Stickies in Recovered Paper Fiber Suspensions: A Tutorial Review

Martin A. Hubbe

The paper industry has achieved relatively high levels of recovery and reuse of cellulosic fibers by the recycling of paper. The industry's record of recovering material from used paper products far exceeds that of, for instance, the plastics industry. However, in the course of that success there are challenges. This paper provides a tutorial review of problems related to the stickies content of recovered used paper material. The review considers what stickies are composed of, how they can affect papermaking and its products, and how papermakers can minimize their adverse effects. Stickies tend to be problematic in mills without deinking systems. Though some stickies can be removed by screening, much of the material is expected to deform and thereby pass through industrial screens. Larger stickies (macrostickies) can be removed using hydrocyclones, whereas smaller ones (microstickies) are often removed using flotation. Other approaches to dealing with stickies include using detackifiers, which essentially means covering the stickies with a polymer or a mineral product. Production teams can optimize conditions to retain the stickies, ideally as small particles, onto cellulosic fibers. Because the processes are complex, and the composition of recovered stock tends to change over time, continuing efforts will be required. Effective control of stickies can be expected to require effective collaboration among people at the mill, chemical supplier companies, and machinery specialists.

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INTRODUCTION

Stickies Definition

Stickies is a term used by modern papermakers to denote petroleum-derived substances that exhibit a sticky or tacky nature (Baumgarten 1984; Mouyal 1996; Doshi 2002; Gribble *et al.* 2010). This review considers their origins, their main effects, their composition, and a variety of ways in which technologists have succeeded in mitigating their adverse effects on paper machine operations and in paper products, including process efficiency and product defects.

Though the main focus of this article is on synthetic compounds, it is important to note that various extractable monomeric compounds from wood also can contribute to tacky deposits on the wetted surfaces of a paper machine and spots in paper products (Allen 2002). Such compounds are often referred to as "pitch." The components of pitch, individually or as mixtures, can deposit onto surfaces within the paper machine system or they can form into agglomerates that are large enough to be visible at the surfaces of paper products (Mouyal 1996). In addition, deposits on papermaking equipment often contain a mixtures of stickies and wood resins (Allen 2002; Sutman and Nelson 2022). Thus, pitch-related problems in papermaking can contribute to stickies-related problems and *vice versa.*

Motivations

Sticky and tacky materials present in the fiber mixtures from which paper is made can adversely affect both the quantity of production and the quality of products (Doshi and Dyer 2000). In the case of stickies, primary blame for the problems usually can be assigned to the usage of recycled paper as a source of fibers. This review will consider different generic sources of stickies, including pressure-sensitive labels, various adhesives, and coating binders. Figure 1 depicts a pressure-sensitive label, together with its adhesive layer and a release paper. Assemblies of labels on continuous rolls of release paper enable rapid printing of information such as address labels. The labels are then automatically applied to mailing envelopes, which soon mostly become recycled as either office waste or mixed waste.

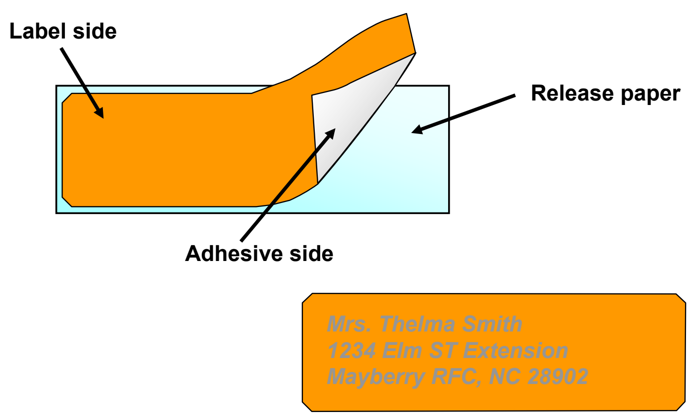


Fig. 1. Format of a pressure-sensitive label, in which the produce is delivered to a printing company in the form of a sandwich, in which the adhesive is between the label paper and a release paper. The highly tacky nature of such products has drawn the attention of many researchers and inventors.

In various cases, stickies can build up on the surfaces within paper machine headboxes, on forming fabrics, on transfer rolls, within wet-press felts, on dryer fabrics, and on the dryer can surfaces. Related losses in production efficiency may be due to the breakage of the paper web, the rejection of substandard product, and the need to stop production to clean the paper machine equipment. Some principal themes of this article are shown in Fig. 2, in which each item is depicted as being on a pressure-sensitive label. The main steps in dealing with problems related to stickies in paper machine systems are shown at left, namely "remove them; render them harmless, and retain the rest". Some underlying goals (test them and control them) are shown at right.

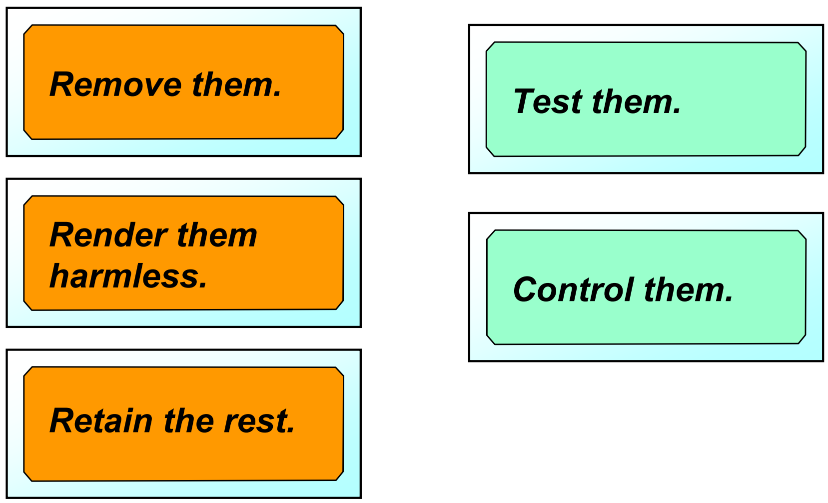


Fig. 2. Some main themes of this article

Contributing Causes

Almost all problems related to stickies in the papermaking process and in paper products ultimately can be traced to the recovery and recycling of used paper. For instance, Douek *et al.* (1997) surveyed stickies issues in eleven newsprint, three fine paper, four paperboard, and two tissue paper mills and traced such problems to specific synthetic compounds, based on spectroscopic evidence. However, it is important to keep in mind that the recycling of coated broke can add to such problems due to the sticky nature of coating binders, *e.g.* ethylene vinylacetate (EVAc) and styrene butadiene resin (SBR) (Grenz *et al.* 1994; Licursi *et al.* 2016). Thus, it is not always possible to place blame on components present in the recovered fibers. Rather, one needs to also consider components of stickies that may have been added at the same paper manufacturing facility.

Though efforts to mitigate the effects of sticky materials in papermaking can be regarded as a relatively mature field of technology, there are reasons to expect papermakers to continue to direct attention to such issues. One reason is that the amounts and nature of sticky materials entering a typical paper recycling operation are highly variable (Jones 2005; MacNeil *et al.* 2010), and the amounts of stickies present in recovered paper have increased over time (Spiess and Renner 2004). Another reason is that new paper and paperboard products are continually being introduced to the market. Some of them will include new variants of stickies, which may fall outside of the experience of production teams in the paper mills. Such issues tend to become magnified over time as the industry places increasing reliance on used paper as a main source of fiber (Hamann and

Blechschmidt 2000). As will be discussed in this review, certain problems related to stickies involve interactions among various different contaminants and process additives within papermaking processes.

As indicated in Fig. 3, increased challenges related to stickies also can be expected in future years due to likely increases in paper recycling (Hamann and Blechschmidt 2000; Van Ewijk *et al.* 2018), greater reuse of process water within paper mills (Carre *et al.* 1998), and high process temperatures. The higher temperatures promote softening of sticky materials, as has been reported in several patent documents (Spence *et al.* 2002-pat; Lasmarias *et al.* 2004-pat; Cowman *et al.* 2019-pat; Findlay *et al.* 2023-pat).

The lower part of Fig. 3 illustrates three loops of reuse and recovery. The widest loop represents the increasing reliance of the paper industry on the recycling of paper wastes. Post-consumer wastes are expected to be the largest component of this outer loop. The middle loop in the figure is meant as a reminder of the fact that recovery and reuse of broke within a paper mill sometimes includes adhesives used in coatings (*e.g.* latex binders) and hot-melt adhesives. The innermost two loops involve recirculation of process water; higher levels of such recirculation tend to concentrate various impurities, which can include stickies.

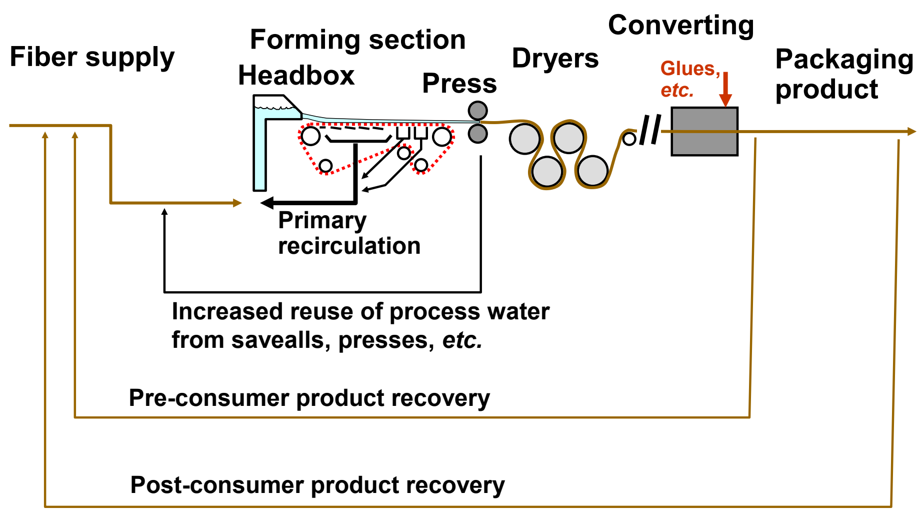


Fig. 3. Illustration of some reasons to anticipate continuing problems related to stickies in paper machine systems in the coming years

The relative amounts of paper recycling, in comparison to the usage of virgin pulp fibers, depends both on the grade of paper and on the region of the world (Zhu and Buongiorno 2002; Ervasti *et al.* 2016). Some regions, such as southern Europe and Korea, produce a lot of paper but have relatively few kraft pulp mills. In those regions the proportional content of recovered fibers in most paper grades is very high, and the fibers get used multiple times.

An emerging category of paper products that is likely to contribute new components and increasing levels of stickies is water-borne barrier coatings for food packaging (Tyagi *et al.* 2021; Adak *et al.* 2025; Benz *et al.* 2025). The development of such products has been motivated by concerns about the environmental persistence of fossil-based plastic components in common single-use food containers and food service items. The waterborne coating formulations that are being developed and implemented to address this challenge have included latex emulsions, nanocellulose, silane-related products, bentonite clays, waxes, and a variety of other components. The goal, in these formulations, is to achieve resistance to transmission of oxygen, water vapor, and grease, while also being able to tolerate immersion in liquid water. The components of such formulations, individually or in combination, can be expected to affect stickies problems when such materials become recycled to recover their fiber content.

While the details of deinking technology lie beyond the scope of the present review, it is important to acknowledge that unit operations employed during deinking can be in many ways parallel to the steps that can be employed for mitigation of stickies. Spiess and Renner (2004) observed that stickies often remain a serious issue even after having employed effective deinking processes. They reported that the amounts of stickies present in deinked pulps more than doubled during the period between 1996 and 2000.

Various aspects related to stickies have been dealt with in earlier review articles (Baumgarten 1984). For example, Abbott (1997) emphasized testing methods for stickies, as well as standardization. Angelac *et al.* (1997) focused on stickies present in newsprint mills. Doshi and Dyer (2002) provide a comprehensive review of stickies, including discussion of their origins, their composition, testing, and ways to overcome problems related to stickies. Blanco *et al.* (2002) highlighted stickies-related issues as being distinct but not isolated from problems related to slime deposits in paper machine systems and slime holes in paper products. Hamann and Strauss (2003) emphasized factors contributing to the seriousness of stickies-related problems observed in paper mills. Hubbe *et al.* (2006) provided a broader overview, emphasizing deposit control technology. Sutman and Nelson (2022) considered the control of organic contaminants in general, in a chapter dealing with both pitch and stickies issues. Bajpai's (2024) textbook on recycling and deinking of recovered paper includes a chapter on stickies control.

CONSEQUENCES OF STICKIES

Various adverse effects of stickies have been widely reported. Highlights of such studies are given in Table 1. It is worth noting that the frequency of the publications describing effects of stickies was highest during a time period of rapidly expending recycling of used paper, *i.e.* the mid-1990s to about 2011.

Table 1. Publications Describing Adverse Effects of Stickies on Either Product Quality or Production Rate or Efficiency

Highlights of the Study's Findings	Citation
Various adverse effects of stickies are described related to the manufacture of printing paper. Stickies were reported based on the number counted per unit area of paper.	Beck 1996
Stickies deposits have been observed on forming fabrics, press felts, and on rolls in paper machine systems.	Mouyal 1996
Spots in the paper tend to be the main stickies-related complaints in the manufacture of fine paper, whereas deposits on dryer fabrics are a main complaint due to stickies in paperboard mills.	Douek *et al.* 1997
Efforts to reduce the amount of water used in manufacturing were reported to increase the frequency of stickies deposition onto forming fabrics, press felts, and dryer fabrics.	Carre *et al.* 1998
Different synthetic compounds, in addition to pitch compounds, were found to have different tendencies to deposit in different parts of the	Klein 2000

Highlights of the Study's Findings	Citation
papermaking process, including the forming section, press section, drying section, and calenders.	
Efforts to deal with stickies problems resulted in a 95% decrease in paper machine downtime.	Crowe & Landstra 2001
Stickies deposits onto forming fabrics, press felts, press rolls, and drying cylinders are reported, in addition to efforts and downtime needed to clean such equipment.	Spedding 2002
The authors consider the feasibility of manufacturing adhesives that can minimize problems if and when the paper product becomes recycled.	Hamann and Strauss 2003
A laboratory-scale simulator was developed to quantify problems related to stickies in the dryer section of a paper machine. Tack forces were found to decrease with increasing temperature in the range from 90 to 120 °C.	Fike *et al.* 2006
Effects of sticky contaminants in the drying section can be especially problematic in the Condebelt system, in which the sheet is dried between a pair of stainless steel belts, one of which is being heated and the other is being cooled.	Lee and Kim 2006
Sticky contaminants often deposit within the paper machine headbox, forming fabrics, press sections, and dryer sections.	Dong *et al.* 2010
The frequency of stickies observed on the paper was correlated to the frequency of web breaks on the paper machine, hurting the rate of production. More than half of the breaks occurred either in the press section or in the early parts of the dryer section.	Salminen *et al.* 2010
The composition of stickies deposited within the dryer section of a paper machine for packaging paper was evaluated.	Ma and Shi 2011
Adhesives from the converting of paper products were reported to fill and clog wet-press felts and other fabrics used on paper machines.	Huber *et al.* 2013
In this review chapter, the authors provide an overview of problems related to stickies and how to overcome such problems.	Sutman & Nelson 2022

Blemishes in the Paper Product

Blemishes present in paper manufactured from recovered fibers have been among the most critical concerns of manufacturers, since such blemishes can result in complaints and in lost revenue. Here it is important to stress that many such complaints may be mainly due to ink spots, which can be regarded as an additional concern that goes beyond the present topic of stickies. Issues related to ink in recovered fibers, the deinking of such fibers, and spots related to ink have been reported elsewhere (Ortner 1981; Seifert and Gilkey 1997; Pala *et al.* 2004; Pathak *et al.* 2011; Saxena and Chauhan 2017).

Operational Problems Affecting Production Rates

As indicated by the contents of Table 1, losses in production rate on paper machines have been widely attributed to stickies. There are diverse contributions to such losses. The deposition of stickies onto transfer rolls or felts in the wet-press section can increase the frequency of web breaks (Salminen *et al.* 2010; Huber *et al.* 2013). Such breaks will stop paper production at least until the web of paper can be rethreaded. The filling of wet-press felts with stickies and associated matter (Mouyal 1996; Douek *et al.* 1997; Carre *et al.* 1998; Salminen *et al.* 2010) can adversely affect dewatering. The papermakers may have to decrease the production speed, thereby allowing more time in the dryer section, so that the paper can reach the target final moisture content.

The fact that the tackiness of stickies can change in response to heating (Doshi and Dyer 2002) can explain some of the observed problems related to deposition of stickies onto dryer fabrics and onto the surfaces of steam-heated dryer cans (Klein 2000; Spedding 2002; Fike *et al*. 2006; Lee and Kim 2006; Dong *et al.* 2010; Salminen *et al.* 2010; Ma and Shi 2011). However, as noted by Moore *et al.* (1998) sometimes a high tackiness of stickies within a paper product does not become problematic until the material has cooled down. Such a situation can explain problems related to stickies during the converting of paper or paperboard that has been manufactured from recovered paper. To overcome such problems, production may have to be stopped more frequently for general washing of the paper machine wet end (boil-out) and the press section (felt washing) (Sutman and Nelson 2022). Such increased outages result in additional non-productive time on the paper machine which will reduce profitability.

Transfer of Stickies from the Paper to the Equipment

Because commercial paper machines usually are run continuously, day and night, the buildup of stickies on wetted surfaces can take place even when the relative amounts of the stickies are low. For example, there can be a gradual transfer of stickies from the paper web surface to forming fabrics, transfer rolls, wet-press fabric surfaces, dryer cans, dryer fabrics, and even to calender rolls (Carre *et al.* 1998; Huber *et al.* 2013). The locations and seriousness of such transfer is often governed by temperature, which often determines the degree of tackiness of the components of the stickies (Klein and Grossman 1995; Moore *et al.* 1998; Gao *et al.* 2012). The mechanism by which deposition of stickies occurs on hot surfaces has been demonstrated using a lab-scale device to simulate aspects of the dryer section of a paper machine (Fike *et al.* 2006). Ling (1998) and Fike *et al.* (2006) reported that the tackiness of stickies decreases with increasing temperature. As illustrated in Fig. 4, the increased tackiness of dryer can surfaces has been found to increase the angle of release of the paper web, thereby making breaks of the paper web more likely. The figure also calls attention to another problem: The present of visible blemishes at the surface of the paper product due to stickies.

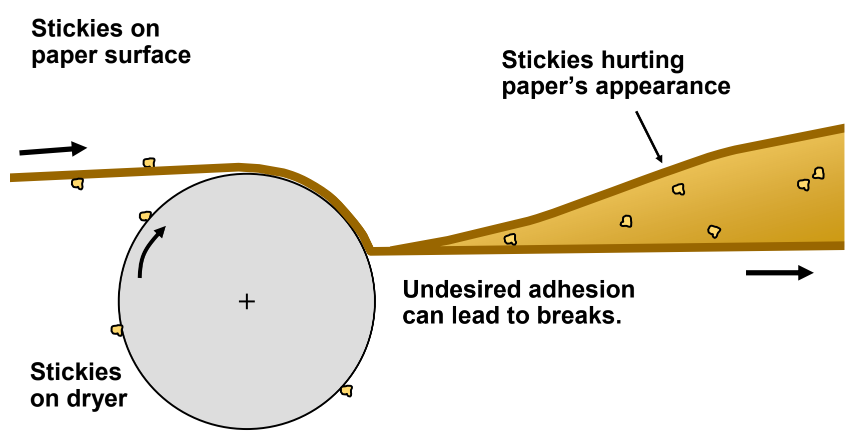


Fig. 4. Illustration of two harmful effects of a continual transfer of stickies from the surface of a paper web to various surfaces within a paper machine system: Clinging of the web to the surfaces of fabrics, rolls, or dryer cans, potentially leading to web breaks; and visible blemishes in the paper product

A different mechanism is likely involved in the filling of wet-press felts. In such operations, water is being forced out of the paper under high pressure. Some stickies present in that water may accompany the flow into the greater void volume of the press felts. Some of the sticky material likely will be removed by felt showers and uhle (suction) boxes, often with the assistance of detergents (Kling and Blickenstorfer 2008; Häusler 2016). However, the generally hydrophobic nature of bat-on-mesh material used in the manufacture of wet-press felts can favor the attachment of the relatively hydrophobic stickies, making them resistant to felt-washing systems. The term “scabs” is sometimes using to describe deposit-related problems associated with calendering of paper. Voosen and Voosen (1997) reported that such scabs, when analyzed, can have compositions similar to those of stickies. In the case considered, the problem was solved by improved removal of stickies from the recovered fiber suspension before the manufacture of the paper. Deposits of stickies within calenders have been reported in several studies (Voosen and Voosen 1997; Klein 2000). In addition, stickies deposition within calender systems have been mentioned in US patents (Basing *et al.* 2017; Luo and Riser 2021-pat).

TEST METHODS

Overview of Test Methods

In manufacturing, often the best ways to solve operational problems start with development and implementation of test methods. There have been many published methods related to stickies, and some have been adopted as standards. Doshi and Dyer (2002) describe a wide assortment of such tests. Some of the questions addressed by the tests concern “how much” stickies are present, what is their composition, and the quantification of their properties, such as particle size or tackiness.

There are several different motivations for the development and usage of test methods related to stickies. For instance, it is sometimes helpful to be able to predict the onset of problems in a paper machine system. It has been found that the levels of stickies in paper recycling mills can vary by large factors over relatively short periods of time, *e.g.* from hour to hour (Jones 2005; MacNeil *et al.* 2010). Papermakers would like to be able to predict what will happen within their process during the upcoming hours. Such predictions can be especially helpful when the operating team is attempting to either develop or optimize some kind of treatment scheme, which might involve minerals, chemical agents, or various processes aimed at removing stickies from the fiber suspension. Customers who receive deinked pulp from a paper recycling facility will want a way to ensure that residual levels of stickies in the pulp will be low enough that they will not encounter serious problems within their own operations, which may include papermaking, converting, or printing. In especially serious cases, the production team may be seeking information about the chemical composition or the tackiness of deposited stickies. This diversity of goals may help to explain the wide diversity of test methods described in the subsections that follow.

Staining

The reason for considering staining first, before various other stickies-related test methods, is that staining often is able to enhance a variety of other test methods, as will be discussed. Staining methods take advantage of the hydrophobic nature of most substances that fall within the category of stickies. Thus, one of the common features of dyes used in the staining of stickies is that they are generally highly hydrophobic. Table 2 lists studies related to stickies, including presentations of test procedures, which use colored dyes to enhance the visibility of stickies are listed in Table 2.

Table 2. Highlights from Studies and Test Procedures in Which Dyes Have Been Used to Increase the Visibility or Instrumental Detection of Stickies

Highlights from the Article	Citation
A Pira deposition device was used to collect stickies on the surfaces of forming fabrics. A hydrophobic dye was used to stain the stickies, making them easier to count.	Venditti *et al.* 1998
Morplas Blue 1003 dye was used to enhance the visibility of stickies in handsheets, with counting done by image analysis. A detailed procedure is provided.	Crossley & Mansen 1999
Stickies particles, related to pressure-sensitive adhesives, were stained with a hydrophobic dye to enhance their ability to be counted, using image analysis.	Huo *et al.* 1999
The authors used a “reverse staining” procedure in which the fibers of handsheets are dyed black as a means of rendering stickies more visible. However, the procedure did not work well with specimens from the paper mill system that was considered in the article.	Crowe and Landstra 2001
This patent claims the use of hydrophobic dyes to aid in the detection of stickies; the dyes can include fluorescent dyes.	Perry *et al.* 2009-pat
A dye was used to render the stickies more visible during video observation in a transparent mechanical refining device used to study dispersion of stickies as a function of temperature.	Zou *et al.* 2010
Morplas Blue 1003 was used to allow better scanning of stickies particles in handsheets.	Fu *et al.* 2012
This patent claims the usage of a hydrophobic dye as a means to judge the relatively hydrophobicity of stickies.	Joensuu & Piironen 2022-pat
In this patent, a fluorescent due was applied to different fractions of stickies, that had been sorted by particles size.	Joensuu *et al.* 2022-pat

Several widely used test methods related to stickies employ Morplas blue 1003 dye (Venditti *et al.* 1998; Huo *et al.* 1999; Doshi and Dyer 2002; Rosenberger and Houtman 2002; Zou *et al.* 2010). The chemical structure of this dye is shown in Fig. 5.

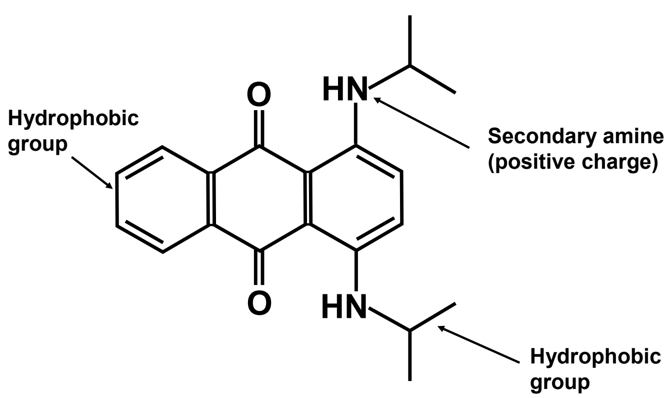


Fig. 5. Chemical structure of Morplas blue 1003 dye, CI 61551 (Oil Blue A, 1,4-bis[(propan-2-yl)amino]anthracene-9,10-dione), which is used in some tests to stain stickies, rendering them more visible, especially when using scanning methods of quantification

Though this dye contains two tertiary nitrogens, which can explain the ability of this dye to dissolve in water at sufficiently low pH, the hydrophobic groups tend to dominate its interactions. Hence, it has been found to have a high affinity and mutual solubility with common components of stickies.

Figure 6 illustrates two common ways in which dyes have been used in the paper industry to help with the quantification of stickies, especially in the case of relatively large particles. Part A of the figure represents the use of a hydrophobic dye such as Morplas blue to stain the stickies so that they can be more easily counted (see later discussion) on a white background such as filter paper or a paper product of interest. Part B of the figure illustrates the type of effect that can be achieved when using a hydrophilic dye, which will tend to stain the paper fibers while leaving the stickies white, again achieving a strong contrast between the stickies and the background.

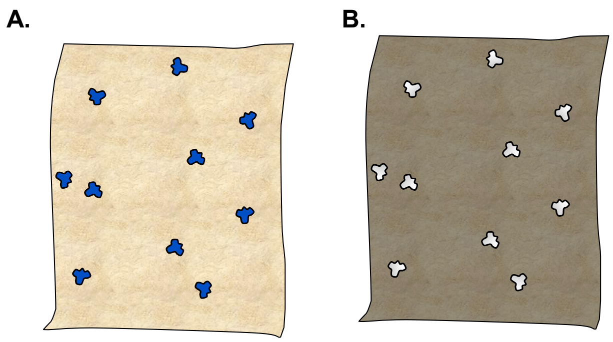


Fig. 6. Schematic diagram contrasting two ways to employ dyes to render stickies more visible on paper surfaces: A. Staining the stickies with a hydrophobic dye; B. Using black filter paper or using a black dye having low affinity for stickies

Though dyes are widely used to enhance the ability of stickies to be counted using a digital scanner, and alternative approach was demonstrated by Fu *et al.* (2012). These authors found that higher performance of counting stickies in paper could be enhanced by selecting a lower contrast setting during the scanning. However, a higher contrast was effective when the goal was to count dirt specks.

Fluorescent dyes

Fluorescent dyes can be especially effective in some test procedures due to their specificity. Such dyes have characteristic emission wavelengths that differ from the incident light. Thus, the outputs can be quantified with relatively high resolution, even when the specimen contains other chromophores. Table 3 summarizes published work that has used fluorescent dyes in the study or control of stickies. As shown by various entries in the table, the specificity of adsorption of certain dyes to certain kinds of contaminants can make it feasible to separately characterize the amounts and approximate particle sizes of different components in a suspension (Holmbom and Vähäsalo 2008). Such information may be obtained either by flow cytometry (Holmbom and Vähäsalo 2008) or by fractionating the stained suspension by size or mass (Joensuu *et al.* 2022-pat). The existence of five US patents covering related technology can be taken as evidence of corporate interest in such testing.

Table 3. Some Themes from Studies and Test Procedures in Which Fluorescent Dyes Were Used to Reveal of Quantify Stickies

Highlights from the Article	Citation
Fluorescent markers were used to differentiate between different components of pitch and stickies, hydrophobic sizing agents, and soaps used in flotation deinking operations. The particles were then used in flow cytometry tests to determine the numbers and sizes of each component.	Holmbom & Vähäsalo 2008
This US patent claims the use of hydrophobic dyes, including fluorescent dyes, to detect organic contaminants in paper pulp and fiber suspensions.	Perry *et al.* 2009-pat
This US patent claims the addition of hydrophobic dye to a paper pulp suspension, followed by evaluation of the hydrophobic contaminants.	Di Cesare 2011-pat
This US patent claims usage of a fluorescent dye as a means of optimizing treatment chemicals to control hydrophobic contaminants.	Yuan 2016-pat
This US patent claims the optical monitoring of a receiving surface for the build-up of deposits, with the optional usage of fluorescent dyes to enhance the detection of certain hydrophobic contaminants.	Piironen *et al.* 2019-pat
This US patent claims the addition of a hydrophobic fluorescent dye, followed by fractionation of mixture by particle size or mass.	Joensuu *et al.* 2022-pat

Inspection of Paper

Several test procedures related to stickies can be roughly described as "paper inspection" tests. A common feature is that the analyst somehow quantifies the stickies that are either in or on the surface of some kind of paper, which may include filter paper. Table 4 provides a listing of articles and/or standards of this type. The method by Doshi *et al.* (1998) has been recommended by subsequent researchers (Rosenberger *et al.* 1999; Doshi *et al.* 2018).

Table 4. Stickies-related Test Methods Involving Inspection of Paper

Highlights of the Test Procedure	Citation
Standard handsheets can be used as a means of quantifying stickies in pulp samples from paper mills, especially when comparing different stages of the process.	Krueger and Bowers 1981
The numbers of stickies are reported per area of paper, according to one of the procedures considered in this work.	Beck 1996
Lab screening of deinked pulp was used to isolate macro-stickies, which were collected on filter paper and quantified by image analysis. Two dye-based methods were used, either staining the stickies dark with a hydrophobic dye or staining them with white powder. By subtracting the results, it is possible to quantify the true stickies, not counting various dirt or ink specks. Alternatively, a black dye can be used to stain the background, making the white stickies highly visible.	Ackermann *et al.* 1997
Rejects from a 6-cut or 4-cut slotted screen are collected on filter paper. Standardized drying results in hydrophobic areas, which stand out after the filter paper is wetted, rendering the background translucent. The method is reported to be quite specific for stickies.	Doshi *et al.* 1998
Stickies particles in paper mill process water were quantified by collecting them onto black-dyed filter paper. Screen rejects, *i.e.* macrostickies, were collected on the filter paper, which was heated and then subjected to image analysis.	Heise *et al.* 1999

Highlights of the Test Procedure	Citation
The numbers of stickies and stickies per area of paper were counted based on microscopic images. Reverse staining of the fibers was used to make the white stickies stand out for easier counting.	Crowe and Landstra 2001
Screened stickies were filtered using filter paper that had been stained black, allowing the white stickies to stand out and be counted.	Ackermann *et al.* 2002
The "overview" chapter by these authors describes various test methods, including testing of handsheets and use of a scanner to count stickies particles, often including the usage of a dye to darken the stickies or a dye to darken the fibers to contrast with undyed stickies.	Doshi & Dyer 2002
Dirt speck analysis was carried out with a scanner to quantify combinations of dirt and stickies.	Klein and Berger 2008

Figure 7 illustrates a general approach to stickies counting based on the sequence of standardized screening, transferring the stickies to the surface of filter paper, and then using a scanner to count the stickies. Note that the process illustrated here can be enhanced by the use of a hydrophobic dye, as was shown in the previous figure. One of the nice features of this kind of testing is that slotted screens often serve as the first unit operation in paper mills where the goal is to remove a large portion of the stickies present in the recovered pulp.

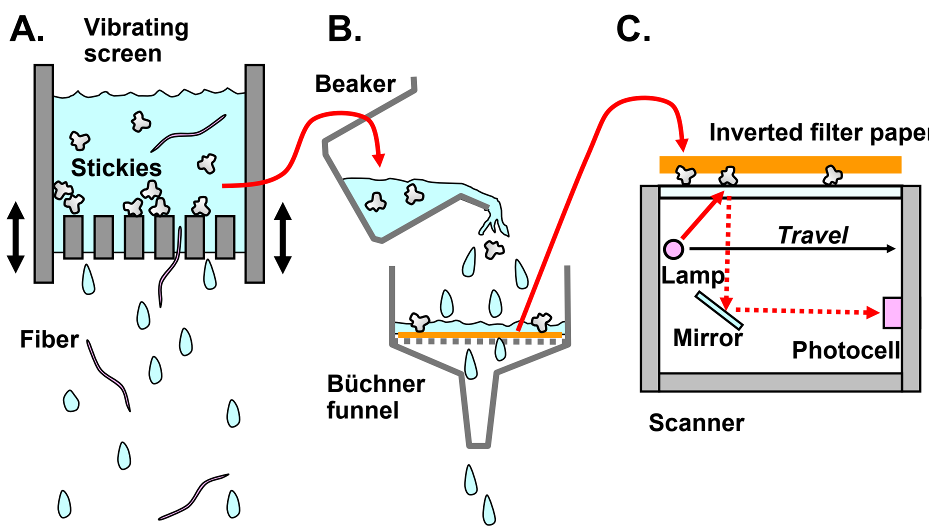


Fig. 7. Concept of using a flat-screen to collect sticky particles from water (A), and the using a Büchner funnel to place them on to surface of filter paper (B), thereby allowing them to be quantified by image analysis (C)

Filtration-related Methods

Some tests for stickies are related to methods that can be used to remove them from recovered fiber suspensions. In particular, filtration-based tests are often used to quantify levels of stickies in such suspensions (Abraham 1997; Doshi and Dyer 2002). Such studies are summarized in Table 5. Because the stickies recovered by filtration are sometimes counted on filter paper surfaces, there is an expected overlap with the previous table.

Table 5. Stickies-related Test Methods Involving Screening of Stickies from Pulp Suspensions

Highlights of the Test Procedure	Citation
Microscopic size determination and counting of stickies were found to provide reliable results.	Abraham 1997
A stickies test based on screening (INGEDE) was able to differentiate between microstickies and macrostickies. A 100 μm slot width was used.	Ackermann *et al.* 1997
This overview chapter discusses various tests in which screening was used to quantify stickies, often with use of dye to stain the stickies. Slot widths of 100 and 150 μm were used.	Doshi & Dyer 2000
Ultrafiltration is used in a patented procedure to differentiate stickies from other components of tested aqueous mixtures.	Banerjee 2005-pat
Screening was a key step in the reported "INGEDE" method for evaluation of stickies. Slot widths of 100 and 150 μm are mentioned.	Gabl *et al.* 2006
Macrostickies are obtained by screening. The screenate is then treated to agglomerate microstickies, which are then collected by screening. The covered mesh size range is 50 to 400. An example shows an approximately 152 μm slot width. Agglomeration of the microstickies was favored by heating to at least 40 °C.	Doshi *et al.* 2008-pat

Abraham (1997) found that a filtration-based test was highly reproducible, whereas a flotation-based assay for stickies that they evaluated was not. It was reported that the size distribution of stickies could be determined reproducibly by optical microscopy. One of the important attributes of screen-based methods is that they are able to directly assess different size classes of stickies (Ackermann *et al.* 1997; Gabl *et al.* 2006).

Deposition Testing

Because the buildup of deposits onto the wetted surfaces of paper machines can take place over the course of weeks of continuous operation, it can be a challenge to attempt to replicate such problems at a laboratory scale. The fact that such laboratory testing has been found to be useful can be used as evidence of the severe nature of some stickies problems that have been encountered in paper machine systems. Table 6 summarizes highlights of reported laboratory work involving assessment of deposition onto solid surfaces.

Table 6. Stickies-related Test Methods Involving Deposition from Fiber Suspensions onto Solid Surfaces, Including Screens, Plates, or Rotors

Highlights of the Test Procedure	Citation
A forming fabric from a paper machine is mounted in a frame, which is agitated while immersed in a suspension of recovered papermaking fibers. Stickies deposits are quantified by image analysis.	Ferguson *et al.* 1997
A plastic forming fabric is attached to a frame and agitated in a pulp suspension. Destabilization of the stickies by addition of poly(ethyleneimine) (PEI) was quantified by image analysis of the forming fabric after drying.	Carre *et al.* 1998
High density polyethylene (HDPE) films are mounted on frames and agitated in suspensions of fibers containing microstickies. The collector surfaces are rinsed, dried, and then weighed.	Doshi *et al.* 1998

Highlights of the Test Procedure	Citation
Using the Doshi method (1998), the authors detected the deposition of hot melts and waxes onto plastic foam squares as a function of temperature during agitation of pulp suspension. Addition of talc decreased the amount of deposition.	Maat and Yordan 1998
Fiber suspensions containing pressure-sensitive adhesives (PSA) are evaluated using the PIRA deposition device, in which a forming fabric is attached to a frame and agitated in a fiber suspension. Deposition is quantified by image analysis, using a dye.	Venditti *et al.* 1998
Stickies levels are quantified by deposition onto solid plates, using a rotor. The deposited material is extracted and weighed.	Blanco *et al.* 2002
The deposition tester described by Carre *et al.* (1998) is used to show the effectiveness of a dissolved air flotation method in removing depositable stickies from a fiber suspension.	Delagoutte *et al.* 2002b
Deposition onto metal or plastic paddle surfaces is quantified by solvent extraction, followed by analysis. Three important classes of stickies are hot melt adhesives, laser toner binders, and contact adhesives.	Miller *et al.* 2004
Destabilization and deposition of stickies, as affected by added coagulants and talc, are evaluated using a specialized rotor that directed flow toward fixed plates. Image analysis, as used in a PIRA method, was used to quantify the deposited stickies.	Monte *et al.* 2004
This patent claims the illumination of a receiving surface and observation of the buildup of stickies.	Piironen *et al.* 2019-pat

Figure 8 illustrates an enhanced deposition test device that can be used to better understand factors affecting the deposition of stickies onto forming fabrics, as well as the effects of treatments to overcome such effects. Carre *et al.* (1998) developed such a device based on an earlier device developed by Pira International (see Venditti *et al.* 1998). The system of reciprocating paddles, as shown in the figure, was able to achieve a more uniform deposition of stickies onto two specimens of forming fabric. The cited authors used image analysis to quantify stickies accumulation onto the forming fabric specimens, after they had been gently rinsed and dried.

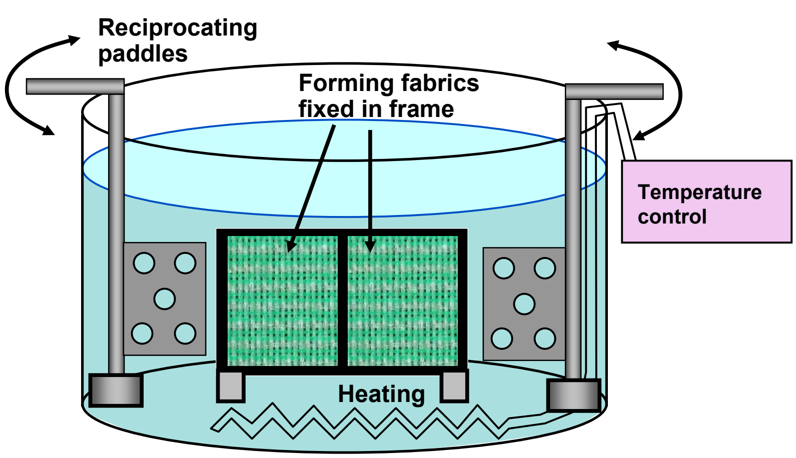


Fig. 8. Sketch of a test developed by Carre *et al.* (1998), based on an earlier device provided by Pira, for evaluation of deposition of stickies from a pulp suspension onto a piece of forming fabric held in a frame and used as an agitator

Analytical and Instrumental Methods

When the goal is to quantify either the composition or some aspect of the behavior of stickies, the associated methods often are called "analytical" or "instrumental." Examples of analytical or instrumental tests that have been used for stickies include near infrared (NIR) (Yu *et al.* 2010; Hempel 2020; Bosco 2024), Fourier transform infrared (FTIR) (Douek *et al.* 1997; Hsu *et al.* 1997; Doshi and Dyer 2002; Shen *et al.* 2017), various types of mass spectrometry (Holmbom and Vähäsalo 2008; Shen *et al.* 2017), thermogravimetric analysis (Gabl *et al.* 2006), contact angle goniometry (Lee *et al.* 2005; Naithani *et al.* 2015), and measurement of tack forces (Fike *et al.* 2006). Articles describing such tests are highlighted in Table 7.

Table 7. Analytical or Instrumental Methods Used to Characterize Stickies

Highlights of the Test Procedure	Citation
A diamond anvil cell/beam condenser system was used to obtain Fourier transform infrared (FTIR) information from individual stickies of dirt specks and stickies in paper and deposits.	Douek *et al.* 1997
Infrared spectroscopy was used to determine the compositions, and hence the likely origins of stickies in deinked pulps.	Hsu *et al.* 1997
Fourier transform infrared (FTIR) was found to be effective, along with screening, deposition testing, and scanning for stickies testing.	Yordan & Maat 1997
Contact angle measurements were used to characterize the wettability (*e.g.* hydrophobicity) of stickies materials.	Lee *et al.* 2005
White pitch (latex from the recycling of coated paper) was characterized by fluorescent staining and flow cytometry. Maximum tack was achieved at a specific temperature.	Vähäsalo & Holmbom 2005
Thermogravimetric analysis was used as a tool to better understand stickies deposits.	Gabl *et al.* 2006
In this dissertation work, tetrahydrofuran was used to dissolve stickies from deinked fiber suspensions. Molecular size was evaluated by size exclusion chromatography. Flotation was found to be an effective method to deal with the stickies in the deinked pulp.	Sarja 2007
Stickies were analyzed by gas chromatography-mass spectrometry (GC-MS), with and without pyrolysis, as well as size exclusion chromatography (SEC) to determine polymer molecular mass distributions.	Holmbom & Vähäsalo 2008
Fourier transform infrared (FTIR) was used, following chloroform extraction of recycled newsprint pulp, to help identify stickies components including polyvinyl acetate, styrene-butadiene resin (SBR), as well as pitch components.	Miranda *et al.* 2008
Pyrolysis GS-MS was used to evaluate the composition of stickies in recycled newsprint furnish.	Wells *et al.* 2008
This patent claims the use of a quartz crystal microbalance (QCM) to monitor the deposition of stickies.	Shevchenko *et al.* 2009-pat
The quartz crystal microbalance (QCM) method was used to quantify both the mass and the deformability of deposited materials at surfaces exposed to aqueous suspensions related to stickies deposition.	Dong *et al.* 2010
Flow cytometry and turbidity tests were used to study the destabilization of stickies by addition of cationic polyelectrolytes.	Jiang & Chen 2010
A rapid method for detection of stickies was developed using near-infrared (NIR) spectrometry, following extraction of stickies from pulp specimens using tetrahydrofuran (THF).	Yu *et al.* 2010

Highlights of the Test Procedure	Citation
Fourier transform infrared (FTIR) was used to help identify stickies components, including ethylene vinyl acetate (EVAc) and phenyl-containing compounds.	Ma & Shi 2011
This patent claims use of a quartz crystal microbalance (QCM) to monitor the deposition of organic deposits in a paper mill system.	Shevchenko & Murcia 2011-pat
Dynamic surface tension tests were used to characterize process water in order to better understand the deposition of stickies.	Genest *et al.* 2015
This patent claims the usage of NIR to example handsheets prepared using an automated sheet forming system.	Hengesbach & Krause 2015-pat
Contact angle measurements were used to compare the relative hydrophobicity of different components of stickies before and after treatment with a protein, which acted as a detackifier.	Naithani *et al.* 2015
This patent claims use of a quartz crystal microbalance (QCM) to monitor the deposition of organic deposits in a paper mill system. Only the top side of the crystal was exposed to the process.	Duggirala & Sheychenko 2016-pat
Fourier transform infrared (FTIR) spectroscopy was used to investigate the action of a lipase enzyme during the breakdown of stickies. The decomposition fragments were evaluated using gas chromatography-mass spectrometry (GC-MS).	Shen *et al.* 2017
This editorial announces work by the Voith company and Papier Techniches Stiftung to develop a stickies test based on near-infrared (NIR) spectrometry.	Hempel 2020
The NIR method for stickies was described as reliable and easy.	Friedrich *et al.* 2021
This article introduces ISO 15360-3, which uses near-infrared (NIR) spectrometry for quantification of stickies on laboratory test paper or commercial paper sheets.	Bosco 2024

Determination of the composition of stickies often can involve an initial step or steps to isolate the stickies. For instance, relatively large stickies (*i.e.* macrostickies) can be separated from process water by using a screen in the laboratory (Doshi and Dyer 2002). The next step can involve adding a water-insoluble solvent, which can dissolve the material and allow its recovery by means of a separatory funnel (Miranda *et al.* 2008; Yu *et al.* 2010). For example, Krueger and Bowers (1981) noted that various different solvents have been used to dissolve various stickies components, but their survey did not indicate any clear favorite. Guo and Douek (1996) used ethanol and hexane as solvents for the extraction of pitch and stickies components. Miranda *et al.* (2008) used ethanol in one stage, and they used ethyl acetate in another stage of a fractionation procedure for stickies components. Salminen *et al.* (2010) used tetrahydrofuran (THF). After evaporation of the solvent, the isolated (but not pure) stickies material can be examined by various instrumental methods, as represented in the table, especially FTIR.

Flow cytometry has been demonstrated as a powerful method by which to quantify dispersed stickies according to their size and their affinities to selected dyes, especially fluorescent dyes (Vähäsalo and Holmbom 2005; Jiang and Chen 2010). The method permits high-resolution analysis of both the size and number of stickies particles. In principle, it is possible to extend this method to different kinds of hydrophobic particles or emulsion droplets, *etc.*, by using dyes having different affinities. As shown in Fig. 9, flow cytometry relies upon a flow cell with a sheath of pure water, such that the particles of interest are present near the middle of a narrow transparent cylinder. To count and quantify the particles, as they pass through the device one by one, a laser light passes through the flow cell. The intensity of scattered light at a 90-degree angle from the incident beam is used as an indication of the amount of material, though it is recognized that the relationship may be highly non-linear. Forward-scattered light is highly dependent on particle size, with a general rule that larger particles give much larger intensities. In addition, such devices may employ a diffraction grating or prism to separate the scattered light into different wavelength groups, which each can be monitored by a photodetector. This makes it possible to detect the presence of one or more fluorescent dyes, which can be selected for use based on their differing affinities for different components of a suspension of particles.

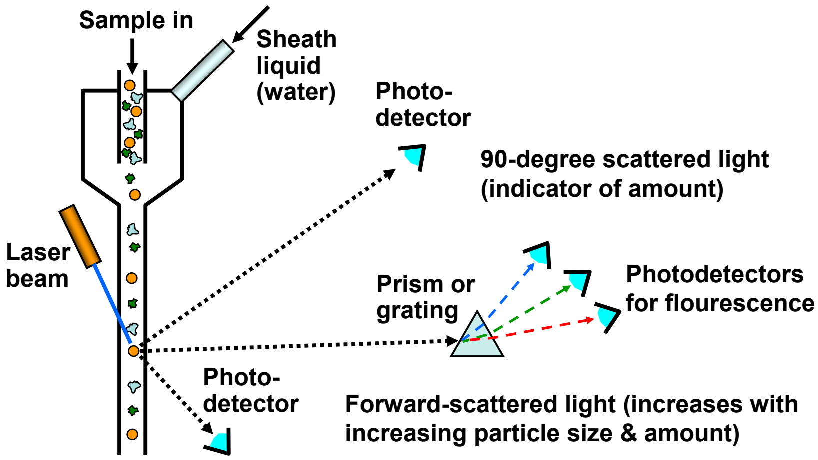


Fig. 9. Schematic diagram of the flow cytometry method

The measurement of tackiness has been considered in various studies. In particular, Fike *et al.* (2006) were able to evaluate effects of heating on tackiness by using a device that simulated key aspects of the drying of paper. The degree of tack acting between a paper surface and a heated metal dyer can was evaluated by monitoring the peel angle of the tested paper under known tension. A tackiness measurement was also included in work reported by Huo *et al.* (1999) and in the INGEDE procedure for stickies evaluation (Gabl *et al.* 2006).

SOURCES, SIZES, COMPOSITION, AND PROPERTIES OF STICKIES

Sources of Stickies

Various sources of stickies have been mentioned in publications. In Table 8, different sources of stickies are arranged in decreasing order of the number of times listed, except that the list is not intended to be complete. The most prominent sources are illustrated schematically in Fig. 10. Parts A, B, and C of the figure represent pressure-sensitive adhesives, hot-melts, and coating binders, respectively. It is worth noting that these three sources of stickies are quite different from each other in quantities, chemical compositions, and overall character. The pressure-sensitive adhesives typically represent a relatively small amount of material, but the material is specifically designed to be highly tacky. The hot-melt adhesives are commonly used in the assembly of corrugated containers, so they can be present in relatively large amounts when old corrugated container (OCC) pulp is being used. The kinds of latex binders used in preparation of coated paper products appear to have received attention in the literature on account of their high quantity of usage in certain types of paper, such as coated boxboard or coated freesheet, which may be recycled.

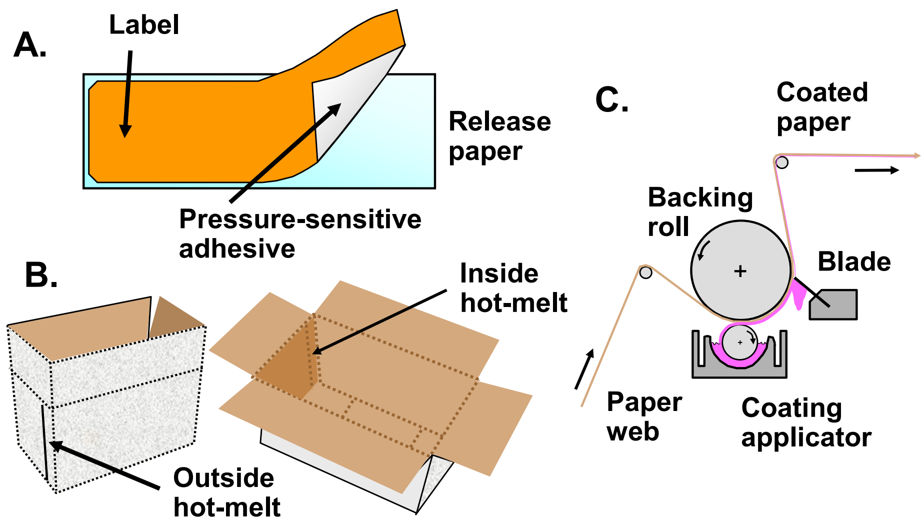


Fig. 10. Illustration of some major sources of stickies

Table 8. Sources of Stickies, According to Some Published Articles

Pressure-sensitive labels	Ling *et al.* 1993; Ackermann *et al.* 1996; Klein and Großman 1998; Venditti *et al.* 1998; Lorenz *et al.* 2000; Doshi & Dyer 2002; Miller *et al.* 2004; Saint Amand 2002; Li *et al.* 2006; Gribble *et al.* 2011; Li *et al.* 2013a,b; Naithani *et al.* 2015; Doshi *et al.* 2018; Sutman & Nelson 2022
Hot-melt adhesives	Ling *et al.* 1993; Ackermann *et al.* 2002; Doshi & Dyer 2002; Miller *et al.* 2004; Sutman & Nelson 2022
Coatings for paper	Grenz *et al.* 1994; Ackermann *et al.* 1996; Klein and Großman 1998; Doshi & Dyer 2002; Gribble *et al.* 2011; Sutman & Nelson 2022
Waxes	Doshi & Dyer 2002; Miller *et al.* 2004; Gribble *et al.* 2011; Sutman & Nelson 2022
Ink components	Ling *et al.* 1993; Guo and Douek 1996; Salminen *et al.* 2010; Sutman & Nelson 2022
Book binding adhesives	Ackermann *et al.* 1996
Envelope adhesives	Ackermann *et al.* 1996
Folding box adhesives	Ackermann *et al.* 2001
Packaging tape adhesives	Ackermann *et al.* 2002
Deinking chemicals	Guo and Douek 1996

Pressure-sensitive adhesives (PSAs), which were among the most often mentioned sources of stickies in the cited articles, are used to attach mailing labels to envelopes, along with other uses, such as affixing name tags to shirts or jackets. During the manufacturing process for preparing such labels, it is common to apply a layer of the tacky adhesive to a continuous roll of release paper. In a subsequent step, the adhesive is transferred to the label paper, except that the release paper may remain as part of a sandwich structure until the label needs to be applied to an envelope or other surface. In fact, some studies of stickies have employed sheets of adhesive mounted onto release paper as a convenient way to introduce a repeatable amount and type of stickies to pulp suspensions (Venditti *et al.* 1998; Doshi and Dyer 2002). Because the PSA material is intended to form firm bonds to solid surfaces upon contact, it makes sense that it can cause problems when it enters a papermaking process in the course of recycling.

Hot-melt adhesives have been widely used as an option for the assembly of corrugated containers (Ackermann *et al.* 2002; Doshi and Dyer 2002). In particular, hot-melt polymers can be used for creating the side-seams and for closing the flaps. As suggested by their name, hot-melt adhesives tend to become tacky when heated, which can lead to problems with deposition onto dryer cans and dryer fabrics on a paper machine (Klein 2000; Fike *et al.* 2006).

The binders used in the formulation of coatings applied to paper, especially for high-end printing paper or paperboard products, are not primarily designed to be tacky, but on the other hand they may be present in relatively high amounts, depending on the source of recovered paper. Therefore, as shown in Table 8, they have often been mentioned as contributing to stickies-related problems.

The fact that inks are mentioned in several articles, for which the primary topic was stickies, can be viewed as evidence of the high priority that many papermakers place on the removal of ink from recovered papermaking fibers (Shrinath *et al.* 1991; Theander and Pugh 2004; Karthikeyan and Krishnamoorthy 2021).

Size Classes of Stickies

Three classes of stickies have been widely considered in published studies. The three classes are macrostickies, microstickies, and secondary stickies. The way that the three classes are distinguished from each other is illustrated schematically in Fig. 11.

Macrostickies

Macrostickies can be defined as those that can be separated from either a fiber suspension or from process water by use of slotted screens (Krauthauf and Putz 1997; Heise *et al.* 1999, 2000a; Blanco *et al.* 2007; Mendes *et al.* 2025). For example, Menes *et al.* (2025) used a Somerville slotted screen device with 150 μm slot openings to separate the stickies from the fibers and finer particles. The INGEDE (2013) Method 4 (Analysis of macrostickies in pulps) specifies 100 μm slot openings. As had been shown earlier in Table 5, retention on either 100 or 150 μm slot openings have been commonly used criteria in tests to quantify macrostickies.

Microstickies

Microstickies, which by definition are able to pass through a standard screen under laboratory conditions, are often collected for quantification by flotation (Abraham 1977; Krauthauf and Putz 1997; Menke 1998; Lee *et al.* 2005; Lee and Kim 2006; Blanco *et al.* 2007). As will be described in more detail later, the generally hydrophobic nature of stickies favors their attachment to rising bubbles, which carry the stickies to the water surface. The froth can be skimmed from the water surface, dried, and weighed and/or extracted, followed by analysis of the extracted material.

Secondary stickies

Secondary stickies can be defined as material that becomes problematic after it has interacted with ions, polymers, or other components of a suspension, causing it to either agglomerate or to deposit upon wetted surfaces in a paper machine system (Carre *et al.* 1998; Gabl *et al.* 2006; Li *et al.* 2006; Blanco *et al.* 2007). In principle, secondary stickies can arise due to colloidal destabilization of microstickies (Hamann and Blechschmidt 2000;

Sarja *et al.* 2004; Blanco *et al.* 2007; Jiang and Chen 2010). For example, Jiang and Chen (2010) reported the growth in sizes of stickies upon addition of highly cationic polymers. Related work was reported by Liu *et al.* (2011) and by Li *et al.* (2013b). Alternatively, secondary stickies might arise due to breakdown of macrostickies into fragments, followed by destabilization and agglomeration of the fragments (Blanco *et al.* 2007). According to Grenz *et al.* (1994) stickies problems related to binders from aqueous coating of paper often can be avoided by efforts to prevent agglomeration of latex particles present in coated broke, *i.e.* repulped coated paper.

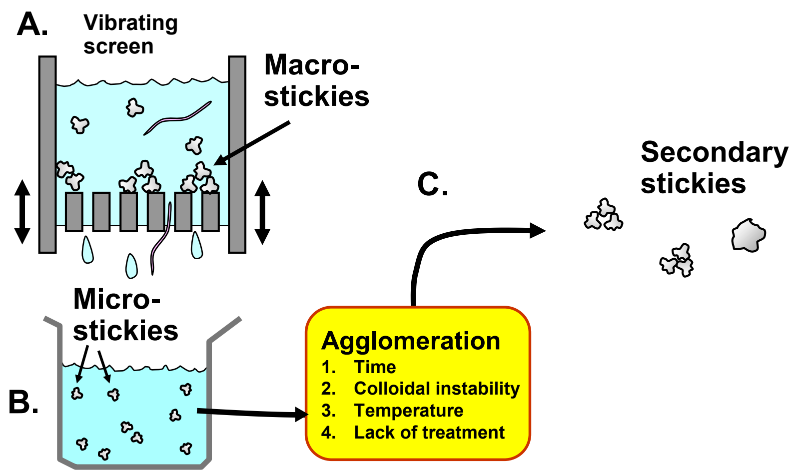


Fig. 11. Conceptual Illustration of three classes of stickies, related to their size or growth: A. macrostickies can be defined generally as those that are retained by the standard screen used by the researchers; B. Microstickies can be defined as those that pass through such a screen; and C: Secondary stickies are those that agglomerate due to effects of processing, including such factors as time, colloidal destabilization, temperatures favorable to tackiness (which depends on the polymer attributes and plasticizers), and a lack of effective detackification treatment.

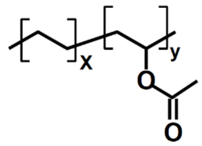
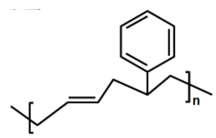
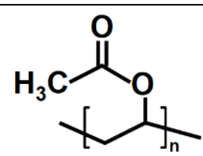
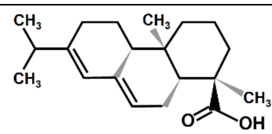
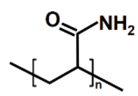
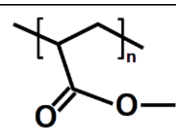
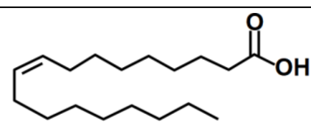
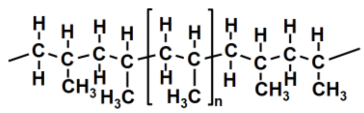
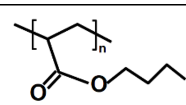
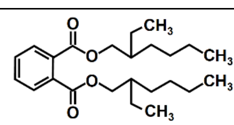
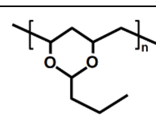
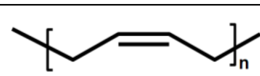
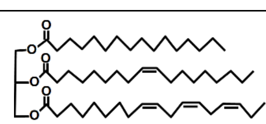
Chemical Compositions of Stickies

Synthetic organic compounds

Certain polymers and certain other organic compounds, both synthetic and plant-based, have been reported to be present in different stickies specimens. Such information is summarized in Table 9. As in the previous table, this table is again arranged in order of decreasing number of times that a certain chemical component of stickies was cited in the literature sources that were considered here.

Some common features become apparent regarding components of stickies, when examining Table 9. For instance, nonionic groups dominate the composition of most stickies. In cases such as rosin, where there is a chargeable group (*i.e.* a carboxyl group), that group is outweighed by the nonionic character of the rest of the molecule. In addition, many of the prominent components of stickies contain ester groups (for example, EVAc, PVAc, and some acrylic latexes). It is also notable that the list contains some wood extractives, namely rosin (shown as abietic acid), and triglyceride fats. Such compounds are likely present as carry-over from pulping operations due to incomplete washing. These compounds are prominent in pitch deposits on paper machine equipment, and it is known that there can be combinations of pitch and stickies in papermaking operations (Mouyal 1996; Allen 2002; Holmbom and Vähäsalo 2008; Sutman and Nelson 2022).

Table 9. Chemical Components of Stickies, According to Some Published Articles

Component	Chemical structure	Citations
Ethylene vinyl-acetate (EVAc); pressure-sensitive adhesive and hot melt adhesives		Klein 2000; Doshi & Dyer 2002; Miller *et al.* 2004; Banerjee 2005-pat; Gray *et al.* 2007-pat; Jiang *et al.* 2011-pat; Ma & Shi 2011; Ban & Thomas 2015; Licursi *et al.* 2016
Styrene-butadiene resin (SBR) coating binder		Guo & Douek 1996; Hutten *et al.* 1997; Klein 2000; Doshi & Dyer 2002; Vähäsalo & and Holmbom 2005; Miranda *et al.* 2008; Gribble *et al.* 2011; Licursi *et al.* 2016
Poly(vinylacetate) (PVAc); hot-melt adhesives		Guo & Douek 1996; Hutten *et al.* 1997; Maat & Yordan 1998; Wilhelm *et al.* 1999; Klein 2000; Miller *et al.* 2004; Miranda *et al.* 2008; Ma & Shi 2011; Ballinas-Casarrubias *et al.* 2020
Rosin (abietic acid)		Guo & Douek 1996; Gruber *et al.* 1998; Allen 2002; Klein 2000; Miranda *et al.* 2008
Polyacrylamide (& acid)		Gruber *et al.* 1998; Klein 2000; Miller *et al.* 2004
Acrylic latex (poly methacrylate)		Wilhelm *et al.* 1999; Miranda *et al.* 2008
Fatty acid (oleic acid)		Guo & Douek 1996; Miranda *et al.* 2008
Polyolefins (isotactic polypropylene)		Guo & Douek 1996
Poly(butyl-acrylate)		Ballinas-Casarrubias *et al.* 2020
Dioctylphthalate		Ballinas-Casarrubias *et al.* 2020
Poly(vinylbutyral)		Miller *et al.* 2004
Poly(butadiene)		Miller *et al.* 2004
Triglycerides		Allen 2002

Dissolved and colloidal substances

In addition to the compounds listed in Table 9, Gribble *et al.* (2011) found several compounds that were associated with defoamer usage on paper machines, including fatty acid esters, mineral oils, and silicone compounds. Foam-control agents, in order to be effective in breaking bubbles, often contain highly hydrophobic components, such as ethylene-bis-stearamide (EBS), polysiloxane oil, or hydrophobized fumed silica (Pelton 1989). Such items can be expected to associate with hydrophobic stickies and end up in the same deposits, whether or not they are the primary cause of problems.

Another component of paper machine process water that may affect stickies deposition has been called "dissolved and colloidal anionic compounds" (DCS) (Hubbe *et al.* 2012). On the one hand, the negative ionic character of DCS might be expected to serve as a stabilizer for stickies, possibly contributing a more hydrophilic surface layer and providing electrostatic repulsion between particles. However, several authors have implicated DCS as a contributing cause of stickies problems (Gruber *et al.* 1998; Monte *et al.* 2004; Li *et al.* 2011). One reason is that DCS can interfere with the function of certain cationic polymers that can be used to retain stickies, hopefully as very small particles, onto fibers or other solids (Li *et al.* 2006, 2011, 2013b). Another reason is that in the presence of DCS, agglomeration and deposition can be triggered by addition of alum or cationic polymers (Monte *et al.* 2004).

Inorganic contents

Though the definition of stickies does not include the word "inorganic," it has been found that deposits of stickies often contain inorganic particles. For example, Guo and Douek (1996) placed about 20% of clay and 14% of calcium carbonate, by mass, in "model mixtures" of stickies to be used in their laboratory tests of stickies deposits and measures to mitigate them. Ma and Shi (2011) evaluated stickies deposits on the dryer cylinders of a paper machine processing recycled fibers. The inorganic content, which was about 6% by mass, included the elements calcium, magnesium, silicon, and aluminum. Such elements are consistent with commonly used fillers and coating pigments used in manufacturing printing grades of paper and paperboard.

FACTORS AFFECTING GROWTH AND DEPOSITION OF STICKIES

Overview of Factors

Many of the problems associated with stickies can be traced to their tendencies to either agglomerate together as increasingly large particles or to deposit and accumulate onto various wetted surfaces within the paper machine system. As noted by Smith (1991), the sizes, shapes, concentrations, and types of stickies all can be expected to affect papermaking operations and the resulting products. Agglomeration is a problem because the large stickies can interfere with operations. For instance, they can plug wet-press felts or cause parts of the paper sheet to adhere too tightly to transfer rolls or dryer can surfaces. The frequency of web breaks is likely to increase, leading to losses in production. Larger stickies also may be apparent as blemishes in the paper product. So even though larger stickies are easier to remove from the system by screening, conditions that result in agglomeration or deposition of stickies are generally regarded as undesirable. This section focusses on certain factors that often have been viewed as contributing to decreased colloidal stability or increased tackiness of stickies. The subsections below consider hydrophobicity, effects of coagulating and bridging ions (as well as cationic polymers), and temperature.

A framework for understanding the effects of various factors on the agglomeration of deposition of stickies in paper machine systems can be provided by considering three main steps, namely destabilization, spreading, and intermixing at a molecular segment level. The first step, destabilization, can be regarded as the most critical. One can envision a hypothetical stickies particle initially present in a pulp system as small (maybe 1 μm), quasi-spherical, and suspended individually. Due to the likely presence of carboxylic acid groups either associated with the stickies or adsorbed substances from the pulping process, the particles can be expected to have a negative surface charge (Hubbe *et al.* 2012). That means that there may be a repulsive electrostatic force that keeps the stickies from either depositing onto surfaces or agglomerating. However, as will be described in this section, there may be other aspects related to chemistry that destabilize the system and allow deposition or agglomeration to occur. Qutubuddin *et al.* (2000) proposed that destabilization of waterborne latex suspensions, which are analogous to stickies, can be either reversible or irreversible. The second step, spreading, will be favored by the fluid-like nature of stickies under the hot conditions of typical paper machine systems, but it also will depend on the rheological characteristics of the stickies themselves. Spreading is a necessary process leading to the establishment of substantial molecular contact area after the initial contact has been achieved. Chang (1997) reviewed the rheological characteristics of pressure-sensitive adhesives. The bulk rheological behavior was found to be predictive of adhesive behaviors. The final step, intermixing at a molecular segment level, depends on the similar solubility behavior of the facing surfaces, as will be described.

Hydrophobicity

The fact that most stickies hate water provides a driving force for them to either self-assemble as larger agglomerates or to deposit on solid surfaces. Either of these outcomes will tend to minimize the interfacial area between incompatible phases (Hubbe *et al.* 2020). Thermodynamic principles dictate that, regardless of what is done to stabilize stickies in suspension, the agglomerated or deposited state will be favored in the long run. Another term that has been used to describe this state of affairs is the hydrophobic effect (Tanford 1980). According to the hydrophobic effect, the self-association of hydrophobic groups or their association with surfaces will enable a higher net amount of hydrogen bonding among water molecules. Due to the relatively high energy content of hydrogen bonds, the hydrophobic effect makes deposition and agglomeration of stickies thermodynamically favorable.

Several articles having to do with the mechanisms involved with stickies problems have identified hydrophobicity as an underlying cause of problems (Gruber *et al.* 1998; Ling 1998; Doshi and Dyer 2002; Petzold *et al.* 2012; Sutman and Nelson 2022). As noted by Doshi and Dyer (2002), the hydrophobic nature of stickies, either when assessing the purified material or when testing the effects of various stabilizing agents, can be determined by measuring the contact angle of water. As illustrated in Fig. 12, if a small water droplet beads up, with a contact angle of greater than 90 degrees, then the material gets the formal designation of being non-wettable due to its hydrophobicity. For instance, such behavior can be expected when placing water droplets onto the fresh surface of a layer of pressure-sensitive adhesive. By contrast, if the water droplet spreads out to achieve an angle less than 90 degrees, then the surface is called wettable, and the values of contact angle can be used to indicate different degrees of hydrophobicity (Lee *et al.* 2005). For example, Fig. 12 also represents a typical case for label paper (relatively wettable on its paper surface, and strongly nonwettable on its fresh, adhesive surface). As noted by Sutman and Nelson (2022), many of the strategies that have been used successfully to mitigate the agglomeration and deposition of stickies can be described as ways to make the surfaces of stickies more hydrophilic.

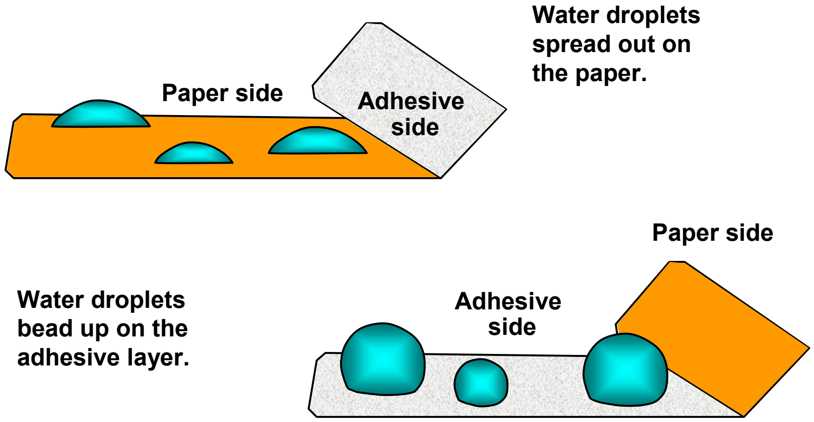


Fig. 12. Schematic illustration of non-wetting and wetting surfaces, based on the angles of contact with droplets of pure water

Coagulating or Bridging Ions

Surfaces of materials suspended in process waters from pulp and paper mills tend to acquire a net negative charge due to adsorption of colloidal materials, which can include hemicellulose, fatty acids, resin acids, as well as various dispersants used in processing the pulp (Hubbe and Rojas 2008; Hubbe *et al.* 2012). On the one hand, the development of a negatively charged layer at the surface of hydrophobic surfaces, such as stickies, can stabilize them, thereby slowing down the eventual processes of agglomeration and deposition. But on the other hand, the negative charges can make the stickies vulnerable to the effects of coagulating ions, such as calcium, aluminum, and high-charge, relatively low-mass cationic polymers (Sigman and Rohlf 1993; Klein and Großmann 1998; Huo *et al*. 2001).

Calcium and water hardness

The concentrations of calcium and magnesium ions in natural waters can vary by large amounts, depending on the location and the presence of absence of limestone. The sum of the concentrations of these ions, based on $CaCO_3$ equivalents, is defined as the water hardness. In addition, the hardness can be increased due to the presence of $CaCO_3$ filler in the paper or pigment content in coatings. Levels of hardness are known to have various effects on paper machine operations, including the formation of deposits (Li *et al.* 2008) and hurting the performance of various papermaking additives (Johnson *et al.* 2025). Because hardness ions are divalent cations, they have the potential of forming transient bridges between carboxylate ions present at the surfaces of suspended particles (Li *et al.* 2008). This type of bridging is shown in a simplified fashion in Fig. 13. Part A of the figure represents stickies in the presence of mainly sodium ions. This interaction between monovalent ions and carboxylate groups is relatively weak, so the carboxylate groups (which might be due to adsorption of hemicellulose byproducts) are expected to contribute to colloidal stability. Part B of the figure represents a bridging effect that is expected in the presence of divalent ions, such as calcium (Rios-Carvajal *et al.* (2019).

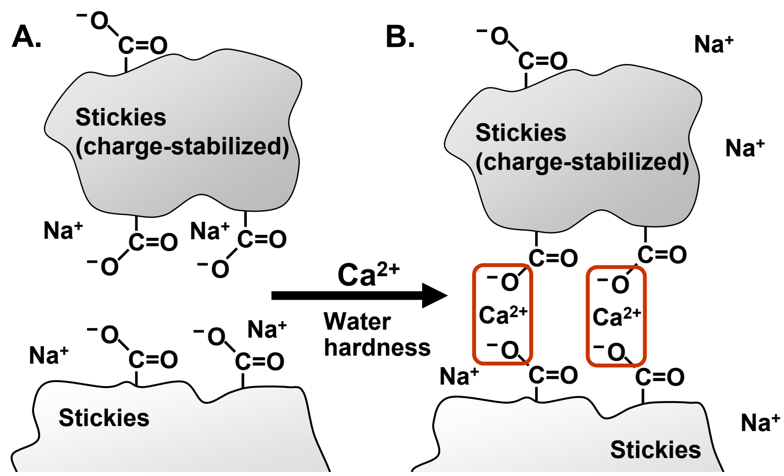


Fig. 13. Conceptual illustration of (A): Charge-stabilized stickies and (B): Stickies destabilized by the presence of divalent metal ions, *e.g.* Ca^{2*}

Aluminum ions

Aluminum ionic species generally have a higher valence there therefore a more aggressive ability to destabilize colloidal suspensions in comparison to hardness ions. In particular, when the pH of the system is in a range from about 4 to 4.5, the dominant forms of aluminum ions are likely to involve clusters of partly hydroxylated aluminum atoms, achieving valences as high as +7 (Akitt *et al.* 1972; Strazdins 1986; Bottero and Fiessinger 1989). By contrast, when the pH is as low as about 3, essentially all of the soluble aluminum species will have been converted to Al^{3+}. The left part of Fig. 14, redrawn based on Rubin and Hayden (1973), illustrates some of the major species of aluminum that tend to be dominant at different levels of pH.

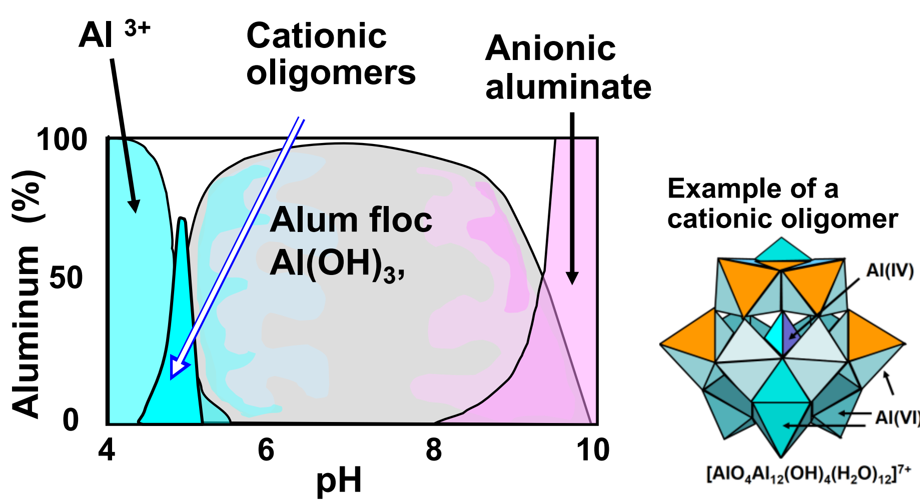


Fig. 14. Illustration of different species of aluminum in water that become dominant at different levels of pH (left image redrawn based on Rubin and Hayden 1973; right image redrawn based on Bottero and Fiessinger 1989)

The information shown in the left part of the figure is approximate, since values are expected to shift in response to different concentration, temperatures, and times of equilibration, *etc*. Note that the "cationic oligomer" depicted at the right of the figure, corresponds to a water-soluble ionic species that is likely to be present at pH values near to 5, *i.e.* the conditions of acidic papermaking, including the rosin-alum systems for hydrophobic sizing of paper.

Reports have implicated the presence of aluminum ions as a cause of the onset of problems related to the deposition of stickies (Huo *et al.* 2001; Doshi and Dyer 2002). On the other hand, Ormerod and Hipilit (1987) pointed to situations in which aluminum ions sometimes can render stickies less tacky and also help to retain them on fibers during the papermaking process. It is worth noting that there is a similar experience of varied effects of aluminum-based treatments in the case of pitch deposits in paper machine systems; aluminum sulfate can function both as a coagulant and as treatment that can render some surfaces more hydrophilic and less tacky (Hubbe *et al.* 2006; Sutman and Nelson 2022).

Effects of changes in pH

The importance of pH with respect to stickies problems follows from the pH-dependence not only of carboxyl groups, but also on the pH dependence of aluminum species and certain polyamine additives to the papermaking process. Thus, Klein and Großmann (1998) included pH in their test matrix. They observed substantially higher content of potentially depositable matter (*i.e.* colloidal stickies) when the pH was 10 rather than 7. The higher pH would allow at least partial deprotonation of the phenolic groups of lignin, in cases where that component of wood is present. It is worth noting that such findings cannot be categorized as necessarily good or bad, given the fact that colloidal stickies often can be efficiently separated by flotation operations or they might respond to pacification treatment (see later). Künzi and Maurer (1998) observed that a higher pH during processing of the furnish may result in more efficient removal of the objectionable material before preparation of the paper. Those results are consistent with the greater colloidal stability of more highly anionic particles, allowing them to be washed from the fibers.

Some effects related to stickies are likely to depend on the acid dissociation constants of carboxylic acid groups that are often associated with the surfaces of either the stickies themselves or of compounds such as hemicellulose, oxidized starch, or dispersants that might be associated with the stickies. The pK_a value of such groups is often in the range of about 3.3 to 5, depending on the detailed chemistry (Hubbe *et al.* 2012). As the pH becomes substantially higher than the pK_a value, there will be an increased likelihood of the formation of the calcium or magnesium salts of the carboxylate groups, and such compounds are expected to be sticky. Rios-Carvajal *et al.* (2019) found evidence to support a bridging mechanism, as discussed above, when organic carboxylic acids were in their carboxylate form and exposed to dissolved divalent metal ions.

A complicating factor, involving pH, is an observed tendency for acid dissociation constants to shift to higher numbers when carboxylic groups are attached to sufficiently large hydrophobic groups (McLean *et al.* 2005; Hubbe *et al.* 2020). Such effects are due to the fact that self-association among hydrophobic groups may force the chargeable groups to be arranged very close to each other. Thus, especially when the ionic strength is low, a portion of the chargeable groups will tend to remain in uncharged form until the concentration of OH^- ions becomes much higher than in the absence of such effects.

Cationic polymers

Effects of cationic polymers may be more complex to define, since such additives are sometimes employed specifically to retain stickies particles to fibers surfaces. Ideally such attachment takes place when the stickies particles are small enough not to cause problems in the paper product. However, especially when stickies-containing process water is combined with cationic polymers in the absence of fibers or other solids, there can be a danger of agglomeration. Thus, Carre *et al.* (1998) found that adding polyethylene imine (PEI) brought about charge neutralization, leading to development of secondary stickies from microstickies. Huo *et al.* (2001) likewise found that adding the high-charge cationic polymer poly(diallyldimethylammonium chloride) tended to destabilize stickies and lead to problems. Confirmatory results were reported by Li *et al.* (2006) and Jiang and Chen (2010). Xu *et al.* (2017) observed the most problematic deposits of stickies when adding a cationic acrylamide retention aid to furnish in a recycled papermaking operation. It is not certain, however, whether such results would be observed in practice, since it appears that the retention aid had been added to process water and fine particles in the absence of fibers.

The most popular type of retention aid, consisting of cationic copolymers of acrylamide (Hubbe *et al.* 2009), has a hydrophilic nature, making it quite unlike typical components of stickies. When used in suitable agitated fiber suspensions, the net effect of such additives is to attach fine particles to cellulosic fibers, allowing those materials to become part of the paper product and not giving the fine particle a change to agglomerate together.

Temperature

Typical stickies components tend to become softer with increasing temperature, and in some cases there may be an intermediate temperature that is associated with maximum tackiness. For example, Fike *et al.* (2006) observed the highest tack force at the lowest temperature in their test range, 90 °C. Ling (1998) likewise observed decreasing tackiness with increasing temperature. Gao *et al.* (2012) found that increasing temperature tended to favor dispersal of stickies, as part of a strategy to render the stickies small enough to be removed by flotation after high shear treatment. Gruber *et al.* (2022) reported a strategy in which the temperatures in the dryer section of the paper machine were increased sharply in an effort to bypass an expected greater deposition temperature at somewhat lower drying temperatures. However, there appears to be a need for testing the tackiness of stickies components and their mixtures over a wider range of temperatures.

MITIGATING THE EFFECTS OF STICKIES

There are two main categories of ways to decrease the adverse effects of stickies when manufacturing paper from recovered fibers. The first relies on methods to remove stickies from the fiber slurries. The second aims at minimizing the adverse impacts of any stickies that remain in the furnish. As will be described below, many researchers have advocated for process changes aimed at high levels of removal of macrostickies – those that are readily removed by slotted screens. But other measures need to be used for stickies that either are small enough to pass through such screens or are either fragmented by shear forces during processing or become extruded through screens due to a combination of high pressure and their softened condition under operating conditions within a paper machine system.

It has been noted that stickies problems tend to be less severe in recovered fiber suspensions that have been subject to deinking treatments (MacNeil *et al.* 2010). The reason for this appears to be straightforward; measures that are effective in removing various kinds of ink also are expected to be at least somewhat effective for removing stickies. And since ink is easily detected, either as spots or as lower brightness, the papermakers often have a strong incentive to achieve high efficiencies of ink removal. However, this section is written without making any assumptions of whether or not the paper mill has a primary goal of removing ink.

Optimization of Pulping Methods

Even before considering some of the main methods that papermakers use to remove or otherwise mitigate the effects of stickies, it is important to stress that there can be an advantage to start by considering the very first steps in a fiber recovery operation. For example, it has sometimes been recommended to employ relatively high consistencies of fiber in the hydropulper (Mannes 1997; AbuBakr and Peng 1999). The justification for that idea may have been that a rubbing action between fibers could facilitate the detachment of stickies from their surfaces. However, tests by Doshi *et al.* (2018) showed that the highest consistency of pulping (15%) in their study yielded an elevated level of small-size stickies, which was not consistent with the goal of removing macrostickies with a screen. Figure 15 envisions a process in which the rubbing between fibers in a pulper not only detaches but also fragments the stickies. The large black arrows in the figure represent a shearing effect in which bunches of entangled fibers are rubbing up against each other. The red "box" in the middle of the figure (at left) depicts two stickies particles that momentarily are still attached to one of the figures that is being subjected to a rubbing action. At the right for the figure, two possible outcomes of the rubbing action are indicated, namely, detachment of stickies from fiber surfaces and fragmentation in the course of detachment.

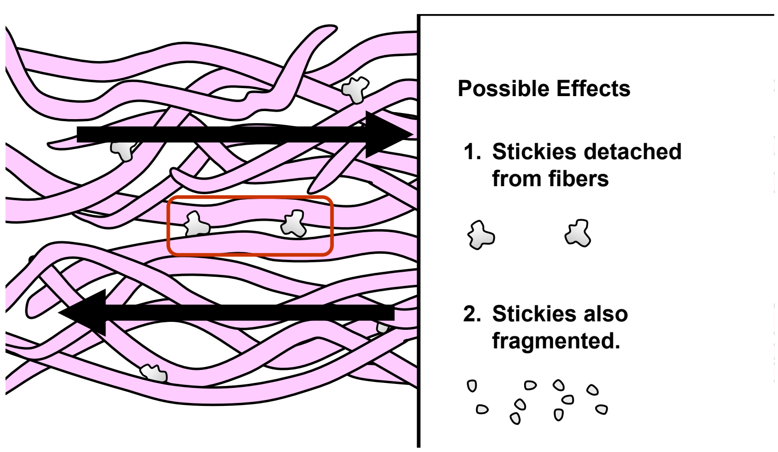


Fig. 15. Schematic Illustration of hypothetical detachment of stickies from fibers and fragmentation of stickies due to shear forces within a pulping operation for recovered fibers

A problem with small-size stickies is that they may build up in the process water of a paper mill (Mannes 1997). The cited authors advocated the use of dispergers as a more direct way to break down stickies into fragments. Such fragments may cause problems if not immediately treated in some way to prevent them from agglomerating or depositing. The usage of dispergers in paper recycling operations will be considered in more detail later in the article.

Removal of Stickies from Pulp Suspensions

In principle, if a portion of the stickies content can be removed from a suspension of recovered fibers, then at least that portion will no longer be able to hurt paper production rate or product quality. Though this approach is highly popular, papermakers carefully consider both the costs and yield losses associated with each unit operation that can be used to remove stickies from the pulp. The unit operations to be considered in this subsection include screening, cleaning (*i.e.* using hydrocyclones), washing (*i.e.* sending dispersed stickies and other solids to wastewater treatment), flotation (especially for microstickies), and extraction.

Screening

In order of application, screening is often the first separation method applied in a fiber recovery operation (AbuBakr and Peng 1999; Gaßmann 1999; Licursi *et al.* 2016; Sutman and Nelson 2022). Positive aspects of screening include its simplicity and its relatively low cost of operation. A limitation of screening is that it is effective only for the removal of relatively large stickie particles, *i.e.* macrostickies (Ackermann *et al.* 1997; Hamann and Blechschmidt 2000; Lee *et al.* 2005; Lee and Kim 2006). In fact, the term microstickies, referring to particles having diameters below about 100 μm (Moss 1998), appears to have emerged due to the fact that substantial amounts of stickies are small enough to pass through the screens employed in fiber recovery operations. A technical leaflet from Zellcheming (2006) has accordingly recommended using retention on screen having a slot width of 100 μm to define macrostickies in the case of fine paper production. They recommended using a slot width of 150 μm for production of packaging papers. In addition, it has been found that high pressures and temperatures associated with some papermaking operations can cause stickies to break down in size or to become extruded through the slots of screening devices (Venditti *et al.* 1999; Saint Amand 2002; Venditti *et al.* 2002). Heise *et al.* (2000a) showed that such extrusion is consistent with levels of pressure, slot sizes, and the elastic moduli of typical stickies at the prevailing operating temperatures. Thus, to maximize separation of macrostickies, it has been recommended to run screening operations under relatively low pressure conditions (Venditti *et al.* 2002).

Advances in screening devices have shown potential to remove somewhat smaller stickies (Moss 1998). Terms such as "fine slotted screens" have been used to describe the most effective devices for removing stickies (Chascin 1997; Davis and Schwarz 1997; Seifert *et al.* 1998; Walsh *et al.* 1998). A practical limitation, which is shared by the pressure screens used on paper machines, is that the slots need to be large enough to allow essentially all of the incoming cellulosic fibers to pass through without clogging the openings or forming a mat. Some authors have recommended a sequence of coarse screening, followed by fine screening (Spiess and Renner 2004), thereby decreasing the chance that that the finer screens will become clogged with stickies. Glass (1997) discusses ways in which screens intended for stickies control may differ from other screens being used in a paper machine system.

Figure 16 has been redrawn from two figures disclosed in a patent by Winkler and Lucas (2013-pat), who claimed the development of a cylindrical screening system especially effective for the separation of stickies from pulp suspensions. Note that in this design the main flow of the cellulosic fiber is from the upper left of the figure towards the screen and through the screen. Due to their narrow size and flexibility, suitably oriented cellulosic fibers can easily pass through such a screen. The purpose of the rotor is to periodically resuspend a portion of the approaching fibers that otherwise tend to build up on the screen surface, while also creating a brief vacuum pulse associated with the trailing part of the rotor blade. The brief reversal of flow also helps to resuspend any collected stickies so that they can be discharged at a lower edge of the screening device. The patent lists the slot widths as being within the range 0.11 to 0.145 mm. The inset on the right side of the figure details some expected local flows, based on a figure in the patent. Note that only the leading edges of the solid pieces (facets) at the entrance side of the screen are depicted in the inset view.

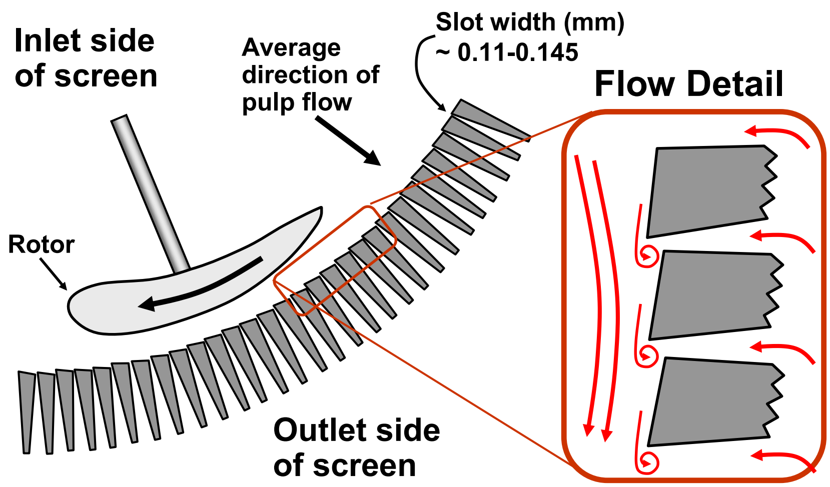


Fig. 16. Redrawn figures from the US patent by Winkler and Lucas (2013) depicting features of a specialized slotted screen designed to remove stickies from recovered fiber suspensions

Reverse cleaning

The term reverse cleaning is used in cases where the solids to be separated from an aqueous mixture have a density that is lower than that of water (Saint Amand 2002). Paraffin wax is an example of a material having a lower density (about 0.9 g/cm^3). Ethylenevinylacetate (EVAc) is somewhat more challenging to remove by such means, since its density is closer to that of water (9.93 to 0.96 g/cm^3).

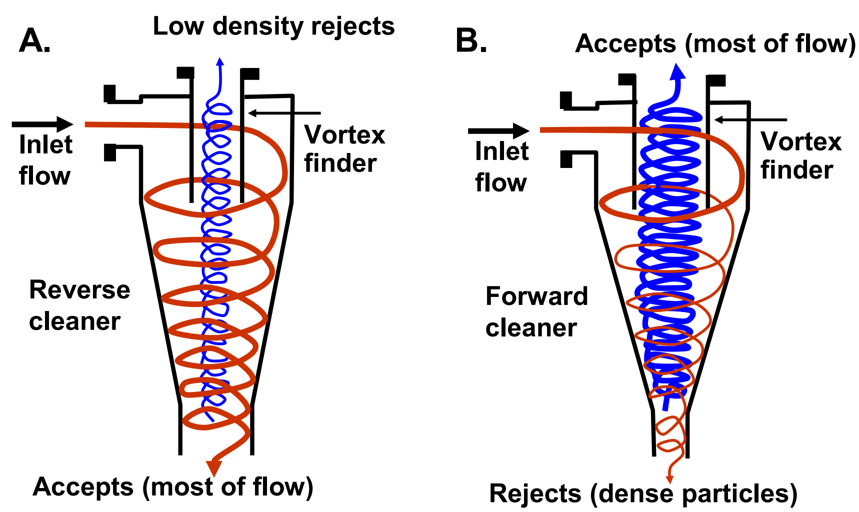


Fig. 17. Schematic Illustration of two classes of hydrocyclones: A. reverse cleaners for maximizing removal of low-density contaminants; B. forward cleaners for removal of high-density contaminants

Part A of Fig. 17 illustrates a hydrocyclone that is designed and set up to remove such fractions, along with obviously low-density contents such as fragments of expanded polystyrene foam. Because such devices are relatively easy to set up and run, they are widely used in paper recycling operations (Doshi and Dyer 2002; Lee *et al.* 2005; Lee and Kim 2006). The key limitation of hydrocyclones is that the target material needs to be both significantly less dense than water and also large enough (say > 10 µm) to be susceptible to this kind of separation. Thus, Bormett *et al.* (1995) reported that separation efficiency increased with decreasing particle density (below the density of water) and increasing particle size. Hall and Ling (1996) showed that separation of low-density stickies in a reverse cleaner operation can be enhanced by agglomeration, leading to larger stickies having greater buoyancy.

In some applications, it has been found useful to employ reverse cleaners in combination with a related type of device called a through-flow cleaner (Bliss 1985; Bormett *et al.* 1995; Byrd *et al.* 2002). Unlike the designs described in Fig. 17, both the accepts and rejects streams pass through the narrow, conical end of a through-flow cleaner. Such devices have been shown to perform well when the rejected stream (low density, coming from the center) constitutes about 5 to 15% of the total volume. It has been found advantageous to employ through-flow cleaners as a second stage to handle the reject stream from a reverse cleaner (Bliss 1985). Early versions of the through-flow cleaner were subject to occasional plugging by large debris, but such problems have been overcome by use of a retractable vortex finder tube at the small end of the cone. In a related development, it has been found useful to insert a cylindrical tube all the way from the wide end of a hydrocyclone (for the exit of the low-density fraction) to a small expansion chamber at the narrow end (Ecofario 2021). Such a device can be effective for removal from water of low-density, small particles falling into the category of microplastics.

As another alternative to hydrocyclones for removal of low-density stickies, similar effects have been achieved in the past by use of a centrifugal effect. Thus, Khong *et al.* (1997) describe a device in which a rapidly spinning horizontal cylinder causes light materials within a flowing mixture to come to the center, where they are continuously removed. Such a device is redrawn in Fig. 18.

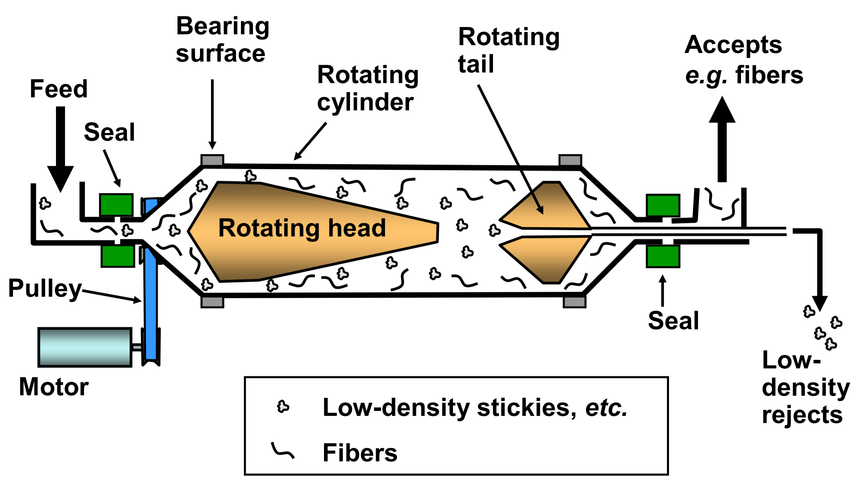


Fig. 18. Schematic Illustration of a flow-through device, based on centrifugal force within a spinning cylinder, allowing removal of light material near to the axis of spin of the cylinder

Note that such a device can fulfill a similar role that is similar to that of the reverse cleaner depicted in the previous figure. Reverse cleaners, sometimes in combination with through-flow cleaners, have become preferred relative to the centrifugal device shown in Fig. 18 due to less problems with fouling.

Forward cleaning

The term forward cleaning is used when the material to be removed is denser than water. For example, forward cleaners are routinely used just before the paper machine for the purpose of removing sand, metal fragments, *etc.* A hydrocyclone set up to work in this manner is shown in Part B of Fig. 17. Devices operating this way can be optimized for removal of relatively dense stickies, for instance those containing a majority of relatively dense components such as rosin or acrylic latex. Because fiber suspensions may contain mixture of both lower-density and higher-density stickies, it has been recommended to use both reverse and forward cleaners sequentially (AbuBakr and Peng 1999). It is also possible to achieve both effects within a single hydrocyclone having a specialized design.

Bize *et al.* (2002) and Yordan *et al.* (1997) showed that a synergistic effect can be achieved by addition of talc to a fiber suspension containing stickies and then passing the mixture through forward cleaners. The talc, which has a density of about 2.75 g/cm^3, has a relatively hydrophobic surface, which favors its attachment to stickies. The cited study showed that talc addition increased the removal efficiency of forward cleaning from about zero to about 50% in a typical case.

Washing

The term “washing” is used to describe equipment that uses rinse water to displace the contaminated water contained in a wet mat of papermaking fibers (Santos and Hart 2014). Washing systems are often set up with counter-current flows, such that the cleanest water is used to displace water from the cleanest fibers, and *vice-versa* (Ala-Kaila *et al.* 2005; Frigieri *et al.* 2016). A favorable attribute of including a washing stage is that it provides a way to remove a wide range of undesired contents from the fibers, *e.g.* deinking chemicals, pitch components, and ink, in addition to stickies. Washing stages have been included as a unit operation for stickies removal (AbuBakr and Peng 1999; Lee *et al.* 2005). A challenge is that some stickies, especially macrostickies, may remain caught within the fiber mat, and stickies of various size may remain adhering to fibers. Surfactants and dispersants can be added to the pulp at moderate dosages to help release them from the fibers (Fogarty 1993). Sharoyan and Nicholson (2023-pat) claimed a treatment using a cationic polymer and a vegetable oil alkyl ester surfactant for pulp washing to remove stickies.

When any kind of washing operation is successful, one of the necessary outcomes is a stream of contaminated water, which in many cases implies discharge to a wastewater treatment operation (Doshi and Dyer 2002). Strauß and Großmann (1997) describe kidney-like measures by which such process water can be treated within the paper mill. When the main contaminants in such rinsate happen to be stickies, pitch components, or ink particles, there are other viable options. For instance, such particles can be separated using a membrane filter (Hamann and Blechschmidt 2000). Yet another option, especially when there are relatively small stickies present in fiber suspension, is the next topic, flotation.

Flotation to remove stickies from process water

During various filtration processes in paper mills, including thickening, washing, sheet-formation, and save-all operations (Smook 1992), the process water is separated from process water. Such instances can provide an opportunity to apply a form of kidney technology to remove stickies from the system. This can be achieved by operation of a flotation device, especially when dissolved air flotation (DAF) technology is used.

Separation of stickies from aqueous suspensions takes advantage of the tendency of bubbles to cling to hydrophobic surfaces (Ling 1994). As already noted, stickies are generally hydrophobic. Sun *et al.* (2006) found that two key parameters to optimize in a flotation operation were the rising action of the bubbles and the lifting of a froth to the water surface. Various researchers have found flotation devices to be effective for the removal of stickies from suspensions of recovered fibers (Abraham 1997; Miranda *et al.* 2006). However, according to Abraham (1997) the method did not appear to be effective for separation of particles larger than about 30 μm. Such particles may be too heavy to be reliably lifted by small bubbles so that they can be skimmed from the water surface and collected. For this reason, flotation is often deployed as a means to remove microstickies after the larger particles have been removed by screening (Schwarz 1997; AbuBakr and Peng 1999). Doshi *et al.* (2003) found that froth flotation was more effective at removing stickies in comparison to cleaning with hydrocyclones. Geistbeck and Wiese (1997) reported a multi-step process in which a flotation operation was preceded by coarse filtration and followed by fine filtration. As another option, Heise *et al.* (2000b) and Hamann and Blechschmidt (2002) showed that flotation of stickies benefited from treatment with a flocculant. Ling (1994) found that the most effective flotation aids were those that tended to preserve the hydrophobic nature of the stickies. Lee *et al.* (2005) found that whereas talc tended to increase the attachment of bubbles to stickies, various hydrophilic polymers tended to do the opposite. Hsu and Dauplaise (1996) showed that flotation performance could be enhanced with a newly designed air injector to create rising bubbles.

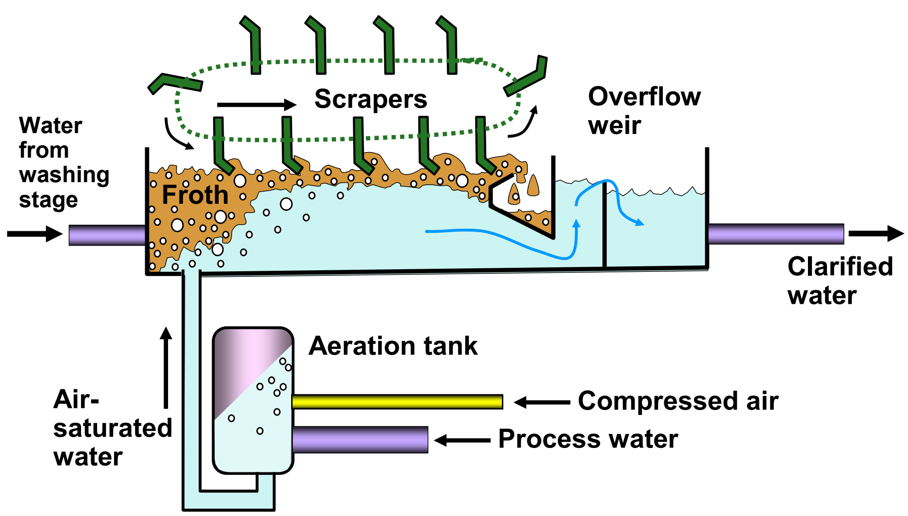


Fig. 19. Schematic diagram of a dissolved air flotation (DAF) unit

A popular approach, called dissolved-air-flotation (DAF), involves dissolving air into water under elevated pressure and then feeding the air-saturated water gradually at the base of a flotation tank (Davis and Schwarz 1997; Delagoutte *et al.* 2002a; Sarja *et al.* 2004; Doshi *et al.* 2008-pat). The drop in pressure as the air-saturated water enters at the base of the flotation cell results in rapid nucleation of tiny bubbles. Such a system is illustrated schematically in Fig. 19. As shown, a supply of pressurized water is equilibrated with a stream of process water in an aeration tank. Because stickies tend to be hydrophobic, they have a natural tendency to adhere to any bubbles with which they happen to collide. As shown in the figure, the rising bubbles with attached stickies float to the surface as a froth, which can be skimmed from the surface of the shallow tank and collected for disposal. Meanwhile, the clarified water flows over a weir and is discharged. Depending on how efficiently the contaminants are removed, the clarified water may continue to be used in the papermaking process.

Extraction

Blaney and Hossain (1997) showed that it is technically feasible to remove stickies from recycled fibers by extraction, using supercritical carbon dioxide or supercritical propane as the solvent. Stickies removal percentages, in the range 69 to 91%, were on the whole higher than could be achieved by Soxhlet extraction with such solvents as an ethanol/benzene mixture, acetone, chloroform, and hexane. An advantage of using supercritical carbon dioxide or propane is that the dissolved matter can be later quickly removed from the solvent just by lowering the pressure. The medium can be used multiple times. Though extraction procedures tend to be expensive, they may offer a back-up option in cases where other technologies fail.

Detackification of Stickies

In contrast to the unit operations just considered, detackification strategies generally are not aimed at removing stickies from the fiber suspension. Rather, the goal is to render the remaining stickies non-tacky. The idea is to prevent them from agglomerating, prevent them from depositing on various surfaces in the paper machine system, and eventually to retain them as a benign component of the paper product being made (Spedding 2002).

Before considering various ways to overcome the tacky nature of stickies, it is worth considering what makes them tacky in the first place. According to Doshi and Dyer (2002) the three critical steps in sticking something to a surface are wetting, adsorption, and diffusion. The hydrophobic nature of most stickies is expected to contribute to the first step. Low-surface-energy fluids can be expected, in general, to wet higher-energy surfaces (Donaldson and Alam 2008). However, the adhesive material, perhaps due to effects of plasticizers or heating, needs to be sufficiently fluid to be able to spread effectively. Contact needs to be achieved at a molecular level over a broad area of contact. The term diffusion is being used here to describe what happens among segments of polymers at the interface between two stickies particles. Hansen (2007) has shown that intermixing of different materials is most favored when they share common values of three different characteristics, namely the cohesive energy density, degree of polarity, and degree of hydrogen bonding ability. Thermal energy and the resulting semi-random motions of polymer segments are involved in the mutual solubilization process at such interfaces. Such intermixing helps to explain why, for instance, chewing gum tends to stay as a single object, even when subjected to aggressive shearing in a wet environment. Detackifiers, of various types, need to somehow coat the surfaces of stickies and prevent one or more of the three steps from happening.

Minerals as detackifiers

Many publications have described the usage of mineral particles as pacifying agents for tacky particles in papermaking fiber suspensions, including not only stickies but also wood extractives (pitch) (Gribble *et al.* 2010). Table 10 provides highlights from such publications. Historically, talc has been regarded as the benchmark against which any other detackifying agents need to prove themselves. Attributes of a high-performing talc product for detackification include a high surface area, which may be achieved by mechanical delamination by the supplier. Talc is known to have somewhat hydrophobic plate surfaces, along with positive charges at the edges of particles. Because anionic dispersants are routinely used to prepare talc suspensions, such charged surfaces are likely to have been reversed to a net-negative sign.

Bentonite, the dominant mineral of which usually is montmorillonite, is a promising substitute for talc. Since its plate surfaces tend to be hydrophilic, it is often rendered cationic to make the surfaces more attractive to stickies.

Though calcium carbonate has been found to act as a detackifier in some circumstances (Doshi *et al.* 2018), such findings can be dependent on the context. Calcium carbonate particles often imply an increased concentration of divalent calcium ions, which can associate with organic carboxylate species (Rios-Carbajal *et al.* 2019), leading to deposits. On the other hand, large amounts of fresh calcium carbonate particles, as in the production of printing paper grades, can provide large amounts of surface that can adhere to any tacky materials that are present.

Table 10. Highlights from Studies in Which Mineral Particles Were Used to Detackify Stickies in Papermaking Fiber Suspensions

Highlights from the Article or Patent	Citation
The detackifying effect of talc for stickies was shown with a deposition tester, infrared spectrometry, and a scanner.	Yordan and Maat 1997
Addition of talc reduced the deposition of poly(vinylacetate) (PVAc) onto foam squares by 80 to 95%, depending on the dosage.	Maat & Yordan 1998
This patent claims the use of bentonite in combination with poly(vinyl alcohol) addition for stickies control.	Kohler *et al.* 2001-pat
Fine talc particles were more effective in increasing the removal of stickies by usage of forward hydrocyclone cleaners. The rejects stream had a 4.8 times higher stickies concentration compared to the incoming fiber suspension.	Biza *et al.* 2002
The review article notes that talc has been widely used as a detackifier for stickies.	Doshi & Dyer 2002
The growth of stickies particle size was mitigated by the addition of talc or by some non-mineral additives.	Venditti *et al.* 2002
Talc addition generally increased the attachment of stickies to air bubbles in flotation experiments.	Lee *et al.* 2005
This patent claims the use of synthetic metal silicates (SMS) as mineral detackifying additives for paper fiber suspensions.	Gray *et al.* 2007-pat
This patent claims the use of bentonite having an optimized ion exchange capacity for control of impurities during paper production.	Sohling *et al.* 2009-pat
An acrylic ester copolymer was tested with aqueous suspensions of various talc products and with modified calcium carbonate, forming monolayers and multilayers.	Gribble *et al.* 2010

Highlights from the Article or Patent	Citation
Modified calcium carbonate achieved higher adsorption of stickies than high-surface area talc and bentonite, with low-surface area talc giving the lowest performance.	Gribble *et al.* 2011
Magnesium aluminum hydroxides were found to be highly effective against model stickies at neutral pH. Drying at temperatures in the range 400 to 600 °C improved the performance.	Li & Liu 2011
When stickies were destabilized by adding cationic polyacrylamide (cPAM), they could be adsorbed onto talc or precipitated calcium carbonate.	Liu *et al.* 2011
The patent claims the addition of talc to the separated process water of a paper mill.	Woiceshyn 2011-pat
This patent claims the use of zeolites for control of organic contaminants.	Ban and Thomas 2015-pat
This patent claims the use of hydrophobized calcium carbonate filler particles as a detackifying agent.	Gantegein *et al.* 2015-pat
A modified kaolin product, with increased hydrophobicity, was found to be effective for collecting stickies.	Basilio 2017
Calcium carbonate is known to have a pacifying effect on stickies, according to these authors, both other work sometimes indicates otherwise, since the Ca^{2+} ion can destabilize stickies particles in suspension.	Doshi *et al.* 2018
A montmorillonite (bentonite) product was found to be most effective for overcoming stickies problems.	Kuna *et al.* 2018
Talc was used as a baseline for comparison with the detackifying effect of chitosan/montmorillonite (bentonite) on stickies in recycled fiber suspensions.	Geng *et al.* 2020
This patent claims delamination of bentonite particles, using high shear, to make them more effective as detackifying agents.	De Carvalho and Barreto 2021-pat
This review article describes talc and bentonite as widely used detackifying agents for stickies. Such treatment provides the stickies with a hydrophilic exterior.	Sutman and Nelson 2022

Modified minerals as detackifiers

There have been considerable efforts to improve upon the performance of as-received mineral products for stickies pacification by modifying them. Highlights of such studies are listed in Table 11. As shown, two promising kinds of treatments aim to provide a higher affinity between the solid particles and stickies. On the one hand, the mineral surfaces can be treated to make them hydrophobic (Spedding 2002; Basilo 2017). On the other hand, a cationic charge adsorbed onto the mineral can make the surface attractive to any carboxylic acid groups associated with the stickies.

Although many common components of stickies lack such negatively charged groups, it is likely that some pitch-like species, such as fatty acids and resin acids (*e.g.* abietic acid), will have become adsorbed onto the stickies. It is worth noting, in this regard, that certain minerals are naturally cationic. For instance, Li and Liu (2011) showed that the cationic mineral magnesium aluminum hydroxide (MAH) was an effective absorbent for pitch and stickies.

Table 11. Highlights from Studies in Which Mineral Particles Were Modified and Then Used to Detackify Stickies in Papermaking Fiber Suspensions

Highlights from the Article	Citation
Bentonite was used in combination with polyethylene oxide to decrease the deposition of stickies. In addition, the combined treatment improved the retention of stickies, as small particles, in the paper product.	Beaudoin *et al.* 1998
Minerals that had been chemically structured were shown to be effective for reducing stickies-related problems.	Konopa 1998
Hydrophobically modified (but not identified) mineral particles were more effective for microstickies pacification. The minerals could be added before a flotation stage.	Spedding 2002
Talc was cationically treated to increase its attachment to stickies.	Yordan *et al.* 2002
This patent claims treatment of talc with cationic polymer to render it more effective for binding of stickies.	Sharma *et al.* 2003-pat
Cationized mineral was added to the papermaking fiber furnish to overcome stickies problems.	Lasmarias *et al.* 2004-pat
This patent claims the cationic treatment of bentonite or other particles to improve detackification of stickies.	Grimsley *et al.* 2005-pat
In this patent, talc or bentonite was modified with terpene to render it more effective for detackification of stickies.	Mah *et al.* 2005-pat
Kaolin was treated to render it more hydrophobic. It was used effectively in combination with an agent designed to facilitate detachment of the stickies from fibers.	Basilo 2017
This patent claims the treatments of kaolin with nonionic surfactant to render it more effective for stickies control.	Basilo & Sheppard 2019-pat

Whether or not the mineral particles had been rendered cationic or not, the general effect can be represented by Fig. 20. As shown, the idea is that the particles basically adhere to the tacky surfaces of stickies and cover it up. Such a mechanism is consistent with the thin, platy nature of the talc and bentonite products that have been widely used for detackification of stickies and pitch.

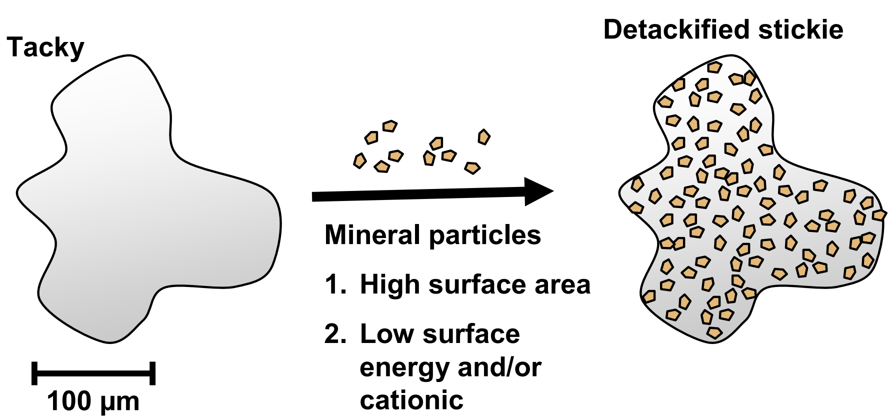


Fig. 20. Schematic illustration involving covering the surfaces of stickies with solid particles

Plastic-like solids as detackifiers

As noted by Doshi and Dyer (2002), synthetic plastic fibers can be effective for removal of stickies from pulp suspensions. Because of their fiber-like shape and hydrophobic nature, acrylic fibers have been shown to be highly effective not only in adsorbing stickies but also in retaining them in paper (Monfared *et al.* 2016). In the cited work, the fibers had been cut to a length of about 2 mm, which is within the range between typical hardwood and softwood fibers. Over half of the microstickies were removed from the process water, and the drainability of the fiber suspension (*i.e.* the freeness) was increased. Parker *et al.* (2020a-pat,b-pat) claimed the use of cellulose acetate fibers, which are hydrophobic and able to attach to the surfaces of stickies in paper mill systems. Similar effects have been achieved by the repulping of silicone release liners (Doshi *et al.* 2018). Apparently, sufficient hydrophobicity remained associated with the repulped material to achieve affinity with stickies, which were rendered less tacky.

Organic nonionic detackifiers

As a major competitor to talc and bentonite detackifier treatments, a wide range of organic detackifying treatments have been developed. Table 12 provides highlights of a group of such products that can be described as nonionic.

Table 12. Highlights from Studies in Which Nonionic Organic Copolymers or Monomers Were Used to Detackify Stickies in Papermaking Fiber Suspensions

Highlights from the Article	Citation
Adsorption of nonionic polymers led to a high contact angle of decane droplets, suggesting low wettability by stickies.	Ling 1993
Nonionic copolymers were optimized to achieve stickies detackification at lower operating temperatures.	Hall & Nguyen 1998
A block copolymer of ethylene oxide and propylene oxide prevented stickies from attaching to bubbles during froth flotation.	Lee *et al.* 2005
This patent claims the use of a hydrophobic copolymer containing lauryl and octyl alkane groups to control stickies.	Dougherty & Gelman 2006-pat
This patent claims the use of a hydrophobic polyethylene glycol for stickies control.	Gu *et al.* 2008-pat
This patent claims the addition of epoxy or glycidoxy functional silanes to paper stock.	Francis *et al.* 2009-pat
This patent claims the use of glycerol-based amphiphilic polymers to overcome problems with stickies.	Li *et al.* 2014-pat
This patent claims the use of a copolymer prepared from a hydrophilic monomer and at least two hydrophobic monomers for stickies control.	Cowman *et al.* 2019-pat
This patent claims the usage of polysiloxanes as release agents, to be added to paper machine systems to prevent deposition of stickies.	Sekiya & Yusa 2021-pat
This review chapter states that copolymers containing both hydrophobic and hydrophilic, nonionic groups have potential to render the surfaces of stickies more hydrophilic.	Sutman and Nelson 2022
This patent claims the addition of a combination of an oil and a surfactant to papermaking furnish to minimize deposition onto dryer fabrics and cylinder surfaces.	Wang *et al.* 2025

Some nonionic detackiers can be described as surface-active, having a combination of hydrophilic and hydrophobic parts. As noted by Hall and Ngugen (1998) and Sutman and Nelson (2022), this kind of treatment, where the hydrophobic groups associate strongly with the stickies, tends to render the surfaces of the stickies more hydrophilic and less likely to deposit.

Figure 21 shows schematically how detackification can be achieved when using a copolymer that includes both hydrophilic and hydrophobic segments. The particle at left is shown without anything on its surface, which is assumed to be highly tacky. The copolymer, in this example, is assumed to be a block copolymer, in which there are hydrophobic segments (shown in dark green) having an affinity for the surfaces of stickies. The hydrophilic segments (shown in violet) are expected to extend outwards into the aqueous medium. The hydrophilic tails or loops extending into the bulk solution can be expected to provide a steric barrier preventing self-agglomeration of the stickies.

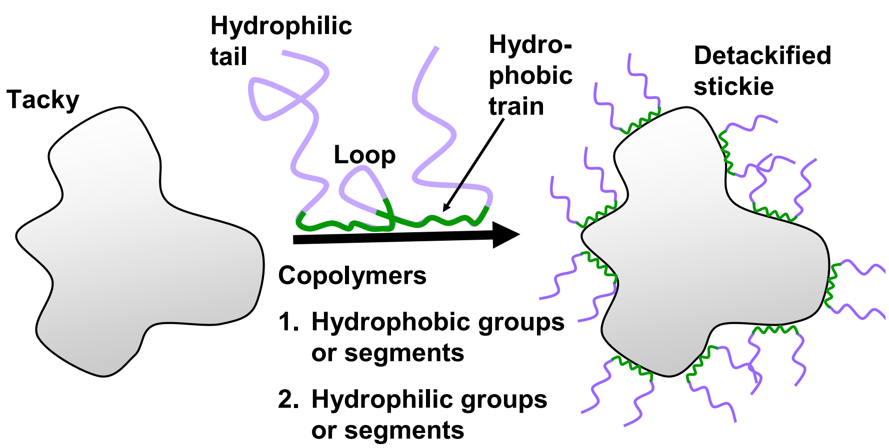


Fig. 21. Schematic of the likely configuration of adsorbed amphiphilic detackifying agents onto the surfaces of stickies

In addition to the items listed in Table 12, Gu *et al.* (2022-pat) claimed the use of N-vinyllactam-containing polymers for stickies control. Though the formula usually used to denote such polymers would be consistent with calling them nonionic, their structures are subject to rearrangement, giving rise to a transient zwitterionic form. It seems likely that such ionization helps to achieve sufficient water-affinity so that the product is able to be dispersed in water and thereby diffuse to the surfaces of hydrophobic particles. Li *et al.* (2013-pat), in addition to their 2014 patent, also claimed an anionic polymer version of a lipophilic glycerol polymer. Ling *et al.* (2017-pat) patented the use of lignin, in solution or particle form, with either uncharged lignin or low anionic charge (due to sulfonation), for control of stickies.

Cationic polymer detackification schemes

Cationic polymeric agents, for control of stickies, are worth considering as a separate group due to the fact that the positive charge can aid in retention of the stickies to fibers, thereby increasing the efficiency of their retention in the paper. Table 13 provides highlights of articles and patents in which the stickies control agents were cationic polymers or copolymers.

Table 13. Highlights from Studies in Which Cationic Organic Copolymers or Cationic Polymers or Soluble Aluminum Products Were Used to Detackify Stickies in Papermaking Fiber Suspensions

Highlights from the Article or Patent	**Citation**
This overview article mentions that cationic compounds can play roles in detackification of stickies as well as their retention in the paper.	Fogarty 1993
Sequential treatment of the furnish with polyaluminum hydroxychloride (a version of polyaluminum chloride, PAC) with colloidal silica was shown to retain stickies in the paper and minimize problems related to tackiness.	Rebarber 1995
This patent claims the use of various cationic oligomers for the control of stickies.	Croft *et al*. 2000-pat
A system for stickies control is described in this article as using a detackifying agent and a coagulant. The system was optimized to retain the stickies in the paper.	Crowe & Landstra 2001
The patent claims the addition of a combination of a cationic polymer and a nonionic surfactant for treatment of press felts to inhibit deposition of stickies.	Hendriks & Cowart 2001-pat
A combination of rosin and alum tended to have a detackifying effect, according to this review article.	Doshi & Dyer 2002
In the presence of rosin and alum, there was less growth of stickies through self-agglomeration.	Venditti *et al.* 2002
This patent claims the addition of a combination of a cationic polymer with hydrophobically modified hydroxyethyl cellulose for overcoming the effects of tacky materials in papermaking.	Steeg *et al.* 2004-pat
This patent claims the addition of vinylamine polymers to paper stock suspensions for control of stickies.	Gu *et al.* 2009-pat
This patent claims the use of a hydrophobically modified poly(amidoamine) cationic polyelectrolyte for stickies control.	Gu *et al.* 2010-pat
Flow cytometer tests were used to demonstrate the beneficial effects of cationic fixatives on the deposition of stickies onto papermaking fibers, thereby allowing the material to be retained in the paper.	Jiang & Chen 2010
A combination of precipitated calcium carbonate particles and cationic polyacrylamide (cPAM) retention aid helped to retain stickies onto fibers and purge them from the paper machine water system.	Liu *et al.* 2011
Starch and chitosan-based polymers were rendered either more cationic by attaching quaternary ammonium groups or more hydrophobic by attaching pendant aromatic groups.	Petzold *et al.* 2012
This patent claims an acylated vinylamine-based polymer for use as a papermaking additive for stickies control.	Gu & McKay 2012-pat
This patent claims the use of vinylamine copolymers for the control of stickies.	Borkar 2013-pat
This patent claims the addition of a cationic polymer fixative, in combination with starch, to papermaking furnish for control of stickies.	Karppi *et al.* 2014-pat
Dynamic surface tension tests were used to provide further insights into the use of starch and chitosan-based polymers that were rendered either more cationic by attaching quaternary ammonium groups or more hydrophobic pendant aromatic groups.	Genest *et al.* 2015

Highlights from the Article or Patent	Citation
This patent claims the usage of cellulose ethers such as hydroxypropyl cellulose, in combination with cationic polymers, for the control of stickies.	Yuan *et al.* 2015-pat
This patent claims the use of cationic acrylamide copolymers in which some units have a pair of quaternary ammonium groups.	Li *et al.* 2018-pat
This patent claims the use of a hydrophobic vinylamine polymer for control of stickies.	Gu *et al.* 2019-pat
Microspheres composed of the cationic natural polymer chitosan with either montmorillonite or ferroferric oxide were effective for removal of stickies. The treated sheets of paper showed less transfer of stickies to aluminum foil that was held in contact with the paper during drying at 130 °C.	Geng *et al.* 2020
This patent claims the addition of a cationic polyacrylamide dispersion (retention aid) to papermaking furnish for the control of stickies.	Laakonen *et al.* 2014-pat

As a way to extend a theme common to several of the studies represented in the table above, Fig. 22 shows how cationic polymers can be employed in a retention aid system, such that most stickies can be retained efficiently in the paper product being manufactured. Ideally, such an approach would be taken only after the remaining stickies are at a suitably low amount and none of them are large enough to be visible in the product. In the scenario shown, it is assumed that the stickies already had been subjected to a detackifying treatment, *e.g.* with the addition of a platy mineral. Addition of a coagulant to such a suspension – especially if the system charge has been optimized – is expected to lead to agglomeration of the fine particles in the suspension, including not only the stickies but also cellulosic fines, mineral filler particles, *etc.* In the next step, papermakers would very likely be treating the mixture with a very-high-mass copolymer such as cationic polyacrylamide (cPAM). Such polymers have been found to be very effective at attaching various particles to papermaking fibers.

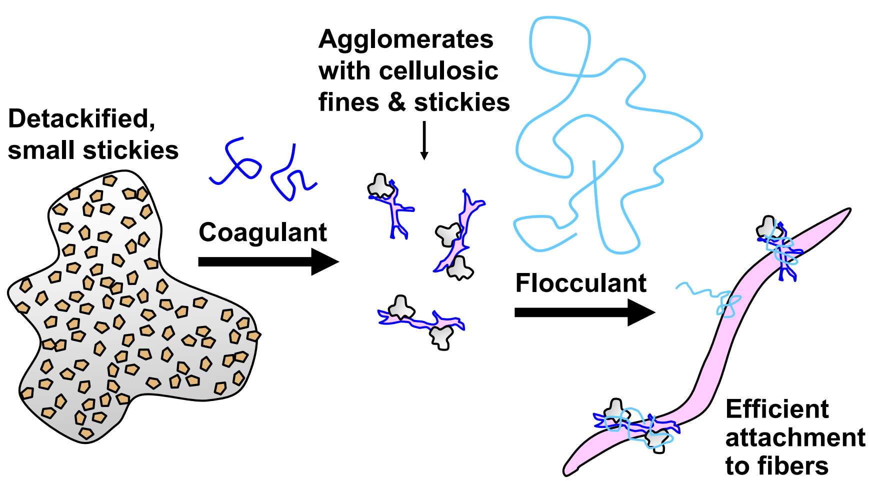


Fig. 22. Schematic illustration of a dual-effect detackification and retention mechanism, whereby the detackified stickies become part of the paper product

The work by Petzold *et al.* (2012) demonstrated two contrasting and effective mechanisms of detackification. The more highly cationic polymers tended to act by a "charge-dominated-removal" of stickies for the system. The more hydrophobic agents followed a "hydrophobicity-dominated" mechanism. Turbidity tests showed that the dosage of the cationic agents could be optimized to achieve high levels of separation of the stickies from the water phase.

Though the tests were carried out in the absence of fibers, it is reasonable to expect that such conditions could be tuned to maximize retention onto fibers and incorporation of stickies in stabilized form in the paper product, thereby flushing them continually from the process water.

Amphoteric copolymers, including proteins, as detackifiers

Proteins also have been found to play a role as detackifiers. Depending on the ratios between different amino acid groups, different proteins have a range of net ionic charge and degrees of hydrophobicity. A patent by Gu (2001) claimed the use of proteins for stickies control. Naithani *et al*. (2015) showed that soy protein could be used effectively as a detackifier. It was shown that adding protein to the papermaking furnish lowered the peel force when removing the paper from a surface. A patent by Juzukonis and Chen (2000-pat) likewise involved usage of a polymer with cationic, anionic, and hydrophobic groups. Song *et al.* (2006-pat) claimed the usage of amphoteric polymers prepared from diallyldimethylammonium chloride (DADMAC) and acrylic acid for control of pitch and stickies.

Cyclodextrin as a detackifier

In addition to the detackification systems and mechanisms considered so far, there appears to be potential for a different, and perhaps complementary approach. Banerjee (2008-pat) claimed a technology by which treatment of stickies with cyclodextrin decreased the tackiness of the stickies. Because cyclodextrin is a small molecule, it does not appear that the effects were attributable to the formation of a surface layer. Rather, the effect may have been due to something else, including possible changes in bulk characteristics of the stickies. Banerjee *et al.* (2012) suggested a solubilization effect. Further studies are needed to follow up on the mechanisms related to this patented technology. Xu *et al.* (2006-pat) claimed the addition of cyclodextrin to pulp to reduce the tackiness of stickies.

Enzymatic Modification of Stickies

Enzymes represent a way to attack the chemical structure of certain stickies, thereby changing their properties. As was noted earlier, many of the components of stickies fall into the category of esters. Among the reported stickies components that were listed in Table 14, the following are esters: ethylenevinylacetate (EVAc), polyvinylacetate (PVAc), poly(methacrylate), poly(butylacrylate), dioctylphthalate, and triglyceride fats. In principle, each of the ester bonds could be cleaved by a suitable esterase product, such as a lipase. By converting ester groups present on the surfaces of stickies to -OH groups, which are more hydrophilic, the tackiness can be reduced. Articles and patents describing such approaches to addressing stickies problems are listed in Table 14.

Table 14. Highlights from Studies in Which Cationic Organic Copolymers or Cationic Polymers or Soluble Aluminum Products Were Used to Detackify Stickies in Papermaking Fiber Suspensions

Highlights from the Article	Citation
This article provides an overview of enzymatic treatment to address stickies problems.	Fitzhenry 2002
This overview summarizes the use of enzymes to control stickies.	Jones 2005
This patent claims the combination of a broad range of enzymes being added together with a broad range of minerals, including bentonite and talc.	Wang *et al.* 2006-pat
This patent claims adding a combination of lipase enzyme and a soluble cellulose derivative, such as methylcellulose for the breakdown of stickies.	Thomas 2008-pat
This patent claims the use of an enzyme, such as lipase, in combination with a nonionic polymer detackifier for the control of stickies.	Xu & Carey 2008-pat
A pectinase was found to decrease dissolved and colloidal substances (DCS) and thereby improve the performance of cationic polymers that were being used for stickies control.	Li *et al.* 2011
Two types of lipases were shown to be effective in addressing stickies problems.	Liu *et al.* 2012
Treatment with an enzyme decreased the amount of microstickies and also reduced the cationic demand in old newspaper pulps.	Pei *et al.* 2013
Enzyme treatment decreased stickies deposition onto paper machine blankets.	Ren *et al.* 2013
This patent claims the use of diatomaceous earth, a detackifier, and an esterase enzyme to combat organic contaminants, including stickies.	Thomas *et al.* 2013-pat
Phospholipase was shown to be effective in controlling stickies in old newspaper pulp.	Shen *et al.* 2017
This patent claims the use of a combination of different enzymes used together to treat papermaking pulp to control stickies.	Ghosh *et al.* 2018-pat
Various lipase enzymes were found to cleave components of stickies, including poly(butylacrylate), dioctylphthalate, poly(vinylacetate), and poly(styrene acrylate).	Ballinas-Casarrubias *et al.* 2020
This review article states that lipases are the most prominent type of enzymes used to combat stickies problems.	Sutman and Nelson 2022
This patent claims the usage of esterases that had been engineered for the breakdown of polyethylene terephthalate.	Lippens *et al.* 2025-pat
These patents claim the usage of specialized esterases for the degradation of certain ester-containing polymers.	Marty *et al.* 2025a-pat,b-pat

Figure 23 presents a hypothetical description of the mechanism by which specific enzymes are able to catalyze the hydrolysis of ester bonds, which happen to be present in several of the main categories of chemical components in stickies. Note that the chemical formula at the upper left corner of the figure represents an ester bond that is the key to maintaining the structure in a stickies component of interest. Hydrolysis involves addition of one water molecule and thereby breaking up the ester into a carboxylic acid and an alcohol. The enzyme, which is depicted as a dark green object, is a large protein, or possibly as many are four large protein molecules stuck together. It is well known that such molecular structures tend to vibrate in characteristic ways due to thermal motions. Such quivering can be expected to place variable stress on the indicated bonds within the ester. Such a mechanism may at least partly explain why enzymes are able to provide a lower-energy path for hydrolysis. Fortuitously, many enzyme products have a maximum in effectiveness within the same temperature range as used in papermaking systems.

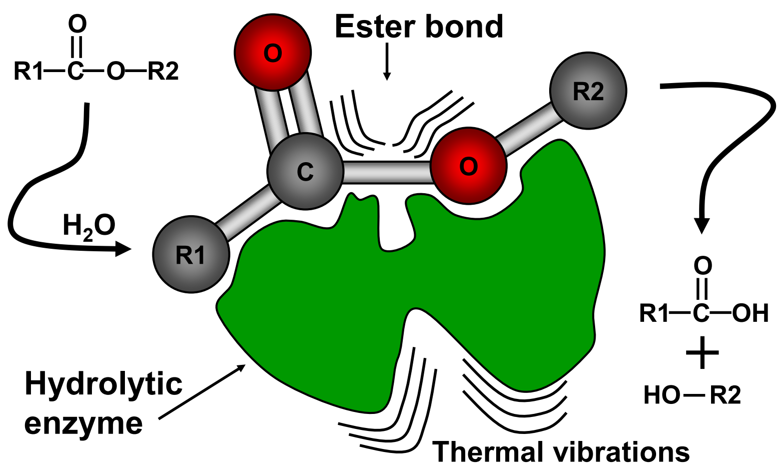


Fig. 23. Concept of the catalytic role of enzymes in facilitating the hydrolytic cleavage of ester groups, including those present in several major components of stickies

When considering the use of enzymes as a means to control stickies or other aspects of papermaking, experience has shown that attention needs to be paid to concentrations, times, and temperatures. The dosage of the enzyme product needs to be well chosen, so as to balance costs and performance. The time of treatment may depend on the size and locations of available chests (large open agitated tanks) within a given paper mill. Different enzyme products will have different ranges of favorable temperature for their best performance. If the temperature is too high for a specific enzyme, it can become deactivated (*i.e.* denatured) too rapidly.

Recalcitrant Stickies

The term "recalcitrant stickies" has been used to refer to material that does not respond well to one or more of the unit operations considered in this work (Wilhelm *et al.* 1999; Miranda *et al*. (2008). For instance, some stickies are difficult to separate by screening or flotation. Miranda *et al.* (2008) found that the compounds most likely to still be present in the furnish and to still cause problems include poly(vinylacetate), polyacrylates, styrene-containing compounds (*e.g.* latex), and wood extractives, including fatty acids and resin acids. Wilhelm *et al.* (1999) found that mixtures of sticky components, such as poly(vinylacetate) (from hot-melt adhesives) with polyacrylate (from pressure-sensitive labels) offered the greatest challenges. In addition, Li *et al.* (2013a) found that the aging of adhesives could render them more difficult to remove. The aging effects were nonuniform, leading to unequal and unpredictable behavior. The term recalcitrant has been applied in various ways, rather than indicating a specific set of behaviors.

Dispersion of Stickies

The topic of dispersion of stickies, *i.e.* treatments specifically intended to make the particles smaller, has been left nearly to the end of this section for a reason. The production team in each paper recycling facility will need to carefully plan the most advantageous position in the system (or not at all) to deploy a dispersion step. On the plus side, dispersion of stickies can make most of them small enough that they cannot be individually seen in a paper product, and sometimes they can be retained in the paper without notable adverse effects. But on the negative side, dispersion necessarily increases the surface area of tacky surfaces, makes the particles more difficult to retain in paper according to filtration mechanisms, and of course should never be done before a screening operation intended for stickies removal. These characteristics provide strong motivation to treat the fiber suspension with detackifying agents before or during dispersion. Another logical approach is to carry out a flotation separation immediately after dispersion.

Fragmentation of stickies into smaller particles can be efficiently achieved by the use of dispergers or by kneading (Fogarty 1993; Miller 1998; Doshi and Dyer 2002). The disperger equipment often consists of a rotor and a stator, with ridges or bumps provided to create a chaotic flow-field and high shear (Mannes 1997). An example of such equipment is shown schematically in Fig. 24. The cited article showed that the best results were obtained at relatively high stock consistencies within the disperger, *e.g.* 25 to 33%, depending on the equipment type. A study by Gao *et al.* (2012) showed that progressively smaller stickies resulted when the temperature was raised in the range from ambient to 100 °C. This effect can be attributed to the decreasing viscosity and strength of stickies components upon heating.

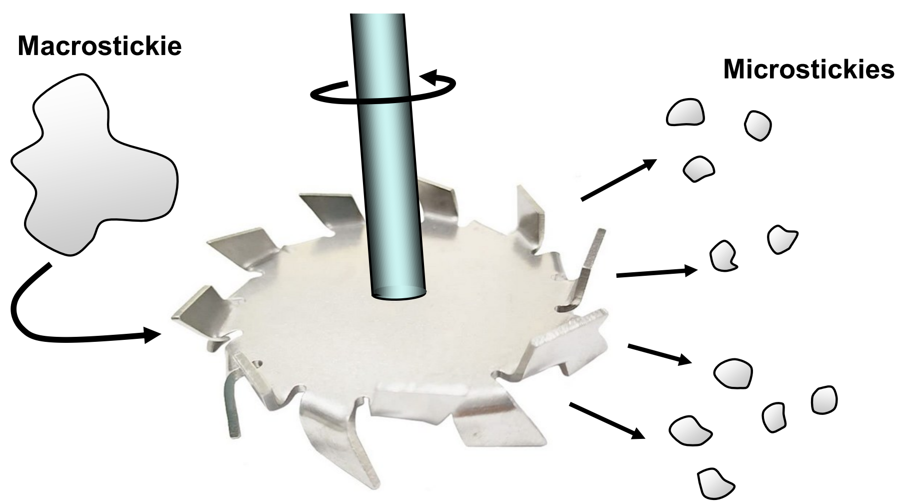


Fig. 24. Schematic illustration of a disc dispersion device

Steam explosion also has been mentioned as a possible approach to dispersing stickies into smaller particles (Luo and Wang 2008; Luo *et al.* 2011). Because of their hydrophobic nature, there are not likely to be substantial amounts of water within the stickies themselves; therefore, steam explosion would not be expected to be very effective at breaking up individual stickies. Rather, steam explosion is more likely to be considered as a way to free the stickies from other surfaces, such as fibers.

Retention of Stickies in the Paper Product

Often the final proactive step by which papermakers can affect the outcome when making paper from stock that still contains some stickies is the judicious injection of a retention aid just before the approach flow to the headbox. Already, as indicated in Table 13, it had been mentioned that various cationic polymers can be used to help attach stickies to the fiber surfaces (Jiang and Chen 2010; Li *et al.* 2013b; Laakonen *et al.* 2024-pat). Stickies that are attached to fibers will be efficiently retained during formation of the sheet. In addition, the stickies then will likely be located relatively evenly throughout the paper structure, which is generally regarded as a favorable outcome. Sigman and Rohlf (1993) showed that such effects, when caused by high-charge cationic polymers, may be maximized under charge-balanced treatment conditions. Charge measurements were recommended as a way to achieve optimum results. Sutman and Nelson (2002) added that in addition to high-charge cationic polymers, aluminum sulfate (alum) also can be used at an optimum dosage for optimization of charge.

Figure 25 represents a certain type of retention aid drainage additive program that is often employed when making printing and writing paper products. The steps shown in the figure are frequently preceded by adding a cationic coagulant (high-charge cationic additive) to neutralize excess negative charges and bring about coagulation of colloidal materials. The next additive may be a cationic retention aid, as was shown earlier in Fig. 22. But this time, the final additive has a very-high surface area. Bentonite was already mentioned as playing a role in detackification system (see Tables 10 and 11).

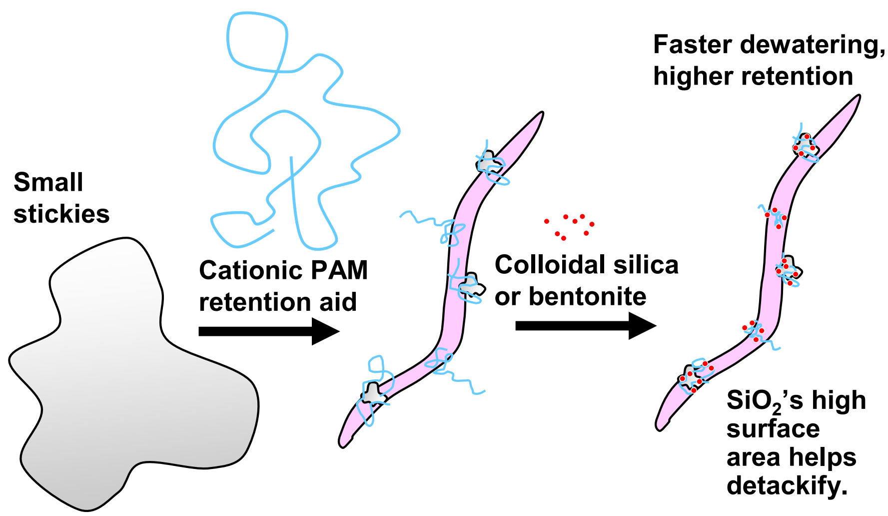


Fig. 25. Schematic illustration of an additive program to enhance drainage, retention, and maybe detackification by sequential treatment with a high-mass cationic polymer (retention aid) followed by colloidal silica

Colloidal silica has a very high surface area too, which is due to its extremely small primary particle size, often about 2 to 5 nm (Andersson and Lindgren 1996). As shown in the figure, the charge interactions between the negative surface of the colloidal silica and the positively charged cPAM can be expected to result in a contraction of loops and tails, thereby bringing about a boost in rates of water release in the course of sheet formation. In addition, the high surface area of bentonite or colloidal silica can be expected to contribute to a detackifying effect. As in the case of colloidal silica, exfoliated bentonite products (usually related to sodium montmorillonite) have been used to promote drainage and retention of fine particles during papermaking (Langley and Litchfield 1986; Hubbe 2005). The extremely thin nature of exfoliated bentonite particles (*e.g.* < 10 nm thick) means that they are a good candidate for providing a detackifying effect.

There may be a natural synergism when using retention aid drainage systems that include the usage of mineral-based microparticles or nanoparticles. For instance, the system reported by Beaudoin *et al.* (1998) comprised sequential addition of polyethylene oxide (PEO) and bentonite clay. The latter has a high surface area – which can help it act as a pacifying agent for the stickies – in addition to its role as a cofactor for the PEO-based retention aid system. The retention system recommended by Rebarber (1995) involved sequential addition of a formulated soluble aluminum coagulant (polyaluminum hydroxychloride) and colloidal silica, the latter of which has a very high surface area. The system described by Liu *et al.* (2011) was in a way similar, except that precipitated calcium carbonate (PCC) filler served the role of a surface to which the stickies can attach. The cited authors injected cPAM (Hagiopol and Johnston 2012) into a fiber suspension that contained PCC.

Multi-step Stickies Control Programs

Based on the publications considered in this review, there are quite many different unit operations that can be chosen to be part of an overall system for overcoming stickies problems. Those who are responsible for the processing of recovered papermaking fibers at a manufacturing facility need to choose wisely regarding which devices to install. They also will need to arrange these operations in sequences that make sense in terms of the types of used paper they are receiving and the types of paper products that they are making. Table 15 summarizes some published examples of sequences of unit operations that have been used. When considering the differences among the six listed systems, it is important to keep in mind that each paper mill will have different ranges of incoming recovered paper types, and each mill is likely to be manufacturing different types of paper products.

Table 15. Examples of Orders of Unit Operations for Combined Mitigation of Stickies-Related Problems

Highlights from the Article	Citation
Loop 1: Pulping/detackification; Fractionation; Flotation; Cleaning; Fractionation; Thickening Loop 2: Dispersing; Bleaching; Flotation; Thickening	Schwarz 1997
Flotation; Fractionation; Cleaning; Fractionation; Cleaning; Thickening; Dispersing; Flotation; Thickening; Bleaching	Künzi & Maurer 1998
Water enters during: Pulping; Screening; Cleaning; Flotation Water extraction during: Kneading; Washing; Bleaching; Dispersion	Moss 1998
High-consistency pulping; Screening; Forward and reverse cleaning; Washing; Flotation (for deinking & stickies control)	AbuBakr & Peng 1999
Loop 1: Cleaning; Coarse screening; Fine screening; Flotation; Cleaning; Screening; Thickening; Dispersion Loop 2: Flotation; Thickening; Storage	Blanco *et al.* 2007
Loop 1: Pulping; Cleaning; Screening; Flotation; Cleaning/screens; Thickening; Dispersion Loop 2: Flotation; Thickening; Screw press; Storage	MacNiel *et al.* 2010

In addition to articles or patents providing entire system designs for dealing with stickies, some other publications have dealt with just some specific arrangements of selected process equipment. For instance, Lee and Kim (2006-pat) specified that screening should be carried out before hydrocyclones are used (*i.e.* cleaning). De Jong *et al.* (2002-pat) claimed a system in which forward cleaners were followed by a flotation cell, and then by another bank of forward cleaners.

Antideposition Treatments

The word "pacification" is often used when referring to treatments that minimize the buildup of stickies or other tacky particles onto the surfaces for forming fabrics, transfer rolls, and wet-press felts (Fogarty 1993; Sutman and Nelson 2022). The most basic version of this approach involves the spraying of a dilute solution of cationic polymer onto forming fabrics (Kenny and Engstrom (1998). As illustrated in Fig. 26, the layer of cationic polymer is expected to attract a corresponding layer of hemicelluloses or other hydrophilic, negatively charged matter, thereby making the fabric surface no longer attractive for stickies deposition (Nguyen and Dreisbach 1996; Kenny and Engstrom 1998; Nguyen 1998).

Table 16. Highlights from Patents and Articles Describing Spray Treatments of Forming Fabrics or Wet-press Felts to Passivate the Surfaces Against Deposition of Stickies

Highlights from the Article	Citation
This patent claims using a mixture of aromatic hydrocarbons and an alcohol ethoxylate surfactant and polypropylene glycol, which is sprayed onto wet-press felts to inhibit the deposition of contaminants.	Dreisbach & Champine 1999-pat
This patent claims the addition of a combination of a cationic polymer and a nonionic surfactant to wet-press felts to inhibit deposition of stickies.	Hendriks and Cowart 2001-pat
This patent claims the use of a combination of cationic polymer and a protein for application onto deposit-prone surfaces of a paper machine to overcome stickies problems.	Nguyen & Gu 2002-pat
This patent claims treating papermaking fabric surfaces with a mixture of cationic polymer, a nonionic surfactant, and an anionic surfactant, such that the mixture remains net cationic.	Szep & Laser 2006-pat
This patent claims a system in which the nonionic polymer anti-deposit treatment was applied to the paper surface and thereby transferred to various equipment surfaces to avoid the transfer of stickies.	Rintala *et al.* 2011-pat
This patent claims the use of a combination of a cationic polymer and a release agent, thereby overcoming the need for hemicellulose, *etc.*, to be present in the process water.	Zhang & Ling 2012-pat
This patent claims the treatment of fabric surfaces in the paper machine system with a combination of cationic polymer and a nonionic surfactant.	Laser & Mahler 2015-pat
This patent claims using an alkaline formulation, together with an anionic dispersant as a means of cleaning fabric surfaces in paper machine applications.	Laser & Mahler 2017-pat

Figure 26 illustrates the general principle underlying several of the spray technologies described in the table. The series at left (series A) describes what happens in the case of an untreated forming fabric, *i.e.* the gradual build-up of stickies. Such deposition occurs despite the widespread usage of high-pressure showers to keep the forming fabrics clean. The right side of the figure (series B) shows what has been observed when the forming fabric is continuously treated with a mist spray of highly diluted cationic polymer. Such a spray is strategically placed in a position later than the high-pressure showers that are being used to clean the fabric. The cationic polymer is expected to adsorb onto the filaments of the forming fabric, which is shown in the figure as a blue-colored molecular layer. The cationic charge then is expected to attract negatively charged polymers, such as hemicellulose byproducts, that are often present in the process water of a paper mill. The negatively charged (anionic) polymers are shown in red. The net result, as depicted schematically at the lower right of the figure, is little or no deposition of tacky materials on the forming fabric. It has been found that though the adsorbed polymers may become unsightly due to adsorption of dyes and other contaminants, they can be effective in preventing deposition of hydrophobic substances.

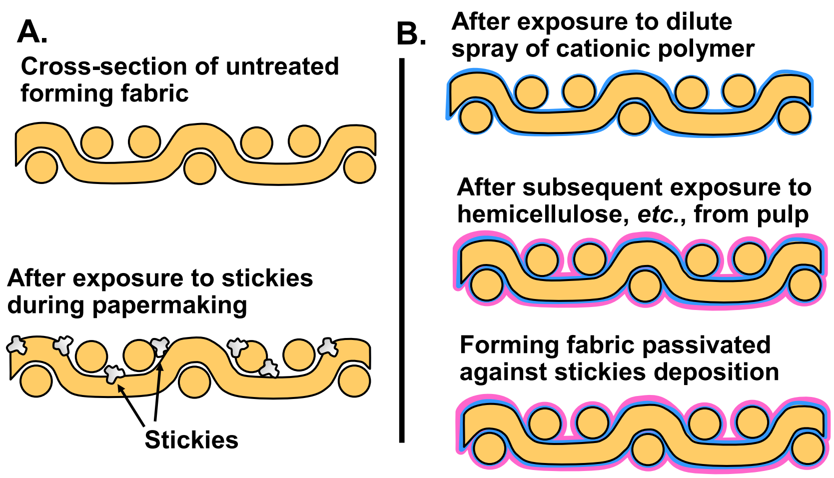


Fig. 26. Sketch of a system in which a forming fabric is passivated by using a continuous mist spray containing a low concentration of cationic polymer, which adsorbs onto the plastic and attracts a subsequent layer of hydrophilic polymers, such as hemicellulose

A different class of treatments has been used to inhibit deposition of stickies onto dryer can surfaces. Sekiya and Sekiya (2009-pat) patented the application of silicone oil as a release agent as an anti-deposit treatment. In practice, mixtures of silicone oil and wax are applied using a traversing spray. The chemical becomes distributed over subsequent cans by means of the paper web, thereby inhibiting buildup of stickies. Related technology to prevent stickies and pitch from building up on dryer can surfaces has been claimed by Wang *et al.* (2024-pat). Their patent covered spray formulations generally contain combinations of oil and surfactants, in the absence of water.

Regulation of Stickies

A more comprehensive approach to overcoming the worst consequences of stickies in recovered paper could involve regulations. The basic idea is to require developers of adhesives for use in paper products to demonstrate that those substances can be repulped using equipment that is commonly deployed within paper recycling facilities. By developing such systems, individual paper companies would not be forced to deal with problems for which solutions had not already been worked out. The feasibility of such an approach has been shown by the US Postal Service (USPS) as part of the “Environmentally Friendly Pressure-Sensitive Adhesive Stamp” project (Abubakr and Peng 2000). The project included pilot-scale testing of so-called "benign" pressure-sensitive adhesives for use in the production of postal stamps (Houtman *et al.* 2000).

Related legislation has been enacted in the European Union in the form of the Mandatory Implementation of Recycling Compatibility (RCA) standards (PPWR 2025). This legislation requires that each component of packaging – including films, coating, and adhesives – has to demonstrate compostability according to EN 13432 or ASTM D6400. It is reasonable to expect there to be a relationship between compostability and repulpability, though more research in this area will be required.

Ways to Use Waste Streams

Very little attention has been paid in the literature to possible value-added uses of stickies and related material that has been separated from recovered fibers by various combinations of unit operations, as has been described in this article. It can be expected that most of the separated stickies end up in landfills. Alternatively, the material is sometimes added to the furnish of one or more center plies in a paperboard product. This is a risky approach, especially if web breaks occur in the mill, causing the stickies contained in a center ply to be returned to the system. Licursi *et al.* (2016) suggested that such material could be combusted as fuel, with production of steam and electricity. Another possible option would be to extract the polymeric materials and then subject them to a refining operation to isolate useful polymer fractions or even monomers. Alternatively, there might be a yet-to-be-identified applications that needs unspecified tacky material to achieve its objectives. As technologists continue to look for ways to achieve circularity, rather than discarding such waste products, there will be continuing motivation to explore such options in future research.

A Papermakers' Wish List Regarding Stickies

Despite much progress in understanding and finding ways to minimize problems related to stickies, papermakers still have unmet needs. If a "wish list" could be put together, one of the top wishes might be a way to predict stickies problems in real time. Papermakers would like up-to-the-minute, online predictions of stickies amounts and compositions, possibly based on the nature of pulp suspensions, or possibly even based on observations of recovered paper arriving at the gate. In the past, wishes for such predictions might have been discounted due to the complexities involved, the time needed for any testing, and the time needed for interpreting test data. But that situation appears to be changing now, due to advances in two areas: online testing, and artificial intelligence (AI). Already, there have been patents related to online determination of stickies components (Hengesback and Krause 2015-pat). The next step may involve a pairing of various online sensor input with artificial intelligence tools. For instance, it has been proposed to use AI tools to predict paper properties based on online information (Arjunan *et al.* 2025). A further advantage of such technology is that it may facilitate better sorting of recovered paper so that some of the worst stickies-prone materials can be excluded (Huesmann and Lambertz 2024). Such sorting has been demonstrated based on near-infrared imaging in the case of textiles (Du *et al.* 2022). A strong point of many AI applications is their ability to rapidly consider many different inputs and make prompt predictions, based on a fixed or continual training process.

Another item for the papermakers' wish list would be source control of adhesive products – namely, mandatory implementation of the Recycling Compatibility of Adhesives (RCA) standard, or an updated standard. The RCA standard was developed by the U.S. Postal Service (USPS) in the context of its ‘environmentally friendly pressure-sensitive adhesive stamp’ project, with the aim of evaluating the removability of different adhesives during wastepaper recycling. If all substances that could become sources of stickies – including pressure-sensitive adhesives, hot-melt adhesives, coating binders, and emerging bio-based coating components – were required to pass RCA certification before entering the market, then paper mills would no longer have to face increasingly complex and ever-changing stickies challenges on their own. The EU Packaging and Packaging Waste Regulation (PPWR) provides a reference precedent for the legislative mandating of recycling compatibility, by requiring compostability for packaging components. Shifting from ‘end-of-pipe treatment’ to ‘source control’ can be the fundamental solution to stickies problems.

CONCLUDING STATEMENTS

By way of summarizing key aspects of this article, Fig. 27 presents a generalized scheme that involves some of the key unit processes that have been discussed. Even though the diagram is based on widely used devices and processes, it is important to bear in mind that systems within real paper mills are often more complicated than can be easily depicted in such a figure. There are cases in which it may make sense to skip one or more unit operations, depending on what is needed. Each unit operation that is being used will need to be tuned, based on equipment set-points, dosages, and monitoring equipment. The twin goals of achieving a high yield of usable fibers and a low presence and impact of stickies remaining in the papermaking furnish will need to be continually balanced, based on customer input, costs, and the availability of time and resources to make needed improvements.

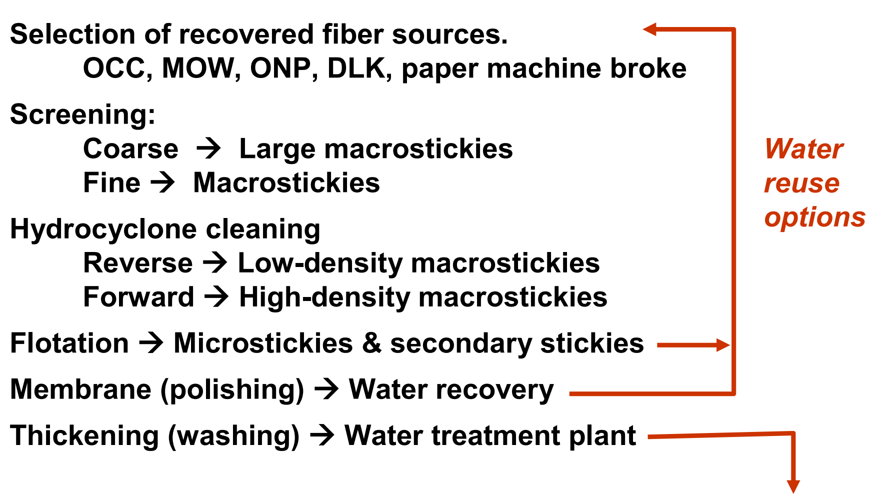


Fig. 27. Listing of the main unit operations that can be regarded as candidates for assembly a system suitable for a given paper mill that uses recovered fibers.

Certain aspects of Fig. 27 should be noted. First, as already has been shown in examples considered earlier in this article, some unit operations may be repeated at different points in an overall scheme. The orders in which steps are done do not need to follow what is shown in this list. For example, it often makes sense to use hydrocyclones to more efficiently isolate relatively highly concentrated streams of macrostickies after coarse screening. The red arrows at the right side of the figure consider options for usage of the clarified water coming from either flotation operations or polishing operations, such as the use of membranes. Advances in membrane technology are making it feasible to achieve suitably high levels of water purity for a wide range of applications in paper mills, but attention always needs to be paid to issues of contamination and plugging of such membranes. Thus, trials would be needed before implementing membrane separation systems in systems that contain stickies.

The downward arrow at the lower right in the figure assumes that there is sufficient capacity in the mill's water treatment system to be able to efficiently collect all of the remaining stickies and incorporate them into sludge, which is most often hauled to a landfill. As was discussed earlier, in the more distant future, one can envision the development of a more fully circular system of recovery in which a valued application would be found even for the recovered sticky materials.

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