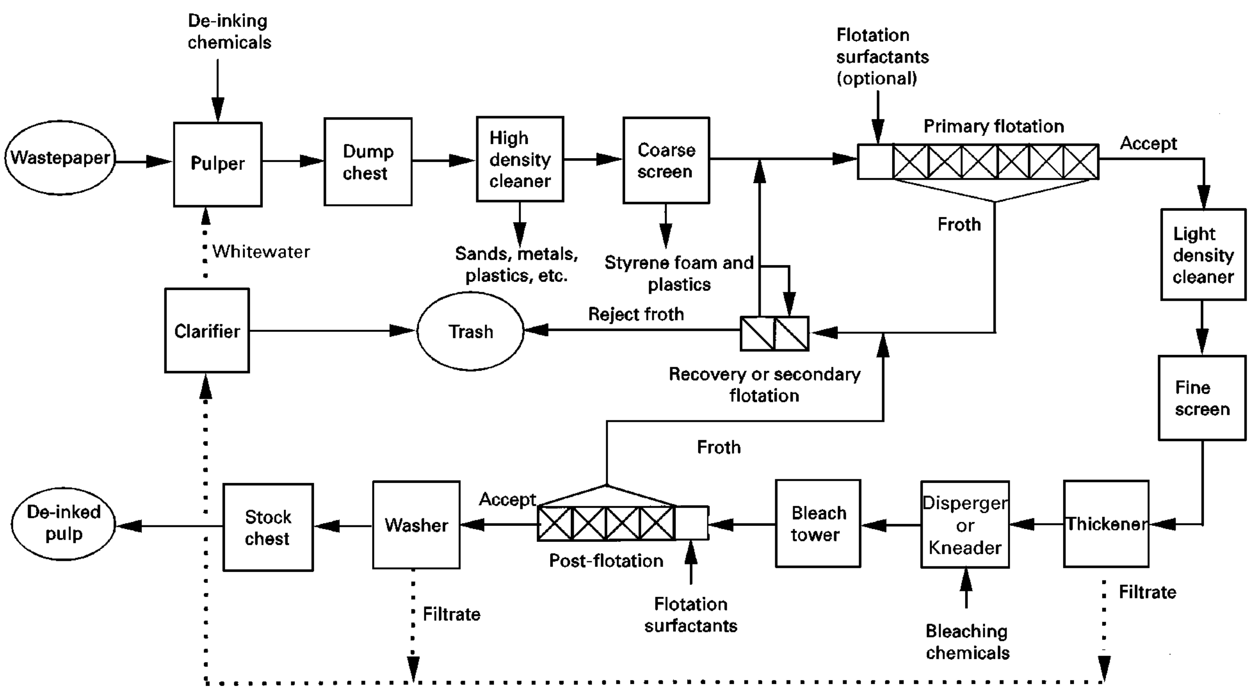

Figure 1 Flow diagram of a typical flotation de-inking mill for mixed paper.

Table 2 Historical evolution of flotation de-inking cells

Year	*Flotation cell name*	*Comments*	*Year*	*Flotation cell name*	*Comments*
1952	Denver cell	First commercial de-inking flotation cell	1986	Lamort DA Verticel	Double aeration
1959	Voith paddle cell	First cell designed specifically for de-inking with improved air mixing	1987	Beloit PDM cell	First cell to use pressure to improve efficiency and pressurized rejects removal First cell totally sealed
1972	Escher Wyss FZ-1 cell	First cell to use compressed air	1990	Voith elliptical cell	Tubular shape compressed from cylindrical to elliptical to promote faster air removal
1975	Swemac Hellberg cell	First cell without agitator and with controlled air bubble sizes			
		First cylindrical cell	1990	Eshcer Wyss CFS cell	Designed for speck removal
1976	Escher Wyess FZ-U cell	No agitator compressed air enters bottom of cell	1991	Black Clawson IHI/BC cell	Turbine acts as an agitator and distributes air through cell
1978	Lamort Verticel	First cell with vacuum to remove rejects	1991	Kamyr gas-sparged cyclone	Cyclone body with porous media
		First cell with multi-feed and aeration stages with no agitator	1992	Eshcer Wyss CFC cell	Stacked cell units
1981	Black Clawson ULTRACELL	First cell with gravity feed between stages	1993	Comer Spidercel	First cell with agitation provided by reactor blades
1981	Voith tubular injector cell	First tubular cell with air drawn through injectors	1994	Thermo/Black Clawson Verticel Mac cell	Similar to Lamort Veticel with multiple aeration closed
1981	Shinhama HIFLO FLOTATORS	Hydrocyclone body	1995	Voith Sulzer EcoCell	Similar to Voith elliptical cell with Escher CF cell air injector
1983	Beloit Lineacell	First cell with separate aeration, mixing and separation stages	1996	Kvaerner Hymac column flotation cell	First cell to use two types of air spargers to provide different size air bubbles
1984	Esher Wyss CF	Step diffuser improves mixing			

of objectionable, noncellulosic materials. However, in terms of ink removal efficiency, older flotation cells perform satisfactorily.

Factors Affecting Pulping and Flotation

The performance of flotation de-inking is affected by many factors such as pH, consistency, temperature, ink/fibre particle size, chemical types, water hardness and air bubble size. Properly controlling these factors ensures the efficient removal of ink.

pH pH significantly affects both the pulping and flotation processes by altering the physical and chemical properties of fibres and inks. High pH helps swelling of fibres and promotes the detachment of inks from fibre. However, if the pH is too high (e.g. > 10), it may cause yellowing or darkening of lignin-containing pulps. The conventional fatty acids and soaps used as ink collectors are only effective at alkaline pHs. Neutral pH flotation de-inking requires the use of more effective and selective nonionic surfactants.

Temperature Pulping and flotation temperatures are typically maintained at 40–55°C and 35–45°C, respectively. In general, elevated temperatures are used to improve the defibrization of special wastepaper such as wet strength paper. Lower temperature is beneficial to high stickies-containing wastepaper, such as magazines.

Consistency Consistency or dry fibre per cent weight in water has a direct impact on the ink particle size distribution. Depending on the types of wastepaper, different pulping consistencies are used. In newsprint mills, low-consistency (4–8%) pulping is generally used. However, in office paper de-inking mills, medium (8–12%) or high consistency (12–18%) pulping is widely applied. In general, the higher the pulping consistency and the longer the pulping time, the smaller the ink particles liberated. Typical fibre consistency in flotation operation is 0.7–1.2%.

Particle size Flotation is most effective for removing ink particles ranging from 10 to 150 μm. In general, particles smaller than 10 μm and larger than 150 μm cannot be efficiently removed by flotation process.

Water hardness In newsprint flotation, fatty acids or soaps are used as ink collectors, and a moderate amount of calcium ions (100–300 p.p.m.) is required to make the ink floatable. No additional hardness or calcium ions are added when nonionic surfactants are used.

Ash or filler content There is a strong relationship between the amount of clay or fillers in the wastepaper and the ink removed in a flotation stage. Flotation de-inking becomes much more effective when the wastepaper has significant ash content. An 8–10% ash is considered a minimum requirement, and 12–14% is preferable.

Evaluation of Flotation Performance

Three major parameters are widely used in the paper industry to characterize the flotation deinking efficiency: brightness, ink removal and reject rate.

Brightness is the percentage of reflectance measurement of pulp or paper products at a wavelength of 457 nm. It is originally developed to evaluate bleaching efficiency. In general, pulp brightness increases as ink is removed. The brightness increase is usually in the order of 10–l5 units for newsprint de-inking and of 5–10 units for white grades.

Reject rate is defined as the mass rate of reject to total stock fed into flotation. A main objective of flotation de-inking is to obtain the maximum ink removal at a minimum reject rate. For mixed office wastepaper (MOW), reject rate is commonly 10% and for ONP/OMG, it is about 15%.

Ink removal is calculated based on the ink concentration of the pulp before and after flotation. Image analysis techniques are used to measure ink particle size (>3 μm), total counts and the total surface area. Effective residual ink concentration (ERIC) measurement was developed to determine the visual effect of residual inks on the de-inked pulp. The visual effect is primarily dependent on the presence of small size ink particles (<3 μm) rather than the total ink content of the paper.

To evaluate the de-inking efficiency, both the ink removal of different size particles and brightness should be reported together with reject rate. For newsprint mills, brightness and ERIC measurements are usually employed and, for white grades, ink count measurement is very common.

De-Inking Chemicals and Recipes

The use of chemicals is involved in almost every aspect of the key processes in de-inking. Chemistry is of great importance in flotation de-inking in terms of fibre swelling, ink detachment, dispersion, anti-redeposition, ink agglomeration, ink collection and removal. Most of the chemicals used for de-inking are fairly standard commodity products, such as sodium hydroxide and sodium silicate. On the other hand, some other chemicals are relatively complex and have multiple functions. In general, most de-inking chemicals are added in the pulper. Commonly used de-inking chemicals in pulping and flotation, their functions and addition points are listed in **Table 3**.

Pulper Chemicals

The chemicals used in the pulper depend strongly on the types of wastepaper processed. The principal chemicals used for pulping and flotation are sodium hydroxide, sodium silicate, chelating agents, hydrogen peroxide, surfactants and solvents. The roles of these major de-inking chemicals are briefly discussed below.

Sodium hydroxide Sodium hydroxide is used to promote fibre swelling and to saponify or hydrolyse the ink resins by increasing pH and alkalinity. The type and amount of alkali required in the pulper depend on the type of mechanical treatment, temperature and pulping time. However, the addition of excessive caustic soda to ground wood-containing furnishes will cause the pulp to yellow or darken. This is termed as 'alkali darkening or yellowing'. Sodium carbonate is rarely used in modern de-inking mills.

Sodium silicate Sodium silicate or water glass is frequently used in conjunction with sodium hydroxide, especially in the de-inking of groundwood papers. It not only serves as an alkali to swell fibre and as a dispersant of ink particles, but also buffers the pulp to a pH range which is favourable to the action of hydrogen peroxide.

Hydrogen peroxide Hydrogen peroxide is one of the most commonly used pulping chemicals in the

Table 3 Chemicals used in flotation de-inking and their functions

Chemical	*Structure/formula*	*Function*	*Furnish type*	*Dosage (% of fibre)*	*Addition point*
Sodium hydroxide	NaOH	Fibre swelling – ink break-up Saponification Ink dispersion	All grades	0–5	Pulper
Sodium silicate	Na_2SiO_3	Wetting Ink dispersion Peroxide stabilization Alkalinity and buffering	Groundwood grades Lightly inked ledger	0.5–5	Pulper
Sodium carbonate	Na_2CO_3	Alkalinity Buffering Water softening	Groundwood grades Lightly inked ledger	0.25–5	Pulper
Hydrogen peroxide	H_2O_2	Prevention of fibre yellowing	Groundwood grades Coloured ledgers	0.5–2.5	Pulper
Sodium hydrosulfite	$Na_2S_2O_4$	Bleach, colour stripping	Groundwood grades Coloured ledgers	0.5–1.5	Pulper Pulp storage
Sodium or potassium phosphate	Hexametaphosphate Tripolyphosphate	Metal ion sequestrant Ink dispersion Alkalinity and buffering Detergency	All grades	0.2–1	Pulper
Chelating agents	EDTA DTPA	Metal ion chelation Peroxide stabilizer	All grades	0–0.5	Pulper
Calcium ions	$CaCl_2$	Fatty acid/soap collector aid	Groundwood grades	90–300 p.p.m.	Flotation Pulper
Hydrophilic polymers	Polyacrylate Carboxymethylcellulose	Ink anti-redeposition Anti-redeposition	All grades	0.1–0.5	Pulper
Nonionic surfactants	Ethoxylated alcohol Ethoxylated alkyl phenols	Ink collector Flotation frother Wetting Emulsification	All grades	0.1–2	Pulper Flotation
Fatty acids or soaps	Stearic acid Oleic acid Fatty acid mixtures	Ink collector Flotation frother	All grades	0.5–3	Pulper Flotation
Solvents	C_1–C_{14} aliphatic saturated hydrocarbons	Ink softening Solvation of wax	Wood-free grades	0.5–2	Pulper

recycling of groundwood wastepaper. It is also widely used as a bleaching chemical. The addition of hydrogen peroxide in the pulper is to offset the formation of chromophores created by high alkaline pH.

Sodium hydrosulfite Hydrosulfite is mainly used as a reductive bleaching agent to bleach recycled pulp and to decolourize the coloured fibres.

Chelating/sequestering agent Chelating compounds are commonly added in the pulper to form complexes with multivalent metal ions to prevent peroxide decomposition. Diethylenetriaminepentaacetic acid (DTPA) and ethyelenediaminetetraacetic acid (EDTA) are the most common chelates used in the paper recycling industry. Compounds like DTPA and EDTA have been banned in some countries, for example, Sweden and Norway.

Dispersants Sodium tripolyphosphate and tetrasodium pyrophosphate are sometimes added to the pulper to provide multiple functions such as ink dispersion and metal chelating. Use of laundering antiredeposition agents such as carboxymethylcellulose and sodium polyacrylate can also help disperse the ink particles, prevent redeposition of ink on the fibre, and increase de-inked pulp brightness.

Solvents Organic solvents were once widely used to dissolve waxes and varnishes, but environmental concern has curtailed the use of these chemicals. Solvents used in wastepaper deinking include C_{12}–C_{14} hydrocarbons and glycol ethers.

Flotation Chemicals

Surfactants are probably the most important chemicals in flotation de-inking. They consist of two principal components – a hydrophilic component and a hydrophobic component. It is assumed that the hydrophilic end of the molecule attaches to the ink particle, leaving the treated surface state hydrophobic. Most surfactants used in flotation de-inking play two important roles. Firstly, they function as ink collectors that selectively render the ink particle surface more hydrophobic and facilitate ink particle–air bubble attachment. Secondly, they serve as flotation frothers that generate moderate foaming. Surfactants used in flotation de-inking can be cationic, anionic, nonionic or amphoteric, and are added either at the pulper or just before the flotation cells.

The most frequently used surfactants are fatty acids and their soaps, as well as nonionic surfactants. Cationic surfactants are not currently used in flotation cells. Commonly used flotation de-inking surfactants and their formulas are shown in **Table 4**.

Fatty acids and soaps Fatty acids and their soaps are early flotation de-inking surfactants, and are commonly used in Europe than in North America. Mixtures of fatty acids with carbon chain lengths of 16–18, such as stearic, oleic, palmitic and linoleic acids, are commonly used as ink collectors. Saturated fatty acid soaps usually have better ink collection while unsaturated fatty acid soaps have higher foaming. To function effectively as ink collectors, fatty acids require the presence of moderate concentration of calcium ions such as at least 12 degree German hardness (dH) or approximately 200 p.p.m. as calcium carbonate. The calcium ions can be sourced from the paper fillers such as calcium carbonate, or from the addition of calcium chloride or oxide. To maximize the function of any source of calcium ions, it is important to maintain the flotation in alkaline conditions (>8–8.5), otherwise fatty acids precipitate. However, the presence of excess calcium ions in the system may cause fibre loss.

Nonionic surfactants Nonionic surfactants encompass a large number of synthetic chemicals of varied types and structures. Major types of nonionic surfactants include fatty ethoxylate, alkyl phenol ethoxylate and fatty acid alkoxylate. Cloud point and hydrophilic/lipophilic balance (HLB) value are two important terms used to describe a given nonionic surfactant. Cloud point is the temperature at which nonionic surfactants become separated from the solution. Below the cloud point, surfactant has higher foaming and above the cloud point, the foaming of surfactants decreases dramatically. HLB value is the ratio of weight percentages of hydrophilic to hydrophobic groups in the structure. Generally, for the same surfactant, the higher the HLB value, the higher the foaming ability, and the lower the ink collection ability. An effective nonionic flotation surfactant usually possesses the properties of good ink collection and adequate foaming.

Some of the most common nonionic surfactants used in flotation deinking are EO/PO copolymers, in

Table 4 Typical flotation de-inking surfactants

Types	*Name*	*Formula and structure*
Anionic	Fatty acid and emulsion	$CH_3(CH_2)_nCOOH$
	Fatty acid soap (stearic/palmitic/oleic acid and soap)	$CH_3(CH_2)_nCOONa$
		$CH_3(CH_2)_nCOONa$
	Alkylbenzene sulfonate	$R–(C_6H_4)–SO_3Na$
	Fatty alcohol sulfate	$R–OSO_3Na$
	Fatty alcohol ether sulfate	$R–O–(CH_2CH_2O)_nSO_3Na$
Cationic	Dodecyltrimethylammonium bromide	$CH_3(CH_2)_{12}NH_4Br$
Amphoteric	Sulfobetaine	$RN^+(CH_3)_2(CH_2)_xSO_3^-$
Nonionic	Fatty alcohol ethoxylate	$R–O–(CH_2CH_2O)_xH$
	Ethoxylated alkyl phenol	$R–(C_6H_4)–O–(CH_2CH_2O)_xH$, $n = 8$–9
	EO/PO copolymers	$HO–(EO)_x–(PO)_y–(EO)_z–H$
	Fatty acid alkoxylate	$RCOO–(CH_2CH_2O)_xH$
	Alkyl phosphate ester	$(RO(CH_2CH_2O)_n)_2POONa$
	Fuel oil	$CH_3(CH_2)_nCH_3$
	Fatty oil alkyleneoxide derivative	

EO, Ethylene oxide; PO, propylene oxide.

which the hydrophilic part is EO (ethylene oxide) and the hydrophobic part is PO (propylene oxide). Alkoxylates of fatty alcohols or fatty acids containing both EO and PO units have been used as flotation surfactants.

As environmental regulations become tougher, de-inking mills tend to prefer to use surfactants that are easily biodegradable. Because of the difficulty of breaking down alkyl phenols in wastewaters, they are gradually being replaced by readily biodegradable products such as alcohol ethoxylates.

Flotation Recipes

The selection of optimal flotation chemistry recipes depends strongly on both ink properties and types of wastepaper. The flotation recipes that are commonly employed are summarized in **Table 5**.

Old newspapers Newsprint (100%) is often de-inked by washing. However, flotation can also be effective to remove newsprint inks with fatty acid/calcium ion chemistry. In the absence of calcium ions, the ink particles do not float using fatty acid collectors. The addition of calcium is indispensable for a fatty acid or a soap to function properly as a collector. Positively charged calcium ions are bonded to the fatty acid and to the negatively charged ink particles, and thereby promote ink flotation. Calcium ions (often as calcium chloride) should be added to the pulp simultaneously or before the fatty acid at a level of above 100–150 p.p.m. as calcium carbonate.

ONP/OMG mixture Ash plays a very important role in the flotation de-inking of newsprint. It is a common practice to include a certain per cent of old magazines (OMG) in old newsprint (ONP) for better flotation de-inking efficacy. Since OMG and mixed office waste (MOW) contain fillers such as calcium carbonate, the presence of these fillers in the waste-paper promotes ink flotation. This is because the fillers can provide the calcium ions needed by the fatty acids. Traditionally, the mixtures of ONP and OMG, usually in the ratios of 70 : 30 and 50 : 50, are de-inked by flotation at an alkaline pH using fatty acids or soaps. A significant improvement in ink removal of newsprint can also be achieved by adding clay to the pulper.

Mixed paper Most of the early plants used alkaline conditions to de-ink mixed wastepaper. However, there is a trend for modern de-inking mills to switch to neutral conditions. Fatty acids are commonly used in Europe and Asia and nonionic surfactants alone are commonly used in North America for de-inking mixed paper. However, fatty acids in combination with nonionic surfactants are found to be the most effective in removing both large and small ink particles.

Flexographic inks Flexographic inks are water-based inks and are difficult to de-ink using flotation due to the hydrophilic nature and very small size (< 5 μm) of the ink particles. Flexographic inks tend

Table 5 Typical flotation recipes of waste paper de-inking

Medium	*Pulping*			*Flotation*	
	Alkali and bleaching agent	*Chelate or dispersant*	*pH*	*Collector and frother*	*Furnishes suitable for the flotation chemistry*
Alkaline de-inking	NaOH Na_2SiO_3 H_2O_2	EDTA DTPA Phosphate	8.5–11.5	Fatty acids or soaps with calcium ions	100% ONP, 100% flexographic ONP/OMG
				Fatty acids or soaps	ONP/OMG, ONP/SOW, OMG trimming/MOW
				Fatty acids or soaps and nonionic surfactants	ONP/OMG, ONP/SOW, OMG trimming/MOW
				Nonionic surfactants	Sorted ledger, MOW, CPO
				Fuel oil and nonionic surfactants	100% flexographic ONP and OMG
Neutral de-inking	NaOH (optional)	EDTA DTPA (optional)	5.5–8.0	Fatty acids or soaps	MOW, sorted ledger, OMG trimming/MOW
				Fatty acids or soaps and nonionic surfactants	MOW, sorted ledger, OMG/MOW, CPO, manifold
				Nonionic surfactants	MOW, sorted ledger, OMG/MOW, toners
				Fuel oil and nonionic surfactants	Flexographic ONP/OMG

For abbreviations, see Table 1.

to redeposit on the fibres and may cause a dramatic brightness drop of the pulp. Similar to 100% newsprint, fatty acid soaps and calcium ions are found to be effective in removing flexographic inks.

Toner inks Xeroxgraphic paper and laser computer printout (LCPO) are frequently found in government publications and general office waste. The inks in these papers are thermoplastic powders or toners, and are firmly bonded to the fibres with a heat fusion printing process. The toner ink particles are hydrophobic, but their removal efficiency by flotation is poor compared with conventional inks since the toner inks are large in size and cannot be sufficiently detached from fibres in the pulper. Effective removal of toner inks can be realized using high consistency mechanical dispersion of the pulp with kneader and disperger followed by flotation using nonionic surfactants. Kneader and disperger assist flotation by improving toner–fibre detachment and by reducing the ink size distribution to a more floatable range.

Future Trends

Flotation de-inking is a complex separation process of inks and other contaminants from fibres. Due to economical reasons and strict environmental regulations, new materials used by paper manufacturers and new printing technologies, paper mills require environmentally benign de-inking technologies which can easily fit into the current de-inking system without extra capital investment.

In recent years, great progress has been made in flotation de-inking technologies with respect to flotation cell design, utilization of new surfactants and the understanding of de-inking chemistry. However, the rapid advances in printing, coating and other modifications of paper make de-inking more difficult. More effort is needed to understand the flotation behaviour of new types of wastepapers.

Flotation chemistry plays the most important role in determining the ink removal efficiency. Neutral flotation de-inking has become increasingly popular in the last 10 years. This is mainly because neutral de-inking has great potential to lower chemical usage and cost, to reduce water treatment cost, to improve product quality and paper machine runnability. Mills will benefit from switching from alkaline to neutral flotation de-inking. Since no caustic or silicate is added in the pulper, fibres are not yellowed or darkened. As a result, bleaching chemicals such as peroxide may not be required.

Enzymatic de-inking represents a new approach to modern paper-recycling mills. Extensive research has been conducted to use enzymes to improve de-inking efficiency. The enzymes used included primarily cellulases, hemicellulases, amylase, lipase or resinase. Commercial application of enzymes to the flotation de-inking of wastepapers showed enhanced ink removal efficiency. Neutral pH de-inking further benefits the use of enzymes since it can improve ink detachment from the fibres and repulping efficiency. Since most enzymes work at acidic pH and lower temperature, enzyme manufacturers have to develop thermophilic and alkaline-stable enzymes to lower usage and enhance their effectiveness.

Further Reading

Borchardt JK (1997) An introduction to deinking chemistry. In: Doshi MR and Dyer JM (eds) *Paper Recycling Challenge*, vol. II. *Deinking and Bleaching*, pp. 18–30. Appleton, Wisconsin: Doshi.

Borchardt JK and Ferguson LD (1998) Deinking chemistry. In: Doshi RM and Dyer JM (eds) *Paper Recycling Challenge*, vol. III. *Process Technology*, pp. 71–81. Appleton, Wisconsin: Doshi.

Ferguson LD (1992) Deinking chemistry: part 1. *Tappi Journal* 75(7): 75–83.

Ferguson LD (1992) Deinking chemistry: part 2. *Tappi Journal* 75(8): 49–58.

Hines PR (1933) US patent no. 2,005,742.

Jelks JW (1954) Development in flotation deinking of waste paper. *Tappi Journal* 37(10): 176A–180A.

Larsson A, Stenius P and Ödberg L (1984) Surface chemistry in flotation deinking, part 2. The importance of ink particle size. *Svensk Papperstidning* 87(18): R165–R169.

McCool M (1993) Flotation deinking. In: Spangenberg RJ (ed.) *Secondary Fiber Recycling*, pp. 141–162. Atlanta, Georgia: TAPPI Press.

McKinney R (1998) Flotation deinking overview. In: Doshi RM and Dyer JM (eds), *Paper Recycling Challenge*, vol. III. *Process Technology*, pp. 99–114. Appleton, Wisconsin: Doshi.

Shrinath A, Szewczak JT and Bowen IJ (1991) A review of ink-removal techniques in current deinking technology. *Tappi Journal* 74(7): 85–93.

Smook GA (1994) *Handbook for Pulp and Paper Technologists*, 2nd edn. Vancouver: Angus Wilde.

Somasundaran P and Zhang L (1998) Fundamentals of flotation deinking. In: Doshi RM and Dyer JM (eds), *Paper Recycling Challenge*, vol. III. *Process Technology*, pp. 83–98. Appleton, Wisconsin: Doshi.

Welt T and Dinus RJ (1997) Enzymatic deinking. In: Doshi MR and Dyer JM (eds), *Paper Recycling Challenge*, vol. II. *Deinking and Bleaching*, pp. 235–246. Appleton, Wisconsin: Doshi.

Woodward TM (1986) Appropriate chemical additives are key to improved deinking operations. *Pulp Paper* 60(11): 59.