DIFFERENTIATED PERMEABILITY SURFACE LAYER (DPSL) PRESSING THEORY

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ABSTRACT

A new theory of wet pressing is proposed to explain web moisture content exiting the press nip. The proposed theory postulates the existence of a differentiated-permeability surface layer (DPSL) on the sheet side facing the press felt. This DPSL influences the level of dewatering, and its effect depends on a variety of parameters, including sheet grammage, furnish type, ingoing sheet dryness, and the coarseness of the felt surface. The proposed theory is supported by laboratory data for handsheets dewatered on a pilot shoe press. Data were gathered over a range of seven grammages (30, 35, 40, 45, 50, 55, and 60 g/m^2) and six designs of press felt. The results suggest that the differences in dryness can be explained solely in terms of surface contact, thus eliminating the need to rely on a hypothetical "rewetting" factor to explain sheet moisture content exiting the press nip.

INTRODUCTION

This paper proposes an explanation for the moisture content measured after a paper machine pressing process. The proposed theory uses the detail of the contact between felt and sheet in the press nip as the major factor controlling moisture content. It is demonstrated that this approach eliminates the need to hypothesize the existence of rewetting during the final part of pressing in order to explain the drynesses obtained for a range of basis weights down to 30 g/m^2.

Vomhoff *(1)* has recently completed an extensive piece of work in which he investigated, among other things, the nature of the paper surface at the felt–paper interface during pressing. He has suggested that a surface layer of the paper varies from point to point in permeability due to the big differences in applied pressure between the nominally contacting and noncontacting parts of the felt. This results in a surface layer that has a much higher permeability than the bulk of the sheet and that, in the absence of this effect, the permeability of the surface would be very low. What this means, from the point of view of wet pressing efficiency, is that a completely even press felt would not produce good dewatering but would, in fact, allow the surface layer in the sheet to remain at a very low permeability, not allowing passage of water from the sheet to the felt and resulting in very poor drynesses. The idea that such a low-permeability layer can exist is an old one *(2)*, but the idea that felt surface unevenness is necessary for its avoidance is a novel approach. This effect was demonstrated by Vomhoff *(1)* using both model visualization experiments and pads of paper material. This surface layer in a paper or board sheet is referred to here as the differentiated permeability surface layer (DPSL). What we are suggesting is that this layer affects the level of dewatering and that its effect depends on a variety of parameters, including sheet grammage, ingoing sheet dryness, and felt surface coarseness. As well as allowing water from the bulk of the sheet to escape, the DPSL will have a relatively high moisture content after pressing, resulting in lower overall dryness than would be obtained for uniform dewatering.

This paper presents dewatering results for paper sheets pressed using a pilot shoe press. The handsheets were prepared from typical LWC (lightweight coated) base and WF (woodfree) paper furnishes. Data were gathered over a range of seven grammages (30, 35, 40, 45, 50, 55, and 60 g/m^2) and six designs of press felt, including three using novel surface treatments. The data were then analyzed in terms of conventional "dewatering and rewetting" and the proposed "DPSL dewatering." It is demonstrated that the differences in dryness can be explained solely in terms of surface contact and that the results are qualitatively supportive of the new explanation of press dewatering suggested here.

BACKGROUND

Let us consider what is meant by "rewetting" and how it has been accounted for in a current theory. The decreasing-permeability theory presented by Kerekes and MacDonald *(3, 4, 5)* was a useful improvement on previous pressing theories because it provided a simple method of calculating press dewatering without relying on some of the rather difficult concepts and assumptions that were previously in use. Effectively, what the authors proposed was that all the pressure applied to the sheet was included in the driving force for dewatering, but that the densification of the sheet due to the flow progressively reduced the permeability of the sheet and therefore reduced the effect of pressing. This simplified approach was shown by pilot and commercial machine studies to give a good approximation to reality. In the last paper in the series, the authors addressed an obvious weak spot in the theory: that it did not account for the discrepancy from expected behavior, which has traditionally been attributed to rewetting. They discovered that they could satisfactorily account for this phenomenon by adding a term to their equation that allocated a constant amount of rewetting for a given pressing operation, independent of grammage. Mathematically, this was expressed as Eq. 1:

$$m = m_0 + \frac{R}{W} \qquad \textbf{(1)}$$

where m = moisture ratio (g water/g fiber) in the sheet as it leaves the nip
m_0 = moisture ratio (g water/g fiber) in the sheet attained in the middle of the nip
R = constant mass of water per unit area causing the shortfall in dryness (g/m^2)
W = oven-dry mass per unit area of the sheet (g/m^2).

At low grammages, a plot of m against $1/W$ (for a set of sheets of different weights but otherwise identical) approximates to a straight line with gradient R and intercept m_0. This is the method suggested by Sweet *(6)* and used extensively by others to estimate the effect of rewetting.

From the previous work by Kerekes and McDonald *(3)*, m_0 could be expressed as:

$$m_0 = m_{\text{in}} \left[1 + \frac{Anm_{\text{in}}^n I}{W^2} \right]^{-\frac{1}{n}} \qquad \textbf{(2)}$$

where m_{in} = moisture ratio (g water/g fiber) in the sheet as it enters the nip
A = permeability coefficient
I = press impulse
n = compressibility factor

Equations 1 and 2 were used, along with a nonlinear curve-fitting program, to calculate values of A, n, and R, which were shown to be consistent with the results of previous investigations in the literature.

It is widely accepted that rewetting occurs, and many other authors, e.g., MacGregor *(2)*, have discussed it. It is thought necessary to consider water that transfers from felt to paper in two separate zones:

1. In the outgoing part of the press nip, where there is still continuity of contact between the roll, sheet, and felt, but where the pressure is reducing and the pressing surfaces are diverging
2. During any subsequent contact between the sheet and felt after this zone (possibly occurring because the nip is double felted or as a result of the geometry of the felt run).

The first of these possibilities is thought of as "true" rewet, and this is the main subject of discussion here. The mechanism for this rewetting process is generally understood as being one of capillary attraction by the expanding sheet for water that is either freely available at the surface of the felt or that can be easily drawn from the larger pores of the felt surface. Consideration of the literature suggests that the evidence for the existence of "nip rewetting" is mostly circumstantial. As discussed above, it is generally related to the shortfall in dryness that is always observed and the way that this shortfall varies with sheet weight, although some researchers such as Hoyland and Wheeldon *(7)* actually made measurements using chemical tracers in the sheet and felt. Vomhoff *(1)* measured the rate of recovery of paper pads after pressing and concluded that this was too slow for reabsorption of moisture at higher speeds. MacGregor *(2)* produced an extensive and complete review of the subject of wet pressing theory and rewetting in particular and stated:

> "Except as a matter of academic interest, rewetting inside the nip is probably discussed and studied out of proportion to its significance in the paper making process. The ultimate sheet dryness out of the press is a much stronger function of the following:
>
> - The sheet flow resistance
> - The pressing time and/or the maximum applied pressure
> - UOPA (uniformity of pressure application) by the press felt and vented roll surfaces
> - The rewetting *outside* of the nip."

The DPSL theory presented here suggests (a) that the microscopic aspects of uneven pressure application by a press felt and their effect on the permeability of the surface layer of the sheet may lead to significantly reduced dewatering and (b) that this reduction is consistent with that usually attributed to nip rewetting.

Previous work on the effect of pressure uniformity on dewatering — discussed extensively by MacGregor *(2)* and Bliesner and MacGregor *(8)* — has suggested that dewatering is reduced due to uneven pressure application, but without considering the existence of this altered DPSL. The historical theories were able to predict lower drynesses as a result of the uniformity of pressure application (UOPA) at various scales. However, because of the clear nonlinearity of the measured shortfall, it was only possible to explain part of the reduction this way, with the rest being accounted for by attributing it to rewetting in the expanding part of the nip and also where the sheet is still in contact with the felt just after the nip. It seems certain that some rewetting occurs, and Bliesner and MacGregor *(8)* have compelling evidence for this (at slow speeds by today's standards), but estimates of the magnitude of this phenomenon have always been variable, and it may not be as important as was previously thought necessary. Where nip geometry allows it, for example in double-felted nips, there is no doubt that extended contact with the felt after the nip results in post-nip rewetting and that this can be significant, but there is doubt that nip rewetting occurs at measurable levels.

THEORY

Vomhoff *(1)* showed that a completely even felt would not dewater the sheet because the permeability of the paper surface would be too low to allow the water to escape. This is true despite the fact that that the permeability of the felt is several orders of magnitude higher than that of the sheet in all cases. Fortunately, it has been shown that the felt only contacts the sheet over approximately 30% of its area *(9)*. Vomhoff *(1)* suggested that, under each area of contact, there would be a very dense, impermeable region surrounded by a compressed, but partially permeable region of the sheet, with the rest being relatively unaffected by the felt contact. The impermeable part would be widest at the surface and rapidly taper off with depth, but the partially compressed region would widen as it went deeper into the sheet. The compressed regions would eventually join up, and beyond this depth — the depth of the DPSL — the pressure would be relatively even. This surface layer would have a large percentage of area with a high permeability and would therefore present little resistance to flow compared with the evenly compressed part below it. The open, uncompressed areas would not be dewatered at all, although the part of the sheet below the DPSL would be evenly and efficiently dewatered. For the purposes of this paper, it has been assumed that the part of the DPSL that is compressed can be represented as a cone, with an angle that is dependent only on the mechanical properties of the furnish and the pressing pressure. Of course, further work is likely to show that this is an oversimplification, but it suffices for understanding the DPSL concept qualitatively. **Figure 1** provides an illustration of how this might be expected to work, with some estimation of dimensions included. In reality, the shapes of the zones would be more complex and the boundaries between them less distinct, but Fig. 1 serves to represent the concept under discussion.

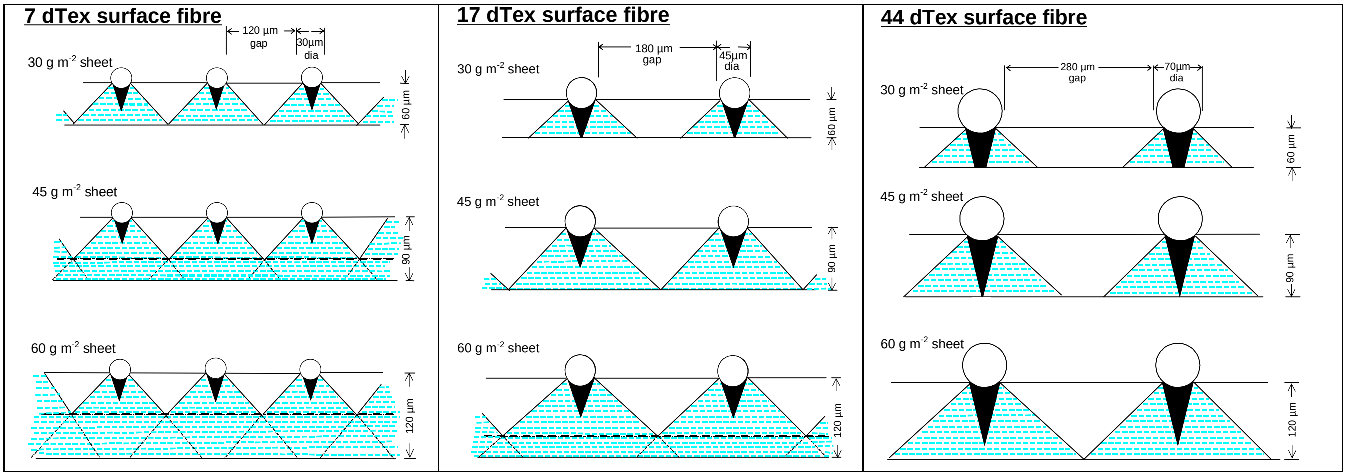


Figure 1. Schematic diagrams of how the DPSL might look for three weights of sheet and three coarsenesses of felt surface batt fiber (seen as shaded circles), assuming approximately 20% contact in each case. The horizontally shaded areas represent "cones" of high pressure, high dryness, and low permeability in the sheet, and the black areas are the highly compressed, effectively zero permeability zones, which occur directly under the points of contact. The clear areas represent low pressure, lower dryness, and high permeability in the sheet. The depth of the DPSL is indicated by a dashed line (in those cases where it is reached). A given felt surface coarseness is expected to produce a DPSL of a constant thickness that is independent of sheet grammage. The DPSL would be thicker for coarser felt surface fibers. Note that, for the 44-dTex surface fiber, a plane of uniform pressure is only just achieved on the bottom side of the 60-g/m^2 sheet.

The reduction in sheet dewatering due to the DPSL, using the simplified model shown in Fig. 1, is independent of sheet grammage (for sheet thicknesses greater than the DPSL), and this can be expressed by an equation identical to the one used to describe rewetting (Eq. 1). The DPSL will result in a shortfall in dryness that varies in a similar way to what has previously been attributed to rewetting, and this could certainly be considered as an additional "perturbation" term. A complete pressing theory for presses that are single-felted and also do not involve post-nip rewetting would consist of an identical expression to the one suggested and verified by MacDonald and Kerekes *(5)*, but the perturbation term now describes the DPSL effect. Equation 1 still applies, but m_0 is now the moisture ratio in the bulk of the sheet (i.e., the part not in the DPSL) and *R* is the mass of the excess water contained in the high-permeability parts of the DPSL. *R* depends on initial moisture content but is otherwise constant for all but the lowest basis weights (where DPSL thickness is greater than sheet thickness) for any particular sheet furnish and felt surface structure.

The DPSL theory assumes that press felt permeability is much higher than that of the sheet in all cases. Reviews of wet pressing (e.g., MacGregor *(2)*) are in agreement that this is the case, although some aspects of wet pressing seem to require much lower values for their explanation, particularly late in the life of a felt. Later in this paper, in the Practical Consequences and Comments section, it will be shown that the DPSL explains most of these anomalies in other ways, validating this assumption. This being the case, the value of dryness achieved by pressing should depend solely on the pattern of contact between felt and sheet for a given press impulse, basis weight, and ingoing moisture content. This level of dryness might then be altered by any rewetting that occurs after leaving the press, but it will be assumed for the present that this does not occur.

EXPERIMENTAL METHODS

It will be possible to develop a quantitative theory using the concepts discussed above. Such a theory will aim to predict press dewatering from sheet properties and one or more measurable parameters that describe sheet–felt contact. For the present, the available results consist of a set of dryness values for six felts. If the suggested model is valid, we would expect a number of patterns to be apparent in the results. At a given basis weight, we would expect to see differences in dryness that are well correlated with the pattern of felt contact. For the lighter sheet weights, it would be expected that the more finely textured felt surfaces would produce better dryness due to the DPSL being thinner in these cases, leading to more efficient dewatering of the sheet. For the heavier sheet weights, it would be expected that a coarser felt surface would lead to improved dryness by producing a thicker, higher-permeability DPSL that would allow the larger quantity of water to escape more easily, with the dryness lost due to the moisture remaining in the DPSL being of secondary importance. Thus it would be expected that the relationship between dryness and felt surface structure would change in a well-behaved way as sheet basis weight was varied.

The experimental pressing work was carried out on the handsheet pilot shoe press (X–1) at the Beloit Corp. Rockton R&D Center. Pressing is carried out on handsheets at realistic machine speeds (762 m/min) by attaching the sheet to a thin, rigid polycarbonate film that is dropped onto the bottom press felt and retrieved in a catching net after the nip. This simulates a single-felted shoe press because the sheet can only dewater upwards into the top felt. The pressing setup consisted of a 10-in. (approximately 254 mm) shoe, a grooved belt, and a load of 1051 kN/m, resulting in a press impulse of 8.29 kPa·s. The temperature of the felts and the sheet was 24°C.

Two different types of sheet were used: a typical LWC mechanical pulp furnish and a typical bleached chemical WF printing/writing furnish. In each case, handsheets were made, couched, and prepressed to drynesses of approximately 25% and 30%, respectively. The average dryness of six sheets was measured for each experimental point. Seven grammages were tested for each of the two furnishes.

Six different felts supplied by Voith Fabrics (formerly Scapa PMC) were used, and they are described in **Table I**. Dryness values for seven grammages and two furnishes were obtained for each felt.

Felt code	Surface fiber	Description	Contact perimeter index, mm^{-1}
3	11/17 dTex blend	One-coat surface treatment	9.40
4	11/17 dTex blend	Two-coat surface treatment	8.79
5	11/17 dTex blend	Untreated	8.18
7	7 dTex	Untreated	13.2
8	7 dTex	One-coat surface treatment	12.2
9	7 dTex	Untreated, alternative base structure	13.8

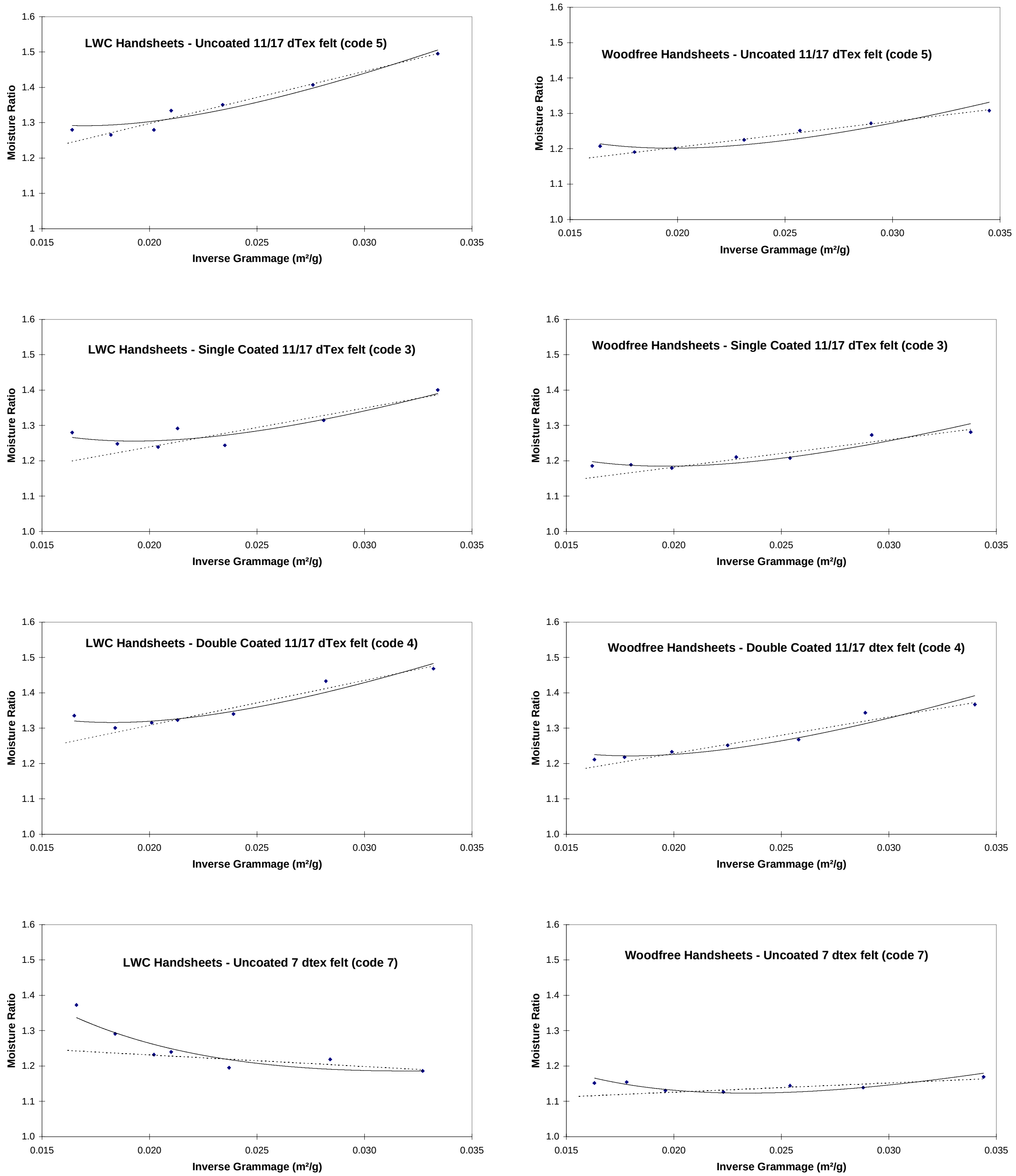
Table I. Description of the felts used in the pilot paper machine trials.

Three of the tested felts had coat treatments applied to their surface. The coating does not migrate into the bulk of the felt and is intended primarily as a way of reducing wear. This creates an unconventional felt surface, which might be expected to behave differently, and certainly looks and feels different. These felts have been supplied commercially for use on some demanding paper and board machine positions. The diameters of 7, 11, and 17 dTex fibers are approximately 28, 35, and 43 µm, respectively. Each of the felts had been run-in on a press simulator for approximately 250,000 nip passes before the start of the experiment.

The contact pattern of the felts was determined by pressing the surface of the felts against pieces of Cronapress Conversion film in a static press at a pressure of 4 MPa. This film consists of a thin layer of emulsion that is broken when exposed to the pressure from a fiber, which subsequently allows light transmission. Unfortunately, this material was a carefully conserved remnant and is no longer available on the market. An alternative method will be sought as a matter of urgency in the future. Pieces of the film were mounted in conventional 35-mm glass slide mounts and analyzed using a Nikon Coolscan II slide and negative scanner. The maximum resolution available on this instrument (2700 dpi or 984 pixels/cm) was used along with the maximum size of square area, resulting in images with 2400 × 2400 pixels. The scans were found to have much less background variation than would be expected using more traditional microscope images to obtain this resolution, and a single scan gave data equivalent to approximately 25 images measuring 512 × 512 pixels. These scanned images of contact impressions of the six felts were thresholded at a constant level using the Lucida software supplied by Kinetic Imaging Ltd. (The value used is not quoted because it depends on scanner settings.) A single-pass "Opening" operation (consisting of an erosion operation followed by a dilation) to remove a small amount of noise was all the preprocessing necessary before taking measurements. The measurement used to characterize the surface contact of the felts was the total length of the perimeter of the contact area, which was around 30% in all cases, as predicted *(9)*. This value is analogous to the Specific Perimeter used as a measure of formation of paper sheets after thresholding at the median basis weight *(10)*. In this case, the threshold used did not result in a segmentation of 50% of the image, so it was decided to call the perimeter divided by scan area the Perimeter Index, with the units being mm^{-1}. This measurement of contact makes sense only if it can be assumed that the contact is evenly distributed over the area examined.

EXPERIMENTAL RESULTS

The dewatering results for each combination of furnish, basis weight, and press felt are given in **Figure 2**. The 12 graphs in Fig. 2 are plotted on the familiar axes (used by Sweet *(6)* and McDonald and Kerekes *(3, 4, 5)*) of Moisture Ratio (mass of water divided by mass of solids) against Inverse Basis Weight.



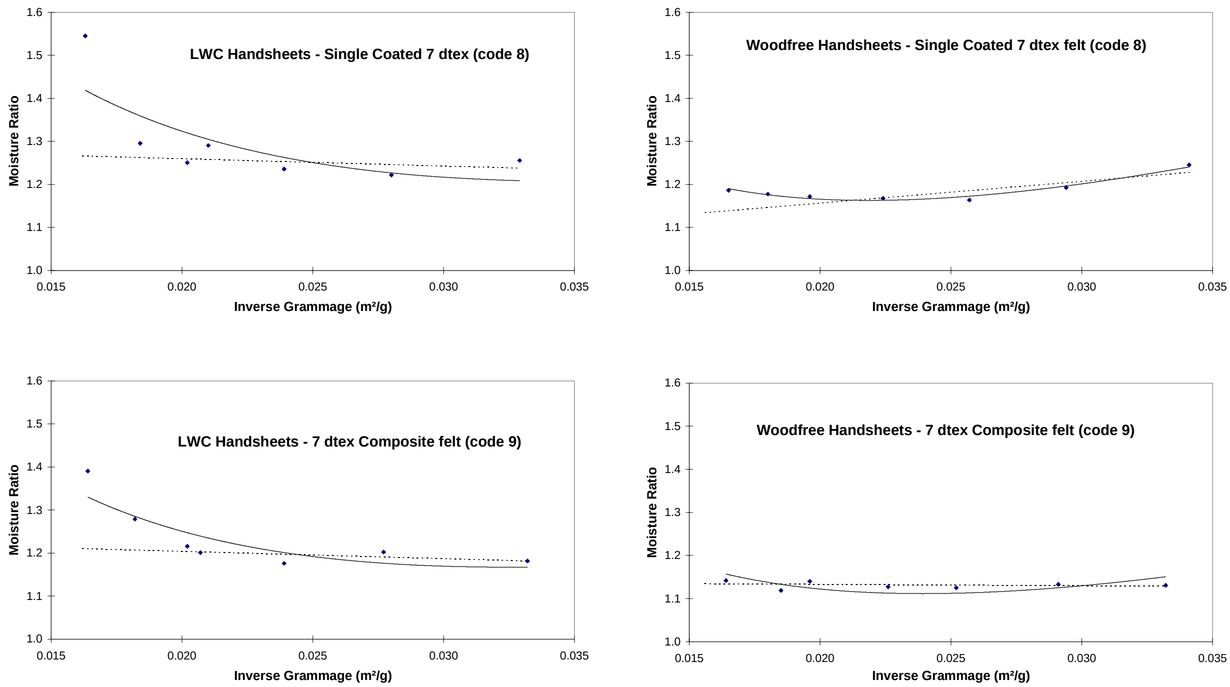


Figure 2. Graphs of Moisture Ratio (mass of water over dry mass) against Inverse Basis Weight for each combination of press felt and furnish. The two methods of analysis used on these data are illustrated by the fitted lines on the graphs: The dashed line is a linear fit excluding the two highest grammage points, while the continuous line is the nonlinear curve fit used for the McDonald and Kerekes (5) theory.

Figure 3 shows small areas, approximately 2 × 2 mm², of the contact imprints of the six felts. The clear visible differences in contact were quantified using the Perimeter Index measurement, and the results are given in Table I.

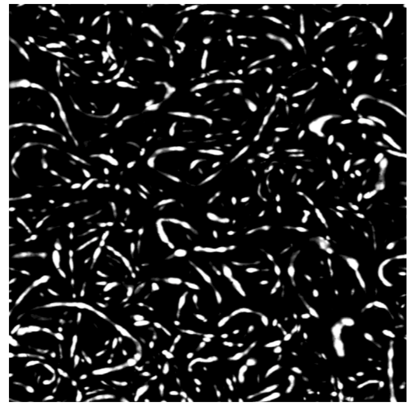
The dewatering results shown in Fig. 2 were analyzed in three different ways:

Method 1

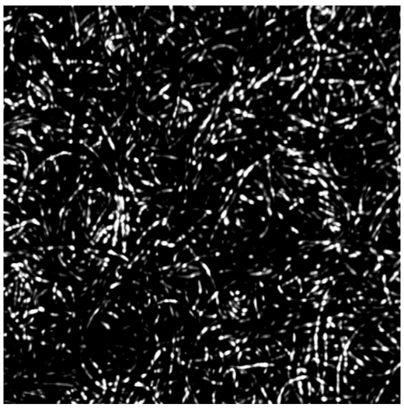
Using the method attributed to Sweet *(6)* and described by McDonald and Kerekes *(5)*, a straight line was drawn through the five lowest-grammage points using the assumption that Eq. 1 was valid. This allowed the “midnip moisture content” m_0 and the “rewetting” R to be calculated. The points were a reasonable fit to a straight line in all cases, with the expected curve toward higher moisture ratio occurring only for grammages above 50 g/m^2. The resulting lines are included in Fig. 2, and the values of R and m_0 are given in **Table II**.

3a. Felt 3: 11/17-dTex surface fiber with one coating treatment layer

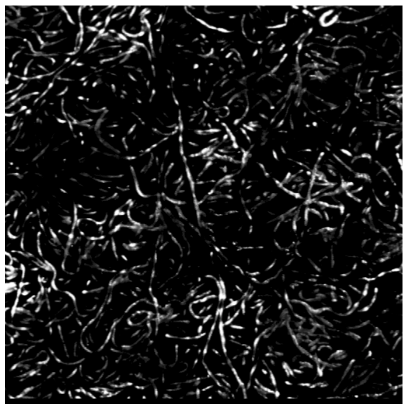
3b. Felt 4: 11/17-dTex surface fiber with two coating treatment layers



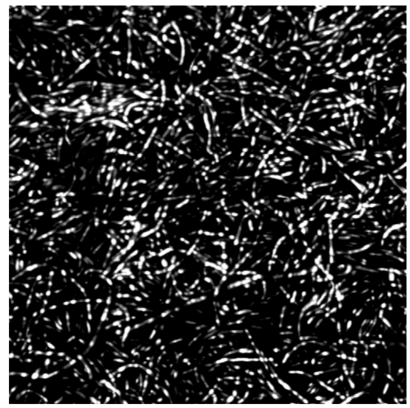
3c. Felt 5: 11/17-dTex surface fiber with no treatment



3d. Felt 7: 7-dTex surface fiber with no treatment



3e. Felt 8: 7-dTex surface fiber with one coating treatment layer



3f. Felt 9: 7-dTex surface fiber with alternative base structure

Figure 3. Imprint images (4-mm² areas) obtained from the six trial felts using Cronapress Conversion film at a pressure of 4 MPa. Note that these impressions were obtained after the felts had been broken in on a pilot press.

Felt code	Lightweight coated (LWC)		Woodfree (WF)	
	m_0	R, g/m^2	m_0	R, g/m^2
3	1.02	11.0	1.03	7.76
4	1.05	12.7	1.02	10.3
5	1.00	14.8	1.06	7.34
7	1.30	–3.28	1.07	2.61
8	1.29	–1.71	1.06	5.07
9	1.24	–1.69	1.14	–0.308

Table II. Value of midnip moisture ratio (m_0) and rewetting (R) obtained by fitting a straight line to the five lightest basis weight results for each combination of furnish and felt for the results shown in Figure 2.

Method 2

McDonald and Kerekes *(5)* used a nonlinear curve-fitting method to obtain values of A, n, and R in Eq. 2:

$$m_0 = m_{\text{in}} \left[1 + \frac{Anm_{\text{in}}^n I}{W^2} \right]^{-\frac{1}{n}} + \frac{R}{W}$$

The same method was applied to these data. The resulting curves are shown in Fig. 2, and the values obtained are given in **Table III**. If all three parameters were allowed to vary, unreasonable values were obtained. The results obtained by McDonald and Kerekes *(4, 5)* suggested that n was always in the region of 3, independent of furnish. So we set n = 3 and fitted R and A to the data.

Felt code	Lightweight coated (LWC)			Woodfree (WF)		
	R, g/m^2	A, kg^2/m^4·kPa·s	n	R, g/m^2	A, kg^2/m^4·kPa·s	n
3	25.8	245	3.0	23.7	271	3.0
4	28.5	235	3.0	26.4	286	3.0
5	30.2	290	3.0	23.9	258	3.0
7	14.8	107	3.0	18.9	225	3.0
8	13.6	83	3.0	20.9	231	3.0
9	14.3	108	3.0	18.2	218	3.0

Table III. Values of rewetting (R), permeability coefficient (A), and compressibility factor (n) calculated using a nonlinear curve-fitting procedure from the data shown in Figure 2.

Method 3

To determine the dependence of sheet dryness on characteristics of the sheet–felt contact, dryness was plotted against Perimeter Index for each nominal basis weight. The grammages are not exactly the same each time because sets of handsheets made in the standard way always have a range of weights. The plotted values were estimated by interpolating smooth curves drawn through graphs of dryness against actual grammage for each combination of press felt and furnish. The resulting plots for both furnishes at the seven tested grammages are shown as **Figure 4**. In each case, a straight line was fitted to the data.

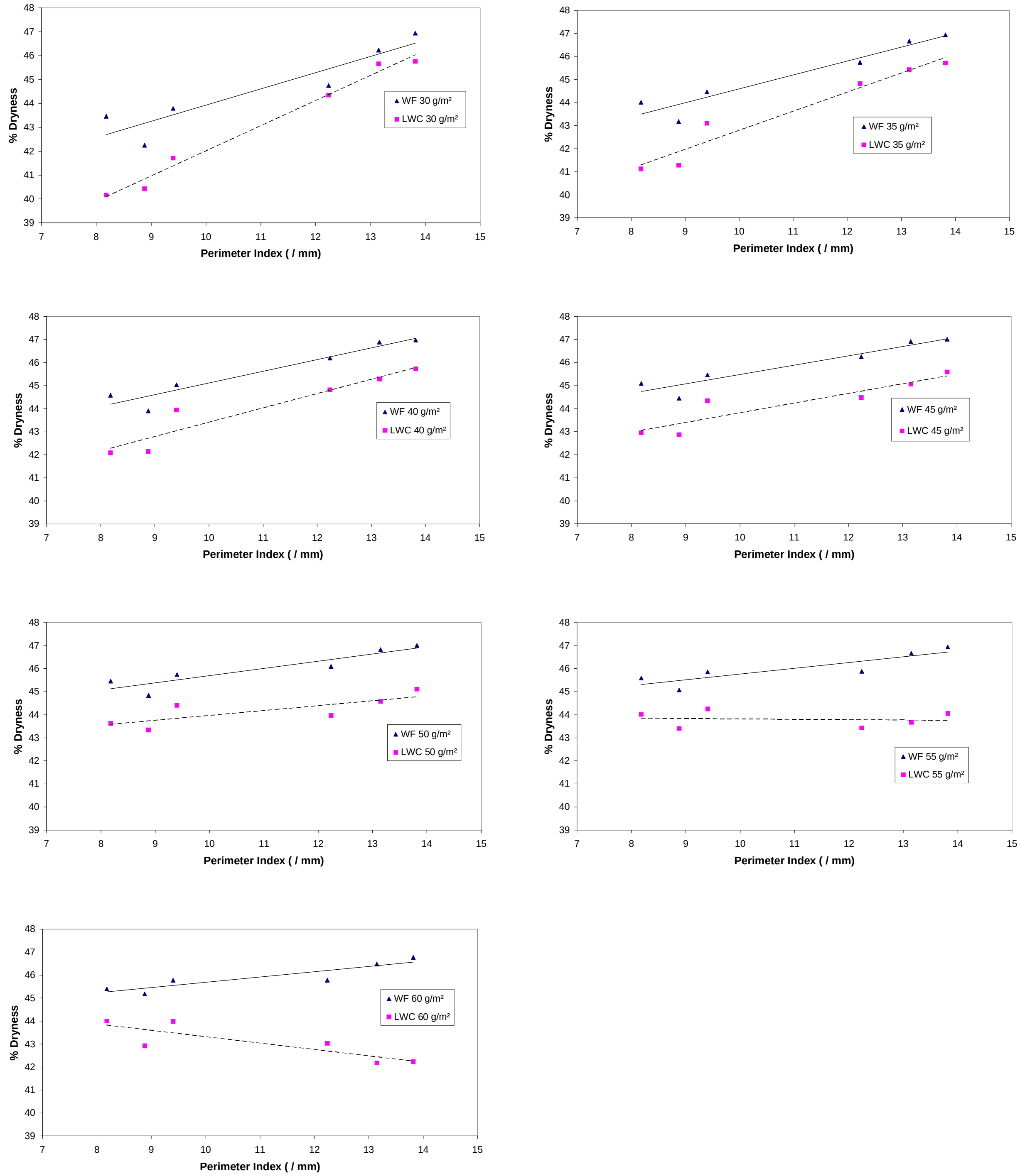


Figure 4. Graphs of sheet dryness (dry mass over total mass) against Perimeter Index for each basis weight. In practice, there is some scatter about these nominal values of basis weight owing to the fact that the paper used consisted of laboratory handsheets. These values of dryness have been calculated by interpolation of the original dryness vs. grammage data using smooth curves (cubic polynomial fits).

This gradient, which showed the effect of Perimeter Index on dewatering within each grammage, was then plotted against basis weight for the two furnishes and this can be seen in the two graphs of **Figure 5**.

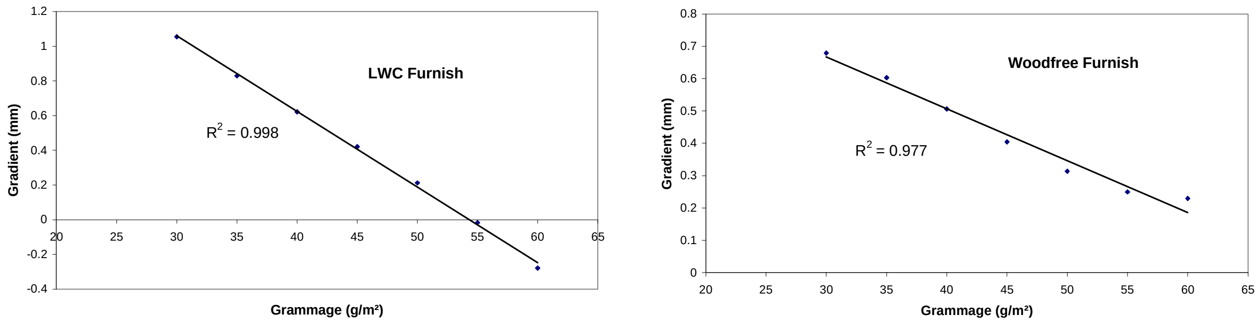


Figure 5. Graphs of the gradients of the fitted lines in Figure 4 against handsheet basis weight. These graphs show how the relationship between sheet dryness and felt surface perimeter index depends on sheet weight for the two furnishes.

DISCUSSION

Method 1

The Sweet *(6)* method of analysis (Method 1) resulted in estimated values of midnip moisture ratio and rewetting for each of the conditions (Table II). It might be expected that different levels of rewetting (*R*) might be measured for the same furnish but different felt construction, but it was expected that the midnip moisture (m_0) would stay much the same, with some small deviations attributable to uniformity of pressure application. However, the results showed a spread that could not be explained in terms of the existing literature. The negative values of rewetting also present a clear inconsistency for this method.

Method 2

Method 2 gives a set of results (Table III) that is impossible to interpret using the existing theory. The values of rewetting (*R*) are of the same order of magnitude as those found by McDonald and Kerekes *(5)*, and the decrease in this value, with the finer surface, is quite satisfactory. However, it is unreasonable that the value of sheet permeability coefficient (*A*) should need to take on such a wide range of values for the same furnish (particularly for LWC). Rather, it should be constant. Unless the true value of compressibility factor (*n*) varies significantly from 3 (it should be constant for each furnish), it is difficult to see how this analysis of these data could be reconciled with any current understanding of pressing.

For both Methods 1 and 2, it might be possible to interpret the data with the help of another variable, perhaps felt permeability, and it is tempting to do so, particularly since three of the felts have been treated with a coating. In reality, however, the permeability of felts is always very much higher than that of a compressed sheet, and it has not been thought to be a significant factor in any respectable theory (e.g., *(2)*) and is only resorted to when other explanations fail.

Method 3

Method 3 provides the two graphs in Fig. 5 for the LWC and WF furnishes. The fact that both graphs show clear correlations is a very significant result. This means that we can effectively predict the efficiency of dewatering for a given combination of Perimeter Index and furnish without any need for further information. No separate consideration of rewetting is needed.

In the theory section, it was predicted that the efficiency of dewatering of the sheet was dependent on the thickness of the DPSL, which, in turn, was controlled by the contact properties of the felt–sheet interface. A coarse contact would lead to a thick DPSL, which would produce poor drynesses at low grammages due to the moisture retained within the DPSL, but better dryness at higher weights, where the high sheet surface permeability is necessary because of the higher volumes of water needing to escape. A fine contact (and hence thin DPSL) would be required to achieve the highest drynesses at low sheet weights. Figures 3 and 4 show that, using Perimeter Index as a measure of the fineness of contact, this is indeed what is happening. Note that the dependence of dryness on Perimeter Index is positive for the low sheet weights and negative for the high sheet weights, particularly for the LWC furnish.

The idea of DPSL and its influence on press dewatering is a theoretical one stemming from the work by Vomhoff *(1)* on sheet permeabilities, but it has been shown that the results from this extensive sequence of trials are completely compatible with this approach. This suggests that this new approach, which is also much simpler, may well be valid. This theory qualitatively clarifies previous apparently contradictory discussions of the effect of pressure uniformity. At this stage, there is not a fully quantitative model allowing prediction of dewatering from measured furnish, but this will be the subject of the next stage of this work. The likely approach will be to use the McDonald and Kerekes *(3, 4, 5)* equation to predict the dryness of the evenly compressed part of the sheet and then use Vomhoff's *(1)* approach to predict the thickness of the DPSL, its permeability, and the amount of excess water contained within the layer.

PRACTICAL CONSEQUENCES AND COMMENTS

The DPSL theory can be used to qualitatively predict many observed aspects of press dewatering. Although there are alternative explanations (again, mainly qualitative), these often rely on doubtful assumptions, to which we can now add the universal occurrence of rewetting. In particular, the idea that felt permeability can affect dewatering is commonly held, even though it is nowhere supported by the literature. Nevertheless, the concept of felt permeability has been necessary to understand the concepts of reduced dewatering of old felts, crushing in early presses, etc. The following list includes a number of regularly observed press phenomena that can be explained very well by a DPSL model:

- *Presses where more water is to be extracted require a coarser felt.* A coarser felt will produce a thicker DPSL. The part of the sheet that is evenly and efficiently dewatered will be correspondingly thinner.
- *Felts dewater better after a break-in period.* As the felt compacts (perhaps by 25%), the felt surface characteristics are changed, the thickness and permeability of the DPSL of the paper sheet change, and the dewatering naturally changes.
- *Precompaction of relatively coarse-fibered pickup felts gives a shorter break-in period.* Precompaction will promote formation of a good pattern of surface contact very quickly

after fitting a new felt. This would be expected to lead to steady-state dewatering and reduce the time required to achieve full machine speed.

- *Fine fibers need to be used for later presses*. Fine-textured contact to achieve a thinner DPSL and more efficient dewatering is necessary to approach maximum possible drynesses where the amount of remaining water is low.
- *Crushing* is caused by excessive hydraulic pressure within the sheet, which is released catastrophically, damaging the structure. The cause of this is not the low permeability of the press felt but, rather, a DPSL of too low permeability in the sheet for a particular press position. This could result from use of too fine fiber in the felt surface or by the surface of a felt becoming filled later in life, causing its fibrous nature to be flattened out and making the pressing contact too even.
- *Poor dewatering later in felt life* could well result from surface fiber on the felt being worn away, uncovering coarser sublayers, leading to a thicker DPSL and loss of efficiency. Alternatively, a filled and flattened surface layer in the felt could result in a thinner DPSL, lower sheet surface permeability for the escaping water, and reduced dryness.

CONCLUSIONS

A new theory for understanding press dewatering is presented. The theory combines the decreasing-permeability model of Kerekes and McDonald *(3, 4)* with new insights into the effect of sheet surface permeability provided by Vomhoff *(1)*. The proposed theory is consistent with observed phenomena and provides a better qualitative understanding of the performance of press felts. Most importantly, the proposed theory eliminates the need to correct results using a doubtful rewetting term. According to the proposed theory, the rewetting term simply describes dewatering that was never achieved in the first place.

Results from an extensive pilot plant experiment involving six felts, two furnishes, and seven grammages are presented and shown to be consistent with this theory to a remarkable level of correlation. Attempts to describe the results using other approaches were much less satisfactory.

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