Implications of converting a kraft pulp mill to a dissolving pulp operation with a hemicellulose extraction stage

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ABSTRACT: Global demand for dissolving pulp has been increasing at a remarkable pace over the last few years. A shortage in cotton and the expansion of the textile, hygiene, and health product markets are behind this booming demand. The Canadian pulp and paper industry has entered these markets by converting several paper-grade pulp mills to dissolving pulp producers. In the kraft process, part of the hemicellulose remains with the pulp after cooking and the rest is burnt in the recovery boiler to produce energy. In dissolving pulp mills, most of the hemicellulose must be removed from the wood chips in a pre-hydrolysis stage before pulping. Hemicellulose hydrolysis and its subsequent extraction will affect energy and chemical balances. In addition, the new operation will require large capital expenditures. The objective of this work was to study the conversion of a kraft pulp mill to a dissolving pulp operation and the extraction of hemicelluloses from the process. The effects of hemicellulose extraction on mill energy balance, equipment requirements, and new operating conditions were analyzed. Computer simulations of the process and thermal pinch analysis were used. The existing bottlenecks (digesters, lime kiln, and recovery boiler) to increasing the dissolving pulp production capacity were identified before and after the conversion. In addition, energy efficiency measures were identified to decrease the energy consumption of the new process.

Application: This work will help kraft mills that envisage a conversion to dissolving pulp operation. The energy, equipment, and operating conditions modifications are shown and an optimal conversion strategy is proposed.

The pulp and paper industry is a major contributor to the Canadian economy, accounting for 1.5% of Canada's gross domestic product [1]. The industry is under heavy pressure to remain competitive; however, because of competition from large and modern mills in tropical regions, reduced demand for commodity products, increasing energy cost, and other factors. The economic downturn in the industry led to the permanent closure of several pulp and paper mills. Therefore, to strengthen its competiveness, the pulp and paper industry needs to improve its energy efficiency, adopt cost saving measures, and diversify its product mix by identifying new, profitable markets. One such market is textile fibers.

Textile fibers are subdivided into three main types: synthetic (e.g., polyester, nylon, and acrylic), natural (e.g., cotton, linen, and wool), and cellulosic man-made fibers (e.g., viscose and acetate). Synthetic fibers have the biggest market share (55%) followed by cotton (38%) and man-made fibers (5%). The latter are produced from dissolving pulps, which are bleached chemical pulps of low hemicellulose content (about 3-4 wt.%) [2]. However, shifts in fashion styles, high oil prices, and increasing environmental concerns relating to the growth of cotton on agricultural land have altered the market dynamics and prices in recent years [3]. In particular, the growth of cotton requires large amounts of water, pesticides, and fertilizer, which negatively affect the environment.

Cellulosic man-made fibers have several advantages over their competitors, including the following [4]: use of land not required for agricultural production, low area required per metric ton of fiber produced (cellulosic = 0.8 ha, cotton = 1.3 ha, wool = 67 ha), low water requirement per metric ton of fiber produced (cotton = 5700 m^3, cellulosic = 350 m^3), and lowest carbon footprint. However, the production of cellulosic man-made fibers requires more energy than is the case for natural fibers [5]. The growing demand for viscose fiber and rayon in China and troubled cotton harvests worldwide [6] have increased the demand for and price of cellulosic fibers.

Pre-hydrolysis kraft pulping is the main process used to produce dissolving pulps. The fibers are used as the feedstock for the production of rayon textile fibers using the viscose or other processes (e.g., Lyocell). The pre-hydrolysis kraft process is a variation of the typical kraft process, with the addition of a pre-hydrolysis stage to extract the hemicellulose from wood chips before cooking. Sulfite processes also can be adapted to dissolving pulp production by modifying their operating conditions (i.e., cooking time and pH) and incorporating an alkaline extraction stage between pulping and bleaching. Dissolving pulps contain a low amount of hemicellulose (3%-4%) compared with typical paper-grade kraft pulp (10%).

Table I lists the existing Canadian dissolving pulp mills [6-9] and mills currently under conversion. Conversion of

Existing	Under Conversion
AV Nackawic, Nackawic, NB	Fortress, Lebel-sur-Quevillon, QC
AV Cell, Atholville, NB	Paper Excellence, Prince Albert, SK
Fortress, Thurso, QC	AV Terrace Bay, Terrace Bay, ON
Neucel, Port Alice, BC	
Tembec, Temiscaming, QC	

I. Existing and potential conversion dissolving pulp mills in Canada [6-9].

kraft pulp mills to dissolving pulp operation has created an opportunity to increase the profitability of existing mills and to restart some of the idle ones. However, the kraft pulp mills that have been converted did it without the advantage of an energy study and without the prospect of extracting hemicellulose from the process for the production of value-added chemicals.

The focus of this work is the conversion of a kraft pulp mill to an energy-optimized dissolving pulp operation, and the removal of hemicellulose from the process. Given the complex energy profile of the process, a simulation model is required to analyze the changes in the operating conditions resulting from the kraft process conversion. For this project, modeling and simulation were performed using CADSIM PLUS (Aurel Systems; Burnaby, BC, Canada), a leading pulp and paper simulation platform. Several technical issues encountered in the conversion were studied, including limitations in the recovery boiler, lime kiln, and digesters, and modifications to the overall energy and water balances. The extraction and removal of hemicellulose also was investigated as a way to debottleneck the recovery boiler. The objective of this study was to identify key energy issues that must be addressed to achieve the conversion as efficiently as possible.

METHODOLOGY

Simulation

A computer simulation of a kraft pulp mill has been developed in CADSIM PLUS, which is a dynamic simulator for pulp and paper processes. Several sources of information were used to define the model, including process and instrumentation diagrams (PIDs), archived data, and on-site measurements. The simulation model includes all process operations, steam and water (utilities) production, and distribution systems. Therefore, any modification to process streams is directly reflected in the utilities systems. A detailed list of compounds was modeled according to the type of process stream: water, fiber, lignin, hemicellulose, and dissolved solids (inorganic and organic). The hemicelluloses were further divided into arabinose, galactose, glucose, mannose, and xylose. Inorganic compounds (e.g., $NaOH$, Na_2S, Na_2CO_3, Na_2SO_4, SO_2, K^+, Cl^-, and $CaCO_3$) also were simulated.

Adjustments to a dissolving pulp operation

Adjustments of the kraft pulp mill simulation to achieve a dissolving pulp operation consisted of changes to the bleaching sequence, configuration of the batch digesters, and the operating conditions. Steam and water pre-hydrolysis approaches were analyzed. The pulping technology also was modified from typical batch to displacement digesters to improve the energy efficiency and alkalinity profile. This option was adopted by some mills that have converted to a dissolving pulp operation [10]. Two cases were evaluated:

1) Limiting pulp production to the existing digesters' pulp capacity
2) Increasing pulp capacity by the addition of new digesters

Hemicellulose extraction

In steam hydrolysis, most of the degraded hemicelluloses remain in the voids of the wood chips and are further degraded to saccharinic acids during the neutralization step, making them impossible to recover. For this reason, a water pre-hydrolysis stage that makes the extraction of hemicellulose feasible was considered and analyzed. The effects of hemicellulose extraction on the overall energy and water balance, recovery boiler, and the pulp production were evaluated.

Energy optimization

An energy optimization of the process was performed for each case. The objective was to evaluate the effects on energy efficiency and options to improve it as conversion proceeds. Thermal pinch analysis was used for this purpose. Pinch analysis is a structured approach used to maximize internal heat recovery within a process and to minimize its need for hot and cold energy supplied by utilities. The principles and application have been described elsewhere [11-13]. Pinch analysis must be applied to the entire process to achieve overall energy savings. The cornerstone of this approach is the display in a temperature versus enthalpy diagram of all possible heat transfers within the process; it consists of the hot composite curve and the cold composite curve, which, respectively, represent the heat availability and demand in the process. In such a diagram, the minimum energy requirement and the pinch point also can be defined. The various utilities levels required to satisfy the remaining heating and cooling demands are determined by means of the grand composite curve (GCC). The GCC represents the net thermal requirements in successive temperature zones characterized by a specific set of hot and cold streams. Internal heat recovery measures are proposed at each stage.

PROCESS DESCRIPTION

The kraft pulp mill studied has an average daily production of 748 a.d. tons/day of highly bleached pulp. The wood furnish consists of a mixture of hardwoods (i.e., maple, aspen, and birch) that are cooked in six batch digesters (185 m^3/each). The maximum steam production capacity of the recovery boiler is 150.5 tons/h. The mill has two modes of evaporation.

High pressure steam is produced in one recovery boiler and two power boilers (one biomass and one bunker oil). High pressure steam is decompressed to medium and low pressure steam to be used in the process by means of throttle valves.

KRAFT VS. DISSOLVING PULP

The essential difference between dissolving pulp and kraft pulp is the lower hemicellulose content of the former (kraft = ~10%, dissolving = ~3%). For this reason, the conversion to a dissolving pulp operation requires a pre-hydrolysis stage to extract the hemicellulose before cooking. A neutralization step also is required to neutralize the acidic compounds generated during the pre-hydrolysis stage (water and steam hydrolysis both are acidic). These additional steps increase the total reaction time and reduce the yield associated with dissolving pulp production (dissolving pulp = 38%; kraft = 48%). As a result, the maximum pulp production capacity is reduced during the conversion. The bleaching chemicals also must be adjusted to meet the target pulp specifications for the dissolving pulp grade. The focus of this work has been to study the modifications to the cooking process, digester configuration, and operating conditions, and their effect on the rest of the process. **Table II** shows the reaction conditions for the scenarios that were investigated. The conditions of steam hydrolysis are taken from an existing mill in operation. Water hydrolysis conditions are taken from the literature [14,15]. The dissolving pulp grade characteristics were as follows: viscosity = 15-18 cP, alpha cellulose ≥94%, pentosans ≤3%, S_{10} <7.9%, and S_{18} <4.9%. The hypochlorite bleaching stage (H) is used in the mill to control the viscosity of the dissolving pulp.

	Kraft	Dissolving Pulp	
		Steam	Water
Yield (%)	46	38.3	38.9
Pre-hydrolysis time (min)	-	116	115[1]
Cooking time (min)	80	48	20[2]
Total reaction time (min)	200	269	269[3]
Bleaching sequence	DEDED	DEHED	DEHED
EA consumption (% on wood)	15.5	17.5	17.5

[1] Chip steaming: 50 min; Pre-hydrolysis with water: 65 min.
[2] Compared to steam hydrolysis, chips hydrolyzed with water cook faster.
[3] Includes the water filling and pre-hydrolysate extraction time: 30 min.

II. Cooking and pre-hydrolysis conditions.

Parameter	Value
Input hot water-to-wood chips ratio	3:1
Extracted hydrolysate-to-wood ratio	2:1
Water temperature	170°C
Pre-hydrolysate cooling temperature	40°C
Sugars concentration in pre-hydrolysate	36 g/L
Other solids (lignin, acetate, etc.) concentration in pre-hydrolysate	23 g/L

III. Parameters for hemicellulose hydrolysis and extraction.

PRE-HYDROLYSIS METHOD

Several pre-hydrolysis processes could be implemented in a dissolving pulp mill, including steam (autohydrolysis), hot water, and acidic or alkaline media. Each of the pretreatment processes has its advantages and disadvantages [16], but the focus of this study is on the two industrially practiced processes: hot water and steam.

Hot water hydrolysis

Hot water hydrolysis is carried out at 150°C-180°C. The cleavage of the acetyl group causes the release of acetic acid which is used as a catalyst to hydrolyze the glycosidic bonds [16]. The resulting pH of the pre-hydrolysate is between 3 and 4. Hence, a neutralization step is needed before the alkaline cooking step. The advantage of this approach is that the extracted hemicelluloses are solubilized in water and can be removed from the digester. These hemicelluloses are mainly in their oligomeric form and might have to be converted to their monomeric form, depending on the type of value-added product to be produced. The pressure in the digesters is normally released to drain the pre-hydrolysate; however, this causes a drop in temperature, which is associated with the formation of pitch-like compounds resulting from condensation reactions (i.e., from lignin) [17,18], with a high tendency for precipitation and stickiness [16]. Therefore, the removal of hemicelluloses following water pre-hydrolysis requires maintaining high pressures and temperatures to avoid lignin condensation.

The concentration of the sugars in the pre-hydrolisate can vary between 20 g/L and 50 g/L, depending on the raw material and operating conditions [14,15]. In the case studied, the conditions shown in **Table III** were used.

Steam hydrolysis

Steam hydrolysis is carried out at 170°C. Essentially, this method follows the same principles as water hydrolysis; however, most of the hemicellulose remains within the chips [16]. The subsequent step is neutralization using an alkaline solution, during which hemicelluloses are degraded. This degradation makes it impossible to recover the sugars initially present in the wood chips.

Steam hydrolysis is probably preferred if the aim is to only produce dissolving pulp. However, if the objective is to maintain the chemical integrity of the hemicelluloses and remove them from the process for the production of high-value chemicals, water hydrolysis is advantageous. Either of these choices has energy implications that will be discussed in the following sections.

Adjustment to dissolving pulp operation

Modifications to the cooking operation conditions based on the specifications of the dissolving pulp grade result in several direct effects in the process:

- **Yield reduction.** Yield reduction causes the decrease of the pulp production capacity, which subsequently affects the fiber line and liquor cycles. The fiber line will be underutilized, because less pulp will be produced from the same amount of chips. However, the amount of solids in the black liquor will increase, which can cause the evaporators or recovery boiler to become process bottlenecks.
- **Pre-hydrolysis stage and cooking time increase**. The longer cooking schedule will result in a reduction in the total input of wood chips to the process, leading to a decrease in pulp production. An increase in the amount of effective alkali required can cause the lime kiln to become a process bottleneck if the input of wood chips is maintained.
- **Bleaching sequence.** The bleaching sequence needs to be changed to adjust the brightness and the viscosity of the pulp to the dissolving pulp grade. The same bleaching towers can be used in the dissolving pulp operation.

After conversion to a dissolving pulp operation, the most likely bottleneck will be the digesters. Typical kraft digesters are stainless steel and designed for alkaline conditions; the acidic pre-hydrolysis in dissolving pulp operation probably will cause corrosion issues if the same digesters are used.

Depending on the process, either the lime kiln or the recovery boiler can be the subsequent bottleneck. Mills have two options: retrofit the existing lime kiln and recovery boiler or include a process stage to remove the hemicelluloses and lignin from black liquor. Both options can be used to maximize the production of dissolving pulp.

Batch displacement technology

The addition or replacement of digesters to increase pulp production gives the opportunity to change the typical batch cooking mode to a displacement operation. Displacement technologies can be retrofitted to the existing digesters' sequence [19]. Displacement operation is more energy efficient; the recirculation of warm and hot liquors can save more than 60% of the steam usage. Additionally, heating to temperature is quick and the alkali profile is even throughout impregnation and cooking. These factors reduce the cooking cycle time and help to improve the quality of the pulp [19,20]. The digester displacement mode of operation is currently used by dissolving pulp mills [10]. This mode helps to avoid precipitation of pitch-like compounds resulting from condensation reactions because the pressure is maintained and the neutralization step is immediately applied.

SIMULATION AND ADJUSTMENT TO DISSOLVING PULP OPERATION

Steam pre-hydrolysis

One type of conversion to dissolving pulp operation is to switch to the displacement mode of operation in the digesters with a steam pre-hydrolysis step. Three cases were analyzed (**Table IV**):

	Kraft	Dissolving Pulp		
		Case 1	Case 2	Case 3
Total steam consumption (tons/h)	241.5	194.60	236.0	250.2
Steam production by the recovery boiler (tons/h)	149.2	127.80	169.1	186.4
Steam produced from external fuels (tons/h)	92.3	66.8	66.9	63.8
Weak black liquor solids content (%)	15.5	18.1	19.6	19.7
Weak black liquor solids (tons/h)	51.2	43.0	60.5	65.1
Pulp production (a.d. tons/day)	748.7	482.8	616	702
Process water consumption (m^3/h)	1561	1363	1452	1579
Water consumption (m^3/a.d. tons)	50.0	67.7	56.6	54.0
Active calcium oxide required (tons/day)	196	168.9	227.8	251.2
EA consumption (tons/day)	234.2	204.2	269.8	292.9
Organic/inorganic ratio in weak black liquor	2.01	2.07	1.77	1.83
Organic solids in weak black liquor (tons/h)	34.2	29.0	38.6	42.1
Bunker oil for steam production (MW)	22.1	2.8	2.7	0.3
Bunker oil for lime kiln (MW)	14.7	12.7	17.6	18.9
(Bark boiler steam production: 63 tons/h; 51 MW)				

IV. Simulation results: steam pre-hydrolysis.

- Case 1: No installation of new digesters (fewer chips in).
- Case 2: Installation of additional digesters to handle the same input of wood chips as the original kraft pulp mill.
- Case 3: Installation of additional digesters to produce approximately the same amount of pulp as the original kraft mill.

For this analysis, the effects on the process without any constraints in the lime kiln and the recovery boiler were considered. All comparisons use the original kraft process as the base case.

Case 1: No additional capacity

The steam requirement of the mill and the production in the recovery boiler are reduced by 19.4% and 14.3%, respectively. The recovery line is underutilized because of excess capacity in the recovery boiler and the lime kiln. The production of the dissolving pulp mill is reduced by 32.5%, which means that the fiber line also is heavily underutilized.

Case 2: Same input

In this case, two additional digesters, with a capacity of 185 m^3 each, will be required to conserve the same input of chips (1540 moisture-free tons/day). The steam consumption remains the same because the increase in steam consumption in the digester is compensated for by a reduction of steam during the evaporation stage. The recovery boiler has potential for 13.4% extra production. However, the amounts of dissolved solids in black liquor and the calcium oxide required in the causticizing department increase by 18.1% and 16.2%, respectively. Therefore, depending on the process, the lime kiln, the recovery boilers, or even the evaporators will be the next bottleneck.

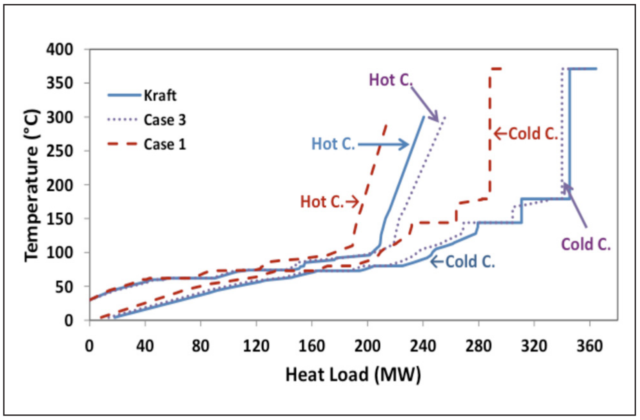
Case 3: Same output

In this case, two additional digesters of 200 m^3 capacity each are required. The total steam consumption increases by 3.6% and maximum production potential of the recovery boilers increases by 24.9%. The amounts of dissolved solids and calcium oxide required increase by 27.1% and 28.2%, respectively.

Energy analysis

For case 3 (the same output), the availability of more hemicellulose in the dissolving pulp operation reduces the need for external fuels (bark + bunker oil) in the mill by ~30%. This reduction can be achieved, assuming that the recovery boilers could handle the increase of solids. Additionally, taking advantage of the extra potential capacity in the recovery boilers could reduce the need for bunker oil for steam production by 87.3%, which exceeds the increase (28.6%) of bunker oil usage in the lime kiln.

The energy required in the digesters for the dissolving pulp operation is higher than that of a typical kraft cooking. The reason is that additional energy demands occur in the digesters of the dissolving pulp operation, apart from cooking, because of the pre-hydrolysis, the neutralization step, and a longer reaction time. The change from batch operation to continuous liquor displacement mode in the digester allows the reutilization of its energy. Therefore, because of this energy reutilization in the case studied, the digesters in the dissolving pulp operation consume only 7.9% more steam (for the same chip input) than the kraft operation.



1. Composite curves comparison.

Figure 1 shows the composite curves of the kraft and dissolving pulp process cases. As expected, the case with the same capacity (case 1, 480 a.d. tons/day) has the lowest energy available in the process. The heat sinks (cold composites) in the dissolving pulp process (case 3, 700 a.d. tons/day) have 5.6 MW less energy than the original kraft process. However, the two processes differ significantly in the available heat sources (hot composites). The heat sources of the dissolving pulp operation (case 3) have 15.3 MW more energy than does the kraft process. These two differences affect their minimum heating requirements (**Table V**). The difference in the hot composite curves is mainly a result of the black liquor cooling (heat available for recovery) in the dissolving pulp. The fact that the energy from the extracted pre-hydrolysis liquor is readily available is an additional advantage of the displacement operation.

In theory, the kraft process should be self-sufficient in terms of energy. This is confirmed by the kraft process minimum energy requirement, which is only 2.6% lower than the maximum production capacity in the recovery boiler (120.9 MW, 150.5 tons/h HP). In the dissolving pulp processes, the minimum requirements are lower than in the kraft process for all cases. This means that if the dissolving pulp operation is completely optimized, there will be an excess of energy that could be used for other purposes (e.g., power production, district heating, etc.). Although it is not technically feasible (and economically prohibitive) to achieve this minimum requirement while retrofitting an existing process, it is used as a benchmark in this study.

The objective of internal heat recovery measures in this case is to liberate steam that can be used to generate additional revenues (i.e., sales of power to the grid). Even though

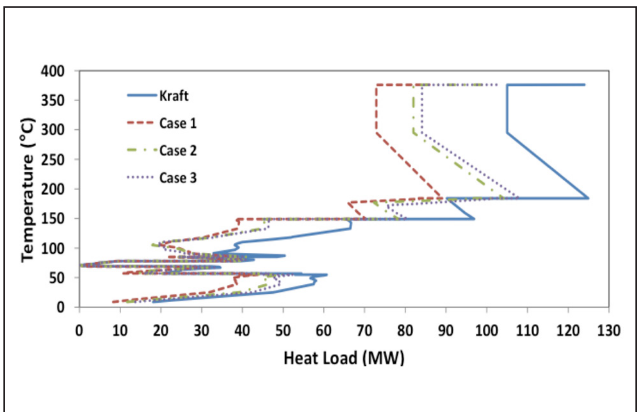
	Kraft	Dissolving Pulp		
		Case 1	Case 2	Case 3
Pinch point (°C)	71	71	71	71
Minimum heating requirement (MW)	129.3	111.3	99.1	103.2
Minimum excess energy in effluent (MW)	18.6	8.4	11.9	13.8
Current heating requirement (MW)	180.8	168.4	171.8	180.2
Current cooling requirement (MW)	69.7	65.5	84.6	90.8
Energy penalties (MW)	51.5	57.1	72.7	77.0

V. Pinch analysis results: steam pre-hydrolysis.

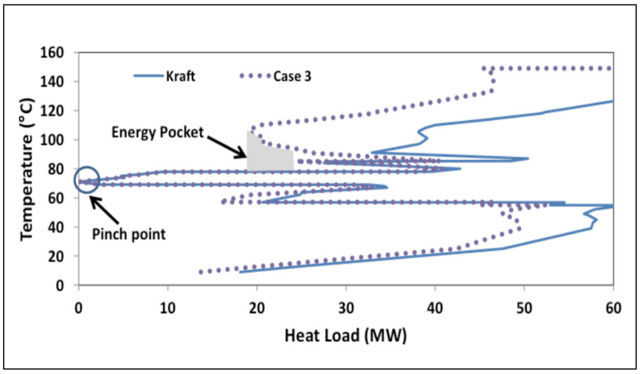
the overall steam consumption of the process increased with the conversion to dissolving pulp, the minimum energy requirements are reduced. For the cases with the same input (case 2) and output of chips (case 3), the respective decreases in the minimum heating requirements with respect to the original kraft operation are 23.3% and 20.2%.

The energy penalties of the dissolving pulp process are mostly related to the use of steam to heat make-up water, and for not recovering the energy available in flue gases and process effluents. Measures to improve the process should focus on preheating the water used in bleaching and for deaeration by recovering the heat in the effluents and black liquor. The energy from the flue gases can be recovered in the pre-concentrators of the evaporator section.

Figure 2 shows the grand composite curves comparison. They reflect the variation of the heating and cooling requirements and the temperature levels of utilities (steam and cooling water) required by the processes. The profile is essentially the same; however, the main differences between the processes are shown around the pinch point. **Figure 3** shows the GCCs of the kraft and dissolving process (case 3, 700 a.d. tons/day) around the pinch point. Above the pinch is an additional energy pocket (heat recovery opportunity) not available in the kraft process profile. This pocket contributes



2. Grand composite curves comparison.



3. Grand composite curves comparison around the pinch point.

to the reduction of the minimum heating requirement. Below the pinch is the energy pocket corresponding to the surface condensers. For the dissolving pulp process, more energy can be recovered from heat sources because more water needs to be heated in the process. Therefore, the excess heat in the effluents (cooling requirement) is reduced.

Bottleneck analysis

The installation of the two additional digesters will increase the pulp production capability and the energy efficiency of the process. However, after the digesters, the maximum capacities of the recovery boiler and lime kiln are the main obstacles to increased pulp production and to take advantage of the energy benefits available in the dissolving pulp operation. In the current process, the capacities are not sufficient to tackle the demands of the dissolving pulp process (case 2 and 3). The extra capacities required in the recovery boiler and lime kiln are 24.9% and 28.2%, respectively. However, it is technically feasible to upgrade and optimize the equipment to increase the capacity of the recovery boiler (without rebuilding) by 2%-20% [21] and the lime kiln by 17%-40% [22,23]. The optimization of the recovery boiler consists mainly of improving the air distribution and velocity measurements. In the lime kiln case, several measures can be taken, such as changing the burner, upgrading the chain, or installing a new lime mud disc filter.

The extraction of hemicellulose after pre-hydrolysis is an alternative option to reduce the extra capacity required in the lime kiln and the recovery boiler. The hemicellulose also could be used to generate new value-added products (e.g., furfural, butanol, ethanol, etc.).

Hemicellulose extraction: water pre-hydrolysis scenario

In this case, hemicellulose is extracted using water hydrolysis. Water is used as a carrier to extract as much hemicellulose as possible from the wood chips during the pre-hydrolysis step. The water pre-hydrolysate is taken out of the process and used as a feedstock in the production of high-value sugars. This analysis considers that water has been heated by steam and the pre-hydrolysate is cooled with cooling water. The removal of hemicellulose also entails a reduction in the consumption of effective alkali for neutralization and cooking because part of the wood components degraded during prehydrolysis has been removed with the pre-hydrolysate. Two cases were evaluated (**Table VI**):

- Case 4: Installation of additional digesters to handle the same input of wood chips as the original kraft pulp mill.
- Case 5: Installation of additional digesters to produce approximately the same amount of pulp as the original kraft mill.

Case 4: Same input

This scenario takes into account that the two additional digesters (discussed earlier) are installed. The steam and water consumption increase by 23.3% and 14.9%, respectively. Because of the extraction of hemicellulose and other solids, the black liquor solids are reduced by 15.5% and, consequently, the steam produced in the recovery boiler also is decreased. As a result, the production of steam from external fuels (mainly the bunker oil) increases by 59.7%. The demand for calcium oxide decreases by 0.6% compared with the kraft process.

Case 5: same output

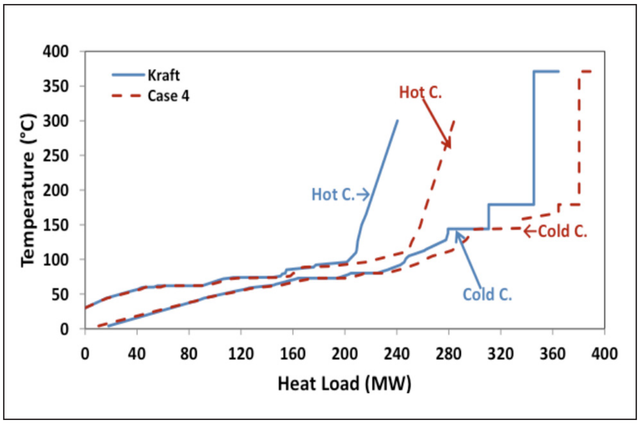
In this case, steam and water consumption increase by 33.4% and 23.5%, respectively. The specific water consumption is lower than in case 4 because the increase in water usage between both cases (7.5%) is offset by the increase in pulp production (10.2%). Calcium oxide consumption increases by 9.5% with respect to the base case.

Energy analysis

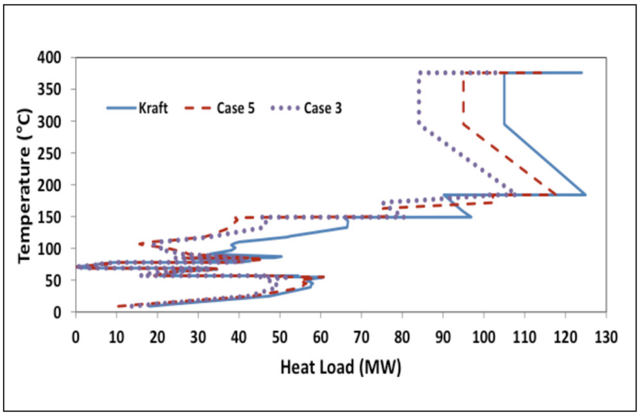
The heat required by the dissolving pulp operation is higher than that of the kraft pulp process, but more heat also is available (**Fig. 4**). The minimum energy requirements also are lower than those of the kraft process, but higher than those of the steam hydrolysis scenario (**Fig. 5**; **Table VII**). The main reason is the additional energy required to heat up water. Pre-hydrolysate must be cooled down (from 160°C to 40°C) before being used for other purposes (e.g., biogas production). Use of this energy to preheat mill make-up water is an

	Kraft	Water Pre-Hydrolysis	
		Case 4	Case 5
Total steam consumption (tons/h)	241.5	297.8	322.2
Steam production recovery boiler (tons/h)	149.2	150.4	166.0
Steam produced from external fuels	92.3	147.4	156.2
Weak black liquor solids content (%)	15.5	13.9	13.8
Weak black liquor solids (tons/h)	51.2	48.8	53.2
Pulp production (a.d. tons/day)	748.7	647.3	713.5
Process water consumption (m^3/h)	1561	1792.9	1927.4
Water consumption (m^3/a.d. ton)	50.0	66.5	64.8
Active calcium oxide required (tons/day)	196	194.9	214.7
EA consumption (tons/day)	234.2	227.1	250.5
Organic/inorganic ratio in weak black liquor	2.01	1.5	1.5
Organic solids in weak black liquor (tons/h)	34.2	28.9	31.8
Bunker oil for steam production (MW)	22.1	67.8	74.9
Bunker oil for lime kiln (MW)	14.7	14.6	16.2

VI. Simulation results: water pre-hydrolysis.



4. Composite curves comparison.



5. Grand composite curve comparison.

energy efficient approach and in accordance with the pinch analysis rules. However, this heat also could be used in combination with other heat sources to better optimize the process. The minimum cooling requirement (excess heat in effluents) is also lower than that of the kraft process because more energy from process effluents (70°C-30°C) could be used for water preheating at low temperature (2°C-60°C).

The steam produced from external fuels (case 5) increases by 69.2%, requiring more than three times more bunker oil. Therefore, heat recovery measures are fundamental for the profitability of water pre-hydrolysis. Using currently wasted heat sources such as effluents, black liquor cooling, and prehydrolysate stream to heat all water used in the process could reduce the need for bunker oil by 65.4% (49 MW). Furthermore, measures that consider the recovery of heat from stack gases could reduce deaeration and evaporator steam consumption, thus further reducing bunker oil usage.

Figure 5 shows a comparison of the GCCs of the kraft, steam, and water hydrolysis options for cases 3 and 5. The water pre-hydrolysis process and the kraft have the same profile below the pinch point. However, because more water needs to be heated for the dissolving pulp operation, the excess energy in the process effluents can be reduced. Above the pinch, the dissolving operations have the same profile and characteristics explained in the previous section.

Power generation makes economic sense when the steam is produced from cheap fuels (i.e., bark and black liquor). In the water hydrolysis case, internal heat recovery measures target the reduction of fossil fuel usage for steam production. Power generation would only be profitable if the heat recovery measures in place result in an excess of steam produced by the biomass boiler.

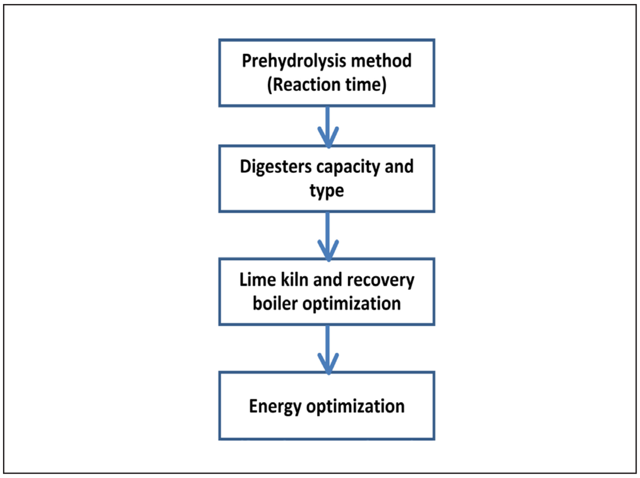
Bottleneck analysis

In case 4, the current capacities of the recovery boiler and lime kiln satisfy the needs of the process. In case 5, the lime kiln and recovery boiler are bottlenecks; the extra capacities required are 9.5% and 10.7%, respectively. The requirements of active calcium oxide in water hydrolysis are not as high as in the steam hydrolysis (case 3).

Extraction of hemicellulose, in combination with optimization of the lime kiln and recovery boiler, will enable the conversion to dissolving pulp operation while maintaining

	Kraft	Case 4	Case 5
Pinch point (°C)	71	71	71
Minimum heating requirement (MW)	129.3	111.6	119.6
Minimum excess energy in effluent (MW)	18.6	10.9	10.5
Current heating requirement (MW)	180.8	204.5	220.5
Current cooling requirement (MW)	69.7	103.8	111.4
Energy penalties (MW)	51.5	92.9	100.9
Energy penalty: current requirement – minimum requirement			

VII. Pinch analysis results: water pre-hydrolysis scenario.



6. Kraft mill conversion strategy.

the pulp production level. The optimization of the lime kiln and recovery boiler in case 5 is not as essential as in the steam hydrolysis scenario (cases 2 and 3).

OPTIMAL CONVERSION STRATEGY

Figure 6 shows the four steps of the optimal strategy for conversion of a kraft pulp mill into a dissolving pulp operation:

1. Determination of the pre-hydrolysis method, based on the possibility to extract hemicellulose. The reaction time (chips filling + hydrolysis + hemicelluloses extraction + neutralization + cooking + blowing) must be minimized to increase pulp production.
2. Additional digesters must be installed to benefit from the existing fiber line capacity to compensate for the reduction in wood yield. Displacement digesters increase energy efficiency and reduce reaction time.
3. Depending on the extra pulp production from the installation of the two new digesters, the lime kiln and the recovery boiler will need to be optimized or upgraded.
4. Energy optimization will have different purposes and will depend on the type of hydrolysis method and the level of improvement that can be achieved in the recovery boiler. For steam hydrolysis, the objective of internal heat recovery measures will be to liberate steam in the biomass boiler so it can be used to increase power production. For water hydrolysis, the initial objective will be to eliminate the consumption of the bunker oil boiler.

CONCLUSIONS

The conversion of a kraft pulping process to a dissolving pulp operation involves technical challenges that affect the energy efficiency of the process. The production of dissolving pulp depends initially on the type and capacity of the digesters, and on the reaction time. The next bottleneck is either the recovery boiler or the lime kiln. If the main objective is to produce dissolving pulp, steam hydrolysis is a better choice because it is a simpler process that does not include hemicelluloses extraction; however, the capacity of the recovery boiler and lime kiln must be optimized to increase production. Water hydrolysis is a better option when value-added products are generated from the extracted hemicellulose. Additionally, depending on the dissolving pulp production level, an increase in the capacity of the recovery boiler and lime kiln might not be required. In the latter case, energy optimization will be required to increase mill profitability through power generation enhancement and reduction of external fuels usage. **TJ**

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ABOUT THE AUTHORS

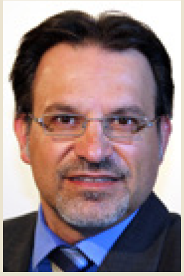
The conversion of kraft mills to dissolving pulp operation is one of the ways to revitalize the pulp and paper industry and create new sources of revenue. This research complements previous experimental studies that established the operating conditions (i.e., hydrolysis, pulping, bleaching, etc.) required to produce dissolving pulp optimally.

For this study, the development of the computer simulation was the most difficult task. This task was addressed by establishing a direct contact line with the mill to gather and validate the required information, and by communicating constantly with the scientists who performed the experimental studies.

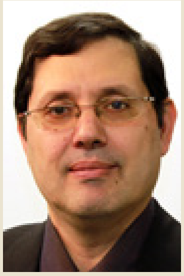
The most surprising result of the study was that the energy efficiency objectives of the mill will change depending on whether hemicellulose is extracted or not from the process.

The information from this study will help mills to elucidate the changes to the process configuration and the modifications to the energy balance of the process associated with conversion to dissolving pulp operation.

Mateos-Espejel



Radiotis



Jemaa

The next step is to evaluate the integration of a hemicellulose based-biorefinery to a dissolving pulp mill. The evaluation will consider the energy interactions and the feasibility of reusing process streams. The objective will be to develop an integrated biorefinery site with high energy efficiency.

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