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A model-based approach for simultaneous water and energy reduction in a pulp and paper mill

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HIGHLIGHTS

► A systematic model-based approach in reducing water and energy consumption.
► Brown stock washing system is the main study section in the pulp and paper mill.
► Significant water and energy savings are achieved through water reuse/recycle.
► Alternative network designs of different network complexity are generated.

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ABSTRACT

Pulp and paper mills receive much attention from environmentalist and authority due to their impact on natural resources, particularly in water and energy consumption. Many research works have been reported for water and energy savings for the pulp and paper mill. However, none of them were targeted at the brown stock washing system (BSWS), where significant water and energy are consumed to perform pulp cleaning and black liquor concentration. This paper presents an optimization model aiming for simultaneous water and energy saving for BSWS in the pulp and paper mills. A mixed integer non-linear programming (MINLP) model has been developed to optimize the water network design. The synthesized water network results in significant reduction in energy and water consumption. Sensitivity analysis is performed to analyse the relationship between washing efficiency and utilities (water and energy) consumption.

1. Introduction

In recent decades, the large-scale exploitation of resources i.e. energy and water by the process industries has exacerbated the imbalance between economic growth and environmental protection [1]. Being one of the biggest consumers of these resources, the process industry is urged to adopt sustainable resource management strategies to minimize overexploitation and pollution [2].

Energy is used for heating purposes in the process plants. Energy embedded in water creates an inextricable link between both resources, in which the conservation of water will directly translate into energy savings [3]. In this regard, *process integration* techniques are widely accepted as effective tools for resource conservation [4,5]. Significant advances were reported in recent years in the development of various *pinch analysis* and *mathematical optimization* tools.

It is worth noting that the early stage of process integration research has been treating heat [6,7] and water [8–12] recovery separately. At much later stage, various works to address simultaneous energy and water minimization were proposed, covering both pinch analysis [9–15] and mathematical optimization approaches [16–18].

Various attempts have been reported on the application of process integration techniques for simultaneous energy and water

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reduction in pulp and paper mill. Wising et al. [19] identify the potential of excess heat recovery in the mill utilising the grand composite curve. On the other hand, Nordman and Berntsson [20] introduce a “tank curve” to identify the maximum excess heat in the mill. Savulescu and Alva-Argáez [21] investigated the non-isothermal mixing point and direct heat transfer to achieve water and energy efficiency. Goortani et al. [22] evaluate the viability of implementing co-generation in pulp and paper industry. The recent works by Mateos-Espejel et al. [23,24] proposed a base case set up procedure and a detailed energy efficiency study through bench-marking analysis. The above-mentioned works use conventional pinch analysis [19,20] and commercial simulation software [21–24], which has limitation when dealing with complex design interactions involving heat and mass transfers.

In this work, water network for a BSWS in an existing pulp and paper mill is optimized using mathematical superstructural approach [25]. The paper is organized as follows; Section 2 presents the problem statement of this work, Section 3 gives an overview of the BSWS process layout, Section 4 describes the mathematical model to optimize the water network (minimizing the total annualized cost of the proposed design), Sections 5–7 present the optimization results and the conclusion.

2. Problem statement

It is given a set of washers with fixed flowrate requirements and displacement ratio (DR). The DR can be treated as the coefficient of material transfer in the pulp mat; where the actual reduction of solids concentration in a washing stage is compared to the maximum possible reduction in that stage. An optimum water reuse/recycle network is to be synthesized among the water *sources* and *sinks* of the washers. Note that the water sources are extracted from the existing process streams (washer filtrate streams and twin roll press pressate) and sent for reuse/recycle in washers shower and for pulp mat inlet streams.

3. Water and energy savings in brown stock washing system

BSWS is the most important washing section in a pulp and paper mill. Its main function is to remove dissolved solids (DS) from the pulp. Black liquor (BL) is the by-product generated during the washing processes, and is concentrated in a series of evaporator to become strong BL, which is then burned in the recovery boiler.

Fig. 1 shows the base case process for a BSWS in an existing pulp and paper mill, simulated using the Cadsim software [25]. As shown in Fig. 1, there are a total of seven washers, arranged in counter-current mode; these include an extended modified continuous cooking (EMCC) washer, two diffusers (Diff), decker washer, washer 1, washer 2 and PreDO washer. As far as counter-current washing mode is concerned, water is recycled from filtrate/pressate tank to the previous washer, through shower stream and the pulp inlet stream for pulp dilution. By referring to Fig. 2, recycle stream flowrate and DS content at shower are given a variable of S_k and C_k^S, respectively; recycle stream flowrate and DS content at pulp inlet are given a variable of P_k and C_k^P, respectively. In the base case model, there are three fresh water feeds supplied at 45 °C, i.e. Decker washer (F1), PreDo washer (F2) and Washer 1 (F3). On the other hand, three major heating sections are identified in

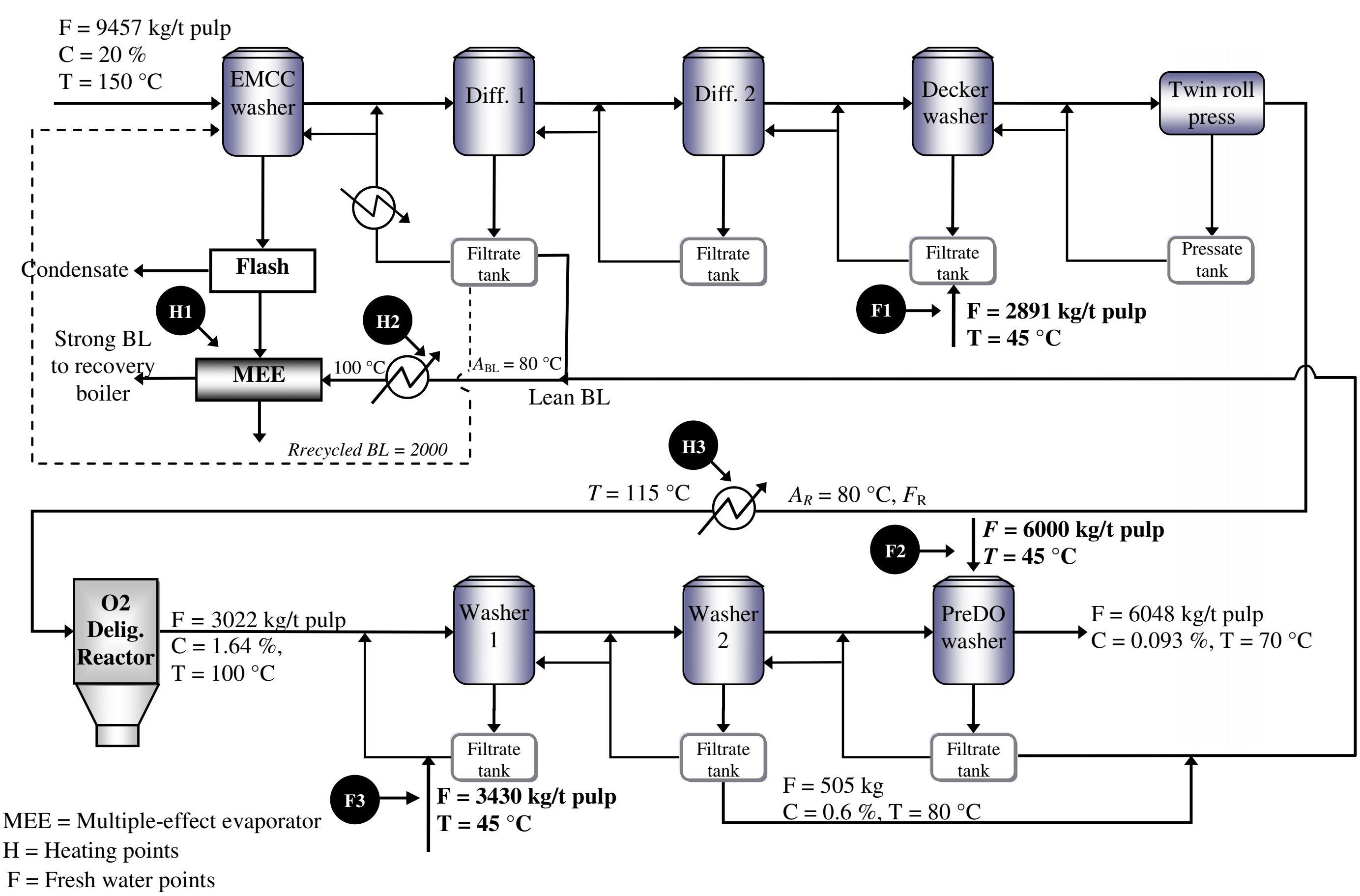

Fig. 1. Base case simulation model for an existing BSWS (symbols *F*, *C* and *T* represent the flowrate, DS concentration and temperature, respectively).