Evaluation of White Water Reuse in the Bleaching Process for Reducing Fresh Water Consumption

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ABSTRACT

The main objective of this work is to study the technical viability of using the effluent generated in paper machines (white water) in the wash presses of bleaching stage, reducing fresh water consumption. As a case study, the industrial process of Ripasa S.A. Celulose e Papel was evaluated. White water rate is about 700 m^3/h and it is not possible to reuse all this volume in the bleaching stage, without causing operational problems (fouling in tubes and clogging in the screens). A mass balance of the bleaching unit was developed in an electronic spreadsheet in order to evaluate the possibility of reducing fresh water consumption, using only a fraction of the available white water in the wash presses. To achieve this objective some physical-chemistry properties of white water stream and of other streams of the process were determined. The maximum concentration of some non-process elements (Si, Ca, Mn and Fe), that could accumulate in the process, were determined in order to establish some parameters to allow process integration of the streams involved, considering operational constraints. The results obtained have shown that it is possible to reduce about 13% of the consumption of fresh water and this methodology has been satisfactory.

KEYWORDS: white water, mass integration, bleaching, non-process elements.

1. INTRODUCTION

In pulp and paper mills the increasing of both fresh water consumption and volume of effluents to be treated, represent a critical point for future expansions of the process, due to environmental restrictions and limitations of the effluent treatment system. Pulp and paper industry is traditionally the greatest fresh water consumption among all others chemical industries, consuming more than 70 m^3/ton of cellulose (Galloway *et al.*, 1994). Considering this, the pulp and paper industry has been looking for new alternatives in order to reduce their effluent generation, and one of them is to reuse wastewater in the process. This enables a reduction in the volume of fresh water used, with positive effects for the environment, also reducing energy costs in the process.

To implement a program for reducing fresh water consumption, first it is necessary to identify the consumption in each part of the industrial unit, concentrating the analysis in the greatest consumers (Del Grande, 2004). In the case of pulp and paper industry, the focus is almost always the bleaching unit, in which there is a great generation of effluent streams. The bleaching unit consumes half of the water used in the kraft process for producing cellulose and also produces half of the effluent generated in the entire process, turning this stage the most important one to be studied for reducing fresh water consumption.

In this work, a case study was developed in the industrial plant of Ripasa S.A. Celulose e Papel, located at the city of Limeira (São Paulo State). Firstly three potential areas in the industry for reducing fresh water consumption were identified: reuse of the effluents from bleaching stage (Parthasarathy and Krishnagopalan, 2001); reuse of the effluents from the paper machine in the washing press of the bleaching and reuse of condensate of the paper drying machines. After a critical analysis of these options, it was decided that the focus of this work would be the study of the reuse of the effluent from the paper machine, called white water, considering its great accessibility and availability for mass integration with fresh water in the washing presses.

So the main objective of this work is to study the technical viability of using white water, together with fresh water, in the washing presses of the bleaching unit, in order to reduce the consumption of the second, using a mass integration approach.

In this case it is of great importance to consider the presence of non-process elements (NPE's) in the integrated process streams, since these elements, originated in the stage of wood digestion, represent mineral compounds which are inert in the process and so, their accumulation interfere in the production, causing operational problems such as corrosion and fouling in the tubes and clogging in the screens, reducing life time of the equipments and it may also interfere in the stoichiometry of the chemical reactions of the process (Freddo *et al.*, 1999). According to Keitaanniemi and Virkola (1978) the NPE's in pulp and paper industry and their sources are: Cl, Si, Mg, Fe and Mn, from wood; K, Mg, Fe, Ca, Al and Si from water; Cl, Ca, Si, Al and Fe, from chemicals used in the process and from erosion of tubes and equipments. Part of these NPE's remains in the effluent streams and may accumulate in the process, especially when there is an integration of these streams.

So, this work intends to test new alternatives that represent innovations, which are feasible technical and economically, bringing real contributions to the improvement of the industrial process, with an impact as minimum as possible in the actual process.

2. METHODS

To accomplish the optimization of the process aiming the maximum reduction of fresh water consumption in the bleaching unit (Figure 01), the methodology used in the development of this work was divided in three parts and each one is described in details in the next items.

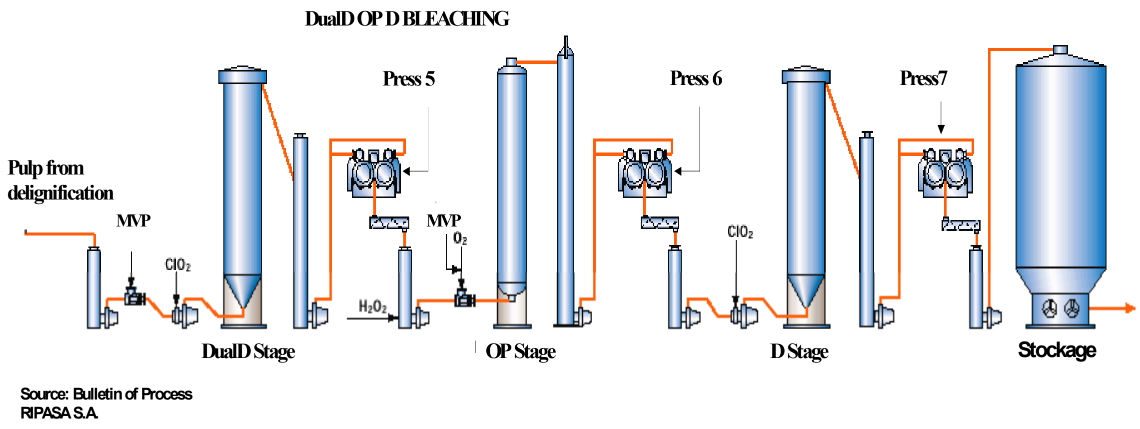

Figure 01 – Bleaching unit fluxogram - Ripasa.

2.1. DATA ACQUISITION

Data of the process streams involved, such as flow rate and pulp consistency, necessary for a complete mass balance of the unit, were taken from a period of three months of operation. These data, a set of more than 3000, were treated, eliminating those related with startups and shut downs of the plant and also those in which the pulp production capacity was lower than the normal plant capacity. The remaining data were then used to obtain correlations to perform a mass balance of the unit, since a phenomenological model, considering the stoichiometry of reactions involved, is not an easy task. These correlations allow the description of the process streams (inputs and outputs) from a basis of calculation taken as being the stream from delignification stage.

During this part of the work, some physical-chemistry properties of the streams, needed for a satisfactory mass balance, such as density, pH, organic material content, hardness, concentration of NPE's and fouling potential were determined in the laboratory.

2.2. MASS BALANCE IN AN ELECTRONIC SPREADSHEET

The second part consisted of implementing this mass balance in an electronic spreadsheet, trying to make it as handle as possible to allow future changes if necessary, in case of process modifications. Initially this was done considering a simple case, where the process streams were consisted of cellulose (fibers) and solution (water and chemicals), at this time NPE's were not taken into consideration. Once this simple mass balance has proved to be in agreement with industrial data, a more complex one was implemented, in which the constraints of NPE's were considered. These constraints are related with the maximum concentration allowed for Ca, Si, Fe and Mn in the process streams, in order to avoid operational problems, and also with organic material concentration in the bleaching unit.

2.3. PROCESS INTEGRATION

Using a process integration approach, simulations were performed in this electronic spreadsheet, trying to reduce fresh water consumption, evaluating the possibility to integrate part of white water stream, from paper machines, to replace a portion of fresh water. The simulations consider the constraints for NPE's and organic material in the streams optimizing the objective function defined as being the minimization of fresh water consumption. Process integration for wastewater minimization has been used to design industrial water system by Wang and Smith (1993) and Alva-Argáez *et al*. (1998).

3. RESULTS AND DISCUSSION

NPE's and organic material constraints were determined from industrial studies performed by Ripasa, based on experimental data. Table 01 shows these constraints (maximum concentration allowed) that are applicable to all presses, considering the sum of the input streams in each one, except for organic material, which constraint is considered only for the input washing streams (press 6 and 7) formed by the integration of fresh water and white water streams.

Table 01 – NPE's and Organic Material (O.M.) Constraints Used in the Simulations.

	NPE's				O.M.
	Fe	Ca	Si	Mn	
Concentration (mg/L)	1.5	15.0	40.0	2.7	15.0

These constraints, as mentioned before, are related with operational problems. For example Ca and Si may cause fouling and Fe and Mn promote reversion in the whiteness of the pulp, besides them, organic material when present in excess in bleaching stages, causes a greater consume of chemicals and contribute to rise BOD (biochemical oxygen demand) and COD (chemical oxygen demand) in the effluents. Considering the constraints showed in Table 01; the average concentration of NPE's in the white water stream (determined by ICP-OES technique using a Perkin Elmer – 3000 DV spectrometer), the electronic spreadsheet developed to perform mass balance with these constraints was used to simulate different sets of input values in order to evaluate the reduction of fresh water consumption, making a sensibility analysis of these variables (upper and lower limits of 50% of the tabulated values). Table 02 shows the results for fresh water consumption reduction, considering the values of Table 01 and the average concentration of NPE's. It was considered an uncertainty of –50% in the constraints for each NPE separately, while keeping constant the constraint of the others and a variation of +50% for the concentration of the NPE's in white water stream, keeping the others constant too. The combination of these uncertainties represents the worst scenery that could be considered, i.e., low tolerance for NPE's and high concentration of them in the streams. All combinations were tested for systems with and without the constraint of organic material.

Table 02 – Influence of NPE's and Organic Material in Fresh Water Consumption Reduction.

NPE	Constraint (mg/L)	Average Concentration (mg/L)	Reduction of fresh water consumption (%)	
			with O.M.	without O.M.
Fe	1.50	1.300	13.6	37.1
		1.950	13.6	13.6
	0.75	1.300	13.6	37.1
		1.950	13.6	24.2
Ca	15.00	24.014	13.6	37.1
		36.021	13.6	19.7
	7.50	24.014	0.0	0.0
		36.021	0.0	0.0
Si	40.00	18.814	13.6	37.1
		22.221	13.6	37.1
	20.00	18.814	13.6	37.1
		22.221	11.9	11.9
Mn	2.70	0.070	13.6	37.1
		0.105	13.6	37.1
	1.35	0.070	13.6	37.1
		0.105	13.6	37.1

As can be seen in Table 02, when the constraint of organic material is considered for using white water, it becomes the most important one and limits the integration of process streams, independently of the concentration of NPE's, for the range studied. Considering the NPE's the results have shown that calcium is the most sensible and that for lower values for its constraint it is not possible to reuse white water in the bleaching process.

Figures 02 and 03 show, the influence of calcium constraint in press and calcium concentration in white water stream, in the reduction of fresh water consumption, respectively for cases with and without the constraint of organic material. In the analysis of the uncertainty of its constraint, a range of ± 15% was adopted, since the results obtained with the simulations beyond these limits have presented no significant differences. For the uncertainty in the value of calcium concentration in white water stream, a range of ± 50% was used, since this is the uncertainty due the chemical analysis method used.

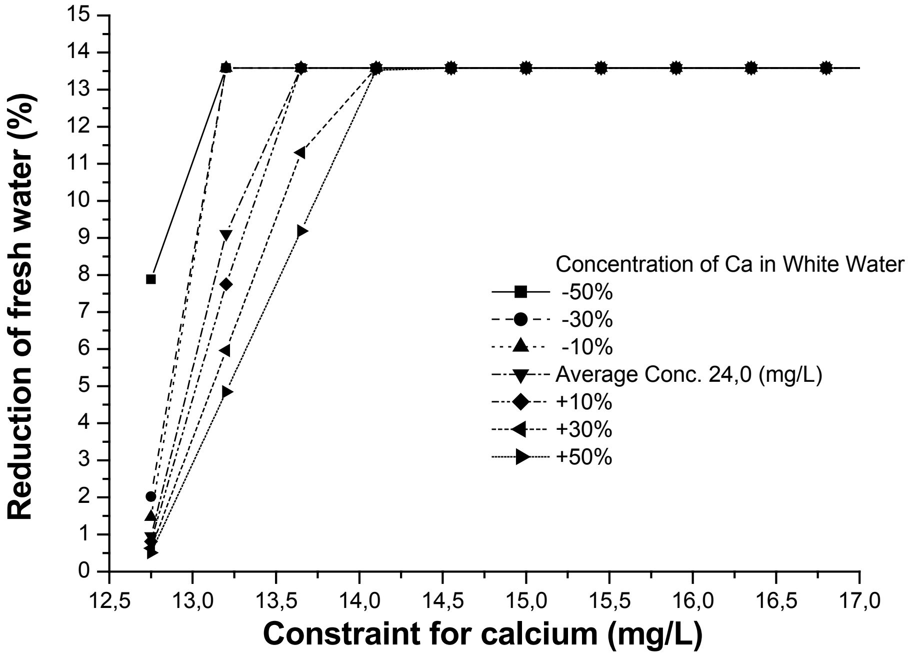

Figure 02 – Calcium influence in reduction of fresh water (with constraint of O.M.).

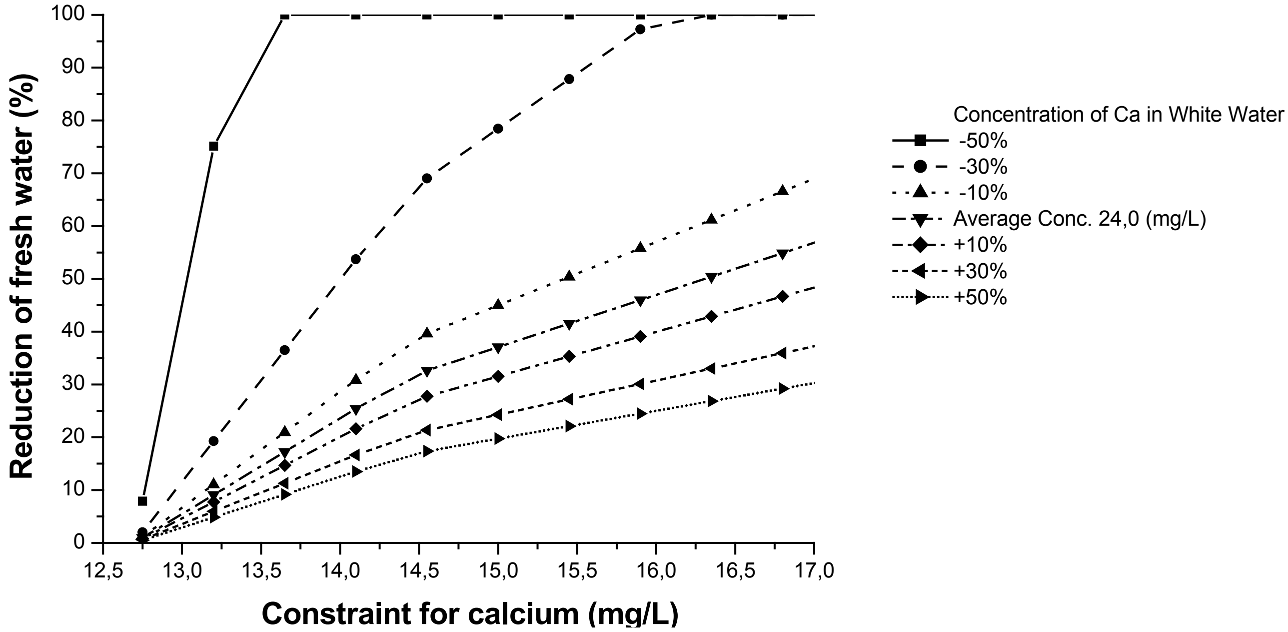

Figure 03 – Calcium influence in reduction of fresh water (without constraint of O.M.)

In the cases where the constraint of organic material was taken into consideration, it is clearly seen that it restricts the use of white water to a maximum, independently of the concentration of calcium or others NPE's. In the case of calcium, the reduction of fresh water consumption presents great sensibility for the constraint in the range of 12.7 to 14.0 mg/L.

When the constraint of organic material was not considered it was possible to obtain much greater reductions in the consumption of fresh water. In these cases it is possible to analyze the influence of NPE's since they become responsible for limiting the reduction.

Table 03 shows two cases in which the extremes of the variables were combined in order to evaluate the effect on the reduction of fresh water.

Table 03 – Percentage Reduction of Fresh Water in Critical Conditions.

Cases		Reduction (%)
1 – With O.M.	Constraints of all NPE's – lower limit	0.96
	Concentration of all NPE's – upper limit	13.58
2 – Without O.M.	Constraints of all NPE's – lower limit	0.96
	Concentration of all NPE's – upper limit	19.74

4. CONCLUSIONS

Using an electronic spreadsheet it was possible to perform a systematic analysis of the bleaching process of a pulp and paper industry, seeking for a reduction of the fresh water used in washing presses in this unit, using an integration process approach. This analysis has shown that part of the effluent of paper machines (white water) may be used, together with fresh water, in the washing presses of bleaching, reducing the consumption of the first with a consequent reduction in the volume of effluents generated in the process. In this analysis the influence of non-process elements (Ca, Fe, Mn and Si) and of organic materials has been considered, since they represent limitations in the quantity of white water use. The results obtained have shown that it is possible to reduce approximately 13% of fresh water, when considering organic material constraint and more than 30% when this constraint is not considered. In this case, calcium becomes the limiting NPE, since the others are present in small concentrations. These conclusions are pointing out for a possible use of white water, which is technically feasible, and with a special treatment of this effluent, to reduce (or remove) organic material and calcium compounds, the reduction of fresh water consumption can reach much higher percentages. Nevertheless this option must necessarily pass through an economic analysis.

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