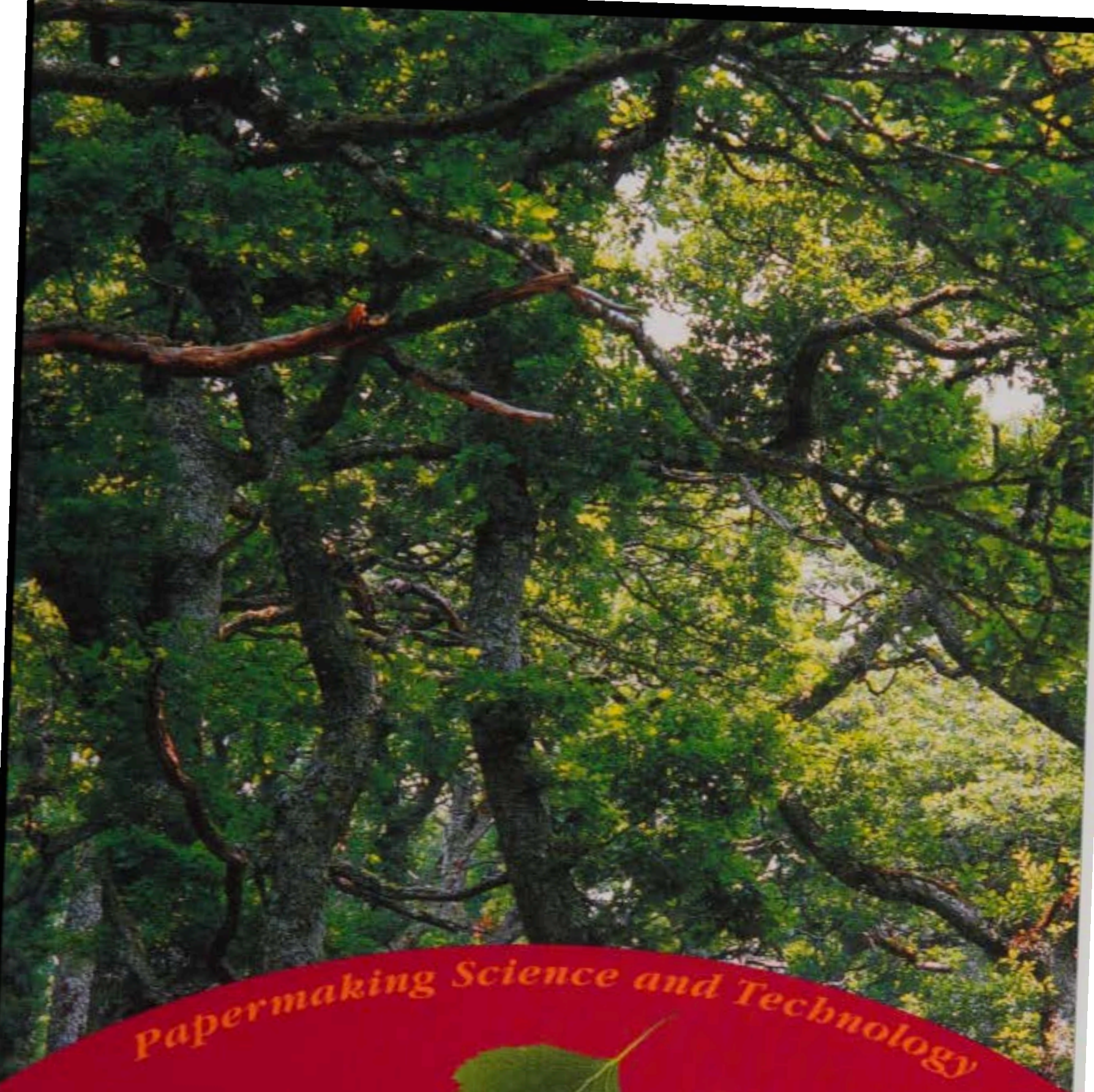




Papermaking Science and Technology



Lothar Göttscbing and Heikki Pakarinen

*R*ecycled Fiber and Deinking

Sigma EX2028 - p.01 of 36
ProAmpac v. Sigma
IPR2025-01143

Cover photo: Suomen Kuvapalvelu, John Lythgoe

ISBN 952-5216-00-4 (the series)

ISBN 952-5216-07-1 (book 7)

Published by Fapet Oy

(Fapet Oy, PO BOX 146, FIN-00171 HELSINKI, FINLAND)

Copyright © 2000 by Fapet Oy. All rights reserved.

Printed by Gummerus Printing, Jyväskylä, Finland 2000



Printed on LumiMatt 100 g/m², Stora Enso Fine Paper, Imatra Mills

Certain figures in this publication have been reprinted by permission of TAPPI.

CHAPTER 11

Stickies in recycled fiber pulp

1	What are stickies?	441
1.1	Classification of stickies	442
1.1.1	Size of stickies	443
1.1.2	Type of stickies	443
1.1.3	Behavior of stickies	444
1.2	Problems caused by stickies	445
1.3	Cost impact of stickies	445
2	Origins of stickies	447
2.1	Adhesives	447
2.1.1	Hot melt adhesives	449
2.1.2	Dispersion adhesives	449
2.1.3	Solvent adhesives	450
2.1.4	Pressure sensitive adhesives	451
2.2	Printing inks	452
2.3	Coating binders	453
2.4	Wood derivatives	453
2.5	Papermaking additives	453
2.6	Chemical substances in potential stickies	454
3	Adsorption of stickies	455
4	Characterization of stickies	458
4.1	Deposit analyses	459
4.2	Handsheet inspection methods	463
4.3	Screening methods	464
4.4	Adsorption methods	468
4.5	Extraction methods	469
4.6	Precipitation methods	470
4.7	Other methods	472
4.8	Conclusions	473
5	Control of stickies	473
5.1	Alteration methods	474
5.2	Avoidance methods	477
5.3	Removal methods	478
5.3.1	Screening	479

Stickies in recycled fiber pulp

1 What are stickies?

The term "stickies" does not have a precise, generally applicable definition. Despite this, papermakers understand it to mean those tacky substances contained in the pulp and process water system that deposit or attempt to deposit on paper machine clothing, cylinders, or rolls at certain stages of papermaking. The particles in the produced paper identified as tacky contaminants are also stickies. Stickies are only one of many different contaminants contained in recovered paper. Scott¹ gives a good general definition of contaminants:

"A contaminant is any fiber or nonfibrous component that is not intentionally added to the system to construct the paper web, to enhance paper properties, or to facilitate the operation or promote the cleanliness of the paper manufacturing system".

This definition does not regard as contaminants functional and process chemicals used for the first time as additives in the papermaking process. The same chemicals are often contaminants if they enter the recycling process with recovered paper.

Another pragmatic definition of contaminants distinguishes between external and internal contaminants (See Fig. 15 in Chapter 10). External contaminants are the materials not physically or chemically bound to paper and board and their fibers but contained in recovered paper such as sand, glass particles, wood pieces, screws, or cans. Considerable removal of these materials should be possible at the time of sorting recovered paper, or they can usually be easily removed from the pulp slurry during recovered paper processing².

Internal contaminants are bound physically or chemically to the paper or board surface or even embedded in the fiber structure. Some components that can later act as contaminants enter as additives during the papermaking process to control certain paper characteristics. Examples of these are the application of starch to enhance the strength of testliner and corrugating medium or the use of wet strength additives for kitchen towels. Other internal contaminants are added during paper converting or by private users. These include plastic coatings of catalog covers or liquid packaging; hot melt materials for binding book or magazine spines; ink use for newspapers, magazines, or books; addition of starch for gluing corrugated board; use of wax coatings for corrugated board; application of pressure sensitive labels in marking the prices of consumable goods; or the use of pressure sensitive note pads in private homes.

CHAPTER 11

5.3.2	Cleaning.....	483
5.3.3	Flotation.....	485
5.3.4	Washing.....	489
5.3.5	Other techniques.....	490
5.4	Dispersion methods.....	491
5.5	Passivation methods.....	492
5.5.1	Minerals.....	492
5.5.2	Synthetic fibers.....	494
5.5.3	Zirconium chemicals.....	495
5.5.4	Other chemicals.....	495
5.6	Prevention methods.....	497
5.6.1	Coating of wires, felts, and rolls.....	497
5.6.2	Machine clothing cleaning.....	498
	References.....	499

These internal contaminants can be soluble or insoluble in water. Water-soluble internal contaminants such as starch, gluing agents, or redispersible adhesives usually transform into the aqueous stage in the pulp and water loop and are frequently included in the term detrimental substances. An appropriate process water and effluent cleaning is necessary to manage these dissolved detrimental substances. Theoretically, an increasingly closed process water system causes an increased concentration of these dissolved substances and favors the formation of deposits and growth of microorganisms or slime.

Insoluble contaminants can be thermoplastic or nonthermoplastic materials. The thermoplastic behavior of contaminants is a precondition for permitting the adsorption of a substance on another solid material. For example, the adhesive of pressure sensitive labels is normally in a permanent thermoplastic state at room temperature. This provides the basis for their durable tack. With hot melts, a certain temperature is necessary to ensure that they melt to develop their tacky properties. This thermoplasticity of hot melts occurs not only between 65°C and 120°C as often claimed but can be reached even at room temperature depending on their chemical composition. Plastics such as polyethylene and polypropylene are also thermoplastic and therefore develop tack at softening temperatures such as encountered in the drying section of paper machines.

Many insoluble contaminants, both thermoplastic and nonthermoplastic, consist of different chemicals. Some are soluble in an aqueous environment. The insoluble components can be tacky but may not necessarily deposit as stickies.

For this reason, the term "stickie-" is generally used in the paper industry for indefinite mixtures of organic compounds that enter the recycling loop with the recovered paper. They can be screened from the pulp suspension as tacky substances, precipitated from the aqueous medium, or deposit within the recycled pulp process on the paper machine, on the paper machine clothing, or in the final product.

1.1 Classification of stickies

The distinguish features of stickies are the following:

- Size
- Type
- Behavior.

Classification by size uses a laboratory screening procedure. The stickies remaining on a slotted screen plate are called macro stickies. The stickies passing the plate are micro stickies. Micro stickies can be finely dispersed (100 µm to 100 nm), colloidal (100 nm to 10 nm), or molecular dissolved (<10 nm)³.

Depending on the type, they can be primary or secondary stickies. Primary stickies are present from the beginning in the disintegrated pulp and can consist of micro and macro stickies. Secondary stickies can develop only during the processing operation or in the paper machine from micro stickies, finely dispersed, molecular dissolved or colloidal substances.

Another classification for stickies uses their behavior. They can be permanently tacky (permanent stickies such as macro and micro stickies) or potentially tacky (potential stickies under certain circumstances such as secondary stickies).

1.1.1 Size of stickies

The most common classification of stickies uses their size. Macro stickies are those that remain as screening residue after laboratory screening with a slotted plate equipped with a slot width of 0.10 or 0.15 mm. Micro stickies are those that can pass the screening slots with the accept after screening with a slotted plate equipped with the same slot width.

The reason for this type of distinction is that macro stickies from recovered paper in industrial processing systems can be removed from the pulp slurry by screens and cleaners. Micro stickies are usually so small that they cannot be eliminated even by the most effective screening units. If the macro stickies content in the headbox of a paper machine or in the produced paper is excessive, the screening of the pulp processing system, the approach flow system, or both require improvement. Micro stickies that pass the screens possibly agglomerate and lead to deposits on the paper machine or its clothing or pass into the product as newly formed secondary macro stickies.

Doshi⁴ prescribes a slot width of 0.15 mm for distinguishing micro and macro stickies. Ackermann *et al.*⁵ use 0.10 mm as the distinguishing criterion for deinked pulp. Since the slot widths in industrial recovered paper processing are becoming increasingly smaller and the developing fiber mat leads to an effective reduction of the actual screen perforation, a minimum slot width should be specified for laboratory screening operations during which no fiber mat is formed. A slot width of 0.10 mm cannot be applied for all recycled fiber pulps. For example, highly contaminated recovered paper grades or samples taken at the beginning of a recovered paper processing system cannot always be screened with 0.10 mm slots due to the risk of plugging the slotted screens or encountering excessive reject rates. In laboratory screening for control of stickies, the use of slotted plates with 0.10 mm slot width is therefore recommended for deinked pulp and with 0.15 mm for pulp from mixed (brown) recovered paper grades.

1.1.2 Type of stickies

A distinction is made between primary and secondary stickies. Primary stickies are identical with the aforementioned macro and micro stickies and characterized as intact tacky particles of adhesives such as hot melts or pressure sensitive adhesives, inks, binders, waxes, plastics, or wet strength resins.

Shock-type, chemical-physical alterations of a pulp suspension are a potential cause for formation of secondary stickies. This includes temperature, pH, or charge changes that cause a colloidal destabilizing and agglomeration of dissolved, colloidal, or both substances. Secondary stickies can then also lead to deposits on the paper machine or its clothing.

Incidentally, comparable problems also occur in the processing of virgin pulp. Papermakers then speak of pitch in connection with tacky substances from wood extractives or white pitch in connection with the processing of coated broke. The interac-

tion of certain process chemicals or resin acids of either natural (wood) or artificial origin plays a dominant role in the formation of secondary stickies and white pitch⁶.

When stickies-related problems occur at a paper mill, primary or secondary stickies may be the culprit. Combating the problem is usually easier if one can determine whether a problem is due primarily to primary or secondary stickies. If no recovered paper is used for example, the cause of stickies-related problems is usually the formation of secondary stickies. This can be counteracted by changing the wet end chemistry or the coating binder system.

1.1.3 Behavior of stickies

Interactions occur that can increase the tack of stickies and the problems experienced with stickies. Such interactions can involve primary or secondary stickies. Figure 1 shows in schematic form some possible interactions between virgin fibers, chemical additives, and contents of the recycled fibers that can cause deposits. For the formation of secondary stickies of Fig. 2, a sudden change (shock) of temperature, pH value, charge, shearing forces, or concentration is the cause of the agglomeration of colloidal or dissolved substances.

Figures 1 and 2 show a highly simplified representation of the complexity of the interactions that can contribute to formation of stickies. Because chemical measures to control stickies usually influence only one described mechanism, an absence of comprehensive knowledge of the interrelations that lead to formation of stickies continues despite many years of research into stickies. Major problems therefore continue to exist in the daily practice of recovered paper processing.

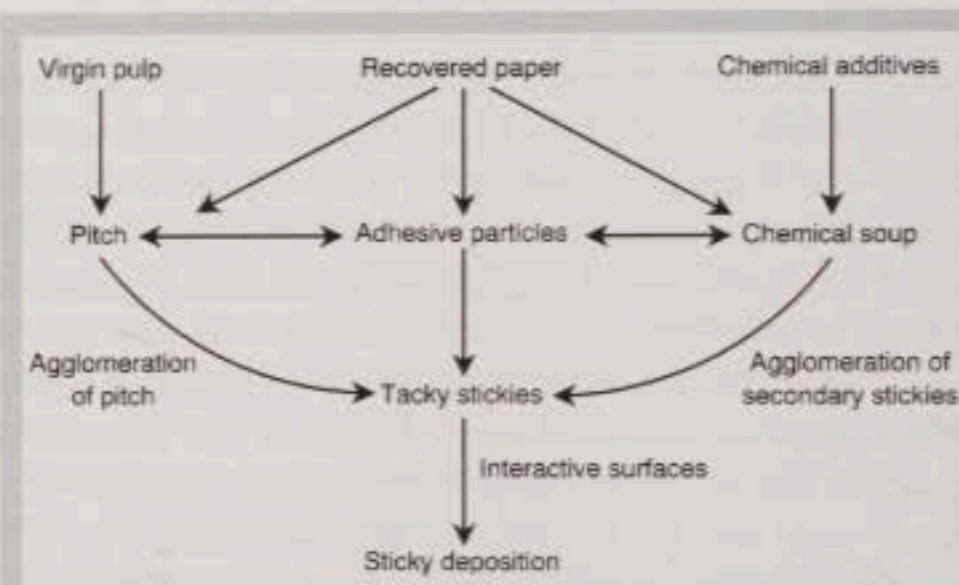


Figure 1. Interactions contributing to deposition of stickies⁶.

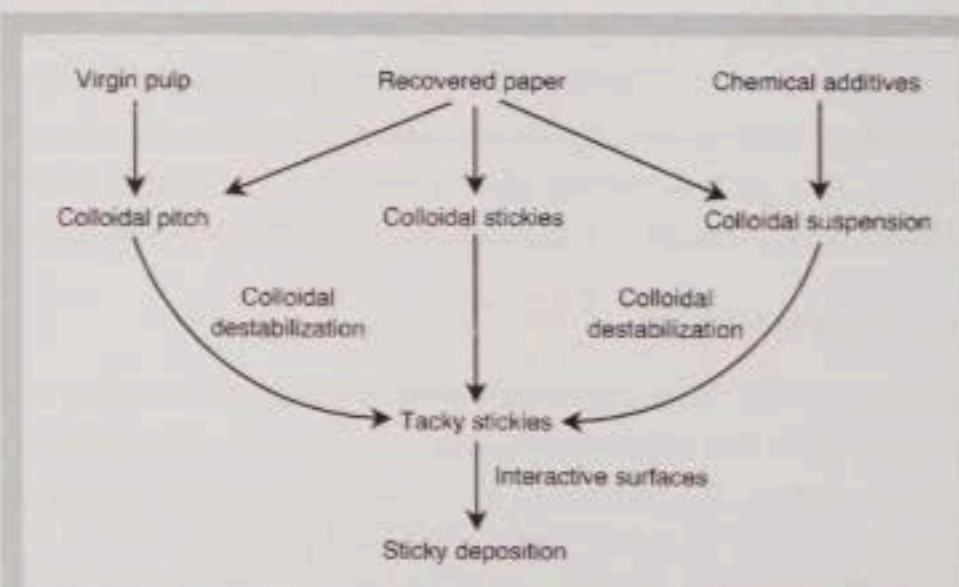


Figure 2. Interactions contributing to formation of secondary stickies⁶.

1.2 Problems caused by stickies

The problems caused by tacky impurities are all too familiar. Deposits occur on stationary parts of a processing system such as pipes and chest walls and in the approach flow system. This includes the inner walls of the deculator in the area of the suspension level or in the headbox itself due to the adhesive character of these materials. Deposits primarily influence moveable parts such as wires, felts, or rolls. Deposits within the paper machine are especially critical since their release can directly cause a web break. A sufficiently intense contact of the running paper web with these tacky substances can also cause picking of fibers.

Disturbances caused in these ways have different effects. Weak spots in the paper web primarily as thinned parts or holes can cause web breaks in the paper machine and in the printing press. They result in lengthy nonproductive cleaning times and reduced levels of productivity. Even if breaks do not occur, holes or spots in the paper cause loss of quality that means the product has use only as second quality material or has to be processed as broke. All problems caused by stickies in the paper machine become more serious with lower basis weight or caliper, lower strength of the paper web, higher paper machine speed, and higher dynamic stress on the paper web⁷.

Even more costly are the problems with stickies that occur after finishing of the paper or board sheet. Due to certain processing conditions of temperature or pressure, stickies bound into the inside of board or thicker paper can reach the outsides of paper or board sheets by melting. This causes unacceptable appearance after printing, varnishing, or laminating. The same applies to stickies on the surface of a paper or board web that have passed through the papermaking process including subsequent finishing without any problem but that cause problems during converting by their adhesion to paper or board blanks they contact. Sometimes, layers stick together during unwinding of a reel causing breaks or surface blemishes.

A particular problem occurs in corrugated board production by wax introduced by recovered paper. If this is insufficiently removed or not neutralized in recovered paper processing, it can result in a decreased coefficient of friction of the liner. Consequently, reels or rolls may telescope during transport. The finished corrugated board blanks could also slip. This would cause imperfect stacking and affect further processing.

As this brief description demonstrates, the problems caused by stickies are many and varied and can occur at practically every stage in the papermaking and paper conversion chain including printing.

1.3 Cost impact of stickies

Little information is available concerning the additional costs due to stickies in the paper production process. In 1984, Baumgarten estimated the costs due to tacky impurities contained in recovered paper as 5–25 US\$/t of recycled fiber pulp but gave no information for this estimation⁸. The cost is higher as basis weight of the paper produced decreases. Included in the estimated figures are the costs incurred in the recovered paper processing system and at the paper machine.

Friberg gave a more recent and detailed estimation of the cost impact of stickies⁹. For the United States, he puts annual losses due to stickies at about 700 million US\$. This figure covers recycled fiber pulp processing, paper production, and the collection and sorting of recovered paper. In relation to the recovered paper consumption in the United States of 28 million tons in 1994, this represents the average cost impact of stickies at 25 US\$/t of recovered paper. Not considered here are the costs of the paper and board converters.

The costs estimated by Friberg in Fig. 3 do consider the additional disposal costs (2%) for stickies that have been removed and the losses for the recovered paper trade due to the lower sales prices for recovered paper grades having an unacceptably high content of stickies (22%). Also considered are the losses (76%) of the producers of different types of paper and board using recycled fiber pulp due to the following:

- Use of chemicals for control of stickies (5 US\$/t)
- Nonproductive paper machine time caused by stickies (104–350 h/year)
- Costs per paper machine hour (10 000–30 000 US\$/h).

These losses vary widely with the type of paper or board produced and the grade of recovered paper used. On this basis, the cost impact of stickies for the processing of recovered paper in major product groups incurs annual costs in the region of 130 million US\$ in the German paper and board industry. The specific costs caused by stickies total an average of 15 US\$/t of recovered paper processed. According to Fig. 3, these costs that are incurred directly at paper mills represent only 76% of the entire related costs of stickies. The total is therefore about 20 US\$/t of recovered paper, and the annual cost to the economy is a minimum of 170 million US\$ in Germany.

The paper and board production structure in the European Union with 50% graphic papers (including 12% newsprint), 40% packaging paper and board, and 10% other types of paper is comparable with the German structure. The related costs of stickies in the European Union may be calculated on the basis of these figures. In 1994 for a consumption of recovered paper of about 28 million tons, the costs were more than 525 million US\$. This also shows that stickies have an enormous influence on the production costs of paper and board.

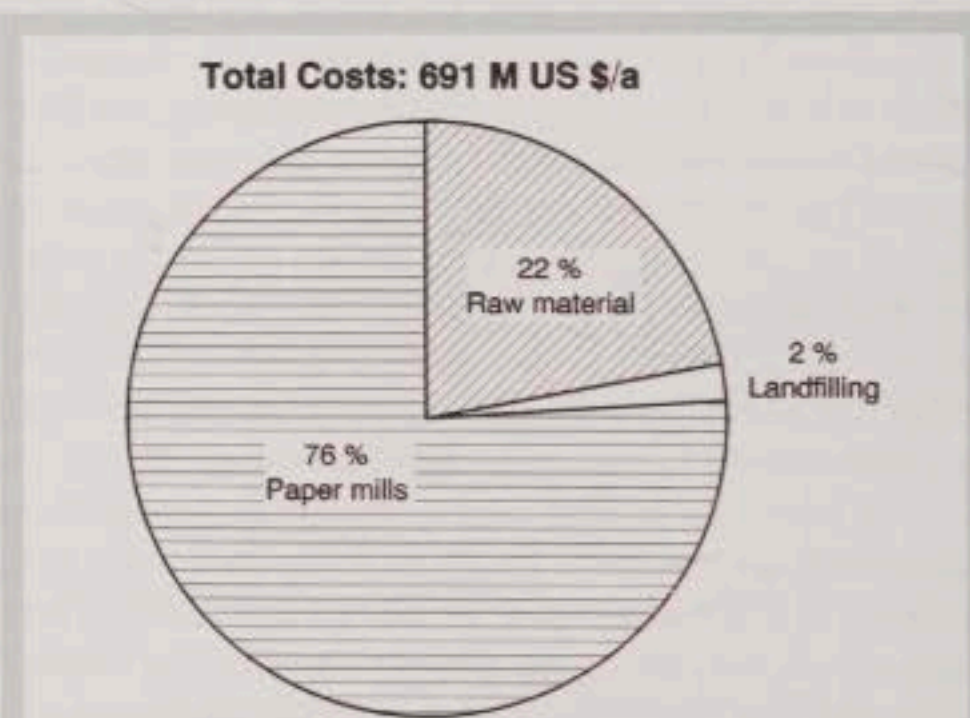


Figure 3. Economic impact of stickies in the United States⁹. (M: million)

2 Origins of stickies

A frequently cited categorization of the chemical origin of tacky impurities comes from Moreland¹⁰. Figure 4 shows this work in a modified form. Starting with organic deposits, the figure follows first the division into synthetic and natural materials. The natural components originate as fatty acids or resin acids from the wood and cause the familiar pitch problems in virgin fiber processing. In accordance with this division, synthetic components originate from coating binders, printing inks, and adhesives. Two of the named groups are subdivided into product classes and listed as typical representatives of the chemicals used whose abbreviations are explained in the text.

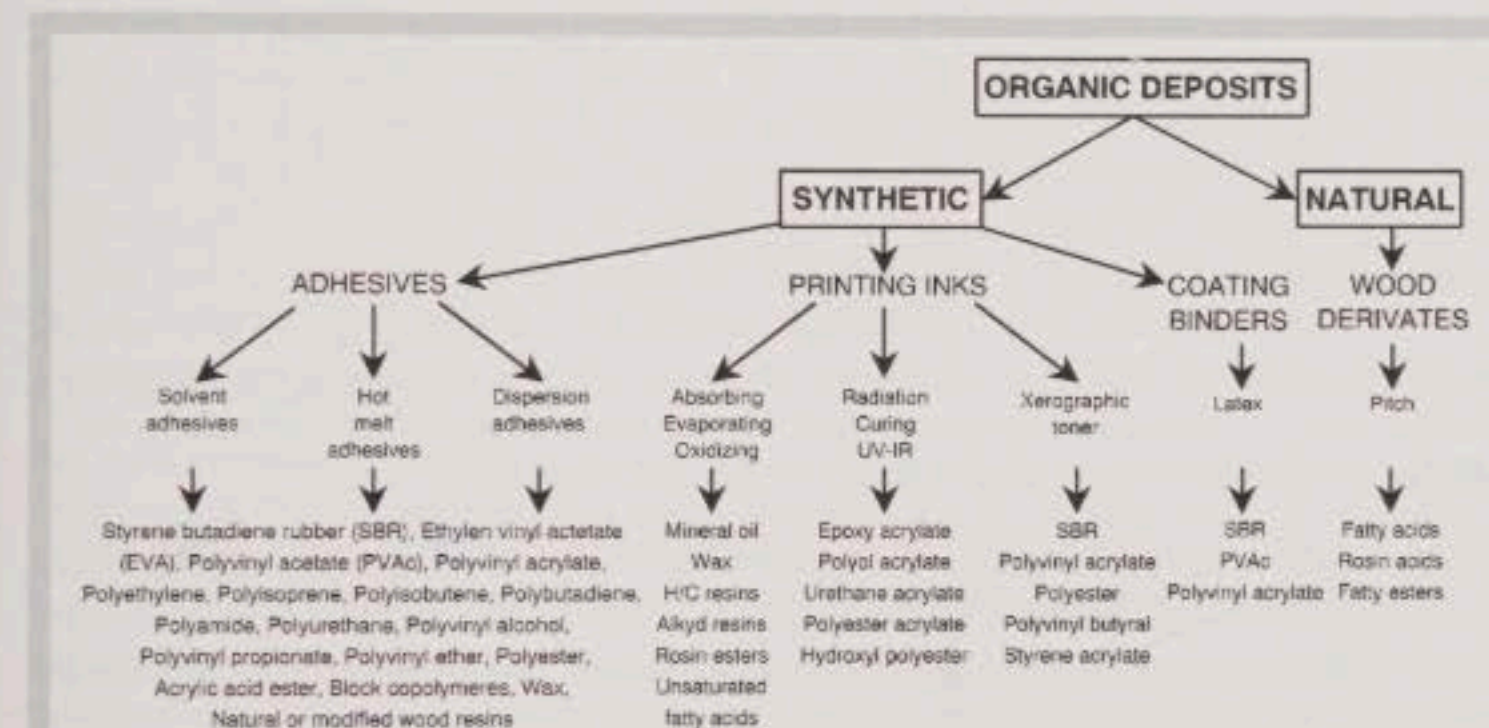


Figure 4. Contaminants frequently identified in paper machine deposits from recovered paper processing mills.

2.1 Adhesives

Adhesives bond two materials together by adhering to the surface of each. Figure 5 shows the use of glues and sealing agents in different industrial applications in Europe. With a total of 35%, the products used in the paper and board industries represent the second-largest market segment after the building industry. Typical applications in the paper converting sector are the binding of magazines and

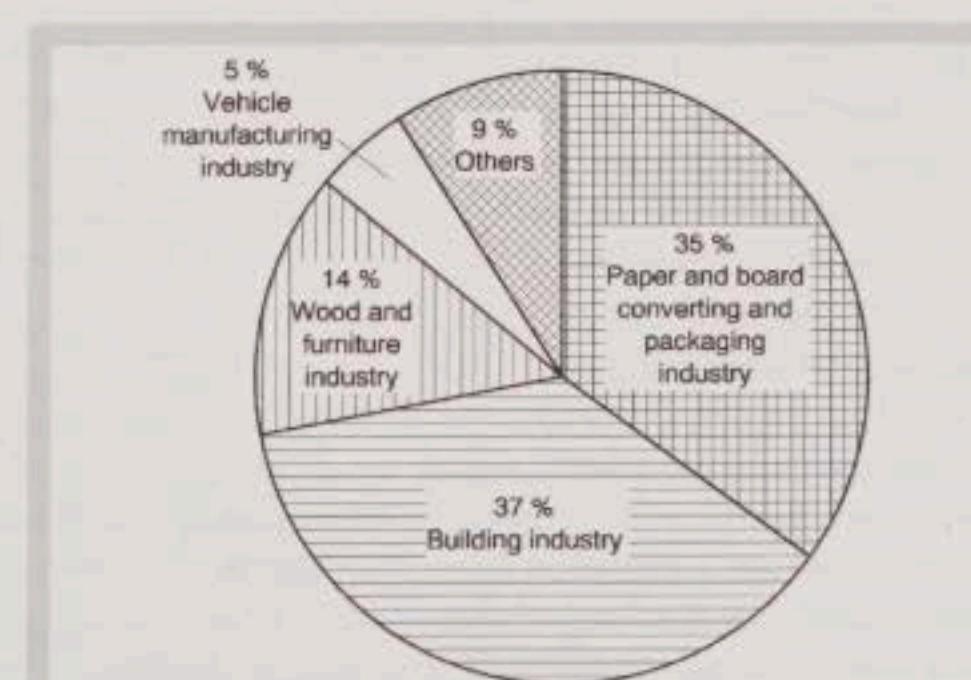


Figure 5. European market of industrial application of adhesives and sealing compounds (1996).

catalogs, coating of pressure sealing labels, and production of self-sealing envelopes, folding boxes, corrugated board containers, etc.

Adhesives must satisfy two major requirements, i.e., have sufficient adhesion and cohesion. At the time of transfer to the materials to be bonded, they should adhere well to the respective surfaces. The close contact of the adhesive molecules with the paper surface occurs by wetting and diffusion processes. To guarantee sufficient adhesive strength (adhesion) between the boundary layers of the adhesive film and the joined parts, the molecules of the adhesive must be in as close contact as possible with the surface of the joined parts. Application of the liquid adhesives accomplishes this technically.

Besides good adhesion, the adhesive requires sufficient internal strength (cohesion) to ensure that the connection between the bonded materials can survive mechanical stress. After application of a glue with good adhesion, the material must solidify into the solid phase to develop sufficient cohesive force. In paper converting and packaging production, the formation of the adhesive film occurs almost exclusively by physical bonding processes characterized by the evaporation of water (dispersion adhesives) or solvents (solvent adhesives) or the cooling of the adhesive film (hot melt adhesives).

Adhesive formulations usually contain several components to satisfy optimally all the gluing requirements. The processing method including its speed and the application systems also influences the composition of the adhesive. Common denominators do exist for the gluing systems used in paper and board converting:

- Aqueous systems have common use for the production of corrugated board. Starch products are dominant.
- Dispersion glues and hot melts have traditional use in bookbinding operations.
- Various glue systems find use in the paper converting industries. Dispersion glues have the greatest share¹¹.

The large number of adhesive formulations are due to the most important basic components. As Fig. 6 shows, dispersion glues at 40% presently account for the largest share of adhesives used in the paper converting industries in Europe. Natural colloidal systems such as starch, dextrin, and casein cover about 25% of the adhesive requirements. Another segment of 30% consists of hot melt adhesives including polyurethane hot melts processed in a liquid state at high

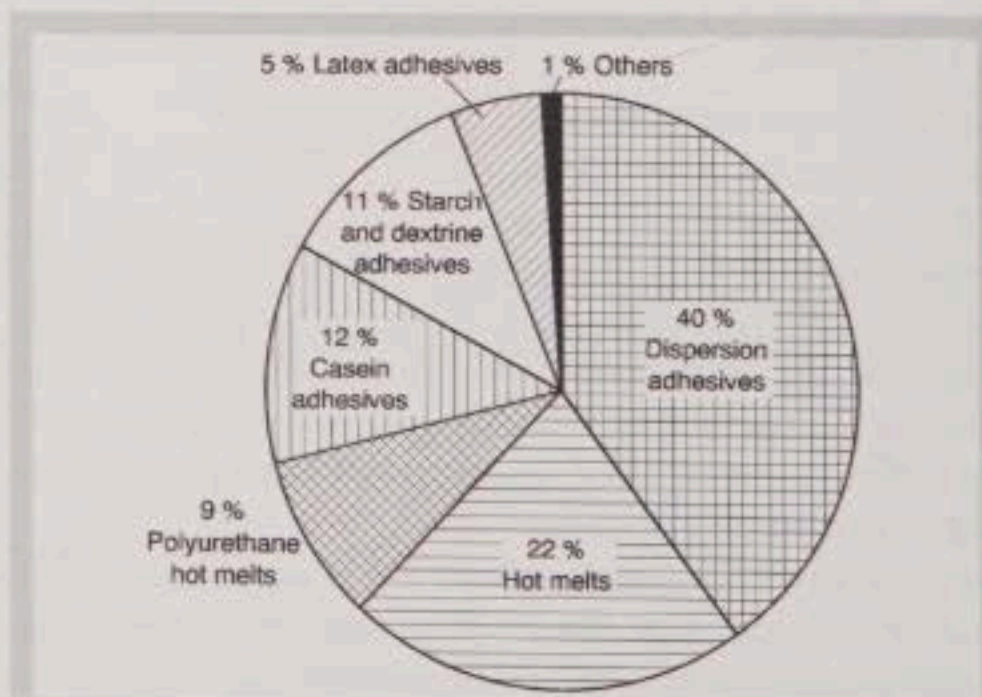


Figure 6. Estimated adhesive consumption in the paper and board converting industries in Europe (1995).

temperatures to form a solid film after cooling. Their market share is especially evident for gluing printed material such as the spines of mail order catalogs or telephone directories.

Conventional gluing uses the following sequential steps:

- Application of the liquid adhesive film
- Joining of the material surfaces to be bonded
- Hardening of the adhesive film by evaporation, cooling, or cross-linking.

With dispersion, solvent, and hot melt adhesives, pressure sensitive adhesives (PSA) are a major source of stickies, but they do not constitute an independent category of adhesive. Instead, all three types of adhesive can be PSA. The term pressure sensitive adhesive is application related and describes how bonding with a pressure sensitive material simply involves joining and exerting slight pressure. Examples are labels or adhesive tapes. Pressure sensitive adhesives simplify many work processes such as envelope sealing. Unfortunately, the lasting tack of the pressure sensitive film means that such adhesives automatically contribute to related problems with stickies. This is why a special section covers this adhesive application technique.

2.1.1 Hot melt adhesives

Hot melt adhesives (HMA) are applied in a liquid state and harden by cooling at room temperature. Their most important areas of application are binding magazines and books and gluing boxes. Ethylene vinyl acetate (EVA), styrene butadiene rubber (SBR), polyethylene, polyamide, polyurethane (PUR), and polyisoprene are common thermoplastic polymers or copolymers used as ingredients. Modified resins, unmodified resins, and synthetic resins can provide the necessary tack. Nonlinear or branched waxes and low molecular weight polyethylene are used to regulate the viscosity and melting point of hot melt adhesives. Small quantities of additives such as fillers, heat stabilizers, and antioxidants also have use¹².

Hot melts are solid at room temperature and usually become soft between 65°C and 120°C. Some hot melt formulations soften at room temperature. Hot melts are usually not redispersible in water under alkaline or acidic conditions but can be dissolved with several organic solvents such as dichloromethane or toluene. The density of hot melts is between 0.9 and 1.0 g/cm³(13).

2.1.2 Dispersion adhesives

Dispersion adhesives are used for a wide range of different applications in paper converting. They contain a tacky polymer substance composed of different monomers that are present in the aqueous phase in a finely dispersed state.

The aqueous phase treats the dispersed medium as an external phase whose high polarity causes the dispersion adhesives to be especially suitable for gluing polar materials such as paper, wood, or textiles. Among adhesives, dispersions have the special advantage of achieving high levels of polymerization at a certain processing viscosity without requiring the solids content to be as low as is necessary when dissolving the adhesive in an organic solvent.

As an internal phase, the dispersed tacky substance always consists of several polymers formed from different monomers. The particles for dispersion require separation from each other by protective colloids or emulsifiers and distribution in the water to prevent reagglomeration. Polyvinyl alcohol is a common protective colloid or emulsifier. Among the monomers for use in making adhesive dispersions are vinyl acetate, ethylene, vinyl propionate, and acrylate. The characteristics of the adhesive dispersions vary within wide tolerances depending on the type of monomer and the different possibilities to form homopolymers, copolymers, or terpolymers¹¹.

Although particle size distribution influences the application characteristics of an aqueous polymer dispersion, the chemical nature of the dispersion largely determines the characteristics of the adhesive joint. Besides the chemical composition and the particle size distribution, the type and quantity of emulsifiers and protective colloids have a decisive influence on the characteristics. A larger inner surface of the polymer dispersion means a more finely dispersed system with a larger demand for these substances. Because these chemicals are integrated into the adhesive film, they have a major influence on its final characteristics such as water resistance of a paper sheet or paper product.

Adhesive films formed from polymer dispersions bond after removal of the aqueous phase. This occurs by absorption into the substrate and by evaporation. Removal of the water increases the particle concentration until the individual particles come into contact. In the intermediate spaces that become smaller, specific capillary forces develop that lead the particles of the internal phase to a homogeneous film due to their plastic behavior. To ensure that this process can occur, a characteristically minimum film forming temperature (threshold temperature) is necessary for each polymer dispersion so that a transparent adhesive film can develop.

Polymer dispersion adhesive films are thermoplastic materials that become soft and plastic at higher temperatures. Depending on the type of polymer dispersion involved, this process occurs between 60°C and 150°C. Within any one group of substances, the softening points are higher with a higher average degree of polymerization. Simultaneously, the higher polymerized products have better heat resistance of the glued joints¹¹.

2.1.3 Solvent adhesives

The classical areas of application for solvent adhesives are pressure sensitive adhesives and do-it-yourself applications. Originally, pressure sensitive adhesives consisted of rubber available only in solvent. With evaporation of the highly volatile solvent, the viscosity of the adhesive increased and its wetting capacity fell. With the increasing molecular weight of the adhesive components, the cohesion within the adhesive film also increased. Rising costs for organic solvents, the environmental legislation, and costs for drying and solvent recovery have resulted in an increasing substitution by solvent-free gluing techniques. The substitution of solvent adhesives in the paper sector occurred primarily by the development of acrylate dispersions that considerably broadened the technical limits on the use of dispersions and the area of application. Today, the share of solvent adhesives of the entire European adhesive market is less than 15% with a decreasing tendency. Such systems therefore have only minor importance in the paper sector.

2.1.4 Pressure sensitive adhesives

The term pressure sensitive adhesive (PSA) includes a range of different adhesives with a common application. PSA materials are extremely high-viscosity, elastic-viscous fluids that provide adhesion to nearly all surfaces in response to slight pressure due to their flow behavior and wetting characteristics. This "permanent adhesive" state distinguishes the management of PSA materials from other types of adhesives and means that they are generally tacky after use.

Products that typically use PSA materials are labels, adhesive tapes, and self-sealing envelopes. In these cases, permanent adhesion is necessary after the first application of the self-sealing material. In some cases, removable or repositionable characteristics are required (e.g., post it notes). Such applications should not leave any residue and attach again and again. As a result of these different requirements, many different chemical components are necessary to satisfy the product demands.

The production of self adhesive labels uses dispersion, solvent, or hot melt adhesives. Today, dispersion adhesives in Europe have 60%–70% share of the market for the production for self adhesive labels followed by hot melt and solvent adhesives that have approximately equal market shares. Due to a greater environmental awareness, expensive solvent recovery, and increased solvent prices, solvent adhesives of all types are increasingly undergoing replacement by other, solvent-free adhesives⁷.

The most important polymers used for PSA materials of this type are styrene butadiene rubber (SBR), natural rubber, butyl rubber, polyisobutene, polyvinyl ether, and polyacrylate. Because most polymers are not tacky, they require mixing with natural or modified resins of which an almost limitless number exists to achieve the permanently adhesive state.

While solvent pressure sensitive adhesives primarily use SBR, dispersion PSA materials usually use a polyacrylate base. Typical recipes for PSA materials use the following¹⁴:

- Polymers:	30%–50%
- Resins:	20%–40%
- Softeners:	0%–40%
- Fillers:	0%–10%
- Stabilizers:	1%–2%

The following categories relate to specific features of processing and use:

- Type A: Adhesives with a natural rubber base
Nonadhesive elastomer, "natural rubber", is made permanently adhesive with resins. Stabilizers are necessary, and plasticizer and fillers are optional. Processing uses organic solvents.
- Type B: Adhesives with a synthetic rubber base
Nonadhesive elastomer, "block copolymer", is made permanently adhesive with resins. Stabilizers are necessary, and plasticizer and fillers optional. Processing uses organic solvents or melting.

- Type C: Adhesives with an acrylate solution base

Elastomer, "polyacrylate", is resin-modified according to adhesion properties already present. Processing uses organic solvents.

- Type D: Adhesives with an acrylate dispersion base

Elastomer, "polyacrylate", is resin-modified according to adhesion properties already present. Viscosity regulator and wetting agent are necessary. Processing uses water¹⁵.

PSA materials attach under low pressure and room temperature. For certain applications, adhesion is also necessary under extreme conditions such as temperatures below 0°C for labeling of frozen food packaging or at high humidity in a subtropical climate. The density of pressure sensitive adhesives is between 0.9 and 1.1 g/cm³. Conventional pressure sensitive adhesives are insoluble in water under neutral or mildly alkaline or acidic conditions but can dissolve quickly in several organic solvents.

The parameter that has a major influence on the adhesive strength of a PSA is one that simultaneously affects its recycling behavior. This is the thickness of the applied adhesive film. Typical layer thickness values are as follows¹⁶:

- Repositionable label:	5 µm
- Paper label:	25 µm
- Paper transfer tape:	25 µm
- Plastic label and decal:	25–40 µm
- Polyester packaging tape:	50–90 µm
- Polypropylene strapping base:	60–100 µm.

High adhesive layer thickness is primarily with tapes, and the lowest layer thickness is for repositionable labels.

2.2 Printing inks

Printing inks are presumably a source of stickies although to date no detailed studies have proven this. Remembering drying methods of the different printing processes, one can distinguish three major categories. Most printing inks belong to the classical printing processes that dry by absorption, evaporation, or oxidation. Figure 4 shows the most important binder components for these inks. For inks dried by infrared (IR) and ultraviolet (UV) radiation, various acrylates and hydroxyl polyester have frequent use¹⁷. For possible tacky impurities from printing inks, one must especially consider toner for copiers and laser printers since they "melt" onto the substrate paper during the printing process by heat and pressure and become fixed to it. Toners using styrene butadiene rubber and polyvinyl acrylate contain the same chemical components as adhesives. Chapter 8 provides more details.

2.3 Coating binders

Polymer dispersions and starch derivatives have use as coating binders. The synthetic latexes and especially those in the form of styrene butadiene rubber, polyvinyl acetate (PVAc), and polyvinyl acrylate are possible causes of stickies as Fig. 4 shows. Paper mills that process coated broke refer to the possible problem of tacky deposits as white pitch. By their selection of coating binders, paper mills that must process their own broke can influence the development of white pitch that leads to deposits primarily on places with considerable shearing force such as foil bodies and in the drying section. The binder particles released at the time of recycling are similar to resin. Both substances can also be easily recognized as colloidal particles under a microscope.

2.4 Wood derivatives

The problems experienced with tacky substances in the processing of virgin fibers especially in the use of mechanical pulps are considered under the term pitch. The tacky components originating from the resins and extractives of wood consist of a mixture of different components having similar physical characteristics. As low molecular weight substances, they are practically insoluble in water under alkaline or acidic conditions. Large proportions are saponifiable. Resin particles can result in deposits on the paper machine or its clothing with resultant impairment of paper quality. The quantity and chemical composition of resins and extractives in virgin pulps depend on the type and age of wood used and the pulping method applied.

2.5 Papermaking additives

Many chemical additives find use in the papermaking process to improve the paper production process or obtain certain paper characteristics. Because of the possibility that these chemicals may react with each other or with other substances of the pulp slurry, they require consideration as potential causes for the formation of secondary stickies. This is especially true because an accumulation of a wide range of different substances cannot be excluded as a result of increasingly closed process water loops. In the processing of wood-free recovered paper for hygienic papers for example, the use of a cationic wet strength agent with an anionic dye resulted in problems with stickies¹⁸.

The collectors used in the flotation deinking process (soaps or saponified fatty acids) are largely removed with the flotation foam. In addition, the water loop of the pulp processing plant and the paper machine are usually separated by dewatering to high pulp consistencies followed by bleaching, pulp storage, or both to minimize carryover into downstream loops. A residual transfer of calcium soaps into the paper machine loop still occurs. Many paper machine deposits contain chemical components of the flotation agents used although they may not be the cause of the corresponding deposit. A deposit may also occur on top of an already existing deposit. According to Mattingley, this carryover of flotation chemicals can consist of particles that are solid but deformable. The application of calcium stearates as flotation chemicals is one reason why these particles do not develop a tacky behavior under pressure¹⁹.

2.6 Chemical substances in potential stickies

The different categories of chemical substances listed for adhesives, printing inks, and coating binders demonstrate that common denominators for their properties exist especially for pressure sensitive adhesives, hot melts, xerographic printing inks, and synthetic coating binders. Figure 7 shows that some chemical compounds have use not only for the production of one type of adhesive, toner, or coating binder but also in two or several different product areas.

As an example, consider the two monomers of styrene and butadiene processed in an emulsion polymerization to a milky-white product with the aid of other chemicals as Fig. 8 shows. This styrene butadiene latex has use in papermaking in coating binders, in various laminates, or for increasing strength in the production of paper-based imitation leather. Its effect relies on the cross-linking of the polymers during water removal above the glass transition temperature.

The latex can also be processed into a polymer group by destabilization and water removal. This is dried styrene butadiene "rubber crumb" (SBR). This SBR can be mixed with silica or carbon black, cross-linked with sulfur

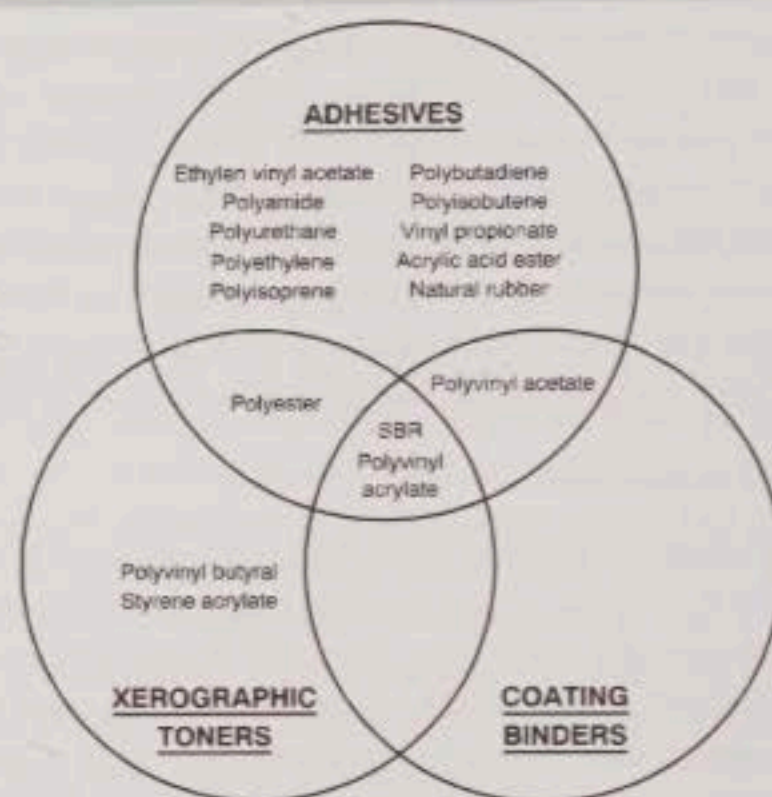


Figure 7. Major chemical components for paper coating and paper and board converting suspected to create problems with stickies in subsequent recovery processes.

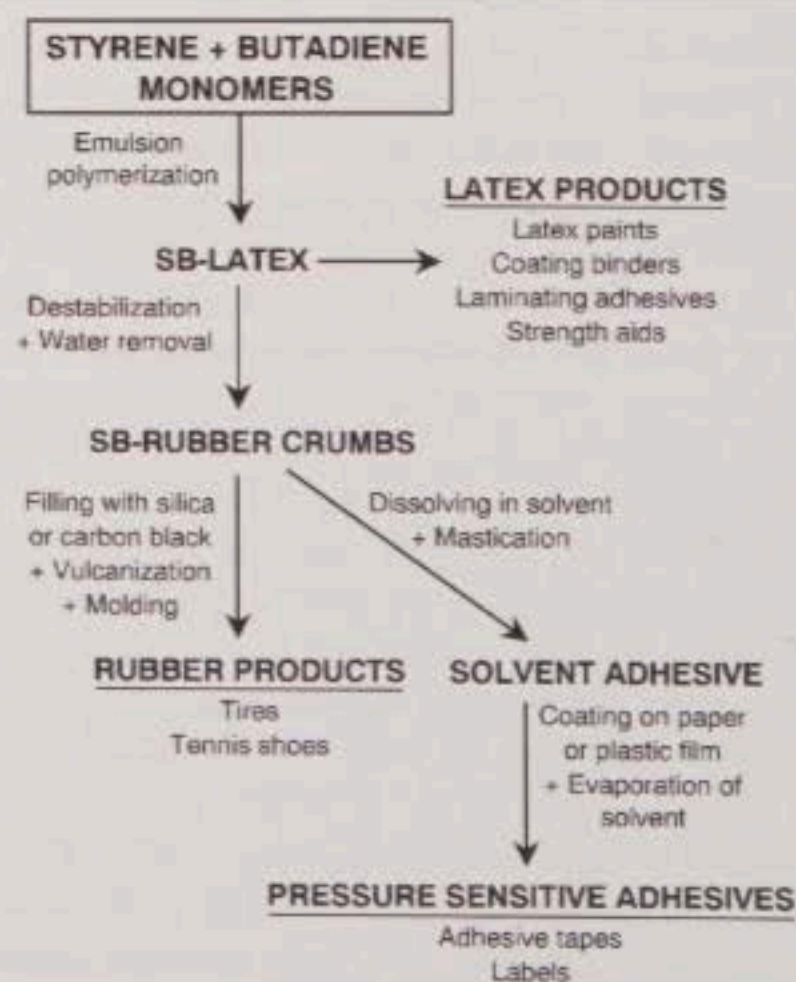


Figure 8. Styrene butadiene emulsion polymerization process¹⁰.

(vulcanized), and molded into different rubber products such as automobile tires or athletic shoes. Alternatively, the dried rubber lumps can be treated with a solvent and homogenized for subsequent application to a specific substrate. After evaporation of the solvent, a pressure sensitive adhesive product is ready for use as address labels or for packaging purposes representing future sources of stickies in recovered paper processing¹⁰.

The possibility to use the same chemical substances in completely different products makes interpretation of chemical analyses very difficult. Additives present in the recovered paper can also react with each other or with the chemicals used in the paper production process. These include wet strength agents, rosin size, aluminum sulfate, or retention agents. They cause secondary agglomerations of stickies²⁰.

3 Adsorption of stickies

The formation of deposits in a recovered paper processing system or on a paper machine is due to adsorption processes that occur exclusively on the surface of a solid phase. The term adsorbent describes the surface of the solid phase. The material to be adsorbed in its free form is the adsorptive as Fig. 9 shows. The term adsorbate covers the combined solid and deposited phase.

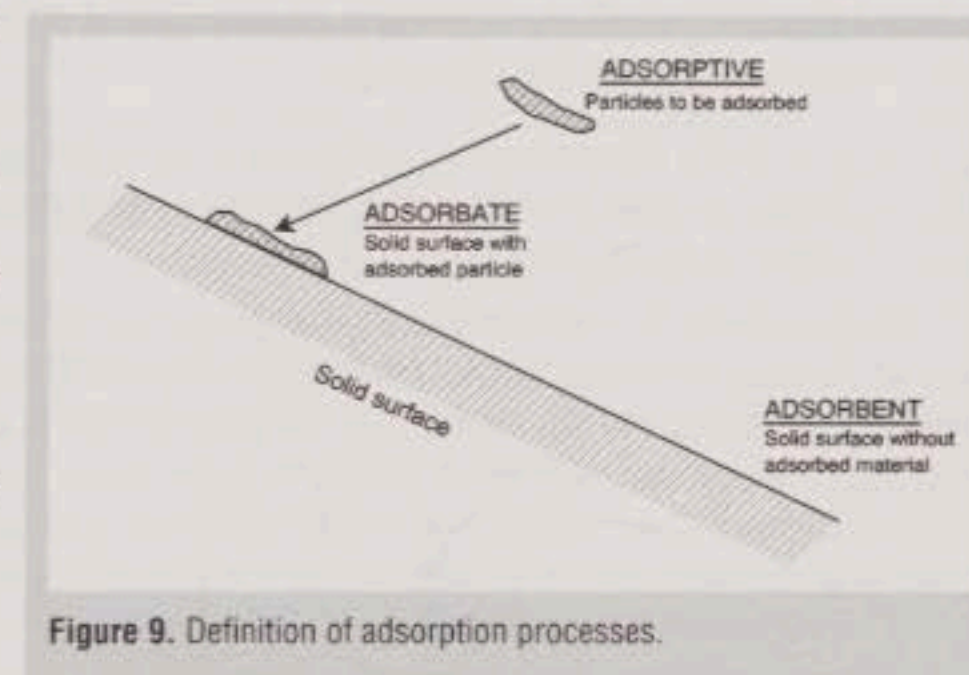


Figure 9. Definition of adsorption processes.

The bonding of the adsorptive to the adsorbent occurs by various types of bonding between atoms and molecules that can be physical or chemical bonding. The chemical bonds represent primary bonds that include the atomic bond (homopolar, nonpolar, and covalent bond), ionic bond (heteropolar, polar, and electrovalent bond), and the metallic bond. The physical bonds are secondary bonds whose bonding energies are considerably lower. These include van der Waals and hydrogen bonds. The forces responsible for the van der Waals bond are dipole forces (Keesom forces) with a range up to 5 Å (1 Å = 10⁻¹⁰ m), induction forces (Debye forces), and dispersion forces (London forces). The final two types have lower bonding energies than the dipole forces²¹.

A basic distinction exists between physical adsorption (physisorption) and chemical adsorption (chemisorption). In addition, adsorption can occur due to electrostatic forces based on chemical and physical forces. This is often called chemisorption. The differences between physical and chemical adsorption are explained below.

Physisorption is characterized by physical bonding forces and especially van der Waals bonding forces. It is reversible, and the bonding energy is less than 60 kJ/mol. Under constant conditions, an adsorption balance develops between adsorption and desorption. With increasing temperature, the probability of desorption due to increasing molecular movements also increases.

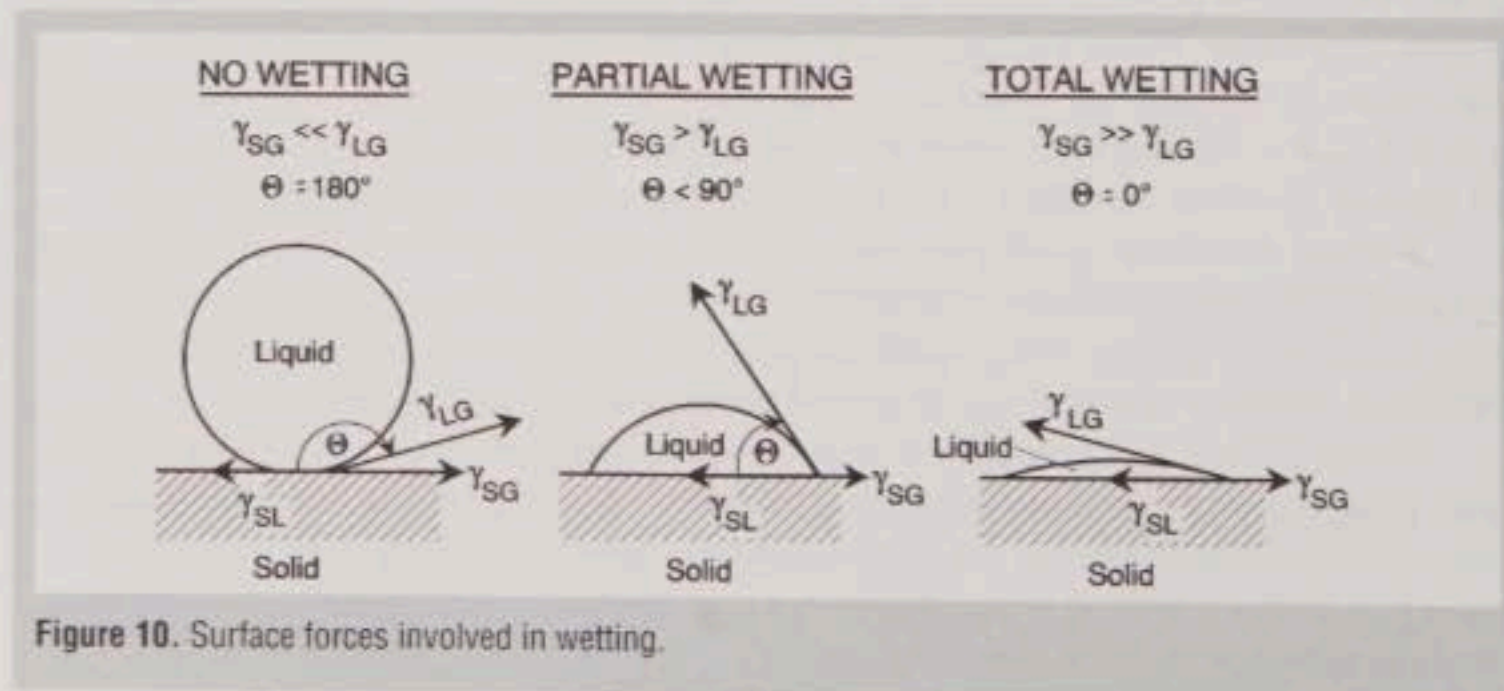
In contrast, chemisorption represents a type of chemical bond. Due to the high bonding energy of 100–800 kJ/mol, the bonds developed by chemisorption are irreversible. The monomolecular layer of the adsorbate represents the maximum possible adsorbable quantity of the adsorptive. As the temperature increases, the adsorption speed increases due to thermal activation.

To permit deposition of finely dispersed tacky particles on solid surfaces, several conditions must be satisfied according to Kamutski²².

- The particles must be sufficiently close to the adsorbent to permit interaction between them.
- To enable particles to deposit, they must wet the adsorbent surface. Insufficient wetting can lead to release of the particles from the adsorbent.
- The tacky particles must be present in a viscous or plastic state to permit them to deposit via deformation.
- The finely dispersed or colloidal particles of the adsorptive must be destabilized, i.e., they may no longer have any active protective colloid, emulsifier cover layer, or both.

To satisfy the first demand, the adsorptive must approach nearer than the distance of the van der Waals interactive forces that are 2.6–5.0 Å when the adsorptive is being transported to the adsorbent. For the laminar flow of suspensions in pipe systems, this distance does not occur due to multiple layers of adsorbed water molecules. For direct contact of the adsorptive to the adsorbent, a turbulent flow is necessary whose kinetic energy allows penetration of the adsorbed water layer.

The surface energy of the fluid (γ_{LG}), the surface tension of the solid surface (γ_{SG}), and the boundary energy between the liquid and solid phase (γ_{SL}) determine the wetting of a solid surface by a fluid. The contact angle is an important thermodynamic parameter and an indicator of the spreading of a fluid on a solid surface. Figure 10 illustrates the two limiting cases: no wetting and total wetting. No wetting occurs when the surface tension of the solid surface (γ_{SG}) is much smaller than that of the fluid phase



(γ_{LG}). The contact angle θ then moves toward 180° . An example of such behavior is mercury on nearly all surfaces where liquid mercury drops freely roll around on the surface. At the other extreme, a spontaneous total wetting occurs if the contact angle θ moves toward zero when the surface tension of the solid surface (γ_{SG}) is much greater than that of the liquid phase (γ_{LG})²³.

Most fluid to solid surface systems reveal a wetting behavior that lies between both extremes (See middle representation in Fig. 10). For adhesives, the term critical surface tension describes this situation. Wetting occurs if the surface tension of the fluid is less than that of the solid surface²².

Figure 11 shows that resin, pitch, and thermoplastic adhesives manufactured from petrochemical materials are nonpolar and have a low surface tension of 20–40 mJ/m². Because of these characteristics, the previously mentioned substances can wet nearly all hydrophobic solid surfaces whose surface tension is greater. An affinity with such surfaces therefore exists. An exception to this is polytetrafluoroethylene (Teflon) with a surface tension of only 18 mJ/m². Due to these reasons, deposits of stickies on polyester and polyamide surfaces such as usually used for paper machine clothing (wire and felt) can occur. In contrast, deposits on metallic surfaces such as copper or nickel despite their high surface tension cannot occur to the same degree because of their hydrophilic character. This is especially true because water has better qualifications for adhesion. It is present in much greater volumes, and its adhesion is strong due to polarity forces²².

Practice shows that deposits can occur even on these hydrophilic surfaces. Weigl *et al.* explain this by the deposition of fatty acids or their esters on copper surfaces that then present hydrophobic parts of their molecules to the surrounding medium. Some work has also shown that changes in pH cause polarity changes so that copper surfaces in an alkaline medium have lower surface tension and polarity. This favors adhesion of tacky contaminants²⁴.

These thermodynamic models for deposit-related problems are valid only for the surface conditions and tensions in each case. Surface active substances can

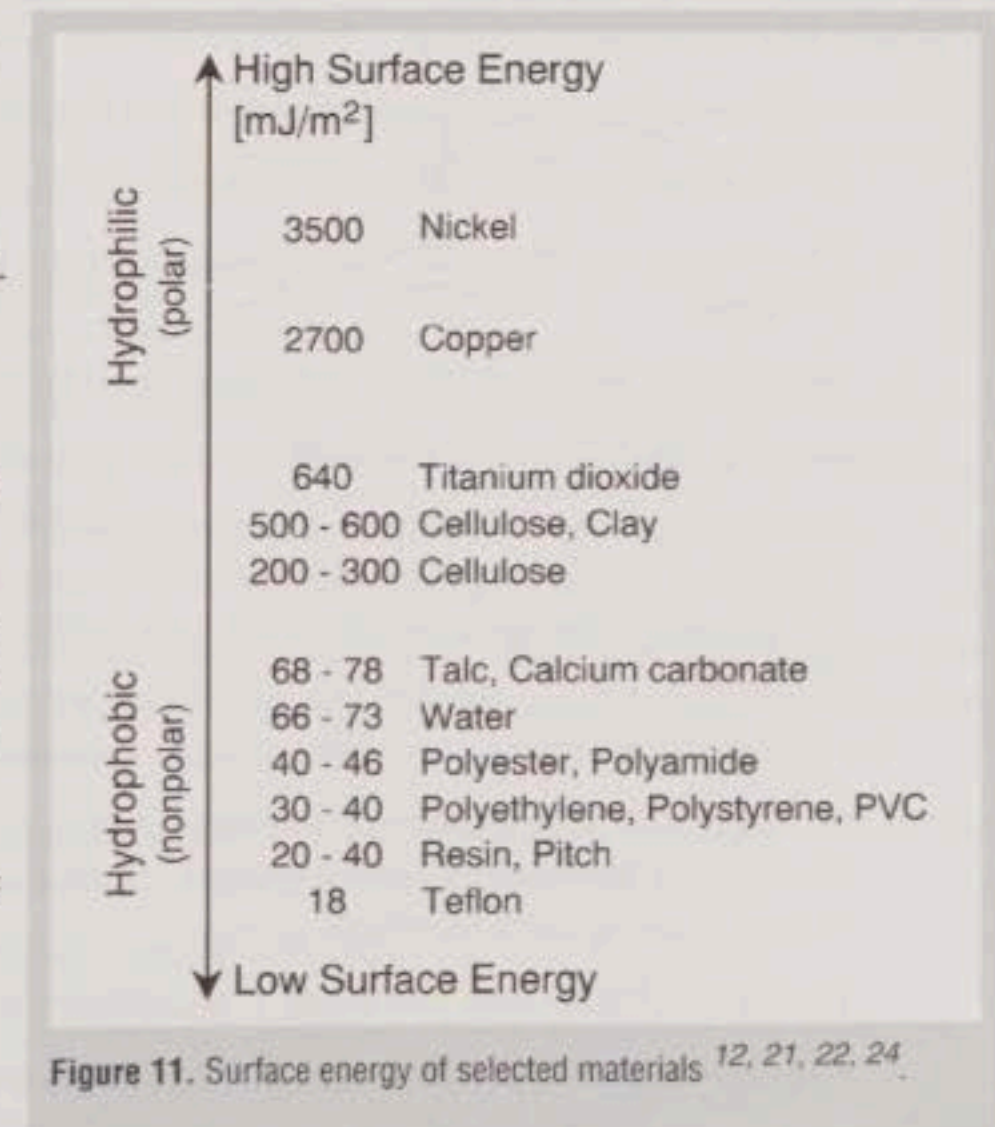


Figure 11. Surface energy of selected materials^{12, 21, 22, 24}

dramatically alter surface characteristics. Remember that after the adsorption of a monomolecular layer of a substance on a solid surface the other surface characteristics are the result of the adsorbed substance. System parameters such as temperature, pH, or salt concentration are also important.

The different electrical charge of materials and therefore their electrostatic attraction may have secondary importance as the cause of adsorption processes on solid polar surfaces in aqueous systems. The explanation of agglomeration processes and the precipitation of negatively charged, potentially tacky contaminants must include the effects of the cationic additives on negatively charged fiber surfaces. In addition, electrostatic charges of wires, felts, or rolls in the paper machine can result in deposits of potentially tacky impurities that are not sufficiently fixed to the paper structure.

4 Characterization of stickies

To date, no standard test methods or standards exist at a national or international level for the characterization of stickies and their content in pulp slurries. This is undoubtedly a reason why individual companies in the paper and supply industries have developed very different test methods for stickies and might continue to do so in the future. Reasons for the absence of test methods are the varying requirements of the test methods including the different types of stickies for testing, the amount of time accepted for the analyses, and the type of conclusions desired. Test methods for stickies are urgently necessary for the following reasons:

- Judging the quality of recovered paper and recycled fiber pulp
- Checking the removal efficiency of stickies for pulp processing equipment
- Determining the effects of process parameters on the effectiveness of removal of stickies
- Verifying the effectiveness of chemicals used for control of stickies
- Judging the recyclability of paper and board products such as adhesive labels
- Establishing a quality control system that prevents the processing of recovered paper highly contaminated with stickies or permits the application of special countermeasures at the time of recycled fiber pulp processing and paper production.

The existing methods for quantifying stickies consider:

- The degree of contamination by stickies of recycled fiber pulp expressed as the count of stickies, the area of stickies, or the mass of stickies per mass unit of pulp or paper area observed
- The tack of the stickies that leads to attachment to different substrates
- The adhesive strength of stickies that has developed on different substrates²⁵.

Stickies that have formed deposits can be submitted for chemical analysis to determine their components. This analysis does not constitute a direct detection method for stickies nor does it supply any information concerning the content of stickies in recycled fiber pulp. Under certain conditions, it provides identification of specific related problems for stickies. The chemical analysis of deposits on paper machine components and paper machine clothing gives an insight into the wide range of chemical compounds that can be contained in the chemical "cocktail" of stickies.

4.1 Deposit analyses

Representative sampling is an important requirement of any analysis. The deposits to be examined consist of a large number of organic and inorganic components. To ensure that one is not merely determining the composition of a sample, the sample size must contain individual components of tacky impurities. This can provide insight into the causes of the deposits. For the chemical analyses, the following instrumental techniques are available:

- Energy dispersive spectroscopy (EDS) is a technique for analysis of inorganic components in deposits.
- Fourier transform infrared spectroscopy (FTIR) is the most common technique for analysis of stickies. It can analyze unknown substances even when only small amounts of deposits are available.
- Gas chromatography (GC) combined with mass spectrometry (MS) can identify unknown substances in raw materials or additives that may result in tacky deposits or both.
- Gel permeation chromatography (GPC) determines molecular weights of organic substances and their distribution.
- High performance liquid chromatography (HPLC) is used for the analysis of high molecular organic substances with boiling points above the optimum range for GC analyses.
- Thin layer chromatography (TLC) identifies oligomers and monomers.
- Inductively coupled plasma spectrometry (ICP) measures the amount of elements in inorganic and organic compounds and is used mainly for the analysis of heavy metals.
- Infrared spectroscopy (IR) is used for identification and quantitative analysis of organic compounds and functional groups of organic substances.
- Mass spectrometry (MS) is used with GC.
- Nuclear magnetic resonance spectroscopy (NMR) is used for the structural analysis of organic substances.
- Pyrolysis-gas chromatography (Py-GC) is gas chromatography with a preceding pyrolysis that results in a characteristic fingerprint for polymers.

- Scanning electron microscope with X-ray analysis (SEM-EDXA) detects inorganic elements with mass number greater than 23.
- Size exclusion chromatography (SEC) separates compounds into fractions having different mol masses.
- Thermogravimetric analysis (TGA) measures the behavior of inorganic and organic substances as a function of temperature and time. TGA is most suitable for the analysis of volatile inorganic and organic compounds.

Performing a chemical analysis must therefore consider the measuring possibilities, i.e. the available instruments and devices. Preparation of the sample and its separation into individual fractions for the selective determination of the chemical components presents major challenges. For certain deposits, the combinations of different analytical procedures described in the following have been successful²⁶⁻²⁸.

In 1984, the Papiertechnische Stiftung (PTS) in Munich, Germany, established an analysis specification using IR, REM, and GC²⁶. The scheme in Fig. 12 has had successful use for the chemical analysis of recovered paper suspected of causing deposits in paper machines and giving impurities in paper and board. The necessary extractions were carried out quantitatively with water and organic solvents including ethanol, acetic acid ethyl ester, and trichloroethylene in a given sequence in Soxhlet devices.

The advantages of a sequential extraction with organic solvents are that all components can be sufficiently dissolved, a preliminary separation is realized in accordance with the solubility and concentration, a small sample quantity is necessary, and the sample preparation is simple. The use of these three extraction agents represents a compromise between a high detection sensitivity and the amount of work necessary. Using a single extraction agent has the inherent risk that any statements concerning the organic components remain incomplete. Due to the potential health hazard of trichloroethylene, this solvent has no use today.

PAPRICAN introduced another analysis scheme for deposits from paper machines used to process recycled fiber pulp in 1995²⁷. This uses FTIR analysis with GC, NMR, TGA, EDS, Py-GC, and ICP. Figure 13 shows this analysis using a sequential solvent extraction followed by analyses of the individual fractions by different techniques. Ethanol is the first solvent since most resin compounds of wood, hydrocarbon oils, and plasticizers have good solubility in hot ethanol. The ethanol extract is dissolved in hexane to separate resin compounds of the wood from other hydrocarbon compounds. The components that are insoluble in ethanol undergo an additional extraction with chloroform since a wide range of the synthetic polymers possibly present in deposits can dissolve in this solvent.

Detailed tests showed that the two-stage extraction with acetone and chloroform did not offer any advantage compared to direct chloroform extraction that is preferred. Using the analyses of deposits in press sections of different newsprint paper machines led to the conclusion that polymers with a wide molecular weight distribution are present in more than one fraction. The deposits also contain large proportions of the carryover of deinking chemicals and ink components that could also play an active part in the formation of deposits.

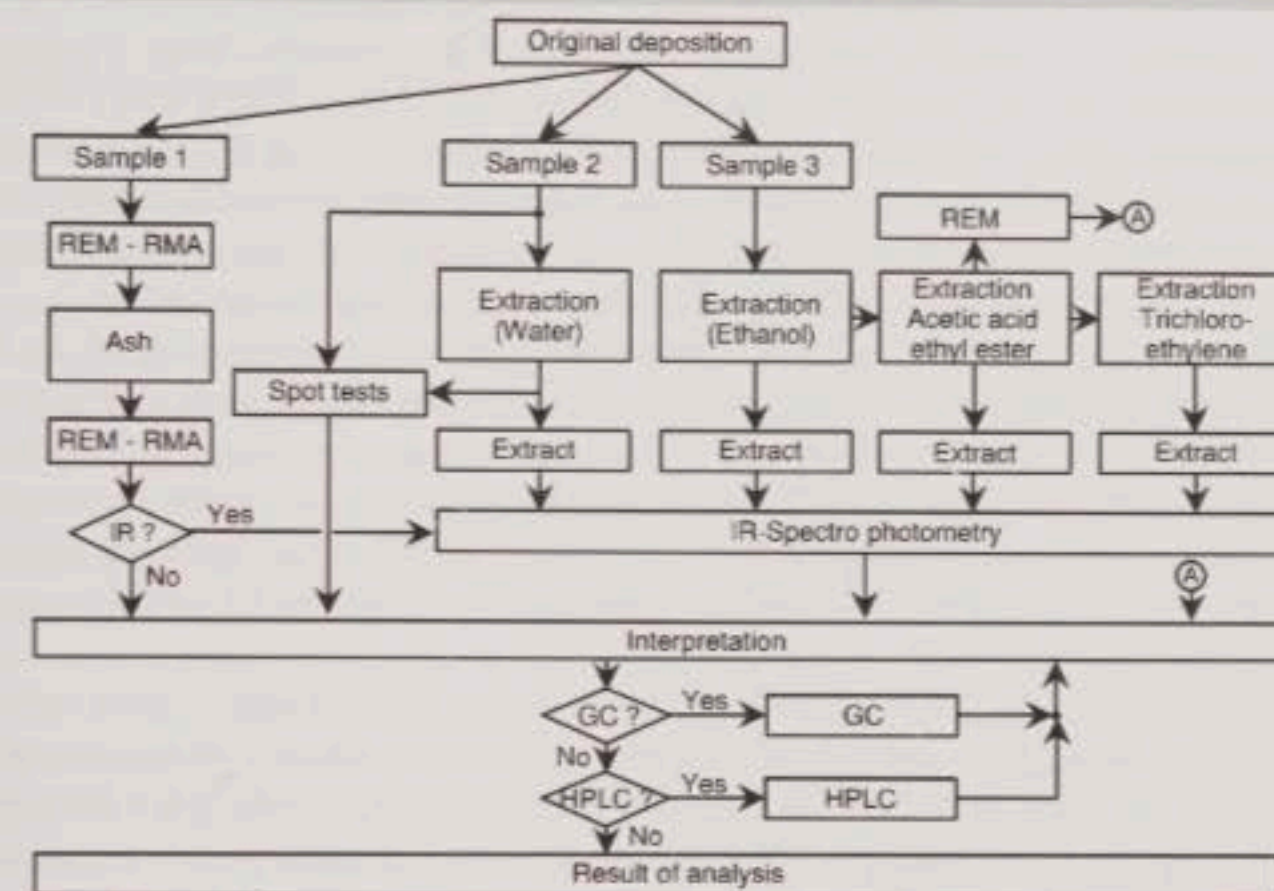


Figure 12. General scheme for deposit analyses according to PTS²⁶.

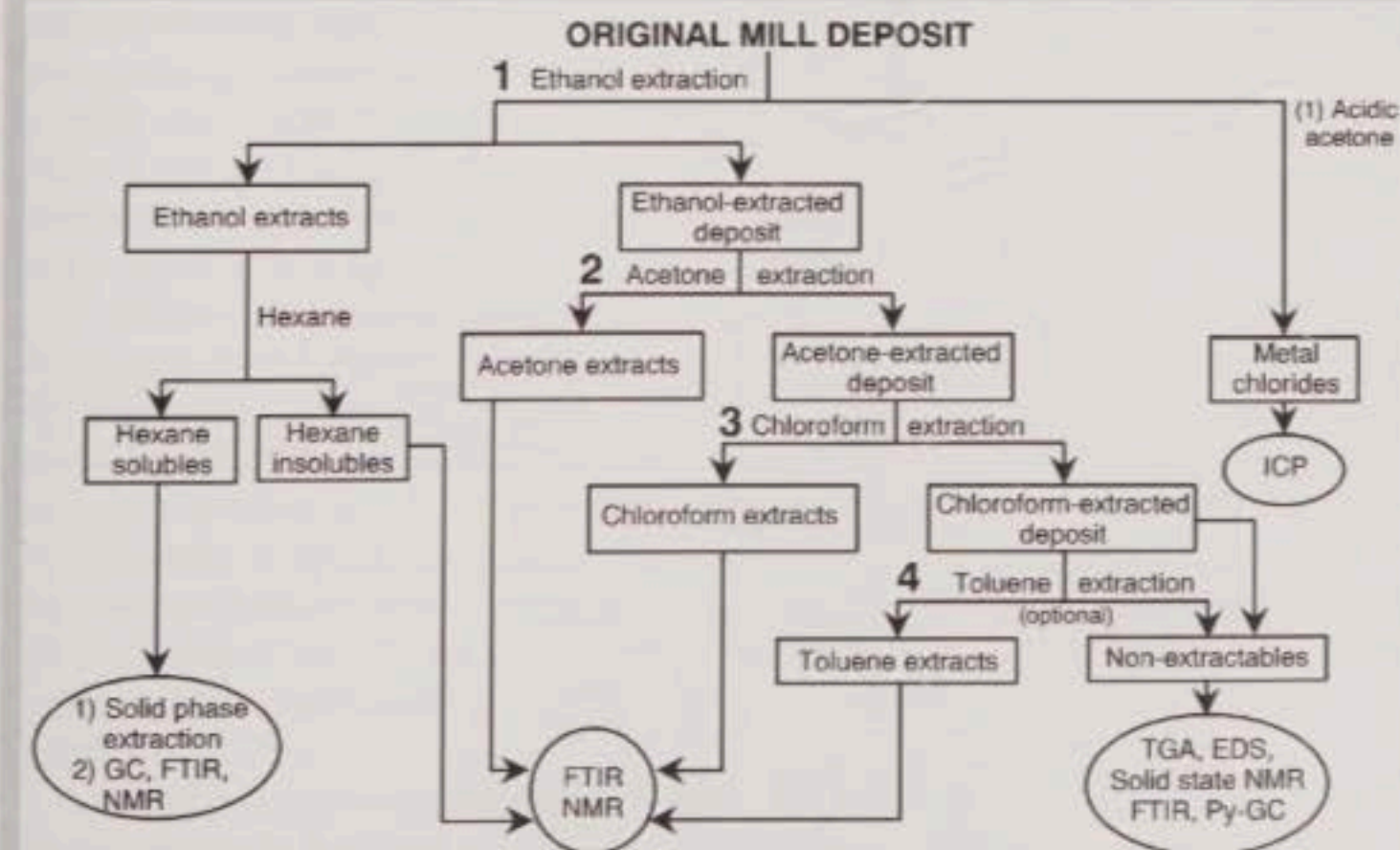


Figure 13. General scheme for deposit analyses according to PAPRICAN²⁷.

The Holmborn technique first uses microscopic examination²⁸. Then the samples are soaked for 16 h in nonstabilized tetrahydrofuran (THF). To support the dissolution, an additional treatment in an ultrasonic bath occurs. The solution is evaporated under nitrogen atmosphere and then methylated with diazomethane in a mixture of diethyl ether and methanol. Finally, the solvent is exchanged for THF as Fig. 14 shows. Using SEC, the solution is separated into different polymers that are free of oligomers and can be analyzed by IR and Py-GC. Methylation is an efficient method for separating oligomer compounds and monomeric acids since methyl esters elute later than the corresponding free acids.

The described techniques allow determination of the mass flow of SBR, EVA, PVAc, and polyacrylates in a recycled fiber pulp processing system with double flotation. A level of 90%–95% of the EVA and PVAc present in recovered paper are removed by the process. Only about 5%–10% approaches the paper machine with the finished pulp. In contrast, the removal of SBR and polyacrylate at 60%–70% is clearly less efficient. Considerable quantities of these two components transfer to the paper machine with the processed pulp^{28,29}.

The disadvantage of chemical deposit analyses is that the detection of individual chemical compounds does not provide any information on the tack of the analyzed substances especially since deposits usually form over a certain period. This is because individual small particles agglomerate to larger particles. Deposits therefore consist primarily of inorganic fillers and pigments that are not naturally tacky and do not deposit. They only become tacky deposits by contact with other tacky substances. In addition, the time required for the described chemical analyses should not be underestimated.

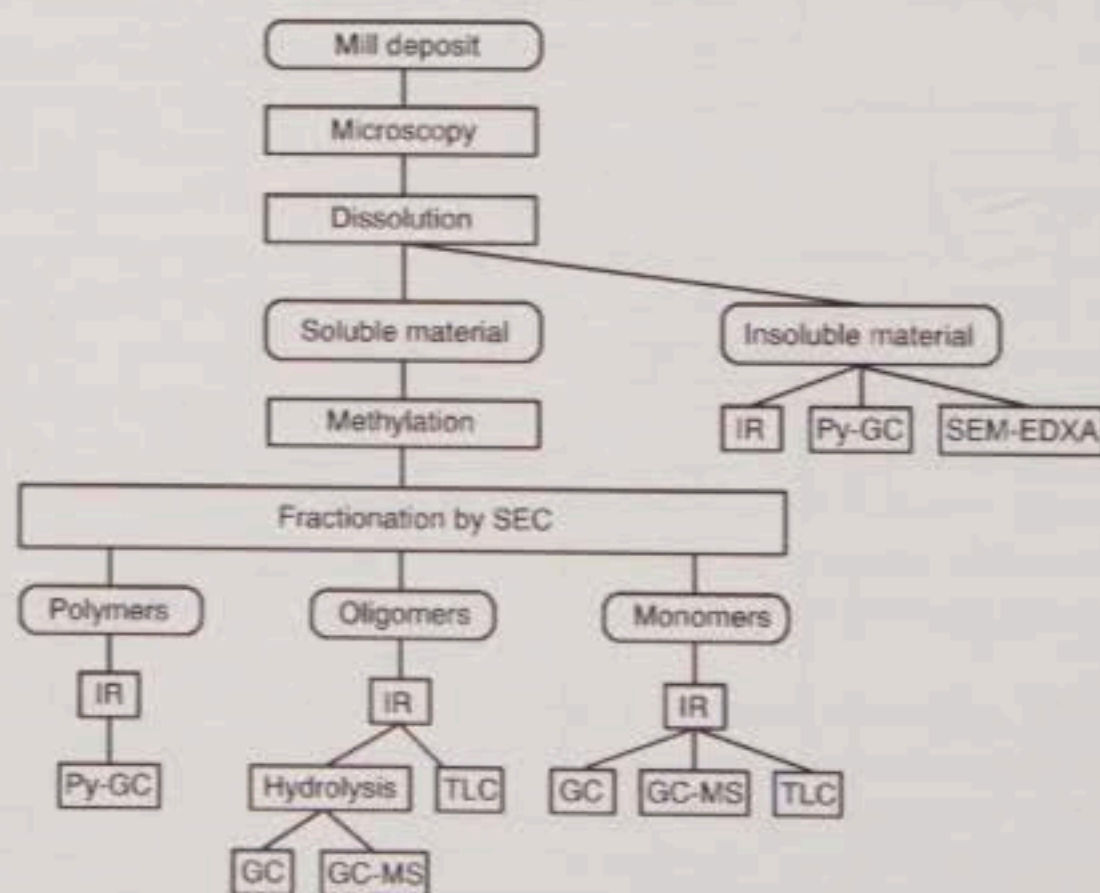


Figure 14. General scheme for deposit analyses according to Åbo Akademi²⁸.

The costs for the individual analysis, the capital costs of the various devices, and the costs of the highly qualified operators are also important factors.

4.2 Handsheet inspection methods

In contrast to chemical analyses, handsheet inspection methods for determining stickies in recycled fiber pulp can use much simpler techniques. The most important items of equipment necessary are a handsheet mold, a dryer, and possibly an image analysis system for evaluation of particles of stickies after their visualization.

In all cases, a handsheet is produced from a pulp sample. The number, area of detectable tacky impurities, or both are determined. Previously, contaminants were almost always visually counted by their number. A dirt estimation chart such as TAPPI T213 or T437 also had use to determine the size or area, respectively. This means the evaluation depends on subjective influences by the technician. In addition, this evaluation step is time consuming. This is especially true where numerous sheets of a pulp sample require analysis such as is necessary to obtain a representative result.

Recently, image analysis systems have found use to determine the number or the area of stickies. By using personal computer-supported image analysis systems, one can perform the determination of stickies very quickly. With sufficient mill experience on pulp samples, changes in the furnish from which a higher load of stickies results can be recognized quickly. The use of image analysis systems involves the risk that other, non-tacky particles such as shives or ink particles are detected with the stickies. This is because they have sufficient contrast to the background.

Most proposed test methods start with handsheet formation with 1.0–1.3 g o.d. recycled fiber pulp for basis weight 35–45 g/m². When using image analysis processes, dyeing the handsheets containing the impurities with black ink after drying is recommended. This results in the dyeing of the hydrophilic components of the handsheets that are primarily the fibers. The hydrophobic particles such as stickies retain their original color. White stickies offer a good contrast to the blackened background. With dark stickies the contrast is not sufficient for detection by image analysis.

Differences between the various methods exist especially in relation to the recommended drying processes using temperatures of up to 130°C for 20 min before dyeing. After dyeing, air-drying in drying rings or drying at 130°C are recommended. Specific drying conditions have enormous effects on the thermoplastic behavior and therefore on the deformation of the stickies. This influences the area of the stickies identified.

Camera systems and scanner systems have use for image analysis evaluation. The measured area of each handsheet should be as large as possible such as 314 cm² with the German method based on the Rapid-Köthen sheet mold. For different methods, 6–10 handsheets should be produced per pulp sample with evaluation of the top and bottom sides^{30–32}.

Modified processes measure the frequently present fluorescence of adhesives to determine visually the number of stickies. The use of such simplified methods that can facilitate the visual detection of stickies also means accepting the disadvantages that not all stickies fluoresce and not all fluorescing areas are necessarily stickies. This is because the pulp may contain optical brighteners from the preceding paper manufacture^{25,33}.

Compared with a previous screening procedure in the laboratory to concentrate stickies, handsheet forming has the advantage that only very small particles of stickies are removed during dewatering. This means a wide range of particle sizes of stickies and not merely macro stickies remain in the test sheet. Obtaining a statistically reliable number of detected stickies in recycled fiber pulp may be difficult especially where the stock concerned is efficiently processed such as deinked pulp for printing paper or market DIP. In these cases, previous screening as described in the following is necessary to concentrate the stickies to be analyzed. Otherwise, the number of handsheets to be produced for a representative result would be very large.

4.3 Screening methods

One reason why screening methods are the most common approach for determining the content of stickies of a pulp sample is that they simulate the removal possibilities of a recovered paper processing system. They therefore reveal whether the industrial process succeeded in removing at least the tacky contaminants from the pulp slurry that laboratory screening conditions can remove. Laboratory screening of recycled fiber pulp samples permits concentration of very small quantities of the stickies in an efficiently processed pulp. Simultaneously, the screening purifies the samples from fibers that could disturb the subsequent analysis or mask tacky particles. Note that when using a laboratory screening process the particles of stickies that are smaller than the perforation of the screening element can be removed as micro stickies with the fiber material as accept and cannot be detected in the reject material.

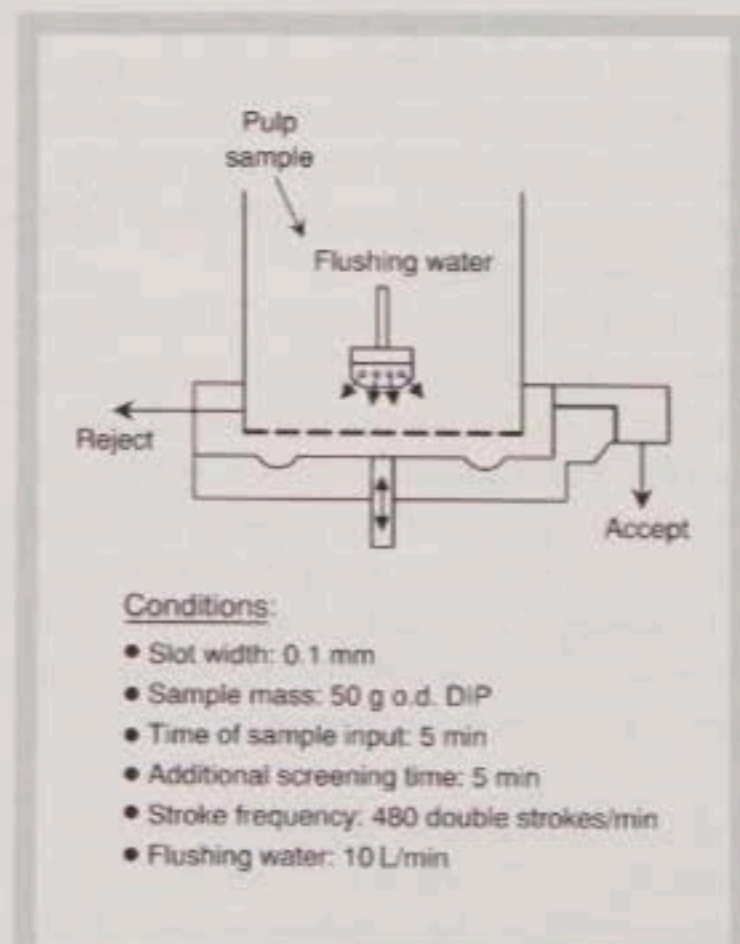


Figure 15. Screening with Haindl classifier.

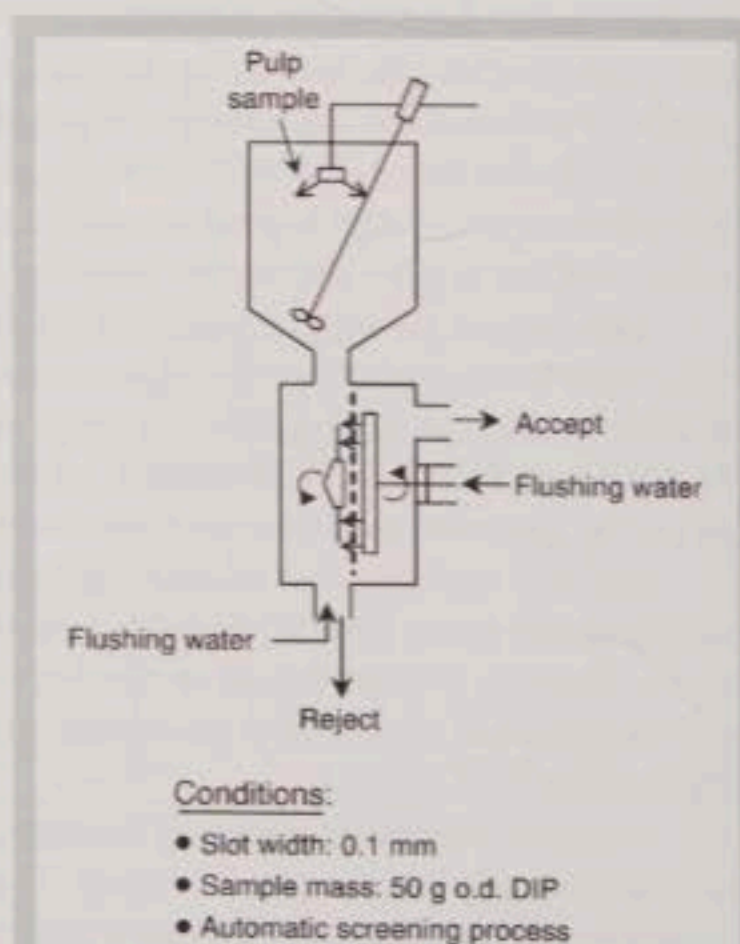


Figure 16. Screening with Pulmac MasterScreen.

Different screening devices have use for laboratory screening. The most common are the Haindl classifier of Fig. 15, the Pulmac MasterScreen of Fig. 16, the Somerville screen, and the Valley screen. All devices work with a flat slotted plate. Except the Pulmac MasterScreen in which a rotor produces the turbulence for the through-flow of the vertically arranged slotted plate, the other devices work with a horizontal slotted plate through which the pulp slurry is washed by flushing water. Although the Pulmac MasterScreen was designed especially for screening stickies, the other devices are more common because of their use in determining the shives content of mechanical pulp.

For all four devices, screening is performed with slotted plates that differ in their external dimensions and the open area of the plate. Slotted plates of 100 μm and 75 μm slot width are presently available as a standard feature only for the Pulmac MasterScreen. For the other devices, the minimum slot widths are currently limited to 150 μm or 200 μm for the Valley screen. Test slotted plates that may differ from the original arrangement of the slots and the open area are now offered by other suppliers at least for the Haindl classifier and the Somerville screen.

Although the use of 150 μm slotted plates may be sufficient for evaluation of the content of stickies in brown recovered paper grades and old corrugated containers (OCC), the use of 100 μm slotted plates for laboratory screening is becoming increasingly necessary for characterizing deinked pulp including market DIP³⁴. This is due to the greater cleanliness of the pulps that result from a more efficient industrial treatment, e.g., using centrifugal cleaners and pressure screens with 150 μm or even 100 μm slot width. In addition, the recovered paper grades used for these deinked pulps are contaminated by smaller quantities of stickies than brown recovered paper grades, e.g., super-market waste or OCC.

When screening recycled fiber pulp for determination of stickies, always remember that the screening of larger quantities of pulp enhances the representative character of the sample analyzed. This is especially true for pulp samples with a low content of stickies. Devices having low mass throughputs require screening of several batches with increased testing time. In the Haindl classifier in a standard operation for example, 10 g o.d. virgin pulp screening takes 20 min. By modifying the device such as increasing the double stroke frequency of the membrane and enlarging the screening chamber, screening 50 g o.d. wood-containing or wood-free deinked pulp is possible in 10 min without any problem. The Pulmac MasterScreen or the Somerville screen permit screening of at least 50 g o.d. pulp in one run without modifying the regular operating conditions^{5,34}.

After feeding with the pulp sample, the Pulmac MasterScreen is the only device that can perform the entire screening process automatically. Filling the supply container with water, screening with flushing and washing cycles, and dewatering of the screening rejects can all be automatic. At the end of the screening process, the dewatered reject can therefore be removed from the device on a filter paper. The other screening devices require manual removal of the slotted plate after screening, rinsing of the reject, and dewatering onto a paper filter.

The different screening devices, quantities of pulp, openings of slotted plates, and applied operating conditions that various individual methods use produce significant differences in measured contents of stickies. Even greater differences result from the evaluation of the produced screening rejects that are usually first transferred from the slotted plate onto a filter paper. The processes used here are as follows:

- The quantitative determination of the screening reject using simple weighing: This process is unsuitable for an evaluation of the content of stickies of a pulp sample since residual fibers and other rejected, nontacky contaminants such as plastic film particles, ink particles, and shives can considerably influence the measured result³⁵.
- The visual control of the screening reject using a pair of tweezers, dissecting needle, and magnifying glass or microscope: In this case, the deformation potential and tack of each particle are examined in a highly time-consuming operation^{36,37}. Due to the subjective estimation of stickies or particles that are not stickies, these methods offer poor reproducibility. The use of image analysis systems can improve the reproducibility although then one cannot directly distinguish between stickies and particles that are not stickies on the basis of tack or deformation potential.
- Image analysis systems using a sufficient contrast between the stickies to be detected and the image background (filter paper): The challenge here is to produce a sufficient contrast between stickies and image background for image analysis measurements. Care is necessary to ensure that it is only the stickies that provide the contrast to the background and not other, nontacky contaminants too.

One method uses white membrane filters of cellulose nitrate onto which the stickies are filtered. After covering with a black photographic board and drying under additional pressure, the stickies cause a tacky bond between the photographic board and the membrane filter. While the membrane filter can be removed at nontacky places, areas contaminated with stickies glue the filter to the photographic board. The stickies covered with the white membrane filter provide sufficient contrast to the black background. The work-intensive aspect of this method is the manual removal of the membrane filter to ensure removal of all nontacky components and retention of all tacky components completely on the black board³⁸.

A different method also uses the tack of the stickies by dusting a black silicon carbide onto the filter paper containing stickies and drying under pressure and heat. If the dimensions of the powder particles are correct, they will attach only to the tacky contaminants and have easy removal from the remainder of the filter paper. The stickies covered by the black powder offer sufficient contrast against the white filter background for measurement by image analysis. A disadvantage of this procedure is that other dark contaminants such as black ink particles and shives are also recorded as stickies when taking measurements³⁹. This is especially disadvantageous when analyzing DIP.

The International Research Association for Deinking Technology (INGEDE) in Munich, commissioned development of an improved method. Dyeing of the filter specimen with a black ink including the filter and shives or fiber components lying on it is the first part of the test. With the method developed, the tack of the stickies gives adhesion of a white powder (special fused alumina). The stickies then appear white against a black background without black ink particles being falsely recorded as stickies^{5,34}. This method is described in more detail in Book 17, "Pulp and Paper Testing," of this series in chapter 4 on "Properties of recycled pulps".

Many other variations of measurements for stickies use the described screening processes. These include the use of chemicals for the agglomeration of stickies before the screening process³⁵ or the activation of the paper filters with "tackifiers"⁴⁰. Publications are available concerning the addition of test screen rejects to virgin pulp from which handsheets are then produced. These are then judged visually by different methods^{2,41}. At individual paper mills, dyed filter papers such as orange or plastic films onto which the stickies are transferred and then measured by image analysis are used for fast visualization in the production control of deinked pulp. This eliminates individual processing steps. The result cannot satisfy the general requirements concerning possible detection of all stickies. On the positive side, such individual "in-house methods" are especially fast and can suffice for certain applications.

Any application of the screening technique for determination of stickies involves tolerating the fact that the test result is influenced by the size and deformability of the stickies and by the physical characteristics during screening in the device used. This includes flow conditions, shearing forces, penetration velocity through the screening opening, slot width, open surface of the slotted plate, pulp consistency, and temperature. Small stickies can pass through the slots without detection, but they may agglomerate later and cause problems on the paper machine as secondary stickies.

The determination of the count of stickies and the measurement of the area of stickies depend on temperature. The applied drying temperatures and pressures vary greatly and influence the deformation behavior of thermoplastic, tacky contaminants. This influences the result of the measured area and the number of stickies since particles of stickies can only be detected above a certain size. For the naked eye, this is about 50 μm . If smaller thermoplastic stickies are not pressed or heated sufficiently, they may not be counted as stickies. To measure the effectiveness of additives used to reduce tack, one must appreciate that screening methods are suitable only if due consideration is given in the test to the actual tack of the screened stickies. For example, this includes adsorption of powder to the surface of the stickies.

Despite the various disadvantages, the screening technique is the most common method to assess the content of stickies for pulp samples. One reason is that many paper mills can adapt the methods easily and can use them for routine inspections. The method also has use to analyze the efficiency of commercial screening equipment regarding the removal of stickies and the effectiveness of chemical and mechanical dispersion on the development of particle size distribution of stickies.

For this reason, the screening technique also forms the basis for the first international draft standard developed by an ISO Task Force Group. In accordance with the draft standard, "Recycled pulps – estimation of stickies and plastics by a visual method" (ISO/DIS15360), an enriched screen reject sample of stickies is produced by laboratory screening and then inspected by magnifying glass or microscope and dissecting needle for the content of stickies. The objects identified as stickies are counted and their area estimated by visual comparison with an "estimation chart of contraries." Because this method is very time-consuming and susceptible to high coefficients of variation and poor reproducibility, it will probably not find routine use in paper mills. Consequently, image analysis techniques such as the INGEDE method described above are more promising.

4.4 Adsorption methods

Adsorption tests in which the stickies can attach to certain reference adsorbents use the tack of stickies in a pulp slurry. These tests cover tacky substances in a pulp slurry with no distinction for size as is the case with the screening methods. Nevertheless, it is frequently observed that especially large stickies do not reliably attach to the adsorbents, or they can be very simply sheared off by turbulence during the test or when cleaning the adsorbents.

With adsorption methods, the pulp suspension to be tested is brought into contact for a specified time and under defined conditions with a substrate on which the tacky contaminants should deposit. The following materials are used as adsorbents:

- Wire samples⁴² or felt materials from paper machines⁴³
- Polyethylene bottles⁴⁴
- Low density polyethylene (LDPE) strips³⁵
- Polypropylene foam⁴⁵
- Microfoam⁴⁶
- Other solid material surfaces made of copper, polyester resin, polyamide, polyethylene, or acrylonitrile butadiene styrene copolymer⁴⁷.

For the different methods, the pulp suspension remains in motion with an agitator, or the substrates are moved in the pulp slurry. After the programmed contact time with the pulp suspension, the adsorbent materials are removed and carefully freed from the attached fibers for a subsequent visual assessment of the deposits. Besides the microscopic and image analysis evaluations of the deposits, the increase in weight of the substrates caused by the stickies retained is usually determined gravimetrically. Because all test configurations work in batch operation with a finite quantity of pulp and the content of stickies of industrial pulp samples is very small (< 1% by weight), the content of stickies by weight is more accurately quantifiable when using lighter substrates⁴⁸.

With application of this method to industrial pulp samples, tacky printing ink binders and other contaminants can lead to additional deposits especially on paper machine wires and felts to influence the result. Counting the stickies visually is frequently necessary since sufficient contrast between the stickies and the adsorbents may not exist. The main advantage of the described procedure is that physico-chemical conditions at the paper machine such as pH, temperature, and water hardness can be simulated in the pulp suspension to be tested. For this reason, investigations of new materials are especially suitable under laboratory conditions. This includes studies of wires or felts that are believed to have a lower tendency to deposit stickies and tests to identify the effectiveness of specific additives intended to reduce the tack of stickies⁴⁹.

Moreland presented an objective test method to assess the effectiveness of chemicals intended to reduce tack¹⁰. In the test, an adhesive coated tape and a polyester strip are treated with a solution that should reduce tack. The two adhesive strips are then pressed together to determine subsequently the separating force between the two plastic strips. This process may well be categorized as objective for the evaluation of different additives with their effects on reducing tack. Where suspended fibers are present, such methods are not suitable for testing the efficiency of pulp processing because determining the separating force of particles of stickies without falsification of the result is not possible.

Despite their weaknesses, adsorption methods are the only test methods for stickies that actually consider the tack of the particles in a suspension. Accordingly, further improved adsorption methods are necessary. At the Department of Paper Science and Technology (IfP) in Darmstadt, Germany, a method was developed where adsorption occurs under additional pressure (forced adsorption contact) between two rolls to avoid the detachment of larger particles of stickies from a very thin adsorbent (basis weight is approximately 20 g/m²). Compared with other test methods, higher temperatures of 80°C and higher consistencies can be used to ensure that increased proportions and amounts of stickies are adsorbed by the plastic substrate⁵⁰.

4.5 Extraction methods

Extraction methods use a solvent such as low molecular weight alcohols, ketones, ethylene, ethyl acetate, or chlorinated compounds such as methyl chloride or dichloromethane. The unscreened, recycled fiber pulp or rejects from laboratory screening are extracted by the solvent, the solvent evaporates, and the remaining residue is weighed.

These test methods are objective and have a low margin of analytical error. The results depend considerably on the solvent used and the applied extraction conditions. The long time necessary for analysis must be considered since different stickies have different dissolving behaviors in the solvents used. In addition, other substances besides stickies can also be extracted and falsify the result. The extraction results therefore do not provide any immediate indication of the content of stickies in a pulp sample. The results of extractions within a system permit the conclusion that higher measured values indicate a greater content of detrimental substances and therefore a greater potential for stickies.

Using this method for a dichloromethane (DCM) extraction, a Sankey diagram of the influence of detrimental substances in deinking systems is published⁵¹. The Sankey diagram for a recovered paper processing system with flotation of Fig. 17 clearly demonstrates that 174 kg DCM extract per hour are introduced by the recovered paper. This is then reduced to about one-third in the processed DIP. Important stages of the removal are screening and flotation. By dewatering the deinked pulp, a considerable DCM load enters the white water loop with the filtrate and comes again into repeated contact with the recycled fiber pulp.

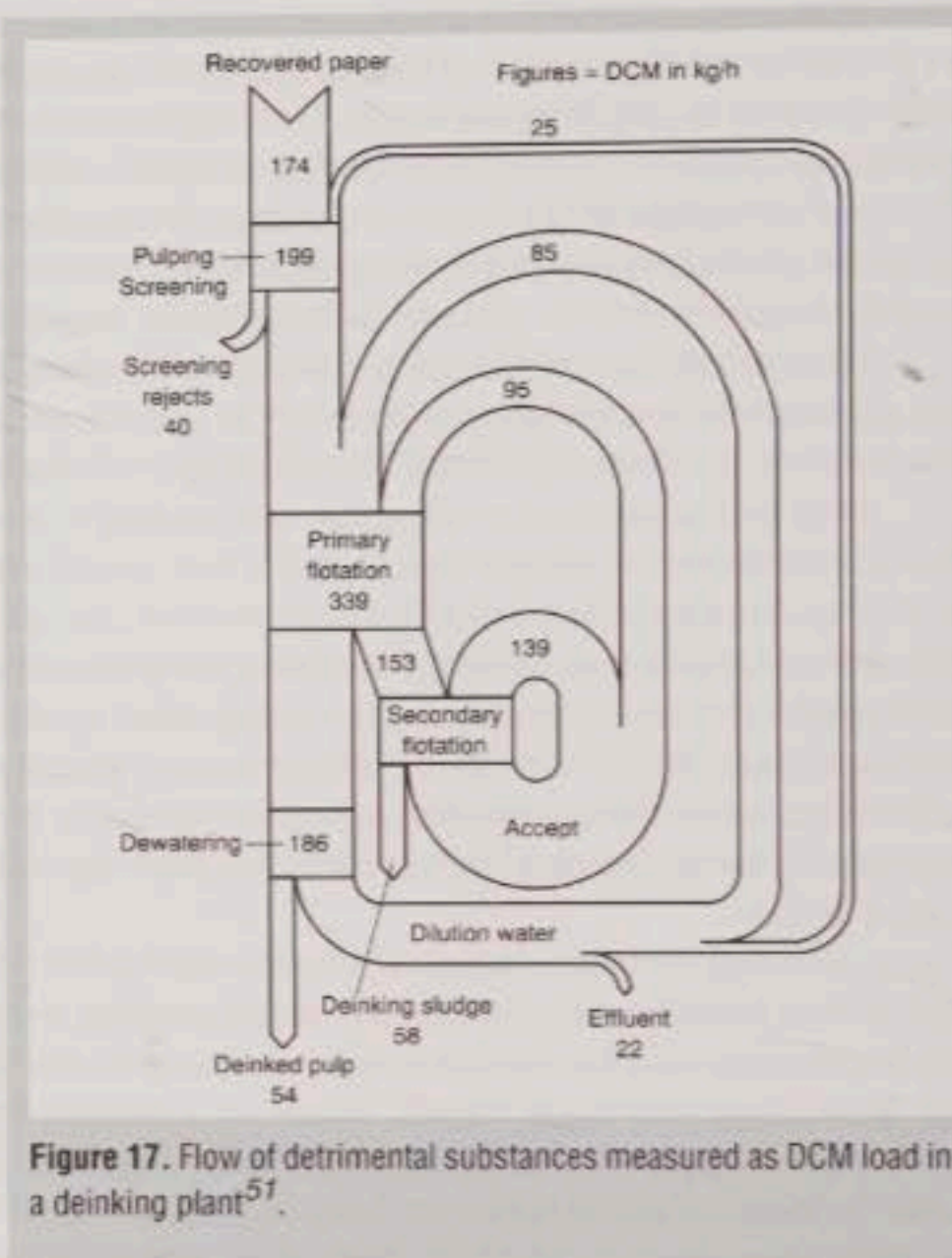


Figure 17. Flow of detrimental substances measured as DCM load in a deinking plant⁵¹.

4.6 Precipitation methods

The methods described so far serve primarily to detect primary stickies in the form of macro stickies that can be screened or micro stickies whose hydrophobic character allows adsorption to solid surfaces. To date, no special methods are available to detect secondary stickies that result from the agglomeration of micro, molecular dissolved, or colloidal stickies. Although several of the aforementioned methods through modification of the test conditions can have use to assess the secondary formation of stickies, no relevant information is available.

Secondary stickies are created mainly by physico-chemical changes that occur following pulp processing. One such important change can be the addition of retention or drainage agents immediately before the headbox of the paper machine. This can partially or fully destabilize the pulp suspension. In this case, the secondary stickies result from the reaction of anionic colloidal substances that become detached from various paper components such as the coating layer, mechanical pulp, or pressure sensitive adhesive during pulping and precipitated by a cationic polyelectrolyte⁵².

The process developed by the Centre Technique du Papier (CTP) in Grenoble, uses two paper machine wires made of polyester or polyamide that are introduced into an agitated pulp suspension under defined conditions of consistency, temperature, and time (Fig. 18). The test then uses controlled destabilization to change the charge of the pulp

suspension. From the aqueous stage of the pulp suspension, the requirement for a cationic polyethyleneimine up to charge neutralization ($= V_{th}$) is determined. Then, different parts of the determined value (usually one-, two-, three-, and five-thirds related to V_{th}) are added to the pulp suspension samples not yet containing polyethyleneimine. Each volume of cationic polymer added has an equilibrium time of 10 min after which the wire is submerged in the suspension for 5 min under shearing action. The wire is removed and rinsed carefully with tap water and dried in an oven. The contamination of stickies is then measured by image analysis, i.e., the holes of the wire that are plugged by secondary stickies. Image analysis is performed by back-scattering illumination under a microscope with a black background (stickies look white). Results are expressed as percentage of wire hole area that is plugged as a function of destabilization. This method of testing shows that the deposition tendency can be increased considerably by charge changes if secondary stickies are present in a pulp suspension. In the case of an overdosage of the cationic polyethyleneimine, the tendency toward deposition decreases again⁵³.

The precipitation method developed by the Papiertechnische Stiftung (PTS) examines finely dispersed and colloidal anionic substances in the pulp and water system. The dispersed coarse particles contained in the suspension are removed by a wire of the Schopper-Riegler drainage tester. A diluted precipitation agent (strongly cationic, long-chain polymer) is dosed into the filtrate until the resulting coacervate reaction has reached a balanced level. The filtrate with the coacervate is then passed through a suction filter. The reference for the precipitated substances is the evaporation residue or the filter residue without precipitation agent added. In principle, the precipitation may be achieved in several cycles.

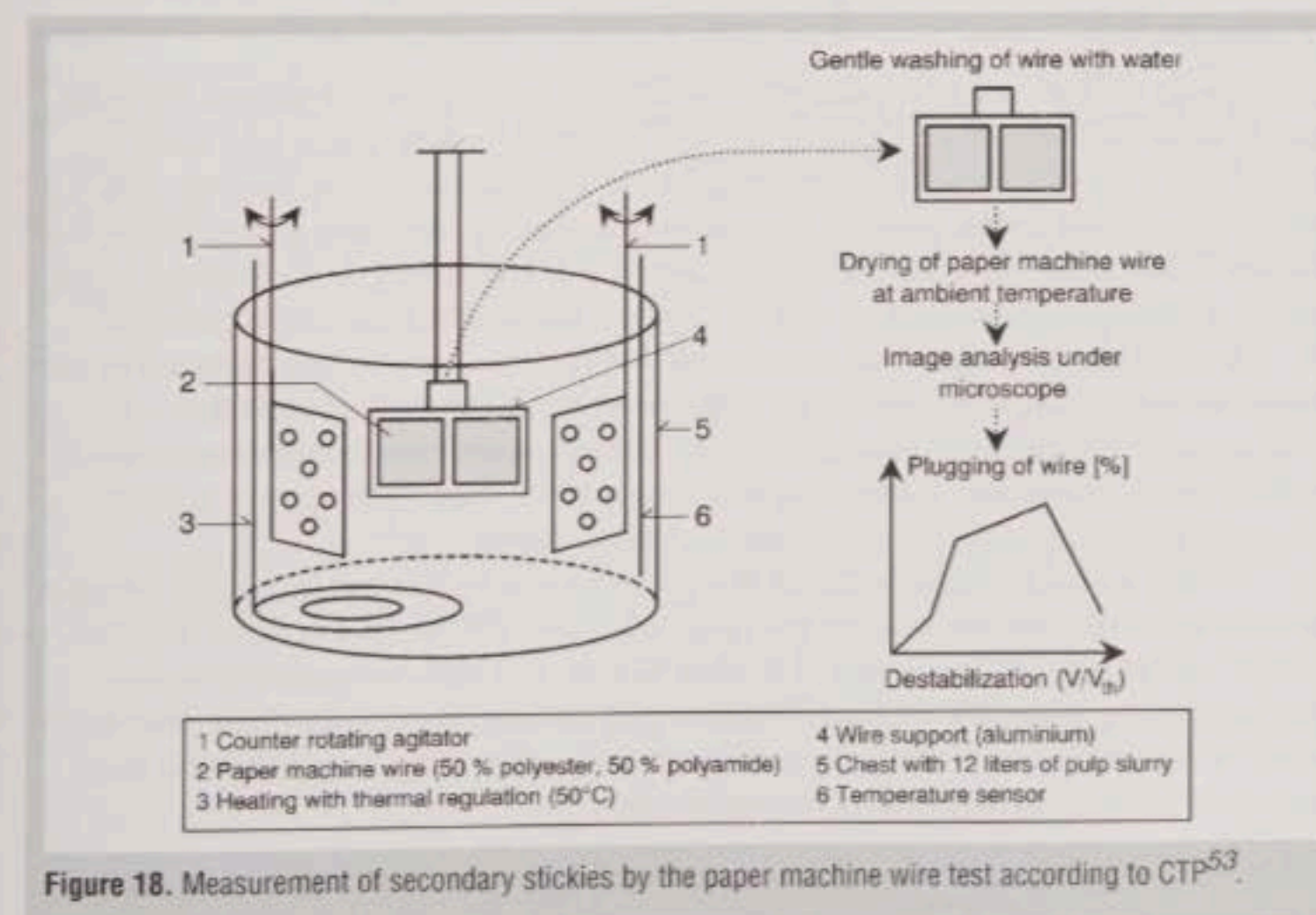


Figure 18. Measurement of secondary stickies by the paper machine wire test according to CTP⁵³.

Using the following formula, one can calculate with this method the minimum precipitation yield of finely dispersed and colloidal particles. The minimum precipitation yield expresses the amount of the coacervation tendency originating as coarsely dispersed stickies from finely dispersed and colloidal particles that are precipitated by adding a highly cationic, long-chain polymer. The expression considers the error variables such as fines, fillers, and even the precipitation agent.

$$P = \frac{m_{PP} - m_{PA} - m_{PF} - m_{FL}}{m_{ER} - m_{TF} - m_{FL}} 100[\%] \quad (1)$$

where P is the minimal precipitation yield
 m_{PP} the mass of precipitated product
 m_{PA} the mass of precipitated additive
 m_{PF} the mass of precipitated fines
 m_{FL} the mass of fillers calculated from ash content
 m_{ER} the mass of evaporation residue
 m_{TF} the total mass of fines calculated from evaporation residue.

Proving that different potential stickies have highly varying minimal precipitation yields is possible. For example, high coacervate masses develop from samples of redispersible adhesives since such adhesives largely redisperse at the time of pulping. Because the resulting coacervate is always tacky, it can be safely assumed that these deposition products cause problems in papermaking⁵⁴.

4.7 Other methods

A wide range of other, partly unpublished methods of determination of stickies are available. To separate contaminants having different densities for example, a laboratory cleaner with a 25 mm diameter was developed that operates with a low pulp consistency and high centrifugal forces. Instead of separating stickies by size using slotted plates, this provides a concentration in the reject by density. If only contaminants are supplied to the cleaner, realizing a separation into stickies having a low and high density is possible⁵⁵.

Another process describes the change that occurs when stickies obtained by laboratory screening are mixed into virgin pulp and dried under defined conditions. All those areas of stickies grow during drying and therefore indicate that they are thermoplastic stickies. In reaction to pressure and temperature, they begin to melt and flow. This method is recommended especially for testing market DIP⁵⁶.

Finally, a new process for identifying stickies uses an infrared technique. Using a thermographic camera in a wavelength range of 700–1 200 nm, the surface temperatures of handsheets are measured in relation to low- and high-temperature regions. Fibers and sticky materials such as polyester, polystyrene, or polypropylene differ significantly in thermal conductivity. By thermographic analysis, tacky surfaces in the fiber stock are supposed to be identified in model pulps⁵⁷.

4.8 Conclusions

Without appropriate and recognized test methods for stickies, progress in controlling problems related to stickies is difficult to achieve. Researchers setting out to develop devices or chemicals for control of stickies must direct their activities first to development of more reliable test methods by which the newly developed device or product can demonstrate its effectiveness. With such test methods, comparisons between different studies on problems related to stickies would be possible. This is impossible today due to the different conditions used for sample preparation and analysis. Nevertheless, justification exists for using different test methods for stickies since not all characteristics of the stickies such as number, size, mass, and tack can be measured comprehensively by one method.

5 Control of stickies

The increasing use of recovered paper inevitably means that growing numbers of paper producers encounter problems caused by stickies. Simultaneously, the intensified recycling of recovered paper contributes to an accumulation of tacky components. Stickies in paper grades containing recycled fibers re-enter the production process via recovered papers. No knowledge is available on how the tacky contaminants in the paper behave at the time of its reprocessing. One can assume that these substances contribute to problems related to stickies experienced during the following recycling loops with the result that an accumulation of stickies can occur with each loop.

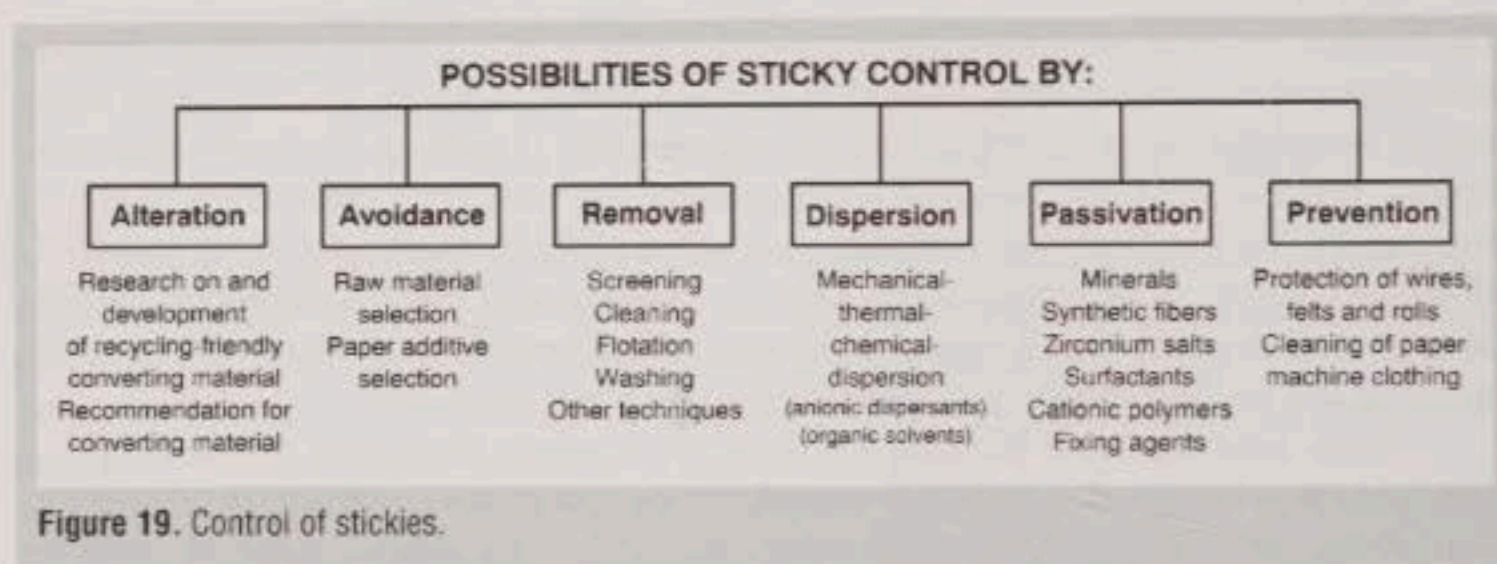
Paper producers and the supply industry (machinery, chemistry, and clothing manufacturers) have had to be highly inventive to control stickies. Despite all endeavors, such efforts will undoubtedly continue to be necessary in the future because no quantitative solution is in sight to solve the problem of stickies. Lost production time due to stickies can significantly reduce the efficiency of paper machines and therefore the economy of paper production. Stickies can also be expected to cause a decrease in paper quality.

As Fig. 19 shows, the following control measures for stickies can occur in paper production:

- Alteration
of the physical properties of the stickies by the manufacturers of the tacky substances so that any of the following methods work better
- Avoidance
of stickies to ensure that potentially tacky substances do not enter the processing system with the recovered paper
- Removal
of stickies by the separating steps within the recovered paper processing operation

- Dispersion
of stickies to ensure that they remain in a very finely dispersed state and are therefore less harmful
- Passivation
to reduce the tack of stickies by attachment of other nontacky materials to the surface of stickies
- Prevention
to control the formation and deposition of stickies within the paper machine.

Included among these different strategies are several possible individual control measures for stickies that are described in greater detail in the following sections. They can be used separately or combined.



Only the first three measures, i.e., alteration, avoidance, and removal, offer the possibility of a long-term solution to the problems related to stickies. The other three measures relieve the problem only temporarily, i.e., directly at the time of paper production. Because of the usual practice of paper recycling, those three methods do not allow a long-term solution. Each industry segment must contribute to the listed control measures for stickies to improve paper recyclability.

Accordingly, every paper mill should closely examine its production process to avoid "homemade" problems with stickies. With a rigorous inspection of the recovered paper upon delivery, one can ensure that the supplied material has a certain quality.

5.1 Alteration methods

The most promising way to avoid problems of stickies in paper production is the development of more recycling-friendly paper and board products (including adhesives and binders) to satisfy the precondition of mastering the problem of stickies with complementary control measures. For example, adhesives with very strong cohesion offer the possibility for removal after disintegration almost completely. In contrast, weak cohesion of adhesives leads to a strong fragmentation during pulping that offers the opportunity that the adhesive particles pass subsequent screening and cleaning stages and cause

problems with stickies on the paper machine. Research is therefore necessary to develop better screenable adhesives resulting in less problems with stickies for the paper manufacturers using recovered paper. In cooperation with the chemical industry, adhesive manufacturers, converters, paper industry, and research organization, one attempt was made to improve recycling-friendly adhesives by the United States Postal Service (USPS) as described in the following section.

USPS pressure sensitive adhesive program

Pressure sensitive adhesives are products that contribute considerably to problems with stickies due to their permanent tack. For this reason, the industry has demanded for some time that such adhesives during processing of recovered paper can be removed with screening systems with perforated and slotted screens. The development of adhesives that could be removed by flotation or separated by lightweight centrifugal cleaners would not suit the entire paper industry since not all processing plants have the necessary machines.

Especially praiseworthy is the USPS program. Because of the continually growing use of pressure sensitive adhesive stamps since 1990, USPS has launched a project with the United States Department of Agriculture (USDA) Forest Products Laboratory called "Research and Development of an Environmentally Benign Pressure Sensitive Adhesive for Use on Postage Stamps". In 1997, 82% of the USPS postage stamps were PSA issues. One estimate is that the USPS uses more than 160 km² of PSA postage stamps and labels annually. This is about 14% of the entire United States market.

As a result of a new USPS environmental strategic plan, the USPS has initiated industry-wide research to satisfy specifications for environmental friendly PSA postage stamps. In 1996, research began with a vertical team concept involving adhesive manufacturers, postage stamp printers, converters, face and liner paper suppliers, recovered paper processing mills, test laboratories, and machine manufacturers. The teams worked on a new type of solution to overcome the problem of the recyclability of PSA products that simultaneously had to satisfy the USPS specifications for use.

USPS wanted to develop the entire stamp laminate construction (face paper, adhesive, and release liner) to be recyclable. For this reason, the recycling test process included examination of two types of postage stamps: pre-consumer stamps with liner and post-consumer stamps without liner. The results of the joint consultations led to a three-stage plan with tests in the laboratory, pilot installations, and industrial scale.

Two philosophies of adhesive removal at the recovered paper processing stage emerged from the discussions held with the recycled paper processing industry. The first included the application of strict pulping conditions for maximum disintegration of the impurities. This used the theory of disintegrating unwanted adhesive particles so flotation removes them. A more comprehensive removal occurs at the water loop cleaning stage. The adhesives developed for this strategy preferably consisted of redispersible adhesives. Size of the dispersed adhesive particles after pulping received special attention. The redispersible adhesives also had negative effects including the possibility of reagglomeration during recovered paper processing and accumulation in closed water loop systems. In addition, these redispersible adhesives could not satisfy the specifications of the USPS high humidity aging performance test.

Consequently, the second philosophy of removing adhesives from recycled fiber slurries received greater attention. This used a minimum disintegration of adhesive particles by gentle pulping conditions at low temperatures⁵⁸. In this case, the removal of the adhesive particles should occur at the screening stages of recycled fiber processing. The ideal adhesive for use with this method has sufficiently large particles after pulping that are relatively nontacky in the wet state. The members of the recovered paper processing industry favored adhesives that could be removed by screening from the fiber suspension as early in the recycling process as possible.

Laboratory tests established that pulping temperature has an influence on the particle size of standard adhesives⁵⁹. Compared with a pulping temperature of 60°C for example, fewer particles with a larger area occur at a temperature of 40°C. The application of lower pulping temperatures therefore increases the removal efficiency of adhesive particles by screening. Under defined pulping conditions, smaller adhesive particles occurred in the pulp slurry with pre-consumer stamps with liner than with post-consumer stamps without liner.

In the pilot scale trials, control adhesives were used for benchmarking the linerless and the standard PSA stamp stock with and without liner. An experimental adhesive was also used. Figure 20 shows results of the contaminant level in the pulp determined by speck check analysis after pulping and pressurized screening^{58,59}. As in the laboratory trials, the standard PSA stamp stock with the liner has a lower screening efficiency apparently due to some material in the liner such as clay or silicone causing some pacification and giving a higher adhesive speck area.

One experimental adhesive gave better screening. It should therefore cause less problems during industrial processing. Even with the release liner, contamination by the adhesive was the same as the control trial with the standard adhesive without liner. Early removal of most adhesive is important since the smaller quantity of adhesive remaining in the pulp has a higher probability of responding to the removal action of the

subsequent unit operations. After additional forward cleaning, two-stage through-flow cleaning, flotation, side hill washing, and dewatering, the observed adhesive contamination was about 20 ppm for the standard PSA stamp stock and 7 and 12 ppm for the experimental PSA stamp stock with and without release liner, respectively^{60,61}.

The work performed in the USPS project is not complete. Additional progress in the development of recycling-friendly (screenable) adhesives resulting in a successful

conclusion of the research project is still desirable. At the end of the project, PSA systems should be available that are technically suitable, economical, and screenable. To improve the recyclability of paper products, the developed screenable PSA should not only be used by USPS applications but also be used more widely in adhesive applications in the United States and Europe where recovered paper recycling has a much higher significance. Additionally, the knowledge obtained by the adhesive manufacturers should also be used for development of other recycling-friendly adhesive applications in the paper and board converting industry.

5.2 Avoidance methods

The avoidance of stickies is also a very effective way to cope with problems of stickies. Before this measure could be applied, knowing every source of the formation of stickies would be necessary. All parties participating in the paper chain would need to observe the proposals on avoidance. If all substances used at the preceding paper production and paper conversion that lead to problems related to stickies were substituted, significant reduction of the problems experienced with tacky contaminants during succeeding paper production based on recycled fibers would occur. The necessary preconditions for this will not occur in the foreseeable future. This is why it will not be sufficient to control the problem of stickies adequately by avoidance measures alone.

Because completely avoiding the entry of tacky substances into the paper cycle by recovered paper will never be possible and a total removal cannot be expected, a certain concentration of stickies will always remain in the processed recycled fiber pulp that is supplied to the paper machine. The paper quality and runnability in the paper machine are greatly influenced by the size of the residual stickies and their concentration. This will decide whether the concentration and size distribution of stickies offered by the recovered paper is acceptable. Because recovered paper processing plants offer only a certain efficiency for the removal of contaminants, increasing loads of stickies in the recovered paper result in a greater stickies contamination of the processed pulp. For this reason, care is necessary when using recovered paper so that it does not exceed a certain amount of tacky contaminants.

A prime difficulty is that seeing when recovered paper contains unacceptable quantities of stickies is almost impossible. Nevertheless, the papermaker knows the paper or board products that are critical for the stickies problem. For example, he is aware of the problems experienced in conventional recovered paper processing plants with excessive quantities of waxed corrugated containers, self-sealing envelopes, or pressure sensitive stickers as magazine inserts. "A conventional recovered paper processing plants" refers to a type of plant that can produce suitable pulp for a certain paper product from a regular recovered paper mix. The limitation to conventional processing plants must be made because special processing plants may exist in which certain problematical types of recovered paper can be processed. These include waxed corrugated containers or composite materials such as polyethylene coated liquid board or corresponding products such as used milk containers.

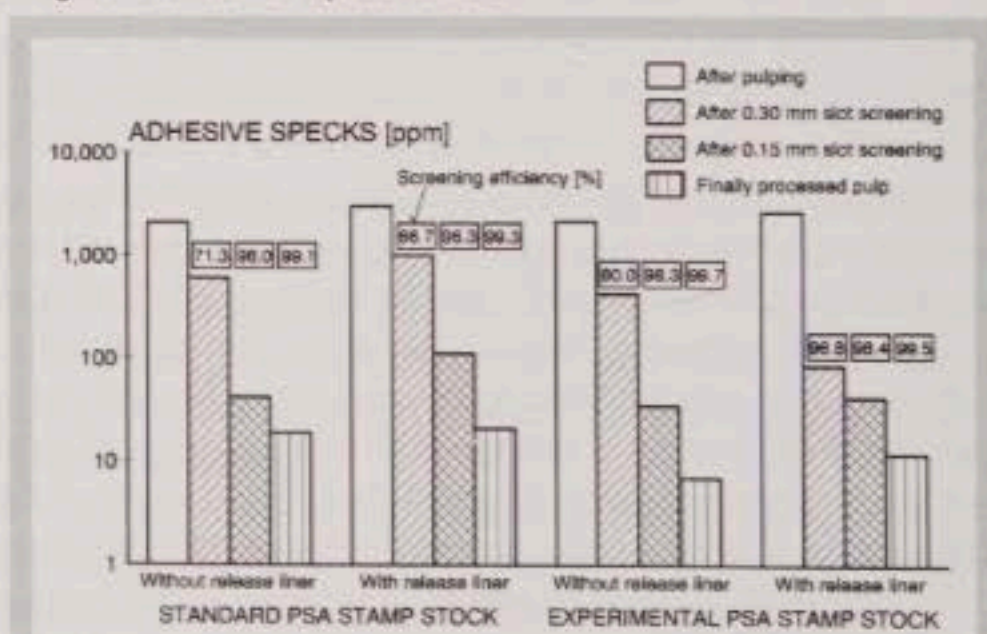


Figure 20. USPS pilot plant results of standard and experimental PSA stamp stock.

For purchased recovered paper, one should make the effort to assess its quality in relation to contamination with stickies and discuss any shortcomings with the recovered paper supplier. This allows demanding that waxed corrugated containers or self-sealing envelopes are removed from the supplied recovered paper to bring at least a reduction in these materials entering into the paper cycle by the recovered paper.

With the processing of over-issue magazines for example, a common stipulation when acquiring recovered paper is that pressure sensitive labels such as Easter rabbits and Santa Claus figures should be manually removed before supply to a paper mill. This removal of pressure sensitive stickers from the over-issues is only possible by using extensive labor. Another alternative would be storing these over-issues having a high content of pressure sensitive stickers separately and placing them in the recovered paper cycle in small volume to avoid putting an excessive load on the processing plant with these unwanted components.

Paper producers should also express their demands, wishes, or fears to other industry partners in the paper chain. Considering the political climate in Europe and elsewhere, all branches of industry must be receptive to the recycling concept and the extended closing of material loops. As a result, reports of problems experienced in the reprocessing of certain products (printed material or packaging) are taken seriously by the supplying industry, e.g., printing ink manufacturers and adhesive manufacturers, or the paper converters, e.g., label manufacturers, and give impetus for new developments of recycling-friendly materials.

Preconditions are that the problems have to be identified and adequately described. Included in this is a statement concerning the desired recycling process of the future. Naturally, this objective can be achieved more easily when more recovered paper processors cooperate and approach other industry partners with joint demands. An especially positive example in this connection is INGEDE. Since 1989, this organization with its 25 member companies has represented the interests of the deinking paper industry throughout Western Europe and can already claim success.

A paper producer must also ensure that he does not cause problems by producing secondary stickies in the production process. This requires careful selection of the retention and fixing agents used and avoidance of drastic pH changes or temperature shocks so that no destabilization of the pulp slurry occurs that can cause precipitation of colloidal or dissolved matter. Special attention is necessary to avoid charge transfer due to a change of retention agents such as cationic polymers since this may cause increased coverage by stickies of a paper machine wire⁵². The use of other substances such as wet strength agents, carboxymethyl cellulose (CMC), dyes, anti-foam agents, or anionic polymers can also influence the formation of stickies¹⁸.

5.3 Removal methods

Chapter 5 of this book discusses methods and equipment to remove different types of contaminants in processing recovered paper. Aspects of stickies related to screening, cleaning, washing, and flotation are topics of the following sections.

5.3.1 Screening

General aspects

Screening of pulp slurries using screens with holes or slots is a basic process in stock preparation lines. Screening processes remove particles according to their size, shape, and deformation behavior. Particles that are larger than the size of openings (holes or slots) of the separating element in all three dimensions are retained provided the particles are not deformable and therefore enter the reject. If one dimension of a particle is smaller than the openings such as pulp fiber diameter compared with the hole diameter or plastic foil caliper compared to the slot width, flow conditions in the screening device and the flexibility of the particle will determine whether it enters the reject or accept of a screen.

The dimension of the perforations alone does not determine the separating efficiency of a screening operation and the resultant removal of stickies. Besides the combination of screening units in several stages, the design features of a pressure screen and the operating conditions also have important influence. The following criteria are examples of such design features:

- Flow inside the machine (centrifugal or centripetal)
- Type and geometry of the rotor (full rotors [bump, lobed, and stepped rotor] or open rotors [foil and blade rotor])
- Type and geometry of the screen (slotted or drilled screens, plain or contoured inlet surfaces of the screen, and shape and angle of the surface profile)
- Body shape (cylindrical or conical).

For example, a screen with 0.15 mm slot width can sometimes achieve a higher level of removal efficiency for stickies than a 0.10 mm slotted screen if a flatter, less angled surface profile is selected for the screen with the larger slot width⁶²⁻⁶⁴.

For operating parameters, stock consistency, rotor speed, pulp throughput, and reject ratio have prime importance. The pulp characteristics such as freeness, fiber length distribution, ash content, contaminant content, and size distribution of contaminants also influence the screening result.

Model calculation of removal of stickies

The claimed levels of efficiency of removal of stickies for screening range from 40% to about 90%^{7,63,65,66}. The percentages relate to the removal efficiency of individual pressure screens and a multi-stage screening system. Analyzing the numerical values requires extreme care. Basically, the removal efficiency depends largely on the determination method for the stickies. Important factors here include whether the content of stickies was determined gravimetrically, i.e., by mass, or optically, i.e., by number or area as discussed earlier in this chapter.

At this stage, a model calculation to illustrate these influences is used as Fig. 21 shows. A commercial pressure screen equipped with a screen of 150 μm slot width is fed with pulp with a total number of 1 500 stickies per unit mass of dry pulp. This figure comprises 1 000 particles with an idealized spherical diameter of 120 μm and 500 particles with a diameter of 200 μm . Where exact observance of the geometry of the screen perforations exists with nondeformable stickies, the screen removes all particles of stickies larger than 150 μm in the screening stage. For purposes of simplification, smaller particles are assumed to enter the accept flow. For our example here, this means that all 500 particles of 200 μm diameter are rejected, and all the particles with 120 μm diameter enter the accept. In calculating the number of stickies, this produces a removal efficiency of 33%. The calculation of the removal efficiency using the mass of stickies and a presumed constant specific density produces an efficiency of 70%.

Because the three-dimensional stickies in this example were considered spherical, an assessment via the removal by area of stickies can occur only if the area for the calculation has been agreed upon. If the area of stickies projected by a sphere is the basis, this removal efficiency would be 58%.

Real screening processes assume that many stickies have an almost two-dimensional expansion. For this reason, thin particles with a larger area than the slot width of the screen can enter the accept flow. Cubical stickies due to their deformability can also pass through perforations. In real screening processes as opposed to this theoretical observation, total removal (100% efficiency) of the particles that are only slightly larger than the perforations is not possible.

Quantitative analysis of the stickies in the feed and accept flow first uses a laboratory screening method with a 100 μm slotted plate as Fig. 22 shows. Presuming ideal laboratory screening conditions, all stickies in the feed and accept will be detected because all stickies in the model pulp are larger than the slot width of the screening plate of the laboratory classifier. An idealized screening implies that no particle agglomeration or fragmentation occurs during laboratory screening and that no fibers or other foreign matter enter the reject of the laboratory screening. The number and mass measured should then correctly reflect the stickies actually contained in the pulp flows. Assuming for purposes of the laboratory determination method for stickies that the numerically determined area corresponds to the projected stickies area, the calculated areas and removal efficiency in relation to number, area, and volume or mass in this example will agree with the conditions of a commercial screen.

If a laboratory screening procedure with 150 μm slotted plate is used for detection of stickies in the same commercial screening example of Fig. 21, all removal efficiencies will increase to 100% independent of whether the evaluation is realized with the number, area, or mass of stickies as Fig. 23 shows. These higher levels of removal efficiency result from the fact that only the 200 μm particles are intercepted with the laboratory screening in the inlet flow. In the commercial screen, these would ideally have been completely screened out. This is why with laboratory screening no more stickies can be detected in the accept with laboratory screening on 150 μm slots. Because some stickies with 120 μm diameter completely escape the laboratory screening in this example,

the determined levels of removal efficiency do not reflect the actual conditions in the industrial screening.

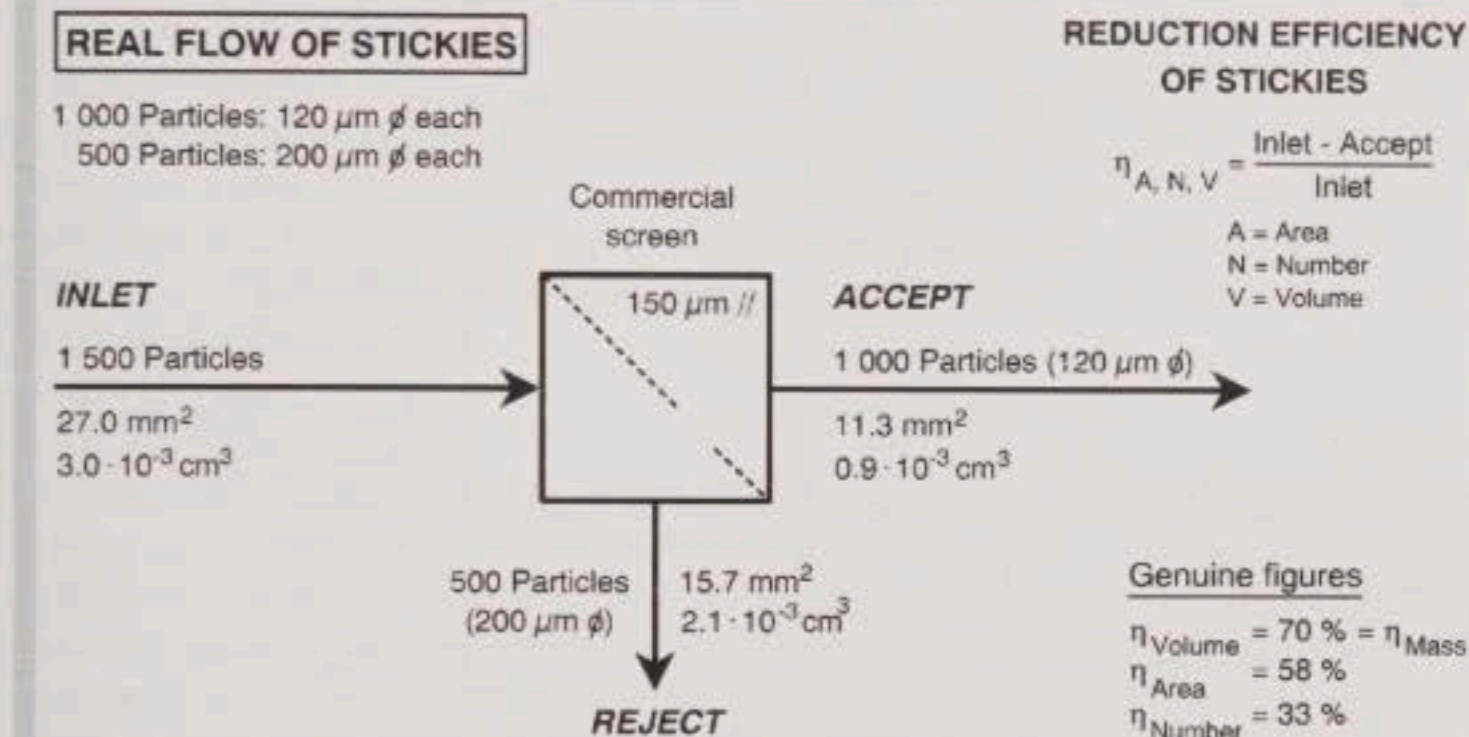


Figure 21. Theoretical flow of stickies in commercial screening equipment and reduction efficiency of stickies.

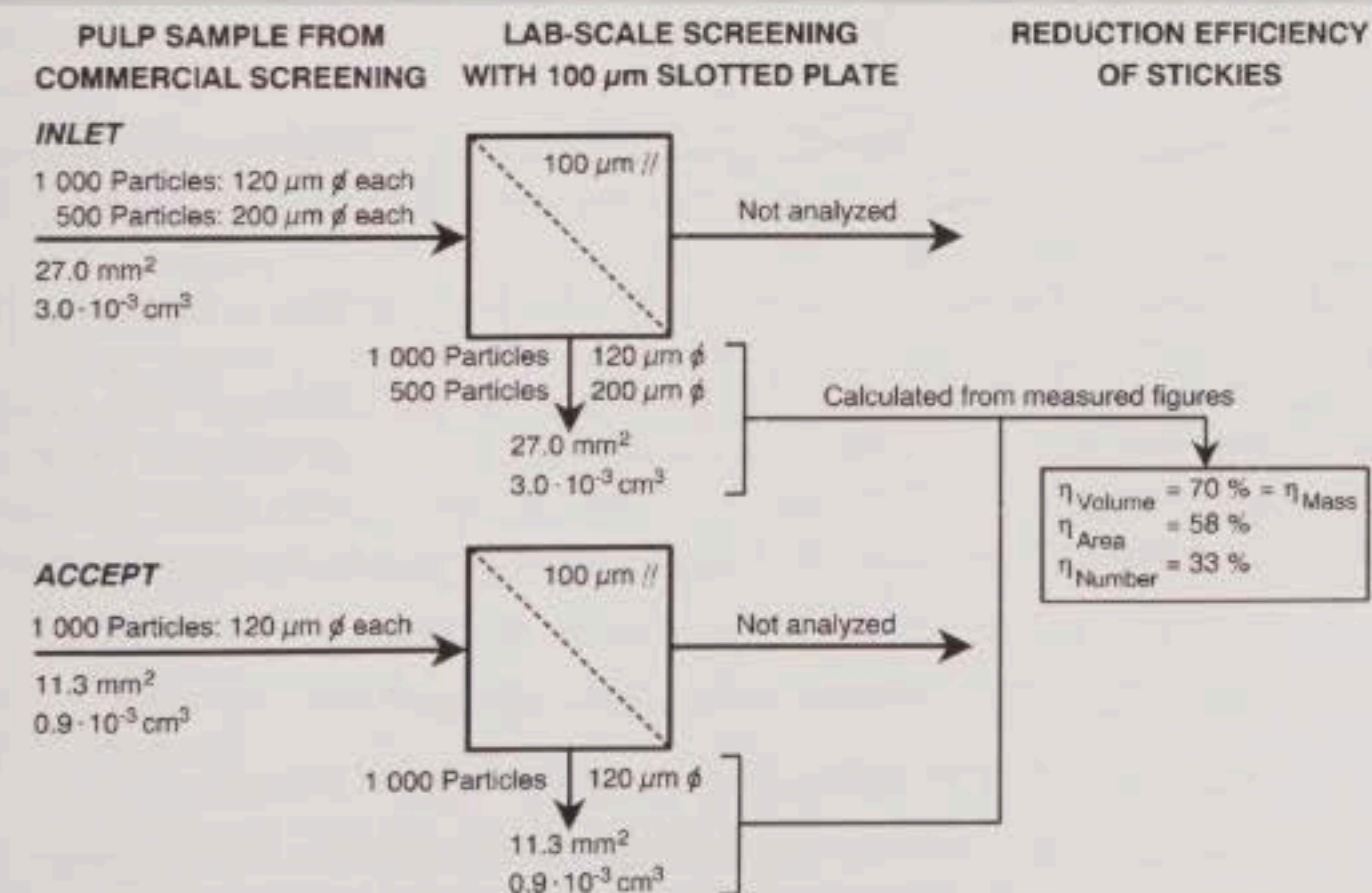


Figure 22. Effect of determination of stickies on their reduction efficiency by laboratory screening (first case).

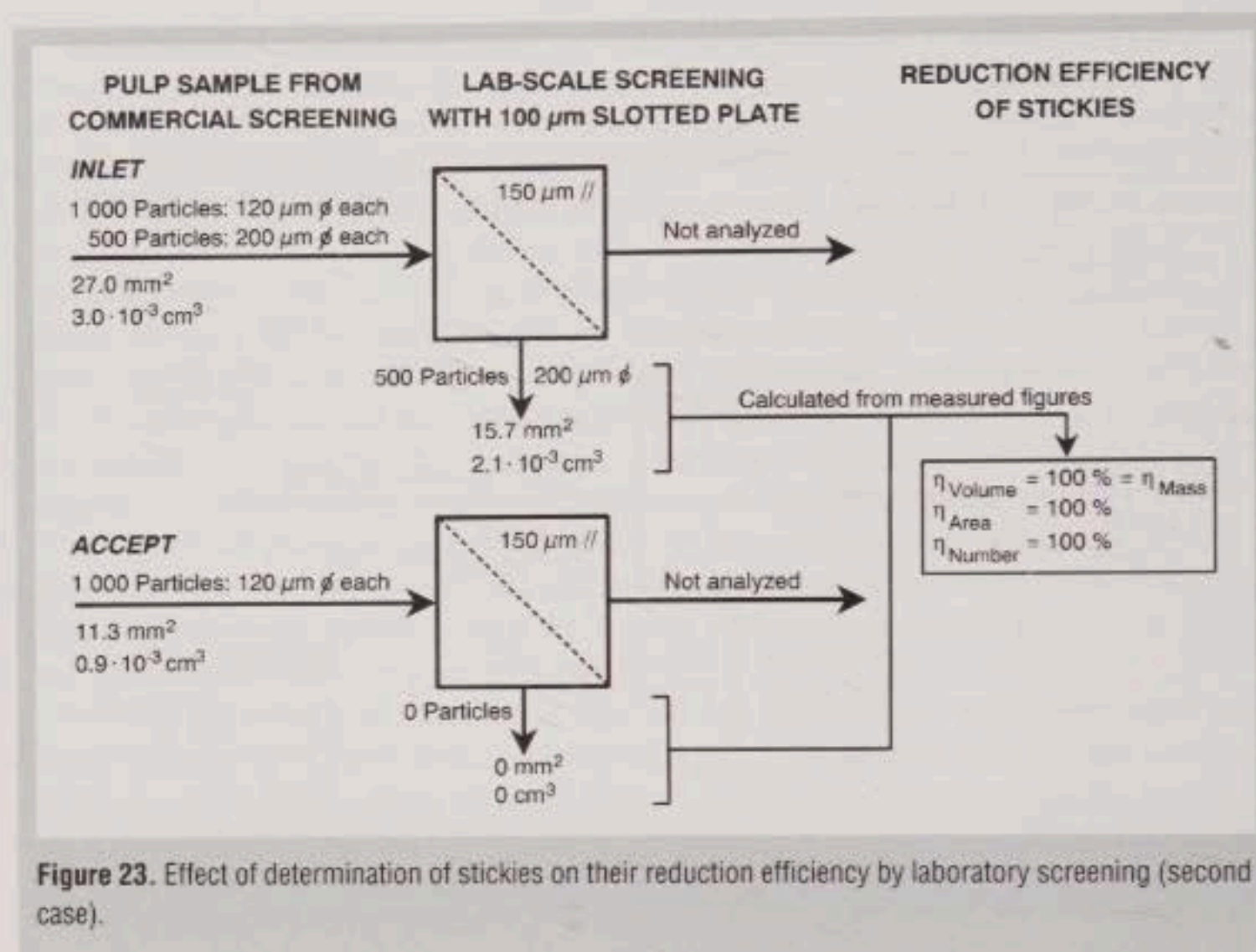


Figure 23. Effect of determination of stickies on their reduction efficiency by laboratory screening (second case).

One can assume that some particles contained in a pulp slurry always escape detection by a laboratory determination method for stickies because they are smaller than the laboratory slotted plate.

In another example, assume the previous 1 000 particles have a diameter of 80 μm instead of 120 μm . Using the 100 μm slotted plate for laboratory screening, the same levels of removal efficiency are calculated as in the first case study: 33% for number of stickies, 58% for area of stickies, or 70% for mass of stickies. Because the 80 μm particles cannot be rejected by laboratory or industrial screening, the actual removal efficiency of stickies for the considered industrial pressure screen decreases as follows:

- From 33% to 20% according to the number of stickies
- From 58% to 49% according to the area of stickies
- From 70% to 64% according to the volume or mass of stickies.

This example shows that the data relating to screening efficiency of stickies depend directly on the evaluation parameters such as number, area, or mass even when using identical methods of sample pre-treatment, i.e., laboratory screening. In addition, determinations using mass flows always produce more positive results in

cases where disproportionately large amounts of larger size particles are included in the calculation. Recycled fiber pulp containing a high proportion of stickies with sizes ranging between the slot width of industrial screening and laboratory screening always produces a poor removal efficiency since the stickies belonging to this size category are not rejected by the industrial screen, whereas they are detected by the laboratory determination method.

Because no method of analysis for stickies currently exists that reflects the actual content in a pulp and because the measured values always depend on marginal conditions, any data relating to removal efficiency of stickies should be considered carefully depending on the slot width of the laboratory screen plates and the number, area, or mass of stickies identified.

5.3.2 Cleaning

The removal of contaminants by means of centrifugal forces is generally called cleaning and occurs in cleaners. In contrast to screening in which size, shape and deformation behavior of particles influence removal, cleaners permit a particle removal using differences of density and hydrodynamic characteristics. The advantage of using cleaners to clean pulp suspensions is the ability to remove very small and soft particles that due to their size and deformability would escape removal by screening since their density varies considerably from that of water and wetted fibers, respectively.

To minimize fiber loss, cleaner systems usually operate in three, four, or even five stages with different types of flow interconnections. An exception is the centrifugal cleaner with rotating housing. Several operate in parallel always in a single-stage process. Different sized devices depending on the volume or mass throughput rate are available⁶⁷⁻⁷¹.

According to Moreland, the following principles apply for operation of forward-, reverse-, and through-flow cleaners⁷²:

- Efficiency of particle removal and throughput volume increase with increasing pressure difference
- Efficiency increases with higher temperature due to decreasing viscosity of the water and increased buoyancy of the light contaminant particles since these expand considerably more than water
- Efficiency decreases with increasing feed consistency due to the limited particle mobility
- Efficiency increases with lower cleaner diameter due to increasing centrifugal forces
- Efficiency increases and throughput volume decreases with smoother cleaner walls
- Efficiency increases with extended retention time with increasing cleaner length since the cone angle of the cleaner becomes smaller.

Although centrifugal cleaning is effective for particles that clearly deviate from the density of the water or wetted fibers, this process is ineffective for removal of particles of about 1.0 g/cm^3 . Table 1 illustrates that the substances in adhesives have a density that is close to 1.0 g/cm^3 .

The density of many components of tacky contaminants of about 1.0 g/cm^3 is the reason why the efficiency of removal of stickies by centrifugal cleaning is far from optimum. Figure 24 shows clearly that forward cleaners with reverse- or through-flow cleaners can be used very effectively for removal of particles that are denser or lighter than water. This example shows a cleanliness efficiency of nearly 100% for a density less than 0.95 g/cm^3 and efficiencies of more than 95% above a density of 1.05 g/cm^3 . It also clearly shows that the removal efficiency drops dramatically in a density range of $0.98\text{--}1.03 \text{ g/cm}^3$ (73).

Barrett reaches a similar conclusion for the lower range of the density spectrum (74). In model tests with specially marked hot melts of different densities from $0.89\text{--}1.02 \text{ g/cm}^3$, substances having a density below 0.95 g/cm^3 can be removed more efficiently independent of the chemical composition of the hot melts.

As stated in the section on screening, numerical values relating to the actual

Table 1. Density of contaminants in recycled fiber pulp (70).

Contaminants	Density [g/cm ³]
Metal	6.00–9.00
Sand	2.00–2.20
Clay	1.80–2.60
Printing ink	1.20–1.60
Asphalt	1.10–1.50
Polystyrene	1.04–1.10
Hot melt	0.95–1.10
Polyethylene	0.91–0.97
Latex, rubber	0.90–1.10
PSA	0.90–1.10
Wax	0.90–1.00
Styrofoam	0.30–0.50

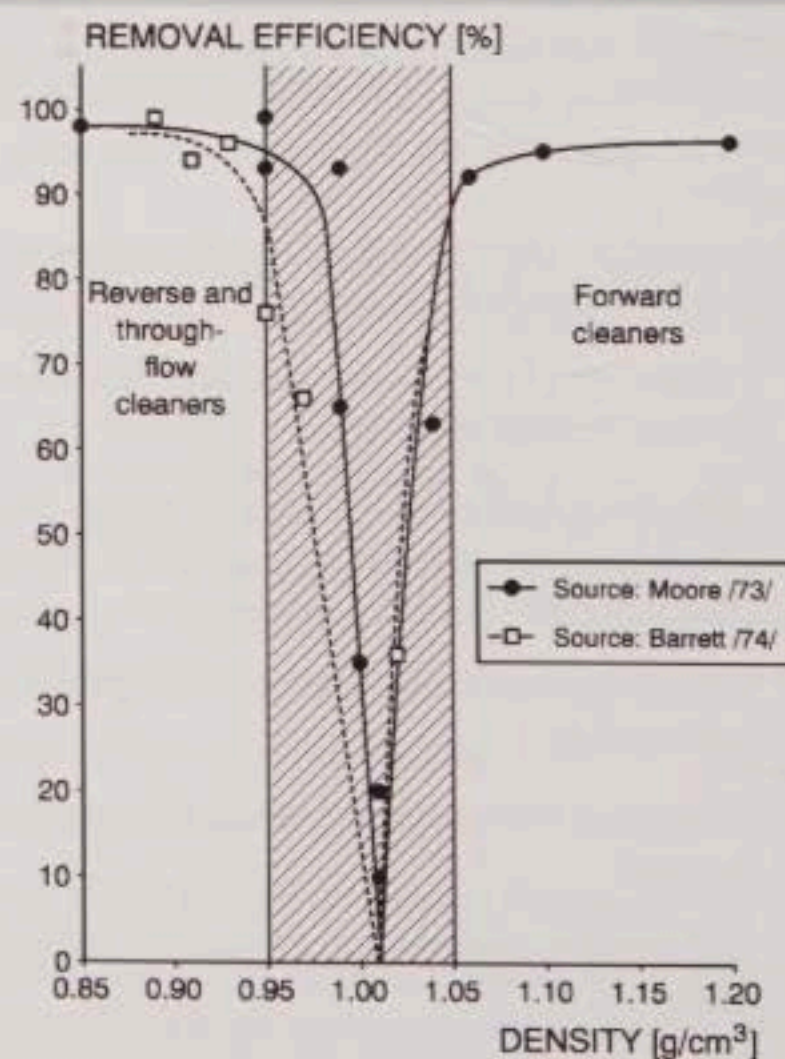


Figure 24. Removal efficiency by cleaning vs. density.

removal of stickies via cleaners in recovered paper processing are influenced by the applied method of determination of stickies. Independently of this, a determination test for stickies using different cleaners under identical operating conditions can provide valuable information. In comparative tests using optimum conditions with forward-, reverse-, and through-flow and rotating cleaners in pilot plant and industrial systems, mass-related reject efficiencies of stickies of about 40% were calculated for each individual cleaner except the through-flow cleaner. While the centrifugal cleaner with rotating housing could achieve this separation effect with a total reject rate of 2%, the reject of forward and reverse cleaners obtained with this reject efficiency for stickies was 20%–30%. This means that a multistage cleaning is absolutely necessary. Independent of the combination of the cleaners applied, the cleaning must result in an additional decrease of the total reject efficiency of stickies. This is not necessary with the centrifugal cleaner with rotating housing. Operating the through-flow cleaner with an overall reject rate of only 2% is possible but with only half the reject efficiency of stickies at approximately 20% (68).

Another comparison concludes that the rotation and through-flow cleaners installed at a paper mill for processing deinked pulp have approximately the same levels of efficiency for removal of stickies. The system under consideration had a two-stage through-flow cleaner with cascade arrangement and a one-stage cleaner with rotating housing used in parallel operation. Both cleaner systems were supplied from the same pulp chest and achieved a reject efficiency level for stickies of less than 20% by mass of stickies and less than 15% by volume of stickies. This efficiency for removal of stickies with light-weight cleaners is much too low. Based on its lower energy requirement, fiber loss, and water consumption, the cleaner with rotating housing had lower operating costs (75).

A new reverse cleaner with high g forces introduced in North America offers efficient removal of particles with density $0.95\text{--}0.99 \text{ g/cm}^3$ (76,77). In that range, conventional cleaner efficiency is very low. Due to its favorable operating conditions, the cleaner accepts streams can be better. The new reverse cleaning system also features a different through-flow cleaner to concentrate the light reject particles into a small volumetric stream. Chapter 5 of this book has more detail.

5.3.3 Flotation

The flotation process should be very suitable for removal of stickies for the following reasons:

- The usually hydrophobic nature of the stickies satisfies the precondition for ensuring the attachment of the air bubbles and guarantees the buoyancy of the particles
- A large proportion of the stickies to be removed is in a size range favorable for flotation because a pre-screening is usually undertaken before flotation so that large stickies should already have been separated.

Despite this, information on the removal of stickies by flotation is seldom available in the literature. A distinction is necessary between the flotation process within stock

preparation and the dissolved air flotation (DAF) type treatment of the process water or effluent. The flotation in pulp processing accomplishes ink removal and should be considered a selective flotation of ink particles although fillers, fibers, and fiber fines are also partially floated.

Flotation in the process water and effluent purification is DAF that ideally addresses flotation of solid matter suspended in the water. Using suitable flocculation agents and precipitation reactions in the DAF system, one can possibly remove at least partly tacky solid particles and dissolved or colloiddally dispersed stickies. Quantification of the efficiency of this removal method of stickies is not possible due to the incompleteness of the analytical methods for determining solid, dissolved, and colloidal stickies in the inlet and accept of a DAF system. The sludge of DAF systems is usually very tacky, i.e., it contains stickies. When such systems are switched off, problems related to stickies are experienced more often on the paper machine⁷⁸.

Besides these preconditions, Stratton notes that a certain air bubble to particle attachment force (F_a) of stickies has special importance for the removal of stickies. This attachment force can be calculated by the following formula^{79,80}:

$$F_a \approx \pi \cdot D \cdot \gamma_{LV} \cdot (1 - \cos^2 \theta) \quad (2)$$

where D is the air bubble diameter
 γ_{LV} the surface tension of the deinking liquor
 θ the contact angle between the deinking liquor and the particles of stickies.

The contact angle depends on the surface tensions of the deinking liquor and the solid particles. Series of tests using four different hot melts having different surface tensions and different deinking chemical additions showed that the results of the mathematical model correlate with the hot melt removal in flotation steps. Figure 25 shows that the hot melt removal improves significantly when the attachment forces are greater than 1

dyne. A consistent removal of approximately 90% starts above about 1.5 dyne.

For a 90% removal of hot melts, Fig. 26 shows that the interfacial tension of the deinking liquor must increase from about 30 to 40 mN/m when the surface energy of the

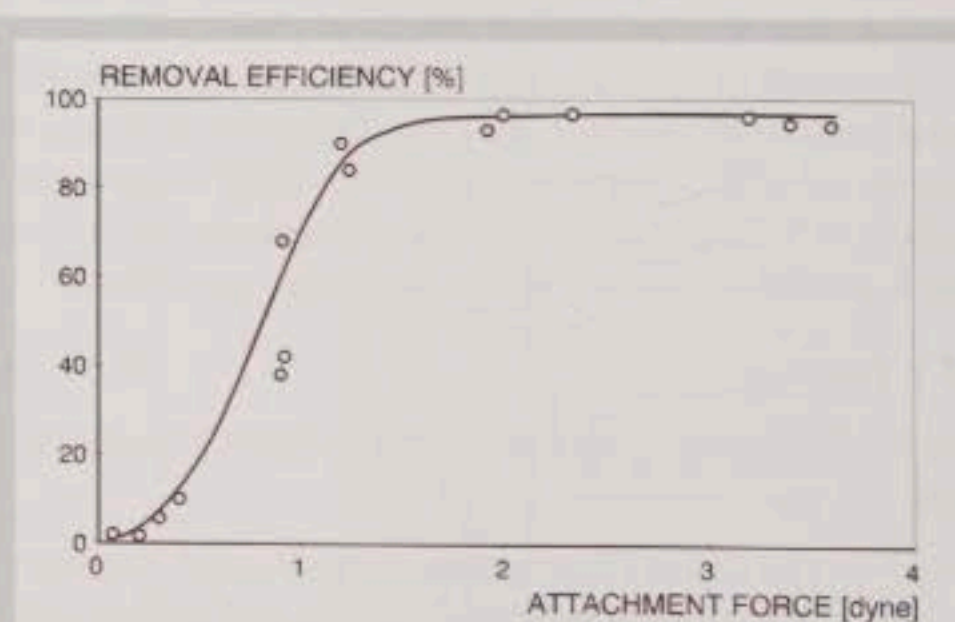


Figure 25. Flotation efficiency of hot melts vs. calculated attachment forces⁷⁹.

stickies increases from 30 and 60 mJ/m² during the tests. Note that the relationships are valid only with the flotation regime, e.g., size of the generated air bubbles or size range of stickies. The relationships highlight the fact that a high surface tension of the deinking liquor, a low surface energy of the stickies, or both improve their flotation. A disadvantage that emerged during the tests was that the surface tension of contaminants

(stickies) is time-dependent. After contact with the deinking liquor, the surface tension of the stickies increases to a constant level within a period corresponding approximately to the pulping time after the addition of the deinking chemicals. This causes the stickies to become more highly polarized or hydrophilic and therefore hinder their removal behavior⁸⁰.

Figure 27 considers an industrial deinking plant for processing deinked pulp for newsprint. In the flotation stage including the existing reject (secondary) flotation, 32% of

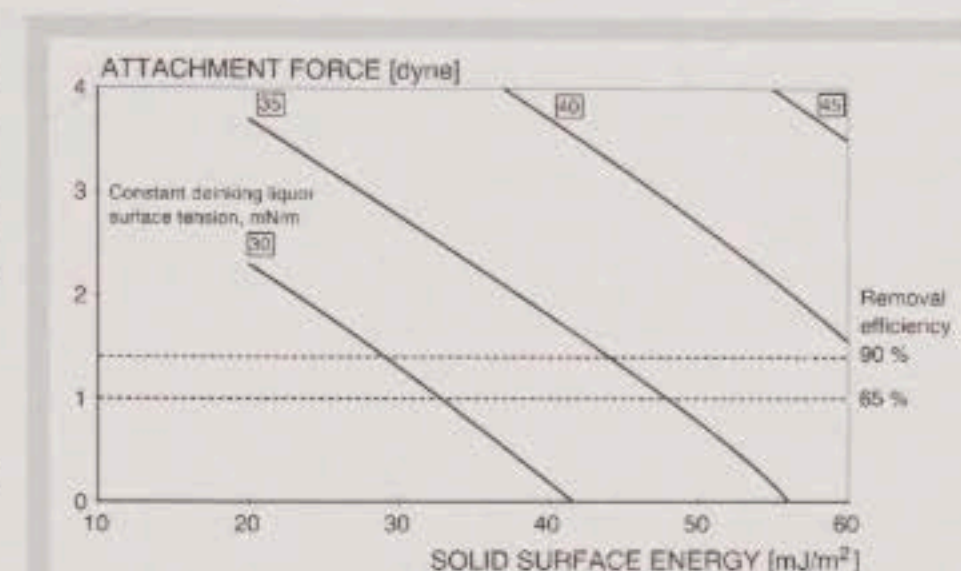


Figure 26. Attachment force between air bubble and stickies vs. surface energy of stickies for various levels of deinking liquor surface tension⁷⁹.

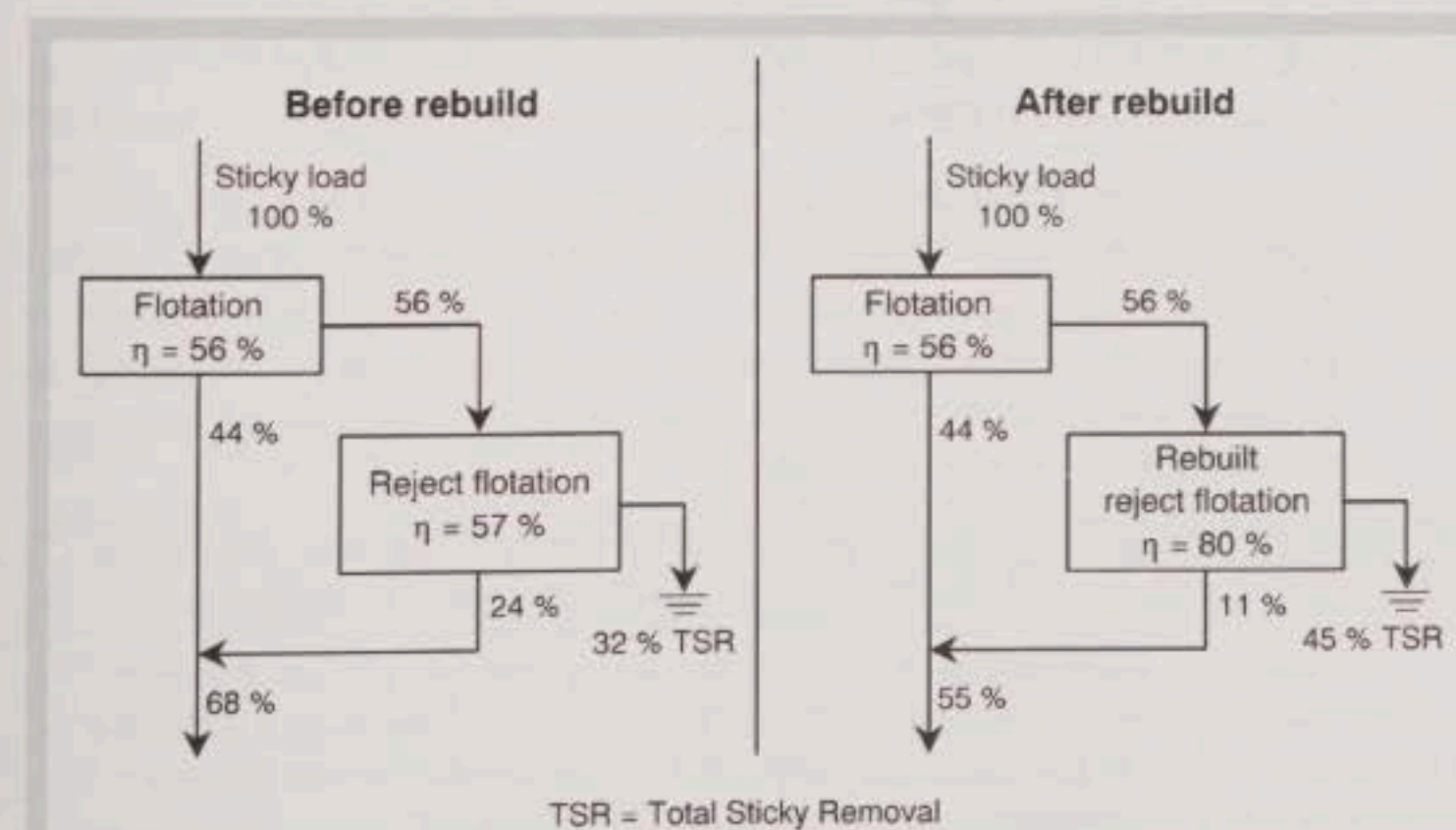


Figure 27. Removal of macro stickies by flotation before and after rebuild of the aeration elements in secondary flotation cells.

the macro stickies present were removed. Laboratory flotation tests with the feed of the reject flotation stage showed that a removal efficiency for stickies of 80%–90% instead of 57% was possible. For this reason, comparative tests were conducted in situ with a new industrial flotation cell in parallel that used a new type of aeration element to improve removal of stickies. After rebuilding the entire reject flotation stage, a removal for stickies of 80% was achieved to raise the total separation of stickies from 32% to 45%.

Simultaneously, increasing brightness by 5% ISO and reducing energy consumption by 33% was possible in the secondary stage. Using these results, flotation operated under appropriate conditions is an important process for elimination of macro stickies in the size range 150–500 μm . Although smaller stickies less than 150 μm were not analyzed, stickies in the size range 5–150 μm could be removed even more effectively. By improving the aeration elements in flotation cells, a removal rate of macro stickies with an efficiency similar to that of screening was possible⁸¹.

For the production of graphic papers based on recovered paper processing with deinking when the screening and cleaning stages are carefully organized and operated and double flotation is integrated into the system, the residual content of stickies of processed pulp is still too high in many cases. This is surprising compared with the processing of recovered paper for packaging paper and board because considerably more intensive process stages are used. The graphic paper is in a clearly lower basis weight range resulting in reduced strength and a greater risk of breaks. This situation is exacerbated by the fact that paper machines for graphic papers are run at higher speeds compared with the packaging paper and board sector.

Despite the fact that flotation occurs in the production of graphic paper, removal of stickies is still not optimum although at least hydrophobic stickies should be floatable. The following factors are presumably the reason for insufficient removal of stickies^{82–84}:

- Stickies of a size that cannot be optimally removed by flotation, e.g., too small
- Optimally sized stickies are insufficiently removed because they have a disk-shaped structure that often allows them to escape flotation in the case of toner particles
- By the adsorption of surfactants on the surface of stickies, the hydrophobic character and therefore the contact angle can be reduced to have a negative influence on the removal of stickies
- Surfactants used to stabilize the foam in flotation also influence the surface tension of the pulp to be deinked with possibly negative consequences.

Flotation units are intended primarily to ensure ink removal and are therefore optimized with this in mind. Any optimization of flotation for best removal of stickies in the production of DIP for graphic paper is possible only when undertaken without adversely affecting ink removal.

5.3.4 Washing

Besides flotation, washing is the second ink removal process used on an industrial scale. The washing process is especially efficient for removing very finely dispersed particles such as ink particles or fillers and dissolved substances from pulp suspensions. To ensure an efficient removal of solid matter by washing, the particles should not exceed about 30 μm in diameter. The extent of particle removal then depends largely on the washing device used and the operating conditions.

In principle, the same machines can be used for washing and thickening. The results depend to a large extent on how the filtrates from these machines are treated. Cleaning of the washing filtrates is therefore necessary to ensure the final removal of ink particles or fillers. The cleaned process water is then re-used in the course of the process. In contrast, thickening is usually applied only to increase the pulp consistency between two process steps in which different consistencies are necessary for optimum operating conditions, e.g., between cleaning and dispersion. Removal of the suspended solid matter and dissolved substances contained in the filtrate of the thickening machines does not occur. They recirculate with the process water.

Finely dispersed stickies should behave similarly to tiny ink particles or fillers in a washing process and be removable from the pulp suspension with the filtrate. No publications are available concerning the efficiency of removal of stickies by washing. One reason is that the available determination methods for stickies are insufficient especially for very small particles (micro stickies). Although determining the amount of stickies in the washing filtrate by precipitation is possible, this cannot be done on the inlet stock. This makes determination of removal efficiency of stickies impossible. To analyze the concentration of finely dispersed stickies in a pulp slurry, the solids would first have to be removed. This would cause a washing effect at the sample preparation stage. For this reason, only indirect conclusions based on the removal of ink particles by washing are possible.

In practice, washing results are usually assessed from the measurement of filler removal since the quantitative determination of the ash or filler content unlike the quantitative determination of the ink or even content of stickies can be carried out very simply. Table 2 shows the ranges of usual operating conditions for industrial washers.

Table 2. The operational range of industrial washers⁸⁵.

Washer	Inlet consistency [%]	Outlet consistency [%]	Filtrate consistency [%]	Ash removal (single-stage) [%]
Sidehill screen	0.6–1.0	3.0–4.0	0.15–0.35	55–60
Gravity decker	0.6–1.0	4.0–6.0	0.04–0.18	50–55
High speed belt	0.6–3.0	8.0–15.0	0.18–0.38	65–85
Screw extractor	2.0–4.0	8.0–12.0	0.25–0.40	40–45
Screw press	2.0–4.5	18.0–28.0	0.15–0.28	35–40

In older industrial plants with inefficient washers, several washing units are sometimes arranged in a series. The wash water is routed in counter-flow fashion to obtain efficient washing. Cleaned filtrate or even fresh water is used for diluting the stock before the final washing stage. The contaminated filtrate is routed countercurrently to the stock flow through earlier stages. At the first washer, the most heavily contaminated wash filtrate is directed to effluent or process water purification. Contained in this filtrate are heavy accumulations of finely dispersed contaminants in the form of ink particles, fillers, and stickies. To guarantee the definitive removal of these contaminants, ensuring the efficient operation of the process water purification system is important.

5.3.5 Other techniques

The processes described above are essentially the only ones that exist for removal of stickies although a wide range of different machine variations are offered on the market for screening, cleaning, flotation, and washing. To assure their most effective performance, the entire stock process system must be optimally sequenced and operated as Chapter 6 discussed. One important variable in this respect is pulper performance. The pulper must operate gently at high consistency and low temperature. This will ensure that contaminants and therefore also stickies are not made unnecessarily smaller since larger particles can be better eliminated by screening or cleaning.

The spinning disc developed by the Forest Products Laboratories in Madison, Wisconsin, offers an alternative to contaminant removal. With this separation technique, a pulp suspension is fed centrally to a fast-rotating disc as Fig. 28 shows. The disc sends the suspension into rotating movement that flows outside as a film. At the disc shoulder, most suspension follows the bend of the disc and is delivered as an accept flow at the lip edge. Two forces at the edge of the disc shoulder act on the particles in the liquid film that are responsible for their removal:

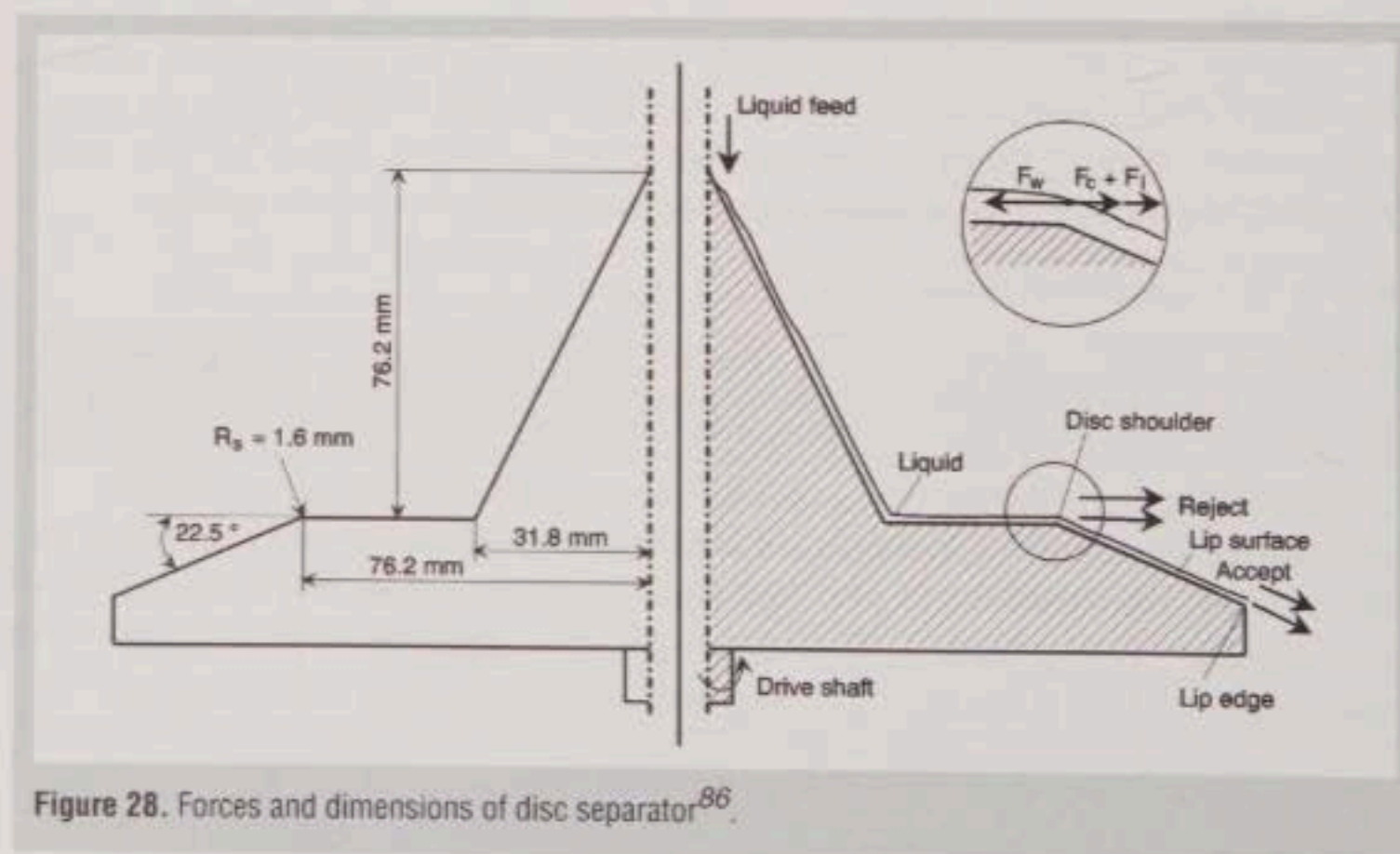


Figure 28. Forces and dimensions of disc separator⁸⁶.

- Inertial force (F_i) that results from the directional change
- Centrifugal force (F_c) that results from the rotational movement of the liquid film.

When the components of the surface tension of the liquid film (F_w) that act upon a particle are smaller than the sum of the two inversely acting removal forces ($F_i + F_c$), the particles will separate from the liquid film and be removed as reject. The surface tension F_w is inversely proportional to the wetting angle. Because the inertial force, F_i , and the centrifugal force, F_c , are determined by the fiber length, the square of the fiber diameter, and the density, a separation of stickies by differences in the wetting angle should be possible⁸⁶.

Despite the positive screening results for hot melts and pressure sensitive adhesives for which removal efficiencies of 90% and 87%, respectively, were recorded, no industrial application worth mentioning has been realized. This is possibly due to scale-up problems. The pilot machines used to date with a disc diameter of 152 mm, a rotational speed of 4 000–9 000 min^{-1} , feed flows of 1–3 m^3/h , and consistencies of about 1% permitted a maximum throughput of only 25 kg/h ⁸⁷.

5.4 Dispersion methods

Dispersion machines do not usually have use in recycled fiber pulp processing primarily for treating stickies. Instead, their use is directed toward the fragmentation of residual ink particles and the additional detachment of ink from the fiber surface in deinked pulp. They also provide a total improvement of the optical homogeneity of fiber stock. This applies for mixed (brown) recovered paper grades for the production of test liner or board and for the treatment of deinked pulps. The stickies also undergo a mechanical treatment although this does not result in their removal but causes a change in their size. Two different types of machines are available for dispersion (See Chapter 5):

- Kneaders have a slow-running rotor with protruding rhombohedrically shaped paddles on the rotor and protruding round or rectangular bars on the stator. Clearance between rotor and stator is large so the stock is treated by intense fiber-to-fiber rubbing action (inter-fiber friction).
- Dispergers consist of a high-speed rotating disk and a stationary disk both equipped with tooth-type designs that operate at much smaller clearances compared with kneaders. In the disperger, the stock undergoes acceleration and deceleration forces with internal pulp friction.

While the two dispersion machines operate at similar consistency, temperature, or specific power demand, the main difference between both machines is the circumferential speed. The kneader runs at a maximum circumferential speed of 15 m/s, but dispergers reach a circumferential speed of 50–100 m/s.

How does the mechanical treatment of the fiber stock carried out at a high consistency in the disperger change the stickies? In the high-speed disperger, the stickies are probably squashed and fragmented by impact against the rotor-stator elements. In the kneader, fiber-to-fiber friction forces crush the stickies or tear them apart. The possibility

also exists that some stickies alter their shape in these machines from flat to round particles and even agglomerate. This facilitates their removal in a subsequent flotation or washing stage. The different behavior is probably due to the nature of the stickies. Strong ones roll into balls, and weak ones disintegrate^{12,88,89}.

One supplier has long included both types of machines in its production program and can therefore make a neutral evaluation using this experience. Comparative tests with both types of machines for office paper have shown that the disperger provides a larger reduction of the average size of the stickies. The range of size reduction of stickies is considerably greater in the case of the kneader. This is partly due to the opposing effects of fragmentation of stickies and agglomeration. Although the operating conditions in the described example are not necessarily identical, similar trends are also true for other types of recovered paper. For this reason, high-speed dispergers are recommended for the dispersion of stickies⁸⁸.

Besides the type of equipment used, temperature, consistency, and specific power demand especially influence the effects that occur during dispersion. Higher temperatures, consistencies, circumferential speeds and power demand give an increasing reduction of the size of stickies. One must always remember that even in cases where the size reduction of stickies would be very significant this does not correspond to a removal of stickies. The total area of stickies increases due to the fragmentation of the stickies and their increasing specific surface area. For the commonly used screening measurement methods for stickies, the size-fragmented stickies cannot be detected especially by a laboratory screening method using a 150 μm or even 100 μm slotted plate if the generated stickies are smaller. This results in a lower total area of stickies and a decreased average diameter of stickies. Hopefully, all stickies fed to the disperger are reduced in size such that the finely dispersed stickies enter the white water loop and are partly removed by process water treatment.

For these reasons, paper mills usually recommend much greater efforts to remove stickies from the systems by smaller slots in screens, highest efficiency reverse and forward cleaners, flotation, etc., rather than relying on dispersion⁹⁰.

5.5 Passivation methods

The final measure to control or take preventive measures against stickies is the use of additives. The additives used in a pulp suspension to reduce the negative effects of stickies can be organic or inorganic. They can also be used to a certain degree directly at the paper machine where they help prevent problems with deposits.

5.5.1 Minerals

A commonly applied method of using additives to control stickies is the addition of minerals to the recycled pulp slurry. The adsorption of the minerals to the surface of stickies reduces tack. Talc has most frequent use for this purpose in addition levels of 5–20 kg/t pulp. Talc is a soft, plate-like mineral that consists of a layered structure in which a magnesium sheet is embedded sandwich-like between two silica sheets. The individual layers are held together by van der Waals forces. This explains the simple delamination of

Table 3. Chemical and physical characteristics of the different minerals available for control of stickies⁹¹.

Mineral	Particle shape	Color	Brightness [%]	B.E.T. surface area [m^2/g]	Charge	Particle size range [μm]	Remarks
Asbestos (Chrysotile)	Silica and magnesium sheets forming long, fibrous fibers	White, gray, green	n/a	4–50	Positive	Variable	1. Health hazard 2. Replaced by talc for pitch control
Bentonite	Aluminum octahedral sheet between two silica sheets	Gray to beige to white	70–90	130	Positive	20–80	1. Reduces sodium silicates 2. Works by entrapment 3. Improves efficiency of polyelectrolytes for retention 4. Replaced by talc for pitch control
Calcium carbonate	Ultrafine grind-irregular, precipitated-scalenohedron (rosette cluster)	White	96	5–11	Negative	0.1–8	1. Used in neutral and alkaline papermaking as a filler 2. Causes foaming in acid systems
Clay	Silica and alumina thin hexagonal plates	White	83–93	13–22	Negative	0.2–30	1. Used in paper filling and coating for lightscattering characteristics, printability, brightness and TiO_2 extension 2. Comes in water-washed, air-floated and calcined forms
Diatomaceous earth	Siliceous skeleton of the diatomine (a unicellular microscopic algae)	Gray to white	75–90	26–28	n/a	0.2–73	1. Works by entrapment 2. Very abrasive 3. Replaced by talc for pitch control
Talc	Magnesium sheet between two silica sheets	White	80–90	6–17	Negative	0.2–20	1. Edge hydrophilic allowing dispersion in water, flat surface hydrophobic and organophilic

talc during the beating process. The special feature of talc is that its structure has a hydrophobic and an organophilic surface although the edges are hydrophilic. This permits its dispersion in water to provide the largest organophilic surface of all known materials. The hydrophobic characteristic is also the reason why talc has often replaced other minerals such as diatomite or clay for control of stickies.

Table 3 shows the physical characteristics of talc compared with several other minerals. Talc offers high specific surface area, low particle size, high brightness, and low abrasion. Due to its charge, talc adsorbs small stickies on the organophilic surface and removes them with the produced paper. Several talc particles can also adsorb on the surface of larger stickies and cause them to be less tacky. The ability of talc to be effective simultaneously on both small and large stickies provides an advantage over other additives. If stickies are no longer tacky due to the influence of talc, an agglomeration of stickies will also be prevented. This permits the removal of stickies with the paper and ensures that they no longer present any potential problems in further processing because the tack has been neutralized^{12,91,92}.

The correct use of talc can often reduce the deposition of stickies in the wet end and in the press section of the paper machine and contribute to considerably better runnability. A reported disadvantage to the use of talc is the poor shearing stability of the talc particles on the stickies, e.g., during pumping or refining processes. This can then be the cause of large agglomerations of stickies⁹³.

5.5.2 Synthetic fibers

Instead of minerals, synthetic fibers have also been proposed for control of stickies. Synthetic fibers with their large specific surface area and extensive affinity to the hydrophobic surface of stickies can almost entirely envelop stickies to deprive them of their tack. In practice, polypropylene fibers are especially suitable. They provide an optimum effectiveness for reducing tack of stickies and deposition of stickies when used at about 0.1–0.3% (1–3 kg/t pulp)⁹⁴.

The recommended synthetic fiber material has a fiber length of 0.8–1.0 mm and a brightness of 95%. Its specific surface area with 5–10 m²/g is much larger than that of chemical pulp fibers. The synthetic fibers suspended in water (consistency of 1.0%–1.25%) should be added to the recycled fiber pulp in the beginning of its processing to allow contact with the stickies as early as possible while they are still predominantly hydrophobic. This causes small stickies to lose their tack before they can agglomerate to larger particles. For deinking systems, synthetic fibers should be used only after the ink removal process. Bleaching processes should be avoided because these process stages alter the surface characteristics of the synthetic fibers and can therefore reduce their effectiveness⁹⁵.

The following advantages can result with the continuous addition of synthetic fibers to a system in the processing of recycled fiber pulp⁹⁶:

- Continuous cleaning of the system of small stickies due to removal via the produced paper

- Avoidance of agglomeration of small stickies to larger particles
- No influence on the wet end chemistry
- No influence on physical paper characteristics
- No abrasion
- Possible improvement of fiber fines retention.

5.5.3 Zirconium chemicals

The use of zirconium for control of stickies was patented for the first time in 1980 by Honshu in Japan. Since then, industrial applications have been reported in the United States and Europe. Zirconium chemicals consist of soluble polymer chains that can be anionic, cationic, or neutral depending on their charge. In all cases, the active zirconium containing groups react with functional groups of the stickies to reduce the negative effects of the stickies. Laboratory tests showed that the tack and tacky area of adhesives (PSA and HMA) in model fiber stock could be reduced significantly following treatment with solutions of zirconium compounds (0.1%–0.3% on recycled fibers)⁹⁷.

In industrial applications of zirconium products, a two-stage dosage is recommended. To begin, a product is used that allows cross-linking of the hydroxyl groups on the stickies to make them less tacky. Depending on whether the pH of the system under consideration is below or above 7, different zirconium products are used. In a second step, an acrylophilic electrolyte is used that reacts selectively with the tacky zirconium complex and retains this in the paper sheet to prevent its release into the process water. With a concentration of these tacky zirconium complexes in the white water, they can mutually react and form larger stickies that can lead to depositions.

By the addition of up to 0.2% of these zirconium compounds, four paper mills succeeded in considerably reducing the problems related to stickies. The use of zirconium chemicals does not constitute a miracle cure because "zirconium chemicals control all the stickies some of the time, some stickies all the time, but not all the stickies all the time"⁹⁸.

5.5.4 Other chemicals

Finely dispersed stickies are not detrimental to paper production if they remain dispersed, i.e., no precipitation occurs or larger agglomerates form. The use of various chemicals is recommended to prevent the agglomeration and precipitation of finely dispersed or even colloidal stickies. Such a treatment should be regarded as a physico-chemical modification of the stickies. In principle, three different mechanisms are possible:

- Chemical dispersion
- Tack reduction
- Fixing.

The chemical dispersion technique leads to stabilization of finely dispersed stickies by surfactants that are anionic or nonionic. With suitable anionic chemicals that adsorb on the tacky surface, a change of the surface charge of stickies is possible. When this surface charge becomes greater by adsorption of anionic chemicals, the repulsion forces between the stickies become greater until no coagulation of the hydrophobic stickies occurs⁹⁹.

Nonionic surfactants form a protective surfactant layer around stickies. The ambivalent characteristic features of the surfactants are used to show in each case hydrophilic and hydrophobic components in the aqueous medium. If the hydrophobic parts of the surfactants are adsorbed on the hydrophobic stickies, this changes the surface characteristic features of the stickies. It becomes hydrophilic and receptive to water molecules so that an agglomeration of stickies is prevented^{35,99}.

The application of chemical dispersion technology presupposes the presence of finely dispersed stickies in the recycled fiber pulp. The small size of the stickies significantly reduces problems experienced with depositions in the dryer section of the paper machine or paper faults due to linting by stickies although the small stickies must also pass through the paper machine¹⁰⁰.

Problems that may occur with the application of surfactants for control of stickies relate to foaming, influence on sizing, and detachment of deposits when using the surfactants for the first time. The use of suitable chemicals positively influences paper machine runnability³⁵.

Besides the described methods involving the use of minerals and synthetic fibers, solutions of chemicals may also be added to reduce the tack of stickies. The use of minerals or synthetic fibers has the basic disadvantage that relatively large particles must settle on the surface of stickies, and these agglomerates do not offer stable shearing behavior. Synthetic fibers have a high affinity to dispersed printing inks that can then occur as colored fibers in the paper. These disadvantages can be avoided with application of nonionic polymers having high molecular weight. The polymers have a segmented composition consisting of alternating hydrophobic and hydrophilic molecular sections. The hydrophobic areas of the nonionic polymer should attach to the hydrophobic stickies, and the hydrophilic sections are attracted to the aqueous phase. These chemicals encapsulate the stickies with a multi-layered shield that effectively covers their surface. It renders the stickies nontacky and reduces their tendency for deposition in the wet end and the press section of the paper machine^{20,93,101}.

The final control method of stickies described here is the fixing of stickies to the fiber surface to remove them with the paper web. For this, cationic polymers with a high charge density and low molecular weight are used to fix anionic stickies to the anionic fibers. The typical place of use of such cationic polymers is the machine chest. High polymer dosages not only contribute to good retention of stickies but also contribute to good fiber fines and filler retention⁹³.

No sharp distinctions exist between the various polymer categories that are offered. One therefore cannot always make a clear distinction between chemicals for chemical dispersion and chemicals for fixing. Both cationic polymers used alone and with other polymers such as an anionic dispersion agent are therefore recommended¹⁰².

TNO (Netherlands Organization for Applied Scientific Research) recommends a special chemical combination for the control of secondary stickies: the BiFRIPS concept (Bi-Functional Removal Intermediate for Potential Stickies). The main components are the A-BiFRIPS particles especially synthesized from methyl acrylic acid, methyl acrylate, and ethyl acrylate. By their chemical structure, these have a strong affinity to styrene butadiene rubber (SBR) and butyl acrylate. They therefore act very selectively on potential stickies. In this context, hydrophilic substances stabilized by a negative charge are defined as potential stickies. Classified with hydrophilic, strongly anionic colloidal substances under the general term of DisCo (dissolved colloids), these substances form the anionic contaminants that are present in addition to the fibers and minerals in the pulp slurry.

The stability of the A-BiFRIPS particles at different pH values, temperatures, water hardness, and concentrations of surfactants with their small size of less than 0.5 μm and their negative surface charges offer favorable conditions for improved stabilizing of the potential stickies. The stickies stabilized negatively with BiFRIPS are agglomerated and removed during white water clarification by cationic precipitation agents. The BiFRIPS complexes of stickies remaining in the pulp can be precipitated onto the fibers by using a cationic fixing agent and removed with the paper web¹⁰³.

The chemical most commonly used by paper producers is alum. This can also contribute to stickies. Alum is necessary in stoichiometric proportions for rosin sizing. In addition, alum can improve the retention behavior in the wet end of a paper machine. Excessive use of alum can favor the coalescence of colloidal particles to cause larger agglomerates of stickies that can then cause increased problems of stickies. For this reason, minimal use of alum is a precondition for controlling problems with stickies effectively¹⁰⁴.

5.6 Prevention methods

5.6.1 Coating of wires, felts, and rolls

Control of stickies occurs not only by certain machines such as screens and chemicals during recovered paper processing but also within the paper machine. With the protection of certain machine parts and paper machine clothing (wires and felts) by the use of special chemicals, the deposition behavior of stickies can be reduced. Naturally, these can only be additional measures aimed at preventing down times (breaks or premature changes of clothing) during paper production.

The use of cationic polymers to neutralize or deactivate anionic trash in a pulp suspension or in white water has the disadvantage that very large amounts of cationic polymers are usually required due to the large amounts of anionic charges. These may then influence the wet end chemistry.

For this reason, a common practice is to spray a cationic polymer with a fresh water shower from the breast roll onto the paper machine wire. This enables the wire surface to be modified such that it is protected against stickies. The protective layer on the wire for the prevention of the deposition of stickies consists of a combined anionic

and cationic substance. The anionic part comes from the anionic trash in the pulp and water system. Because the finely dispersed stickies are removed with the paper web, assuming that the tendency toward deposition of the stickies on foils, suction boxes, felts, press rolls and in the dryer section will be reduced is logical.

Typical quantities of cationic polymers used are 5–15 mL/min/m wire width. This results in a polymer consumption for coating of about 1.0–1.3 kg/t paper. In comparison, cationic polymers usually are added to the pulp slurry at a rate of 2–5 kg/t paper. This shows the economic benefit of wire application of cationic polymers^{105,106}.

5.6.2 Machine clothing cleaning

The cleaning of paper machine clothing is another supporting measure in control of stickies. In many cases, solvents are used to clean wires and felts, to address massive deposits of stickies during operation, or to be part of regular, scheduled cleaning tasks. Cleaning with the solvents should always be carried out as effectively as possible with care to ensure that the solvent containing the stickies is not returned to the papermaking process. Accordingly, this cleaning work is done intermittently to keep the pollution with volatile organic compounds (VOC) to a minimum¹⁰¹.

References

1. Scott, W.E., "A survey of the various contaminants present in recycled wastepaper white water systems", TAPPI 1989 Seminar: Contaminant Problems and Strategies in Wastepaper Recycling, TAPPI PRESS, Atlanta, p. 69.
2. Anon., *Progress in Paper Recycling* 2(3):80(1993).
3. Gruber, E., Großmann, K., and Pätzold, R., *Wochenbl. Papierfabr.* 126(13):645(1998).
4. Doshi, M.R., *Progress in Paper Recycling* 4(2):103(1995).
5. Ackermann, C., Putz, H.-J., and Göttching, L., *Progress in Paper Recycling* 7(2):22(1998).
6. McKinney, R.W.J., "A review of stickie control methods including the role of surface phenomena control", TAPPI 1989 Seminar: Contaminant Problems and Strategies in Wastepaper Recycling, TAPPI PRESS, Atlanta, p. 101.
7. Ackermann, C., Putz, H.-J., and Göttching, L., *Wochenbl. Papierfabr.* 124(11/12):508(1996).
8. Baumgarten, H.-L., *Das Papier* 38(10A):V121(1984).
9. Friberg, T., *Progress in Paper Recycling* 6(1):70(1996).
10. Moreland, R.D., "Stickies control by detackification", TAPPI 1986 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 193.
11. Onusseit, H., *Allg. Papierrundschau* 118(20):518(1994).
12. Galland, G., "Stickies: origins and solutions", 2nd Advanced Training Course on Deinking, CTP, Grenoble, 1995, Session 13, 36 pp.
13. Doshi, M.R., *Progress in Paper Recycling* 1(1):54(1991).
14. Müller, W.J., "Haftklebstoffe", Special Issue TI/ED 1194d, BASF, Ludwigshafen, Germany, 1993, 18 pp.
15. Kirchner, C., *Labels & Labelling* 14(2):48(1992).
16. Scholz, W., *Progress in Paper Recycling* 4(1):71(1994).
17. Bassemir, R.W., "The chemical nature of modern printing inks", TAPPI 1982 Annual Meeting Proceedings, TAPPI PRESS, Atlanta, p. 99.
18. de Jong, R.L., *Wochenbl. Papierfabr.* 118(17):763(1990).
19. Mattingley, J.T., *Tappi J.* 67(6):74(1984).

20. Miller, P.C., "Chemical treatment programs for stickies control", in *Recycling Paper: From Fiber to Finished Product* (M. J. Coleman, Ed.), TAPPI PRESS, Atlanta, 1990, Vol. 2, p. 471.
21. Klein, R. and Großmann, H., "Use of surface and rheological properties in stickies removal and control", PTS Report, Papiertechnische Stiftung, Munich, 1993, 61 pp.
22. Kamutzki, W., *Wochenbl. Papierfabr.* 111(20):753(1983).
23. Ling, T.F., *Pulp Paper Can.* 94(10):T273(1993).
24. Weigl, J. and Wilken, R., "Formation mechanisms of stickies in waste paper pulp used in papermaking", in *Pulp, Paper and Board* (I. F. Hendry and W. J. H. Hanssens, Eds.), Elsevier Applied Science, London, 1987, p. 60.
25. McKinney, R.W.J., "Test methods for assessing stickie contamination – a review", TAPPI 1987 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 725.
26. Wilken, R. and Strauss, J., *Allg. Papierrundschau* 108(11/12):292(1984).
27. Guo, X.-Y. and Douek, M., "A new scheme to analyze deposits/stickies from mills using recycled fiber", 1995 CPPA 3rd Research Forum on Recycling, CPPA, Montreal, p. 91.
28. Sjöström, J. and Holmbom, B., *Paperi Puu* 70(2):151(1988).
29. Asp, F., Engstrand, P., Holmbom, B., et al., "Evaluation of contaminant flow in a deinking process and estimations of the value of the raw material", 1994 PIRA International Paper Recycling Conference, PIRA, Leatherhead, UK, 25 pp.
30. Jean, M. and Nguyen, X.T., "Quantification and removal of stickies from OCC waste papers", 1993 CPPA 2nd Research Forum on Recycling, CPPA, Montreal, p. 61.
31. Klungness, J.H., Fernandez, L.E., and Plantinga, P.L., "Image analysis for measuring adhesive contaminants in pulp", in *Recycling Paper: From Fiber to Finished Product* (M. J. Coleman, Ed.), TAPPI PRESS, Atlanta, 1990, Vol. 1, p. 455.
32. Hacker, M.P., *Tappi J.* 75(7):63(1992).
33. Doshi, M.R., Dyer, J.M., and Krueger, W.C., *Pulp Paper* 58(3):113(1984).
34. Ackermann, C., Putz, H.-J., and Göttching, L., *Das Papier* 51(6):271(1997).
35. Elsby, L.E., "Experiences from tissue and board production using stickies additives", TAPPI 1986 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 187.
36. Bittner, M.J., "Stickies collection and quantification within a production environment", TAPPI 1994 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 445.
37. Gordon, A., *Paper Technology & Industry* 29(8):399(1988).
38. Matzke, W. and Selder, H., "Additional benefits from pressureless high consistency dispersing of secondary fiber stock", TAPPI 1986 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 597.
39. Biza, P. and Lippert, G.V., *Wochenbl. Papierfabr.* 120(11/12):439(1992).
40. Burrows, P.R.M. and Small, J.D., "Removal of sticky contaminants from waste-based papermaking furnishes" 1982 European Seminar on Technological Progress in Recycling of Paper and Board, European Communities, Brussels, Report No. 14, 20 pp.
41. Forester, W., "Methods for the detection of stickies in pulp", TAPPI 1993 Deinking Short Course Notes, TAPPI PRESS, Atlanta, Session 4-2, 14 pp.
42. Cathie, K., Haydock, R., and Dias, I., *Pulp Paper Can.* 93(12):T392(1992).
43. Fukui, T. and Okagawa, A., *Tappi J.* 69(9):134(1986).
44. Dykstra, G.M., Hoekstra, P.M., and Suzuki, T., "A new method for measuring depositable pitch and stickies and evaluating control agents", TAPPI 1988 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 327.
45. Doshi, M.R., "Additives to combat sticky contaminants in secondary fibers", TAPPI 1989 Seminar: Contaminant Problems and Strategies in Wastepaper Recycling, TAPPI PRESS, Atlanta, p. 81.
46. Ling, T.F., Hall, J.D., and Walker, M.M., *Pulp Paper Can.* 94(12):T420(1993).
47. Klein, R. and Großmann, H., *Wochenbl. Papierfabr.* 123(19):871(1995).
48. Krauthauf, T., Ackermann, C., and Putz, H.-J., *Wochenbl. Papierfabr.* 126(3):81(1998).
49. Doshi, M.R., *Progress in Paper Recycling* 2(1):45(1992).
50. Krauthauf, T., Putz, H.-J., and Göttching, L., "Forced adsorption contact – A new way of stickie evaluation in recycled pulps", TAPPI 1999 Recycling Symposium Proceedings, TAPPI PRESS, Atlanta, p. 661.
51. Kolb, W. and Heusser, U., *Wochenbl. Papierfabr.* 114(1):1(1986).
52. Carré, B., Brun, J., and Galland, G., "The incidence of the destabilization of the pulp suspension on the deposition of secondary stickies", 1995 CPPA 3rd Research Forum on Recycling, CPPA, Montreal, p. 187.
53. Carré, B., Fabry, B., and Brun, J., *Progress in Paper Recycling* 5(1):68(1995).
54. Klein, R. and Großmann, H., *Paper Technology* 38(6):45(1997).
55. Doshi, M.R., *Progress in Paper Recycling* 4(4):77(1995).
56. Darlington, W. B. and Blair, W.R., *Progress in Paper Recycling* 4(3):68(1995).
57. Lobbes, T.J. and Forester, W.K., *Progress in Paper Recycling* 5(2):78(1996).
58. Abubakr, S. and Bormett, D., "Pilot testing and recycling evaluation of newly developed environmentally benign pressure sensitive adhesives", TAPPI 1998 Recycling Symposium Proceedings, TAPPI PRESS, Atlanta, p. 339.

59. Abubakr, S. and Peng, J., "Development of environmentally benign pressure sensitive adhesives", 8th PTS-CTP-Deinking-Symposium Proceedings, Munich, 1998, No. 12E. 25 pp.
60. Peng, J.Y., "Environmentally benign pressure sensitive adhesive R&D program", TAPPI 1998 Recycling Symposium Proceedings, TAPPI PRESS, Atlanta, p. 327.
61. Donermeyer, D., "Laboratory recycling of benign pressure sensitive adhesive stamp material", TAPPI 1998 Recycling Symposium Proceedings, TAPPI PRESS, Atlanta, p. 417.
62. Brettschneider, W., *Wochenbl. Papierfabr.* 121(13):531(1993).
63. Rienecker, R., *Wochenbl. Papierfabr.* 125(17):787(1997).
64. Schabel, S. and Respondek, P., *Wochenbl. Papierfabr.* 125(16):736(1997).
65. Doshi, M.R., *Progress in Paper Recycling* 3(4):69(1994).
66. Vitori, C.M., "Stock velocity and stickies removal efficiency in slotted pressure screens", 1991 CPPA 1st Research Forum on Recycling, CPPA, Montreal, p. 133.
67. Fallows, J.D., "Forward cleaners", TAPPI 1993 Deinking Short Course Notes, TAPPI PRESS, Atlanta, Session 2-5, 6 pp.
68. Berger, J., *Wochenbl. Papierfabr.* 113(21):810(1985).
69. Serres, A. and Fejoz, R., *Wochenbl. Papierfabr.* 117(7):259(1989).
70. Ferguson, L.D., "Through-flow cleaners", TAPPI 1993 Deinking Short Course Notes, TAPPI PRESS, Atlanta, Session 3-1, 9 pp.
71. McBride, D., "High density cleaners", TAPPI 1993 Deinking Short Course Notes, TAPPI PRESS, Atlanta, Session 2-2, 9 pp.
72. Moreland, L.B., *Progress in Paper Recycling* 1(1):78(1991).
73. Pearson, N. and Moore, G.K., "Tackling stickies problems at source", 1995 EUCEPA Recycling Symposium, EUCEPA, Paris, p. 67.
74. Barrett, A.E., *Progress in Paper Recycling* 3(4):37(1994).
75. Rivals, P., "Stickies removal by hydrocloning – Gyroclean and uniflow comparison at a newsprint mill scale", 1995 PIRA International Wastepaper Conference, PIRA, Leatherhead, UK, Paper No. 14, 7 pp.
76. Maze, E.L., *Progress in Paper Recycling* 6(3):40(1997).
77. Shaw, M., *Pulp & Paper* 71(12):51(1997).
78. Eisenschmid, K. and Steinbeis, B., *Wochenbl. Papierfabr.* 118(16):709(1990).
79. Stratton, R.A., *Progress in Paper Recycling* 1(4):31(1992).
80. Stratton, R.A., *J. Pulp Paper Sci.* 18(6):J221(1992).
81. Geistbeck, M. and Wiese, H., *Wochenbl. Papierfabr.* 125(16):733(1997).
82. Hodgson, K.T., "Surface science and process factors affecting removal of sticky contaminants", in *Paper Recycling Challenge* (M.R. Doshi and J.M. Dyer, Eds.), Vol. 1, Doshi & Associates Inc., Appleton, 1997, p. 71.
83. Schmidt, D.C. and Berg, J.C., *Progress in Paper Recycling* 5(2):67(1996).
84. Ling, T.F., *Pulp Paper Can.* 95(12):T501(1994).
85. Horacek, R.G., "Deinking washers", TAPPI 1993 Deinking Short Course Notes, TAPPI PRESS, Atlanta, Session 3-2, 10 pp.
86. Klungness, J.H., *Tappi J.* 70(7):125(1987).
87. Klungness, J.H., *Tappi J.* 70(3):131(1987).
88. Mannes, W., *Wochenbl. Papierfabr.* 125(19):938(1997).
89. McBride, D.H., "Dispersion", TAPPI 1993 Deinking Short Course Notes, TAPPI PRESS, Atlanta, Session 3-4, 21 pp.
90. Pimley, I.I., *Paper Asia* 14(15):22(1998).
91. Williams, G.R., "Physical chemistry of the absorption of talc, clay and other additives on the surface of sticky contaminants", TAPPI 1987 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 563.
92. Doshi, M.R., "Additives to combat sticky contaminants in secondary fibers", TAPPI 1989 Seminar: Contaminant Problems and Strategies in Wastepaper Recycling, TAPPI PRESS, Atlanta, p. 81.
93. Fogarty, T.J., "Cost effective, common sense approach to stickies control", TAPPI 1992 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 429.
94. McKinney, R.W.J. and Currie, P.C.G., "Sticky pacification – new additive shows considerable promise", TAPPI 1986 Papermakers Conference Proceedings, TAPPI PRESS, Atlanta, p. 161.
95. Wade, D.E., *Pulp Paper Can.* 90(1):154(1989).
96. Wade, D.E., "Sticky pacification with synthetic pulps", in *Recycling Paper: From Fiber to Finished Product* (M. J. Coleman, Ed.), Vol. 2, TAPPI PRESS, Atlanta, 1990, p. 536.
97. Mann, S., "Sticky moments", 1993 PIRA Conference: Developments in Wastepaper Technology, Leatherhead, UK, Paper No. 10, 13 pp.
98. Goldberg, J.Q., "Use of zirconium chemical in sticky contaminants control", TAPPI 1987 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 585.
99. Hoekstra, P.M. and May, O.W., "Developments in the control of stickies", TAPPI 1987 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 573.
100. Gould, I., "Chemical control of stickies", 1993 PIRA Conference: Developments in Wastepaper Technology, PIRA, Leatherhead, UK, Paper No. 11, 11 pp.

101. Gould, I., "Contaminant control – stickies", 1995 PIRA International Wastepaper Technology Conference, PIRA, Leatherhead, UK, Paper No. 15, 14 pp.
102. Dykstra, P.M. and May, O.W., "Controlling stickies with water-soluble polymers", TAPPI 1989 Seminar: Contaminant Problems and Strategies in Wastepaper Recycling, TAPPI PRESS, Atlanta, p. 97.
103. Hooimeijer, A. and Blaak, R., "Chemicals to control secondary stickies – making money or a waste of money?" 1995 PIRA International Wastepaper Technology Conference, PIRA, Leatherhead, UK, Paper No. 16, 12 pp.
104. Ormerod, D.L. and Hipolit, K.J., "Aluminum control prevents stickies problems", in *Recycling Paper: From Fiber to Finished Product* (M. J. Coleman, Ed.), Vol. 2, TAPPI PRESS, Atlanta, 1990, p. 489.
105. Kenney, R.M. and Engstrom, G.G., "New technology for stickies/pitch control with increased production/profitability", TAPPI 1988 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 339.
106. Duffy, R.J. and Aston, D.A., *Pulp Paper Can.* 90(7):89(1989).

CHAPTER 12

Final fate of waste from recovered paper processing and non-recycled paper products

1	Categories of paper mill waste	507
2	Use and final disposal of solid waste from recovered paper processing	509
2.1	Solid waste composition and characteristics	510
2.1.1	Rejects.....	511
2.1.2	Deinking sludges	512
2.2	In-mill pre-handling	516
2.2.1	Dewatering	516
2.2.2	Drying.....	517
2.3	Energy recovery in internal and external combustion facilities	519
2.3.1	Grate combustion	521
2.3.2	Fluidized bed combustion	522
2.3.3	Multiple hearth combustion.....	524
2.3.4	Which combustion technology for which type of waste?.....	525
2.3.5	Emissions.....	525
2.3.6	Ash composition and ash use.....	529
2.3.7	Co-firing of sludges and rejects.....	530
2.4	Composting and agricultural use	531
2.4.1	Composting conditions.....	531
2.4.2	Composting processes	533
2.4.3	Compost applications	535
2.4.4	Composting of rejects and sludges.....	536
2.4.5	Agricultural use	537
2.5	Use in other industries	538
2.5.1	Cement production	538
2.5.2	Brick production	541
2.6	Landfilling	542
2.6.1	Types of landfills	543
2.6.2	Landfill gas generation	544
2.6.3	Leakage generation.....	545
2.6.4	Landfill sealing systems	545
2.6.5	Landfilling of waste from recovered paper processing mills.....	546
2.7	New developments	547
2.7.1	Wet oxidation processes.....	547
2.7.2	Filler recovery from combustion ashes.....	551