FROM KRAFT MILLS TO FOREST BIOREFINERY: AN ENERGY AND WATER PERSPECTIVE. I. METHODOLOGY

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The conversion of a Kraft mill into a forest biorefinery increases the demands for water and energy, while the optimization of such utility systems is of paramount importance for the profitability of a Kraft-based biorefinery. This paper is the first part of a more extensive work undertaken to evaluate the energy impacts of a Kraft pulp mill conversion into a biorefinery. Thus, Part I presents the methodology developed to identify the complex interactions between steam and water systems, and the process for determining their impacts on the implementation of energy efficiency measures. This methodology has been illustrated by its application to an operating Kraft mill situated in Eastern Canada. Several energy enhancing techniques, such as internal heat recovery, water reutilization, elimination of non-isothermal mixing and energy upgrading and conversion have been considered. The steam and water savings achieved will allow the conversion of the mill into a green biorefinery requiring no substantial increments of the energy demand and no fossil fuel. In Part II, the process of hemicellulose extraction and conversion for the production of furfural, xylitol and ethanol is presented.

Keywords: energy efficiency, water and energy, Kraft process, forest biorefinery

INTRODUCTION

Energy and water management strategies bringing in increased mill profitability can be identified by the application of plant-wide system approaches.[1-3] For the conversion of a Kraft mill into a forest biorefinery, revamping of the water and energy network should be performed to achieve the optimal integration of the biorefining technologies with minimum investment cost and maximum site profitability. The interactions of the biorefinery site with the utility system have to be evaluated systematically, to balance most efficiently the bioprocess technology integration.

An analysis of a Kraft-based biorefinery from the perspective of water and energy should support decision-making for optimal process and technology integration.[4] Consequently, minimum energy and water consumption will be achieved, as well as the maximization of profits through new value-added products and power generation. The following elements will be considered for the selection of technologies: energy use and distribution profiles through the heat exchanger network, production and distribution of hot water, and steam generation and power production strategies. The complex interactions that emerge from the operation of these subsystems will be elucidated by means of a novel methodology that will provide guidance for the conversion from Kraft to biorefinery.

The present paper is the first part of a work undertaken to evaluate the energy impacts of a Kraft pulp mill conversion into a biorefinery. The various impacts of process changes on the water, energy and utility systems of an existing Kraft mill have been investigated by this methodology. Several measures to reduce steam consumption and increase power generation are proposed. In Part, II the potential application of the hemicellulose extracted from wood chips as a source of value-added products (furfural, ethanol, xylitol) is evaluated, and the energy demands of the biorefinery, as well as the impact on the Kraft process are presented.

Kraft process

The Kraft process is the main manufacturing process by which wood chips are transformed into paper pulp, the intermediate material from which a very broad spectrum of finished or semi-finished paper products are made.[5] The core of the Kraft process is a chemical delignification step, in which the individual cellulosic fibers are separated to form the pulp. After delignification, the fibers are washed and chemically bleached. Finally, they are drained, pressed and thermally dried in the pulp machine. A key characteristic of the process is that the spent delignification liquor (black liquor), separated from fibers in the washing step, is concentrated and burnt to utilize its energy content and to recover the regenerated spent reactants. A schematic representation of the Kraft process is given in Figure 1.

Methodology

The methodology applied consists of four successive stages,[6] as shown in Figure 2. The inner ring represents the base case definition. Computer simulation, focused on energy and water systems, is developed in this step. The second ring corresponds to the benchmarking analysis. The base case is evaluated by comparing its efficiency to the current industrial practice, and by the application of new energy and exergy content indicators. The minimum energy and water requirements of the process are also determined in this step. The third ring is the core of the methodology, representing the formulation of the technically feasible energy enhancing options. Several techniques are iteratively applied, to cast light on their synergies and counter-actions, and the most advantageous solutions are retained. The fourth ring represents the implementation strategy. A three-phase strategy was selected for the specific base case, in the context of its management strategic plan, namely, elimination of fossil fuel, production of power and liberation of steam capacity for the biorefinery.

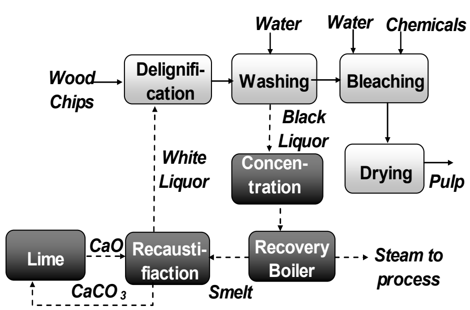

Figure 1: Simplified diagram of the Kraft process

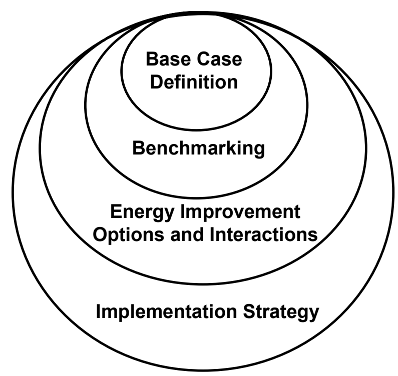

Figure 2: Methodology

Base Case

The mill has an average production of 700 adt/d (adt = air dried ton) of high-grade bleached pulp. The necessary steam is supplied by four boilers that generate high pressure steam (HP = 3100 kPa, T = 371 °C): two spent liquor recovery boilers (RB), a biomass boiler (Bi) and a small fossil fuel boiler (FF). Medium (MP = 965 kPa, T = 179 °C) and low pressure (LP = 345 kPa, T = 143.5 °C) steam is produced through desuperheating and depressurization of the HP steam in pressure reduction valves (PRV). Part of the condensate produced in the process is recovered and mixed with makeup water at the deaerator. The total consumption of steam is 172 MW. A small amount of steam is exported to a nearby sawmill.

Water is used at 5 temperature levels: cold (winter: 4 °C, summer: 20 °C), warm (44 °C), and hot (58, 62 and 71 °C). The warm water is generated in the condensers of the black liquor concentration plant. Hot water of 58 °C is produced by indirect heat exchange, with effluents from the concentration section. The rest of the hot water is produced as follows: the temperature of the warm water is increased to 53 °C by means of internal heat recovery, then to 62 °C, by direct steam injection. Part of the water of 62 °C is directly used, the rest is heated to 71 °C by indirect heat exchange with steam. The total consumption of water by the process is 3212 m^3/h.

Benchmarking

A benchmarking procedure has been developed to evaluate the current state of the process, involving three steps: comparison with the current practice, utilization of additional performance indicators based on energy and exergy content, and targeting by Pinch Analysis[7] and Water Pinch.[8]

The steam consumption of the mill is above the Canadian average of 150 MW. The net thermal deficit (difference between the steam produced by the recovery boilers and the steam used by the process) is 65.6 MW, which is much above the Canadian average of 19.4 MW. The overall water consumption is also clearly superior to the average of 2190 m^3/h.

Exergy is a measure of both quality and quantity of the energy involved in transformations within a system and transfers across its boundary. Exergy has been used as indicator of the process inefficiencies. About 60% of the exergy supplied by fuels is destroyed, which suggests that an important potential for energy conversion is unused. The destruction of exergy in heat exchangers cannot be eliminated, but could be significantly reduced by the optimization of the steam pressure levels and by the improvement of boiler efficiency. The implementation of turbines reduces the exergy destroyed by the PRVs.

A minimum heating requirement (MHR) of 123 MW, a minimum cooling requirement (MCR) of 10 MW and a pinch point (PP) of 71 °C were obtained. The maximum internal heat recovery that the process can achieve is of 192 MW (Fig. 3). The minimum water requirement (MWR) is of 1000 m^3/h, the minimum effluent production (MEP) – 880 m^3/h, the maximum water reutilization – 1360 m^3/h (Fig. 4), the pinch point occurs at DSC = 0 ppm.

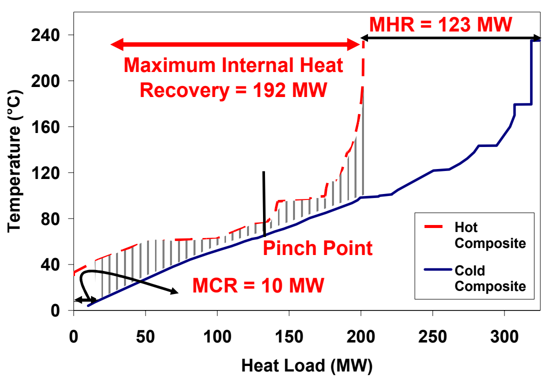

Figure 3: Thermal composite curves of the process

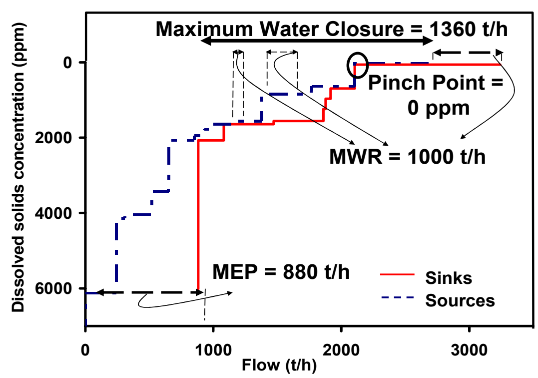

Figure 4: Water composite curves of the process

Interaction analysis

Figure 5 presents the interactions between the energy improvement techniques.

The improvement of internal heat recovery (IHR) in the process is attained by the implementation of heat exchanger network (HEN) retrofit projects. HEN configuration depends on the rate of water reutilization and presence of non-isothermal mixing (NIM). Water reutilization (WR) measures the saved water and steam.[9] Elimination of the NIMs points can be done by changing stream mixing arrangements or by internal heat recovery.[10-11] The NIM points should be eliminated after water reutilization has been implemented. Energy upgrading (EU) recovers the heat from the low temperature streams still available, after internal heat recovery has been maximized. However, the HEN design can be re-oriented so as to create opportunities for the integration of heat pumps. The increase in the condensate recovery (CR) rate should be based on a process in which steam savings have been already achieved by other means. The implementation of energy conversion (EC) technologies, such as turbines, should be performed after the maximization of the steam savings, while targeting an increased power production potential. Depending on the turbine arrangement, the heat load of the deaerator (steam system), as well as the water consumption of the process can be modified. These aspects may affect the HEN configuration and elimination of the NIM points. The energy content indicators, the steam demand reductions and the heat exchange surface required are used to assess the extent of interactions.

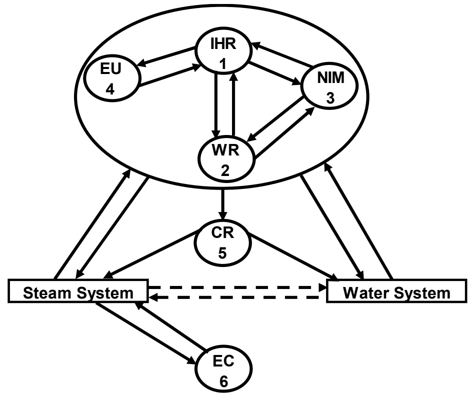

Figure 5: Scheme of system interactions

Implementation strategy

As the existing process configuration and operating conditions vary from mill to mill, it is important to develop a strategy for the implementation of energy improvement programs in the most advantageous way. The economic factors are predominant in the formulation of the strategy. For this case study, a three-phase strategy has been proposed:

- Phase I: Base steam demand reduction and shutdown of fossil fuel boiler
- Phase II: Additional steam demand reductions
- Phase III: Implementation of energy upgrading and conversion

The overall implementation with a one-year PBT is economically attractive at the current price of energy (Table 1). Further increases in the price of biomass and electrical power, combined with the potential creation of carbon credits could reduce the PBT.

Table 1
Economics of full strategy implementation

	Steam saved (MW)	Water saved (m^3/h)	Power (MW)	Inv. (M$)	Rev. (M$/a)	PBT (a)
Phase I	30.1	540		8.65	13.1	0.7
Phase II	10.4			4.2	0.5	8.4
Phase III	5.6	540	44.4	18.7	18.2	1
Total	46.1	1080	44.4	31.6	31.8	1

CONCLUSIONS

The implementation of the proposed methodology improves the profitability of the Kraft process, which becomes fossil fuel-free and sustainable. Following a similar approach with the biorefining technologies added as heat and water sources and sinks will assist in evaluating the impacts of retrofitting a Kraft mill into a biorefinery. It is expected that some interesting and complex trade-offs will emerge, for instance, between the energy demand for the biorefinery and the biomass management; in other words, there will be alternatives to process the biomass as a fuel and energy source, or as a raw material for value-added products. The optimal balance between the various biomass processing pathways will be dictated by integration strategies and economics. The anticipated steam production capacity can satisfy the needs of a biorefinery, as shown in Part II.

Energy optimization is a vital step for a successful conversion of a conventional

Kraft pulp mill into an integrated forest biorefinery.

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