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RECYCLE, REUSE AND DISPOSAL OF PAPER AND BOARD

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ABSTRACT

The current emphasis on the environment and its impact on recycling is placed into context with an introduction of how life cycle analysis and assessment techniques will play an increasing role in determining the direction of industrial development and legislation.

The review is based around the subjects identified by European Paper industry experts on recycling and recycling research as being the most critical to the long term development of the industry. These are the characterisation of the changes which occur to fibres and their surfaces on recycling; the influence of chemicals on water quality and production efficiency; the fundamentals of flotation deinking and recycling models. In addition a section on alternative uses for wastepaper is included.

Recent reviews on the effects of recycling on paper properties are summarised and an explanation for the apparent anomalies and

differences given. Results on post paper manufacturing treatment on recycle potential are also included.

The information on the effect of chemicals on recycling is sparse and tends to be empirical. The greatest effects are on paper strength and brightness where bleaches or brightening agents are used. The chemicals which dissolve also have a detrimental effect on process additive efficiency and add to effluent treatment and discharge costs.

The deinking section is subdivided into - a brief review of the chemistries and drying methods of inks and toners and their influence on particle size on repulping; the chemistry of the repulping process; the flotation process. The influences of chemicals on flotation and the fundamental phenomena which occur during the process are described.

Models for assessing age distribution and product properties at various levels of recycling are explored. In addition the build up of materials within a recycling loop is examined along with the energy balance of recycling compared with manufacture from virgin materials.

Alternative uses of wastepaper considered include energy generation, composting and as a raw material for a variety of applications. None of these are likely to become major uses, competitive with wastepaper used for paper and board production in the near future.

It is concluded that there are various studies of a fundamental nature which need to be completed to advance the technology of recycling. Greater emphasis on the supply side of wastepaper would also yield industrial benefit.

INTRODUCTION

Throughout the developed world there are considerable societal pressures to reduce consumption of 'unnecessary' products and to minimise the impact of industry and commerce on the environment. The environment is a loosely defined term and has different interpretations in different contexts. Broadly there are issues which have to be addressed at local, regional, national and global levels. These include visual appearance and noise at the local level; solid waste disposal and discharging to water courses at regional and national levels; global warming and ozone layer depletion at the global scale. It is beyond the scope of this review to discuss and tackle these complex issues where objectivity and scientific integrity are often subservient to fashion, single issue focus, politics and the use of the environment to gain commercial advantage.

The paper and board industry has a high profile in the environmental debate. This is partly because it is a major international industry the consumption of whose products are a mark of national esteem and an indication of the state of civilisation reached(1). With the change in emphasis from an acquisitive to a caring society it is the volume of paper and board products consumed and their visibility to consumers (approximately 35% of the content of domestic waste is paper and board - Figure 1(2)) that draws attention to the industry. This in turn brings into focus the raw materials used, particularly wood, the high energy consumption and the use of chlorine containing compounds for bleaching.

Political pressure has alighted on the solid waste issue. Solid waste is visible and it is easy to demonstrate that something is happening to solve the problem. Individual consumers can also play their part and an overall 'feel good factor' is generated. A hierarchy of options for solid waste disposal has evolved(3) and is embodied in proposed EC legislation(4). Essentially the preferred order is - reduce waste at source, reuse, recycle, compost, incinerate with energy recovery, incinerate and landfill. Intuitively this order is sensible but because of the complexities of supply and demand within industrialised societies may not prove to be correct for all materials and locations.

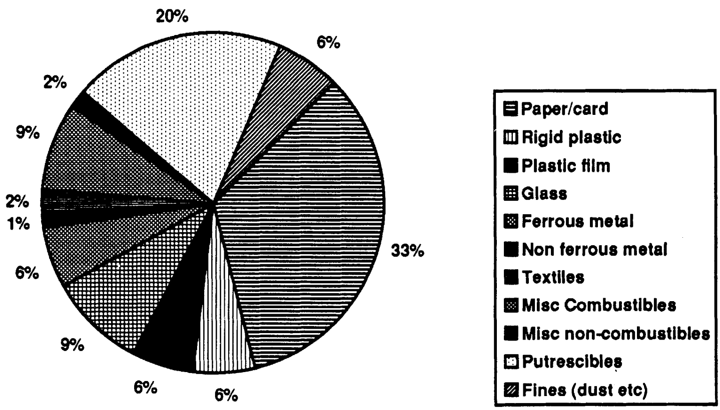


Figure 1: Composition of UK domestic (Dustbin) waste by weight

However, whatever the rights and wrongs of the hierarchy sufficient momentum has built up in Europe and North America to ensure that it is applied by national governments. We must accept that legislation will increase the availability of wastepaper by diverting it from landfill. Whether this wastepaper can be used for paper and board production will depend on the total economic and environmental costs of its collection, separation, grading and processing as a raw material. This is a complex topic, dependent on the treatment the wastepaper receives at all stages in the paper chain - original manufacture, coating, conversion, printing, end use, collection and separation and reuse. Up to and including the collection stages an increasing number of chemicals and other materials are added to ensure the functionality of the paper and board product or are introduced accidentally. (This is illustrated in Table 1.)

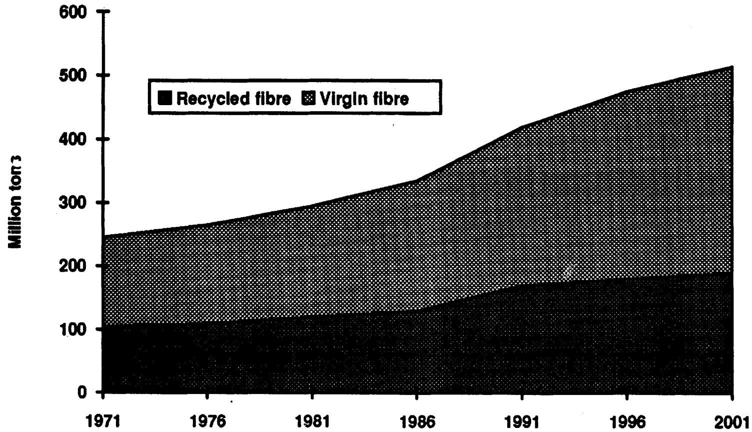
Process	Additives	Recyclability problem/opportunity
Papermaking	Process - retention, drainage aids Product - starch, strength aids, sizes wet strength fillers	 Starch dissolution Wet strength Fillers
Coating	Binders, fillers, viscosity and rheology modifiers	Binders Dispersants Fillers
Printing	Pigments Binders Varnishes	Varnishes Binders Pigments
Converting	Adhesives Plastic films Metal films	Adhesives Plastics
Usage	Dirt Contamination with other materials	Contamination resulting from mixing
Collection	Contamination Ropes Steel bands Plastics bands	Mixing of materials
Sorting		Automation Optimise material stream
Recycling process	Bleaching chemicals Surfactants Sequestrants Chelants	Fibre fractionation Filler reuse Ash Deinking residue/sludge
Papermaking		Wastes from process - solid eg ash, fibre Soluble materials

Table 1: The Paper Chain

Effective recycling depends on the ability to remove selectively and economically those materials that detrimentally affect the performance of paper and board products made from wastepaper.

This task is made complex because these materials affect the performance of different products differently (eg residual ink is detrimental for a printing paper but not for the centre of a solid board). In addition to the presence of contaminants the papermaking and downstream processes change the properties of the fibres reducing their value as a raw material.

There are assumptions made that a great deal of this waste will be used for paper production with a predominant growth in the amount of wastepaper used for graphic grades(5) - Figure 2. This presents scientists, technologists and others with the challenge of making it happen.



Source: Jaakko Pöyry

Figure 2: Consumption of virgin and recycled fibre in paper and board production in the World 1971-2001

What is frequently ignored is that recycling has downsides in that it consumes energy derived from non renewable resources and produces both solid and liquid wastes. The comparative environmental effects have been studied by a number of groups(6,7) using life cycle analysis techniques. Their conclusions are not clear cut because of flaws in the data and in life cycle analysis methodology.

Life cycle analysis is 'a method used to quantify environmental burden based on an inventory of environmental factors for a product process or activity from the extraction of raw materials to their final disposal'(8). (Environmental factors include the consumption of raw materials and energy and emissions to air and water as well as the generation and disposal of solid waste.)

As such it is an inventory method which generates a list of substances which are consumed by the system studied either in material or energy form and produced by the system as useful products or wastes. To determine the relative overall impacts of two different systems some form of weighting of environmental discharges is needed - this constitutes life cycle assessment.

This is an area of research in which the paper industry must be active. The fundamental science extends far beyond the boundaries of that the industry is accustomed to into climatology etc.

Techniques such as life cycle analysis can be used to determine where in a system the greatest environmental impact is occurring. Some models(9) are available in software which will run on PCs and can be used readily to predict the effect of future changes in technology and paper and board consumption. Primary production of wood(10) and pulp(11,12) in the future will have lower environmental impact. These changes will alter the environmental balance between paper and board manufactured from virgin materials and wastepaper.

Wastepaper recycling is a very broad topic with a vast body of supporting technical literature. In order to produce a communicable review a focus is required. Originally the concept was to apply life cycle analysis to identify where recycling has a high environmental impact. The literature search revealed that the data is not available. An alternative approach was used in which European experts in science and technology were asked to identify the barriers to recycling and the key areas requiring research(13).

The research topics and the overall objectives identified by these experts are:

- to characterise morphological and chemical changes that occur in and on fibres during recycling; the effects of these on their papermaking potential and investigate strategies to reduce or ameliorate these disadvantageous effects.
- to determine the influences of chemicals added during various parts of the paper chain on process water quality and production efficiency in wastepaper using paper mills.
- to increase basic understanding of the mechanisms of ink removal from paper surfaces in the deinking process and the factors which control ink particle size distribution.
- to create a platform for the exchange of information on paper recycling and paper production models with the purpose of developing a common approach to life cycle analysis methodology and use.

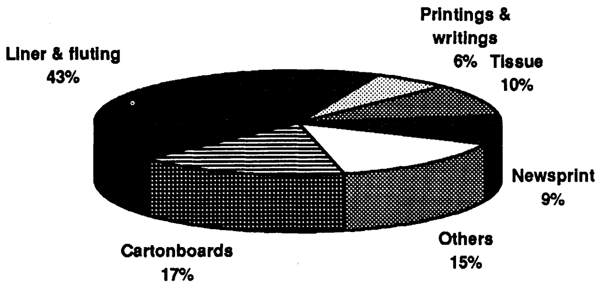
These subjects will form the sections within this review. In addition alternative uses for wastepaper will be reviewed eg composting, incineration and as a raw material for other industrial processes.

This 'selection' is not intended to diminish the importance of other topics such as designing recyclability into products via pulp preparation(14), paper manufacture(15), coating(16) and downstream processes such as ink formulation modification(17). Wastepaper collection and sorting systems should also be the subject of scientific attention as well as the identification of the recycled fibre content in paper products.

RECYCLING OF PAPERMAKING FIBRES

Background

The users of paper may require that it contains recycled fibres. They also demand that it performs its intended function satisfactorily. This is achieved for many packaging grades and newsprint as evidenced by the proportion of these products manufactured from wastepaper(5) - see Figure 3.



Source: Jaakko Pöyry

Figure 3:Estimated wastepaper use by end product in 1990 (%)

The reason for this is largely economic - the wastepaper available can be converted into products at a cost which is competitive with virgin pulps. The wastepaper available meets the prime requirement for economic recycling - the materials specification, after suitable treatment at the flow box, meets the performance specification for the paper and board machine and the product manufactured (see Figure 4).

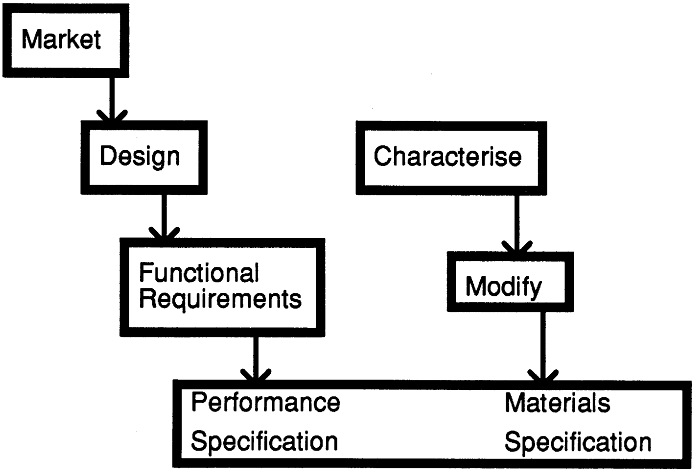


Figure 4: Recycling supply/demand model(18)

This indicates that there must be a market for products manufactured from the waste. This in turn leads to a design for the product and the manufacturing process. This feeds through into functional requirements for the process and performance specifications for it. To perform satisfactorily the materials must have defined properties ie specifications. It is the process of matching these to the waste collected by modifying the collection and separation stages which is critical.

In practice the whole process is iterative. Non recycling industries have an advantage in that they can attack the problem of reusing waste materials from first principles. The paper industry tends to concentrate its efforts on modifying the process to account for changes in the waste rather than modifying the waste in the collection separation stages.

The effects of recycling on paper and fibre properties

Paper like other materials such as glass and synthetic polymers suffers a reduction in its properties when recycled. This reduction in properties may not preclude its use because it is not necessary to exploit the full potential of the fibres for many grades. The increased pressure to recycle has focused attention on the question of how many times a fibre can be recycled. Much research of an empirical nature has been devoted to carrying out experiments to answer this question. Many of these experiments have been devoted to looking at single fibre furnishes which is a singularly artificial situation when it is recognised that most paper and board products are manufactured from a mixture of pulps usually in the presence of chemicals.

The deterioration of fibre properties in recycling has attracted the attention of researchers since the 1930s. In most decades there have been one study which has attracted attention(19,20,21,22) and served as a reference work and stimulus for others. Little new work was reported in the 1980s where attention switched to process problems such as stickies removal and deinking. There has been a considerable revival of interest in the 1990s stimulated by a return to further understanding of the fundamental causes of changes to fibre properties caused by the papermaking process which show up when they are recycled. Two recent reviews(23,24) which build on those published in the late 1980s(eg 25) have highlighted the major studies and findings and have pointed to the need for future work. The reader is directed to these reviews to obtain a detailed appreciation of the depth and breadth of work which has been completed.

Workers have been concerned to study the influence of recycling on papermachine runnability and on the strength and optical properties of paper made from recycled fibres. There is general agreement that the absolute effects of recycling depend on:

- the wood type

- the pulping process
- the yield after pulping and bleaching
- the refining treatment prior to sheetmaking
- the pH and ionic state of the pulp during stock preparation and sheetmaking
- the tension applied to the sheet during drying
- the moisture content after drying
- the temperature reached by the sheet during drying
- post manufacturing treatment eg calendering, corrugating
- storage of the paper and board(26).

The greatest influences are the pulp yield and the moisture content post drying. A general conclusion reached is that chemical and mechanical pulps recycle differently (see Figure 5)(23).

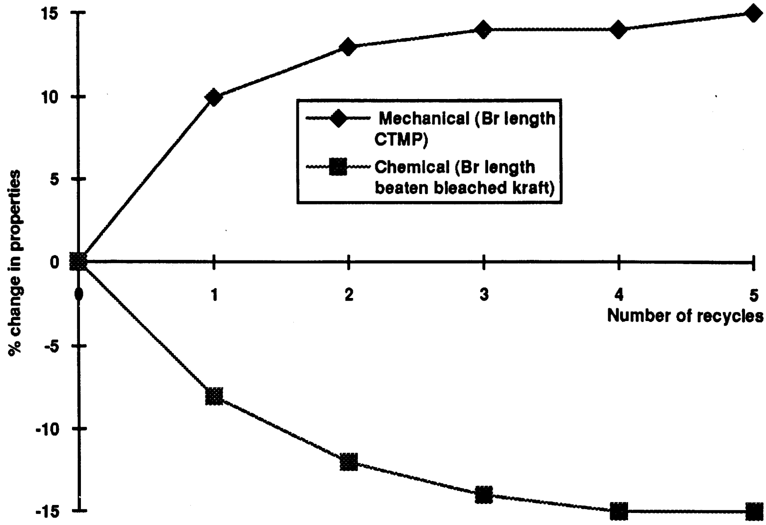


Figure 5: Chemical and mechanical pulps recycle differently

In the case of chemical pulps strength properties (sometimes with the exception of tear) are reduced - the greatest reduction occurring the first time the fibres are dried and recycled. Apparent density usually decreases. Recycled chemical pulps have a greater tendency to produce fines on refining than their virgin equivalents. It is not clear whether this is because fines which are bonded to the surface of the fibres are released during dispersion and the early stages of refining or the intrinsic weakening of fibres caused by drying.

Mechanical pulps, in contrast, show very little change in strength properties on recycling but tend to have higher apparent densities. Very little work on the recycling of mechanical pulps has been undertaken possibly because of their lower importance as market pulps or the fact that they recycled well was known instinctively as a result of the amounts recycled in grades such as newsprint.

Authors have disagreed on aspects of the influence of recycling on paper properties and papermachine runnability. Examples include:

- the effect of wet pressing on recycle potential
- the effect of recycling on the tear strength of chemical pulps
- the influence of fines on recycling
- the influence of recycling on machine runnability and wet pressing.

Howard's(23) and Ferguson's(24) reviews have highlighted that most of these differences can be explained by the different experimental conditions used for stock preparation, sheetmaking and drying and recycling. For example changes in tear strength when chemical pulp is recycled depend on how far up the refining curve the pulp was before being converted into paper. The influence of wet pressing depends on the moisture content ex press for reasons which are explained by Scallan(27).

Most mill personnel are convinced that recycled fibres run wetter and are more difficult to press. This runs counter to the laboratory recycling experiments which show little difference or increased freeness and a lower water retention value. The influence of wet pressing on water removal and strength development of virgin and recycled fibres has been studied by Wicks(28) at the pilot scale. He observed that:

- dryness ex press was higher for recycled chemical pulp which was not refined (see Figure 6)
- strength development was lower for the recycled chemical compared to the virgin pulp (see Figure 7)
- strength could not be developed by pressing for either virgin or recycled mechanical pulps.

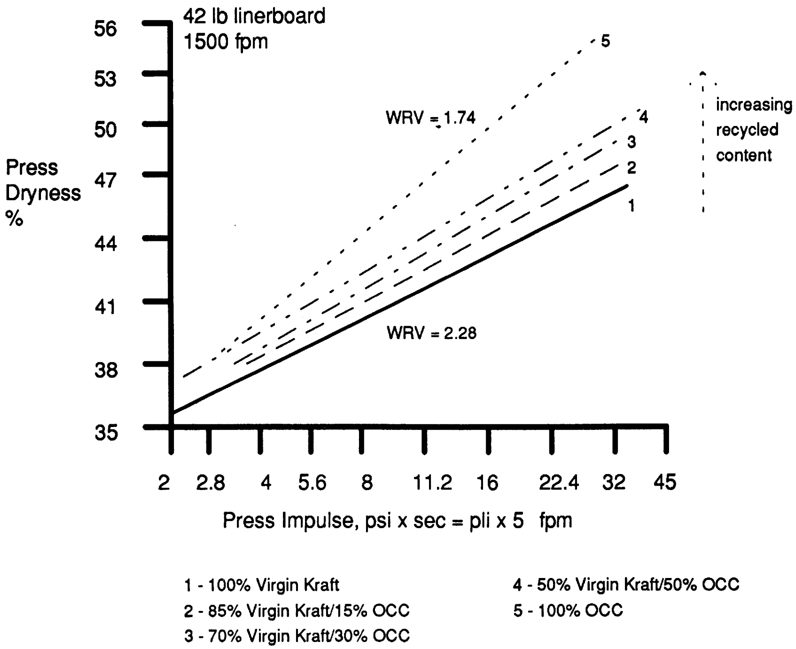
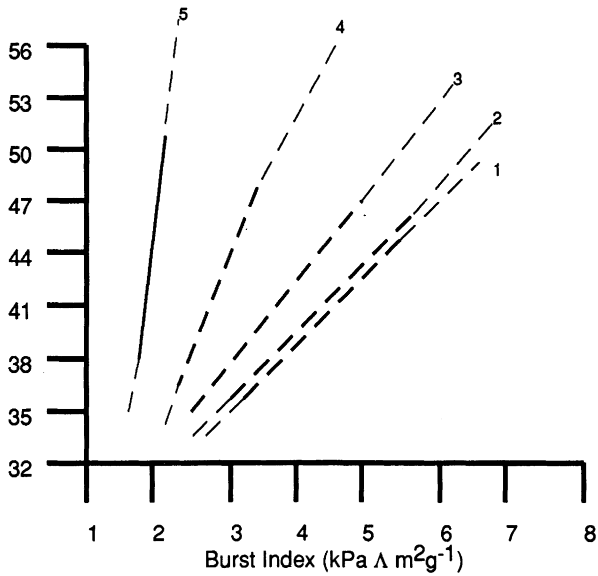


Figure 6: Press Impulse versus Press Dryness - Kraft Furnish



1 - 100% Virgin Kraft
2 - 85% Virgin Kraft/15% OCC
3 - 70% Virgin Kraft/30% OCC
4 - 50% Virgin Kraft/50% OCC
5 - 100% OCC

Figure 7: Burst Index versus Press Dryness - Kraft Furnish

In practice the strength of the recycled furnish would have to be developed by other means such as refining. The effect of this would be to generate fines and increase water retention value. This leads to reduced drainage and water removal due to pressing.

The tensile strength of paper is a combination of the intrinsic strength of the fibres and the strength of the bonds between them(29). The overwhelming evidence is that the average intrinsic fibre strength remains unchanged on recycling(23). Evidence has been advanced by Wuu et al(30) that the strength of fibres in the MD increase whilst those in the CD decrease. They use this argument to explain why there are reports of increased intrinsic fibre strength resulting from recycling.

The reduction on recycling in the tensile strength of papers made from chemical fibres can only be due to a fall in bonding strength. Bond strength is dependent on the area of overlap between fibres and the strength per unit area of overlap(29). In practice it is difficult to separate these effects.

The extent of overlap depends on fibre flexibility which is related to fibre swelling which has been known to be reduced by recycling(30) since the end 1940s. Chatterjee et al(31) have proved, (Figure 8), that there is a strong regression between fibre saturation point and breaking length for recycled kraft pulps. This suggests that the majority of the loss in bonding strength is caused by the reduced overlap between fibres on recycling. Indirect evidence for this can also be obtained from plots of apparent density against breaking length for recycled and virgin pulps, (Figure 9), (32).

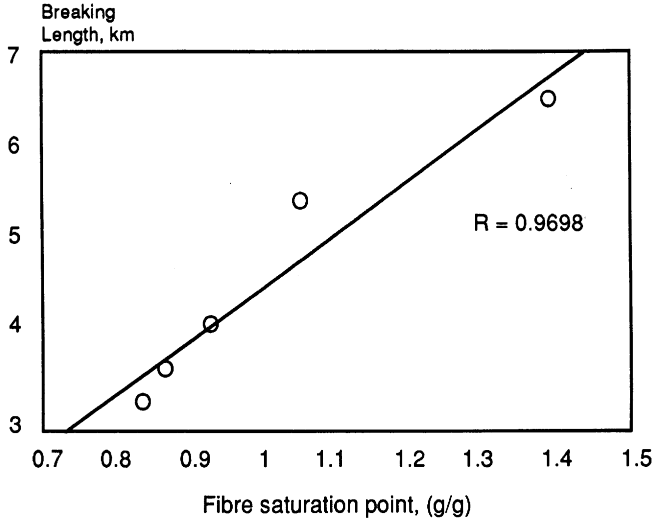


Figure 8: Regression between breaking length and fibre saturation point for recycled kraft pulps

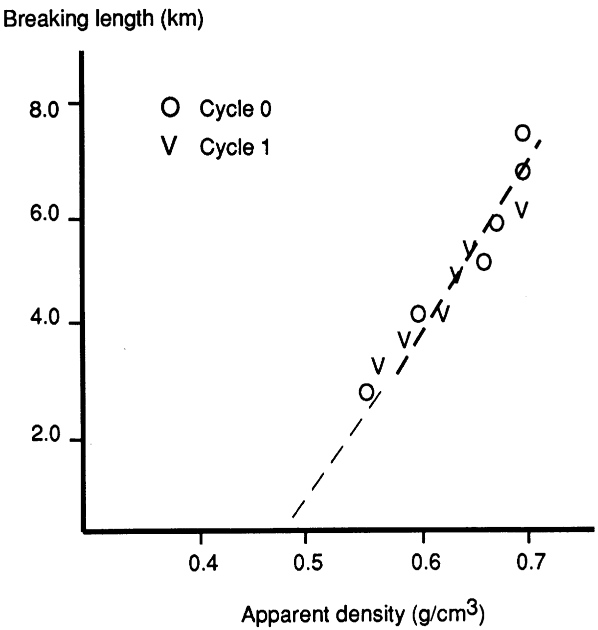


Figure 9: Strength density relationship holds for recycled unbleached kraft

Recycling may influence the surface energy of fibres. Chatterjee(33) reported an increase in surface free energy for an ultra high yield sulphite pulp, (Figure 10). The reason advanced for this behaviour was the washing out of hydrophobic material deposited on surfaces on recycling(31).

Oye et al(34) found that the contact angle of individual fibres increased with recycling, (Figure 11). The opposite result was found for TMP fibres(35).

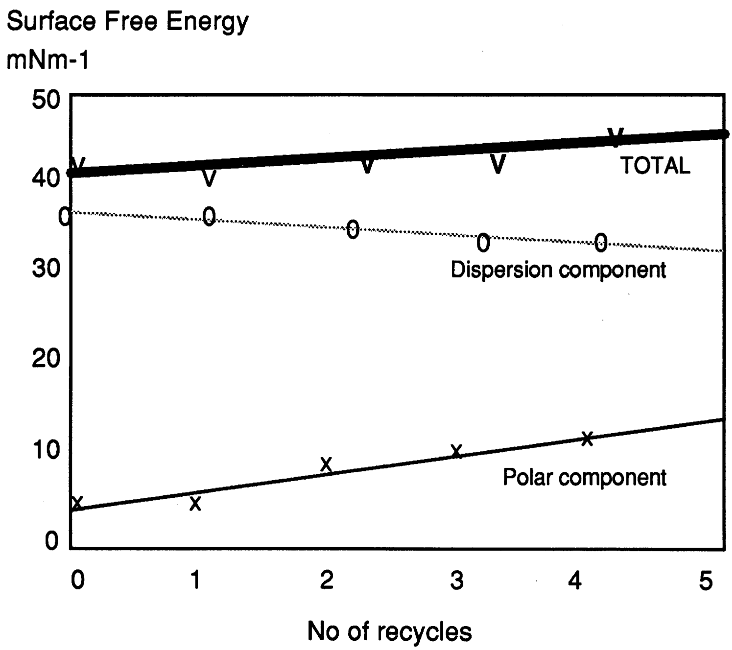


Figure 10: Change in surface free energy of ultra high yield sulphite

Explanation for influence of recycling on fibre properties

Researchers have sought to explain the reasons for the reduction in swelling of chemical fibres and the different recycle behaviours of chemical and mechanical fibres. The most complete and authoritative explanation is provided by Scallan(27) who measured the elastic modulus of fibre cell walls over a range of pulp yields and in virgin and once dried states. The effect of pulp yield and recycling on fibre saturation point is shown in Figure 12. This indicates that the loss of swelling is associated with low yield pulps.

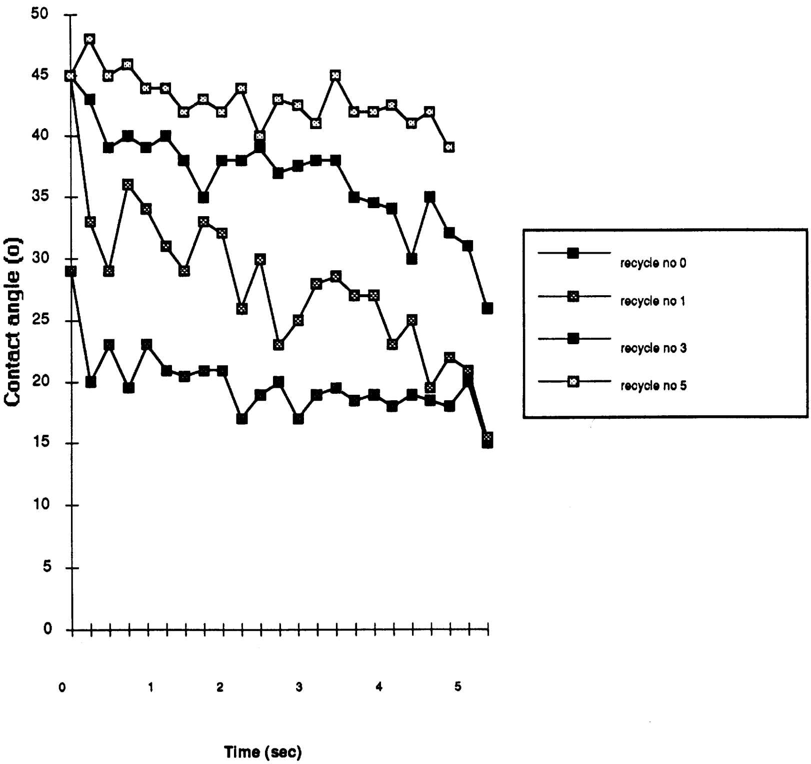


Figure 11: Contact angle of individual fibres increase with recycling

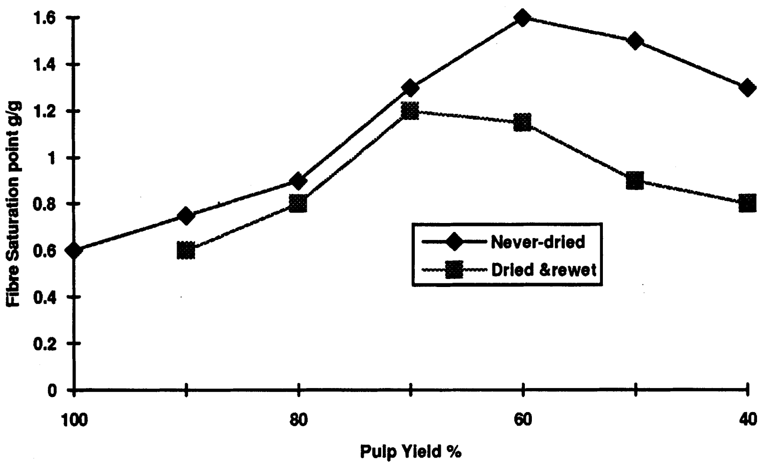


Figure 12: The degrees of swelling of pulps in never-dried and dried and rewet states (sodium forms) are shown as a function of pulp yield. Appreciable loss of swelling (hornification) is a property of low yield pulps.

The influence on elastic modulus is shown in Figure 13. Here the elastic modulus of pulps of yield >60% are unchanged by recycling. At lower yields the elastic modulus of the wet fibre is increased by drying.

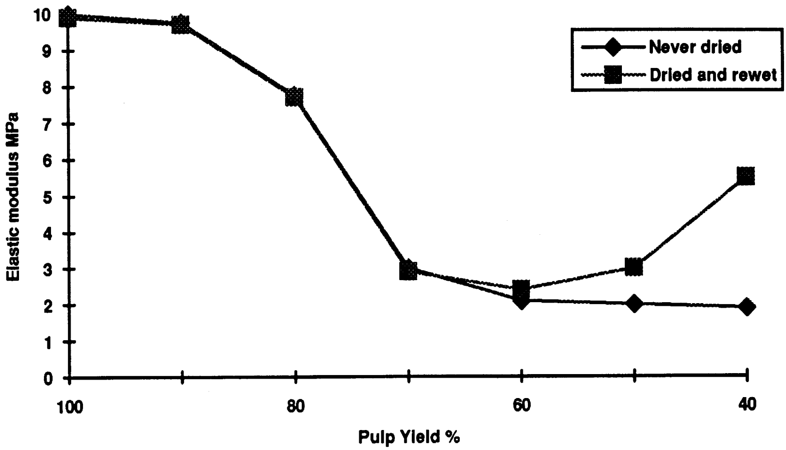


Figure 13: The elastic modulus of the never-dried cell wall decreases steadily throughout the yield range. Drying and rewetting has little effect on the modulus at high yields but increases the modulus at yields below 65%

The explanation for this behaviour provided by Scallan(27) involves the structure of the cell wall of wood. The wall consists of cellulose microfibrils bonded together by hydrogen bonds on their radial faces. These have a width of 35Å and the matrix separators are of the same magnitude(36,37,38,39,40). The amorphous interstitial region is divided into a sandwich-like structure of lignin rich material between layers of hemicellulose. The hemicellulose acts as a mediator on the surface of the microfibrils. Pores within the cellulose structure are filled with ligno-hemicellulose which forms a microporous gel when wet. Cross linking occurs via a mixture of covalent bonding and hydrogen bonding through the ligno-hemicellulose gel.

Pulping modifies and removes the properties of the ligno-hemicellulose gel causing a reduction in the elastic modulus. Initially and down to yields of 65%, the fall in elastic modulus is caused by cleavage of covalent bonds. As the gel is removed this is partly balanced by increased hydrogen bonding between the cellulose microfibrils.

More hydrogen bonds will be formed on drying the low yield fibres. These bonds may be inaccessible to water on rewetting and cannot be broken. The crystallinity of cellulose has been reported to increase on drying(41,42) which supports this contention. In the case of high yield fibres less hydrogen bonds exist between the cellulose microfibrils as they are prevented from forming by the ligno-cellulose gel.

Post paper manufacturing influences on recycling

Where fibres are subject to mechanical treatment after paper manufacture other degradation mechanisms may come in to play. Gottsching and Steiner(43) in a study of the calendering of groundwood and woodfree paper discovered that:

- the heavier the calendering the greater the loss in breaking length, average fibre length and reduction in water retention value
- the effects are greatest for lightly beaten stock.

Their explanation for these results was the mechanical damage caused by the nip compressing the fibres.

A more recent study by Gratton(44) has examined a range of calendering techniques. The results presented in Table 2 and Figure 14 show that thermal gradient calendering has a smaller influence on recycling potential loss than conventional and extreme calendering treatments.

	Uncalendered	Conventional	Thermal Gradient	Extreme
freeness (ml)	143	140	147	151
fibre length (mm)	1.51	1.31	1.42	1.14
fines (%)	35	36	36	38

Table 2: Bulk and strength properties of handsheets

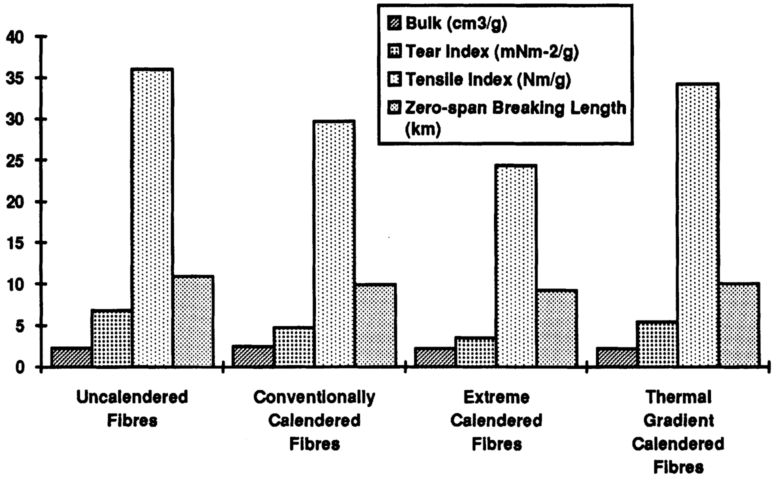


Figure 14: Properties of reslushed pulps prepared from newsprint calendered in different ways

Handsheets from the uncalendered and conventionally calendered fibres contained a high proportion of uncollapsed fibres. In the case of the extreme calendering conditions used most of the fibres were permanently flattened. Thermal gradient calendering causes plasticisation and deformation of the surface fibres but does not compact the middle of the sheet. For this reason there are relatively few flattened fibres. The calendering processes reduce the zero-span breaking length of the fibres - the effect being greater for conventional than thermal gradient calendering. It is suggested by Gratton(44) that conventional calendering builds stresses into the fibres which remain after reslushing and sheet making.

The work on calendering illustrates that in manufacture and use the fibres are subject to other treatments which may limit their recycling potential by more than occurs by drying. If the thermal gradient calendering results translate to full scale practice it is possible to improve process technology to enhance the abilities of the fibres to recycle.

Practical significance and future work

Most recycling studies in the laboratory are made with single furnishes. Where mixtures have been used(45,46) the effect of recycling on papermaking potential has not been great, (Figure 15). This fits in with industrial experience where the complaint about lack of strength from recycled fibres is due to the high filler content or been replaced by the lack of consistency in properties and the growing level of contraries.

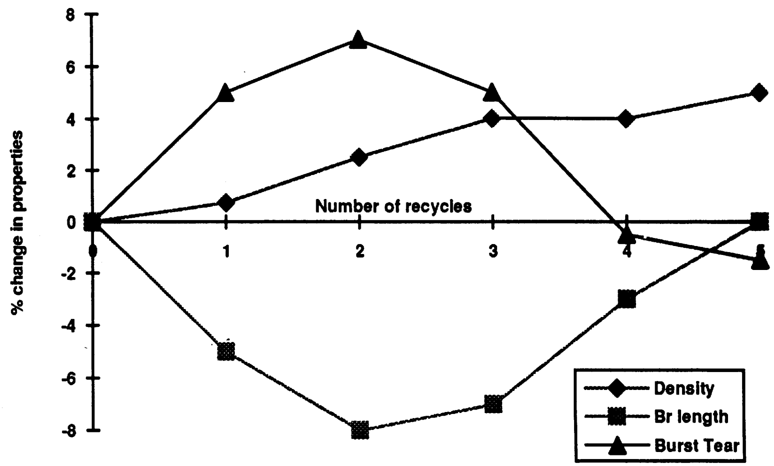


Figure 15: TMP/beaten bleached kraft: the percentage change in sheet properties during recycling

There is a need to standardise on experimental procedures to determine the potential impact of new pulps and chemicals on recycling. Data should be reported on scales of absolute properties rather than a percentage of an initial or cycle 0 property. (Paper is sold against absolute values laid down in specifications!). It should also be recognised that it is rare for the full potential of papermaking fibres to be realised in any paper product when designing the test conditions. Data from standard tests on recyclability could be used to:

- prevent the introduction of pulping, bleaching, post treatment technology which would harm the economics or increase the environmental burden of recycling
- provide data to models to determine the economic and environmental limits to recycling.

The next step in research thinking should be to apply our knowledge to:

- improve the recyclability of fibres by modifying existing processes whilst meeting specification criteria for machine runnability and end use
- reverse the effects of recycling on fibres - amelioration(47) may be the best we can hope to achieve.

The use of chemicals to reinforce bonds or increase swelling, improved refining treatment to prevent the formation of fines and more sophisticated fractionation techniques are being researched and may provide opportunities.

THE EFFECT OF CHEMICAL ADDITIVES

Table 1 indicated where chemicals are introduced accidentally or deliberately into the paper cycle. The effects of chemicals on recycling are complex - they tend to be adverse in a number of ways. For example they can:

- cause deposition problems throughout the stock preparation system and on the paper machine or detract from the properties of the paper and board manufactured
- slow down the rate of defibration and/or swelling of the fibres when repulped
- inhibit the performance of chemicals such as brightening agents used to enhance the properties of recycled fibre stocks
- dissolve in the process water causing interference with process and product performance enhancing additives
- remain within the water circulation system eventually passing through the effluent treatment plant and being discharged to receiving waterways.

Many(eg 13) consider the dissolution to be the most important issue to be tackled by the research community as it could ultimately restrict the level of recycling from both economic and environmental aspects.

The literature review revealed no systematic study of all aspects of chemicals on recycling. The greatest emphasis has been placed on the effects of adhesives and ink and their methods of removal. Adhesives give rise to stickies problems - a subject which is beyond the scope of this review. Deinking is a major industrial process and is discussed in detail later in this review.

The simplest chemicals which influence recycle potential of fibres are cations. Lindstrom and Carlsson(48) demonstrated that the chemical environment during sheetmaking affected the swelling of the pulp after drying and recycling as shown in Figure 16. In practical papermaking there are relatively few opportunities to convert a pulp into a specific ionic form and maintain it in this form during sheet forming.

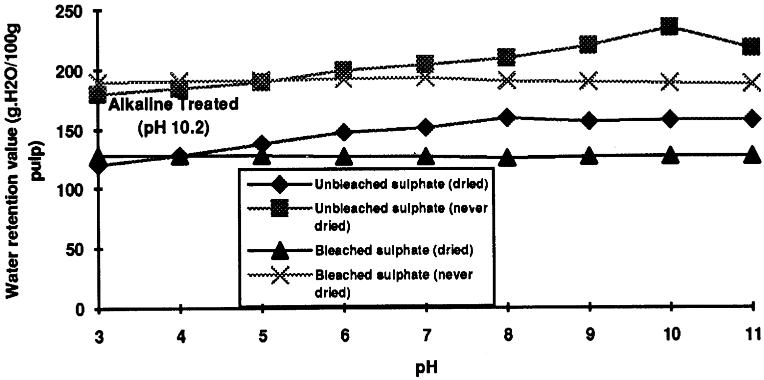


Figure 16: Influence of pH on swelling after drying and reslushing

A number of studies have been undertaken on the influence of sizes on recycling. Rosin/alum sizing causes an additional loss in recycling potential(49) which is caused primarily by a slowing down in the rate of wetting and at which water is absorbed into the paper on repulping. The effect of rosin/alum can be reversed by addition of caustic soda or other alkalis.

Reported work on alkyl ketene dimer sizing is surprisingly limited(49,50) and was undertaken with size formulations which are unlikely to be used today. As might be anticipated the adverse effect of AKD is not reversed by the addition of caustic soda or other alkalis.

A comprehensive study on the influence of chemicals on recycling behaviour in the brightening stage has been undertaken by Gottsching et al(51). The effect of three retention aids on bleaching results with peroxide and dithionite are shown in Figure 17.

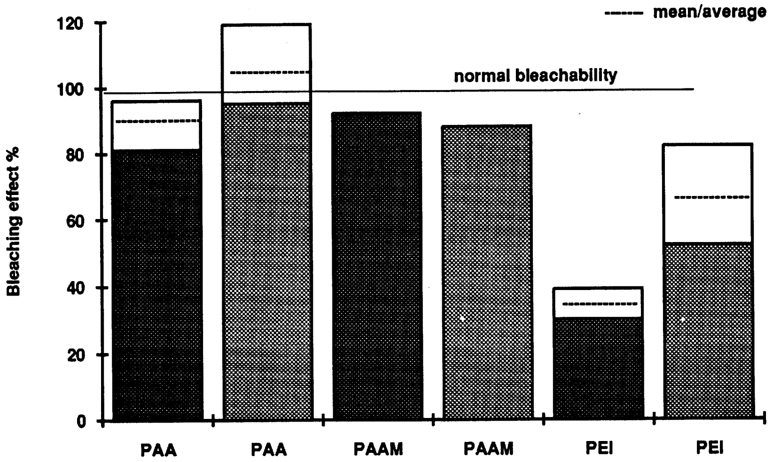


Figure 17: Influence of different retention aids on the bleachability of ground wood

The chemical which is commonly released into process waters on recycling is starch. The effects on process chemistry have been described in general terms(52) but not studied systematically. Laboratory experiments have shown that conventional size press starches are almost completely dissolved on repulping - a result in line with industrial experience.

The amount of materials released may be decreased by substituting cationic starch. The economics of this have not been modelled satisfactorily. The extra cost of the cationic starch is counterbalanced by the simplified wet end and reduced need for chemical additives. However, it may be more cost effective to accept the higher level of dissolved materials from native starches and install an effluent treatment plant to cope with the higher dissolved organics loading. This is running contrary to the greater emphasis placed on incorporating clean technologies into production plant design.

The ultimate fate of many of the chemicals entering the paper chain is not known. They must partition between the process water (ultimately the water discharged from the mill), the paper or board produced and the solid waste or sludge generated. Little work on this important topic has been published although private studies for Government agencies have been conducted(53).

DEINKING

Background

Deinking is a major area of growth in investment throughout the world in order to utilise waste which can no longer be landfilled, to meet customer needs and conform to legislation. Essentially in deinking plants the operators are attempting to remove sufficient ink to reach the brightness required whilst removing all ink particles which are visible to consumers ie particles of >40µm in diameter. At the same time deinkers also require to minimise the energy consumed and maximise yield. This latter point is becoming more important as there will be increased restrictions on the disposal of the sludge from the process.

A large body of literature on deinking and deinking technology has been generated particularly in the last three years. Much of this describes practical experience in full scale plants and laboratory and pilot plant studies by chemical suppliers, equipment manufacturers and research institutes. There are relatively few fundamental studies reported. Much of the literature is contradictory and often confusing. In many cases the boundary conditions of experiments are not properly defined for commercial reasons or because there is insufficient knowledge to do so.

Deinking plant installations are becoming more complex as the range of furnishes and wastepaper grades processed and their variability increase. The objectives of the various process stages involved can in the simplest terms be described as:

- to remove ink from the surface of the fibres or coating in the repulping stage via a combination of chemical and mechanical means
- to prevent ink from redepositing on the fibres also by chemical and mechanical means
- to remove ink selectively by screening, filtration or washing (in other words to exploit physical, chemical and surface chemical differences between the fibres and inks)
- to reduce remaining large ink particles in size so they are no longer visible
- to brighten or bleach the stock after deinking to reach the required brightness.

The last two processes are optional depending on the wastepaper grade used and the properties required. In some cases it is also necessary to remove dissolved substances introduced during deinking to prevent runnability problems on the papermachine. This is accomplished by a thickening stage and/or altering pH from alkali to acid.

Ideally the mechanical and chemical conditions are controlled to ensure that the particle sizes before each separation stage fall into the optimum removal range. This has been described by McCool(54) and is often requoted (Figure 18). Less or no attention is paid in the literature to the control of the chemical conditions to ensure adequate dispersion before washing stages or surface charge before a flotation stage.

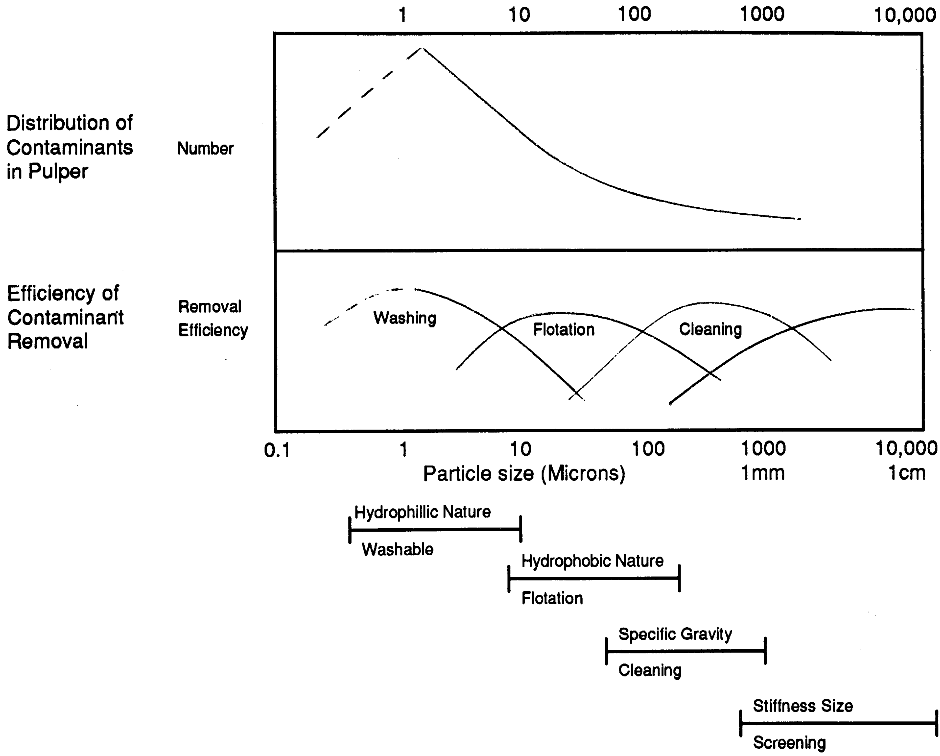


Figure 18: Particle size and removal efficiency

It is beyond the scope of this review to examine all aspects of deinking and deinking technology. General comments on aspects of:

- ink formulations and drying methods
- the function of repulping and the processes occurring
- flotation mechanics and chemistry

will be made with the intention of stimulating discussion in order to focus future attention on fundamental scientific issues.

Ink formulations

Inks for conventional impact printing processes are essentially made up of three components - colourants, modifiers and the vehicle. The colourant can either be a pigment or a dye. Modifiers are used to impart a specific property to the ink to facilitate its use or improve its performance. Typical modifiers are dispersants to prevent coagulation, soaps to speed up drying, antioxidants to control drying and waxes to increase scuff resistance. The vehicle is a key component of the formulation as it acts as a carrier for the colourant to the paper and bonds it to the printed surface. The type of vehicle used depends on the printing process. A generic list may be found in Table 3(55).

Vehicle	Description	Use
Non-drying oil	Penetrating non-drying oils such as petroleum or rosin oils	News
Drying oil	Oils such as linseed, soybean, cottonseed or rosin, combined with synthetic resin	Letterpress Litho (offset)
Solvent-resin	Low boiling hydrocarbon solvents in combination with modified rosins	Gravure
	Alcohol, water or other fast evaporating solvent with synthetic resins	Flexographic
	High boiling petroleum solvents in combination with rosin effects	Heat set inks letterpress litho
Glycol	Glycol solvents in combination with resins insoluble in water	Moisture set precipitation inks
Resin-oil	Balanced combination of resin, oil and solvent	Quick set inks for letterpress litho
Water soluble	Water soluble vinyl or styrene acrylate copolymers	Flexographic
Photo reactive	Reactive monomer and initiator	UV cured inks

Table 3: Commonly used ink vehicles

It must be recognised that ink formulations change with market demand. Greatest changes to ink formulations and printing processes will come from environmental pressures(56). Although no major changes, in principle, to printing processes are expected the impact of environmental concerns on the printing and publishing industries are already evident in paper products, ink formulations and solvent usage. This impact is likely to increase.

The greatest environmental concern at present is the emission of solvents. Solvents such as alcohols, esters and ketones are used in inks primarily to ensure rapid drying under fast running press conditions. Current legislation in most countries limits the amounts and types of solvents that can be released. This legislation is set to become more demanding in the next five years, with a total ban on some emissions towards the end of the 1990s.

Controls on the use of solvents have the potential to impact greatly on flexo and gravure printing with lesser effect on litho.

Ink Drying

Ink properties and hence their influence on recycling are changed by drying which changes the chemical and/or physical state of the vehicle. Drying mechanisms employed depend on application and include one or more of absorption, cross linking, evaporation, oxidation, polymerisation and precipitation. These may be induced by heat or the application of radiation.

This has a major effect on the deinkability characteristics. A summary of the ink drying methods used and their effect on ink removal is given in Table 4(55).

Method	Description	Vehicle or binder	Process	Deinkability	Comments
Absorption	Penetration or absorption of vehicle into pores of paper via capillary action. Never dries hard	Hydrocarbon oils Hydrocarbon resins	Letterpress (news)	Emulsification or mechanical removal	Easy to deink
Solvent evaporation	Printed surface is subjected to high velocity hot air or gas flame. Solvent portion of the ink is heated to a point where it boils and evaporates, leaving the resin binding pigment on the surface	High boiling point hydrocarbon solvent and rosin esters, metal resinates, or hydrocarbon resins	Flexographic Gravure (magazines, catalogues)	Rosin esters are difficult to saponify. Metal resinates are saponifiable under strong alkali conditions. Hydrocarbon resins must be emulsified.	Difficult to deink
Resin precipitation	Upon heating, precipitation rather than evaporation occurs	Rosin modified phenolic varnish	Letterpress	Partial saponification occurs under strong alkali conditions	Difficult to deink
Oxidation	Absorption of oxygen by drying oil causes polymerisation and hardening	Drying oils, alkyd varnishes	Letterpress Lithographic	Tougher, more flexible films. Can only be partially saponified by strong alkali at high temperatures	Difficult to deink
Heat	Condensation and cross-inking reactions. Occurs after heating to 150-175°C.	Volatile solvent (low boiling alcohols, aromatic hydrocarbons) and synthetic resins	Overprint varnishes	Resistant to attack from normal reagents and solvents	Very difficult to deink

Table 4: Ink drying methods and their deinkability

'Non-impact' printing

Non impact printing processes are gaining an increasing market share and are the predominant printing process in many offices. The principal techniques used are photocopying and laser printing. Essentially the printing method is similar for these toner based systems though the method of generating the image is different.

The basis of the toner-based printing process is the photoconductor or photoreceptor which holds a charge in darkness but conducts electricity when exposed to light. Two types of photoreceptor are used:

- selenium which holds a positive charge
- organic which holds a negative charge.

The photoreceptor is charged with ions of the appropriate polarity and then the image to be printed formed by discharging the non image areas on the photoreceptor. Toner of opposite sign to the latent image is then brought into contact with the photoreceptor (in the case of selenium, a negative toner). The image is transferred to the paper by bringing the photoreceptor into contact with it and applying a charge to its back opposite to that of the toner.

The final stage is to fuse the toner to the paper. This is accomplished by:

- running between heated rolls
- exposure to radiant heat from a lamp
- exposure to short term high intensity radiation
- high pressure, with or without the presence of solvent but without heat.

Toner remains attached to the photoreceptor and has to be cleaned by brushing usually with a charge bias opposite to that of the toner.

Toners perform a number of tasks including the production of an adequate print system, flow on to and adherence to the photoreceptor, release from the photoreceptor to the paper, fusing to the paper and release from the fuser roll.

Toner design is complex and requires the presence of a number of different chemicals. Toners can be dry or less commonly liquid.

Dry toners may be a single component or used with carrier beads to charge the toner. The 'chemicals' used are resins, colourants, charge control agents, surface additives, magnetic additives, release agents. The toner particle size is typically 10-20μm but may be smaller where colour is used to maintain print quality.

The resin is the major component in the toner (~90% by weight). Resin choice is conditioned by flow properties and the differing requirements of hot and cold fusing. Where cold fusing is used low molecular weight polyethylenes, polypropylenes and ethylene vinylacetate copolymers are suitable.

The three forms of 'hot' fusing require different resin properties:

- continuous radiant sources need polyester and epoxy resins with a Tg of 50-60°C, a molecular weight of 5,000 to 50,000
- flash fusing can result in the resin temperature exceeding 200°C so thermal stability is critical. Higher molecular weight styrene copolymers, epoxies and polycarbonates are suitable
- roll fusing requires a resin of molecular weight 30,000 to 100,000. Styrene acrylates, styrene methacrylates and styrene butadienes are used commonly.

The colourant can make up to 15% of the weight of the toner, though 5-10% is more typical. The most common pigment is carbon black, where a variety of types can be used. Coloured pigments are usually chosen for their 'lightfast' properties.

Charge control additives are typically quaternary ammonium salts or nigrosines for positive toners. 'Special' carbon blacks are used for negative toners usually in combination with fumed silica. The latter also acts as a surface additive in combination with zinc stearate.

Magnetite is used where the print is required to be magnetic. Release agents are usually silicon oil or low molecular weight polyethylene or polypropylene waxes.

Liquid toners are less common but have some advantages for colour applications or where high 'quality' is needed. The basic particle size is <3μm because it has to be in the form of a colloidal suspension.

The resins used include polyethylene, polystyrene, polyacrylates, polymethacrylates; ethylvinyl acetate, ethylacrylic acid and ethyl methacrylic acid copolymers; acrylics, styrene butadiene and styrene acrylates. The dispersants are C9-C12 isoparaffin hydrocarbons with boiling points of 155-210°C. The charge control agent also stabilises the colloid. Typical chemicals are alkylaryl sulphonates, succinamides and n-vinyl pyrrolidine.

The various types of printing processes and diversities of inks, toners which are found in wastepaper presents the technologist with a major challenge to remove them cost effectively. The technologist faced with this problem has tended to undertake practically orientated studies with poorly defined raw materials in terms of ink composition, drying method, paper composition and the conditions in which the paper has been stored.

The effect of the printing process on deinking

Attempts have been made to assess the effects of various printing processes, drying methods and ageing on the ink particle size after repulping, ink removal in flotation and process efficiency in terms of yield. These are summarised in Table 5 for wood-containing furnishes(57-61).

Printing Process	Ink Formulation(57)	Drying Method(58)	Effect of ageing	Effect on pulping	Effect of flotation deinking	Effect on fibre yield obtained on flotation
Offset litho	pigment 10-20%, bitumen solution 60-70%, additives 5-15%	Penetration of vehicle into fibre web	Ages over months and years due to creeping(57). Binding agents react with oxygen and crosslink thus are difficult to remove(57)	Mixture of ink particle sizes produced 2-100μm(58). Some large ink particles >100μm not loosened(57)	After flotation some particles remain stuck to the fibres due to the high proportion of bitumen present. Small particles released on pulping are removed(57)	Low stock loss before ageing as carbon partciles are encased in polymerised network. On ageing a large number of carbon particles are released thus stock loss is high(59)
Letterpress	pigment 10-15% hardresins 0-5% mineral oils 80-90%	Penetration of vehicle into fibre web	Ages after approximately 10 days, effect similar to that experienced with offset inks(57)	The film of printing ink spreads out into particles mainly up to 100μm in size(57). Particles between 1-15μm are produced(58)	Ink particle sizes are suitable for flotation, but margin brightness is not necessarily regained as the pigment used has a high affinity for fibres(57)	Low fibre loss and change on ageing as carbon particles are mainly encased in oil therefore are not capable of interacting with calcium ions(59)

Flexo	pigment 10-20% hard resins 30-40% solvents 40-60% additives 5-15%	Penetration of water into fibre web plus resin dissolution with pH shock	Ageing does not affect particle size or the number of particles produced(59). With certain inks ageing may enhance ink removal from fibres(60)	Under alkaline conditions the binder becomes totally soluble therefore the soot and pigment particles are released as their original size(61), 0.3-2μm(58)	Particles are too small to be removed by flotation and are hydrophillic. They also have a tendency to stain fibres(60)	Initial stock loss is higher than with other inks as carbon particles are covered in polyacrylate and can interact with calcium ions. This effect worsens on ageing(59)
Gravure	pigment 10-20% hard resins 30-40% additives 5-15%	Solvent evaporation	Little change on ageing(59). Composition of the binding agents differ dependent on usage, but they do not normally contain oxidative drying components(57)	The film of ink disperses under chemical and mechanical action to particles 2-100μm(57,58). Particles are barely bonded to fibres therefore become detached and remain freely suspensed(57)	This ink type can be almost completely deinked by flotation as there is little penetration of ink into the fibre structure(57).	Low fibre loss due to strong networks firmly encasing carbon and other particles. Little change on ageing(59).

Table 5:Influence of ink type on deinkability of a woody furnish

Studies on characterised toner based printed products have been undertaken recently. Okada and Urushibata(62) found that polyester type toners were easier to deink than their styrene based equivalents. Their explanation was that polyester hydrolyses under the alkaline conditions used for pulping to produce smaller particles. In direct contrast to this, Carr(63) showed that the amount of toner specks remaining in the pulp after flotation was substantially increased where a polyester based toner was used (Table 6)(63).

Machine characteristics			
Toner	Fusing System	Roll Lubrication	Flotation Accepts specks /g fibre
Styrene/acrylic	hot roll	Teflon/silicone	179
Styrene/acrylic	silicone	heat/pressure	21
Polyester	radiant	none	990
Acrylic	radiant	none	17
Liquid solvent	evaporative	n/a	44

Table 6: Pulp quality depends on toner and fusing system

Okada and Urushibata(62) concluded that as no correlation between deinkability and physical toner properties, such as glass transition temperature (Tg), Tm and zeta potential could be found, toner particle size and the affinity between the toner resin and deinking agent must be more important. However, as shown by the results in Table 6 other factors such as the fusing system used could be important(63). Recent work by Cathie et al suggests that base paper(64,65) and/or ageing of the ink(66) may also influence ink characteristics and therefore deinking effectiveness.

Ink formulation, its drying characteristics and its interaction with paper have a major influence on the way in which it behaves in deinking. A systematic characterisation of ink properties and its adhesion to paper may yield valuable insights into the fundamental factors controlling deinking. Co-operation between the chemical suppliers, ink suppliers and scientists involved in the recycling industry could provide an opportunity to make significant advances in our understanding.

Repulping

A key area in deinking is the repulping stage in which three important functions are carried out - the separation of the fibres, the separation of the ink from the fibres or coating and the control of the size of other contaminants such as stickies. The literature on repulping is contradictory in terms of the advantages of high and low stock consistency treatment. Essentially a range of repulping consistencies and repulper types can be used but they have to be controlled carefully to ensure that the ink particle size is in the range needed for efficient removal in downstream processes.

The chemicals added in the repulping stage perform a range of functions including wetting, saponification, fibre swelling, emulsification and dispersion. These can occur simultaneously and interact with each other. The chemical balance, the mechanical forces applied and ink types etc present on the wastepaper control the rate of ink particle removal from the fibres and the size of the ink particles released. Once released the ink particles are subject to further chemical and mechanical forces which can alter their size. Some ink films released will be elastic and will withstand the mechanical forces applied. Others will be brittle and will split into smaller particles.

It is the diversity of ink films released and their differing responses to chemical conditions and mechanical forces which cause the confusion in the literature about the role of various additives. There is a need for systematic research to characterise the ink/fibre interaction more fully and study the impact of wetting, saponification etc in detail. The physical properties of the films released and their response to the chemical and mechanical environment encountered should also be studied.

Studies on the effect of surfactants on the attachment of ink have been undertaken by Morsink and Daane(67). Their experimental procedure involved rotating an ink-covered paper strip wound on a cylinder while partly immersed in a surfactant solution at a fixed temperature. Simultaneously the strip above the liquid is contacted against a foam rubber roll rotating in the same direction as the cylinder. After treatment the strips are flushed with demineralised water at pH5 to remove residual chemicals and dried at ambient conditions.

Some of the results obtained are shown in Figure 19. Anionic surfactants are effective in removing non impact (laser printed) ink, while particular non ionics were effective on impact printed strips. The detachment depended strongly on pH and temperature. They also found the good detachment and flotation deinking efficiency were not synomonous.

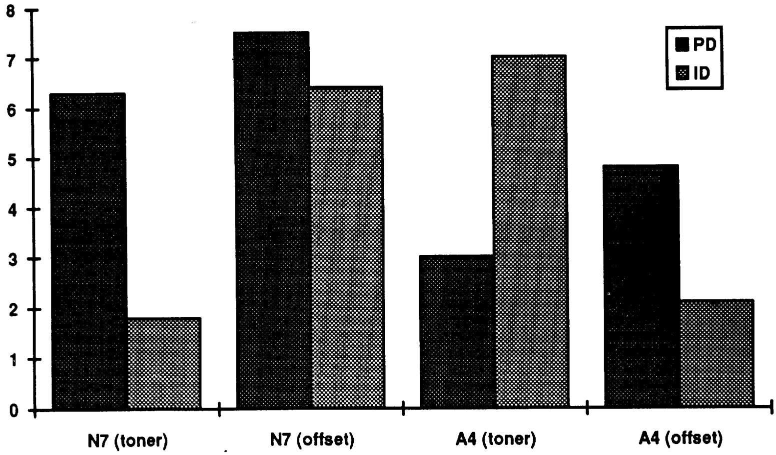


Figure 19: Comparison of performances in Ink Detaching (ID) and overall Paper Deinking (PD)

The removal of ink from fibres surfaces is similar in some aspects to that of soil removal from textiles(68,69). Borchardt(70) has undertaken elegant work to examine the influences of critical micelle concentration, oil-water interfacial tension, cloud point, viscosity, pour point and flash point to deinking using a range of alcohol ethoxylates.

Critical micelle concentration, (CMC), is the concentration at which independent surfactant molecules interact to form micelles. It gives rise to the unique properties of surfactants. Oily soil removal from textile fibres becomes effective above the CMC(71).

Borchardt(70) has surmised that to promote ink removal a surfactant with a lower interfacial tension would be required. The literature on surfactants also indicates that its cloud point should be 20-30°C lower than the temperature used in the process to be an effective stain remover(72).

The other critical property of a surfactant to consider is the hydrophilic:hydrophobic, (HLB), balance. Reports on changing the HLB value for deinking(73,74,75) have not distinguished between the influence at the initial pulping stage and after washing.

Flotation deinking - chemical influences
In the flotation process air is bubbled through the paper stock in a specially designed cell. Chemical additives are used to modify the surface energy of the air/liquid interface and the ink particles in order to ensure that the latter are selectively attached to the former. The bubbles with attached ink rise to the surface, form a stable foam and are removed mechanically or by flowing over a weir. In commercial practice the optimum size for ink particles for removal is 30-60µm(76). The energy of collision with smaller particles may be insufficient to overcome the barriers needed to ensure adhesion. In the case of larger particles there may be insufficient momentum to enable the air/ink particle to rise to the surface.

Effective flotation requires the presence of surface active agents typically fatty acids. The ionic form, usually calcium, is required for effective flotation.

The hydrophobic insoluble soap of the fatty acid is formed which deposits on the ink particles. Larsson, Stenius and Odberg(77) theorised that the ink particles surface becomes that of the precipated calcium soap which increases the adhesive strengths between the ink and air bubbles. Larsson et al also discovered a correlation between flotation efficiency and surface charge. Decreasing zeta potential from 85 to 40mv increased flotation rate. They surmised that the change in surface charge destabilised the dispersion and that ink particles collided with each other forming agglomerates.

Theoretical considerations

The theory of flotation as applied to deinking is not well understood. This is a little surprising in that the flotation process is well established industrially and is applied widely in other industry sectors such as mining. The success of the process is largely dependent on:

- collisions or interactions between the bubble and the particles to be removed
- the initial adhesion between the particle and the bubble
- the strength of the 'bond' between the particle/bubble pair to prevent their separation by interaction with fibres when they rise to the surface of the cell.

There are three micro processes essential for bubble/particle interaction(78):

- approach of the bubble and particle to form a thin liquid film
- rupture of this film to form a three-phase content
- stabilisation of the bubble/particle aggregate against the stress forces.

The overall probability of the process occuring can be expressed as a probability of each of these three sub processes(79)

$$P = Pc \cdot Pa \cdot Ps$$

where Pc is the probability of initial collision
Pa is the probability of attachment
Ps is the probability of stabilisation.

These three micro processes take place simultaneously which makes it impossible to determine unambiguously their relative effects.

The probability of collision

Pan, Bousfield and Thompson(79) describe the approach and attachment stage in outline in a paper in which they detail the development of a model of the flotation process for deinking. Collisions between a bubble and a particle can only occur if the particle trajectory is within the 'streaming tube' of limiting radius,Rc. The collision probability, Pc, is $(R_C/R_B)^2$ where, R_B is the radius of the bubble.

Particle trajectories deviate from straight lines for various reasons which leads to a variety of collision effects (80,81). These are:

- ideal collision, where the approach is without any change of magnitude or particle velocity
- interception, where the particles follow the stream lines of the bubble without any change of direction
- inertial effect, where the inertial forces of the particle result in increased collision compared with the interception effect
- gravitational effect, where gravitational forces lead to increased collisions
- diffusion effect, where the collision is caused by diffuse or turbulent particle motion
- cloud effect, where the particle is held by a number of bubbles the spacing of which are smaller than the solid particles.

The first four effects have been reviewed by Schulze(82) who derived mathematical equations to quantify collision efficiency.

There are two types of interaction which can occur when a particle approaches a bubble as indicated in Figure 20:

- collision, where the bubble surface is strongly deformed and the particle rebounds unless attachment takes place during the first collision
- sliding, where the particle moves along the bubble surface with a weak deformation of the bubble surface.

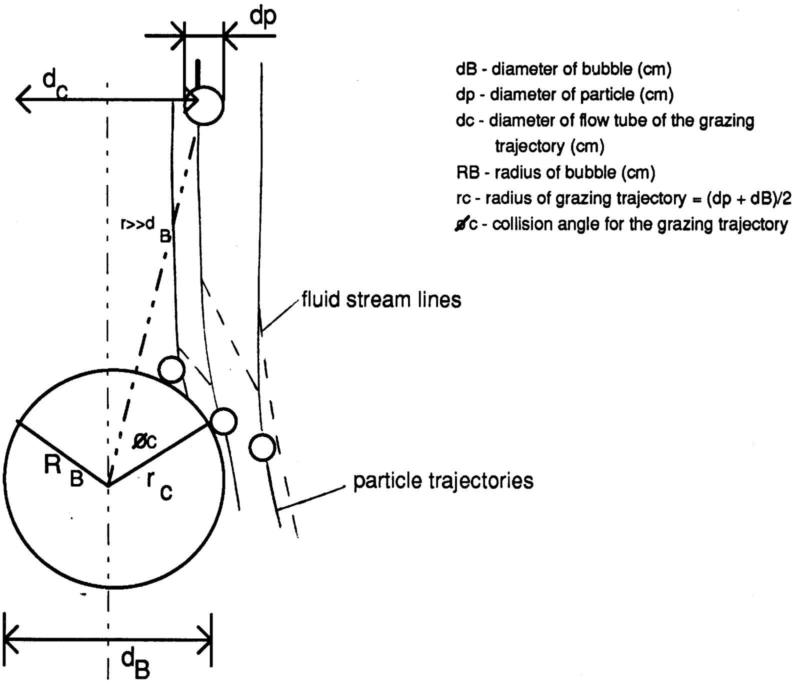


Figure 20: Schematic representation of the collision of a particle with a gas bubble

Schulze(82) believes that collision events change into sliding events when the colliding particles lose sufficient energy. Collisions predominate with large particles and high relative velocities radially directed to the bubble surface. Sliding is favoured where the inertial forces are unimportant due to their small mass and velocity and where the bubble is rigid due to surfactant absorption.

Schulze(82) demonstrated that collison processes of particles with bubbles were less effective than sliding processes because of their short time and the deformation of the bubble at the collision point.

Attachment and stabilisation

Once the bubble and particle have interacted a minimum time of contact is needed to develop attachment where the three phase contact angle $\Theta > O$. This is called the induction time, ti, in which the fluid film between the bubble and the particle thins to rupture. If the sliding time is ts, the condition for attachment is that ts $\geq$ ti. Yoon and Luttrell(83) demonstrated that the attachment probability is related to the limiting angle of approach θo such that $Pa = \sin^2\vartheta o$. Pa is dependent on the flow field and the surface and physical characteristics of the bubble. The driving force for final film rupture is dispersive London-van der Waals type forces as electrostatic, hydrodynamic and surface tension forces will act to prevent attachment.

A method of determining the probability of attachment or detachment of particles to gas particles is centrifugation as described by Schulze et al(84). There are no reported studies of the use of this method on ink particles.

The strength of attachment of stickie particles to air bubbles has been measured by Stratton(85). The materials used and their surface energies are shown in Table 7.

Stickie	Surface energy ($\gamma_s d$), mL/m^2	Composition
Wax-coated kraft (WCK)	28.0	Paraffin wax
Hot melt adhesive		
HMD	27.1	Polyvinyl acetate + polystyrene + paraffinic hydrocarbon
HMB	50.7	Glycerol ester of polymerized rosin
HME	41.7	Polyethylene base

Table 7: Composition and surface energies of Stickies

The contact angles in the deinking liquors are shown in Table 8.

		γ_L,	θ, deg			
Liquor	pH	mN/m	WCK	HMD	HMB	HME
1	12.4	39.2	76.3	71.3	54.0	58.7
2	12.4	29.9	47.7	43.0	22.0	29.0
4	10.1	39.4	75.0	69.3	54.0	63.0
5	10.1	29.7	47.3	43.7	23.3	28.3

Table 8: Contact angles at five seconds

The hot melts were treated in a flotation cell under a variety of conditions. The force of attachment was calculated from:

$$F = \Pi D\,(d/D)\,\Upsilon_{LV} \sin \theta$$

where D is the diameter of the bubble and d is the distance over which the particle is attached to the bubble.

The removal efficiency plotted against the calculated attachment force is shown in Figure 21(85).

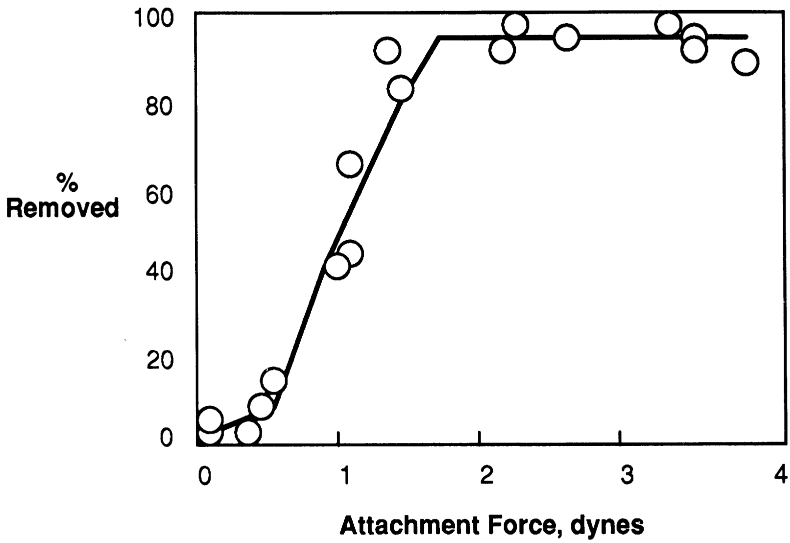


Figure 21: Flotation efficiency of hot melts as a function of calculated attachment force

Modelling of flotation of ink

Thompson et al's(79) simulation model is based on Stokesian dynamics(86). They have modelled single particle/single bubble interactions; two particle/single bubble interactions and many particle/single bubble interactions and have calculated the disjoining film. Their model for single particle/single bubble interaction indicates the effect of Reynolds number on the limiting attachment radius at various particle surface smoothnesses in Figure 22. They conclude that:

- as the Reynolds number approaches 'infinity' inertial effects dominate and short-range hydrodynamic interactions disappear
- as the Reynolds number becomes small viscous effects dominate and inertial effects become unimportant. The limiting value becomes smaller than R_b, the radius of the bubble

- in the range of typical flotation operation $10 < Re_B < 1000$ the limiting attachment radius changes rapidly. Viscous and inertial effects are both important. This implies that flotation efficiency is dependent on factors which effect either the Reynolds number or the surface roughness of the particle.

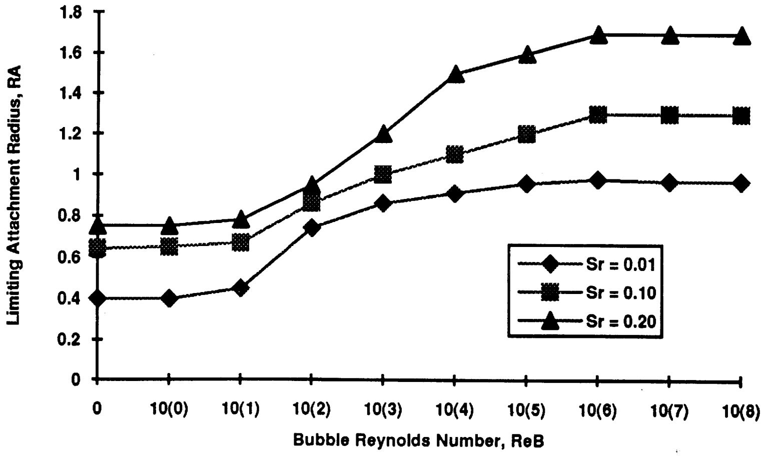


Figure 22: Limiting attachment radius vs bubble Reynolds number for three values of surface roughness

Practical experience

Practical experience to confirm the model is limited. The literature is sparse on how changes in operating conditions of deinking cells affect ink removal efficiency. Control of bubble size is obviously of importance(87,88), though the view as to the optimum bubble size is contradictory. There are reports that their total surface area must be as large as possible to maximise ink removal(89). This implies that more smaller bubbles are required at constant air to stock volume ratio. There is, however, a lower limit of 0.1μm diameter(89) where the bubbles adhere to the fibres reducing yield though increasing brightness(90). Practical experience suggests that only bubbles greater than 0.3µm have sufficient buoyancy to find their way through the elastic network of fibres and reach the top of the cell(88,89). This is obviously several orders of magnitude smaller than the size needed for optimum removal - where the ratio of diameters of bubble to ink particle should be 5:1 or 6:1 from experience with mineral flotation(91).

Isobe, Koike and Manyo(88) have studied the infuence of bubble size on bubble rising rate . Their results are shown in Figure 23.

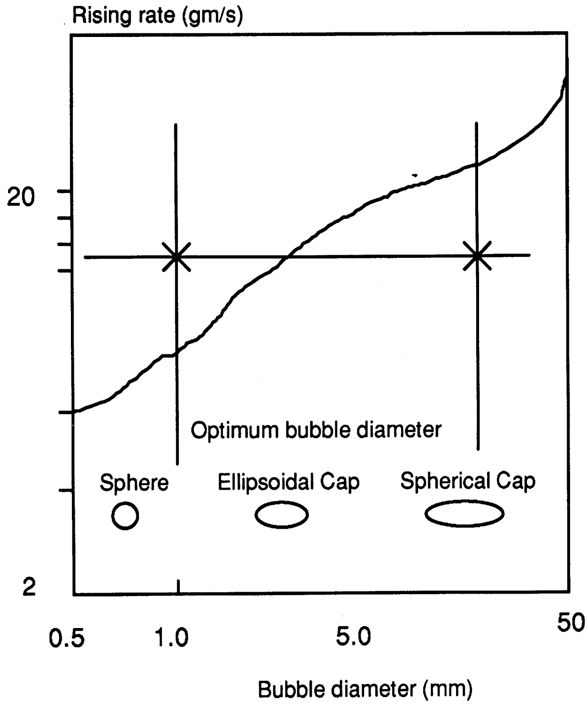


Figure 23: Bubble shape effects rising rate through a stock suspension

Their view was that the small bubbles rise too slowly to be effective, while the larger bubbles have too low a total surface area to adsorb ink efficiently. The larger bubbles also interfered with the formation of a stable foam layer, further decreasing ink removal efficiency.

At Reynolds numbers higher than 700, bubbles deviate strongly from a spherical shape and their surface oscillates intensely. Isobe et al(88) believe that the ideal shape for ink removal is an ellipsoid cap - but this conclusion may be an artefact of their experimental design.

Air volume to stock volume has an important influence on the removal efficiency of ink. An example of the effect is shown in Figure 24(92).

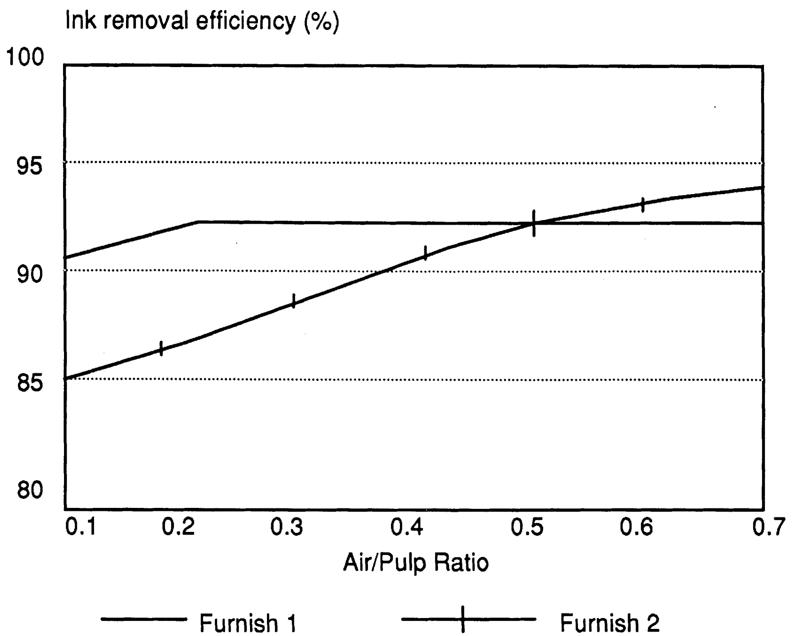


Figure 24: The relationship between ink removal and air volume is furnish dependent

These results are confirmed by a study of Julien Saint Amand and Perrin(90) in a specially designed cell in which air bubble size could also be varied. Their results are illustrated in Figure 25 in terms of brightness gain.

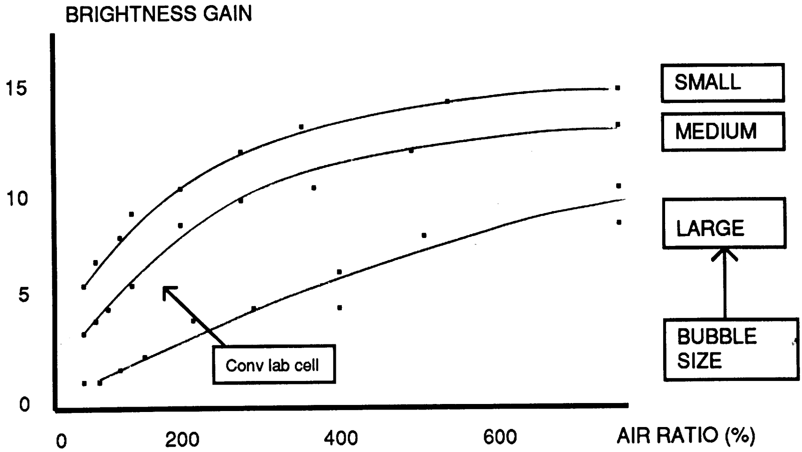


Figure 25: Effect of bubble size on ink flotation

Smaller bubbles give the highest brightness but at the lowest yield because fibre loss is higher.

The air ratio in conventional plants may be 150% or more. Bubble sizes will also cover a wide spectrum dependent on the design of the injectors and other aeration devices. Unfortunately there is no published information on bubble size distribution in flotation cells, possibly because there is no available method which can measure this reliably and conveniently.

Theoretically Larsson, Stenius and Odberg(93) have derived a first order kinetic model for ink particle removal in idealised conditions, ie

$$\frac{dN}{dt} = -kN$$

Where N = number of ink particles per litre of stock
t = flotation time.

The flotation rate constant, k, is dependent on the type of contaminants, chemicals, temperature, type of pulp, consistency, bubble size distribution and the cell design.

Julien Saint Amand and Perrin(90) assessed the effect of particle size on flotation. Their results are shown in Figure 26 which indicate that first order kinetics apply.

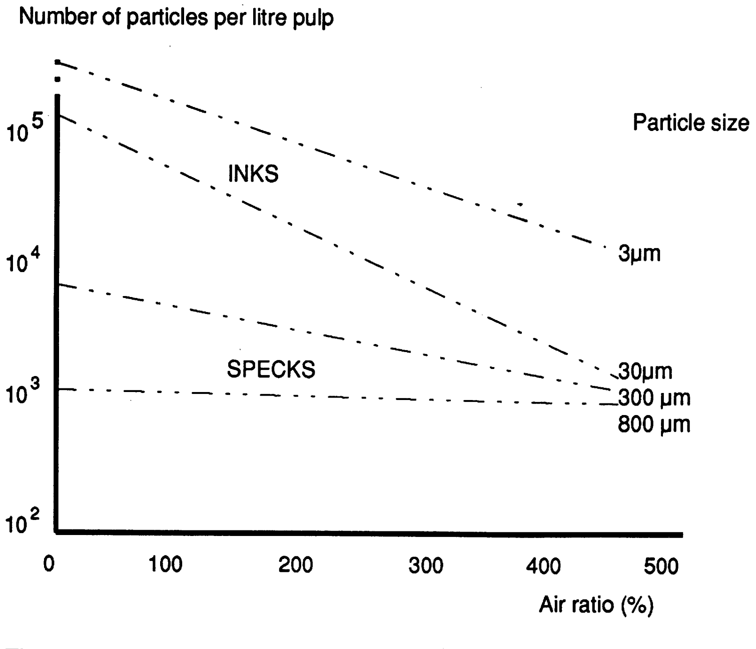


Figure 26: Ink and speck consistency decrease during flotation on the CTP cell at 2% pulp consistency

The highest rates are obtained for ink particles of approximately 30µm as shown in Figure 27.

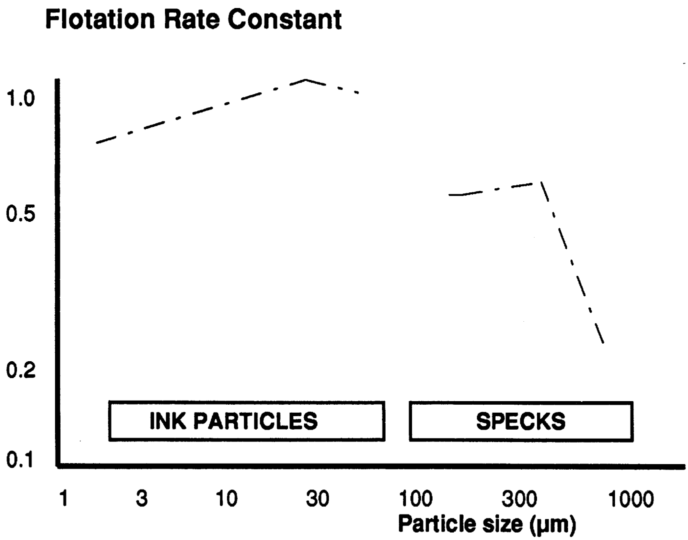


Figure 27: Flotation rate constants of ink particles and specks. Mean results on the CTP cell (5-20 g/l)

The results for the removal of small ink particles are better than those reported in other studies(76,93,95). This is possibly due to the agglomeration of small ink particles within the cell increasing their effective size.

Ink flotation was not influenced by consistency, (Figure 28), whereas specks were. Julien Saint Amand(90) considered that a consistency increase would increase the detachment probability of large particles in relation to the turbulence level and bubble size distribution.

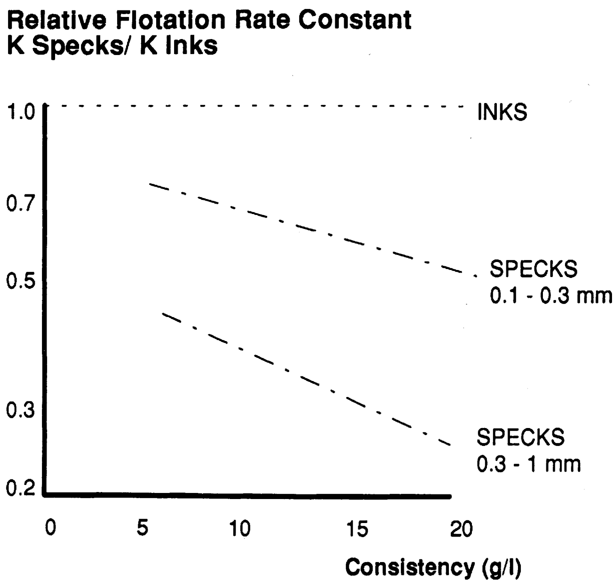


Figure 28: Effect of consistency on the flotation rate of specks compared to the mean ink flotation rate

Ink removal efficiencies

Deinking has developed empirically and is not efficient - typically 60-80% of the ink is removed and overall yields are in the range 75-90%. The low yields lead to solid residues and aqueous effluents which have to be disposed of. The flocculation or coagulation of the dissolved solids, the removal of water from the sludge and its disposal are all vital issues which affect the economics of deinking.

Practical studies on ink removal(95,96,97) give widely differing results; 65%, 50-70%, 45-80% respectively. These results reflect different furnishes and practical conditions but cannot be compared directly because different assessment methods were used. The effectiveness of deinking is often measured by indirect means - a comparison between the brightness of the deinked stock and the margin or the lift in brightness across the system. This makes the assumption that there is a direct correlation between brightness and ink particle concentration. Fischer(98) has reviewed the problem of measuring ink removal. The results are affected by the size and shape of the ink particles where optical devices are used to infer ink quality. Similar problems are encountered when brightness and image analysis methods are used.

In order to solve this problem the volume or mass of the ink must be measured. Blechschmidt, Strunz and Knittel(99) have used a spectral reflection technique to overcome this problem. Their results, (Figure 29), show that different papers printed with the same inks change the ink removal efficiency in a laboratory flotation system.

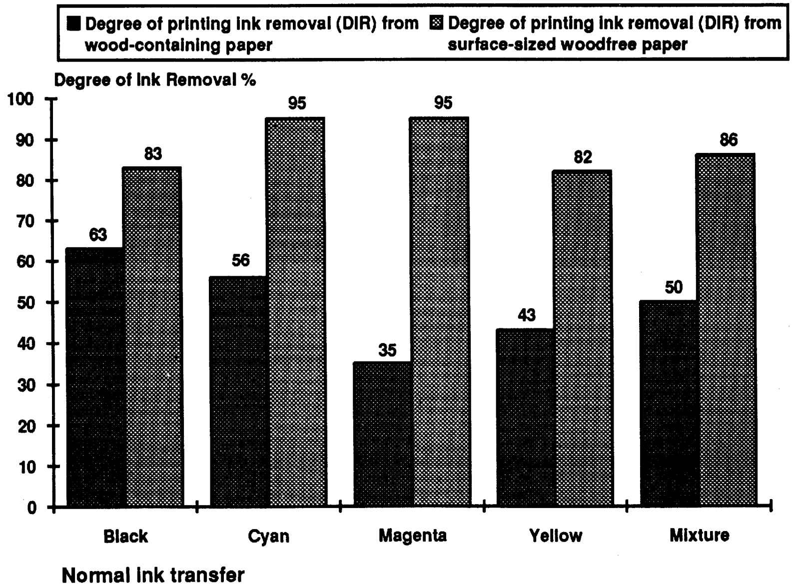


Figure 29: Ink removal depends on the ink and paper

A totally efficient process would remove all ink while retaining the papermaking fibres. A standardised method of reporting true efficiencies relating ink removal to total yield would provide more meaningful comparisons of the data obtained by various workers. It may also point to means for improvement.

Doshi(100) has reviewed methods which can be used. The nomenclature is derived from TAPPI(101) where:

T/D = mass flow rate
C = ovendry consistency
S = debris by weight in %
i = inlet stream
a = accept stream
r = reject stream.

The key efficiencies are:

E_R = (Sr/Si)/Rw (the reject efficiency)
E_C = 1 - (Sa/Si) (the cleanliness efficiency).

The screening quotient(102):

$$Q = E_C/E_R = 1 - (Sa/Sr)$$

is also an important measure of process effectiveness. There are other definitions of efficiency that can be used, eg those of Rietema(103) and Worrell(104).

Progress in recycling research and technology would advance more rapidly if the experiments were designed to measure efficiency of separation and were reported as such.

Further work needed

To increase the amount of used paper recycled it will be important to incorporate it into higher standard products used for office and publication purposes. Critical properties of these products are brightness, shade and freedom from specks. These are achieved by a complex industrial process designed to remove ink from the paper. Essentially chemicals and energy are used to separate the ink from the fibres and subsequent stages exploit physical and surface chemical differences between the fibres and ink particles to effect separation. The control of ink particle size distribution and surface chemistry are critical to the efficiency of the deinking process.

The removal of ink from wastepaper stocks is a very complex process which is worthy of a fundamental study to enhance its efficiency.

Information is needed to determine how to add chemicals and apply energy within a deinking system more efficiently. This may also lead to an insight on how ink manufacturers could modify their formulations to improve the deinkability of the printed products.

Subjects which need to be investigated include:

- the development of analytical methods to characterise dried ink properties - cohesion, adhesion to paper surfaces, 'dispersibility'
- the derivation and use of methods to determine the relative rates of fibre/fibre and fibre, (paper surface)/ink separation
- the derivation and use of methods to determine the effect of energy, (intensity of application, overall level), on ink particle size distribution
- the application of analytical methods to determine the factors which influence ink redeposition on fibres and the rate of deposition
- the development of alternative chemical regimes and chemical application strategies to deinking.

Our lack of theoretical knowledge about the phenomena which occur at the repulping stage needs to be filled. Further detailed studies on the flotation process along the lines suggested by Julien Saint Amand(90) and Thompson(79) are essential.

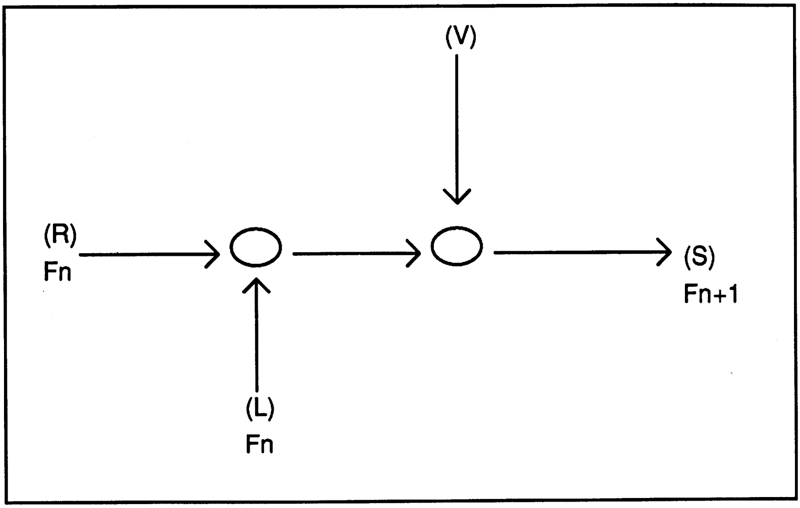
LIFE CYCLE AND PAPER RECYCLING MODELS

There is a great deal of controversy about the impact on the environment of the legislation designed to enhance recycling and divert paper from landfill. A way to resolve some of these arguments is to produce models which predict the effects on fibre properties and processability and hence the overall environmental impact.

A number of models have been produced which examine the age distribution of fibres within paper products(105,106,107,108), the properties of papers resulting from various levels of recycling(106,107), the build up of impurities at different recycling levels(108) and the influence of recycling on CO_2 production and energy use(6,109).

Age distribution

Much work on this subject has been conducted by Göttsching and co-workers (eg 105). Cullinan (106) has developed Göttsching's (105) original model. He uses a simple stream splitting approach as indicated in Figure 30.



Fn is the fraction of fibre in the sheet which has been reprocessed n times, R is the flow of secondary fibre, L the flow of secondary fibre lost in reprocessing, V is the flow of virgin fibre and S the rate of production of new paper.

Figure 30: The basis of the Cullinan model

Cullinan(106) derives an age distribution function:

$$Fn = \frac{(1-Ku)\,Ku^{n}}{-Ku^{n}}, \quad 1 \leq n \leq m$$

Where Ku = the overall recycled fibre utilisation rate

and m = the maximum number of possible recycling steps, which is set to 10 in many of the calculations reported.

The effect of extremes of recycling with Ku set to 50% and 90% are shown in Figures 31 and 32.

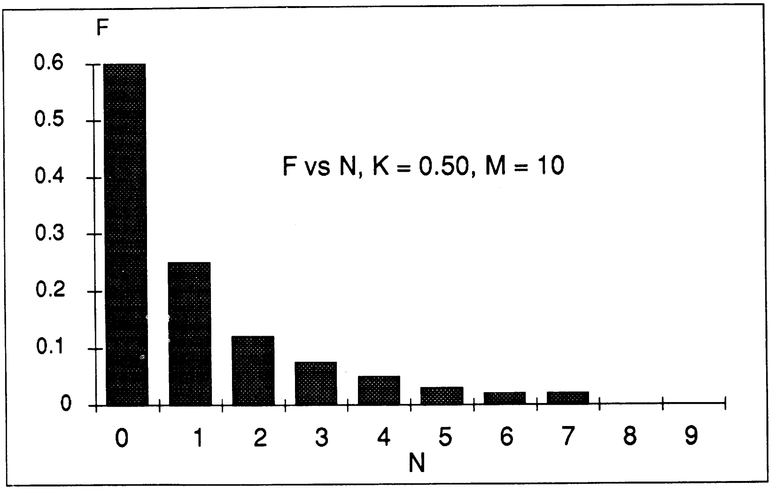


Figure 31: At 50% recycling rate very few fibres are recycled more than twice

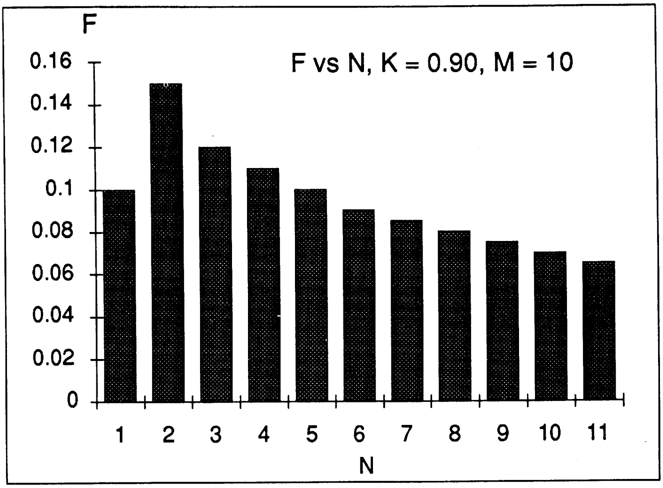


Figure 32:At 90% recycling rate the spread of fibre is extensive

This shows that at the lower utilisation rate the furnish consists of young fibres while at the higher rate there is an even spread.

Cullinan's(106) work is artificial because the industry practices downcycling ie fibres are introduced from higher grade products during recycling. There is also a situation in many countries where imported products contain virgin fibres to 'enrich' the indigenous stream. Grossman, Wawrzyn and Andre(108) have included these factors into their model for newsprint manufactured in Germany and Havelock(107) into the situation within the UK, (see Figure 33).

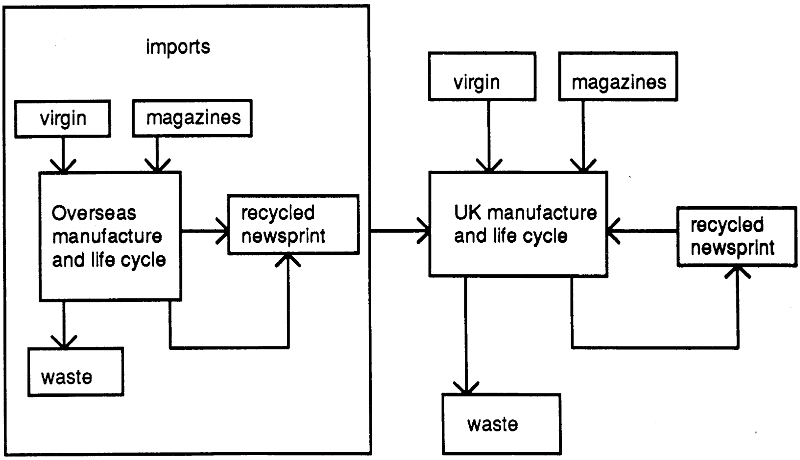


Figure 33: The basis of Havelock's model

Havelock's model also recognises that the imported newsprint will contain recycled fibres.

Paper properties

Cullinan(106) has extended his model to assess the effects of recycling on paper properties. He uses the expression:

$$P = Po\left[1 - \frac{\tilde{n}}{m+1}\right]$$

where P is the sheet property, Po the contribution to property P from virgin fibre, ñ the average age of the fibres in the sheet and in the maximum number of recycling steps.

The fractional property reduction at various levels of utilisation rate is shown in Figure 34.

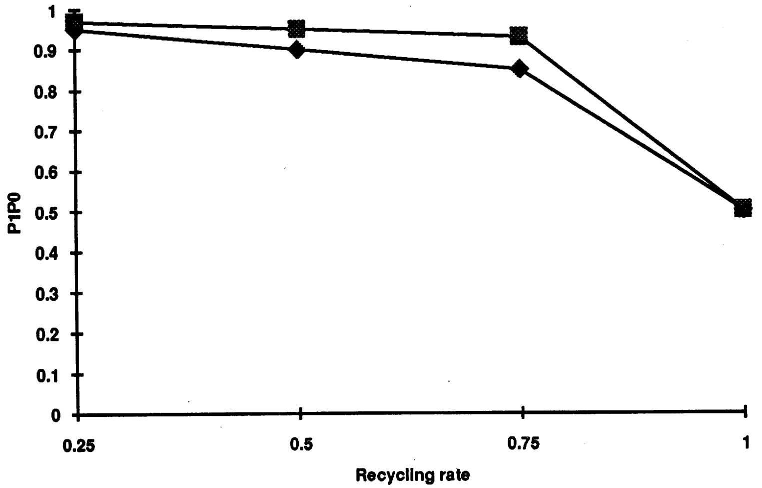


Figure 34: Property reduction is rapid after 75% recycling rate is reached

This indicates a dramatic drop in properties at a utilisation rate in excess of 75%.

Havelock's model uses the Kubelka-Munk relationship to determine brightness and is allied to an optimisation routine to specify furnish costs.

Build up of Impurities

Grossman et al(108) have addressed the problem of the recycling of impurities. They use a simplified model, (Figure 35), to examine the points of addition of impurities into a recycling system.

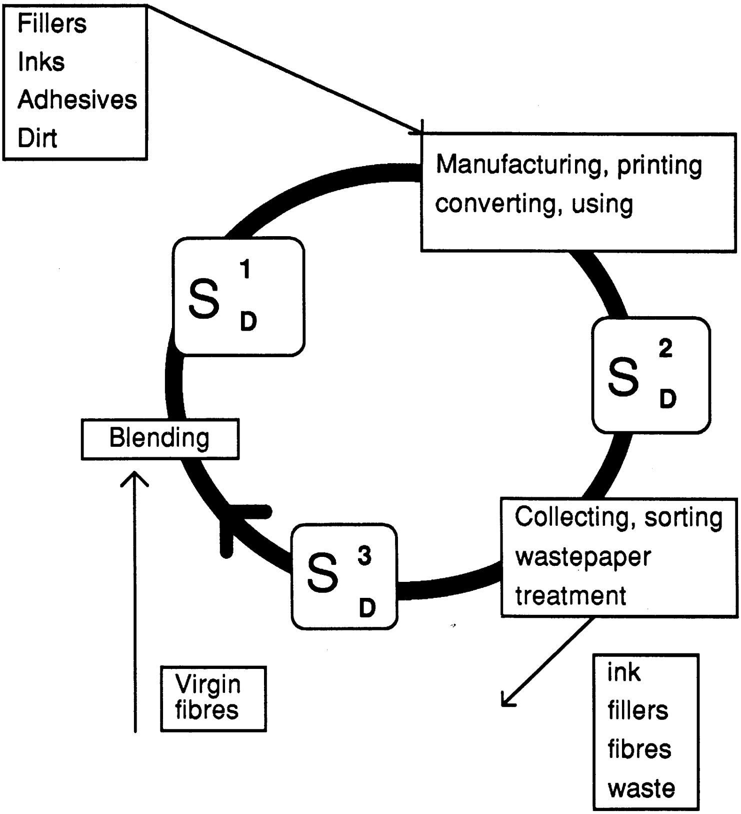


Figure 35: Definition of impurity concentrations, s_D.

Grossman et al(108) assume that between position 3 and 2 ink will be lost from the system which they deal with by using a transfer factor t. Their model also considers:

- the wastepaper utilisation rate, a
- the amount of contrary material, M added per cycle
- the amount of ink, m_D, within the contrary materials
- the ink concentration, s_D, at various locations within the cycle.

The equation they derive is related to the maximum ink quantity, S_∞, which equals

$$\frac{a\, t_N\, m}{1 + M - a\, t_O.}$$

They also use a factor S_∞/m which they define as the relative contamination of new paper, v.

The results obtained using this expression assuming that the transfer rate for newly introduced impurities is the same as that for old are shown in Figure 36, (108).

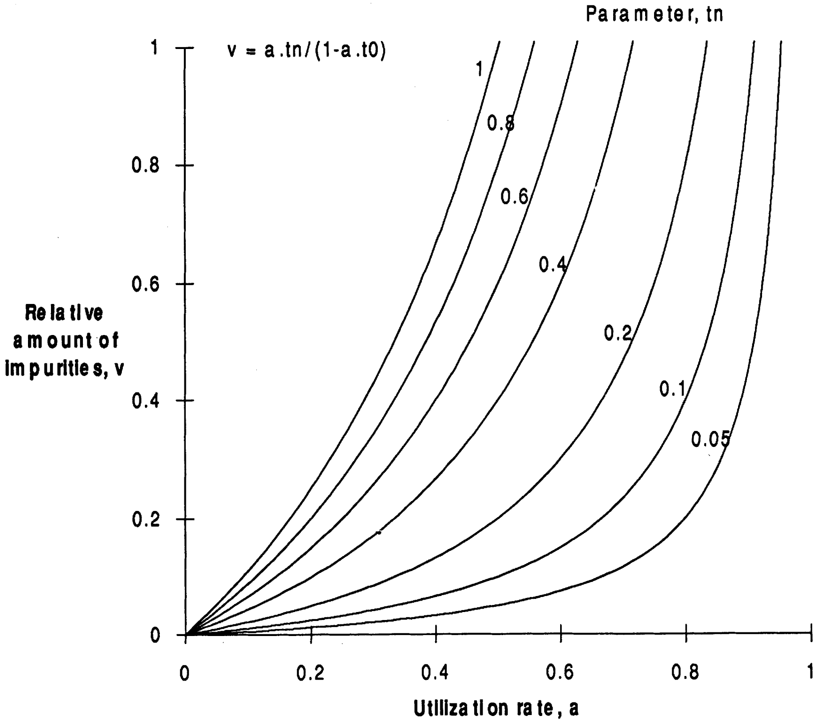


Figure 36: Impurities concentration against utilisation rate

At a typical transfer factor of 0.4, (ie 60% ink removal) the relative amount of impurities changes very little over practicable utilisation rates.

Energy consumption and CO_2 release

Gilbreath(109) studied the energy usage and CO_2 emissions resulting from the production of virgin and recycled linerboard. The energy consumption is shown in Figure 37, (109).

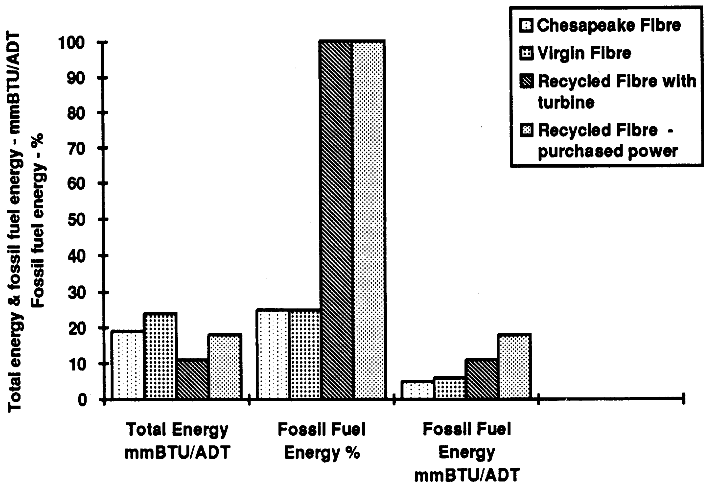


Figure 37: Total and fossil fuel energy - Linerboard, Chesapeake Fibre, Virgin Fibre and Recycled Fibre.

The virgin product consumes more energy but less fossil fuel energy.

The situation as far as CO_2 emissions are concerned is shown in Figure 38, (109).

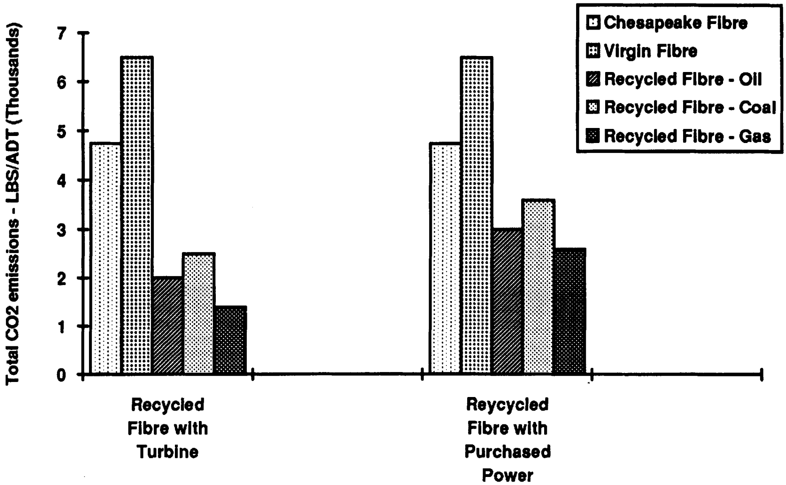


Figure 38: Total CO_2 emissions - Linerboard Chesapeake Fibre, Virgin Fibre and Recycled Fibre.

Clearly the CO_2 emission is greater from the virgin product. The advantage of recycling is not as clear cut when the effect of cutting and replanting forests is considered on the overall CO_2 balance. As forests mature their capacity for fixing CO_2 declines. The effect of this is shown in Figure 39, (109).

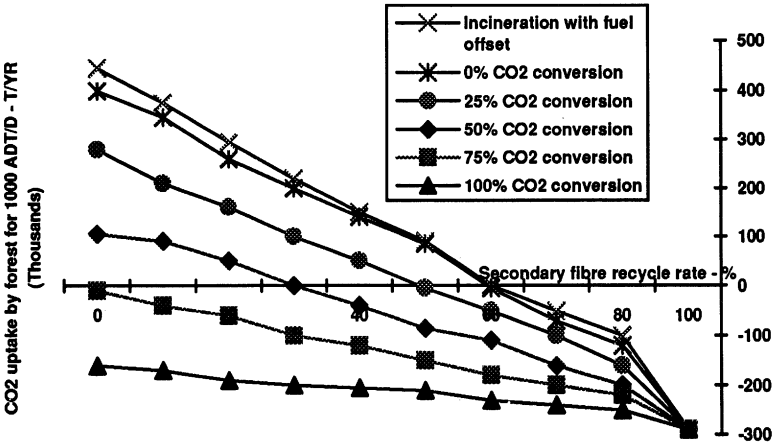


Figure 39: The CO_2 balance with various forestry practises

The global CO_2 balance with reafforestation for a 1000ton/day recycled mill produces 280,000 ton/yr of CO_2 when combined with the CO_2 uptake of an old growth forest. Virgin fibre production leads to a CO_2 uptake of 465,000 ton/yr.

The calculations presented by Gilbreath(109) will be disputed by others because there is no accepted method for carrying out the calculations. The effects of transport are ignored etc. Other environmental impacts such as liquid waste, NO_x, SO_x generation are also not considered.

Further work needed

Modelling can be a powerful tool to support an argument. The data used must be transparent as well as the method. Most existing models are limited in their scope to one country or one grade. They tend to ignore the practice of downcycling and do not address the problems of where to introduce wastepaper into the complex recycling system.

A start has been made with the approach of Robertson(110) who has calculated that the limit for recycling in fine papers is 78% and suggested the means for achieving this. As wastepaper is derived from fibres produced from wood or annual crops, the influences of total fibre balance must be considered, which will include alternative uses for wastepaper and for wood.

The current move to increase recycling has been environmentally driven by the concern to reduce the pressure on landfill volumes. This single issue focus will change with the realisation that the critical environmental issue is that of the management of the carbon cycle. Worldwide 2 x 10^{11} tonnes of carbon are fixed annually by photosynthesis - this needs to be increased to balance the emissions from our society. The growth of trees and the management of forestry must contribute to the increase in carbon fixations. Virtanen and Nilsson(6) caution that too great an emphasis on recycling could result in the paper industry not being in a position to use forest thinnings and the residues of the timber industry.

ALTERNATIVE USES OF WASTEPAPER

Three alternative uses of wastepaper are; to manufacture non paper products, incinerate to recover energy and compost to produce a saleable agricultural adduct.

Non paper products

Non paper products divide into three categories: loose fibre; composites and chemical derivatives. There is not much data on the use of paper as a raw material for these applications. The most recent has been gathered by Friberg(111) for the USA. This is shown in Table 9.

	1990
Moulded pulp	500,000
Insulation	300,000
Fillers and fibres	260,000
Animal bedding	125,000
Internal packaging	100,000
Hydromulch	100,000
Wallboard	90,000
Medium density board	80,000

Table 9: Alternative uses for recycled paper in the USA, 1990 (tons per year)

The moulded products include applications for food packaging, food service and horticultural use. Paper has an advantage in certain agricultural products, eg plant pots since it is biodegradable and some growth in this market may be possible.

The competitive product as far as animal bedding is concerned is straw. Penetration of this traditional market for straw is dependent on the relative prices of the two waste materials. Shredded paper may have some practical advantages as indicated in Table 10,(112).

More sterile, so less bacteria and mold grow
No fly eggs to hatch in the barn
Little or no dust
Fewer heavy metals in newspaper than in straw
More absorbent by 50 to 100% than straw or wood shavings
Less expensive to purchase
16% less bedding is needed for a given job
Better thermal insulating properties for young animals
Lower building heating costs
Fewer accidents for newborn animals, because it is less slippery
Fewer odours, such as ammonia from manure
Less mixing time and clogging in manure removal systems, especially slurry type systems
Faster decomposition in the fields
Reduced storage space required on the farm,

Table 10: Reasons why paper bedding is preferred to other bedding materials.

The major potential area for use in composite products is fibre board for building application. Others are shown in Table 11, (111).

Organic binders
Low density
Insulation board (perlite with asphalt binder)
Filters
Medium density
Underlayment
Roof decking
Floor decking
Sidewall sheathing, interior and exterior
High density
Plastic lumber (plastic/fibre composite)
Stress skins/panels
Molded
Furniture
Trays
Encasements
Inorganic binders
Cement board
Gypsum board
Wallboard (gypsum core, paper facing)
Fibreboard (using gypsum binder)
Sheathing
Siding
Tile backing

Source: Weyerhauser Company 1992

Table 11: Various composites from recovered paper fibre

Fibre boards are generally not suitable for load-bearing applications and have to satisfy fire regulations. Building materials are also subject to various regulations and standards which can act as a barrier to new product development.

Chemical products could be made from paper but costs are high and there are competitive alternative sources of raw materials eg straw which have a higher purity. Biotechnology is a rapidly expanding science with a great potential for exploitation. The paper industry needs to be aware of potential solutions to its waste problems which will arise.

Energy recovery

Energy recovery from wastepaper is potentially the greatest threat to the supply of wastepaper for industrial use as a raw material. The energy of various fuels are shown in Table 12.

Material	Calorific value MJ/Kg
Oil/Gas	47.0
Polyethylene	46.3
Polypropylene	45.4
Polystyrene	41.5
Nylon	31.7
Anthracite (coal)	30.9
Polyvinyl Chloride	23.0
Cellulose Acetate	20.0
Cellulose Film	16.0

Source: Warren Spring Laboratory, Courtaulds

Table 12: Calorific values of selected materials

Mixed paper has low sulphur content and when burned is low in NO_X emissions(113). There are no special problems with burning mixed paper fuels either with regard to air emissions or ash disposal(114).

Composting

Composting is 'the decomposition of organic materials released by living plants, animal or microbial cells and the breakdown of dead organics brought about by microbial saprophytes'(115). Alternatively it is 'the exothermic biological oxidative transformation of organic matter'(116). The process is essentially microbiological, mediated by prokaryotes and fungi. The composting of organic wastes is affected by the organic feedstock and the temperature used within the process. In practice it is also necessary to use a bulking agent to give the composting medium structure, facilitating the diffusion of gases into and out of the process.

Many organic materials decompose readily during composting and are referred to as putrescibles. Putrescible materials contain lipids, starches, glycogens, proteins, nucleic acids, sugars, fatty acids, amino acids, dutin, pectins, hemicelluloses and cellulose.

Not all biological materials decompose fully during composting. Lignin is decomposed slowly because of cross linked structure and chemical substitutions in the polymer which impede enzyme activity(117,118,119,120,121). Cellulose is resistant to biodegradation when associated with lignin as lignocellulose in paper(117-121). Papermaking renders cellulose resistant to composting by altering its chemical composition and its physical structure(120-124). Partially degraded paper is a visible contaminant of municipal composts and can lead to nitrogen immobilisation when applied to soil.

Composing of wastepaper itself is unlikely to be an alternative disposal route unless there are advances in the micro-organisms that are used to treat it. The research into the biopulping and biobleaching of wood and pulp respectively may usefully be extended to examine how to dispose of paper after it has served its useful primary function.

Composting of paper mill sludge is commercially practised. There are examples in the literature of co-composting primary sludge with cattle slurry, abattoir waste and chicken liver(125) and secondary sludge(126).

Co-composting is often necessary to ensure that an optimum carbon to nitrogen ratio is present.

Market forces will determine which of the alternative uses of wastepaper will survive and thrive. Technological developments may play a part in determining which predominates. There is a danger that environmental pressures will distort market forces and push development and investment along paths which ultimately will not be environmental and economic optima. The possibility that the 'ideal' waste disposal route will vary with location and raw material has yet to be recognised by many in the environmental movement and the politicians. Models of raw material usage and optimum disposal routes could provide a fact base on which to plan.

CONCLUSIONS

This has been a selective view of recycling and recycling literature. A considerable number of important topics have not been considered. To assist the reader a list of topics and recent articles and/or reviews is given below:

- Screening(127)
- Cleaners(128)
- Use of surfactants(129,130)
- Stickies(131,132)
- Refining(133,134)
- Stock preparation(135)
- Wash deinking(87)
- Bleaching/brightening(136)

- Life cycle analysis/assessment(137)

This list is present to reinforce the point that recycling is complex. The range of scientific disciplines needed to understand the practicalities and develop the technology is wide.

The paper and board industry is concerned to reduce its overall impact on the environment and has introduced a number of process improvements which reduce energy consumption, increase yield and result in 'light-weighted' products etc. The future direction the industry takes is difficult to define because of the complexities of the processes and the array of possible raw materials which could be used. Proponents of a particular raw material and process use techniques such as environmental life cycle analysis to support their case. These claims can be disputed because there is no standard agreement on the methodology or the data which are used. This leads to confusion inside the industry, amongst the industry's customers and in the minds of legislators.

Another problem faced by users of life cycle analysis is that their conclusions are based on existing industry practice and are invariably historic perceptions. Knowledge of newer processes and technologies is not fed into the models used. The models are used rarely to assist in evaluating and developing new technologies. It is thus important that closer links are forged between researchers and life cycle analysis practitioners.

S ≠ T ≠ I

Morita(138) the Chief Executive of Sony used this symbolism to emphasise that science, technology and innovation are not the same, nor are interchangeable. The innovation process has to be managed. Research is a tool to assist businesses meet their objectives over a range of timescales.

As this is a fundamental conference our efforts are directed at generating new knowledge which will meet long term industrial objectives. This is becoming increasingly difficult with the understandable present short term focus of the paper and board industry. However we must provide some leadership to anticipate future knowledge requirements for the industry.

There are competitive threats long term which the industry will have to face. These could be the impact of new media which could replace paper as a traditional communications medium. The arguments about the environmental friendliness of different packaging substrates could adversely influence the demand for paper unless the paper industry can demonstrate that it is taking its environmental responsibilities seriously.

Too much attention is being and has been paid within paper recycling research to empirical studies based on existing technology. There may be opportunities within other process industries or in developing technologies such as microbiology and information. Other industries are faced with the challenge of improving their environmental performance and increasing their recycling rates. The opportunities for synergy must be explored.
Paper recycling cannot be isolated from the original manufacturing process. An industry wide view, which involves an attitudinal change, to consider waste management positively as resource optimisation is required. Wastepaper is a resource which can be managed. This type of thinking would concentrate more research effort on the supply side - waste collection and segregation and design for recycling.

The use of wastepaper as a raw material leads to the consumption of fossil fuels and the emission of carbon dioxide and other wastes which have a negative impact on the environment. Applied research attention has to be focused on methods of reducing energy consumption, increasing yield and minimising solid and liquid emissions. Effort should also be made to devise new processes which are essentially 'cleaner'.

This literature review revealed a great amount of data but comparatively little information. The reason for this is that a variety of methods were used by the various workers often on uncharacterised materials. Greater emphasis is needed on developing reporting standards which include experimental procedures, measurement methods and removal efficiencies.

More effort is needed to be devoted to understanding what happens at a fundamental level at all stages on the recycling loop and in recycling plants rather than repeating empirical experiments which add data rather than information. Some of the subjects on which to concentrate are indicated in the text.

ACKNOWLEDGEMENTS

This review could not have been completed without the work of those who are referred to within it. There are also other scientists who will have contributed but are not recognised formally.

The assistance and support of colleagues particularly Kate Cathie, Damian Rodgers and Graham Moore is acknowledged along with the help and patience of Lesley Grant who word processed this manuscript, learning new skills in the process.

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Transcription of Discussion

RECYCLING, REUSE AND DISPOSAL OF PAPER AND BOARD

D A Guest (Review Paper)

Dr N Dunlop-Jones, Sandoz Chemicals (UK) Ltd

How much effort is being put into developing inks that are recyclable? It seems it may be possible to have pigments or black particles that are bleachable and in that case one would not have to spend considerable time and money developing processes for separating the coloured materials from waste.

D Guest

Basically, the chemical manufacturers and that includes the ink manufacturers are very concerned about their environmental performance because nobody wants to be accused of introducing a new ink or new chemical which has a negative environmental impact. Most life cycle analysis studies have been carried out in the chemical industry. There is work going on the development of inks which are easier to recycle but through conventional de-inking plants. I do not know of anybody who is looking at more innovative approaches, but again they would not publish it.

N Dunlop-Jones

We have shown that you can develop an ink which is easily bleachable but the problem is who is going to pay for it as the printer does not want to pay more for the ink. It is more a question of somehow sharing the cost across the industry.

D Guest

There is a realisation amongst some of the bigger companies (big publishers) that they have a duty to the environment as well and they are starting to look at their operating procedures. Recently I have seen a lot more interest in this concept of designing products to be recyclable so that the work you are doing here may find its application in a few years time.

Prof J Lindsay, Institute Paper Science & Technology, USA
First I would like to thank you for an excellent review. I was especially happy with some of the very good references you brought into the text. You referred to the mechanism of particle attachment during flotation deinking and talked about the sliding mechanism which you discuss very well on Page 1186. The comment here is that it is true that the literature refers to this as the dominant mechanism but they are all drawing their conclusion from data in the mineral flotation area. Schultze who you quote here has done the same thing and this is also a mineral flotation study. One of the reasons why experience or data is not applicable extensively in the paper area is that the hydrodynamics are quite different. In the mineral flotation we have very low Reynolds numbers, viscous flows, low velocity and the Reynolds numbers in the mixing region may differ by several orders of magnitude from minerals to paper flotation deinking. It is probably very likely that in typical modern paper flotation processes that the collision mechanism is much more important than people have believed. We have Reynolds numbers in the mixing region in the order of 10^5 where there is very strong turbulence and they are designed to create collisions between ink particles and bubbles. A number of people working in the hydrodynamics area suspect that people are missing the boat when they are emphasising the sliding mechanism.

D Guest

I agree with you. There is very little work that has been carried out directly on the deinking process. There is far more on the mineral processing. It is quite likely that the mechanisms are different.

Dr R Shet, Kimberly-Clark Corporation, USA

I have not gone through your paper completely, but what I want to find out is whether there are any references regarding the charges on ink particles which may help both removal as well as recovery of the ink particles. Something like charged pigments they use in the automobile industry.

D Guest

I am not quite sure I understood the question. There will be charges on the inks and ink particles and they will vary very much with the type of printing process that has been used. One of the problems people have in carrying out research in the whole deinking field is that you have a vast range of raw materials and inks that are used and it is very difficult to pick some which are typical and give you results which are then applicable elsewhere. There have been studies on the ink particle charge and the effect of ink particle charge on ink removal.

Dr K Ebeling, Kymmene Corporation, Finland

Thank you very much David for an excellent review. I am especially pleased with the time you spent with life cycle analysis. It is a method we need to develop and to find a common procedure how to use it, otherwise everyone can use it to their own best cause. The reason why I mentioned the life cycle analysis was that the experiments we have carried out show that the so called totally chlorine free bleached fibres have a lower recyclability than the conventionally ie elemental chlorine free (ECF) bleached fibres. So in trying to get one of the vicious things out of the environment we are making fibres that disappear very easily in the recycling process.

D Guest

Thank you very much for that because I was going to ask if anybody knows of any studies on recyclability of chlorine free bleached fibres. The danger as you quite rightly point out, is that life cycle analysis studies are appearing throughout the literature and these studies say "my product is better than his product" . What you have to consider is when you read these articles is what assumptions are made. In particular how did they treat the recycling loop because if you treat the recycling loop in a different way you can come up with a vastly different answer.