Solving Rewet to Produce Drier Web

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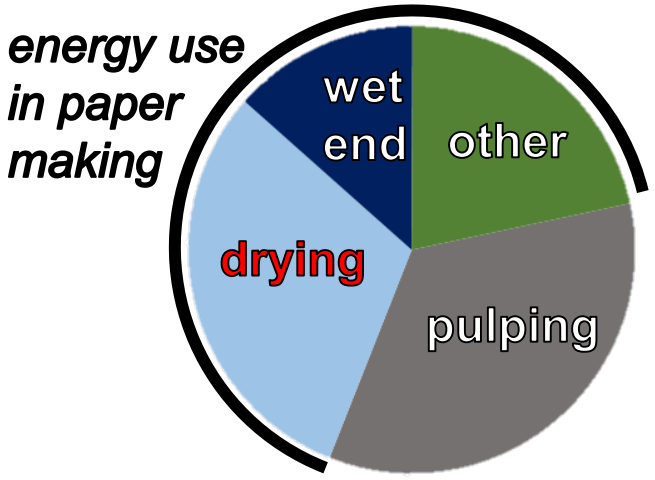
Evaporative Drying in Papermaking

- Pulp & Paper industry consumes significant energy
  - *8.4 quadrillion BTU annually*
    – as much as France!
  - *4th largest industry sector globally*
- 30% used in a single process
  - *Evaporative drying*
  - *High latent heat of water in the sheet*
- Industry Holy Grail:

  "Drier web entering the dryer"
  (APPTI Roadmap)



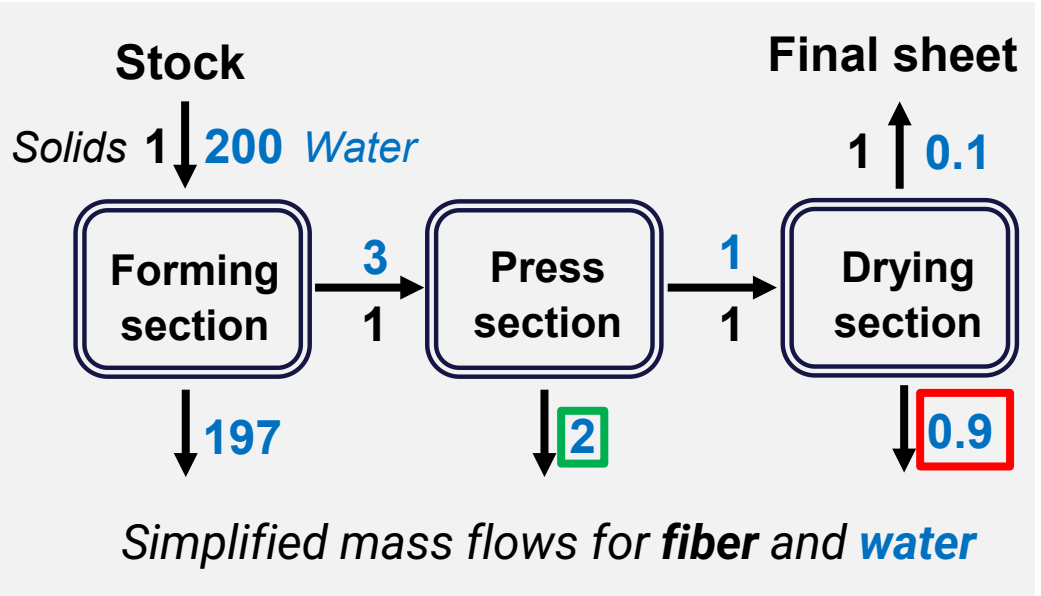
Dept. of Energy

Papermaking Process

- Purpose of the machine
  - *Form and consolidate the web*
  - *Dewater sheet to final dryness*
- Three increasingly energy-intensive stages
  - *Forming section: gravity/vacuum*
  - *Press section: mechanical*
  - *Dryer section: thermal*

Dryer removes relatively small fraction of total water

→ Small improvements in water removal in press section can yield big energy savings

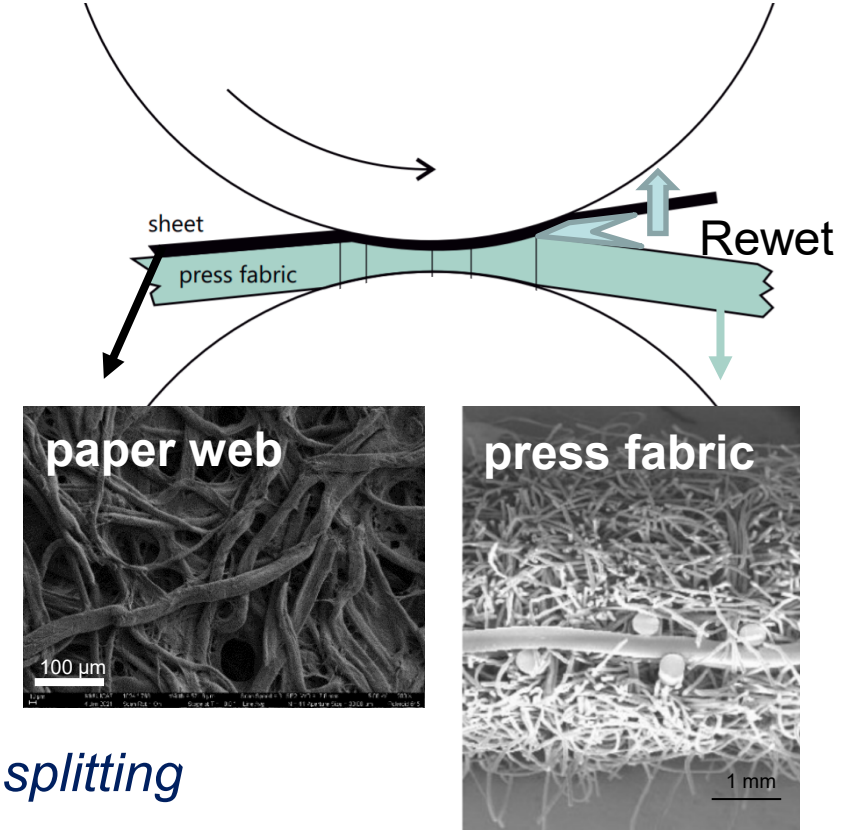


*Simplified mass flows for **fiber** and **water***

Press Section

"Remove water from a sponge by pressing against another sponge"

- **Rewet** occurs upon pressure relief
  - *Expelled water returns to the web post-nip*
  - *Exit moisture ratio can be 50% higher than in-nip minimum*
- Flow rewet
  - *Capillary forces soak water back*
- Separation rewet
  - *Interstitial water sides with web upon splitting*

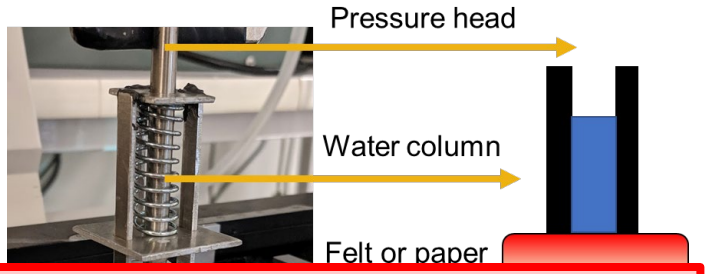


Understanding and controlling transport in porous media essential to improved dewatering

Engineering Barriers Against Rewet

Original idea:

- Create hydrophobicity gradients in felts/paper via plasma-assisted deposition of fluorocarbon film



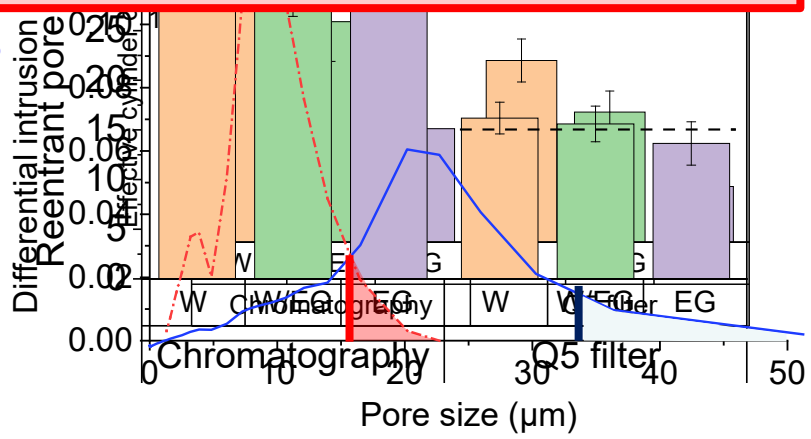
Creating a hydrophobic barrier in press felt requires:

- ***Too thin yarns***
- ***Too small pores (clogging, low permeability)***

→ Not technically feasible

+ Statistics

Cimadoro *et al.*, *Soft Matter* (2019)

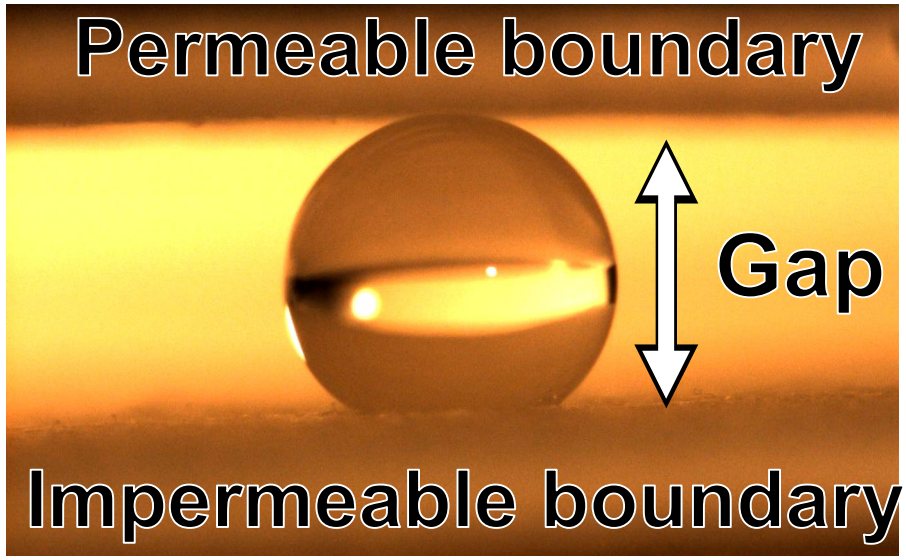


Dudick *et al.*, *Langmuir* (*accepted;* 2022)

Preventing Rewet – *New Concept*

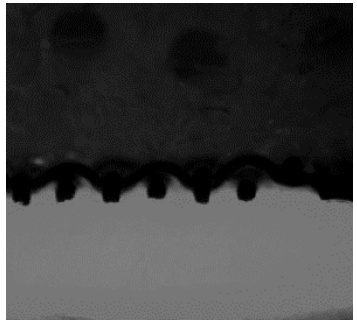
"What if the fabric and paper never touch?"

Observation:
Water can carry itself across an open gap and cut the liquid bridge at end of transfer



Desired boundary conditions:

- *Fabric is permeable*
- *Paper web is impermeable*
- *Porous spacer layer to cut water bridges*



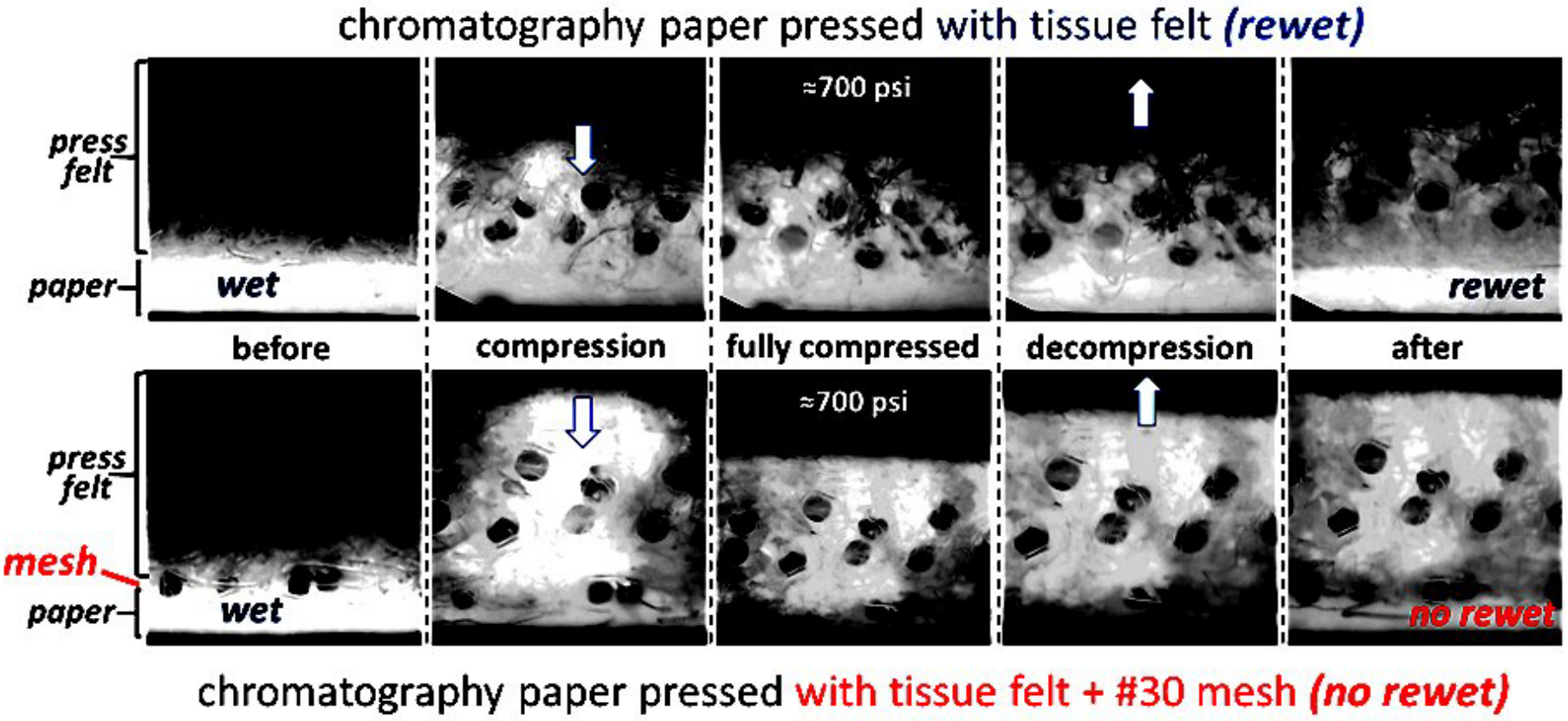
→ Can be achieved under nip pressure conditions if:

$$E_{paper} < P_{nip} < E_{felt} \leq E_{spacer}$$

provisional patent 63/270,627 (2021)

Preventing Rewet: *Stiff Spacer Layer*

Video frames

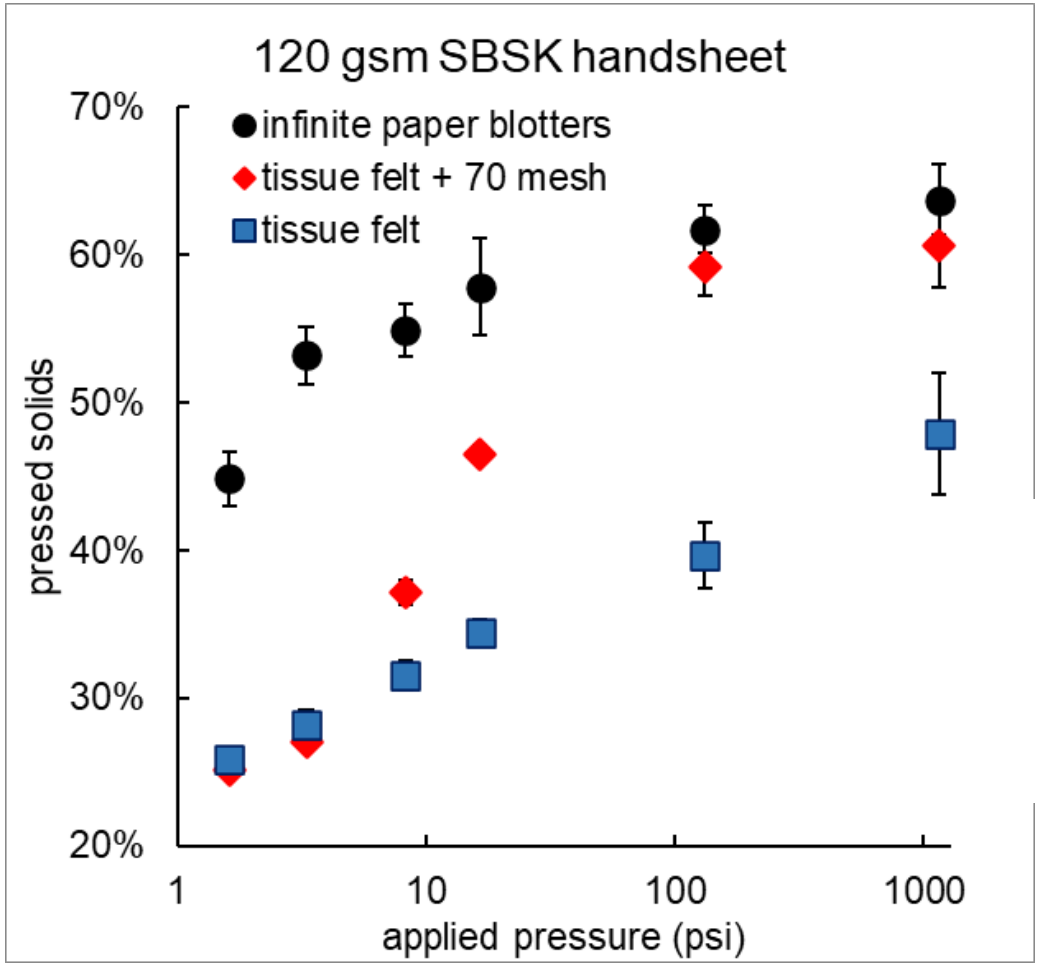


provisional patent 63/270,627 (2021)

Preventing Rewet – *Experiments*

- Screw press
  - *Spatially uniform pressure distribution*
- Force sensor used to determine applied stress
  - *Up to 10 MPa*
- SBSK handsheets
  - *Southern Bleached Softwood Kraft*
  - *Standard pulp furnish in many applications*
- Press solids: %solids after pressing

Preventing Rewet with Stiff Spacer



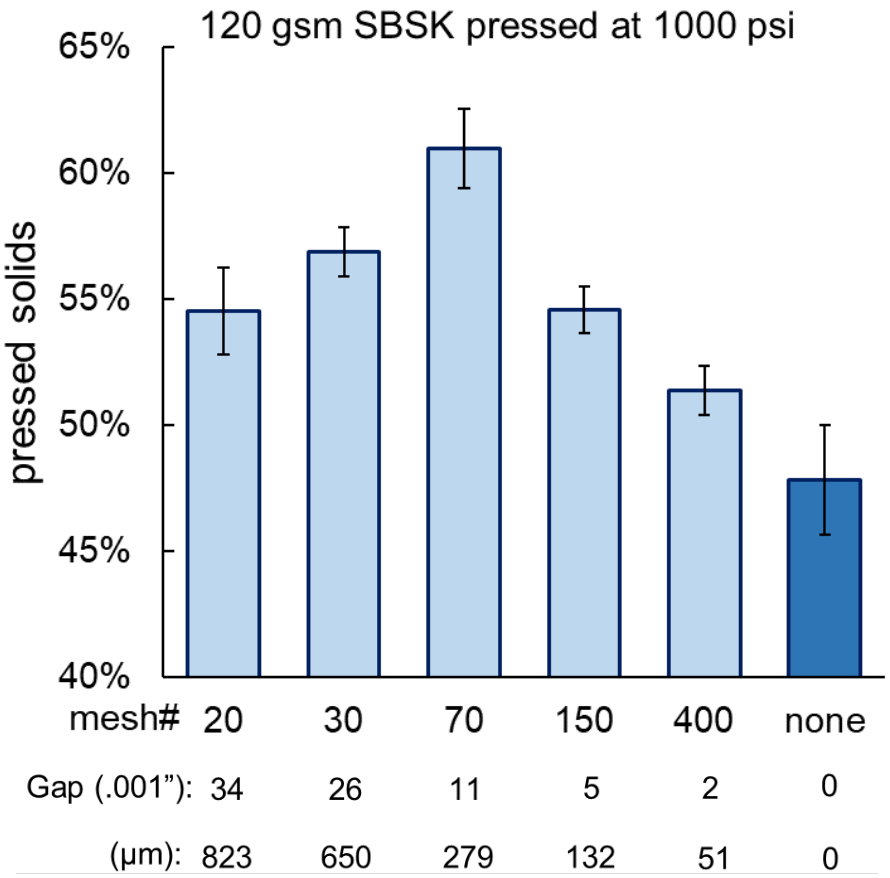
- Initial solids = 25%
  - *Mimics papermaking*
- The wet web pressed three times at a given pressure
  - *Simulates series of nips*
- Infinite blotters captures theoretical limit of no rewet
  - *Mesh closes gap between existing technology and the ideal limit*

→ 42% reduction in dryer load

provisional patent 63/270,627 (2021)
Dudick et al., *Tappi J.* (accepted; 2022)

Preventing Rewet with Stiff Spacer – *Optimization*

- The structure of the spacer can be optimized
- Too thick
  - *Poor contact between paper & felt*
  - *Uneven pressure distribution*
  - *Liquid bridge could break in middle*
- Too thin
  - *Felt remains in contact with paper after pressing*
  - *Liquid bridges more stable and less likely to break*



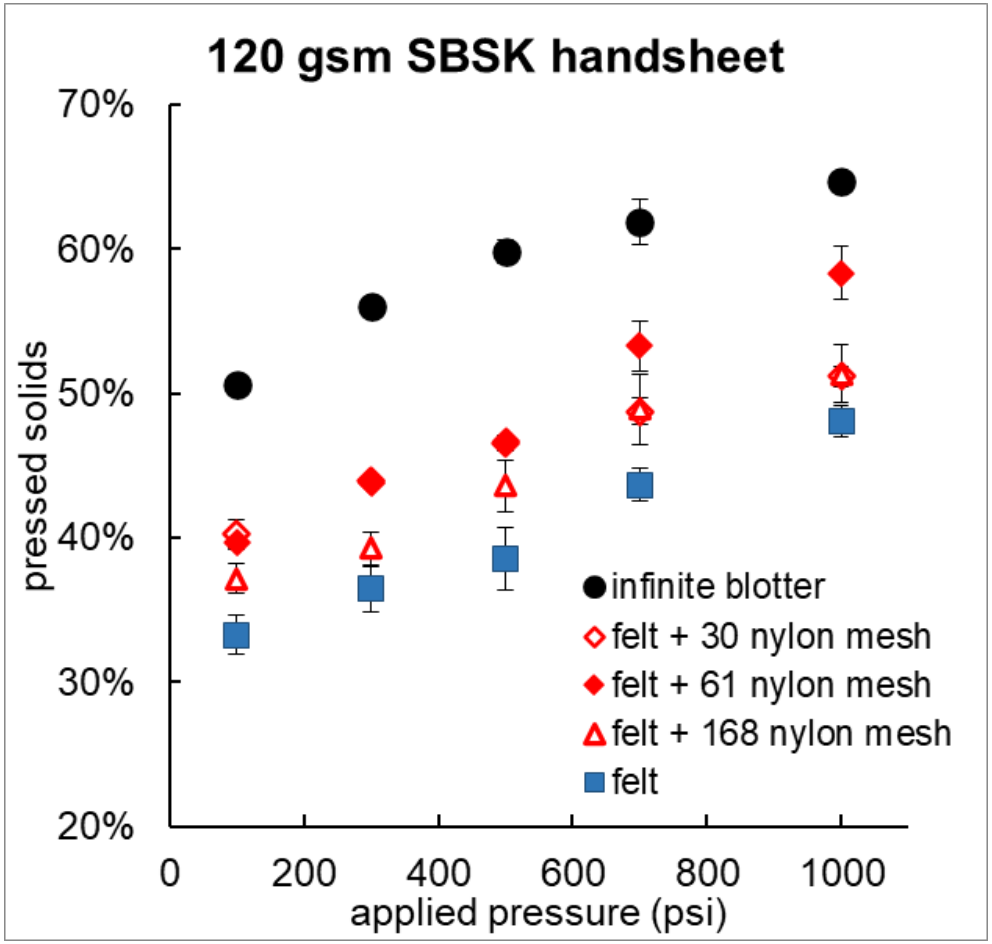
provisional patent 63/270,627 (2021)
Dudick et al., *Tappi J.* (accepted; 2022)

Preventing Rewet with Stiff Spacer – *Materials*

- **Metal problematic for press nips in machines**
- Hypothesis: any sufficiently stiff spacer will work

  $E > 100{,}000$ psi $\approx E_{nylon}$
- Significant improvement in solids still observed
- Finding right spacer dimensions is critical

  → *design rather than use commercial meshes*
- Candidate material for testing in a nip



provisional patent 63/270,627 (2021)
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Preventing Rewet with Stiff Spacer
– *Open Questions and Future Work*

- **Dynamic testing in press nip**
  - *Time effects?*
  - *Machine direction pressure gradient effects?*
- **Other stiff materials with machine compatibility**
- **Optimize design of stiff spacer layer**
  - *Dimensional parameters:*
    thickness, opening size, geometry
  - *Pore shape*
  - *Surface smoothness*
  - *Surface chemistry*

  → Optimal design likely depends on paper grade
- **Does better nip dewatering reveal upstream bottleneck?**

  → Improve drainage in forming section

provisional patent 63/270,627 (2021)

Preventing Rewet – *Energy Impact?*

Potential energy savings

- *~$20/ton in energy cost for sheet drying*
- *330 million tons produced annually sector-wide*

→ 100 million tons affected by technology (conservative estimate)

- *20% reduction in dryer load*

→ **$400 million/year**

Preventing Rewet – *Carbon Impact?*

Potential carbon footprint reduction

- Depends a lot on mill energy profile, which varies significantly
- **Worst-case scenario**:
  all energy in mill generated from fossil fuels
  → % carbon reduction ≈ % energy savings
- **Better-case scenario**:
  part of energy in mill already generated from low-carbon source (e.g. biomass)

  → % carbon reduction > % energy savings
  (savings increase fraction of low-carbon energy)

  → Further research/modeling needed

Acknowledgments

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AstenJohnson

- *Press felts*