A high-fidelity model for coupling flow and mechanical deformation of the porous paper web in paper making

CPS Agreement Number: 29332 Project Period: October 2015 – September 2016

Lawrence Livermore National Laboratory / Lawrence Berkeley National Laboratory / Agenda 2020
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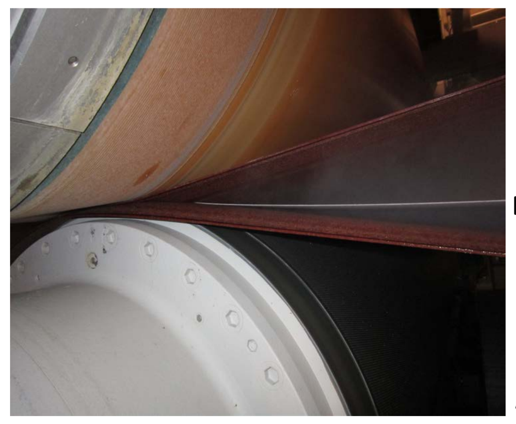
Project Objective

- Maximizing water removal can significantly reduce the energy-intensive drying process in paper-making.
- After pressing water from the paper pulp, re-wetting is occurring.
- Paper de-watering and re-wet phenomena are not currently well understood.


Paper machine press section


Close-up view of press nip

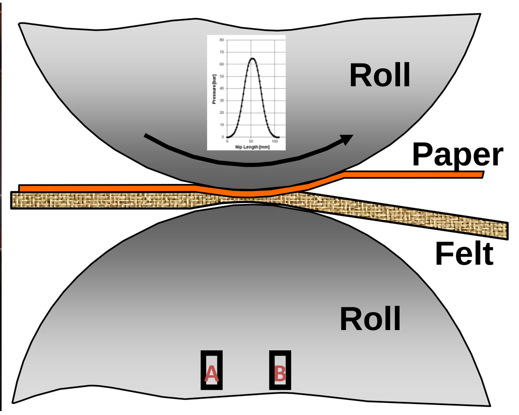


Illustration of press nip

- The objectives of this project are to
  - Leverage the HPC capabilities at LLNL and LBNL to develop an integrated, multi-physics modeling framework as a critical first step to understanding and reducing rewet at the press section.
  - Provide the pulp and paper manufacturing industry with insights to inform the designs of more energy efficient processes and equipment, resulting in energy reduction.

Measure of Success

- The resulting model will help guide the paper manufacturing process to achieve a 10% improvement in solid content of the paper web entering dryer section.
- This will lead to 20% drying energy saving, or 80 trillion Btu, worth approximately $250 million annually.

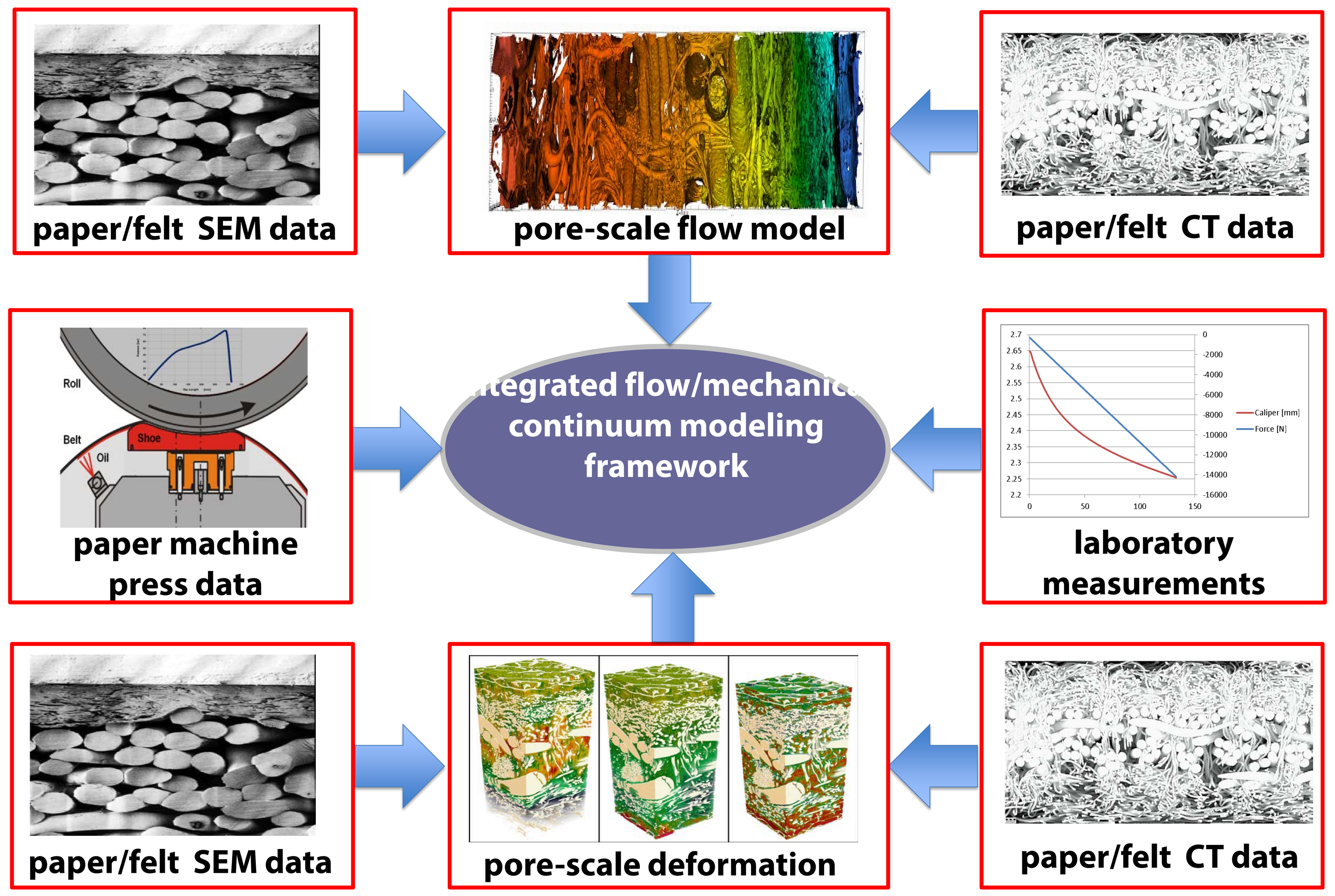
Project Management and Budget

- Project duration: October, 2015 – September, 2016
- Project milestones:
  - Develop a coupled two-phase flow and poro-elasto-plastic continuum modeling framework (completed)
  - Develop a pore-scale flow model (70% completed)
  - Calibrate and validate the model (on-going)
  - Develop a one-dimensional rewet model (on-going)
  - Apply the model to simulate paper-pressing operations.
- Progress measured via monthly and quarterly reporting and briefing to Agenda 2020, LLNL and AMO to track and document progress

Total Project Budget	
DOE Investment	$300,000
Cost Share	$62,000
Project Total	$362,000

Technical Innovation and Approach

- Today, the exact mechanism of "re-wet" is not known, primarily due to lack of sufficient data and reliable models describing de-watering and re-wet processes.
- We are leveraging advanced simulation capabilities, experimental measurements and paper machine data to develop an integrated, mul physics modeling framework.



Integrated multi-physics modeling framework for dewatering simulation

- LLNL is developing a continuum simulation framework to couple mechanical and two-phase flow models
  - Use Richards' equation to describe two-phase flow in paper and felt
  - Consider elastic and elastoplastic behaviors of paper and felt
  - Employ modified Cam-Clay model to describe paper plastic deformation
- LBNL is developing pore-scale flow modeling capabilities
  - Perform high-resolution direct simulation of microscale flow in complex pore structures in paper pulp and press felts
  - Use pore-scale modeling of flow in realistic geometries obtained from f image data to inform better parametrization of porosity and permeabi for continuum-scale computations
- Agenda 2020 is providing the domain expertise and data to support model calibration, validation, and application

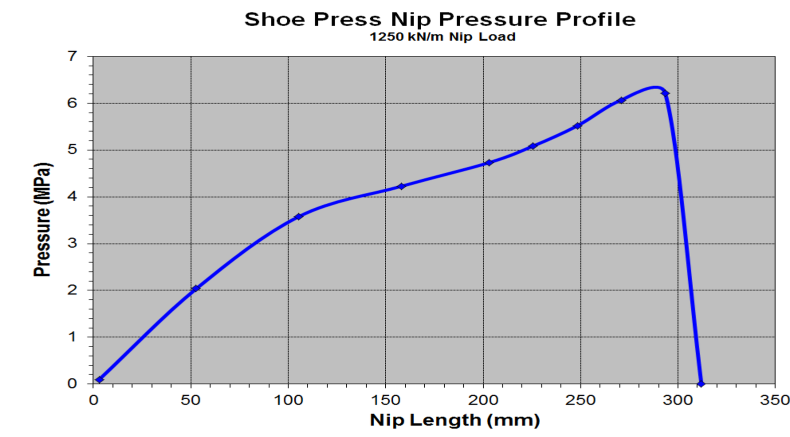
Transition and Deployment

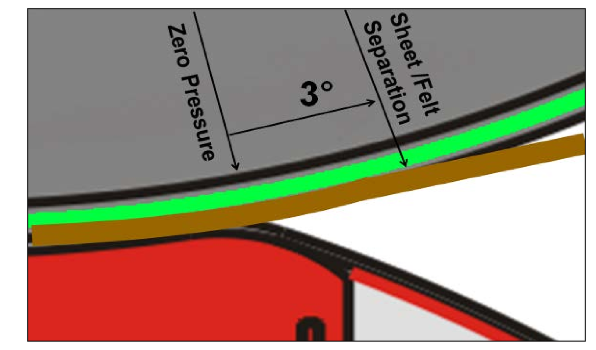
- Results will be made available to the scientific community through technical presentation and publication.
- We will work with paper industry to apply the developed model to help guide press section configuration and roll/felt design to minimize rewet.

Results and Accomplishments

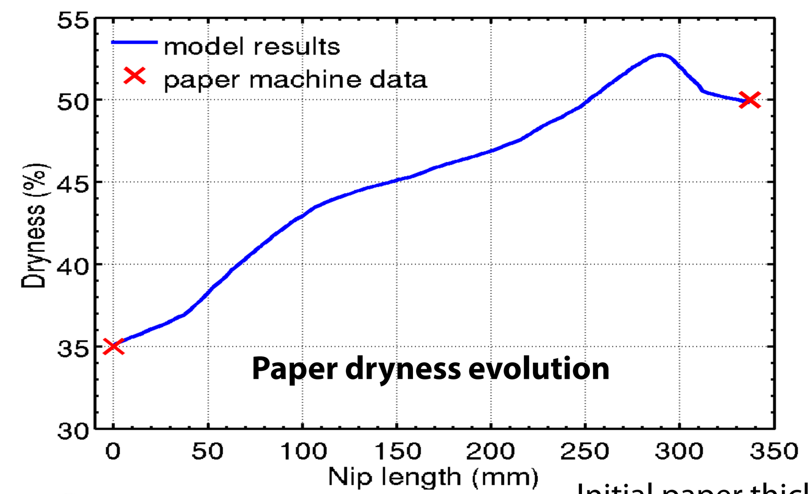
- **Continuum modeling framework**

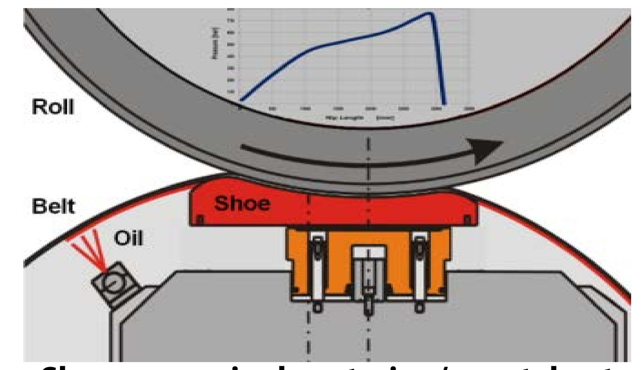
The model is able to fit the measured machine data, and predict that pressing increases the web solid content from 35% to 50%.



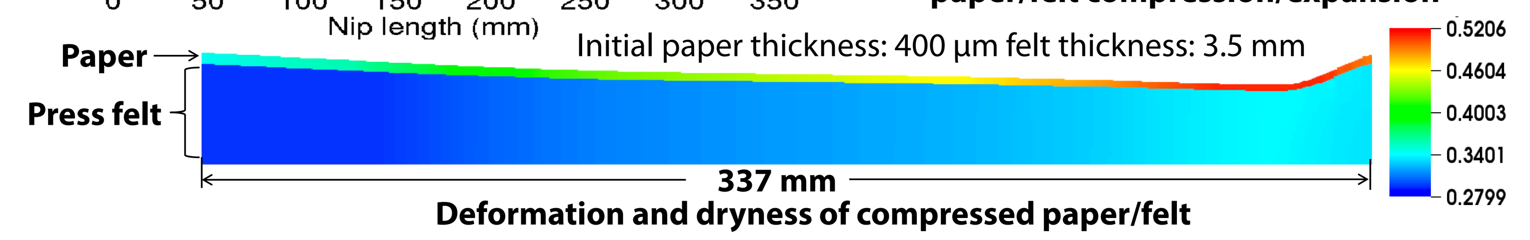


Post-nip rewet before paper/felt separation — pressure goes to zero at 312 mm



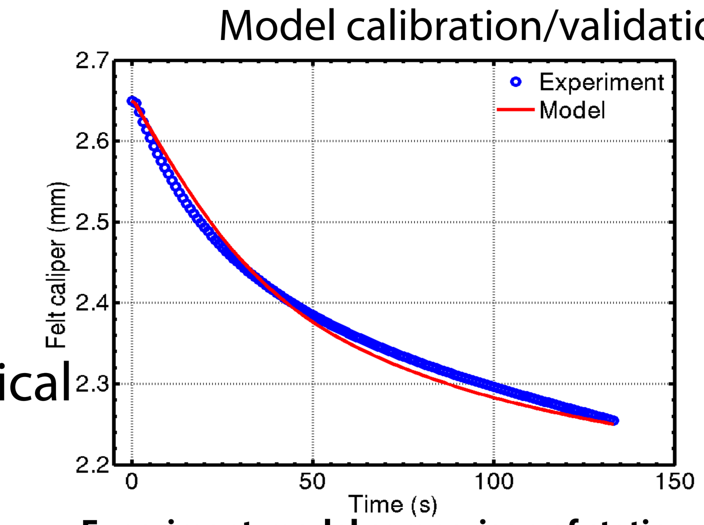


Shoe press-nip dewatering/rewet due to paper/felt compression/expansion

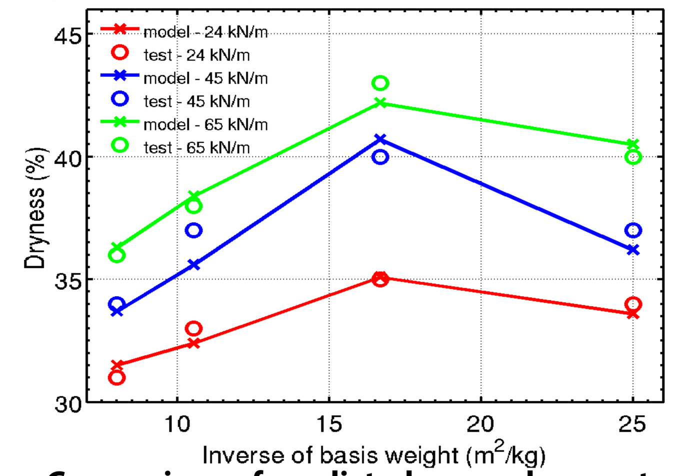


Deformation and dryness of compressed paper/felt

Model calibration/validation spans multiple scales



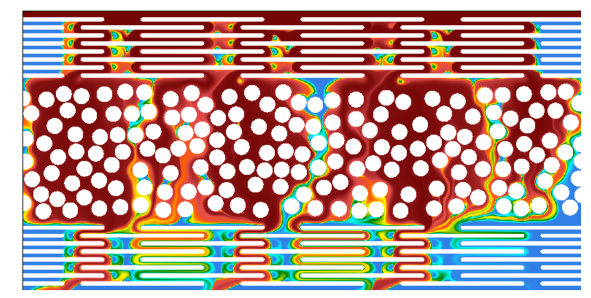
Experiment-model comparison of static felt compression



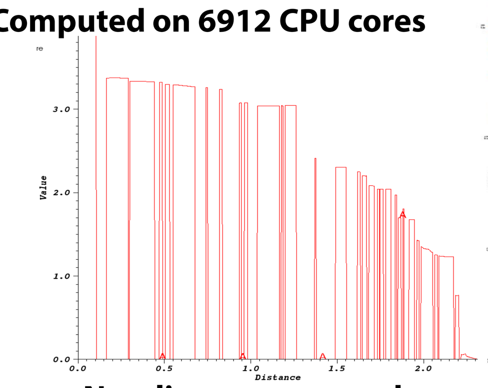
Comparison of predicted paper dryness to pilot roll press data for different nip loads

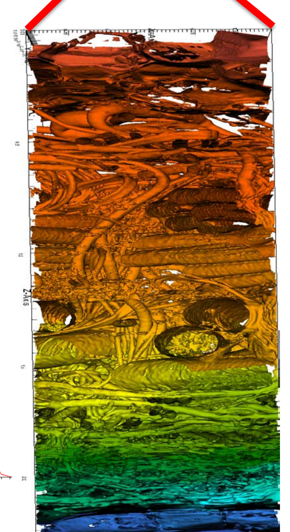
- **Pore-scale flow model**

Slice from felt CT image


2D pore-scale felt model using synthetic geometry (velocity data shown)

3D pore-scale felt model using geometry reconstructed from image data (pressure shown) permeability k = 7.732×10^{-11} m^2 Computed on 6912 CPU cores


Non-linear pressure drop



- We have demonstrated complex flow simulation in a synthetic pore scale representation of image data.
- We have performed DNS of flow in the felt from image data.
- Preliminary data shows a nonlinear pressure drop in press direction such that constant permeability assumption does not hold.
- Finer resolution on 56K CPU cores

Wei Wang, Joshua White, and Michael Homel (LLNL), and David Lange, David McDonald, and Stefan Probst–Schendzielorz (Agenda 2020)

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