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Energy and water in the pulp and paper industry: the two solitudes

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Energy analysis of the kraft pulping process combined with water analysis of the bleaching department has been applied in order to study the interactions between energy and water. Strategies for reducing water consumption which consists in reuse of the water in the process have been suggested. The impact of the proposed improvement of the water network on the energetic efficiency of the process has been observed. As a result of the strong interactions between water and energy, reducing water consumption influences the energy demand. This work showed that the correct way to identify appropriate projects for energy and water savings is to consider and analyze them together.

1. Introduction

The pulp and paper industry is among the largest consumers of energy and water; rising energy costs and more stringent environmental regulations have lead to refocus efforts toward identifying ways to improve energy and water conservation. Over the last twenty years, process integration methods have been proposed as an alternative way to find cost-effective process designs, involving increased heat recovery and direct recycle and reuse of water.

Process integration studies done in the pulp and paper industry investigate analysis and optimization of thermal efficiency or water networks but mostly energy and water have been studied separately. Most of the studies on the thermal side of the process show opportunities for energy savings, dealing with all forms of energy such as heating, cooling, power generation, depressurization and fuel (Sarimveis et al., 2003; Brown et al., 2005). The standard tool used for determining the thermal efficiency of the process and finding ways to improve it is thermal pinch analysis (Linnhoff, 1993).

On the other side, wastewater reduction and water conservation are becoming more important issues in the industry, because of the large utilization of water in pulp and paper mills for transportation, cooling, dilution, washing and production of steam. Several research efforts have focused on the development of process design methodologies and approach that cover a variety of techniques ranging from graphical based approaches, such as water pinch analysis (Dhole, 1998; Wang and Smith, 1994) and the source-sink methodology (Dunn and Wenzel, 2001) to mathematical optimization-based approaches (Shafiei et al., 2004).

Energy and water are, however, strongly interconnected. The larger the amount of water consumed and effluent produced, the larger the energy required for heating, cooling and pumping. Also, the cost of effluent treatment decreases with water reuse since this cost is directly related to the volume of wastewater treated. Understanding these interactions is of prime importance for solving the problem of energy savings and water consumption reduction. Attempts to study the possible synergistic effects between energy and water have been reported. Shaareman et al (2000) proposed an iterative method for water and thermal pinch, Savulescu et al (2005) developed a method which is only applied in the water network and Lafourcade et al (2006) based their method on the thermal pinch and considered the effects of system closure.

To reduce the energy and water costs, an example of combined energy and water analysis has been applied to the bleaching department of a Kraft pulp mill, located in Canada. The objective of this research was to study the mutual influence of energy and water in order to determine if the proposed improvement in the water network of the bleaching department would increase the energetic efficiency of the process.

2. Case study

The kraft pulping process involves the digesting of wood chips at elevated temperature and pressure in liquor, which chemically dissolves the lignin that binds the cellulose fibres together. When cooking is complete, the contents of the digesters are transferred to a depressurizing tank and from there to pulp washers, where the spent cooking liquor is separated from the pulp. The pulp then proceeds through a stage of bleaching, after which it is pressed and dried into a finished product. Spent cooking liquor and the pulp wash water are mixed to form weak black liquor which is concentrated in a multiple-effect evaporator system and burnt in recovery boiler. Inorganic chemicals present in the black liquor collect as a smelt at the bottom of the recovery boiler. The smelt is transferred to a causticizing tank where calcium oxide is added to regenerate the digesting liquor which is reused. For process heating, for driving equipment, for providing electric power, the mill needs steam which is produced on site by two recovery boilers, a biomass boiler using wood residue and a bunker oil boiler.

In this study special attention is given to the bleaching department where the mill consumes most of the water. The objective of pulp bleaching is to remove the lignin that remains in the fibres after the chemical pulping operation to produce a clean pulp with high brightness and high cellulose content. The mill which was studied uses a five stage bleaching process each with a basic flow diagram shown in Figure 1. After each bleaching stage the pulp passes through a washer where the spent liquor and the dissolved solids are separated from the pulp. One part of the effluents from the washer is recirculated to the bleaching tower, a part is reused and the rest is purged to the sewer. Steam is injected to the washed pulp to bring it to the required temperature in the next stage.

3. Combined analysis

The heat and mass flowrates were determined by process simulation using CADSIM® Plus (Aurel Systems Inc.). In the first stage of the analysis, the thermal pinch analysis of the complete pulping process was done. The current heat exchanges were instigated using the thermal composite curves. Parallel to the thermal pinch, the

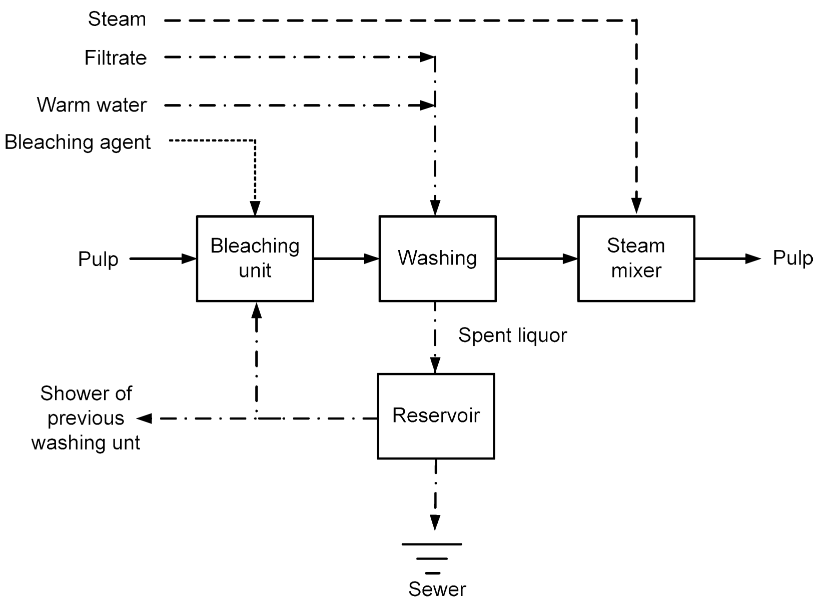

Figure 1. Schematic of single bleaching stage.

water pinch diagram of the bleaching department was used to analyze the current system closure and to identify strategies to reduce water consumption. The next step consists in determining the impact of the proposed strategies on the thermal side of the process by identifying changes in the thermal composite curves.

3.1 Thermal pinch analysis of the process

The thermal composite curves are represented on Figure 2. A ΔT_{min}=10°C was chosen based on equipment design and typical values used in the pulp and paper industry. The pinch point was found at 71°C. The minimum heating and cooling demands are 108 MW and 16 MW respectively. The current heat exchanges in the process were analyzed according to the pinch rules: a hot utility cannot be used to heat a cold stream below the pinch point, a cold utility cannot be used to cool a hot stream above the pinch point, and a hot stream above the pinch cannot be used to heat a cold stream below it. Pinch violations were found in the dryers, steam production department, heat recovery loop, in the pulp preparation department (hot water tank and hot water accumulator) and bleaching department (utilization of steam below the pinch point in the steam mixers after the pre-washer and the first bleaching stage). The possible solution to be used in the bleaching department could be the utilization of its effluent streams or the ones from the evaporators to raise the water temperature used in the washers. In this way the steam demand by the mixers would be reduced, avoiding the violations.

3.2 Water pinch analysis of the bleaching department

Parallel to the thermal pinch, the water pinch was applied to the bleaching section, for analyzing the current system closure and to propose strategies for improving it. This

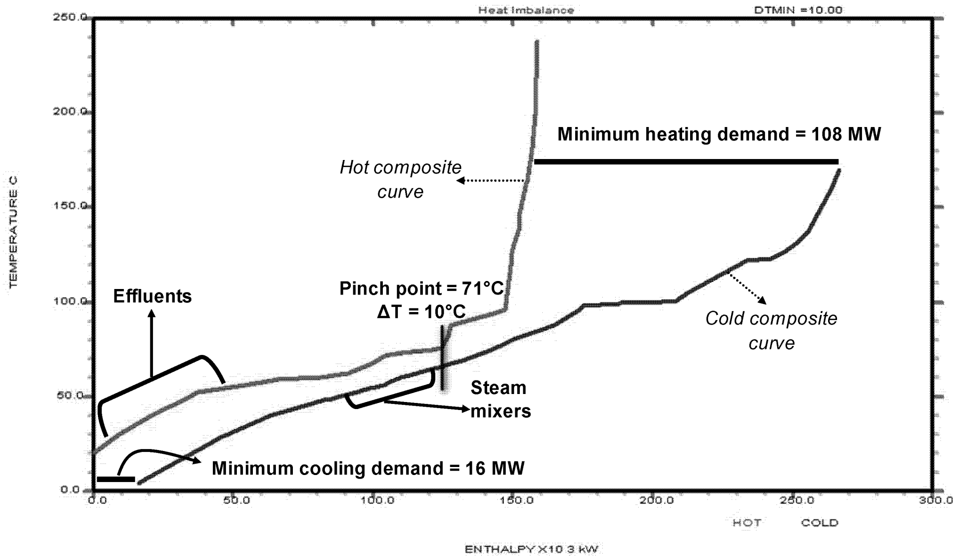

Figure 2. Thermal composite curves of the kraft pulping process.

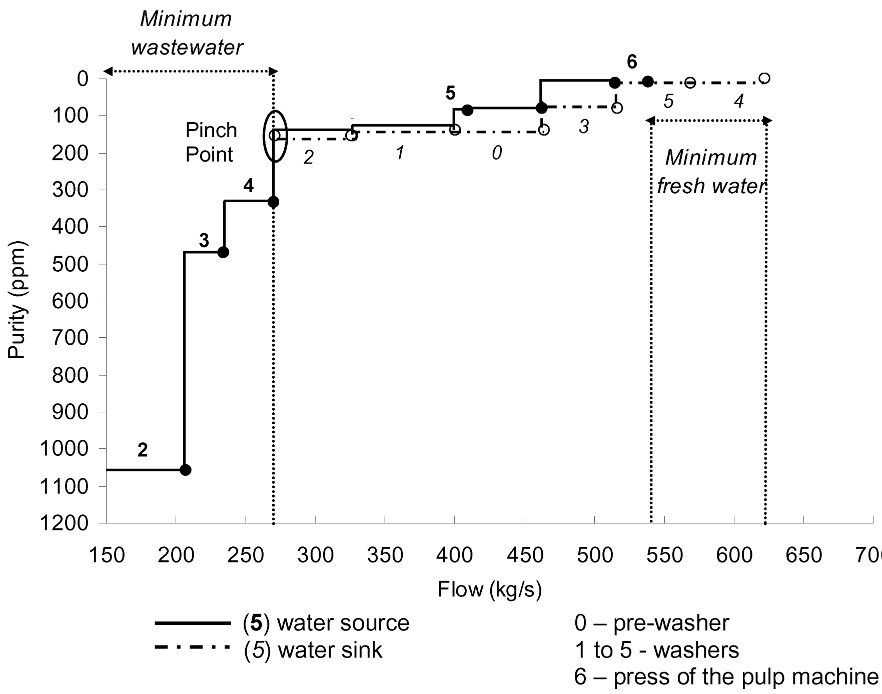

Figure 3. Water source and sink composite curves of the bleaching department.

analysis was applied only in the bleaching department, for illustration of the proposed methodology. Figure 3 depicts the water composite curves, representing water sources (waters streams rejected by equipment) and sinks (water required by equipment). The overlap of the source and sink curves indicates the scope for water reuse; it is limited by the pinch point where the two curves touch each other. The segments that are not overlapping represent the minimum freshwater consumption and minimum wastewater generation. In the bleaching department there is already partial closure, but as shown in the water composite curves, it can be increased. In order to reduce the freshwater consumption and the wastewater discharge of the bleaching, some source streams have been mixed to satisfy the purity requirements of sinks, taking into account that a source can only satisfy a demand of lower quality. There are 2 source streams available for reuse: filtrate from the 5th bleaching stage and white water produced as an effluent in the pulp machine with low level of contamination. The analysis of the curves shows that two principal strategies can be applied, using these two streams: Strategy 1 consists of substitution of warm water in the pre-washer and Strategy 2 consists of substitution of hot water in the 1st stage. Only if the water pinch aspects are considered both alternatives are equally good, as the water savings and effluent reductions are similar (Table 1), so the economic factor would be the one which decides which strategy is the best.

4. Results

It can be appreciated that the two individual analyses (water and thermal pinch) have been applied considering the same streams, effluents and steam mixers, but with different purposes, without regarding the interactions between them. In order to consider the two aspects at the same time, the water network must be imbedded in the thermal composite curves, in this way the closure strategy can be analyzed considering also the global heat exchange limitations.

In Figure 2 the location of the streams involved in the closure is shown. They are all situated below the pinch point, so the exchange between them is correct. The thermal impact of the two strategies is different and both of them affect pinch violations in steam mixers. Strategy 1 diminishes the impact of the violation in the pre-washer, since it entails not only reduction in water, but also on heating and cooling demands. Strategy 2 increases the impact of the violation in the steam mixer and decreases the one in the hot water tank. As the temperature of the effluents (60°C) is lower than the hot water (70°C), the heating demand on the mixer increases and the cooling demand decreases (the temperature of the effluent in this stage is lower than earlier); but as the hot water is reduced so does the heat demand in the hot water tank. Therefore the combined analysis is a necessity to obtain an optimum solution. Since only the bleaching department was considered for the water closure, the pinch point and the minimum energy requirements were not affected, but if the level of closure increases, taking into account the whole process (streams above and below the pinch), the impact would be more profound and should be analyzed. The economical analysis is of principal importance because it determines the option to be implemented, considering water and energy aspects. For this case it is obvious that Strategy 1 is the best as water, heating and cooling demands are saved (Table 1).

Table 1. Comparison between the strategies suggested.

	Equipment affected	W saved (t/h)	HC (MW) before	HC (MW) after	CD saved (MW)
1	Steam mixer	106	1.7	0	1.5
2	Steam mixer and hot water tank	100	1.8	2.2	1.9

* W-water, HC-heating consumption, CD-cooling demand

5. Conclusion

Energy analysis of a kraft pulping process combined with water analysis of the bleaching department has been applied. There is a strong interaction between the two aspects, energy and water, and can be appreciated in this study. The proposal is to combine the analysis by locating the water network in the thermal composite curve, in this way the water closure will also be considered in the thermal heat exchange limitations. The closure not only saves water but also helps to correct the thermal pinch violations. If the pinch point would have changed, the strategies for improving the heat recovery would have changed too. Therefore it is imperative to analyze the two aspects at the same time to get an optimum, which considers all the elements and consequences that are never analyzed when the two solitudes, water and energy, are applied isolated.

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