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# Implementation of lignin-based biorefinery into a Canadian softwood kraft pulp mill: Optimal resources integration and economic viability assessment

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ABSTRACT

Implementation of a lignin-based biorefinery into one of the existing kraft pulp mills calls for increased consumption of resources such as steam (by up to 21.5%), water (by up to 3%), carbon dioxide (by up to 16.2%), and sulphuric acid (by up to 11.3%). To compensate for these extra demands on resources, an advanced process integration method was used to identify steam, water, and chemicals savings options and resource recovery opportunities within the kraft process. Given the importance of the lignin-based biorefinery, an economic viability assessment was carried out toward four scenarios, namely: a reference case relating to a stand-alone kraft pulp mill without a pulp production increase but with/without advanced process integration (scenarios #1 and #2) as well as to an integrated biorefinery with a pulp production increase by 5, 10 and 15% (scenarios #3 and #4).



## 1. Introduction

Over the last ten years, Canadian kraft pulp has faced stiff competition from low-cost producers in tropical countries. As a result, 10 out of 43 such mills have been closed over the last 7 years. In an effort to improve financial performance and competitiveness, the currently operating mills are revising their business models to include new sources of revenue from a diversified product portfolio. In this context, biorefinery-based technologies are being considered for the production

*Abbreviations:* adt, air dry metric tonne; API, advanced process integration; BL, black liquor; CAPEX, capital expenses; HEX, heat exchanger; HHV, higher heating value; MEA, monoethanolamine; OPEX, operating expenses; PBP, payback period; P&P, pulp and paper; SC, solids content.

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of bioenergy, biochemicals and biomaterials. However, each biorefinery option involves a unique and/or novel technology which might pose technological, market and environmental risks to any mill under consideration. Therefore, it is important to develop energy-efficient and cost-effective biorefinery design strategies and assessment tools for technology selection and implementation as well as for optimal allocation of resources (i.e., biomass, energy, utilities, water, and chemical reactants). Within this context, the production capacity of about 70% of North-American kraft pulp mills is constrained by the operational limits of the recovery boiler. The offloading of the recovery boiler by precipitating a portion of the lignin contained in the mill's black liquor is one of the main solutions leading to immediate benefit from the resulting incremental increase in pulp production. Acid precipitation technology using $CO_2$ as a precipitating agent has been identified as the most promising biorefinery route for lignin recovery from kraft black liquor in terms of yield [1–4] and cost [5,6]. The recovered lignin can, prospectively, be used in several high-value applications, including the replacement of phenol in phenol formaldehyde resins, polyols in rigid polyurethane foams, and carbon black in rubber (e.g., tires). In addition, lignin could be used as a component of thermoplastic materials, an adhesive in various applications, and a feedstock to make specialty activated carbons and carbon fiber. The profitability of such a lignin recovery process depends highly on the cost of $CO_2$ as the precipitation agent, process energy requirements, and the end use of lignin.

Fig. 1 illustrates the separation process of lignin from kraft black liquor comprising in combination: a black liquor reservoir, a multiple-effect evaporator from which black liquor is withdrawn at about 30–40% solids, an acidification reactor to precipitate lignin using $CO_2$ as an acidic reactant to lower pH from 12–14 to 9–10 at 72–75 °C, a lignin coagulation vessel in which the temperature and pH are, respectively, maintained at 60–70 °C and 9–10, a washing-filtration train in which the liquor with coagulated lignin is filtered and the cake is washed with $H_2SO_4$ and water, a crusher to reduce the size of filtered and washed lignin, a conveyor, a dryer, and a collector in which the dried pure lignin is stored before being sold as a feedstock or transformed by chemical and/or pharmaceutical plants into high-value biochemical products. The filtered liquor containing mainly water, small amounts of lignin, and inorganic salts (i.e., $Na_2CO_3$ and $Na_2SO_4$) is entirely or partly recycled to the weak kraft black liquor reservoir. The purity of the recovered lignin can reach 98% on a dry solids basis with a solids content ranging from 50 to 70%, w/w and an ash content from 1 to 3%, w/w. Recent research and development efforts were focused on: (a) optimizing the washing-filtration train [7,8], and (b) integrating a black liquor oxidizer prior to lignin precipitation to destroy the total reduced sulphur compounds (i.e., hydrogen sulphide, methyl mercaptan, dimethyl sulphide, and dimethyl disulfide) and to convert a part of the organic compounds into carboxylic acids [8].

The implementation of a lignin recovery process into a kraft mill, as depicted in Fig. 1, certainly offers new opportunities to improve the competitiveness of the mill. However, it requires additional use of steam and chemical reactants such as $CO_2$ and $H_2SO_4$ as well as NaOH to maintain Na/S balance which affects the control of kraft liquor cycle in the mill. In particular, any Na/S unbalances will influence the chemical composition of the white liquor and its quality in terms of

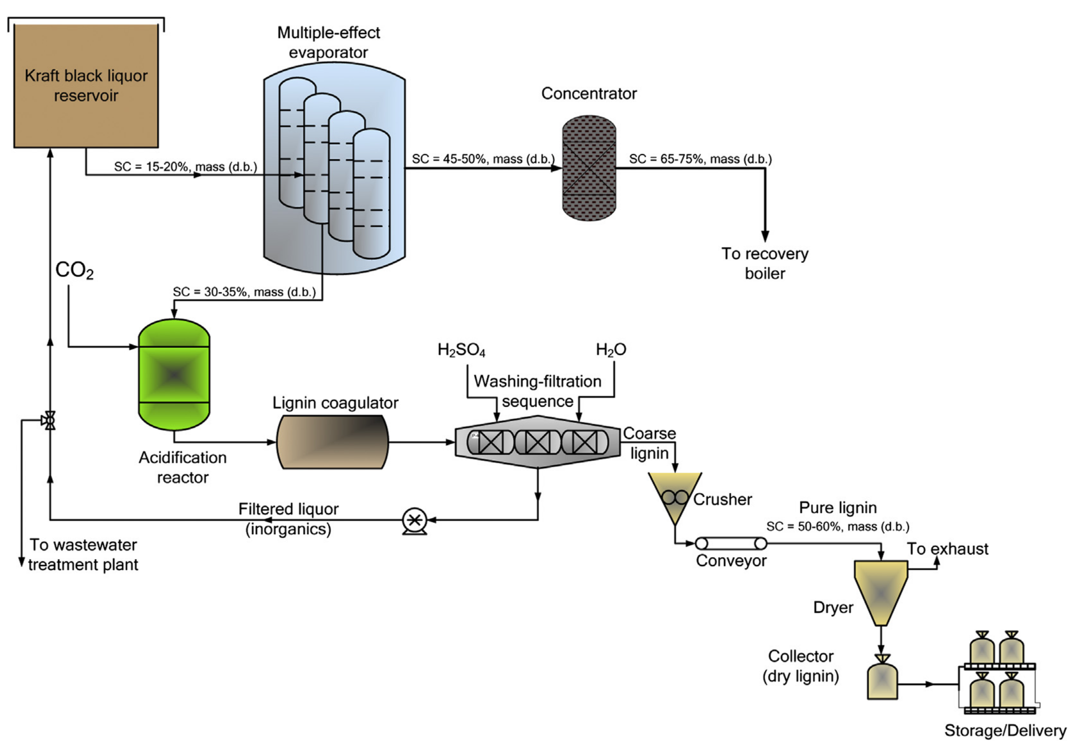


**Fig. 1 – General flowchart for the lignin recovery process.**