SENIOR CAPSTONE/ SENIOR DESIGN EXPERIENCE 2025

Corn Fiber Alcohol Wipes

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Objective

- To develop sustainable corn fiber-based alcohol wipes that deliver effective sanitization.
- Replace conventional plastic-laden wipes with a fully biodegradable, 100% renewable solution that aligns with sustainability expectations.

Market trends and impact

- In 2022, the North American wet wipes market generated about $9.78 billion which is expected to reach $12 billion by 2030 at a pace of about 3% growth annually.
- Globally, biodegradable wipes only about 12% of the overall market. However, consumers response to eco-friendly wipes has been positive leading to name brands like Clorox to start more sustainable lines of products.
- The proposed product is 100% plant based. This is a huge advantage compared to the competition that uses composite materials.

Global Factors


GOV.UK
Home > Environment > Pollution and environmental quality
Press release
UK-wide ban on wet wipes containing plastic to be put into law
The UK Government will introduce new world-leading legislation to ban wet wipes containing plastic.

Figure 1. *Plastic based wipes headline – outlines the centrality of this issue in the public eye.*

Top Producing Countries

Market	% of Global Production	Total Production (2024/2025, Metric Tons)
United States	31%	377.63 Million
China	24%	294.92 Million
Brazil	10%	126 Million
European Union	5%	59.31 Million
Argentina	4%	50 Million
India	3%	40 Million
Ukraine	2%	26.8 Million
Mexico	2%	23.3 Million
South Africa	1%	16 Million
Canada	1%	15.35 Million

Figure 2. Top corn producing countries data given by USDA

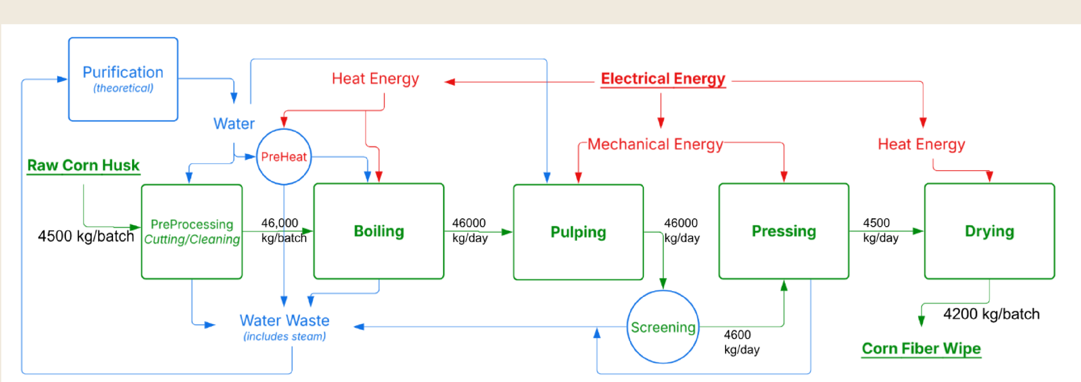


Figure 3. *Process flow diagram for semicontinuous batch production of corn fiber-based wipes.*

Literature Review & Process Flow

- **Lignocellulosic Content**: Corn husks are rich in cellulose and hemicellulose, which can be hydrolyzed into fermentable sugars—an essential step in bioethanol production (Zhao et al., 2009).
- **Sustainable Feedstock**: As an agricultural byproduct, corn husks offer a low-cost, renewable, and abundant raw material for bioethanol, aligning with circular economy principles (Sun & Cheng, 2002)
- **Biodegradability & Waste Reduction**: Incorporating corn husk fibers into the wipe substrate enhances biodegradability and leverages agricultural waste, reducing reliance on synthetic polymers (Kumar et al., 2021).

The proposed process flow diagram is pictured above.

Experimentation and Analysis

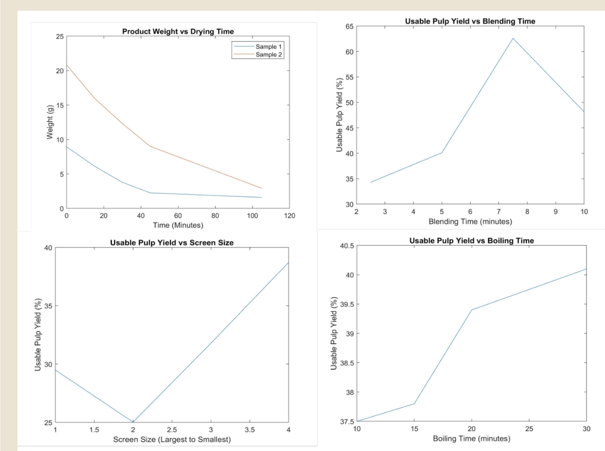


Figure 4. *Performance curves for boiling time, blending duration, screen size, and drying time versus pulp yield or weight loss. These inform optimal conditions for each unit operation.*

	Pattern	Boiling Time	Blending Time	Cut in Paper	Drying Time	Cut Across Grain	Yeild
1	---+-	-1	-1	-1	1	-1	•
2	--+--	-1	-1	1	-1	-1	•
3	--+-+	-1	-1	1	-1	1	•
4	-+--+	-1	1	-1	-1	1	•
5	-+-++	-1	1	-1	1	1	•
6	-+++-	-1	1	1	1	-1	•
7	+---+	1	-1	-1	-1	1	•
8	+--+-	1	-1	-1	1	-1	•
9	+-+++	1	-1	1	1	1	•
10	++---	1	1	-1	-1	-1	•
11	+++--	1	1	1	-1	-1	•
12	+++++	1	1	1	1	1	•

Figure 5. *Plackett-Burman DOE matrix outlining high and low levels for process parameters to identify significant factors influencing yield.*

- Empirical tests across boiling, blending, screening, and drying identified key parameters influencing pulp yield and wipe quality.
- Optimal conditions included 30-minute boiling, 7.5-minute blending with a smoothie blender, and smallest screen pore size for highest usable pulp.
- Drying trials established moisture loss curves and revealed cracking issues linked to incomplete screening and over-thick sheets.
- A Plackett-Burman DOE was developed to statistically evaluate the impact of major process variables and guide future optimization.

Design of Process Operations

Heating and Mixing:

Mixer Optimization:
•Impeller speed was varied to minimize mixing time while reducing energy consumption.

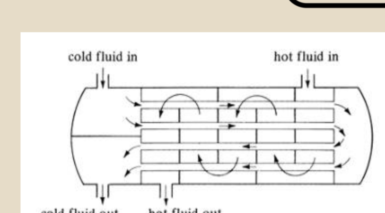
•Dimensionless analysis was used to simulate and evaluate mixer performance across various operating conditions.

Heat Exchanger goals: to soften husk fibers for processing.

•The system was designed to heat the corn fiber mixture to 100 °C with minimal energy input.

•Design improvements aimed to reduce both heat transfer area and capital investment.

•Thermodynamic properties were used to model system performance and support energy efficiency goals.



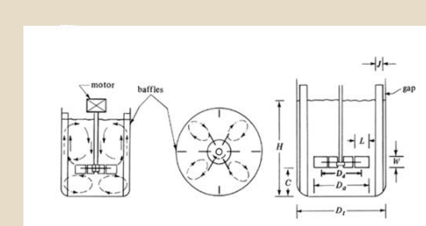


Figure 6. Drawing for a 2-pass shell and tube heat exchanger.
Figure 7: Drawing for a baffled mixer and its dimensions.

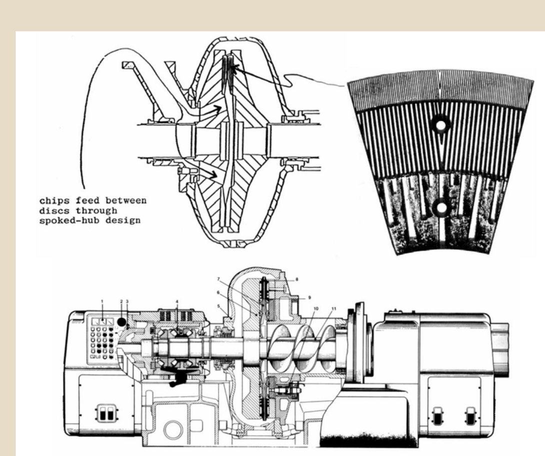
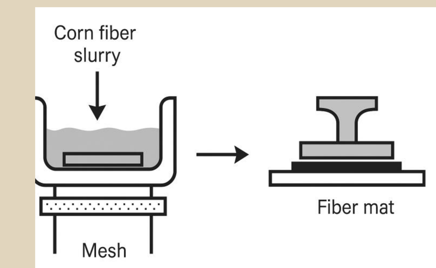


Figure 8. Technical drawing of possible pulper for use in the size reduction of husk fibers.

Pulping

- Target: optimal size reduction for use papermaking application.
- Tradeoff: More energy input means greater size reduction ratio, but more cost.
- Experimental data: 0.06 kWh was needed for processing a 50-gram husk sample.
- 40,000 kg fluid processed per batch, so full scale equipment was sized and costed accordingly.
- Impact of design variables: changing the impeller speed will change the necessary residence time of husk fibers, reducing the size needed to process one batch in a given amount of time.

Screening and Pressing:



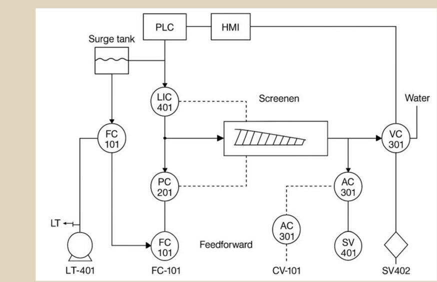


Figure 9. *Optimization results for screen pore diameter. Net Present Worth (NPW) peaks at 75 µm due to high fiber retention, with a plateau extending to 90 µm. Retention efficiency follows a sigmoid curve, indicating steep declines above 100 µm. Fiber retention was the largest contributor to total cost, significantly influencing annual savings.*
Figure 10. *Simplified schematic of screening and pressing unit operation. Corn fiber slurry is poured into the holder and filtered through a mesh screen. A press flattens the fiber mat, forming the basis of the wipe sheet.*

- Screen pore sizes assessed from 20–400 µm; the optimal diameter was 75 µm, balancing fiber retention and energy use.
- Fiber retention was the strongest economic driver in the model—screens with ≥95% retention sharply reduced material loss and recycle costs, directly boosting NPW.
- The optimization included pressure drop, utility costs, and capital scaling, and revealed a high-value NPW plateau between 75–90 µm for design flexibility.
- An ISA-standard control system was designed with feedforward-feedback loops to adjust vibration and flow rate based on measured fiber consistency and pressure drop.
- Simulations showed that integrating real-time fiber load sensing with predictive adjustments minimized screen fouling, stabilized pressure, and reduced water and energy waste.

Drying:

- **Process Analysis and Scale-up Considerations:** The drying process analysis ensures that the evaporation rate (242.4 kg water/hr) aligns with the required moisture content reduction while maintaining a constant drying time of 100 minutes.
- **Simulation of Through-Air Drying (TAD) System:** A TAD system simulation calculates the necessary air flow (6.938 kg/s) and heat exchange (522 kW) to achieve the required moisture content reduction. Computational models also estimate power requirements for both air circulation and heating, ensuring efficient design parameters for industrial-scale systems.
- **Impact of Design Variables on Moisture Content:** Simulations explore the effects of drying time, solid mass-to-surface area ratio (Ls/A), and inlet air flow rate on the final product moisture content. Through iterative simulations, the relationship between air flow and drying efficiency is optimized to ensure consistent product quality and energy efficiency.

Optimization Curves

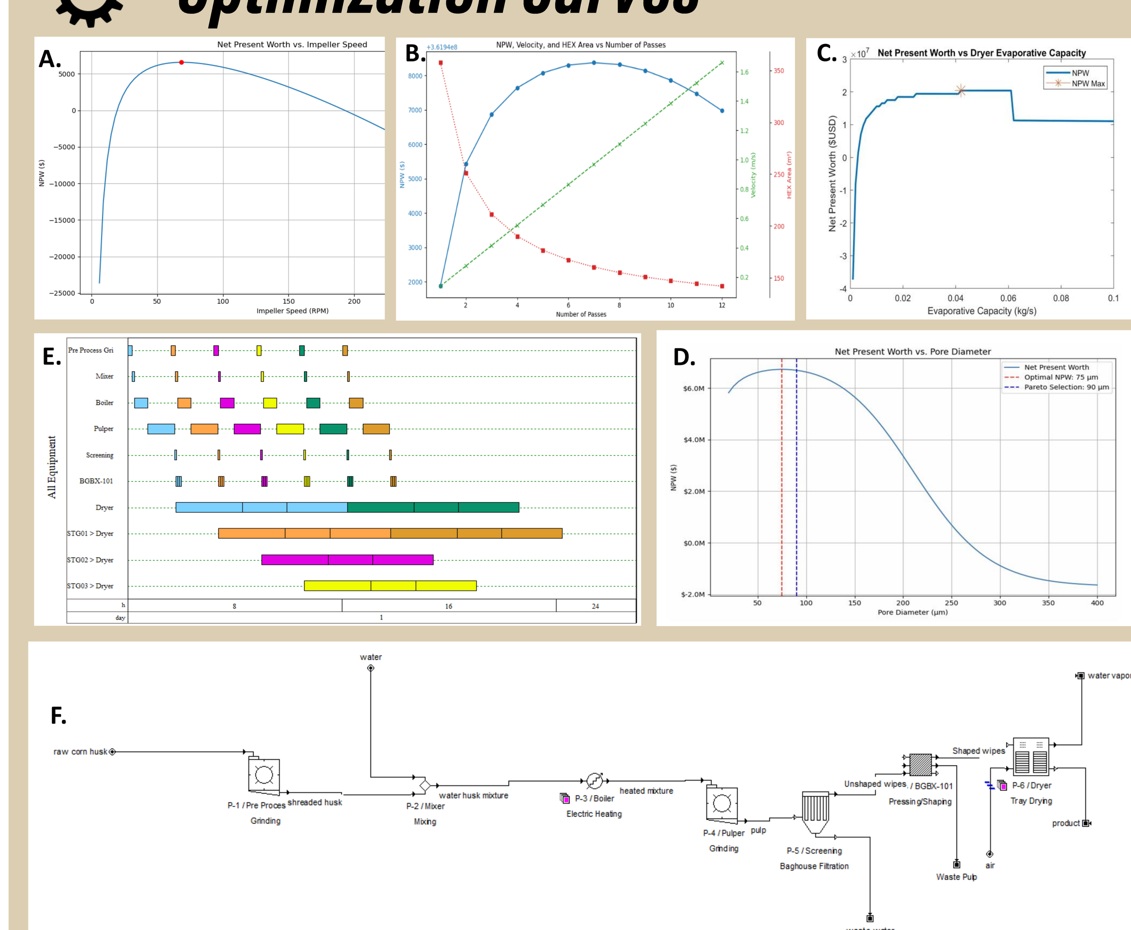


***Figure 11A-F: A.** The economic optimization result for the pulping and grinding step is shown. The optimal impeller speed is marked. **B.** Economic optimization curves for the mixing step are shown. **C.** The economic optimization result for the drying step is shown. The optimal evaporative capacity is marked **D.** The economic optimization for the screening step is shown. The optimal pore diameter is marked. **E.** The semi-continuous process timing is visualized **F.** The final process flow diagram is shown as designed in SuperPro.*

Final Design

Heating and Mixing:

- **Optimization Variable:** Number of tube passes in the shell-and-tube heat exchanger
- **Result:** A 4-pass configuration provided the best trade-off, improving heat transfer while minimizing operational cost and maximizing net present worth (NPW)

Pulping and Grinding:

- **Optimization Variable:** Optimization variable is the **impeller speed (N)**, which directly affects both the capital cost and operating cost .
- **Result:** The optimal impeller speed was found to be ~70 **RPM**, balancing reduced tank volume (capital cost) with increased energy consumption (operating cost).

Screening and Pressing:

- **Optimization Variable:** The **screen pore diameter** was optimized by evaluating 77 candidates from 20–400 µm using a mechanistic and economic model focused on maximizing Net Present Worth (NPW).
- **Result:** The **optimal pore size was 75 µm**, achieving the highest NPW ($6.73 million) with 96.7% fiber retention, while a **pareto-optimal alternative at 90 µm** offered slightly lower NPW but reduced capital cost.

Drying:

- **Optimization Variable**: The key variable optimized was the **evaporative capacity** of the drying unit. An economic model evaluated over 100 capacity values to maximize net present worth (NPW), balancing capital costs (number of dryers, air pump, and heat exchanger sizing) with utility and labor operating expenses.
- **Result**: The **optimal evaporative capacity** was found to be **0.0420 kg/s**, where utility savings and minimized dryer units intersect for the highest NPW.

Optimized Scheduling Strategy for Corn Fiber Wipe Production

- **Semi-Continuous Upgrade:** Introducing 3 additional dryers enabled process overlap and reduced total cycle time—doubling throughput (3 → 6 batches/day). This setup minimizes idle time, particularly in drying.
- **Zero-Waste Design:** A wastewater coagulation tank was designed to accommodate the reuse of wastewater from the drying step. The coagulation steps involves Ferric (III) Chloride coagulant addition to the runoff water from the screening and pressing step to remove organic polymers like lignin and cellulose.

Figure 12: Packaging for the final product.

Future Considerations

- Optimizing control system for unit operations (PIDs)
- Implementation of quality assurance best practices
- Improved waste treatment system
- Conversion to fully continuous processing