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1.0 INTRODUCTION

Conferences covered in this semiannual review include the TAPPI Recycling Symposium and the 9th PTS/CTP Deinking Symposium.

The intent of this feature is to present a synopsis of the 'significant research results and industry ideas related to paper recycling reported at these conferences. Due to space constraints, we are not able to cover all of the presented papers in detail. Readers are encouraged to obtain the original articles for more information.

2.0 GENERAL

2.1 Recovered Paper Utilization

Uutela reported that global recovered paper consumption grew by 49.4 million tons (58%) between 1990 and 1998 reaching 135 million tons in 1998 (PC-1). The global paper utilization rate, calculated as the relationship between recovered paper consumption and paper and board production increased from 35.8% to 44.9%. In 2005, it is forecast that 174 million tons of recovered paper will be used globally, a 1998 - 2005 rate of increase of 3.6% annually. According to Uutela, the future of deinked pulp in fine paper in Europe remains questionable but could be forced by legislation. Uutela thinks the current market deinked pulp situation (which he calls a disappointment) is unlikely to change.

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Kibat forecasts increased paper recycling in the European free trade zone due to legislation including new environmental taxes and societal pressures to limit harvesting of trees (PC-2). In the next decade he predicts European use of recovered paper will increase by 15 million tons. He believes the lack of a clear legal definition of when recovered papers cease to be waste hampers efforts to increase the use of recovered papers and recommends this issue be clarified as soon as possible.

The 1999 consumption of recovered paper in the Iberian peninsula was very high, 81.3%, according to Reinoso (PC-3). Legislation promoted an increase in the collection rate from 41% in 1996 to 47% in 1999 with possible further increases in the future. The National Plan on Waste calls for a recovery rate of 75% in 2006. Currently, recovered paper collection systems do not adequately meet paper industry needs and Spain imports about 20% of the recovered paper processed.

INGEDE, the International Deinking Research Association is a consortium of deinking mills that has conducted joint research projects with other members of the paper chain to establish basic criteria for recyclability (PC-5). INGEDE has established methods of inspection for recovered papers.

2.2 Automatic Sorting of Recovered Papers

Manual sorting of recovered paper is required to remove contaminants from the paper and separate it into grades usable by paper mills. However, manual sorting is costly and potentially hazardous to workers. An alliance of MSS Inc. and Weyerhaeuser has developed optical sorting technology for the separation of different paper grades from mixed paper (R-17). The system includes feed conveyers moving paper into an active disc screen followed by an inclined conveyer and an acceleration conveyer taking the paper to an air compressor and pinning device. An optical sensor then analyzes the

paper. This sensor activates air compressors that blow pieces of paper to take away conveyers. These signals are based on paper color and fluorescence. The optical sensor can distinguish between white paper; newspaper; solid color sheets of blue, red, green and other colors; brown paper and cardboard; off-white papers and coated and glossy papers. A commercial unit began operating at Weyerhaeuser's Baltimore sorting facility in the first quarter of 2000. Performance data are available at the www.magsep.com website.

2.3 Inks and Printing Technology

A total of about 500,000 tons of ink is consumed in Europe to print paper (PC-4). The largest single use, 29%, is to print newspaper and newspaper-like printed products. These are almost exclusively produced using web offset printing without drying (coldset). The major trends are increased use of colored inks and the use of lighter weight papers. This results in more frequent printing problems such as "show through" and "strike through" of ink and reduced deinkability due to higher ink-to-paper ratios. Print and illustration products produced by gravure printing account for about 21% of ink consumption. No significant gravure printing technology changes are expected. Web offset heatset printing accounts for 18% of print products and is used for magazines, catalogs and brochures produced in medium and long print runs. Sheet fed offset printing is used to produce 11% of all print products. Vegetable oil-based inks are replacing mineral oil-based inks in this technology. Frank sees no other major changes in any of these ink technologies (PC-4).

Many previous reports indicated that water-based flexographic newsprint inks are difficult to deink. Brightness of deinked flexographic newspapers can be 20% less than deinked pulp prepared identically using offset newspapers (PC-9). Inclusion of anionic binders in the flexographic ink composition can result in deinkability similar to that of current offset newsprint inks while providing print quality equivalent to that of conventional flexographic ink.

Frank (PC-4) and Krauthauf (PC-5) recommend that recyclability become a consideration when formulating inks and adhesives. Krauthauf commented, "Without incentives such as government mandates, the adhesives industry will not take action to develop more recyclable adhesive products." He pointed to the USPS leadership in the development of recyclable pressure sensitive stamps as an example of constructive government leadership.

3.0 US POSTAL SERVICE (USPS) PROGRAM

3.1 Lessons Learned and Goals

Many lessons were learned since the beginning of the USPS initiative for developing an environmentally benign adhesive (R-3, R-4).

- No criterion for adhesive recyclability was available.
- Screening, cleaning and flotation all are required for effective adhesive removal.
- No universal test method was available for measuring stickies.
- Cooperation among researchers, adhesives manufacturers, papermakers, printers and recyclers is essential to assure a recyclable PSA(R-3).
- Consumer preference for PSAs outweighed environmental concerns.
- Some universal test methods can be developed and accepted by the affected industries.
- Technical societies can provide a neutral forum to present technical data and results.
- Involvement of government agencies can facilitate implementation.

While much progress has been made, major challenges remain - especially with the silicone coated release liners. Continued leadership is needed to sustain this initiative (R-4).

Joe Peng (R-5) of the USPS described implementation of the PSA work and outlined the focus of Phase V: recyclability of the silicone coated release liners. Recyclers currently refuse recovered paper containing release liners due to potential problems of the silicone interference with fiber bonding of the recycled pulp or process water contamination. Performance and test methods will have to be established for measuring the fate of silicone during recycling of the laminates. Candidate laminates will be evaluated and alternate recycling options will be explored (R-5).

3.2 USPS Recycling Efforts

The USPS assembled a Greening the Mail Task Force comprised of a diverse mix of stakeholders to find ways to enhance the environmental performance of mail while continuing to meet the needs of business (R-6). Greening the Mail Initative was developed to: prevent waste in the design of mailings, incorporate both reusable materials and recycled content materials, and promote recycling of mail. These mailing practices will benefit the environment by saving trees, reducing greenhouse gas emissions and water discharges, minimizing energy

using; and the amount of paper landfilled or incinerated (R-6).

In compliance with the Pollution Prevention Act, the USPS is committed to reducing waste and increasing revenues by recycling Undeliverable Standard Mail (USM), replacing wooden pallets with reusable plastic pallets and communicating environmental responsibilities and plans for implementation to postal employees (R-7). A mutually beneficial partnership could be made between recycling mills, paper brokers and the USPS for more efficient utilization of USM (R-7). While the research and development of recyclable PSAs has been highlighted in recent years, the USPS is equally committed to reducing the cost of stamp production, such as development of linerless coils and two-sided release sheets for stamps. Up to 50% recycled content is also required in postal stamp paper and envelope products (R-8).

The Postal Service purchases more than $160 million of recycled content products annually, clearly establishing them as a leader in environmentally preferable purchasing (R-9). Approximately 25% of this annual expenditure is for Expedited Mail Packaging. These products are designed to be more than just functionally adequate and cost effective; they are designed to be environmentally superior as well. Features such as recycled and bleached paper content, lightweight and durable materials to decrease shipping costs, and printing with low VOC inks are taken into consideration.

The Postal Service has one of the largest construction programs in the nation, occupying 35,000 facilities and building about 500-700 new facilities a year (R-10). The first "green" Postal Office building extends the environmental commitment of the USPS to structures built with ecologically superior products and designed to exemplify responsible ownership. A model building in Fort Worth, TX described in this presentation covers energy efficiency, air quality, composition of furnishings, interior design materials and landscaping.

3.3 Formulation of benign PSAs (Panel Discussion)

Solutia Inc. developed a novel repulpable emulsion acrylic PSA (R-11). This adhesive has excellent initial performance that is maintained after aging. It also has good moisture resistance and repulpability. The repulpability stems from polymer characteristics, such as, no tack under required pulping conditions, removal by screening/flotation, and clean detachment from paper fibers that increases fiber yield.

The Avery Dennison Group explored several strategies for stickies reduction (R-12): (1) design the PSA to agglomerate during repulping to facilitate removal by screening, and (2) tailor the PSA properties so that it disperses in the aqueous phase during repulping to enable separation from fiber during dewatering. A basic concern was how to measure repulpability of an adhesive. Recycling mills want an adhesive that performs well on the paper machine; PSA manufacturers are more interested in performance during repulping. Methods developed by Avery Dennison for characterizing PSAs based on their behavior during recycling were described.

The approach taken by Air Products Polymers L.P. was to research multiple facets of building a benign stamp laminate including appropriate facestock and liner as well as meeting coating requirements and selecting the right PSA (R-13).

Dyna-Tech Adhesives, Inc. identified performance parameters necessary for development of an acceptable water based adhesive (R-14): high shear rheology, surface tension, viscosity stability, and particle size distribution. These properties are critical since an adhesive must be able to wet out any liner, run on any coater and be able to be printed and converted into final material. The processing parameters were controlled by the use of an optimized rheology package.

The polymer unit of Franklin International developed a primer that can be coated directly on any facestock prior to coating the adhesive (R-15). The primer is a non-blocking, non-PSA acrylic emulsion that adheres well to most PSAs and strengthens them during pulping. Prior technology of this type has been used in the stamp program either to reinforce release coating or the adhesive. In addition, adhesives specifically developed for the USPS requirements and adhesives in their current product line were evaluated to determine their potential for repulpability. This paper describes the evaluation of a variety of adhesives for use in applications that require an environmentally benign PSA.

Research efforts at 3M focused on developing water insoluble adhesives (R-16). Characteristics of the selection criteria for candidate adhesives included: stamp performance, aging stability, processability, pulpability, and the ability to agglomerate and be removed by screening.

3.4 Release coatings

Silicones are one of the most versatile classes of synthetic polymers. The most common type of silicone polymer is polydimethylsiloxane (PDMS). These materials have a unique range of properties that allow them to be used in a myriad of applications (R-22). However, some of the more important of these properties such as their chemical inertness, low surface energy and hydrophobicity make silicone difficult to remove during the recycling of release liners.

Approximately 18 billion square meters of substrates were coated with silicone release coating in 1999 (R-23). Super calendared grade of paper is the primary (over 55%) substrate for these coatings made in North America. Another 35% of the substrates include clay coated and polyolefin grades. They are all coated with a thin layer of cured, unfilled silicone elastomer that provides easy release to a variety of sticky materials. About 65-70% of these liners are used to protect pressure sensitive adhesives between the times the adhesive is laminated to the face stock until the time it is used. When dimethylsiloxanes are cross-linked into elastomeric materials, they retain their release characteristics but acquire a non-migratory nature by virtue of the cross-linked network. For release liners a thin film (approximately one micron thick) of a non-migratory poly siloxane is coated on a paper substrate. In addition to unique release properties, the silicone film provides good repellency to many liquids. While it is easy to detach silicone from paper, separating the silicone material from the cellulosic fibers is more difficult and depends on the silicone elastomer and the method by which it was made. Nearly 70% of all silicone coatings are made by a solventless method currently. Because solvent based coatings become soft, sticky and flexible when recycled, this type of adhesive is more difficult to remove than the hard, inflexible solventless type.

Experiences utilizing silicone release liner as feedstock to an integrated deinking mill were discussed (R-24). Ramifications of producing high quality printing and writing grade papers from this deinked pulp were presented. Wilhelm concluded that the quality of the recycled pulp depended upon the quality of the silicone coated scrap material, the recycling process design, and the type of paper being made.

Alternate methods for utilizing silicone release liners were offered by Channeled Resources (R-25). Frost distinguished between recycling and reusing. Even though silicone liners are technically repulpable, the resulting fiber quality and yield may not meet mill requirements for papermaking. Non-recyclables can be recycled into some useful product. One example of reuse could be for a sheet coated on two sides that is used as an interleaver for rolls of tape or PSA labels or for making fuel pellets.

Newing noted that recycling facilities avoid liner material primarily due to the perceived decrease in strength and printability of the resulting deinked pulp (R-26). At present, it is not known how liner will perform during repulping, how much silicon would remain in the resulting pulp or whether it would remain hydrophobic or be converted into a hydrophilic species. The immediate task is to develop appropriate methods to accurately quantify residual silicone content of pulp and paper and to measure silicone present in process water loop during recycling. These tests could evaluate the impact of residual silicone on both wettability and strength as well as provide guidelines for determining the upper limits for liner content tolerance during repulping. More importantly, these analytical methods would provide the tools necessary to optimize repulping parameters to assure successful recycling of liner-containing furnishes. Various techniques for measuring silicon might include:

- X-ray fluorescence
- Atomic absorption for silicone content in water
- Use of silicone taggants for tracking silicone during processing
- Wettability/printability of recycled paper
- Tensile determination on recycled fiber handsheets.
- Effect of surfactant HLB on flotation

Alternate approaches might include modification of the silicone to facilitate repulpability or to improve quantification methods. Once these techniques have been worked out, laboratory repulping studies will be conducted to ascertain whether the protocol can be applied to all three forms of siliconized surfaces made for PSA stamp constructions: the siliconized liner, stamp laminate, and siliconized face of self-wound stamps. Pilot repulping studies will be conducted to confirm laboratory investigations and eventually mill trials will conclude the testing.

If it is determined that there is no useful or economical method to repulp liner materials for producing printing and writing grades of paper,

alternate products such as paper towels, packaging materials, tissue, or wallboard could be investigated (R-26).

3.5 Converter's Experience with Benign PSAs (Panel Discussion)

Michael Landa provided an overview of the self-adhesive laminating process and described the self-adhesive postage stamp as a multi-ply laminate composed of functional paper layers and coating chemistry (R-27). The seven functional layers include: phosphor printcoat, facestock, water removable primer, adhesive, release coating, release liner, and print coating. PSA stamps are coated and laminated through a continuous series of operations This process is outlined as follows:

- Liner paper release coated
- Release coating cured
- Adhesive coated onto release coating
- Adhesive dried
- Pre-phosphored face paper - primer coated
- Primed face paper laminated to adhesive-coated release liner
- PSA laminate wound into master rolls for slitting and finishing.

Adhesive coating methods include solvent, emulsion and hot melt. Basic PSA is comprised of two types: chemical, including rubber and acrylic bases, and functional, including permanent, removable, ultra-removable and re-positionable.

Al Kuhl of Spinnaker Coating discussed curl control in PSA stamp paper. Requirements put forth by USPS-S-1238E define curl. Wrinkles and distortions, misregistration, feeding and delivery, packaging and handling are problems associated with curl. Causes of curl are outlined and methods for decurling mechanically or by remoisturization are discussed. Curl can be tested with the USPS method, TAPPI T 466 cm 82 and crosshatch. Moisture content can be measured by TAPPI T412 om 94 or with bench top moisture meters. Online measurement may also be used.

Robert Davis of Moore Research Center addressed the company's approach for evaluating adhesives, facestocks and liners for laminate constructions that met requirements set by USPS 1238. Stamp laminate manufacture, coating, handling, and environmental issues were also discussed.

The traditional vertical research team involves the supplier, coater and printer. In addition, the USPS team integrates objective laboratory and pilot plant test groups. USPS 12383 defines all project components and lists approved suppliers allowing for greater focus on the interactions between these groups, testing facilities and end users.

Kevin Kary of Kanzaki Specialty Papers Inc. summarized splice and waste reduction efforts at the converter level. Pressure sensitive converters are faced with leftover raw material waste and excess laminated waste. Unlike leftover raw material, laminated waste, containing both adhesive and silicone, poses a potentially major problem were it to enter the conventional recycling stream. By matching face and liner in a two-sided stamp, splices and waste could be reduced. It was suggested that if suppliers of upstream stamp materials better understood the supply chain, waste reduction might be possible at all stages of production.

3.6 Printers Experience with Benign PSAs (Panel Discussion)

Sennett Security Products has been the supplier of US postage stamps since 1990 (R-31). The major change in the stamp formats has been the conversion from wettable gum to self-adhesive stamps currently dominating the USPS market. This shift resulted in major changes in the raw materials, printing and finishing of postage stamps. The panel– representatives of engravers, printers, and adhesive producers – summarized the processes associated with stamp production, compared stamp products with other label products, and highlighted the problem of disposal of the PSA waste material. Preconsumer waste generated by printer's spoilage, design trim and process spoilage averages 15%. The current PSA construction does not afford the manufacturer the option to recycle or reclaim the waste. As a result these security product rejects are generally disintegrated and incinerated.

3.7 International Experience with PSAs

Various procedures for assessing pilot plant screenability of specially designed PSAs for recycling are used at the Centre Technique Du Papier in Grenoble (R-35). They have shown that the size and shape distribution of the adhesive during pulping is the key parameter influencing screening efficiency. Fragmentation of adhesives caused by shear during pulping has to be minimized. Screening conditions need to be optimized according to size and rheological properties of the adhesive. Pa-

rameters that influence screening efficiency include: pulp consistency, passing velocity, rotor velocity and design, slot width and design, and fiber length and coarseness. Cleaning and flotation also need to be considered for good adhesive removal.

The USPS effort to develop a benign PSA confirms work done over the past 10 years by INGEDE. A technical committee of INGEDE concluded that formulation of redispersible adhesives was the wrong approach; adhesives need to be screenable (R-36). Anew FAC (Forced Adsorption Contactor) method, for measuring stickies by weight was developed at the University of Darmstadt. The acceptable adhesive limit in good quality paper for recycling has been set at 100g/ton DIP, emphasizing the need for recyclable adhesives.

Leppanen observed that the modification of adhesives alone is not sufficient to achieve recyclability (R-37). The process used to remove or deactivate the stickies also plays a key role. Process conditions and chemistry, flotation and microflotation as well as fine screens contribute to adhesive removal efficiency. A potential concern is the rapidly growing quantity of release liner. Silicone release liner is recyclable. However, segregation of the contaminants from the paper stream appears to be the main problem.

3.8 Environmental Impact of PSAs

A field test mail trial was designed and implemented by Specialized Technology Resources (STR) and the USPS (R-38). As designed, 126 pre-qualified sample material configurations comprised the field test matrix. As implemented, 4,064,000 test-mail units bearing 30,622,000 benign PSA test stamps were exposed to typical first class mail processing in 50 different US postal regions. The processed test samples were regrouped according to material and test stamp performance was evaluated. Less than 1% of the stamp units failed the quality performance targets. Test mail envelopes were later used as a source of post-consumer feedstock in subsequent laboratory, pilot and mill scale recycling trials. Materials not converted into test stamps comprised the pre-consumer stream for the recycling mill trials.

The ultimate goal of the USPS Environmentally Benign Stamp Program is to develop adhesives that can be removed by unit operations in recycling mills (R-39). The maintenance of final product quality specifications while loading the feedstock with a significant quantity of adhesive is the criterion for success. Since it is neither prudent nor cost-effective to test all experimental adhesive materials at mill-scale, protocols for laboratory-scale and pilot-scale evaluations were established by STR and the Forest Products Laboratory (FPL). Since adhesive quantification methods are critical to testing of all trials, a computer image analysis protocol, using hydrophobic dyes to provide contrast between fiber and adhesive particles, has also been developed. Detailed descriptions of each processing stage of both laboratory and pilot plant protocols and the image analysis technique for adhesive quantification are included in the Proceedings.

Results of laboratory and pilot scale recycling trials of experimental PSAs and different printing methods were reported by Ross Sutherland and Donermeyer (R-40). Fourteen experimental PSAs printed by intaglio, offset, and gravure were evaluated. The three printing methods behaved differently during recycling. Gravure printing broke up into very small ink particles while offset and intaglio produced larger ink particles that were more difficult to remove. However, most of the experimental stamp materials were recycled quite satisfactorily.

3.9 Fundamental Studies of PSA Behavior

A representative of the USPS, Rajendra Kumar, described some of the challenges involved in the development of PSA stamps including meeting requirements of philatelists, the public, paper recyclers, adhesive producers, and the USPS (R-47). From the viewpoint of the USPS, PSA stamps have to withstand a number of environments in manufacturing, storage, printing, and mail processing. Philatelic requirements are quite stringent ranging from paper quality and printing, to perforations/ die cutting. Other requirements of the philatelic community include:

- water removability (30 min soak at room temperature)
- absence of curl
- no migration of adhesive or ink
- cancellation
- storage under temperature and humidity fluctuations.

There are a number of test methods available in TAPPI and ASTM to predict life expectancy of permanent records; however, no standard test covers the total construction currently.

Postage stamps are much more than labels adhered to envelopes. They are prepaid receipts for services rendered in the conveyance of mail and an essential component of modern automated mail processing (R-48). Stamps are also miniature works of art and, as such, collectable. The functional performance requirements that postage stamps must fulfill can be classified into the following categories: mail processing, philatelic, economics, production/manufacturing, design, materials, environmental, and customer/end user.

As performance requirements for stamps evolved, the specifications have also evolved to reflect the changing requirements. Postage stamp specifications have also been modified over time to reflect advances in technology.

Combinations of three different "next generation" PSAs with both offset and intaglio printing on test stamps were examined with regard to particle size distribution upon recycling (R-49). Rubber, acrylic, and tackified acrylic adhesives were investigated and compared to an offset printed baseline adhesive sample. All of the newer adhesives performed as well or better than the baseline material in removal by screening. A "screenability" index was calculated and corroborated the findings of the particle size distributions. The study concluded that the printing method used for stamps does affect the ability to remove the adhesive by screening.

Little has been reported pertaining to the behavior of release liner in paper recycling (R-50). It has become a significant component of pre-consumer recovered material, making the recyclability of the silicone liners an important focus for the next phase of the USPS work. A study reported by Venditti found that the presence of release liner in a paper furnish caused a decrease in particle size and an increase in the number of adhesive particles after pulping. The recyclability was evaluated by laboratory pulping, screening, centrifugal cleaning and flotation processes. Screening and cleaning were the most efficient processes for removal; however, flotation was not effective. The presence of residual release liner particles in recycled paper decreased both the strength and printing properties of the recycled paper significantly.

3.10 A Pilot Plant Study of the Recyclability of PSAs

The screening system was the main focus of trials conducted at Beloit's Pulping Pilot Plant in Pittsfield, MA (R-51). The pilot plant was configured to resemble a typical recycling mill. The screening systems used the same sized baskets in the primary stage for both trials, but the configuration of the secondary screening was changed. Cascade feedback and feed forward screening systems were compared for removal efficiencies. Crossley et al. report that the feed forward design is more efficient than feedback for stickies removal. This leads to a high mass reject rate, which may account for the increased removal efficiency. They postulate that coarse screen forward feed with fine screen feedback would be the most effective method of stickies removal.

Several trials of PSAs were run at Voith Sulzer's industrial scale pilot facility to validate results from laboratory and FPL's pilot plant evaluations (R-52). The first trial tested the screenability of a mixture of three PSAs; the second examined a single highly tacky PSA. The tacky PSA was run with closed water loop and DAF clarification. Results showed no negative impact of the adhesive on final pulp quality or deposition on internal piping and equipment. This PSA material exhibited a higher level of shear as well as a propensity to adhere to itself forming balled stickies that were rejected in the coarse screening. Almost 99% of the adhesive was removed during recycling.

Two pressure sensitive adhesives were tested at the Western Michigan University pilot plant facilities in Kalamazoo, Michigan, using USPS protocols for system setup and samples analysis (R-53). Particles were most effectively removed with pressure screens when they were larger than that of the paper fibers. Cameron and Forester found that particle size was the most important factor in removal of PSAs from their system.

The USPS recycling system used at FPL for screening candidate adhesives was replicated as closely as possible at three off-site pilot facilities (R-54). Each facility ran the control PSA material used throughout the study plus at least one experimental material. Pulp samples taken at each process point in the recycling system were made into handsheets and measured by image analysis (IA). While actual stickies counts differed between FPL and the alternate facilities, similar trend lines were observed. Variability in results can be attributed to sampling, sheet preparation and IA methods used at the different facilities. Equipment, processing parameters and water clarification also impacted comparative results. Efforts are underway to upgrade equipment and to standardize the image analysis protocol.

3.11 Mill Trials

A key objective of the USPS Environmentally Benign PSA Program is to clearly demonstrate that the top candidate laminates prove no hardship to commercial recycling mills. To fulfill this objective, full-scale commercial recycling trials were commissioned by the USPS at six commercial full-scale recycling facilities (R-65). Successful trials during this final qualification stage provide to the recycling industry convincing and incontrovertible evidence that the EBA Stamp Products are benign within their product specifications. In this panel discussion, representatives from the six participating sites discussed their experiences from the mill trial program. Mill representatives qualified successful trials as those that proved significant in the PSA loading, yet promoted no hardships with respect to process performance or product quality. In general, the recycling mills were highly encouraged by the demonstrated benign nature of the USPS PSA products. The representatives expressed appreciation and commendations toward the USPS for promoting this project, and endorsed such collaborative efforts among industries.

American Fiber Resources (AFR) tested three PSAs, two newly formulated adhesives designated as acceptable from the USPS laboratory and pilot plant trials and one baseline product, in full-scale mill trials (R-32). Enough adhesive (up to 0.12%) was introduced into the pulper during each trial to register several spikes in stickies measurements. Detailed results of the stickies level during each trial are reported. Neither of the candidate PSA formulations resulted in off-quality pulp production nor caused problems in processing. The PSAs evaluated were judged to be benign, confirming pilot plant results.

4.0 WAX REMOVAL FROM OCC

Cable, Boyd and Finn presented an example of the problem solving techniques applied at the Inland Paperboard and Packaging plant (R-44). Wax contamination problems in this 100% recycled OCC facility caused poor linerboard appearance and low coefficient of friction. An integrated approach involving input from all levels of their process was taken in an attempt to eliminate wax entirely. Process simulation software (Win GEMS 4.0) was used to evaluate the impact of possible changes without shutdowns and expenditures. Improvements made to some pieces of equipment, the DAF clarifier, Gyroclean, and fine slotted screens, obviated the need for the dispersion unit and resulted in lower operating costs.

Flotation, currently used for ink removal, is not used in OCC recycling mills in the U.S. However, Doshi, et al., suggest it could be used to remove wax and stickies from OCC stock (R-45). Experiments conducted at Voith Sulzer's pilot plant demonstrated that the addition of froth flotation to a typical OCC recycling system improved the wax and stickie removal without significant fiber loss nor reduction in strength properties. Flotation could reduce the need for dispersion or kneading; however an efficient water clarification system is necessary to remove wax and stickies from the water loop. This finding is especially important at a time when the demand for clean feedstock surpasses the supply of wax-free OCC.

Test runs using a special three-part wax dispersant chemical were conducted at Inland-Maysville mill to determine if wax spots could be reduced and slide angle improved in the top sheet (R-46). This blend contained a melting point reducing agent for the paraffin wax, a dispersant to emulsify liquid wax to less than one micron in size, and a wetting agent to prevent adhesion to process equipment. Two types of trials, continuous application and intermittent dosing, were conducted to eliminate large concentrations of wax. In both instances this blend improved the quality of the surface without removing wax from the system; however, the continuous mode was more effective,

5.0 PULPING

A process to impregnate OCC, milk cartons, wet-strength paper or old newspapers with a weak alkaline solution prior to pulping facilitates fiberization and enhances strength properties of the resulting pulp (R-19). Bales of recovered paper are subjected to a partial vacuum in an autoclave to introduce the treating liquid into the paper prior to pulping. Results of laboratory, pilot and mill scale trials are encouraging.

Rosatzin discussed the importance of ink detachment from fibers to subsequent flotation deinking results (PC-18). The advantages of pulping at neutral pH were given as: reduced chemical requirements in the pulper; lower operating costs; a reduced COD load resulting in lower waste water treatment costs; and a decrease in the formation of microstickies. In addition, pulping at neutral pH can minimize the negative effects of sodium sili-

cate on pulp dewatering and formation of depositions on wires, on felts and in pipes. While nonionic surfactants can be effective in detaching ink from fibers, dispersing the ink and reducing ink redeposition, the ink particles formed in the pulper in the presence of nonionic surfactants tend to be smaller thus making ink removal in subsequent flotation more difficult. Careful selection of the deinking agent and the chemical dosage sequence can reduce this problem. Also, the use of a post-flotation washing step can be helpful.

Traditionally, recycled fiber pulping and screening processes use four or five separate pieces of equipment to prepare the stock. Ahlstrom Machinery's innovative fibreflow concept enables mills to perform pulping, detrashing, and screening in just two devices: a drum pulper and the MODUScreen CR (R-33). This report summarizes the results of a trial using this equipment at a 600 t/d Swedish board mill. The fibreflow equipment enabled the use of lower grade furnishes without compromising board quality. A significant savings also was realized in energy consumption.

6.0 STICKIES AND SCREENING

Microsphere adhesives are small, crosslinked particles used in many repositionable adhesive products (R-55). This adhesive is synthesized and coated as individual particles rather than as a continuous film. These polymerized acrylate adhesives are neither soluble in any solvent nor dispersible into smaller particles. Because microsphere adhesives resemble toner powder in size and surface chemistry, flotation is the most effective method for removal. Laboratory and pilot scale repulpability trials conducted on Post-it Notes, an example of microsphere adhesives, confirmed that screening removed only the largest agglomerates of adhesive, whereas flotation removed approximately 90% of the adhesive. Transmitted light and a higher resolution scanner or microscope camera are better methods than image analysis for measuring residual microsphere adhesives. A dual polymer retention aid system permits residual adhesives to be retained in the pulp during papermaking.

The TAPPI T 277 test method describes a procedure for determining heat-set area and number of macro stickies in a specified amount of screened pulp (R-56). The recycle process separates macro stickies from the pulp slurry with a high degree of efficiency. Fine slotted pressure screens and, in same cases, flotation have been the key process modules in separating macro stickies from the recycled fiber. However, the stickies balance around these process modules often do not add up, leading to the hypothesis that disintegration or agglomeration of macro stickies is taking place in the process equipment. This test method divides the macro stickies into ten classes according to size. Application of statistical tools enables calculation of the disintegration or agglomeration probability of macro stickies, thereby explaining discrepancies in the stickies balance. These calculated findings are significant tools, for example, for designing screening equipment to minimize shear forces on the viscoelastic stickies. Analyzing flotation stickies balances utilizing the hypothesis test (t-test) will help in explaining effectiveness of flotation in removing macro stickies in various situations.

The modern screens operate at a consistency of 3.5-4.0% and create very selective screening with compact machines (R-57). Operation at high consistency decreases screen size and cost. The special rotor shape distributes stock over the entire screen basket surface eliminating plugging and rejects thickening. A low passing speed (0.9-1.5m/s) insures a low pressure drop, minimum stickies deformation and reduced power consumption.

Screening can be an effective stickies removal process. Saint Amand and Perrin studied the effect of screen operating conditions and particle size and shape on contaminant removal and fiber loss (PC-26). The effective slot passing velocity was a key parameter. Increasing the accepts flow rate, and changing the rotor increases this velocity thus increasing both pulp and contaminant passage through the slots. The selectivity of the separations between fibers and thin contaminants (films and shives) was difficult to improve. An extended reverse pulp rotor increased fiber passage compared to the foil rotor, at least at low passing velocity. Wedge wire design slots improved fiber passage but did not improve screening selectivity of the tested contaminants compared to machined screen plates. The authors proposed that lower friction factor of the wedge wire design and differences in the slot inlet design were responsible for higher pulp passage at a given passing velocity compared to machined screen plates. Particles are subjected to shear and contact induced acceleration at the screen plate and short duration hydrodynamic forces at the slot inlet. These forces can promote both fragmentation and extrusion.

Parameters influencing screen performance include the reject ratio, input consistency and basket wear.

These parameters can be altered in the mill. Catsburg reported results of modeling study to predict the effect of these parameters on screening plus results obtained at five wood-free deinking mills in the Netherlands (PC-29). Optimum pulp consistency and flow rates in the screen are dependent on pulp composition and product quality requirements. In most cases, frequency of using the de-aeration valve can be reduced in most mills. Variations in input pulp flow rate and consistency need to be controlled before screen consistency can be optimized. Baskets were worn within six months but this could be extended to eight months by adjusting the reject ratio. Using the de-aeration valve of the screen can cause as much as 25% of the observed fiber loss.

7.0 DEINKING

The commissioning phase begins after a deinking plant start-up. During this time most of the organization's energies are focused on meeting plant runnability and output tonnage goals. Other factors, such as consistent product quality and low operating cost, tend to get little attention; however, these factors are important to the plant's customers, management, and investors. This paper describes the development of deinking plant optimization models that address the issues quickly and serves as the foundation for a good optimization plan (R-34). This plan provides a dynamic solids model for making cost effective decisions regarding redesign or modifications to the deink plant and a maximized profit model for operating in the most efficient manner in the interim.

Furnish variations can result in variations in deinked pulp brightness. Gehr described the recently developed EcoBright™ brightness control system which enables chemical dosages and bleaching stage process parameters to be controlled thereby maximizing brightness of deinked pulp while minimizing brightness variability (PC-11). This permits significant reduction in the chemical costs and operating costs.

7.1 ONP and OMG Deinking

Ackerman noted that the reflectance (brightness) after deinking has been an adequate measure of deinkability (PC-6). However, brightness does not provide a measure of how much ink has been removed from the pulp. Also, brightness is often measured using pulp prepared at conditions specific to a particular mill and using varying sheet preparation techniques. These factors make comparison of results from different mills difficult. Ackerman described results of round robin testing at seven facilities to determine deinkability of a particular paper product. She concluded that differences in results among the participating laboratories were due to both different test methods and the specific equipment used in the laboratories. This shows it is important to standardize the measurement method and sample preparation technique as well as the equipment and processing conditions used. Carré described "Free Ink," an extensive benchmarking of deinking performance carried out at 20 mills in the U.S. and Canada in 1998 and 1999 and in eleven mills in Europe in 1999 (PC-7). For six months, samples from the first flotation (pre-flotation) accepts and the final pulps were collected on a weekly basis and brightness and ERIC (Effective Residual Ink Concentration) measurements made on paper pads prepared from these samples. ERIC values from the European mills were higher than those from the American mills in the summer months indicating greater ink fragmentation was occurring in the European mills. The significant seasonal variation in ink removal efficiency earlier noted in the North American mills also occurred in the European mills beginning in mid-July and lasting until mid-September. The larger the fraction of old newspapers in the furnish, the larger the amount of small ink particles attached to the fibers during the summer months. The use of additional hydrogen peroxide in the pulper compensated for this lower brightness. ERIC results for hyperwashed pulps indicated that dispersion followed by post-flotation reduced thenumber of small ink particles attached to the pulp thus increasing brightness.

Colloidal and dissolved materials are released from cellulose fibers primarily during pulping and bleaching (PC-36). The amount and nature of these materials depends on the furnish being processed and the chemical conditions used. These colloidal and dissolved materials can result in deposition of secondary stickies on paper machine wires. Dewatering and retention experiments can indicate the effect of these materials on paper machine runnability. CTP researchers studied these concerns in pilot scale deinking of a 60% ONP/40% OMG furnish in 2.5% sodium hydroxide solution. As a result of their findings, they recommended separating the deinking process water circuits from the paper machine water circuit as much as possible. To do this, the authors recommended thickening the pulp as much as possible (to 35-40% consistency) be-

tween the deinking process and the paper machine using a screw press. This will reduce carryover of anionic colloids to the paper machine and reduce fresh water consumption. The best location to remove anionic colloids from the process water is in a dissolved air flotation cell of the last process loop. The best place to add a cationic coagulant is in the head-box of the paper machine rather than earlier in the process. Suitable cationic coagulants can reduce the adverse effects of anionic colloid precipitation. They also recommend using counter-current dilution as much as possible.

Pakarinen described the use of carbon dioxide as an alternative to alum or sulfuric acid for pulp acidification prior to papermaking (PC-19). No changes in wet end chemistry were needed. The carbon dioxide provided a better buffering capacity reducing pH fluctuations in the system. According to Pakarinen, the use of carbon dioxide reduced the severity of the brightness-lowering summer effect and of calcium oxalate scaling and other deposits on the wires and press sections.

Rodriguez described Spain's new greenfield mill near Madrid (PC-20). The Papelera Peninsular mill produces newsprint, office paper and copy paper from 100% recovered paper, Paper sources are household collections and about 10% recovered office paper. The plant operates two high consistency (18%) batch pulpers each with its own feed conveyer and dump chest. This is followed by high-density cleaners, coarse screening with 1.2 mm diameter holes and three-stage 0.25mm slot fine screening. After reduction of pulp consistency to 1.2%, the stock is passed through a pre-flotation system of six primary and two secondary cells. The accepts are diluted to 0.8% consistency for four-stage cleaning followed by four-stage 0.15 mm slot screening. The stock is then sequentially thickened in a disc filter and a screw press to 30% consistency before going through a disperger. This is followed by peroxide bleaching, stock dilution to 1.2% consistency and post-flotation using four primary and one secondary cells. After thickening, the stock passes through a reductive bleaching tower with a twenty-minute residence time.

Stora Enso modified its Saxony (Germany) newspaper deinking mill to expand secondary pre-flotation and secondary post-flotation stages (PC-21). Prior to the rebuild, the pre-flotation comprised two lines with four primary flotation cells. The rejects of both lines were combined and subjected to a post-flotation in a single cell with the accepts being returned to the inlet of the pre-flotation. A new secondary pre-flotation system of five cells was installed. The accepts of this new secondary pre-flotation are being fed forward to the inflow of the post-flotation. The post-flotation formerly comprised three primary cells arranged in two lines with a common secondary cell. As part of the rebuild, this secondary flotation cell was supplemented with the original secondary preflotation cell. At a given yield, the rebuild enables improved ink removal.

Cartiere Burgo, Italy's largest paper group, recently started up a new deinking line in its Mantova newsprint mill (PC-32). Capacity of the new line is 1,250 tons/day. The line produces two grades of deinked pulp; a newsprint grade for the Mantova mill and a lightweight coated (LWC) grade for Burgo's LWC mills. The line has to be able to produce the higher quality deinked pulp required for LWC papers. In addition, the line had to be able to process a high level of colored papers. All of Italy's many sports magazines are printed on pink papers. The make-up water coming from the paper machine to the deink line is often colored.

The mill is designed as a three-loop system with the first two loops producing the pulp for newsprint applications (PC-32). About half this pulp is processed in the third loop to upgrade it to the LWC requirements. The first two loops consist of pulping, HD cleaning, prescreening,, flotation, cleaning, screening, disk filter and dispersion followed by oxidative bleaching, flotation and additional screening. The pulp intended for newsprint use is then subjected to reductive bleaching. The pulp for LWC goes to the third process loop, which consists of dispersion, oxidative bleaching, gyrocleaning, high-turbulence washing and reductive bleaching. Product ISO brightness specification of the pulp for newsprint is 61-63 while that for LWC is 70-73. Stickies content (mm^2/kg) specification is 150-230 for the newsprint pulp and 15-80 for the LWC pulp. Yield of the newsprint pulp is 82% while that of the LWC line is 75%. The LWC line provides an ISO brightness increase of 9.5, a 54% reduction of dirt specks, a 70% reduction of stickies and a 40% increase in tensile strength.

Measuring ink content is essential to determining ink removal efficiency of unit operations and the overall effectiveness of different deinking processes (R-61). Reproducible sample preparation containing a representative sample of the ink population in the pulp is essential to measurement of brightness and ERIC value. Sheet formers tend to remove additional ink during sheet formation while the

amount of ink lost in sheet making is much less using a Buchner funnel procedure. Haynes predicted on-line monitoring of dirt count and ERIC values will allow mills to control their deinking processes considerably better than at present. In his tests, flotation removal of ink particles less than 10 microns in size was 68% and increased to 80% for particles between 10 and 125 microns in diameter. He postulated that most of the attached ink or redeposited ink was on the inside of the fiber making its subsequent removal very difficult.

Of particular concern in water loop closure in newspaper deinking mills is the effect of very small ink particles such as those associated with water-based inks. The small ink particles have the greatest adverse effect on pulp brightness. To study problems associated with ink particle redeposition and process water recycle, Borchardt described a laboratory apparatus modeling a flotation - wash deinking process using a 70:30 blend of old newspapers (R-41, PC-16). Unlike test results from deinking office papers (PC-161, the largest brightness gain occurred in the post-flotation washing step. Trends in pilot plant and in the laboratory deinking systems were similar; increased levels of flexographic ink in the furnish reduced brightness and resulted in a greater brightness decline with increasing process water recycle. Based on results obtained with carboxymethyl cellulose and a zeolite, anti-redeposition agents (often used in laundering), could result in a brightness improvement after pulping but will not significantly improve pulp brightness after flotation and washing.

Pilot plant studies at CTP (Grenoble, France) indicated that redeposition of water-based inks onto cellulose fibers is greater at neutral pH than under alkaline conditions (R-43). At alkaline pH, negative charges on the cellulose carboxyl groups lead to electrostatic repulsive forces with the flexographic ink (presumably with negative charges on acrylate ink binder resins) resulting in reduced ink redeposition. Surfactants can reduce redeposition in neutral pH conditions but not below the levels obtained in alkaline pH. Under neutral conditions, flexographic ink redeposition occurs mostly on fiber surfaces. Under alkaline conditions and with a high ink load such as would occur when recycling washer reject water, redeposition in the fiber lumen as well as on fiber surfaces occurs. Adsorption onto the lumen appears to be irreversible. The CTP workers recommend that for furnishes containing water-based inks, the best process would be flotation at neutral pH, which would provide relatively good flotation ink removal efficiency. Removal of oil-based inks would be lower but overall pulp quality would be higher than obtained at alkaline pulping conditions.

Davies and Duke described an apparatus that images bubbles ranging in diameter from 0.2–1.7mm in a clear tube (R-42). The goal is to characterize ink removal rates and behavior in flotation deinking and dissolved air flotation. Air bubbles are suspended in a vertical tube in which a downward flow of water prevents the bubbles from rising. Ink adsorption onto air bubbles was observed and the images captured on digital video using a CCD camera. Adsorption of soybean oil-based inks onto air bubbles occurred using sodium oleate deinking chemistry while no such adsorption was observed with flexographic ink particles. Ink removal rates for single air bubbles can be determined.

Cao and coworkers reported deinking results for a new generation Voith laboratory flotation cell, the Delta25™ (R-60). The major difference from previous Voith lab cells is the addition of an automatic foam skimmer. Old telephone directories (OTD) were chosen for study because there are 750,000 tons available annually and fiber properties are comparable to old newsprint. A brightness gain of 9.5 points was obtained on flotation but the yellow color sheet resulted in a post-flotation brightness of only 46%. Each 10% addition of OTD to an ONP/OMG furnish resulted in a 1.4 point brightness drop. Because the printer switched from yellow dyed pages to printed yellow pages, reductive bleaching (hydrosulfite and FAS) was ineffective. According to authors “a traditional surfactant - fatty acid” chemistry removed all the black ink as indicated by no change in the ERIC number on hyperwashing.

7.2 Office Paper Deinking

The participants in a panel dicussion, “Limitations on recycled fiber use in graphic papers,” concluded that flotation ink removal efficiency had improved in the last ten years (PC-24). The primary barrier to improved ink removal is ink detachment from cellulose in dispersion.

Ferguson reported that some mills are able to produce deinked market pulp virtually indistinguishable from virgin pulp (PC-8). The process uses 100% mixed office recovered paper and includes high consistency pulping, extensive cleaning and screening, kneading and dispersion and two stages of flotation and washing. The twice-dried nature of deinked market pulp reduces the refining energy needed

as only slight post-refining is usually necessary. In addition, the twice-dried nature of the deinked market pulp results in the fibers draining significantly faster than virgin pulp. The dry line on the paper machine can be seen to move back allowing faster paper machine speeds and/or lower dryer temperature. Physical (burst, tear and tensile strength and also smoothness) and optical (brightness, opacity and dirt count) properties of this deinked market pulp are comparable to those of a virgin hardwood pulp.

In 1997, SCA Hygiene Products replaced an HD pulper in their Mainz-Kostheim with a drum pulper with the objectives of increasing pulping capacity, more effectively pulping papers that are difficult to defiber, improving management of high reject rates and reducing specific energy consumption (PC-22). Pulp quality criteria include shives, dirt count and stickies. An important factor was removal of increasing levels of fillers present in the furnish. The successful project increased pulping capacity while allowing lower paper grades to be processed.

As mills close their water loops, issues associated with process water reuse become increasingly important. These include possible product quality and operational problems caused by increased levels of suspended ink, stickies problems caused by aggregation of microstickies, corrosion problems caused by increased numbers of microorganisms in the system and foaming problems caused by surfactant build-up in the system. In addition, interference of process chemicals from different parts of the mill with each other can reduce the effectiveness of the deinking process. Borchardt described the design and operation of a laboratory apparatus built to study these issues and evaluate deinking and water clarification chemicals (PC-16). Data indicated that the apparatus provided reproducible office paper deinking results (brightness and ERIC values) and that results were generally consistent with a pilot plant study of a similar furnish using the same deinking chemical and process water recycle.

The interaction of toner particles is important in office paper deinking. Azevedo reported that interaction parameters of styrene–methyl methacrylate block copolymer toners are dependent on pH shifting from attractive to repulsive with increasing system alkalinity (R-29). Both attraction and repulsion behavior is a function of the conformation of poly(methyl methacrylate) segments of the copolymer. These segments exist as spherical domains in a matrix of polystyrene segments, which account for 0.8 volume fraction of the polymer. Despite the dominance by volume of the polystyrene segments, the poly(methyl methacrylate) segments control the interaction forces between toner particles. In acidic conditions, these segments are tightly coiled and toner particles are attracted to each other by hydrophobic interactions. In alkaline conditions the segments are elongated and extend into the aqueous phase. In this situation, the toner particles remain dispersed due to steric forces. These interaction forces were measured in different aqueous systems using atomic force microscopy.

Ramasubramian described a modified ultrasonic process to remove toner-ink particles from sheet surfaces (R-1). Acoustic Coaxing Induced Microcavitation (ACIM) uses pulsed ultrasonic energy to generate microcavitation at the paper-toner interface. This detaches the ink particle releasing it into the water. In the laboratory test design used by the authors, the intact paper sample is placed below a layer of water. A 1.06 megahertz transducer generates a burst of energy focused on the ink particle. The authors propose that air bubbles formed in the process could float the ink particles away from the paper surface after detachment. This study is in its initial stages and experiments have determined the required residence time of the energy beam on an ink particle and the effect of process variables on detachment of a 4 mm ink spot.

7.3 Flotation Deinking

Hess described what Voith Sulzer calls the SFD concept to increase the ink - air bubble collision probability (PC-14). This involves a secondary flotation of the rejects with forward flow of the accepts of the secondary flotation (which join the accepts of the primary flotation) or a preferred mode in which the secondary flotation accepts are joined with the feed to the primary flotation. Units as large as 730 tons/day are in operation. In addition, a technique of washing the foam to return fibers to the pulp thereby reducing yield loss was described. Finally, the desirability of reducing flotation cell turbulence to increase the likelihood of the ink particle and air bubble remaining attached was discussed.

Nellessen also discussed rejects flotation with return of the secondary flotation accepts to the inlet of the primary flotation stage (PC-15). Again, a primary objective was to increase process yield. Improved results were obtained when additional flotation agent (0.4% fatty acid soap) was added to the secondary flotation. Most of the information presented was the results of model calculations. Pfitzner described (see above) installation of sec-

ondary pre-flotation and secondary post-flotation stages at Stora Enso's Saxony mill newspaper deinking mill (PC-21).

Yoon reviewed mineral processing techniques that could be used in paper deinking and recycling municipal solid wastes, automobile scraps and waste plastics (R-2). The kinetics of ink flotation are first order and fit the following equation for the flotation rate constant:

$$k = (1/4)\, S_b[(3/2) + (4Re^{0.72}/15)]\, (R_1/R_2)^2 \exp(-E_1/E_k)(1-\exp[\{-\gamma_{lv}\, \pi R_1^2(1-\cos\theta)2 + E_1\}/E_k'])$$

in which: R_1 is the particle size
R_2 is the bubble size
Re is the bubble Reynolds number
E_k is the kinetic energy of the bubble - particle collision
E_k' is the kinetic energy of bubble detachment
θ is the water contact angle of the particle under consideration
γ_{lv} is the surface tension of the water/air interface

The flotation rate should vary as R_1^2 thus accounting for the difficulty in flotation of very small ink particles. The $(R_1/R_2)^2$ power relationship suggests that very small air bubbles should be more effective in removing very small ink particles.

Another important parameter affecting the flotation rate of ink removal is E_1, the energy barrier for the process of bubble - particle adhesion (R-2). The interaction energy of adhesion is the summation of interaction energies due to electrostatic, dispersion and hydrophobic forces. The only attractive force is the hydrophobic force, which increases with increasing θ (increasing hydrophobic character of the ink particle surface).

7.4 Wash Deinking

Valmet has developed a new washer, called the GapWasher, based on paper machine Gapformer technology providing controllable two-sided dewatering (PC-33). This results in a compact design providing a high productivity per meter of useful width. According to Hoheisel, this design doubles the wash capacity compared with a conventional washer of the same width. The unit is said to provide good control of washing efficiency permitting high removal of ash and fines. The high inlet consistencies used with this washer reduce the water volume going to microfiltration. Energy consumption of the unit is said to be low.

8.0 BLEACHING AND COLOR STRIPPING

Contaminants in the form of dyed papers and brown unbleached fibers from kraft envelopes were added to a wood-free deinked pulp of standard composition to determine the comparative bleaching performance of various bleaching agents on wood-free pulps of well-defined compositions (PC-12). The different laboratory bleaching sequences evaluated were peroxide (P), peroxide under oxygen pressure (O/P), hydrosulfite (Y), FAS, ozone (Z), chlorine dioxide (D), hypochlorite (H), peracetic acid and potassium monopersulfate. Chlorine dioxide was the most effective in destroying fluorescence followed by ozone, and potassium permanganate and potassium persulfate (both at low pH). For color stripping of a white recovered office paper pulp contaminated with colored fibers using a single bleaching stage, the reductive bleaching agents were the most effective followed by ozone, potassium permonosulfate and peracetic acid (both at low pH). The best multi-stage treatment was ZP_{60}-Y and DP_{60}-Y where P_{60} is a 60°C hydrogen peroxide bleaching stage.

The red color sometimes observed in deinked pulp and process water limits the use of these fibers in high quality grades of graphic papers. The red shade may be quantified using the a* value (PC-10). Shading dyes can sometimes be used to compensate for the red color. Samples of red-colored pulp and process water were obtained from five paper recycling mills and the constituents causing the red coloration determined using a combination of thin layer chromatography and high pressure liquid chromatography. The results indicated three pigments and one dye caused the red coloration. The authors noted that the improvement of peroxide by oxygen pressure for color stripping reported by other workers was not apparent in their own study.

Recycling of dyed paper is limited by the difficulty of color removal (R-20). This presentation examined recycling goldenrod bond paper using an enzyme pretreatment followed by bleaching with various oxidative and reductive bleach chemicals. Dye removal primarily was influenced by the pulp consistency and mixing intensity; the enzyme preparation used on this dye had no effect on brightness or color removal.

Silicates can stabilize hydrogen peroxide bleaching agents against decomposition promoted by heavy metal ions and also can function as buffers in bleaching. Rieber and Burka have shown that

silicates can provide improved brightness and chromaticity in reductive bleaching (sodium hydrosulfite and FAS) in the presence of heavy metals such as iron and manganese(PC-13).

Fernandes studied bleaching sequences using ozone as a function of pH, temperature and bleaching agent concentration (R-21). Bleaching stages were performed with ozone alone or in combination with other oxidative bleaches. Most tests were performed in a pilot plant that required modifications to make the equipment more compatible with ozone and limited results have been obtained to date. At the low ozone charges used, the ozone had little effect on sheet brightness. An ozone - peroxide bleaching stage was effective in color stripping and reduced fluorescence by about 50%. There was no effect of an ozone - peroxide bleaching stage on burst index, breaking length and tear index.

Chlorine dioxide, long been known as an effective bleaching agent for chemical pulps, also can be used to remove fluorescence from recycled fiber. Laboratory and mill scale studies reported here show that chlorine dioxide reacts with optical brighteners added during papermaking, destroying their fluorescent properties and permanently removing these compounds from the fiber (R-30). Chlorine dioxide is very specific and selective—brightness loss is limited to fluorescence loss and cellulose is not degraded. A simple, low capital ClO_2 generator using sodium chlorite for on-site generation of chlorine dioxide for stand-alone deinking mills is also described.

9.0 STICKIES

9.1 Quantification of Stickies

Deposition of macro and micro stickies was simulated under laboratory conditions to better understand some fundamentals of the stickie problem during papermaking (R-62). In trials with PSAs, the INGEDE FAC-Analyzer showed good recovery rates of particles of all sizes, including micro stickies. Trials were conducted with uncoated paper and paper coated with coating compounds differing only in the composition of the binder. All were printed in a rotogravure press. PSA was added either as the original dispersion or after its application on labels. The results showed significant changes of the deposition behavior of the various coating binders. Deinking chemicals also impacted the deposition results.

The USPS benign PSA initiative has prompted the development of laboratory and pilot protocols for assessing the recyclability of recovered papers that contain adhesives. These protocols have served as a tool for adhesives manufacture during the development of recycling-friendly adhesives. An overview of the methods used to quantify sticky contaminants was presented (R-63). Stickies are broadly categorized based on their size as macro or micro. Macro stickies quantification methods rely on a fine-slotted screening step to separate stickies from pulp, followed by examination of the stickies by image analysis or a manual counting method. Micro stickies, which are able to pass through screen slots, are generally quantified by measuring the accumulation of tacky contaminants that adsorb onto a hydrophobic collector suspended in the pulp slurry.

The color image analysis system developed by Rosenberger to measure and classify handsheet contaminants is capable of separating and quantifying contaminants on the basis of color, residual ink, and dyed particles in a single step. A common property that differentiates contaminants in a recycle process stream is color. This system classifies and eliminates each contaminant by color using an orderly progression until no classifiable objects remain in the original image. Because this system quantifies contaminants by both color and reflected light, it allows mill operators to more fully characterize visible contaminants. The method has been especially useful for the automatic measurement of stickies. A rapid drying technique was used to dry handsheets dyed with Morplas Blue to stain stickies for image analysis (R-64). This image analysis method can be implemented as a process quality control protocol in a recycle mill to report stickies, dirt, and other colored contaminants present by using one image analysis step.

9.2 Control of Stickies

(See also Section 6.0 STICKIES AND SCREENING)

As mills close their water loops, organic dissolved and colloidal material (pitch, white pitch and microstickies) become what Blanco calls “paper recyclers’ worst enemies’’ (PC-30). They can cause deposits in the equipment and in the final paper product, web breaks, wet-end chemistry modifications, corrosion and other problems. Destabilization of dissolved and colloidal material can cause agglomeration and precipitate formation. Causes of this destabilization include addition of cationic polymers (retention aids), water evaporation in the dryer section and pH or temperature shocks. Higher

paper machine speeds increase sensitivity to contaminants.

Hamann and Blechschmidt defined microstickies as particles in the size range below 100 micrometers and noted they are becoming of increasing concern as mills close their process water loops (PC-25). Secondary stickies formed from microstickies can result in deposits in the drying and press sections and in calenders. The authors reviewed microfiltration, pressurized filtration and membrane filtration and conclude that these technologies "provide sustainable solution concepts for microstickies control."

E&M Lamort and Thermo Black Clawson have developed a single screen with 3 basket sections separated by two intermediate deflocculation devices (PC-27). The unit is called the ScreenONE. The rotor is a major influence in determining the capacity and separation efficiency of the unit. The authors reported that in a large number of tests with various types of papers, "We have not seen any difference in stickies size distribution" as a result of screening. Depending on operating conditions, separation efficiencies of 78-92% were obtained for newspaper/magazine and 80% for OCC.

Klar and Burkhardt presented data indicating that the stickies area (mm^2/kg) in the Mainz-Kostheim SCA Hygiene Products mill in Germany increased by a factor of approximately five since 1991 (PC-22). The authors noted that some of this increase may have been due to improved stickies measurement techniques. Gassmann stressed that operating screens and cleaners under mild conditions substantially increased stickies removal compared to operating the same equipment under aggressive conditions (PC-23). A slower transit speed through screen slots reduces particle deformation and extrusion with fibers. He advocated pressured filtration as a means of removing stickies from recycled process water.

In contrast to the increase in stickies at the Mainz-Kostheim SCA Hygiene Products Mill, the Haindl Paper Schwedt mill in Germany reduced adhesives content of the stock by nearly 33% through quality control measures (PC-31). At the same time (1994 - 1999), the adhesive elimination rate for the overall mill increased from about 90% to more than 98%, primarily through optimization of the baskets used in pre-screening and post-screening stages. Adhesives content in recycled fiber pulps is below 100 mm^2/kg. The Ettringen mill of Gebr. Lang GmbH achieves a 65% removal of stickies in screens (PC-28). The mill processes ONP and OMG.

Online measurements of adhesives and stickies is desirable as a process monitoring tool but Lazonder and Catsburg believe automated lab-scale measurements would be a more attractive alternative for process optimization (PC-31). The authors suggest that the FAC (Forced Adsorption Contactor) deposit analyzer under development by the Papermaking Institute of Darmstadt Technical University could become such an instrument.

10.0 IMAGE ANALYSIS

After reviewing the basics of image analysis, Godart described the morphological characterization of residual ink particles at the inlet and outlet of a pilot plant kneader and after the post-flotation step (PC-34). Ink particles were recovered on handsheets. Individual measurements, individual ink particle size and equivalent diameter, and global measurements such as the fraction of surface area occupied by ink particles and the total number of ink particles per unit sheet area were determined. The Feret diameter and the geodesic length are suitable for the characterization of elongated particles and shape analysis using shape factors. The Feret diameter is the maximum particle diameter in one defined dimension and is defined as the distance between two lines drawn tangent to the particle edges. The geodesic length is the shortest path between the most distant extremities of the particle without leaving the particle. Kneading reduces the geodesic shape factor suggesting that long, thin particles are broken apart or folded along their longest axis. Flotation resulted in a smaller reduction in the geodesic shape factor.

Klein reviewed problem areas and important parameters in ink speck measurement using scanner-based image analysis systems (PC-35). Analytical results can deviate by as much as ±20% with 8-10% considered normal. The darkness threshhold level is critical in determining the measurement results. Thus the method of its determination is very important. System calibration, sample preparation and the mechanics of instrument operation are also important in determining image analysis results.

Both the amount of the ink present and the size of the residual ink particles affect measurement of deinked sheet brightness. The same amount of ink, when in the form of small ink particles has a greater

adverse effect on brightness than when in the form of larger ink particles. A new image analyzer based on automatic acquisition of a series of images by optical microscopy with a specifically designed 3-axis motorized stage followed by computation of particle size distributions based on particle count or relative particle surface area on the sheet (ppm) was reported (R-18). The commercial software Visilog 5 was used to program the autofocus, segmentation, validation and computation of granulometric values modules controlling the automatic image acquisition.

11.0 PAPER PROPERTIES

Paper mechanical strength first increases with increasing fines concentration and then decreases. Zhang reported that there is a critical fines concentration corresponding to a maximum tensile strength, burst strength and ring crush in both virgin and recycled sheets (R-58). Unbleached kraft pulp was used in this study with recycled sheets being prepared from virgin handsheets. The maximum strength of the virgin sheets is greater and occurs at a higher fines concentration than is the case for the recycled sheets. Tear strength of both virgin and recycled sheets decreases linearly with increasing fines concentration and the maximum virgin sheet tear strength is greater than that of the recycled sheets. Zhang attributed the observed results to increased bonding strength and relative bonded area and reduced effective fiber length with increasing fines content of the pulp.

Klungness and coworkers have studied fiber loading of recycled pulp for several years. They reasoned that fiber loading of bleached pulp before drying could prevent irreversible bonding of cellulose components within the fiber wall by preventing their contact (R-59). They found that fiber loading restores the water retention value (which has been shown to correlate well with handsheet strength properties) while increasing the Canadian Standard Freeness of once-dried bleached hardwood kraft pulp. The water retention value was proportional to the amount of fiber-loaded precipitated calcium carbonate.

Scott reported on the development of a device to evaluate toner adhesion onto copier paper (R-28). The objective was to determine the utility of the Rolling-Fold Durability Tester in characterizing toner durability, which is related to the extent of toner fracturing after repeated folding of the substrate paper. The authors hypothesize that toner chemistry plays a major role in toner adhesion with greater ductility (resistance to fracturing) or higher brittleness (the formation of many fractures forming small toner fragments less likely to peel from the paper) being important. Toner thickness is also important but is often difficult to control in photocopiers. Paper parameters such as orientation, recycle content and moisture content influence toner adhesion. Toner durability was greater on paper tested in the cross-machine direction probably due to stiffness effects. The authors theorized that increased porosity resulting in better toner mechanical binding to the sheet and lower bending stiffness for less severe sheet creasing may account for better durability of the toner on recycled fibers. The authors concluded that the apparatus would be useful in a study of factors influencing toner adhesion onto fibers,

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