Linting and Surface Contamination: Current status

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Abstract: Over the last 20 years and more, great progress has been made in the reduction of linting and picking of newsprint and other uncoated papers. But changing printing technology and customer demands for ever-increasing quality mean that our quest for the perfectly clean sheet surface is a moving target. Despite many improvements, we have yet to find the ideal lint test for the finished product: precise, representative, and fast. Improving mechanical pulp quality remains a priority in lint reduction, in terms of reducing the content of unbonded ray cells. The evolution of low freeness, low coarseness, thin-walled fibres is continuing, through improved refining and processing, although much remains to be done. Recent work on relating colloidal properties of fines to their specific surface area and so to linting propensity is of value in controlling pulp quality, while on-line fibre classifiers also show great promise. New techniques of surface consolidation are of interest in reducing linting, although excess consolidation can make linting worse. Even low amounts of surface size can produce a very large reduction in lint.

FOREWORD

You see, it takes all the running you can do to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that.
Red Queen to Alice, Lewis Carroll, *Through the Looking Glass*

When the author started in the Canadian pulp and paper industry in 1980, the rule of thumb for an offset newspaper was that 50,000 impressions between lint wash-ups were "acceptable". Twenty years later, this figure is absolutely unacceptable. For most newspapers, 100,000 impressions between wash-ups represent a minimum, and some publishers have targets of 150,000 impressions or more. Commercial printing plants are even more demanding, and some may

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even attempt to have no washups at all during a single shift. Similarly, users of fine papers have become increasingly unforgiving of vessel element picking.

In the 1960s and the 1970s, lint tended to contain more stiff, coarse material (Figure 1) [1]. Today, "good" lint samples contain much finer material: mostly ray cells (Figure 2) [2], which are notorious for their inability to develop specific surface area and to form strong fibre-fibre bonds.

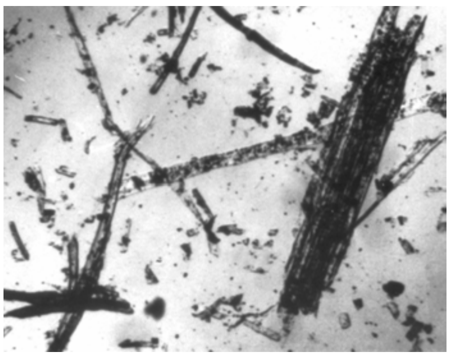

Figure 1: Typical lint sample from 1975 [1]. Note the presence of a large amount of coarse material and mini-shives.

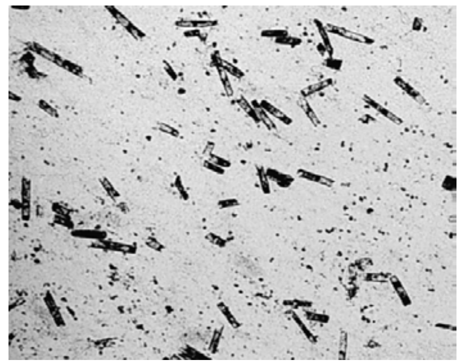

Figure 2: A good lint sample by today's standards. Note the preponderance of small ray cells [2].

INTRODUCTION

Since the rise of offset lithography to dominance, surface contamination has risen to the level of a critical factor. Classical reasons include the following:

i. Offset inks have a much higher tack than other inks.
ii. The presence of water in the offset fountain solution weakens the paper surface and of itself removes debris.
iii. Customer demands are greater with regard to quality and run length.
iv. The flat offset blanket and plate give no place for lint and other debris to hide.

Paper-related issues

Within the paper mill, the following factors are critical to understanding linting:

i. Pulp quality.
ii. Changes to wet end chemistry (retention aids, lint reduction aids, etc.).
iii. Installation of size presses.
iv. Paper machine design and operation.
v. Calendering changes.
vi. Control of airborne dust within the paper mill and printing plant.

A large variety of techniques have been used to monitor linting and other forms of surface contamination. At the same time, many strategies have been attempted in different mills to reduce linting. These strategies will be summarised, and recent progress will be presented later in this review. Variations in fibre supply and fibre quality and variations in the uniformity of surface and internal treatment (if any) can lead to variations in linting. Long and short-term variations on the paper machine - frequently studied in control research – are another poorly understood factor in linting.

Press factors

The first difficulty in lint testing is inherent to the offset process. With the dozens of variables in the offset process, it is effectively impossible to recreate a real offset press in the laboratory. Variables include:

i. Press design and configuration: speed, roll diameter, takeoff angle of the paper in the nip, dampening system.
ii. Offset blanket: hardness, roughness, compressibility, age.
iii. Plate: degree of micro-roughness (on the scale of about 1 μm). This may be affected by linting, since the lint itself can cause plate wear; which reduces water pickup by the non-image areas of the plate. Plate wear can also be a prelude to scumming [e.g., 3].
iv. Ink: tack, viscosity, and degree of water emulsification.
v. Fountain solution: amount, viscosity, surface tension, and conductivity.

Key factors within the printing plant include:

i. Control of temperature and humidity.
ii. Control of ink tack.
iii. Control of fountain solution properties.
iv. Control of dust within the printing environment.
v. Press maintenance where (for example) excess nip pressure, improperly packed blankets, and overall mechanical condition are an issue.

Other contaminants

Not all contaminants come from paper. Tape pulls to remove the contaminants from the blanket are essential, since a simple visual examination of the problem print may not give the full answer. Chemical, spectroscopic, and microscopic analysis can then be carried out directly on the contaminant. Although not an exhaustive list, common contaminants other than paper fibres include:

i. Ink skin
ii. Clay or calcium carbonate: usually from fillers and coatings.
iii. Coloured pigments: from inks.
iv. Polyamide (nylon) fibres: paper machine felt hairs, or from the brush dampeners used on some presses to apply the offset fountain solution.
v. Polyester or cotton fibres: frequently from printing press cleaning rags.
vi. Short choppy fibres - frequently from slitter dust (either from the paper mill or the printing plant).

HISTORICAL LINT TESTS

In 1987 [4] Mangin reviewed offset linting methods. Even at that time, there were dozens of different tests. All had been used at one time or another, if only by a single producer, while some were at the level of quasi-standards. Some are still in use, and other test methods have been introduced since 1987.

i. "Rubbing" tests:

a. A black velvet cloth (Figure 3) is manually held against the reel at the winder (or sometimes against the edge of the roll).

b. In the Elphick test [5], freshly printed newsprint is tested in an ink ruboff tester, and the lint is evaluated with a microscope. Although newspapers occasionally refer to this test, in the author's experience, the test has little or no merit.

Figure 3: A "black velvet cloth" showing lint fibres collected after contact with the moving paper.

ii. "Pulling" tests:

a. The wax pick test uses wax sticks of increasing hardness and melting point [6]. An appropriate range of sticks are melted onto the paper surface. Once cooled, the sticks are lifted off the paper surface. The highest melting wax that the paper can withstand without surface damage is taken as the surface strength of the paper. This is more of a pick than a lint test, and is used for coated and fine papers. It is still occasionally used for newsprint, with little justification.

b. Tests in which the paper is "printed" with a tacky material, such as a poly(isobutene) oil or a solution of a polymer in a mineral oil. Pigmented inks containing carbon black may be used.
The IGT pick number [7] is the velocity at which the paper was moving when picking started, so a higher number is better. While the repeatability can be very good, operator variation is a problem [8]. Also, the relevance of a "pick" test to linting is in question. In a *qualitative* IGT test, the damage to the test print is compared to the degree of damage on a set of standard prints. As shown below, a newer test method allows small amounts of fibre to be quantified using an optical fibre classifier.

IMPORTANT LINT TESTING AREAS TODAY

Full-scale press testing
While testing in the customer's plant is important, for more detailed work, tests can be done on commercial presses in controlled environments – usually a training college or research institute. While providing the most precise linting data, tests on such presses are inherently inconvenient. Rolls must be prepared and transported long distances to the test site, usually at considerable expense.

Small sheetfed offset presses are used by some mills. A fixed number of sheets are printed, and the lint is collected and quantified. In some cases, the paper is passed through the press with dampening alone (no ink), and in at least one test, the paper is passed through a dry nip, and the lint collected from the blanket.

Small web presses have also been used for many years. The Apollo press has been used by many mills to predict linting, although the number of mills is diminishing. A narrow roll is printed for a fixed number of impressions (minimum of 2,000), and the lint is collected. As discussed below this test has had several key successes in lint analysis and understanding.

As much of the following information must be recorded during a trial:

i. Press: Model, speed, colour sequence, plate, run length.
ii. Blankets: Supplier, age, hardness, surface finish (e.g., smooth or rough.)
iii. Ink: Supplier, colour, batch number, tack, other details (e.g., heatset, quickset, vegetable oil, etc.)
iv. Fountain solution: Supplier, pH, conductivity, viscosity, amount of gum arabic, amount (if any) of co-solvent.
v. Paper: Supplier, grade, roll number, as much pulping or manufacturing information as possible. Key furnish details include wood species and the proportion of kraft, TMP, deinked pulp, SGW, etc. For a given TMP, important details include freeness, fibre coarseness and average fibre length, and average percentage of rejects past the first refiner. Paper machine details include manufacturer and class of former, forming fabrics, and details of the press section. Other details could include retention aids (if any).
vi. Sampling point on the blanket: The type and amount of lint changes with the position on the press. Even on the same unit, lint in the non-image area can be more plentiful than in the image area, but the image area lint may be made of coarser, larger material. Halftone area lint changes with the size of the dots, since each dot edge presents a new interface to "peel" the paper surface. One of several possible solutions [2] is to collect the lint from a group of halftone areas (e.g., 25%, 50%, 75%, and solid coverage areas), thereby averaging out these effects.

Analysing press lint

Tape pull analysis

Tape pulls are especially useful for on-the-spot investigations of press runs. A roll of 2"-wide transparent plastic tape (or sheets of a commercial adhesive tape supplied by, for example, 3M Corp.) and sheets of Mylar™ or cellulose acetate are all that is needed. The adhesive tape is placed firmly on the press blanket. As the tape is peeled away, lint, other surface contaminants, and much of the ink on the blanket is removed. The tape is placed onto the plastic sheet for safe transport and storage. *It is necessary to specify a clear plastic film to support the tape, since the author has seen many cases where tape pulls representing hours or days of effort have been placed against a sheet of paper!* After such treatment, the lint and other material on the adhesive tape are useless. Tapes that are folded against each other or crumpled into a plastic bag are not much better. A good tape can then be used for:

i. Qualitative analysis of lint by microscopy.
ii. Quantitative analysis of lint, by washing the lint from the tape and evaluating it gravimetrically or with a fibre classifier.
iii. Quantitative analysis of lint by image analysis.
iv. Qualitative analysis of "sticky" deposits by (e.g.) infrared spectroscopy.

Quantitative lint removal and analysis

Heintze [9] reviewed his company's experience, including its development of a patented device for washing lint from a known blanket area [10]. He found a good correlation between lint from a commercial heatset offset press, lint from the IGT visual rating, the Pulp Linting Propensity Index (below), and Apollo press lint. This collector was used by Wood *et al.* [2] to analyse lint from commercial newspaper and heatset offset trials. The lint is washed from a known blanket area, and is reported as the weight of coarse fibres (retained by 150 mesh screen) and fine fibres (passed by 150 mesh screen, retained by a 400 mesh screen). At least one test centre uses a third screen to collect filler particles as fine as 1 μm.

Image analysis

Waech [11] developed an image analysis technique for determining the amount of lint on press tape pulls. The moisture content of the fibres on the tape pull can affect the count, since fibres with a higher moisture are more transparent.

Examples of web press studies

Wood [12] showed a correlation between the Paprican lint test (below) and the lint from the top side of top former sheets on a heatset offset press ($R^2 = 0.73$) and a coldset offset newspaper press ($R^2 = 0.62$). Wood *et al.* [2] concluded that:

i. There is a correlation between the amount of lint measured on the newspaper press and the commercial heatset offset press ($R^2 = 0.59$, top; $R^2 = 0.80$, bottom). Nevertheless, the press makes a major difference to the amount of lint.

ii. There is a correlation between the total amount and average size of lint (R^2 = 0.47, top; R^2 = 0.74, bottom).
iii. There is a correlation between lint and the Pulp Linting Propensity Index (below); R^2 = 0.49, top; R^2 = 0.58, bottom.

Heintze [13] compared laboratory testing (GFL press) to linting on the Apollo press. His statistical analysis showed the following major factors:

i. Blanket age, suggesting that an older blanket may be a tackier blanket. This may be due to the absorption of ink oil and cleaning solvent.
ii. Ink tack and ink batch.
iii. Testing temperature, through increases in ink tack at lower temperature.
iv. Ink feed setting and paper type, as shown by Mangin [14] and Aspler *et al.* [15] on the influence of ink film thickness on linting, picking, and ink tack measured in the printing nip.

The paper machine has its own characteristics, as seen from a case study of two machines. With one, the linting changed very little over a range of printing speed and pressure. With the other, lint increased with increased printing speed and increased nip pressure. Heintze also stressed the need to consider two-sidedness of the printing press, in addition to the two-sidedness in the paper.

Moller and co-workers [16] carried out several laboratory and commercial studies. Commercial press lint results were compared to laboratory testing. The GFL fluff tester, in which sheets of paper are passed through a nip containing a metered amount of water, was claimed to be useful, with the lint results correlating with non-image area linting.

Small-scale testing

Mangin and Dalphond introduced the Paprican Lint Test, in the literature [17, 18] and in a PAPTAC Useful Method [19]. This test simulates on a laboratory press the forces exerted during offset printing [20]. Another innovation was the use of an optical fibre classifier – at the time, the Kajaani FS-100, and now the FQA (Fibre Quality Analyser). Other models have also been tried. Past techniques had been limited by the difficulty in weighing lint samples of a few milligrams or less. An optical classifier can easily count a few hundred fibres weighing a fraction of a milligram.

Unpublished work at Paprican using a reslushed newsprint as a linting "standard" (including fines) showed that the reproducibility of the lint test using the FQA is about ±20% (95% confidence limits)*. Quantitative lint accumulation

* With several thousand fibres, FQA the precision is about ± 5%. However, since a typical lint sample contains only a few hundred fibres, the precision in the linting evaluation is correspondingly poorer.

on-press is notoriously imprecise, due to the paper and press variables detailed in the Introduction. Due to the lack of published data, it is difficult to set a limit beyond which lint differences between newsprints are significant, but it is safe to say that linting differences within ±20% are not significant.

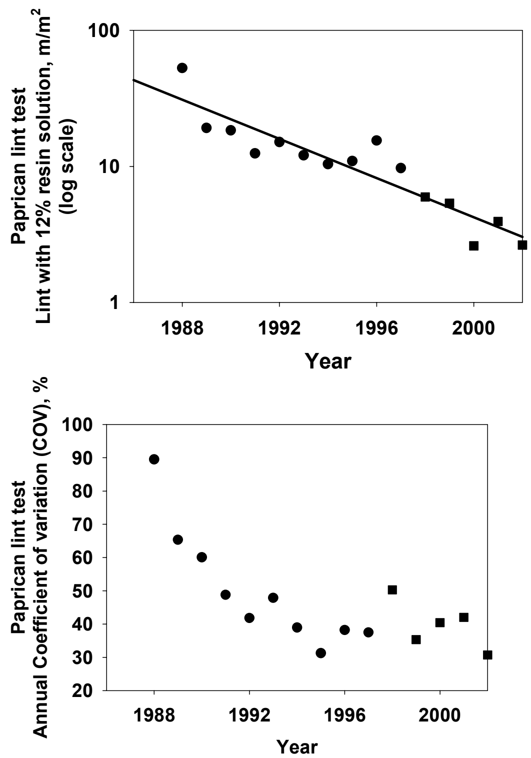

Figure 4 Top: Change in average newsprint lint, 1988 – 2002. Bottom: Change in the yearly coefficient of variation in linting for the same samples.

● Kajaani FS-100 (1988 – 1997)

■ Fibre Quality Analyser (FQA) (1998 – 2002)

Figure 4 shows the change in linting for a large number of mills and machines over a 15-year period, as monitored by the Paprican lint test. Not only has the total amount of lint dropped, but so also has the coefficient of variation within each year's samples. That is, not only has the average amount of lint decreased, but the difference from best to worst has also become smaller. Aspler [21] also showed a good correlation between lint recovered from used flexographic newspaper plates and the Paprican lint test.

Heintze and Ravary [22] found a correlation between ranking of linting and lint visual assessment of IGT test prints against pre-rated visual standards. They washed the fibres from the printing disc, to collect, screen, and weigh them. They considered this to be faster than the fibre classification required by the Paprican lint test [17,18]. They showed that IGT press speed has the largest effect on linting, but that ink level, packing on the printing sector, and pressure all have effects as well. They also recommended the use of a control paper.

Lint testing on the paper machine

Mason [23] introduced the MacMillan-Bloedel lint tester, or MB tester. Other devices have attempted to quantify linting by removing lint with a vacuum. The MB tester differs by disrupting the paper surface with an air jet, which claims to be similar to surface disruption in the printing nip (Figure 5). The lint is

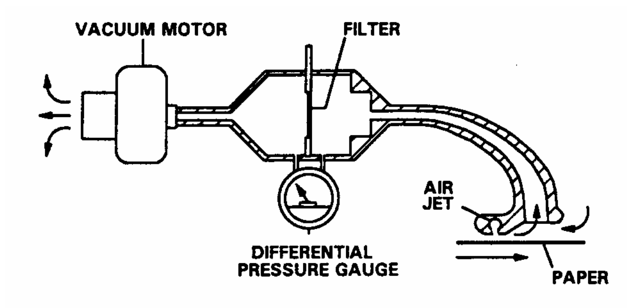

Figure 5 Schematic diagram of the MacMillan-Bloedel online lint tester [24].

collected on a filter, and the time for the pressure to drop by a fixed value is measured. A good correlation was found with the Apollo press test. During a real-time mill test of the MB tester Wood *et al*. [24] found that swings in linting performance matched swings in pulp freeness (Figure 6) in the short term a measure of applied specific energy. They also found correlations between the MB test and linting on newspaper and heatset offset presses. Some users collect material from the filter to identify contaminants (felt hairs, fibre bundles, etc.). The Quebec City based CRIQ (Centre de recherche industrielle du Québec) recently announced that they are developing a device called the Fibrometer, which uses the MB test head to remove the lint, but then uses a computer-based vision system to determine a linting index.

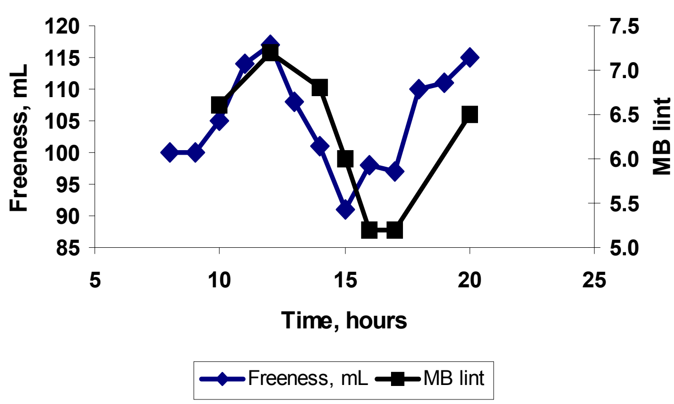

Figure 6: In a real-time (short term) mill test with the MB lint tester, swings in pulp freeness were matched by swings in linting performance [24].

Pulp quality testing related to linting

Wood *et al.*used a laboratory turbidity meter [25], a simple and inexpensive device. At constant consistency, turbidity increases with specific surface area, so low specific area material such as ray cells can be characterised. They found a correlation between filtration resistance of the pulp and turbidity. They later [26] showed that specific area of a pulp suspension can be derived from turbidity. Turbidity measurements are sensitive to fine material such as fillers, and to the presence of colloidal material always found in paper machine white water. Robertson *et al.* [27] showed that the Fibre Quality Analyser (FQA) is effective at measuring fibre properties such as length, coarseness, and shape on-line in a pulp stream. The implications for routine linting quality control are obvious.

In 1988, Hoc [28] described a device which uses image analysis to quantify fibre rising. Although this device was not developed for linting, some mills have used it as a lint tester. The link between fibre rising and linting is interesting, and the possibility that a single test might predict both is worth exploring.

LINT REDUCTION IN THE CONVERTING AND PRINTING PLANT

Dust reduction

Many patents and articles exist on contaminant removal on the press, either by preventing the generation of dust, or by removing dust from the surface before the printing nip. Although there are far too many devices to list, with at least 300 patents in the literature, a sampling by class and by function is summarised:

i. Mill strategies, including keeping knives sharp and at an optimum cutting angle [29]. However, Brandt *et al*. [30] claimed "even *the best geometry cannot prevent dust being produced by slitting*." The greater the amount of filler in the sheet, the greater the amount of dust.
ii. Vacuum devices. Simple vacuum-cleaner type devices can be used to clean the web before printing.
iii. Devices based on mechanical "brushing", which claim to clean away loose material [31, 32].
iv. Devices based on static elimination. These can be as simple as having the moving web contact metal foil strips. High voltage discharge can be effective [33, 34]. Electrostatic attraction may also be used on the small scale (e.g., in a photocopy machine) [35]. One device uses both high-pressure air and electrostatic precipitation to remove debris [36].

Other press strategies

A Canadian patent [37] described heating the blanket cylinder and the paper web to reduce linting, by momentarily decreasing ink viscosity. Waech [11] showed that increasing pressroom humidity and increasing pressroom temperature lowered linting. Increasing both had the greatest effect. Linting was reduced by two-thirds in the range from 19° – 32° C and from 31% – 66% relative humidity. Higher temperature lowers ink tack, while higher humidity (within reason) improves the fracture resistance of fibre-fibre bonds.

Moller *et al.* [16] examined linting with a group of suppliers They found that the more gum in the fountain solution, the lower the lint. They claimed that changes in the fountain solution alone are sufficient to change a newsprint from acceptable to unacceptable (double or more the lint). Increased nip pressure may clean lint deposits from the blanket, but may cause more plate damage.

In the author's experience, the influence of fountain solution was demonstrated at a large newspaper. The pressroom encountered severe non-image area linting problems, as sheets similar to those in Figure 7. The problem was not subtle: from nearly 200,000 impressions of satisfactory quality, to the point where the printed page was illegible after only 50,000 impressions. The culprit turned out to have been a change in the fountain solution. The exact nature of the change was not made public, but this does confirm the importance of the interaction between fibres, blanket, and fountain solution.

Figure 7:"Sheets" of lint - mostly ray cells - peeled from the blanket of a heatset offset press [2].

LINT REDUCTION BY CHANGES IN PULPING AND PAPERMAKING

Mechanical pulp quality

Pulp quality – especially the quality of mechanical pulp– is critical to linting. Lower specific surface pulps tend to bond more poorly, and so are more subject to linting. The first successful test to predict the presence of lint candidate fibres in pulp was the Pulp Linting Propensity Index (PLPI) [38] which separates fibres according to their specific surface area, using a miniature hydrocyclone.

A poor mechanical pulp is susceptible to linting. Common causes include:

i. Insufficient specific energy.
ii. Non-uniform wood supply. With poor control of the proportions in which different wood species are fed into the system, it is impossible to ensure that the appropriate specific energy is used.
iii. Unstable pulp mill operation: lack of control of key pulp properties such as freeness, coarseness, and average fibre length.
iv. Inadequate screening, cleaning, and rejects refining.

Fibre rising tests were previously discussed in terms of their potential as lint predictors. Fibre rising and linting are not precisely the same, but there is overwhelming evidence to show that similar fibre properties correlate with both. The common factor in fibre rising and linting is inadequate surface development. For fibre rising, the problem is the long fibres, while for linting, the problem is insufficient high specific surface area fines to consolidate the surface, plus the presence of coarse and other poorly bonding material.

Amiri *et al.* [39] examined pulp variables in the wet end. Using the MB lint tester, they found that low linting is strongly correlated to the specific surface area of the headbox stock and of the white water from the forming section (high specific surface area leading to better bonding and so to less linting). They also found a strong correlation between low linting and the R14 (long fibre) content. However, they suggested that the relation between low linting and long fibre content is not a causal one. Rather, stable conditions during pulping favour the production of long fibres and at the same time reduce linting.

In 1993, Karnis [40] presented evidence for a "peeling-off" mechanism, in which fibres are developed as they delaminate during refining, and material peels off the fibre wall (Figure 8). This has the desirable effect of reducing fibre coarseness, improving bonding, and so reducing linting. In 1995, Karnis then discussed [41] the influence of species and pulping conditions on linting and fibre rising. He showed that refining below the glass transition temperature of the lignin gives fewer lint candidate fibres, and suggested that at higher temperatures, the fibres separate through the middle lamellae, and so the development of specific surface area is inhibited.

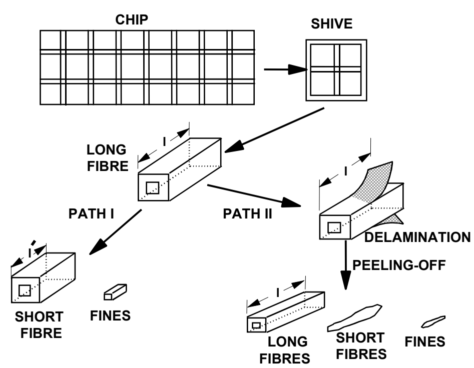

Figure 8: Mechanism proposed by Karnis [40] for fibre development by peeling of material from the fibre wall.

Both the Pulp Linting Propensity Index (PLPI) and fibre rising decrease with increased specific energy. However, post-refining was claimed to be less effective, since post-refining reduces fibre length by cutting without reducing fibre coarseness. That is, post-refining is not as effective in lint reduction since the fibre cutting that occurs does not develop the full specific surface area (and so bonding potential) of the fibres.

Ray cell linting

Beaulieu and Shallhorn [42] showed that when there are more intact ray cells, the specific surface area of the fines is less; another way of showing the importance of specific area on reduced linting. They also concluded that:

i. The paper mill is "transparent" to ray cells. "*What is discharged from the chip refiners winds up in the newsprint sheet"*.
ii. Current equipment is not very efficient at "*isolating, concentrating, retaining, and breaking down ray cells*." More efficient, smaller hydrocyclones are better at isolating and concentrating ray cells.
iii. Better surface consolidation is needed.

One important difference from 1975 until today (Figures 1 and 2) is that refined rejects today make up a larger proportion of the total furnish: for newsprint, between 20 and 30%, compared to less than 10% in the 1970s. For the highest grades of mechanical printing papers, the reject rate from the first refiners could be more than 40%. This has been a key factor in lint reduction.

By 1989, lint had changed to being predominantly ray cells. In their 1992 report, Wood and Karnis [1] also reviewed past experience, concluding that:

i. Sulfonation of whole wood chips has little effect on the PLPI. However, sulfonation of fibres is very effective at reducing the PLPI, since sulfonated fibres are more flexible and also more polar (due to the introduction of sulfonate groups), leading to better hydrogen bonding.
ii. Centricleaner rejects require a far higher specific energy than screen rejects to get to the same PLPI, showing their coarse nature.

Since the average lint is smaller, they recommended that the Pulp Linting Propensity Index test be modified. The hydrocyclone should be smaller, and they suggested that only fines be tested in the PLPI, rather than the whole pulp.

They also had four questions for future work:

i. Why does the manufacturing process liberate ray cells and other material with such poor specific surface development?
ii. How are lint candidates distributed?
iii. Can this material be efficiently separated into a reject stream?
iv. If so, how can this material be treated to improve its bonding potential?

Wood *et al.* [2] suggested that the papers with the poorest linting tendencies are still those that produce lint samples containing the most shives and poorly refined long fibres. They also showed "sheets" of lint that had built up on non-image area of the heatset offset blanket (Figure 7). The fact that this was *non-image area* lint shows the influence of the fountain solution alone.

Some mills have examined using the low specific surface area of ray cells as a means to separate them from the system. In that light, Wood *et al.* [43]

demonstrated that alkaline peroxide treatment of ray cells (fractionated or in the whole pulp) can reduce linting by about one third, even where mechanical treatment of the ray cells has failed. A likely mechanism is the oxidation of the ray cells, leading to better hydrogen bonding. Similarly Minor *et al.* [44] showed that gas phase ozone treatment of recycled paper improves tensile strength, and suggested that the cause is improved interfibre bonding, via surface oxidation and possibly delignification. It is likely that linting would improve as well.

Wet-end additives and retention of fillers and fines

Many companies market retention aids that are meant to reduce dusting and linting. Unfortunately, most of the information is either proprietary or anecdotal. It has been our experience that wet end additives cannot cure a major linting problem. If the mechanical pulp quality is inferior, additives will not make the paper acceptable. However, the appropriate use of additives can help retain and distribute fines and fillers, and so reduce linting.

Auhorn *et al.* [45] discussed using wet-end additives and surface sizing to improve newsprint quality and reduce linting. They used hydrophobic, modified cationic dispersions as well as wax emulsion internal sizes, both in newsprint and in SC paper. Their photographs of offset blanket tape pulls and IGT test strips showed improvements, but they presented no quantitative data.

Miyanashi [46] examined increased linting in newsprints filled with precipitated calcium carbonate (PCC). A high molecular weight, cationic polyacrylamide was claimed to improve the situation, based on a doubling of the IGT pick strength velocity*. Hornaeus [47] claimed that the wet-end addition of 0.3% carboxymethyl cellulose (CMC) reduced both linting and fibre rising of a clay-filled SC grade, and also reduced linting in a machine-finished grade - typically by about 25% on a small newspaper press.

Jordan *et al.* [48] showed that, for a series of filled woodfree fine papers, the samples with the greatest amount of dusting on a heatset offset press showed that the poor samples contained surface agglomerates of filler. Poorly distributed fillers are more likely to cause dusting, since agglomerates tend to be more poorly bonded to the surface [49].

There have been conflicting reports on linting of recycled newsprint [50]. The traditional idea is that fibres are weakened by recycling, leading to more linting. It has also been suggested that for mechanical fibres, linting may actually be *reduced*, since the mechanical and chemical action of the deinking plant may *improve* sheet strength [51]. Since recycled grades tend to include chemical pulp

* It is often said that IGT pick strength is only a rough indication of linting. However, a large difference in IGT pick strength is still a good indication of potential lint differences.

fibres, linting may be in fact reduced. Moller *et al.* [16] found that buildup of filler left over from the deinking process was more of a problem than fibre buildup. They suggested that fillers are preferentially removed from the paper before fibres, and so the good retention and bonding of filler onto the fibres within the deinked sheet is a key problem. The correct use of wet-end retention aids may help reduce the amount of filler removed from the deinked sheets.

Surface sizing

Surface sizing has been used for centuries. New technology (e.g., Figure 9) has made the process more user-friendly, enabling papermakers to apply thin (< 1 g/m^2) starch films to newsprint at normal machine speeds.

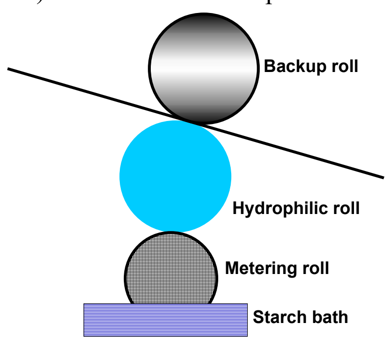

Figure 9: Schematic diagram of a metering size press. Note the resemblance to a gravure or flexographic printing system.

As shown in Figure 9 (a generic illustration), starch is transferred from a bath to a metering roll. From the metering roll, the solution is transferred to a hydrophilic, engraved roll that transfers the starch to paper. Hanson and Klass [52] showed decreases in linting (up to 80%) with the application of low amounts of starch. Akesson and Bergh [53] showed that surface strength more than doubled even for low amounts (0.5 g/m^2) of starch. Waech [11] showed that starch sizing of newsprint reduced the total amount of lint by 80%, while the average lint particle size was reduced by one third. Trouvé and Takala [54] suggested using cross-linking agents, which is common practice in coated paper.

Impact of paper machine operation

While pulp quality may be the key factor, there is a contribution from the paper machine, in terms of surface consolidation. As shown in Figure 10, linting is affected by drainage, where the poor sample lints more, due to the extreme loss of surface fines. A paper machine simulator has also been developed which lets the operator "change" properties, including linting propensity [55].

Waech [11] showed that increasing the load in the paper machine press section gave a 20% reduction in Apollo press lint, by improving surface consolidation. Wood *et al.* [56] noted, that the forming and press have a major impact on linting. "*Recent evidence suggests that low linting sheets should have a high concentration of fine material at the surface, as long as it is well consolidated"*.

Using published data [57], they divided the linting tendencies of 31 newsprint machines into “high", “moderate", and “low” categories. Aside from furnish quality, the 31 machines showed differences in linting propensity, resulting from surface consolidation differences in the design of the forming and press sections

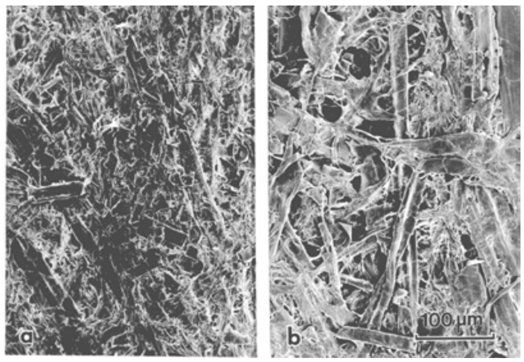

Figure 10: Two newsprint surfaces. The newsprint on the left had a good linting performance. The newsprint on the right had a poorly consolidated surface due to drainage problems, and so had a poor linting performance [2].

Increasing press section nip load decreased linting, due to improved surface consolidation. However, this improvement was measured over the widest range of nip loading, beyond any practical range on the average paper machine. Therefore, more work is required to determine the effect of realistic load changes. In the same work, the MB lint tester was used to monitor changes in linting as press section settings were modified on Paprican’s pilot paper machine. Densification of the sheet, especially in the first nip, decreased linting.

McDonald *et al.* [58] showed that excess pressing can increase linting, using a “pre-calendar” which presses newsprint at a moisture content between 18% and 30%. While there was only a slight increase in linting with the low tack fluid in the Paprican lint test, lint collected with the high tack test fluid more than doubled. This could cause problems with higher tack heatset offset inks. On the other hand, gloss was improved by the same process that increased linting.

One side-effect of conventional calendering is the reduction in tensile strength,

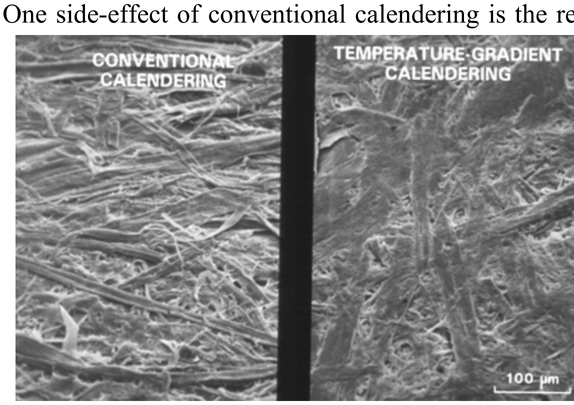

Figure 11: Newsprint, calendered at 50°C (left) and at 200°C (right). Note the extremely smooth surface of the 200° calendered (low linting) newsprint, replicating

through fibre crushing. Less commonly understood is that over-calendering also increases linting [56]. Mangin [59] showed that when paper is calendered at 200° C, linting is reduced compared to conventional calendering. Since the paper surface is plasticised at >200°C (Figure 11 [60]), the likely cause is better surface bonding. Waech [61] demonstrated that lint decreased by about 75% after calendering at 230°, compared to 21°. Sipi and Kosa [62] claimed that soft calendering of deinked papers gave less linting, since the lower line pressure also gives less surface damage. However, this would be true of any paper grade.

VESSEL ELEMENT PICKING

Hardwood vessel picking is a common problem with uncoated fine papers, which usually include a large amount of hardwood. Because of their stiffness, size and low specific surface area, vessels bond poorly into the surface, and are easily picked out (Figure 12). The problem may also occur with lightweight coated papers, since not only will a vessel be poorly bonded within the basesheet, but it will also be poorly covered.

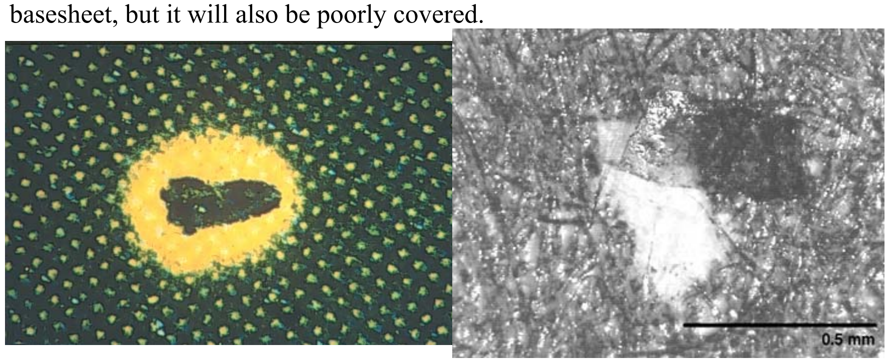

Figure 12: Left: "donut" or "hickey" on a print, resulting from debris on the offset blanket. Right: Vessel element removed from, but partly adhering to, the paper surface.

Mechanical action will help break down vessels [e.g., 63, 64]. This must be carefully controlled, as drainage will suffer with excess mechanical action. Hamada and Matsumoto [65] suggested that high consistency refining reduced vessel picking by promoting entanglement of the vessels within the sheet. Ogata [66] separated eucalyptus vessels from the pulp, dyed the vessels, and reintroduced them into the pulp. Cross sections showed that the vessels were uniformly distributed in the z-direction, but only a small fraction of vessel elements were removed during printing. This is true of all "lint candidate fibres".

Shallhorn and Heintze [67] examined vessel picking of woodfree fine papers, using tape pulls from a sheetfed offset press. They showed an excellent correlation between visual and instrumental assessment. The judges were more sensitive to small increments at low pick levels. For high pick levels, all samples were ranked (almost) equally poorly (Figure 13). Variations of up to ± 35% in the count are common. Heintze and Shallhorn [68] showed that vessel picking was greater for aged chips. Improved consolidation of the web in the press section of a pilot paper machine reduced vessel picking by up to 50%. Increased refining decreased vessel pick by up to 80%. They concluded that, just as considerable work has been done on tropical hardwoods, more work needs to be done on the North American varieties.

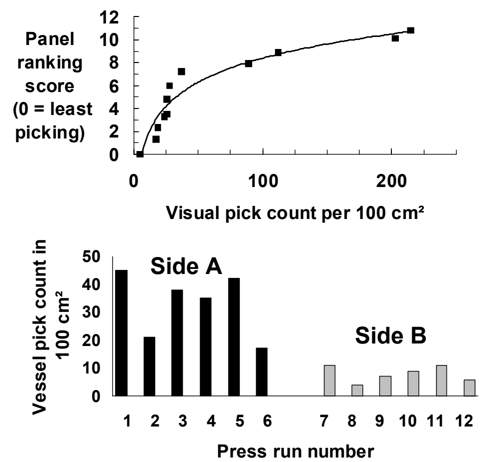

Figure 13: Top: At low vessel levels, small increases in vessel counts are perceived as being more severe. Bottom: Repeatability of vessel picking on a Heidelberg sheetfed offset press [73].

Cisneros [69] showed that while hardwood CTMP pulps contain large amounts of vessel elements, in thermomechanical pulps, the destruction of vessel elements is nearly complete. The additional mechanical action can break down the vessel elements, where a milder chemical treatment cannot. In that work, only pulp samples were examined, not paper or prints. Uchimoto [70] claimed that cellulase could reduce the number of vessel picks by 90%. Cooper [71] suggested that a mixture of cellulase and xylanese could reduce vessel picking by 50%, by softening the vessels, making them more amenable to mechanical breakdown, and improving bonding within the sheet.

TRENDS IN PRINTING THAT MAY INFLUENCE LINTING

Over the last 25 years, the state-of-the-art speed of commercial heatset offset presses has doubled, from 1500 fpm (7.5 m/s) to 3000 fpm (15 m/s). Increased press speed alone can increase linting through increased film splitting separation forces in the nip, so further press speed increases are a matter for concern.

"Conventional wisdom" has held that waterless offset can be used only for short runs on high quality coated paper. However, Durand *et al.* [72] described waterless offset inks which allowed long runs on uncoated paper before linting became a problem: 100,000 impressions on uncoated woodfree paper, and 30,000 impressions on newsprint. At the DRUPA show in 2000, a major press manufacturer introduced a prototype waterless offset newspaper press, with potential linting problems not yet fully understood.

By 2020, up to 25% of printing may be done digitally. In conventional photocopiers, it has long been known that paper dust and lint can cause wear of the imaging cylinder, and can reduce image quality. We can expect that as run lengths increase and as customers become more demanding, digital printing will have to contend more and more with surface contamination problems.

CONCLUSIONS

Over the last 20 years or more, great progress has been made in the reduction of linting and other forms of surface contamination in the pressroom. On the other hand, changing printing technologies and customer demands for ever-increasing quality mean that our quest for the "perfect" surface sheet is a moving target.

Despite many improvements, we have yet to find the ideal lint test: precise, representative, and fast. However, the MacMillan-Bloedel online lint tester is useful for real-time on-machine evaluations. The Domtar Lint Collector is useful for quantifying lint from commercial press runs, and the Paprican Lint Test is useful for examining small amounts of paper in the laboratory.

Improving mechanical pulp quality remains a priority in lint reduction, in terms of reducing the content of unbonded ray cells. The evolution of low freeness, low coarseness, thin-walled fibres is continuing, through improved refining and processing, although much remains to be done. Recent work on relating colloidal properties of fines to their specific surface area and so to linting propensity is of value in controlling pulp quality, while on-line fibre classifiers also show great promise. New techniques of surface consolidation are of interest in reducing linting, although excess consolidation can make linting worse. Even low amounts of surface size can produce a very large reduction in lint.

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