

Crossflow filtration of green liquor for increased pulp production, improved green liquor quality, and energy savings

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ABSTRACT: A new green liquor filtration system has been installed and commissioned at the Ence pulp mill in Pontevedra, Spain. The filtration system is based on microfiltration and was developed in collaboration with the KTH Royal Institute of Technology in Stockholm, Sweden. The patented method for efficient purification of green liquor decreases the non-process element (NPE) content by providing more efficient solids/liquid separation, reducing energy and chemical consumption in pulp mills and increasing production capacity by eliminating certain capacity bottlenecks. The process has been continuously tested at the Aspa Bruk Mill outside Askersund, Sweden, since 2013. The technology has proven to create nearly particulate-free green liquor during the purification process. The technology can also be used to polish white liquor to provide higher pulp quality.

To provide for a simple and cost-effective installation, the system was designed as a skid-mounted unit that is pre-piped, instrumented, and tested before shipment. The system is modular and allows for easy expansion of capacity.

This paper discusses the process design, process integration, and startup of the new system, along with experiences from the first months of operation.

Application: The patented and trademarked CleanFlow system is a technology designed to increase the capacity of a kraft mill recausticizing plant. Crossflow ceramic membranes are used to filter a portion of the green liquor, debottlenecking the existing green liquor clarifiers' filters. The liquor quality is improved by reducing the buildup of NPEs. CleanFlow can also be implemented to filter white liquor, either the entire stream for improved pulp quality or just a portion, such as with preparing oxidized white liquor for pulp delignification after cooking, or for scrubbing of bleaching system vents.

Cooking liquor for the digesters is generated by the recausticizing process. The green liquor from the dissolving tank is clarified/filtered to remove dregs and insoluble matter. The clean green liquor is then causticized with lime (CaO) to convert sodium carbonate (Na_2CO_3) to sodium hydroxide (NaOH) according to the slaking and causticizing reactions:

Slaking: $\text{CaO}(s) + \text{H}_2\text{O}(aq) \Rightarrow \text{Ca}(\text{OH})_2(s)$

Causticizing: $\text{Na}_2\text{CO}_3(aq) + \text{Ca}(\text{OH})_2(s) \rightleftharpoons 2\text{NaOH}(aq) + \text{CaCO}_3(s)$

The causticized liquor, known as white liquor, contains mainly NaOH , sodium sulfide (Na_2S), Na_2CO_3 and precipitated calcium carbonate (CaCO_3 , lime mud) that is subsequently separated by clarification/filtration. The clarified/filtered white liquor is fed to the digester as cooking liquor. After separation, lime mud is washed and then dewatered on a precoat filter. The washing water (weak wash) is returned to the dissolving tank to dissolve the smelt used to produce green liquor. The thickened mud is dried, heated, and calcined in a lime kiln to produce lime, which is recycled to the slaker. The calcination reaction is:

Calcination: $\text{CaCO}_3(s) \Rightarrow \text{CaO}(s) + \text{CO}_2(g)$ [1]

Non-process elements

Non-process elements (NPEs) mainly enter the recausticizing process through wood, water, and makeup chemicals and are of two kinds—soluble and insoluble. Process modifications over the years like improved brownstock washing, partial or total recovery of bleach plant effluent, and recovery boiler precipitator dust purification processes to selectively remove chloride and potassium have significantly reduced the typical chemical losses in a pulp mill. This has led to a buildup of NPEs, inerts, and heavy metals in the liquor cycle [2]. Typical lime mud composition is given in **Table I**. The buildup of NPEs in the recausticizing cycle is widely acknowledged to be accompanied by the following issues [2-11,15,16]:

- Poor mud washing/filtration
- Loss of causticizing efficiency
- Poor settling of lime mud
- Increased kiln dusting and ring formation
- Increased lime kiln fuel consumption
- Reduced lime quality (availability)
- Increased turbidity in white liquor
- Reduced service life of refractory bricks in the lime kiln
- Increased purchased lime consumption
- Poor cooking conditions
- Increased digester scale

	Average, wt%	Range, wt%
CaCO ₃	95	92–97
MgO	1.04	0.4–1.6
Al ₂ O ₃	0.14	0.05–0.4
SiO ₂	0.5	0.1–1.0
P ₂ O ₅	0.86	0.2–1.4
SO ₃	0.91	0.3–2.5
K ₂ O	0.09	0.04–0.12
Fe ₂ O ₃	0.05	0.01–0.4
Na ₂ O	1.14	0.5–1.6

CaCO₃ = calcium carbonate; MgO = magnesium oxide; Al₂O₃ = aluminum oxide; SiO₂ = silicon dioxide; P₂O₅ = phosphorous oxide; SO₃ = sulfur trioxide; K₂O = potassium oxide; Fe₂O₃ = ferric oxide; Na₂O = sodium oxide.

1. Typical lime mud composition [3].

- Increased consumption of bleaching chemicals
- Lower pulp brightness
- Increased scale in the recausticizing plant
- Increased metal content in pulp that negatively affects pulp quality

Silicon

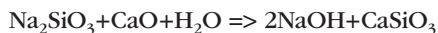
Silicon (Si) is mostly found in dissolved form in the green liquor, and its main sources include wood, talc, biosludge, and dust (sand). Excessive application of silicon-based foamers can also be a source of silica [11]. Silica (SiO₂) is one of the components of scale formed on heat transfer surfaces in the evaporation of black liquor and digester [16]. High levels of silica buildup reduce lime reactivity and porosity and lead to formation of calcium silicate that remains in the lime mud during the causticizing reaction because of its low solubility in the white liquor. Lime availability decreases by about 6% by weight if the lime contains 1% Si by weight [16]. Silica forms dicalcium silicate with CaO in

the lime kiln and binds moisture to the lime mud as it creates a large surface area after reacting with water. As a result, lime mud pre-coat filter cake discharge solids drop, leading to an increase in lime kiln fuel consumption.

Figure 1 shows lime mud dry solids level after the lime mud filter at different SiO₂ levels.

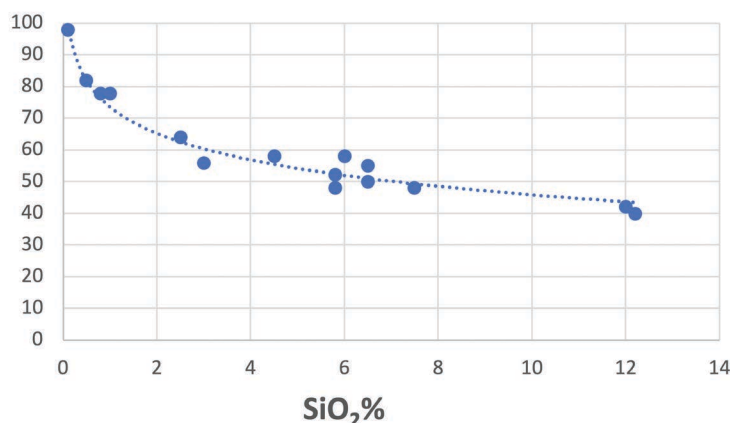
Silica causes a reduction in the rate of sludge sedimentation in the liquor clarifiers, reduces the reactivity of the re-burnt lime, increases ring formation due to sintering in the lime kiln, and is responsible for inferior quality of the burnt lime. It also reduces causticizing efficiency, resulting in higher alkali losses as mills tend to discharge a higher amount of lime sludge. Silica also increases grits rejection in the slaker. This, in turn, increases the makeup lime content and handling expenses for discharged lime sludge [4,6].

Mills in India that see high silica content when using nonwood fibers such as rice straw, reed, and/or bamboo for pulp production are following a two-stage causticizing process to purge silicon. The two-stage causticizing concept is based on the faster reaction of burnt lime with sodium silicone (tri)oxide.



Lime is added in two stages in green liquor. In some mills the high silicon lime mud generated in first stage is used by the cement industry, whereas in others it is purged. Low silicon mud from the second stage is used in the lime kiln [7].

Recent data has suggested that silica precipitates as an unknown compound composed of magnesium-aluminum-silicon (Mg-Al-Si) in green liquor sludge and green liquor filters. The unknown compound is shown to have drastically poor filtration properties [5]. Silica can be effectively removed from green liquor by the addition of magnesium sulfate (MgSO₄) or carbonate and can be reduced by a factor of 10 by addition at a 5:1 ratio of Mg:Si (atoms Mg/atoms Si) in raw green liquor. Silica intake in the white and black liquor can be controlled by using a low Si content lime [16].



1. Variability of lime mud dry solids with silica (SiO₂) level in lime mud [15].

Aluminum

Aluminum (Al) forms sodium aluminate and is moderately soluble in green liquor and white liquor. It enters the mill through wood, biosludge, makeup chemicals, and dust (sand). Apart from acting as an inert in the lime cycle, Al is also one of the components of scale formed on heat transfer surfaces in evaporation of black liquor and the digester [16]. Aluminum is purged from the liquor cycle as it forms hydrotalcite with magnesium (Mg) and aluminosilicates with Si. Excess aluminum can be purged by precipitation by adding MgSO_4 to green liquor to obtain an Mg/Al ratio of greater than 3:1 (preferably 5:1) [4,5,11].

Magnesium

Magnesium originates from MgSO_4 , talc, wood, biosludge, and lime makeup and resembles lime in its chemical reactions. Magnesium can cause corrosion in the evaporation process of black liquors [16]. Magnesium oxide scale formation is rare but is observed if dregs removal is inefficient [11]. Magnesium hampers mud filtration, as it has a large surface area per unit mass and resembles free lime in lime mud. High levels of Mg lead to formation of gelatinous magnesium hydroxide ($\text{Mg}(\text{OH})_2$) that does not causticize Na_2CO_3 and hinders lime mud separation. The $\text{Mg}(\text{OH})_2$ also causes problems with green liquor clarification, as it forms fine particles that are difficult to settle without using flocculation aids. The Mg/Al ratio in green liquor is crucial, as Mg precipitates as hydrotalcite with good dewatering properties and can be removed with dregs [4,5].

Iron

Iron (Fe) enters the mill through wood and makeup chemicals and as a result of corrosion. Iron catalyzes hydrogen peroxide decomposition under alkaline conditions, resulting in poor pulp strength properties and low pup viscosity [16]. Iron negatively affects the pulp and viscose process [13]. Iron precipitates as ferrous sulfide (FeS) in green liquor and is removed with the green liquor dregs. Accumulation of Fe in the lime cycle causes FeS to convert into dicalcium ferrite during recalcination, changing the lime mud color to green but not significantly affecting the causticizing or filtration properties. The dust concentration in the lime kiln can significantly increase due to accumulation of iron. Iron exists as ferrous hydroxide ($\text{Fe}(\text{OH})_2$) in white liquor and weak wash and has been attributed to filter cloth plugging of a crossflow green liquor filter at LP Samoa [4,5,9]. Iron has low solubility in green liquor and is ejected with the green liquor dregs [16].

Manganese

Manganese (Mn) is introduced mainly via wood and has low solubility in green liquor and white liquor. Manganese catalyzes hydrogen peroxide decomposition under alkaline conditions, resulting in poor pulp strength properties and low pup viscosity [16]. Manganese dioxide scale formation is un-

Element	% in d.s.
Al	0.25–0.5
Fe	0.6–0.2
Mn	1.5–2.5
Mg	3–5
Ca	8–15
C (char)	2–10
d.s. = dry solids; Al = aluminum; Fe = iron; Mn = manganese; Mg = magnesium; Ca = calcium.	

II. Composition of green liquor dregs [15].

Element	Distribution	
	% Dissolved	% in Dregs
Mg	<3	>97
Mn	<6	>94
Fe	<11	>89
Al	92	8
Si	99.5	0.5
Mg = magnesium; Mn = manganese; Fe= iron; Al = aluminum; Si = silicon.		

III. Distribution of non-process elements (NPEs) in green liquor [15].

common but is observed if dregs removal is inadequate [11]. Manganese forms manganese hydroxide or manganese sulfide and is mostly removed along with the dregs [4,5,9].

Phosphorous

Phosphorous (P) enters the mill through wood, biosludge, and possibly lime kiln fuel and low-quality makeup lime, and has high solubility in both green liquor and white liquor. It tends to accumulate in the lime cycle, as the removal through green liquor dregs is very low. Phosphate will also bind available lime to form calcium phosphate and thus increase the inert load in the lime cycle, reducing the availability of lime by 5.4 wt% for every 1 wt% of P. Calcium phosphate compounds formed during slaking have low solubility in green and white liquors. Not all P reacts with calcium in slaking and recausticizing. The unreacted P gets carried by the white liquor to the digesters and ends up in the black liquor, with the main purge points being slaker grits and precipitator catch to sewer [4,5,8].

Green liquor clarification and filtration

Green liquor dregs removal is perhaps the most important mechanism for removal of NPEs from the kraft process. **Table II** gives an example of the composition of green liquor dregs. **Table III** shows that the major portion of impurities in green liquor—such as Mg, Mn, and Fe—is present in suspended form and can be separated employing mechanical separation techniques. A comparison of green liquor treatment is shown in **Table IV**.

Green Liquor	Suspended Solids	Mg	Mn	Fe	Cu	Al	Si	Ca	Ba	Pb
Clarifiers	83–90	98	67–72	48–51	38–52	21–28	-	-	-	-
Filtration technologies	98–99	96–99	88–94	53–94	30–54	33–69	17	47	52	21

Mg = magnesium; Mn = manganese; Fe = iron; Cu = copper; Al = aluminum; Si = silicon; Ca = calcium; Ba = barium; Pb = lead.

IV. Percentage removal of impurities by various green liquor treatments [2,15].

Clarification

Green liquor mainly consists of Na_2CO_3 , sodium sulfate (Na_2SO_4), Na_2S , unburnt char, and NPEs. Green liquor should be purified by removing dregs to protect the lime cycle from contamination, decrease the amount of makeup lime required, and reduce other issues in the recausticizing cycle, as discussed in the previous section. Sedimentation that uses the density difference between the solid material and the green liquor has been the traditional way of separating green liquor dregs. The green liquor clarifier overflow rise rates are in the range of 0.4–0.5 m/h and should not exceed 0.6 m/h, with a typical retention time of 12 h. The dregs that settle at the bottom are removed through an outlet with the help of a rake. The purified green liquor in the overflow often contains 60–100 mg/L of suspended solids, whereas the consistency of the dregs underflow is 2%–5% [4,10,14].

Pressure disc filters

Pressure disc filters are used to purify both green and white liquor to achieve less than 20 mg/L of suspended solids by applying pressure in a closed cylindrical vessel that rotates on a central axis with several filter discs. Lime mud is used as a filter precoat and acts as a filtration media, allowing the fresh mud to be washed and dewatered while minimizing blinding of the filter screen by fine lime mud particles present in fresh mud. Wash showers are used to wash the sludge cake, which is continuously scraped off and disposed under the scraper [4,10].

Cassette filters

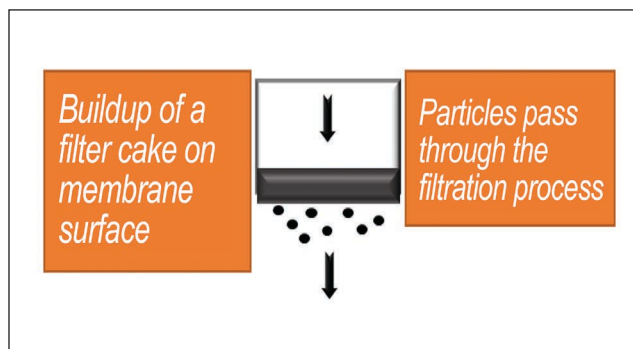
The purified liquor normally flows through the inside of the filter elements. At a predetermined total volume or a target pressure setpoint, filter elements of the cassette filter are periodically cleaned of dregs using a short reverse flow, low-pressure back-pulse that knocks the dregs cake off. There is no lime mud consumption in the cassette filter, but common challenges include plugging and rupture of filter medium [4,10].

Falling film filters

Filtration occurs across the flow direction by use of a falling film and thus effectively avoids plugging of the filter elements. In this design, the filter vessel is under pressure and consists of number of vertical filter elements. Green

liquor flows from top of the vessel, forming a film on the surface of the filter media to the bottom of the vessel from where it is recirculated to the top again. Compressed air provides the driving force for the green liquor to pass across the filter media while the dregs form a cake on the surface of the filter elements. This kind of filter does not use lime mud as a filter aid and provides a relatively higher dregs solid content. However, the dregs must be washed and dried before being sent to landfill [4,10].

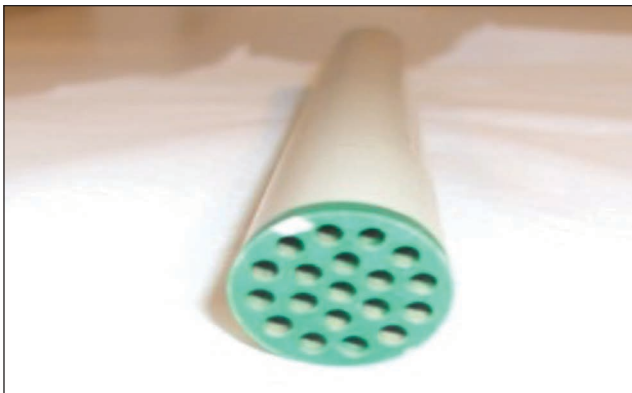
The pulp and paper industry frequently faces challenges that require process improvements to remain competitive. These challenges may include a need to increase production capacity and profitability, improve product quality, meet more stringent environmental regulations, reduce water usage, and adopt stricter energy policies. Microfiltra-



2. Traditional dead end filtration.



3. Crossflow filtration.



4. Ceramic microfiltration rod.

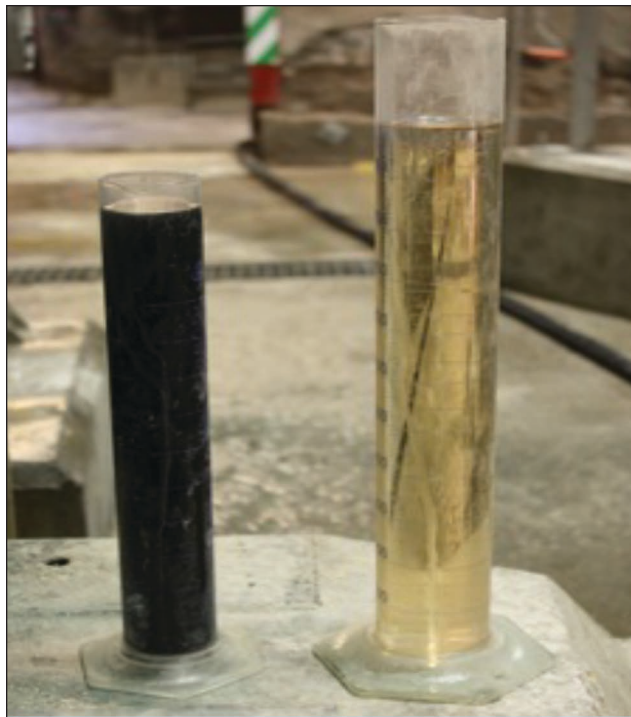


5. Filter holder.

tion removes nearly all suspended particles of the green liquor, leading to potential economic gains. Increase in capacity can be achieved by installing the system in parallel with the existing overloaded conventional liquor filters or clarifiers. Alternatively, improvement in liquor quality can be accomplished by installing microfiltration in series as a polishing step after the existing white liquor filtration or clarification equipment. The use of microfiltration could lead to an increase in process uptime and a decrease in makeup lime consumption and filter wear and maintenance. In addition, the other advantages of a decrease in NPE's are discussed in the previous sections.

MICROFILTRATION SYSTEM

Microfiltration is a way of removing contaminants in the size range of 0.1–10 μm from fluids or gases by passing through a microporous medium, such as a membrane. Microfiltration covers both dead end filtration and crossflow filtration. Dead end filtration is generally used for concentrating compounds, whereas crossflow is mostly used to filter liquids with higher concentration of suspended solids. Dead end filtration, as shown in **Fig. 2**, is a batch process, and it is the most basic form of filtration in which the filtered matter accumulates on the surface of the membrane while the feed passes through it. Eventually, the filtration capacity decreases due to clogging, after which the accu-



6. Green liquor before and after filtration: 3000 mg/L reduced to <6 mg/L.

mulated matter is removed. In crossflow filtration, the fluid stream runs tangential to the membrane (**Fig. 3**), establishing a pressure differential across the membrane causing some of the particles to pass through the membrane while the remaining continue to flow across the membrane, “cleaning” it. The use of turbulent tangential flow prevents thicker particles from building up a filter cake on the membrane [12]. The purified liquid passing through the membrane is called permeate, and the concentrated sludge flow fraction not passing through the membrane is called retentate. Continuous operation without frequent cleaning is the main advantage of a crossflow filter over other filters.

CleanFlow technology

The patented CleanFlow™ technology is based on crossflow filtration, enables removal of practically all particles, and was developed in collaboration with the Royal Institute of Technology in Sweden (KTH). The crossflow filter (**Fig. 4**) consists of a long tubular ceramic membrane element of 1.5 m in length perforated with 19 parallel channels. The ceramic rods have a pore size of 0.1 μm –1 μm . The green liquor flows through these channels, with the filtrate passing through the porous membrane channel walls in a radial direction from the inside to the outside of the channels. The rods have a proven lifetime of approximately 3 years. The ceramic rods are housed in a filter holder that holds up to 46 of them (**Fig. 5**). The system comes in modules with two filter brackets forming one filter module.

Figure 6 shows green liquor reduced to <6 mg/L from 3000 mg/L after filtration. Measurements have been carried

Parameter	Unit	Unfiltered Liquor	Filtered Liquor
Ca	mg/L	54.6	<10
Fe	mg/L	7.26	<0.5
Mg	mg/L	49.7	<7
Al	µg/L	21,900	8,440
As	µg/L	<20	58.1
Ba	µg/L	2050	1520
Cd	µg/L	19.9	<1
Co	µg/L	10.8	<5
Cr	µg/L	321	<20
Cu	µg/L	<20	<20
Hg	µg/L	<10	<10
Mn	µg/L	31,800	935
Ni	µg/L	229	95.5
Pb	µg/L	<10	<10
Zn	µg/L	2970	<90

Ca = calcium; Fe = iron; Mg = magnesium; Al = aluminum;
As = arsenic; Ba = barium; Cd = cadmium; Co = cobalt;
Cr = chromium; Cu = copper; Hg = mercury; Mn = manganese;
Ni = Nickel; Pb = lead; Zn = zinc.

V. Chemicals in a green liquor sample before and after crossflow filtration.

out on the green liquor at Munksjö Aspa Bruk AB mill in Sweden, where the microfiltration technology has been commercially used since 2014. The analysis of green liquor in **Table V** shows significant results in removal of metal ions such as Mn, Al, Ca, Fe, and Mn after filtration.

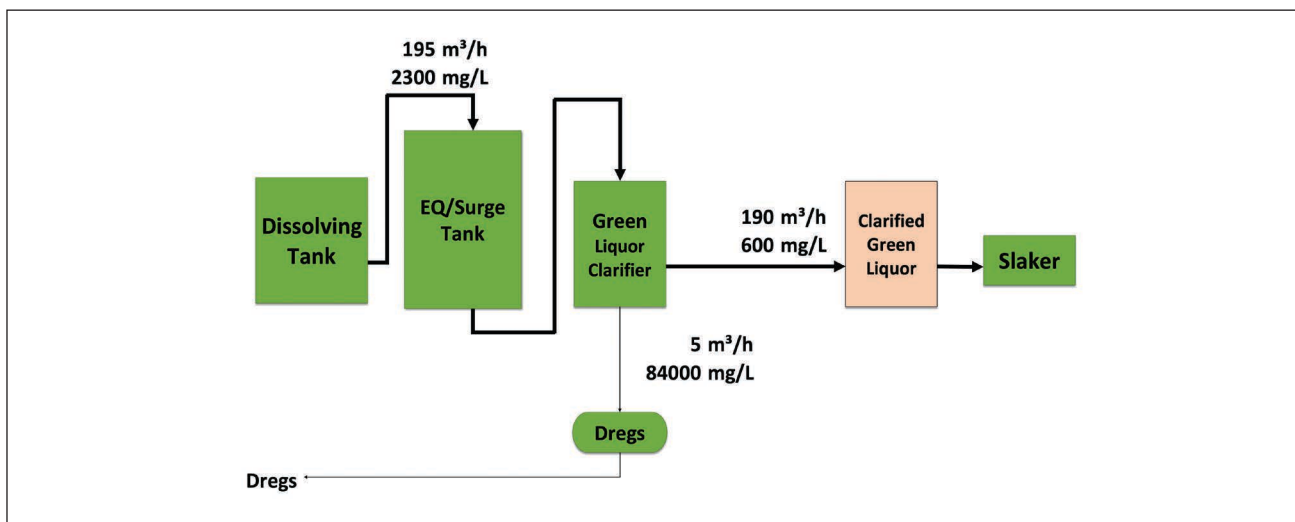
Flow diagram

Green liquor

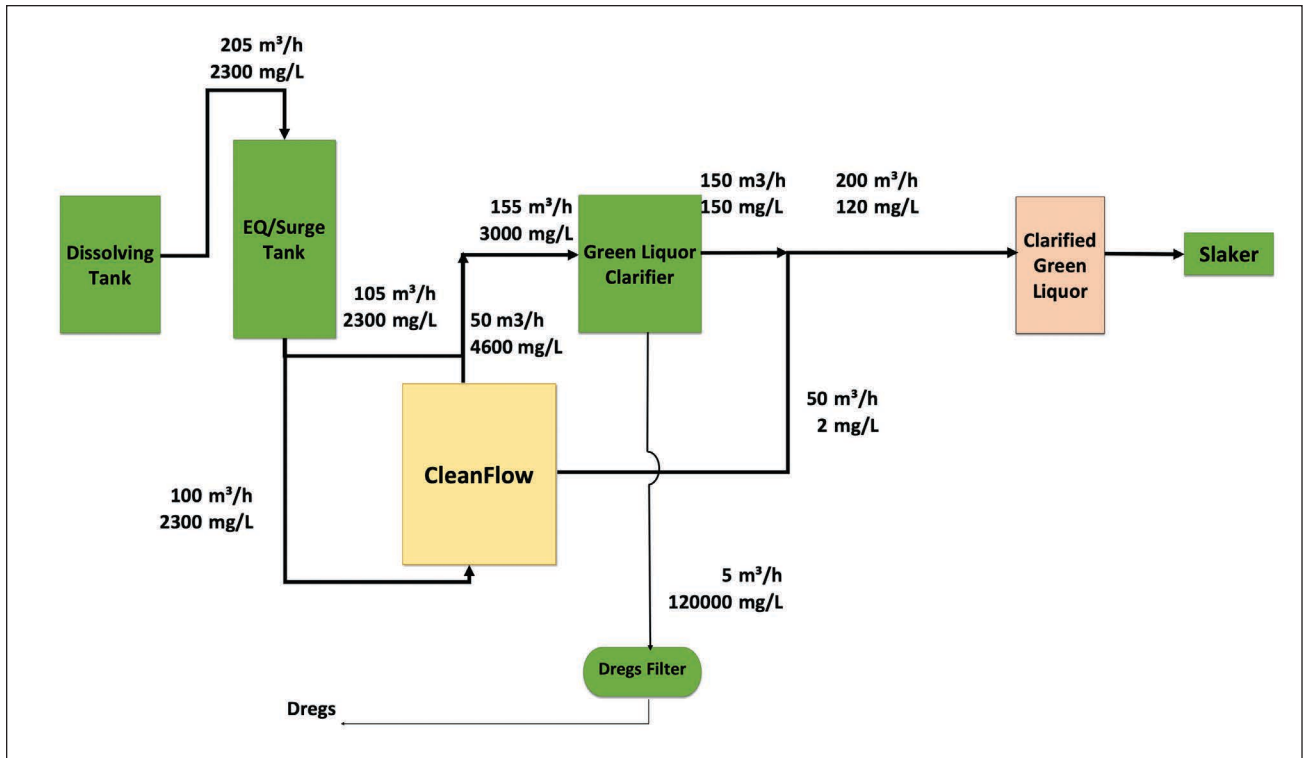
Figures 7 and 8 show a typical installation to debottle-neck green liquor systems. Prior to upgrading with the microfiltration system, the existing green liquor clarifier was too small for the flow of 195 m³/h to the green liquor clarifier from the surge tank, resulting in a dregs content of 600 mg/L to the slaker. In this case, the objective of the microfiltration system was to increase green liquor production by 10 m³/h and reduce the dregs carryover. In this application, 100 m³/h from the dissolving tank is pumped to the microfiltration system, producing 50 m³/h of permeate at 2 mg/L dregs and 50 m³/hr of retentate. With the implementation of the microfiltration system, the flow to the clarifier is reduced to 155 m³/h, reducing the rise rate to an acceptable level and allowing for a lower dregs content of 150 mg/L in the clarifier overflow. When combined with the 50 m³/h from the microfiltration system, the resulting green liquor flow to the slaker is increased to 200 m³/h and the dregs to the slaker are reduced to 120 mg/L compared to 600 mg/L before installing the microfiltration system. There are two separate cleaning sequences for the membranes, both engaged automatically.

White liquor

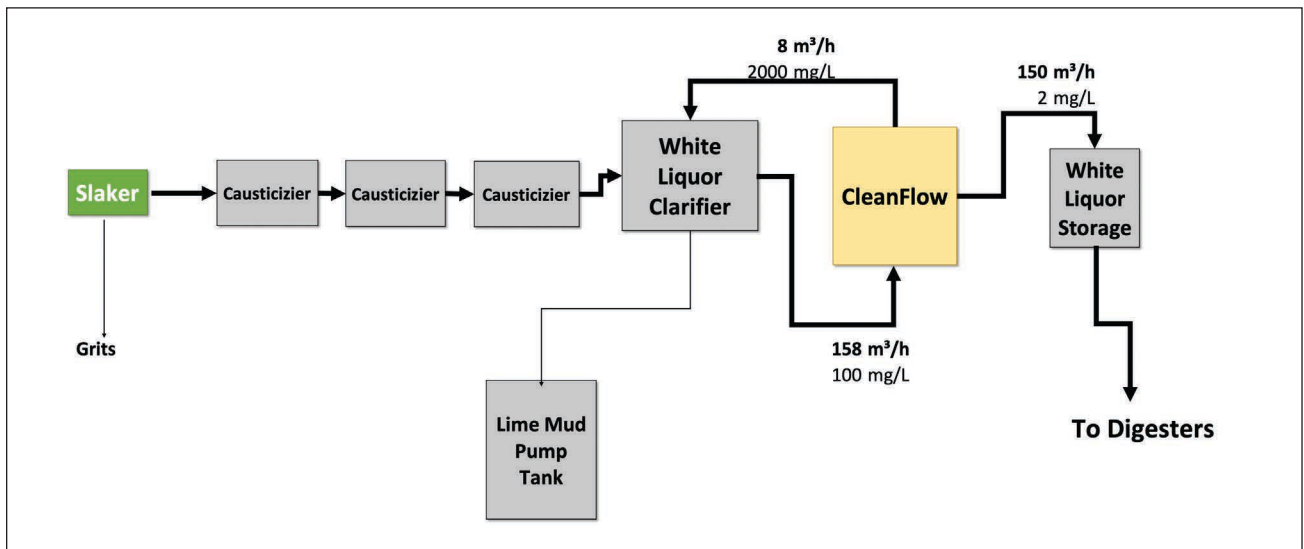
Microfiltration can also be implemented to filter white liquor, either the entire stream where white liquor clarity is required (such as dissolving pulp mills) or just a portion, for oxidized white liquor production and for scrubbing of the bleaching system vents. White liquor can be further polished by the microfiltration system, as shown **Fig. 9**. The suspended solids content in the design flow of 150 m³/h is reduced from 100 mg/L to 2 mg/L by installing a microfiltration system, with only 8 m³/h returned to the white liquor clarifier.



7. Overloaded green liquor clarifier.



8. Green liquor clarifier with microfiltration system (EQ = equalization).



9. Typical white liquor microfiltration system.

Process description

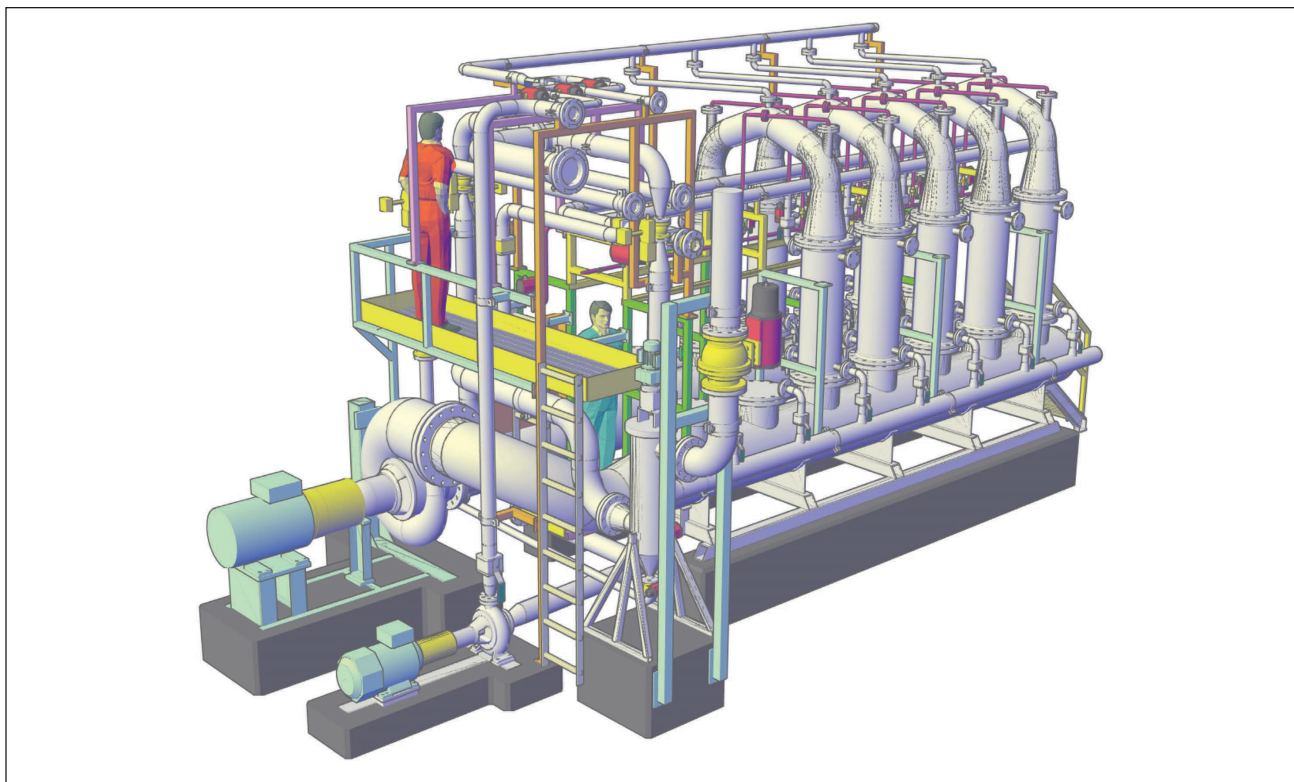
A microfiltration system designed for 100 m³/h is shown in **Fig. 10**. The microfiltration system package consists of the following main pieces of equipment:

- Transfer pump
- Pre-filter (coarse)
- Ceramic filter modules (fine)
- Circulation pump
- Drainage/draining pump
- Acid pump

- Nozzle clean pump
- Instrumentation and wiring

Transfer pump and prefilter

The transfer pump pumps the flow from the dissolving tank or equalization tank to the microfiltration system and keeps the system pressurized to a target value. Oversized particles and scale from the equalization tank, larger than 300 µm, are removed by a prefilter before entering the ceramic rods to prevent clogging of the ceramic rods.



10. A 3D-model of the microfiltration system.

Circulation and crossflow filtration

After the prefilter, the liquor enters the microfiltration system at the suction side of the circulation pump. The circulation pump maintains a turbulent flow to eliminate the risk of sedimentation inside the ceramic channels. The system pressure is adjusted to maintain the filtered green liquor flow setpoint.

The microfiltration is done in ceramic modules, containing multiple ceramic rods per module. Each rod is approximately 25 mm in diameter. The filter modules are placed in parallel lines with two modules in series.

The accepted filtrate from the ceramic rods is sent to the green liquor storage on flow control. A bleed from the circulating loop is sent to the existing green liquor clarifiers on flow control. The ceramic rods are secured in the module with a flange at both ends. An O-ring is used to ensure the system is leak free. In each ceramic rod, there are multiple channels. The expected lifetime of the ceramic rods is 2–4 years.

The system is fully automated and is delivered with a programmable logic controller (PLC) system, which means that the operators can run the system from the control room. The integrated clean-in-place (CIP) system also makes it possible to run fully-automated cleaning sequences, which reduces the system's downtime. The CIP consists of two separate sequences: one uses formic acid to remove acid soluble substances, and the other removes non-acid soluble substances.

Process control

The guiding principles for the microfiltration process control are to optimize the energy efficiency of the unit, while maximizing the runtime between acid washes and maintaining a high availability of the unit. The unit is automated with sequences for start, acid wash, nozzle clean, stop, standby mode, and resume.

The pressure in the system is set depending on the capacity and is optimized so that the permeate flow control valves are open to minimize the power consumption on the transfer pump. System pressures are less than 5 bar.

Acid wash system

An acid wash is necessary to clean the membranes from acid soluble deposits such as lime mud particles. The acid wash system consists of an acid tank, acid pump, and flow meter. The whole wash sequence is planned to take less than 30 min. The typical time between acid clean cycles is 1–4 days and depends on the incoming dregs content.

Nozzle clean special wash

Every 2–4 weeks, an additional wash is required to clean the membranes of any acid insoluble deposits. Spray nozzles are installed on the top of the modules and are connected to the top headers. The wash chemical is transported from the dosage pump into the nozzles in a sequence. The expected duration of the nozzle clean is 45 min.

CROSSFLOW MICROFILTRATION SYSTEM AT ENCE PONTEVEDRA MILL

Overview

CleanFlow AB (Forshaga, Sweden) delivered a 100 m³/h green liquor system during the summer of 2019 to the Ence Pontevedra pulp mill in Spain. The system was manufactured in Forshaga, Sweden, including instrumentation and PLC. The factory acceptance testing and water batching was performed in Forshaga to enable for a quick startup on site.

The disassembly and shipment was smoothly accomplished, as the system is modular and constructed to fit in a trailer, as shown in **Fig. 11**.

The flow diagram of the microfiltration system is shown in **Fig. 12**. Microfiltration at the Ence mill works as a booster to existing green liquor filtration that was limited by capacity. In this case, the entire flow of 182 m³/h from the equalization tank is pumped to the microfiltration system. The dregs content in the green liquor being pumped from the equalization tank is ~3000 ppm. In the microfiltration system, 100 m³/h of permeate generated by cross-flow filtration is sent to the pump tank and eventually to the slaker, whereas 82 m³/h of retentate is sent to existing clarifiers. The sludge is then removed from the system by the outtake on the clarifiers.

Green liquor quality before and after

The incoming sludge content from the dissolving and equalization tank is normally 3000 mg/L. **Table VI** shows that before the microfiltration installation, the two existing clarifiers were hydraulically overloaded, with the rise rate

at 0.76 m/h compared to a recommended rate of 0.4–0.55 m/h [14]. The suspended solids content in clarified green liquor going to the slaker was 250 mg/L. The hydraulic load on the existing clarifiers was reduced after the installation of microfiltration, with the suspended solids from the clarifiers dropping below 50 mg/L. The suspended solids content in the permeate flow from microfiltration is below 6 mg/L. The flows from the clarifiers and microfiltration are mixed and as a result, the combined flow going to the slaker is 176 m³/h with a much-reduced sludge content of 25 mg/L compared to the previous value of 250 mg/L.

Results and discussion

Since the microfiltration system is premanufactured before the delivery, the installation on site works relatively smoothly. The customer had molded the foundations for the skid and the pumps before the equipment arrived, and the skid was lifted in place by a crane on site.

While the system was being installed, education sessions were held with the operation and maintenance staff to prepare them for startup.

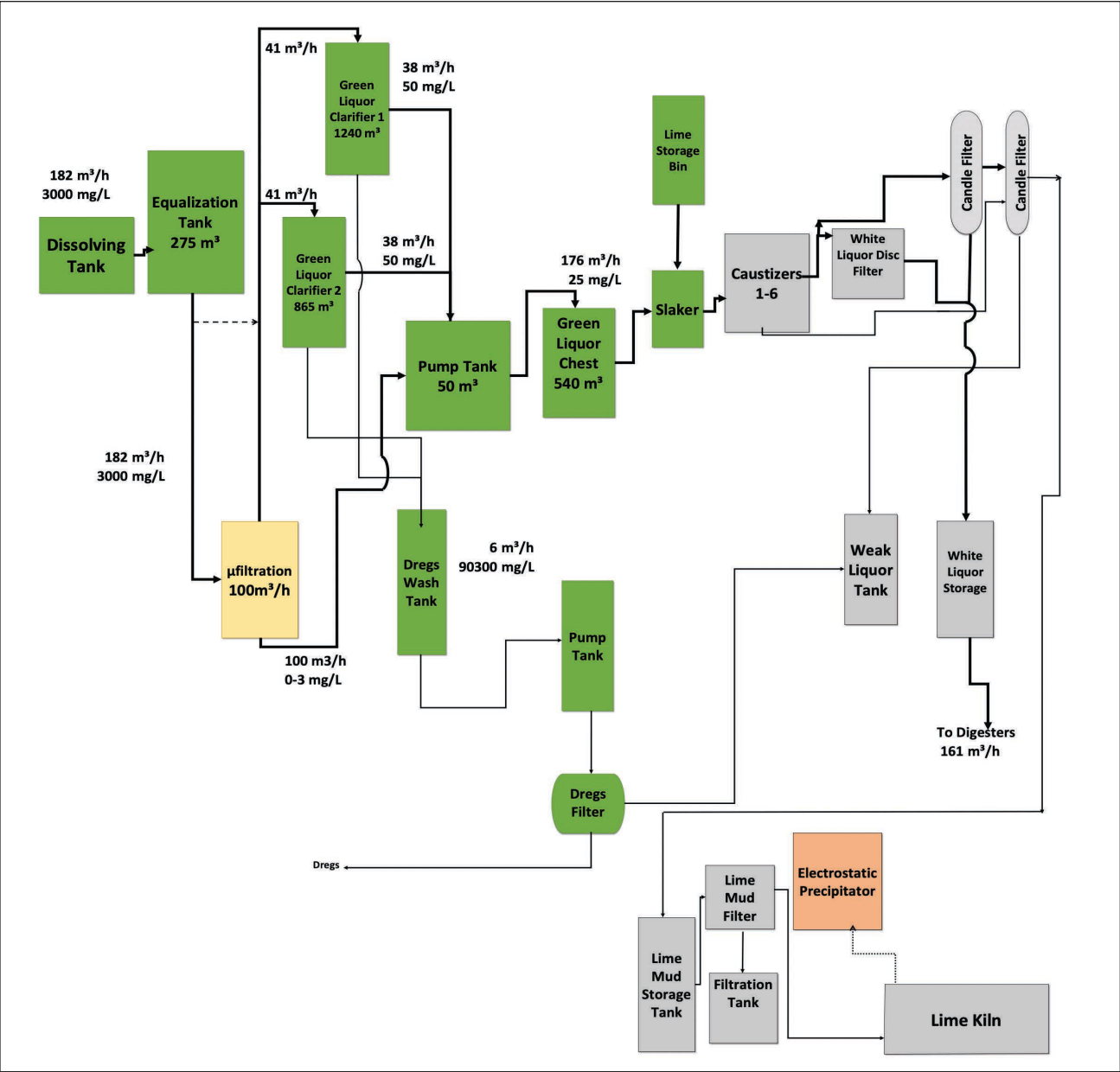
The first few days of test runs were smooth, with clear permeate flow. However, after the initial run, minor abrasion on the prefilter scrapers was observed. The prefilter is crucial for runnability, as it removes oversized particles and prevents them from entering the channels of the ceramic rods. To troubleshoot, the pump's connection was raised to a minimum of 1.5 m above the bottom level to avoid scale and chunks from the equalization tank entering the system.

Calculations of the sludge content impact when it decreases



11. Skid for the Ence Pontevedra mill's patented CleanFlow system.

PULPING



12. Flow diagram for the complete recausticizing.

	Unit	Without Microfiltration	With Microfiltration Booster of 100 m³/h
Load on green liquor clarifiers	m³/h	171	82
Green liquor to slaker	m³/h	165	176
Green liquor to microfiltration	m³/h	0	182
Solids in green liquor to slaker	ppm	250	25
Residence time in green liquor clarifier 1	h	14.6	30.4
Rise rate in green liquor clarifier 1	m/h	0.76	0.36
Residence time in green liquor clarifier 2	h	10.1	21.2
Rise rate in green liquor clarifier 2	m/h	0.76	0.36

VI. Comparison of a few key variables before and after microfiltration installation.

es from 200 ppm to 5 ppm for a standard mill demonstrate that the energy savings in the lime kiln and from reduced fresh lime usage is in the range of \$USD 0.5–1 MM per year.

CONCLUSIONS

Microfiltration removes nearly all particles from the green liquor: from 3000 mg/L of sludge to <6 mg/L and is an efficient method for removing NPEs. The effective removal of non-process related substances allows for the lowest possible pulp production cost and landfill needs. The purity allows for a lower degree of makeup chemicals or for a lower degree of inert content at the same degree of makeup chemicals. The lowered amount of inert content reduces makeup lime consumption, improves the lime dewatering, and lowers the energy consumption. Microfiltration of white liquor provides an opportunity for pulp mills to optimize chemical management along with effectively removing

metal particles, leading to a near-zero metal content in pulp that results in high-quality paper products and high-quality dissolving pulp. Microfiltration provides additional filtration capacity in modules that can be adapted to the needs of the mill. The microfiltration system can be effectively applied to increase the capacity of the recausticizing plant, along with increasing quality of both green and white liquors by providing effective solids/liquid separation. **TJ**

LITERATURE CITED

1. Green, R.P. and Hough, G.S., Eds., *Chemical Recovery in the Alkaline Pulp Processes*, 3rd edn., TAPPI Press, Peachtree Corners, GA, USA, 1992, pp. 119-124.
2. Marcelo, M., "Green liquor filtration at Aracruz Celulose Mill: Causticizing and effluent close-up, pilot plant and practical results," *Int. Chem. Recovery Conf.*, TAPPI Press, Peachtree Corners, 1998, pp. 547-560.

ABOUT THE AUTHORS

Recausticizing limitations resulting from the push to increase pulp production for competitiveness in global markets; non-process elements (NPEs); and the growing popularity of the microfiltration technique led to the research in this paper. The research is based on a mill project that was carried out to troubleshoot recausticizing capacity limitations and green and white liquor clarity issues. This research provides a detailed literature review of the effects of NPEs and a unique study of a kraft pulp mill that employs a microfiltration system on green liquor.

The most difficult aspect of this research was to narrow down the list of multiple variables that affected recausticizing capacity and quality. We addressed this issue through a thorough literature survey and chemical analysis of green liquor.

We discovered that the microfiltration technique can be effectively adapted for the pulp and paper industry for purposes of filtering green and white liquor. We also discovered the specific role of NPEs in the recausticizing process. Our most interesting findings were that the clarity of green and white liquor can be substantially improved by the crossflow filtration technique, along with the positive effects of flushing NPEs from the system.

Mills can benefit from the extensive literature on NPEs and existing green and white liquor clarification/filtration technologies in this paper. They can also benefit from the detailed information on adapting the crossflow microfiltration technique for the recausticizing process.

Our next step is to gather more data from mills



Bandekar



Oldmark



Lindstrom



Kallen



Liedberg



Foan



Wearing

that will potentially install this microfiltration system and also from a pilot crossflow filtration system.

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PULPING

3. Tran, H., "Lime kiln chemistry and effects on kiln operation," *TAPPI Kraft Recovery Course*, TAPPI Press, Peachtree Corners, 2007.
4. Gullichsen, J., Paulapuro, H., and Fogelholm, C.-J., Eds., *Papermaking Science and Technology, Book 6B. Chemical Pulping*, Fapet Oy, Helsinki, 2000, pp. 135-200.
5. Bialik, M., Jensen, A., and Ahlroth, M., *TAPPI J.* 14(7): 421(2015). <https://doi.org/10.32964/TJ14.7.421>.
6. El-Ebiary, M. and Hackl, H., "Desilication of black liquors," *Pulping Conf.*, TAPPI Press, Peachtree Corners, 1982, p. 219.
7. Baskaran, S., Palanisamy, C., and Chinnaraj, S., *IPPTA* 25(2): 131(2013).
8. Mousavi, S. and DeMartini, N., "Fate of phosphorous in the lime cycle of the kraft pulping process," *TAPPI PEERS Conf.*, TAPPI Press, Peachtree Corners, 2019.
9. Ledbetter, R., Pettit, R., Jaegel, F., et al., "Impact of falling film, crossflow green liquor filtration and modified kraft cooking on mill closure at Louisiana Pacific, Samoa Mill," *Minimum Effluent Mills Symp., Proc.*, TAPPI Press, Peachtree Corners, 1997.
10. Shrinath, A. and Buettner, C., "A review of issues related to green liquor quality, and approaches towards improved clarification," *Pulp Pap. Int. Congr.*, ABTCP/TAPPI, São Paulo/Peachtree Corners, 2000.
11. Hart, P., *TAPPI J.* 17(10): 571(2018). <https://doi.org/10.32964/TJ17.10.571>.
12. Porter, M.C., *Handbook of Industrial Membrane Technology*, Noyes Publications, Westwood, NJ, USA, 1990.
13. Christoffersson, K.E., "Dissolving pulp—Multivariate characterisation and analysis of reactivity and spectroscopic properties," Ph.D. thesis, Umeå University, Umeå, Sweden, 2005.

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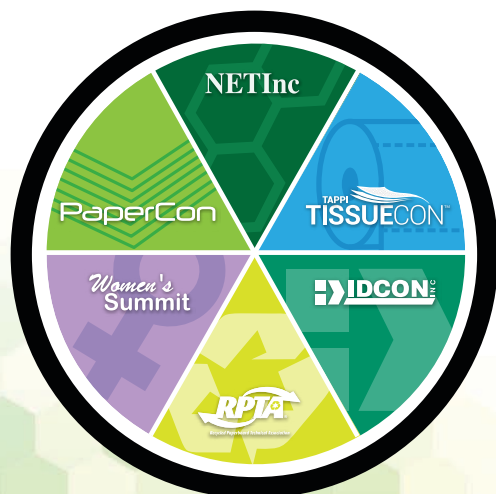
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14. Sanchez, D., "Recausticizing principles and practice," *TAPPI Kraft Recovery Course*, TAPPI Press, Peachtree Corners, 2000, p. 17.
15. Nevalainen, A., "Opportunities in green & white liquor handling towards MIM-concept," *Minimum Effluent Mills Symp., Proc.*, TAPPI Press, Peachtree Corners, 1997.
16. Ulmgren, P., "Non-process elements in a bleached kraft pulp mill with increased system closure," *Minimum Effluent Mills Symp., Proc.*, TAPPI Press, Peachtree Corners, 1996.



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