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# Opportunities for the integration of absorption heat pumps in the pulp and paper process

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ABSTRACT

Implementation of absorption heat pumps (AHPs) in a Kraft pulping process was studied using a new methodology for the optimal integration of those devices in a process. Two generic opportunities were identified for an energy and water optimized mill: (i) integration of a double lift chiller in the bleaching chemical making plant to produce chilled and hot water simultaneously, using MP steam as the driving energy and, (ii) installation of a single stage heat pump to concentrate the black liquor and produce useful hot water by upgrading heat from the bleaching effluent and using MP steam as driving energy. The principles of AHPs operation and their efficient integration into a process are described. The simple payback time (SPB) and net present value (NPV) were used to evaluate the interest of such implementations. Considering 63 $/MWh for the steam price, SPB of 2.7 and 1.7 years have been estimated for the two cases.



## 1. Introduction

Pulp and paper (P&P) manufacturing is among the most energy intensive industrial sector. For example, an old Kraft mill in Canada consumes 25 GJ/ adt (air dried ton) of pulp produced while a modern mill consumes 12.2 GJ/adt [1]. Over the years, this industry has invested much effort to reduce its energy bill and significant progress has been made by the application of a broad spectrum of energy enhancing measures [2]. Unfortunately considerable amount of energy is still rejected to the environment because of its low temperature. Heat pumps (HP) could be used to upgrade this heat to useful temperature levels. HPs are energy conversion devices which are used to upgrade the quality of heat by raising the temperature at which it is available [3]. Absorption heat pumps are emerging as a potential alternative to the more common vapor recompression heat pumps (VRHP). They are thermally driven and when judiciously positioned into an industrial process, they can be operated with practically no purchased power. They also use environmentally benign working fluids.

To our knowledge, there are only few reports of actual implementation of absorption heat pumps (AHPs) in the P&P industry in the scientific literature. The first documented AHP unit installed in a P&P mill has been in operation for 15 years [4]. It is a 200 kW heat transformer that delivers steam at 125 °C using secondary vapor at 85 °C from the liquor evaporation plant. At a pulp factory in Japan, an AHP was installed to recover heat from the alkaline bleaching effluents, at about 50 °C and used to increase the temperature of water supplied to the boiler from 22 to 80 °C by using 1.05 MW of steam (0.4 MPa, 165 °C) [5]. Several experimental developments and feasibility studies have been reported. Hester et al. [6] present a conceptual design and economic evaluation of a heat recovery/ heat pump system as an integral part of a pulp and paper plant. Robb et al. [7] present a feasibility study for upgrading heat rejected by newsprint processes to displace fossil fuel generally used to dry the product. Abrahamsson et al. [8] present two different potential applications of AHPs in the P&P industry. In the first application, optimal energy conservation strategies were investigated using a heat transformer system incorporated with the evaporation plant of the pulping process. In the second application, simulation results were presented for different process configurations where an absorption heat pump was suggested to be incorporated in an existing paper drying plant. Costa et al. [9] present two feasibility studies of implementation of AHPs in a Kraft process. One involved the insertion of a heat transformer in the heat recovery loop from the digesters blow-down tanks; the second presented the installation of a chiller to replace the barometric condenser in the bleaching chemical making plant.

In none of these reported feasibility studies is Pinch Analysis [10] taken into account. As will be discussed in this paper, it can

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easily be shown that when the HP is not positioned correctly, the net benefits are practically nil. The methodology of integration of some types of HPs, such as VRHP or electrically driven compression HPs, is well defined and discussed in the literature [11,12]. Recently, Bakhtiari et al. [13] presented a new methodology for process integration of AHPs. It will be summarized in this paper and used to identify generic opportunities in a Kraft process.

The work presented here illustrates the potential use of AHPs for heat upgrading in the P&P industry. It shows that even for a fully energy and water optimized mill, there is still a potential for further utility savings. Two generic opportunities have been identified that involve a broad spectrum of machine configurations, mode of operation and integration context. To provide background for this case study, the principles and operation of heat pumps are first briefly reviewed and a method based on Pinch Analysis to appropriately position an AHP in a process is presented.

## 2. Absorption heat pumps

Much scientific and technical literature has been devoted to the fundamental principles, modes of operation and engineering design of HPs [3,14–16]. A heat pump is a mechanical device able to raise the temperature at which a certain quantity of heat is available to a higher temperature where it can be used more advantageously. This is accomplished by circulating a working fluid (called the refrigerant) between an evaporator, E, and a condenser, C, which is operated at higher temperature and pressure (Fig. 1a). The circulation of the working fluid between the evaporator and the condenser is caused by a pressure raising device (PRD), which is driven by high quality energy. The condensed working fluid then is throttled through a pressure-lowering device (PLD) like an expansion valve or capillary tube to complete the loop (Fig. 1a). In the case of the AHP, the PRD consists of a secondary loop (Fig. 1b) where a binary solution is circulated between an absorber, A, operating at the same pressure as the evaporator and a desorber, generally called the generator, G, at the same pressure as the condenser. The binary solution contains a refrigerant, which is the more volatile component, and the solvent. The absorption process involves an exothermic reaction where the vaporized refrigerant exiting the evaporator is absorbed by the solvent strong solution releasing additional useful heat, $Q_A$. The solvent weak solution thus formed is pumped up to the generator and released at higher pressure and temperature under the effect of driving energy supplied as heat, $Q_G$. In an actual machine a fifth heat exchanger, the solution heat exchanger (SHX) is inserted between the generator and the absorber to enhance the cycle efficiency. AHPs are generally used to upgrade the temperature level of some available heat at a low temperature level ($Q_E$) to recover useful heat at an intermediate temperature ($Q_C + Q_A$) using the high temperature heat source as the driving energy ($Q_G$). In the majority of AHPs developed for use in industrial applications, $NH_3$–$H_2O$ and $H_2O$–LiBr have been the working fluid pairs of choice. Other working fluid pairs are also reviewed in the literature [13].

For preliminary investigations, comparisons of working fluids and thermal analysis of an AHP, the pressure–temperature diagram (or vapor pressure diagram as it is often referred to) is a very useful tool. It is convenient to represent the cycle in such a phase diagram of the binary solution (Fig. 2) illustrating the thermal operating constraints imposed on the system, the pure refrigerant evaporation line on the low temperature side and the solvent crystallization line on the high temperature side. A schematic representation of the configuration of AHPs based on the pressure–temperature diagram is often used; Fig. 3a is such a symbolic representation of an AHP. AHPs can be implemented in a variety of arrangements to overcome the limitations imposed by the thermodynamics and the irreversible effects associated with heat transfer. Of interest to this work is one other configuration, the double lift AHP in which the higher temperature lift can be achieved by coupling cycles (Fig. 3b).

The efficiency of an AHP or its coefficient of performance (COP) is the ratio of the energy released by the machine to the driving energy as follows: $COP = (Q_C + Q_A)/(Q_G)$.

## 3. Appropriate positioning of absorption heat pumps in a process

This section, presents how an AHP should be integrated in industrial processes. It has been shown that a heat pump should be implemented in the process based on the results of Pinch Analysis [11–13]. Pinch Technology is a rigorous, structured approach that may be used to tackle a wide range of improvements related to process and site utility and maximize the internal heat recovery is one of these improvements [17]. A basic step of the method is the representation in the temperature vs. enthalpy diagram of the aggregate of all possible heat transfers between process streams. It consists of two composite curves (CC), one for the streams that can be used as heat sources (hot streams) and one for the streams that can be used as heat demands (cold streams). The composite curves are used to determine the pinch temperature and energy targets as minimum heating requirement (MHR) and minimum cooling

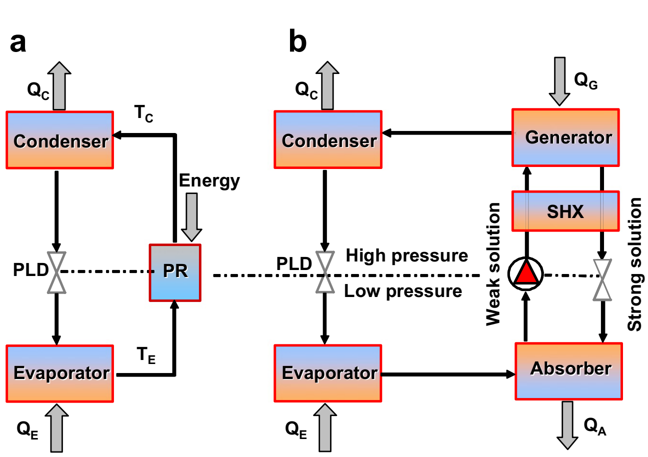


**Fig. 1.** Principle of heat pumping. (a) General; (b) absorption heat pump (AHP).

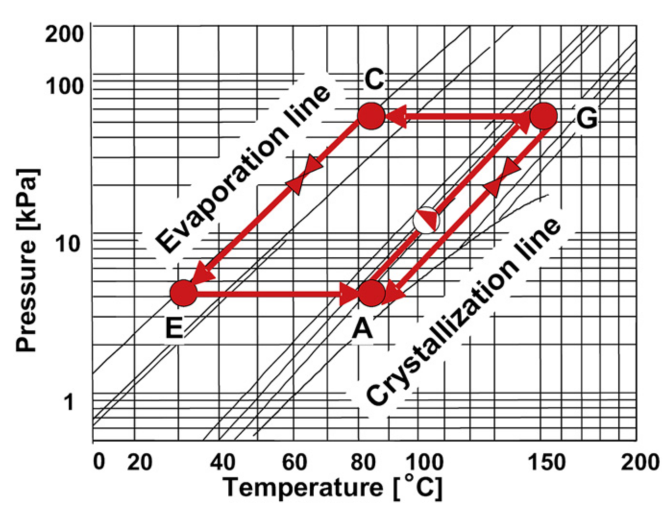


**Fig. 2.** AHP representations in $H_2O$–LiBr phase diagram.