Rewet suppression through press felt engineering

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ABSTRACT: Due to the immense energy and associated financial cost of drying paper, achieving a drier web entering the dryers is a key objective in paper manufacture. One major research thrust has been finding a way to increase press solids by mitigating or eliminating rewet in the press section. For decades, solutions to this problem have remained elusive.

In this work, we develop a novel approach that significantly reduces rewet by rupturing the liquid channels between felt and web. We illustrate the effects that altering the mechanical and surface properties of the press felt matrix have on the stability of these liquid channels. In a laboratory-scale platen press, a 40% reduction in the residual water of 120 g/m^2 southern bleached softwood kraft (SBSK) pulp handsheets after pressing was observed, corresponding to an increase in press solids from 48% to 61%. For reference, pressing under identical conditions with paper blotters, in which minimal rewet is presumed to occur, resulted in 64% solids. Furthermore, we observed enhanced dewatering across a range of basis weights, applied pressures, and felt types. In addition to measuring the solids content of pressed sheets, we capture and analyze video evidence of the mechanisms at play in our improved dewatering technology.

Application: This work describes a novel approach to prevent rewet in the press section. The authors hope that the papermaking community will use these insights to design press fabrics that increase the energy efficiency of the mill.

Since the 1960s, papermakers have been aware that reflux of water to the sheet after pressing compromises the efficiency of mechanical dewatering [1]. Efforts to improve press section performance by mitigating rewet have included primary strategies such as creating a hydrophobic barrier within the felt [2], including superhydrophilic regenerated cellulose filaments [3]; adding angular filament profiles in the fabric [4]; placing one-way valves in the felt that open and close with applied pressure [5], including a low porosity flow control layer in the felt [6]; and designing ever finer batt filaments to combat the capillary forces in the sheet [7]. For various physical and practical reasons, many of these approaches have been limited in the results they deliver when tested on production paper machines. Still, the previous decades have seen tremendous progress in pressing technology. With improved fabric designs and extended nips, the state of the art can achieve up to 55% solids after pressing on certain grades. Although longer dwell times have pushed press sections close to achieving minimum equilibrium moisture in-nip, rewet continues to be a major challenge.

We propose a new approach to mitigating rewet that relies on placing a stiff, porous spacer at the felt surface, such that direct contact between the felt and the paper web is reduced. Doing so decouples felt-web separation from decompression exiting the nip. When the spacer layer is well-designed, fluid channels connecting the paper and felt are destabilized; they break, resulting in fully dewatered paper that has no contact with the felt, all before the layers are pulled apart. When the expanding paper, upon decompression, creates a capillary driving force for reflux of water towards the sheet, pathways for water flow have been disrupted, and rewet is avoided.

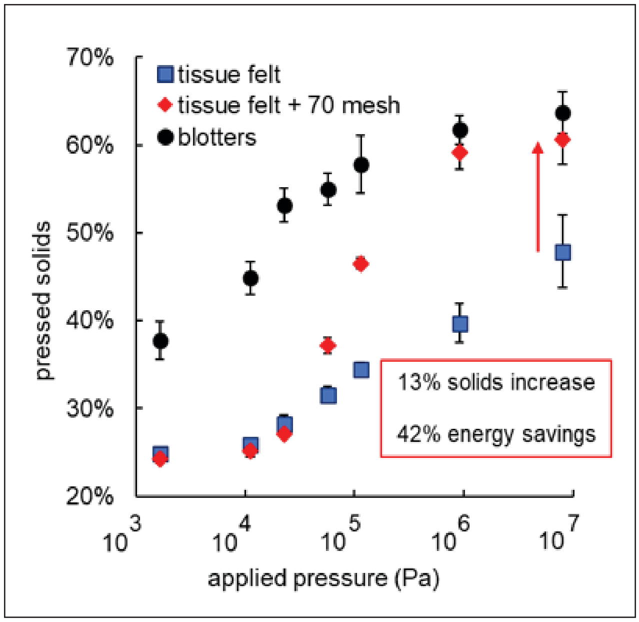
EXPERIMENTAL METHODS

Wet handsheets were prepared at different basis weights from southern bleached softwood kraft (SBSK) pulp, which was obtained as dry lap and resuspended in water. The handsheet protocol followed the TAPPI Standard Test Method "Forming handsheets for physical tests of pulp," up until pressing. Instead of pressing, the wet webs were adjusted to a moisture ratio (MR) of 3 (25% solids) to simulate the couch solids on a paper machine. The MR and solids content are defined by the mass composition of water and fiber in the sheet:

$$MR = \frac{m_{water}}{m_{fiber}} \qquad solids = \frac{m_{fiber}}{m_{fiber} + m_{water}}$$

The wet web was then pressed against various felt configurations in a benchtop screw press (**Fig. 1**). A force sensor allows the applied stress to be measured and controlled. One primary advantage of using a platen press is that the imposed pressure gradient is essentially unidirectional. This simplifies the problem of analyzing flow in three di-

1. *Screw press used for dewatering trials. Shown from bottom to top: the bottom platen, paper, press felt, top platen, force sensor, and screw press.*



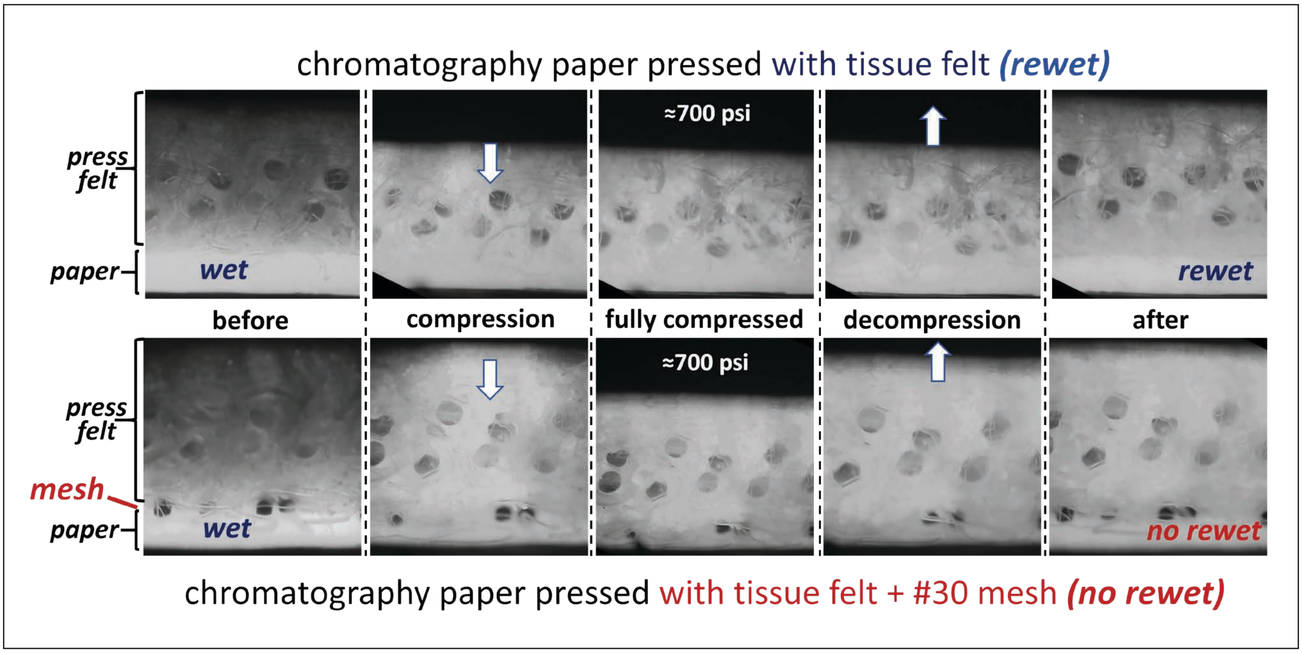
2. *Pressed solids of 120 g/m² southern bleached softwood kraft (SBSK) pulp handsheet vs. applied pressure for various pressing conditions: (blue squares) commercial tissue felt, (black circles) stack of dry blotters that represents limit of maximum drying, and (red diamonds) tissue felt with metal #70 mesh.*

mensions—which is already complicated by the heterogeneity of the materials involved. The paper is pressed three times at a given pressure to simulate the sequence of nips on the machine, to reduce variation introduced from control of the initial moisture ratio, and to show the limits of enhanced dewatering. Following pressing, the moisture content of the paper was determined by comparing the weight to that after oven drying at 105°C for 8 h.

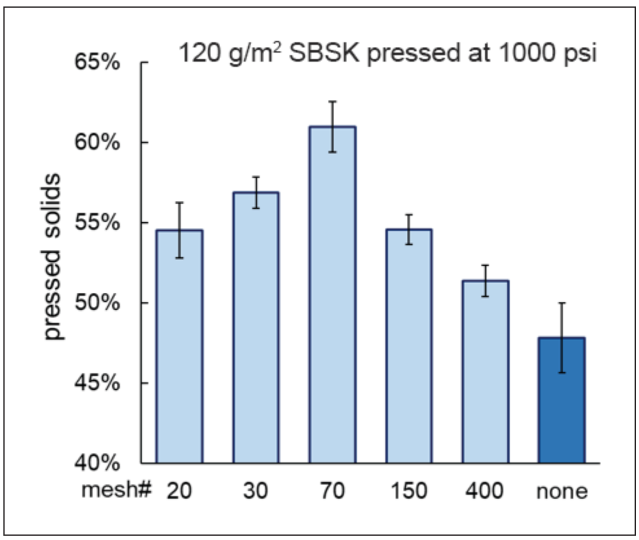
RESULTS

The impact of sandwiching a mechanically stiff layer between the press felt and web is illustrated in **Fig. 2**. In this case, a commercially available #70 stainless-steel mesh was used as the stiff spacer layer (red data series). The blue series, which represents pressing with a commercial tissue felt, serves as the base case. The black series, in which the paper is pressed with a thick stack of blotters, shows the upper limit of solids that can be realized at a given pressure in the absence of rewet. At low pressures, no mechanical dewatering is done; the blotters' result improved solids because of the strong capillary forces they exert. As pressure is increased, more water is expelled from the web, resulting in higher press solids. At pressures relevant to industrial conditions (7 MPa), the web is significantly deformed, resulting in dewatering. The presence of a stiff spacer layer enhances the dewatering potential of the press felt, as seen in the transition of the red series from the blue series to the black series. Pressing has shifted to a scenario where limited rewet occurs. An improvement of 13% solids from 48% to 61% corresponds to a 40% reduction in the residual moisture content of the sheet. That translates to a 42% reduction in the dryer load, assuming the sheet is dried to 95% solids.

To illustrate how sandwiching a spacer between the felt and web improves dewatering, we videographed the paper and felt as they were pressed. **Figure 3** depicts frames from these videos. Fluorescent dye was added to the water so that it would be easily detectable under the microscope. The brighter a region, the more water it contains. As time progresses from left to right, the pressure is increased, then reduced. A stark difference can be observed between pressing only with the felt (top row of images) and with the mesh-added felt (bottom row). Initially, both start the same: the (wet) paper is very bright, and there is no water in the felt. Upon compression, water is driven from the sheet into the felt. Here, the mechanism of the technology can be seen; the mesh layer destabilizes liquid bridges between the paper and felt. In the top images, a continuous bright channel spans the paper and felt. Upon decompression, water flows back through this channel, rewetting the paper. In the bottom row, the liquid bridges snap once water is transported into the felt. Upon decompression, there is no path for water to rewet the paper. After pressing, water has moved from the paper into the felt, regardless of the felt configuration. With the mesh-added felt, however, the paper is noticeably drier.



3. Still images from videos taken during the pressing of wet chromatography paper (initial solids 25%) up to maximum pressure of ~5 MPa with: (top) commercial felt, and (bottom) commercial felt plus #30 mesh (wire thickness 165 μm; openings 681 μm). Sideview image with fluorescently labeled water; greater brightness indicates larger amounts of water present.



4. Effect of mesh size on press solids. The dimensions of the spacer layer have a significant impact on dewatering. A mid-size mesh balances tradeoffs between gap thickness, pressure distribution, and sheet contact.

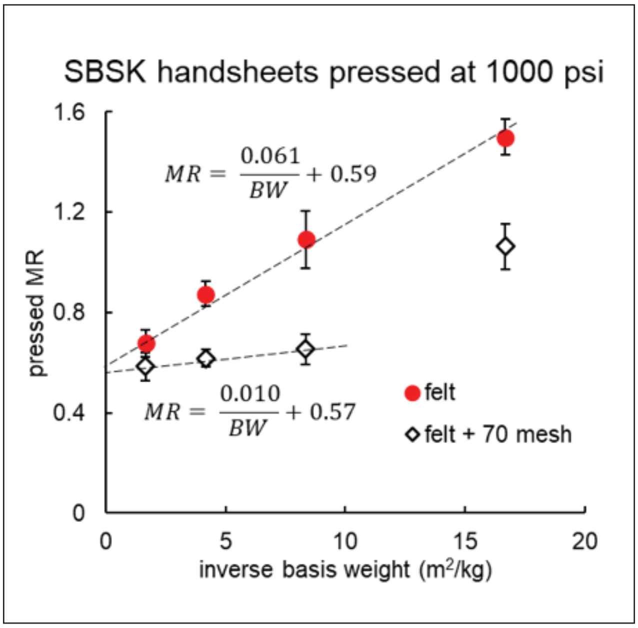
Effect of mesh size

The dimensions of the spacer layer have a significant effect on the stability of liquid channels between the felt and paper. The pressed solids obtained with different commercially available meshes between the felt and paper are shown in **Fig. 4**. The solids appear to go through a maximum as the mesh size is changed; this suggests a certain tradeoff between various contributions. If the mesh number is too low (thick wires and large openings), the pressure applied to the sheet will not be uniform. Also, there is a greater volume of fluid within the liquid bridges (i.e., mesh openings). When these bridges are disrupted, more fluid can return to the sheet. On the other hand, high mesh numbers have small mesh openings that are similar in size to the filament and pore sizes already present in the felt. If the gap is too small, the liquid bridges are less likely to break, and the mesh-added felt system begins to resemble the felt alone. The optimum mesh size depends on the basis weight of the sheet, since deformation of the paper web into the spacer pores affects the gap height and, thus, liquid breakup.

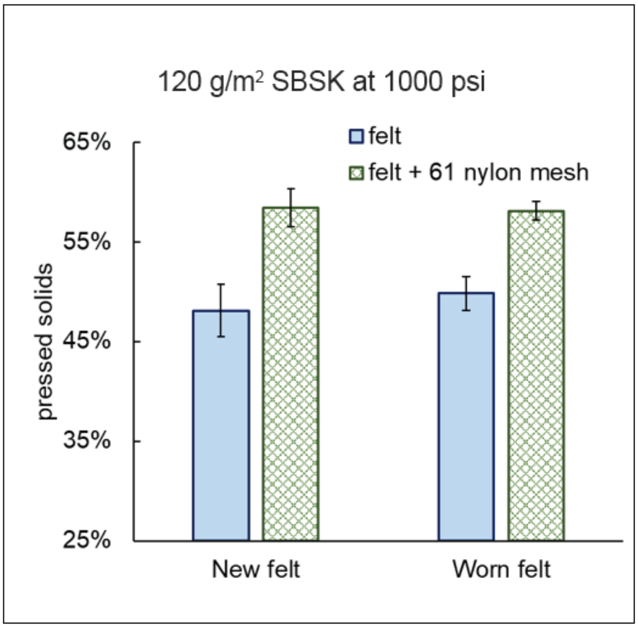
Effect of basis weight

Figure 5 shows a Sweet plot of the moisture ratio obtained at different basis weights. Reassuringly, the technology is effective over a wide range of basis weights. At high basis weight, the effect of reducing rewet on solids is lower because rewet constitutes a lower fraction of the sheet's mass. At lower basis weights, the spacer layers that were used did not perform as well as hoped. Two factors likely contribute. First, issues with pressure uniformity introduced by a stiff layer are exacerbated by a thinner sheet. Second, there is likely not enough water initially in the sheet to fill the open spaces in the mesh and span the gap introduced by the spacer. For low basis weight sheets, the design of the spacer will have to be optimized beyond these standard meshes to effectively mitigate rewet.

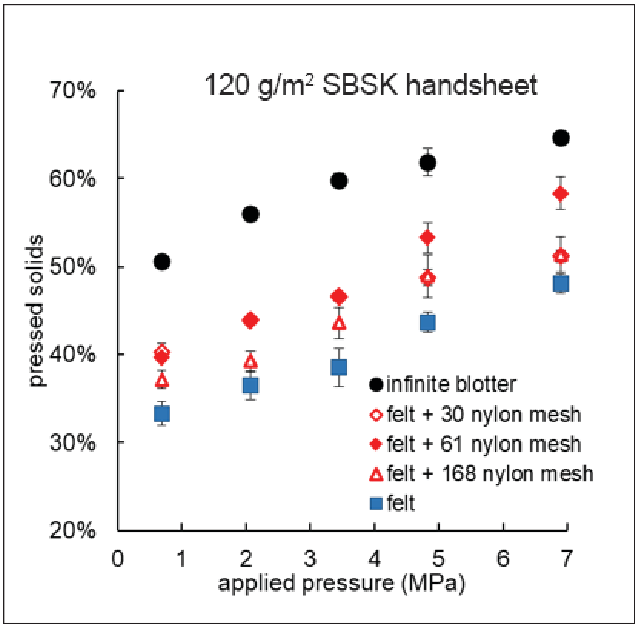
Sweet plots enable regression to estimate the rewet and equilibrium moisture in the press [7]. Plotting moisture ratio vs. inverse basis weight produces a line whose slope



5. Effect of basis weight (BW) on dewatering. The technology is effective over a range of basis weights, reducing rewet by a factor of 6 (MR = moisture ratio).



7. Enhanced dewatering observed with new and used tissue felts.



6. Enhanced dewatering observed with nylon meshes. The medium-size mesh (#61) performs best of the ones tested, for reasons previously discussed. Two of the mesh series, #30 and #168, fall on top of one another.

is equal to the rewet and whose intercept is equal to the equilibrium moisture ratio of the paper. For reasons mentioned previously, the data point of mesh-added felt at lowest basis weight was excluded from the regression, because its dewatering is not fully representative of liquid channel breakup. As expected, the series share the same intercept, because equilibrium moisture of the sheet should only depend on the furnish properties and pressure applied—not the felt characteristics. The series have different slopes, however, suggesting that rewet has been reduced from 61 g/m² to 10 g/m² by adding the mesh. These values display excellent agreement with those of the rewet values suggested by Fig. 2, 62 g/m² and 9.6 g/m².

Nylon meshes

For reasons of safety and wear, metal structures would be difficult to implement in a paper machine press nip. Metal materials, however, should not be necessary to achieve the desired liquid bridge breakup. Provided that the spacer layer is sufficiently stiff to resist significant deformation under nip loads, the approach should work well. Given that stress applied in the nip is around 10 MPa, any material that has a stiffness (i.e., elastic modulus) of at least 1 GPa will likely work. Fortunately, there are many candidate materials that satisfy this criterion. Among them, nylon meshes are a natural choice, as nylon is already used in press fabrics.

Figure 6 shows the enhanced dewatering performance that nylon meshes add to a commercially available felt. Similar to the effect demonstrated with metal meshes, we observed lower residual water in the sheet after pressing when the spacer layer is included. Once more, the dimensional parameters of the spacer layer have a significant impact on the mitigation of rewet. Compared to pressing with the felt alone, each of the mesh-added felts showed at least some improvement in press solids. The greatest improvement was seen with the medium-sized mesh, implying that there is an opportunity to optimize the design of the spacer layer beyond the commercially available meshes. As in Fig. 2, the gap between the blue and red series highlights the progress already made in developing this technology. The gap between the red and black series corresponds to the opportunity to further optimize this process. Although less improvement was seen with the nylon meshes compared to metal meshes, this is more indicative of only testing three structures, which is less likely to capture the optimum value.

Different felts

Because the technology works by disrupting the fluid phase, improved dewatering should be observed regardless of what felt is used, or in what condition the felt may be. **Figure 7** shows results obtained from pressing a 120 g/m² SBSK handsheet at 1000 psi (7 MPa) with new and used felts. Addition of a mesh improved dewatering in both cases. The used felt appears to have marginally better dewatering ability, compared to the new felt. However, this is only because the new felt has not been sufficiently well conditioned. Overall, it is encouraging to see that the technology has high potential to work over the lifetime of the felt.

ECONOMIC IMPACT

The financial value of reducing rewet comes in two main ways: energy savings and increased production. By removing more water in the press section, less has to be dried later—a notoriously intensive and costly process. Reducing the drying load by 40% would result in an enormous reduction in energy. Assuming that, in the base case, energy devoted to drying the sheet costs about US$20/finished ton, the impact on energy savings would be US$8/finished ton. In application, the control/base case—pressing with conventional press fabric—could perform better than suggested by experiments on the platen press, simply due to dynamics. Even if the drying load were only reduced by 10%, energy savings would still be about US$2/finished ton, an attractive value for technology that is essentially drop-in.

The value that could be created from increased production in debottlenecking the dryers is more difficult to estimate. For those mills currently struggling with dryer limitations, marginal profitability attained with higher production volume could be at least as valuable as energy savings. The analysis is complicated by other process streams that would then become production-limiting. In theory, reducing the dryer load by 40% could result in up to 40% increase in production for this case. However, in practice, upstream processes engineered around the initial dryer limitation would quickly become new bottlenecks. Understanding how reducing energy use in the dryers results in higher production requires a detailed analysis that would have to be performed on a mill-by-mill basis. Additionally, the economic considerations complicate quickly. Significant increases in production, especially those that can be realized sector-wide, are likely to affect the pricing—and thus, profitability—of marginal tons.

FUTURE WORK

Additional work is needed to improve the design of the spacer layer. One limitation of working with commercially available meshes is that the thickness (gap size) and mesh opening width cannot be varied independently. For breaking water channels, we hypothesize that more slender openings relative to gap thickness would be preferable. Another disadvantage of the commercial samples is the mesh geometry itself. Because of the filaments' cylindrical profile, some water is likely getting trapped near the paper surface. This could potentially be avoided by choosing a different pore geometry in the spacer.

Another limitation of using meshes is their roughness, which creates two main problems. The first is sheet smoothness. Placing a mesh between the web and the felt negatively impacts sheet smoothness, although the exact extent of the effect—which will ultimately depend on drying and potential calendering—is difficult to assess in our current laboratory setup. The second potential problem with roughness created by mesh weave is that it creates larger channels along the interface of the web. When the applied pressure gradient is unidirectional, such as in our platen press, this presents no issue. However, once machine-direction pressure gradients are introduced, such as might be observed in a nip, dewatering could be severely compromised. Both these problems could be resolved by engineering a spacer layer with high surface smoothness and stiffness that is matched to the felt and web, while maintaining appropriate dimensions for channel breakup.

Assessing the effect of the spacer's surface wettability is an ongoing study. Although the primary function of the spacer is mechanical, we have observed there is potentially a marginal improvement from making the pore walls of the spacer more hydrophobic. How this may interact with the time scales and pressure gradients in a nip vs. platen press will have to be determined.

Overall, designing structures with the goal of controlling liquid channel rupture is a new paradigm for press fabric design and suggests an encouraging future for this body of work.

CONCLUSIONS

Enhanced dewatering can be realized by severing the liquid channels that would otherwise span the felt-web interface. One, mechanical, way of accomplishing this is to introduce a stiff, porous spacer between the felt and web. Doing so effectively changes the boundary conditions of the interface while it is in the nip. Because the mechanism works by disrupting the fluid phase, it should only be indirectly influenced by other parameters in the system like nip load, pulp furnish, or press fabric. This means that application is likely to be wide-ranging, although we do expect some of the design optimization to depend on paper grade. While there is additional work to be done, initial results of this approach are promising. Improved dewatering observed on the laboratory scale, coupled with a preliminary economic analysis, shows that structures that destabilize liquid channels at the felt-web interface have enormous potential in paper manufacture. **TJ**

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About this journal

ABOUT THE AUTHORS

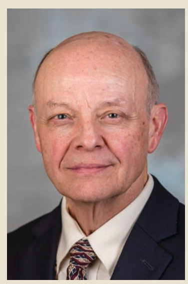
We chose to research rewet in the press section because of the immense energy savings that could be realized with enhanced dewatering. This research complements developments in press nip design, which have previously attained close to equilibrium moisture in-nip. Our fabric designs have the unique potential to fully realize the value of this technology by mitigating the effect of rewet.

The most difficult aspect of this research was visualizing the flow of water in the felt/paper system. This was addressed largely with the expertise of the corresponding author's background.

We discovered that rethinking some basic assumptions can lead to great leaps in engineering. Our most interesting result was that adding a stiff spacer can lead to better dewatering.

Mills would benefit from this research's energy savings in the dryer section and increased production. The next step is to design our own spacers, considering the impacts on sheet smoothness, wear, permeability, and multidimensional flow.

Dudick



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