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Title

FIELD VALIDATION OF A Pilot-Scale Black Liquor Membrane for Water Removal at a Paper Mill

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Pilot-Scale Black Liquor Membrane for Water Removal

Photo from Getty Images 72779003

FOSSIL FUEL CONSUMPTION[1]

↓ 5,545 Btu/hour

due to reduced steam usage in the evaporator

SCOPE 1 CARBON EMISSIONS[2]

↓ 4.47 tons CO_2equivalent/year

ELECTRICITY CONSUMPTION

↑ 1.28 kilowatts

due to increased electricity to run membrane feed pumps

SCOPE 2 CARBON EMISSIONS[3]

↑ 4.60 tons CO_2equivalent/year

The U.S. Department of Energy's Industrial Efficiency and Decarbonization Office Industrial Technology Validation program is open to all industrial sites that want to team with technology providers to evaluate innovative technologies in their plants, reduce greenhouse gas emissions, and meet decarbonization goals.

Partial Electrification of Fossil-Based Black Liquor Concentration Process

Pulp and paper processing is considered one of the most energy-intensive industries in the manufacturing sector. Concentrating black liquor is a particularly energy-intensive process in this industry, used to recover pulping chemicals and generate high-pressure steam from dissolved wood solids. About 7% of pulp and paper energy usage, or nearly 164 trillion British thermal units (Btu) per year, is used to remove water from black liquor in U.S. kraft mills.[4]

The U.S. Department of Energy's Industrial Efficiency and Decarbonization Office is interested in this black liquor membrane technology because it offers the potential for a more energy-efficient and less carbon-intensive kraft pulping process. The membrane is intended to pretreat black liquor to reduce natural gas usage in evaporators that remove water from black liquor. This technology has the potential to be replicated across 99 kraft pulp mills in 24 states.

This membrane technology is considered precommercial, and the demonstration was a small-scale side-stream field validation. To make an assessment on performance with a higher level of certainty, additional studies at larger scales are recommended.

[1] For a typical U.S. pulp and paper industry with boiler fuel mix of 44% wood, 28% coal, 27% natural gas, and 1% residual oil, based on a median steam economy of 2.2 kilograms (kg) of water removed per 1 kg of steam.

[2] Reduction in scope 1 CO_2e based on a median steam economy of 2.2 kg of water removed per 1 kg of steam used.

[3] Assuming the U.S. national average available through the Environmental Protection Agency (EPA) Emissions and Generation Resource Integrated Database (eGRID) for data year 2020 is 822.6 lbs. CO_2e/MWh.

[4] Agenda 2020 Technology Alliance 2016, Black Liquor Concentration Research Roadmap. https://www.researchgate.net/publication/304013184_Black_liquor_concentration.

The Via Separations filtration skid enables black liquor concentration at a fraction of the energy required by the existing process. *Photo from Ahlstrom-Munksjö*

Technology Performance Assessment

Membrane System To Electrify the Process of Removing Water From Weak Black Liquor

THE PROCESS

The kraft process is a chemical means of converting wood into pulp that generates black liquor as a byproduct. Black liquor is formed when digesting pulpwood into paper pulp removing lignin and other extractives from the wood, to free the cellulose fibers and allow for the papermaking process to occur. Traditionally, a set of multi-effect evaporators (MEEs) extracts water from the liquor, concentrating it from weak black liquor (WBL) into strong black liquor (SBL)(See Figure 1). This process increases the concentration of total dissolved solids (TDS) through highly energy-intensive thermal evaporation. A membrane filtration system could help reduce the energy requirements for this process and increase mill throughput and output of co-products, which are reused in paper production.

THE TECHNOLOGY

Via Separations developed and provided the filtration technology tested in this validation. It is a graphene oxide membrane-based system to produce SBL and permeate using electricity instead of the conventional technology, which uses thermal energy, generated by steam from fossil-fuel-powered boilers. The membrane rejects concentrated constituents while allowing the diluted portions to pass through as permeate, which undergoes brownstock washing to recover spent chemicals. High-pressure pumps driven by electric motors push the fluid through the membrane, a process (see Figure 1) that requires less fuel because the black liquor entering the evaporator set has already been concentrated by the membrane.

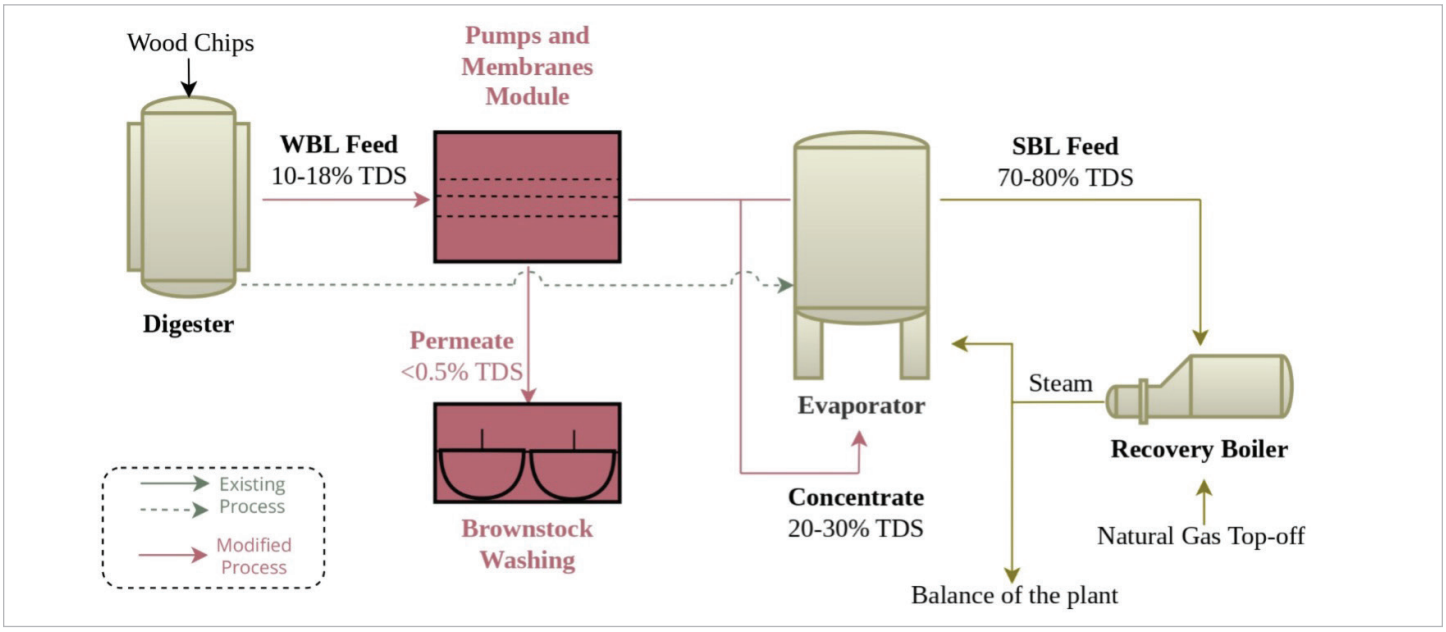

Figure 1. The Via Separations pre-concentrators enable black liquor concentration. This diagram depicts a simplified installation into a kraft paper mill's existing process. *Graphic from Lawrence Berkeley National Laboratory*

THE DEMONSTRATION SITE

The selected host site Ahlstrom-Munksjö's Mosinee, Wisconsin, paper mill was constructed in 1910 and purchased by Ahlstrom-Munksjö in 2018. The mill produces a variety of specialty food packaging and technical paper grades. The site has a kraft pulp mill to process soft and hardwoods and its pulp mill generates up to 340 air-dried tons of pulp daily and operates for 355 days annually.

STEAM SAVINGS, ELECTRICAL ENERGY CONSUMPTION, AND ASSOCIATED CO_2 IMPACT

The results from this small-scale demonstration and evaluation show that the membrane system removes water from the WBL to create a more SBL stream and supports the existing thermal based evaporator system. The membrane system saves steam energy by preconcentrating the black liquor with a membrane compared to an exclusively thermally operated evaporator system.

Researchers at Lawrence Berkeley National Laboratory evaluated the performance of the Via Separations membrane system in a pilot-scale demonstration that can process 3 gallons per minute of WBL, a fraction of the paper mill's total WBL flow. The evaluation included the evaporator system with all evaporator effects and the membrane system but excluded the boilers, pulp washers, and digesters. This study effort followed International Performance Measurement and Verification Protocol Option B – Retrofit Isolation with all parameter measurement.

Max Barton of Via Separations installs remote monitoring equipment. *Photo from Via Separations*

The steam savings were analyzed on a range of typical steam economies associated with the MEEs due to the lack of site-specific baseline data for the site's evaporator and boiler systems. Fossil fuel savings were based on a typical U.S. pulp and paper industry boiler fuel mix of 44% wood, 28% coal, 27% natural gas, and 1% residual oil, on range of steam economies from 1.9-2.5 kilograms of water removed per 1 kg of steam used. The membrane system saved steam energy used in the evaporator system by preconcentrating black liquor, reducing the thermal demand in the evaporator set. The modified process could reduce the fossil fuel usage by 5,545 Btu per hour by the recovery boiler for a median steam economy of 2.2 kg of water removed per 1 kg of steam used thereby reducing Scope 1 greenhouse gas emissions by 0.54 kg of CO_2 per hour.[5]

Conversely, the system increased electricity demand to pump WBL through the membrane. This was calculated to be 1.28 kW, resulting in an increase of Scope 2 greenhouse gas emissions by 0.48 kg lbs of CO_2 per hour assuming the current U.S. grid-averaged emissions factor for electricity.

However, the extent of impact depends on the emissions factor of the local grid, which is highly variable relative to the national average. Installations in regions or companies with higher contributions from renewable power would see higher reduction in net carbon emissions with this technology. Increased adoption of renewable sources of electricity generation could further deepen carbon impact of this technology.

NEXT STEPS

To improve the accuracy and confidence levels associated with this evaluation, at least six months of hourly trend data would be recommended for both MEE and membrane systems at a larger scale. The analyses of this data would achieve results with better confidence that can further be analyzed to assess the energy and greenhouse gas impact associated with larger black liquor systems. The complete list of the MEE and membrane system data points recommended for a more comprehensive evaluation are included in the full report. Since starting this pilot-scale study, Via Separations

[5] Analysis found a reduction of 4,929-6,337 Btu per hour from reduced steam usage, resulting in Scope 1 greenhouse gas emissions reductions of 0.41-0.53 kg CO_2 per hour.

conducted subsequent evaluations based on the lessons learned. The results from those and Ahlstrom-Munksjö's analysis were included in a recently published *Technical Association of the Pulp and Paper Industry* paper[6] showing improved energy performance and reliability of the system.

POTENTIAL IMPACTS

The total energy consumption in the pulp and paper sector is estimated to be 2,343 trillion Btu, with an annual paper output of 45 million tons across 99 kraft pulp mills in the United States, contributing approximately 200 million tons of CO_2 equivalent in greenhouse gas emissions.[4] Currently, the energy consumption to process black liquor stands at 3.6 million Btu per 1 ton of airdried unbleached pulp, with a carbon footprint of 3,042 kg per ton, using the traditional steam-based evaporator system for black liquor concentration. Based on this analysis, adopting the membrane system to preconcentrate WBL to support the MEEs would save 0.31 million Btu per ton, while resulting in an increase in electricity consumption of 70 kilowatt-hours per ton. Although there may not be a carbon impact from this technology based on the current electric grid carbon compositions, with ongoing efforts to clean up electric grid emissions nationwide, the carbon impact for this electrification technology is expected to improve in the future. Based on the market projections, if the technology were adopted across all pulp and paper plants in a similar configuration, it would reduce net greenhouse gas emissions by 0.8 million tons in CO_2 equivalent based on projected 2030 grid composition.[7]

The Via Separations filtration skid enables black liquor concentration set up at the Ahlstrom-Munksjö Mosinee mill. *Photo from Ahlstrom-Munksjö*

[6] Rae, Sam, Ella V. Richards, Max Kleiman-Lynch, Brent D. Keller, and Brandon I. MacDonald. 2023. "Pilot Scale Black Liquor Concentration Using Pressure Driven Membrane Separation." *TAPPI*. https://imisrise.tappi.org/TAPPI/Products/22/22PEE/22PEE17.aspx.

[7] Kinstrey, R., and D. White. 2007. "Pulp & Paper Industry Energy Bandwidth Study." Presented as Paper 27-1 at the 2007 TAPPI Engineering, Pulping & Environmental Conference in Jacksonville, Florida, held October 2007.

These findings are based on the Industrial Technology Validation report: "Field Validation of a Pilot-Scale Black Liquor Membrane for Water Removal at Ahlstrom-Munksjö Paper Mill in Mosinee, Wisconsin", which can be found on the program website: https://bit.ly/4ejtfHS

For more information contact U.S. Department of Energy's Industrial Technology Validation program at ITV-Support@lbl.gov.

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