Reuse Of Water In The Pulp And Paper Industry Using The Water Source Diagram As Tool

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Water is an important natural resource and is used in large scale in the pulp and paper industry for several applications as: washer filters, bleaching, liquors clarification, cooling towers and boilers. Therefore the process generates a great quantity of effluents. The concern with the environmental and also with the fresh water cost, has taken researchers to develop several procedures about water consumption minimization through reuse. The aim of this work is the application, in the pulp and paper industry, of the procedure called Water Source Diagram (WSD), developed by Gomes et al. (2007). It is based on the synthesis of mass exchange network through a heuristical algorithmic procedure, in which the objective is the water consumption minimization and the wastewater generation. The WSD procedure was capable to minimize about 46% the water consumption, considering maximum reuse and about 76,8% considering regeneration with reuse.

1. Introduction

The pulp and paper industry consumes large volume of water and one of its latest trends is the water and wastewater minimization. Several methodologies are been developed to synthesize mass exchange networks focusing in water and wastewater reuse. As reuse causes problems of accumulation of non process elements, the use of regeneration processes in order to reduce contaminants concentration becomes necessary.

Wang and Smith (1994) used the limiting water profile to minimize the water flow rate in systems with single and multiple contaminants, considering reuse, and regeneration and reuse of effluents. In order to overcome the problems concerned with the method proposed by Wang and Smith (1995), Castro et al. (1999) developed a procedure in which the water consumption and the synthesis of mass exchange network were attained simultaneously. This procedure was used in systems with single contaminants and considered only the reuse of effluent streams to reduce fresh water consumption.

Partasarathy and Krishnagopalan (2001) used the mass integration in the minimization of the external water consumption in the bleaching process of kraft pulp; first through graphical method (source sink diagram and path diagram) and followed by non-linear mathematical programming, where the final fluxogram is obtained. The source sink diagram identifies the external water sources as well as all the possible internal sources generated as effluent of the several operations, allowing visualize the sources most adequate to satisfy the specifications of the entrance conditions of each operation. The rule based on lever arm, derived from the mass balance, was the criterion used for the reuse of effluent in one determined process; it consists in calculate the flow rate necessary from the source(s) chosen to assure that be transferred the exactly mass amount to satisfy the minimum flow rate of entrance and the maximum exit concentration of chloride in that operation. It was considered: direct reuse, mixing between two sources (effluent) and reuse, and mixing and reuse with fresh water.

The only contaminant chosen in the procedure application was the chloride (non-process elements). The effect of the accumulation of these elements due to reuse and recycle of streams, can be observed in the path diagram, whose equations were included in the mathematical optimization program. This program also considers the initial solutions obtained in the source sink diagram.

Diverse solutions were obtained; also considering regeneration of streams, in order to become reuse and recycle thermodynamicaly viable. It was observed that when increases the number of recycle operations, increases the cost with regeneration of streams, although the water consumption is lower. The result consists in the reduction of the consumption of 57% of fresh water, supplying three options of regeneration processes, with investments for about 7.2 to 3.6 millions dollars in effluent treatment and operational costs of 2.1 millions to 880 thousand dollars/year.

The Water Source Diagram Procedure presented in Gomes et al. (2007) and here proposed, can be considered as an improvement of Castro et al. (1999) and Gomez et al. (2000) procedures. It is able to take into account a variety of situations, such as: (i) reuse; (ii) multiple water sources; (iii) water losses along the process; (iv) flow rate constraints; (v) regeneration and reuse; and (vi) regeneration and recycling.

In this work the water source diagram procedure (WSD) is applied in the pulp and paper industry to synthesize mass exchange networks with minimum water consumption through reuse, and regeneration and reuse. One case is studied involving the WSD procedure and showing its applicability.

2. Methodology

The Water Source Diagram divides the process in concentration intervals and water is allowed to be reused between intervals. Concentration limits of each interval are considered sources of water. Water supply and regenerated water are considered external water sources. These concentrations are ordered and represented into a grid of concentrations. Then the amount of mass transferred ($\Delta m_{k,i}$) in each operation (k) in each interval of concentration (i) is calculated and indicated between parenthesis.

After initial construction, heuristics rules are followed: i) external water sources are allowed to be used only when internal water sources are not available, ii) the greatest amount of mass must be transferred into the interval of concentration, iii) when an operation is present in several intervals, its water flow must remain along these intervals until its end. The advantage of this procedure is that the network structure is obtained simultaneously with the minimum fresh water consumption target.

The amount of mass transferred in each operation k and each interval i (Δm_{ki}) is calculated by equation 1.

$$\Delta m_{ki} = f_k (C_{fi} - C_{ii}) \quad (1)$$

in which C_{fi} is the final concentration of interval i, C_{ii} is the initial concentration of interval i, f_k (t/h) is the mass flow rate through k operation, k = 1..., $N_{op.}$ The concentration intervals are identified by the index i, where i = 1..., N_{int}; and N_{int} is the number of concentration intervals i. Concentrations are in ppm, therefore the amounts of mass transferred (Δm) are in g/h.

The flow rate required from the water source p for operation k, in the interval of concentration i, can be determined by the following equations:

- External water sources:

$$f^{e}_{pki} = \frac{\Delta m_{ki} - \sum_{j=1}^{N_{fia,i}} (f^{i}_{jki} x[C_{fi} - C_{ij}]}{C_{fi} - C^{e}_{p}} \quad (2)$$

- Internal water sources:

$$f^{i}_{pki} = \frac{\Delta m_{ki} - \sum_{j=p-1}^{p} (f^{i}_{jki} x[C_{fi} - C_{ij}]}{C_{fi} - C^{i}_{p}} \quad (3)$$

where C_{ij} is the concentration in which internal source j is used in interval i, C^{e}_{p} the concentration of the external source p, C_{fi} the final concentration of interval i and $N_{fia,i}$ is the number of available internal sources in interval i. One must use internal source in the interval, and the respective values of f^{i}_{jki} are calculated before f^{e}_{pki}. The sum in the eq. (3) represents the amount of contaminant removed by the internal sources, in operation k in interval i, that has preference on the external sources.

The minimum external water source flow rate at 0 ppm can be calculated:

$$f^{e}_{p} = \sum_{k=1}^{N_{op}} \sum_{i=1}^{N_{i}} f^{e}_{pki} \quad (4)$$

More details about WSD can be seen in Gomes et al. (2007) and also are illustrated in the following examples.

3. Case study

The WSD procedure was applied in a example extracted from Parthasarathy and Krishnagopalan (2001). It involves the minimization of water consumption through maximum reuse and alternatively by regeneration and reuse in a pulp mill. The example uses only one contaminant: chloride. Proposals for reducing fresh water consumption are developed in this case by the Water Source Diagram procedure (WSD) application.

Figure 1 presents major operations concerning water consumption in this pulp mill process.

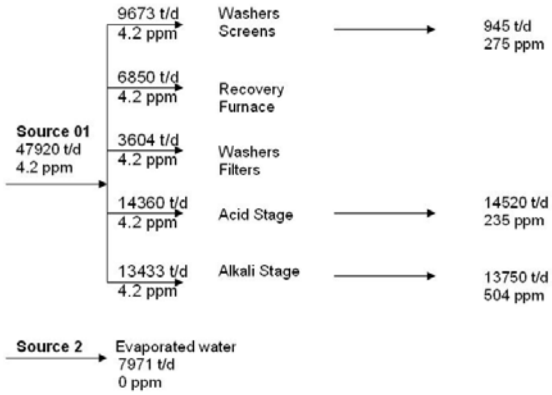

Figure 1: Initial water consumption in pulp mill process (Parthasarathy and Krishnagopalan, 2001)

Table 1 presents operational data for the ones cited in Figure 1. For WSD application, operations which present water gain or loss are divided in two parts. The first is the one with fixed flow rate and the second represents the water gain or loss. For example, operation 1.2 represents water loss, and operations 4.2 and 5.2 water gain, according to Figure 1. In this process, operations with fixed flow rates are not present. Table 1 also shows the results for the amount of mass transferred ($\Delta m_{k,i}$) in each operation, assuming operational conditions.

Table 1
Operational data with corresponding mass transferred ($\Delta m_{k,i}$)

Operations	f (t/d)	C_{in} (ppm)	C_{out} (ppm)	$\Delta m_{k,i}$ (kg/d)
1.1 - Washers screens	945	4.2	275	255.906
1.2 - Washers screens	8728.5	4.2	---	36.6597
2 - Recovery Furnace	6850	4.2	---	28.7700
3 - Washer Filters	3603.9	4.2	---	15.1364
4.1 - Acid Stage	14360	4.2	235	3314.2880
4.2 - Acid Stage	160	4.2	---	0.6720
5.1 - Alkali Stage	13433	4.2	504	6713.8134
5.2 - Alkali Stage	317	4.2	---	1.3314

In Table 2 all maximum inlet and outlet contaminant concentrations is presented; these are directly related to limits of corrosion, plugging, scale and deposit formation and accumulation of inert in lime cycle according to Parthasarathy and Krishnagopalan (2001).

From these concentrations, using eq. (1) and also considering that the amount of mass transferred is maintained in each operation, the limit flow rates of each operation are recalculated.

Table 2
Limiting data of the pulp mill process, $f_{lim,min}$

Operations	$f_{lim,mín}$ (t/d)	$C_{in,máx}$ (ppm)	$C_{out,máx}$ (ppm)	$\Delta m_{k,i}$ (kg/d)
1.1 - Washers screens	1550.95	110.0	275.00	255.91
1.2 - Washers screens	333.27	110	---	36.66
2 - Recovery Furnace	5230.91	5.50	---	28.77
3 - Washers Filters	393.15	38.50	---	15.14
4.1 - Acid Stage	14738.03	10.12	235.00	3314.29
4.2 - Acid Stage	66.40	10.12	---	0.67
5.1 - Alkali Stage	13679.33	13.20	504.00	6713.81
5.2 - Alkali Stage	100.86	13.20	---	1.33

Figure 2 presents the Water Source Diagram (WSD) considering maximum reuse, related to data of Table 2, obtained by the proposed procedure.

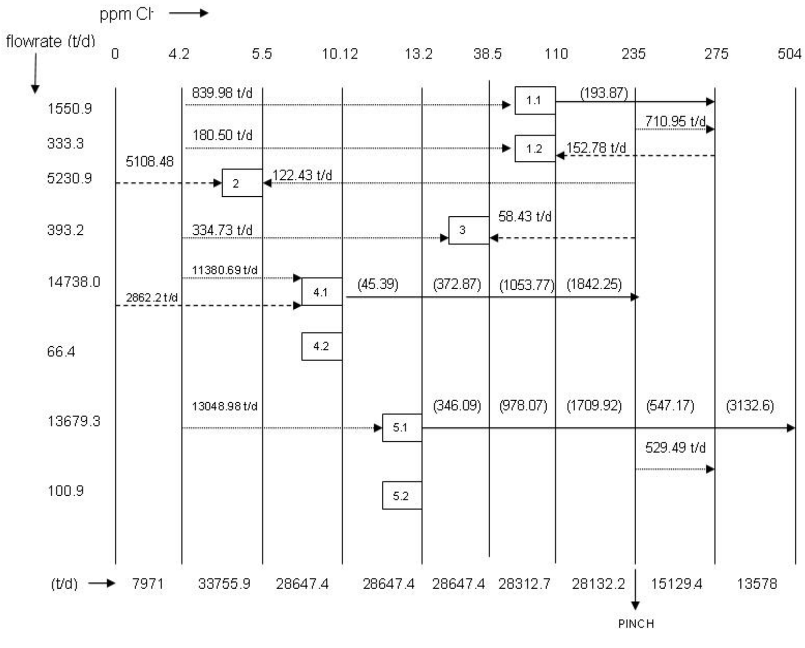

Figure 2: WSD of pulp and paper mill with maximum reuse.

It can be seen that the minimum water consumption with 4.2 ppm is 25784.88 t/d. Figure 3 shows the mass exchange network corresponding to the WSD of Figure 2.

As observed in Figure 3, the consumption of water at 4.2 ppm was reduced from 47920 t/d to 25784.9 t/d.

One of the latest trends in pulp and paper industry turns towards closing-up the process water systems. However, water reuse is accomplished with accumulation of non process elements and the increase of microbiological activity into the process, causing problems related to deposits, corrosion and odors. In order to consider these aspects, regeneration has become an important tool to reduce contaminant concentration before water/wastewater reuse. The WSD procedure can easily include the regenerated water, considering it an external water source. Operations flow rates using regenerated water are calculated using eq. (3), although the regenerated water flow rate available is limited by process effluents flow rates.

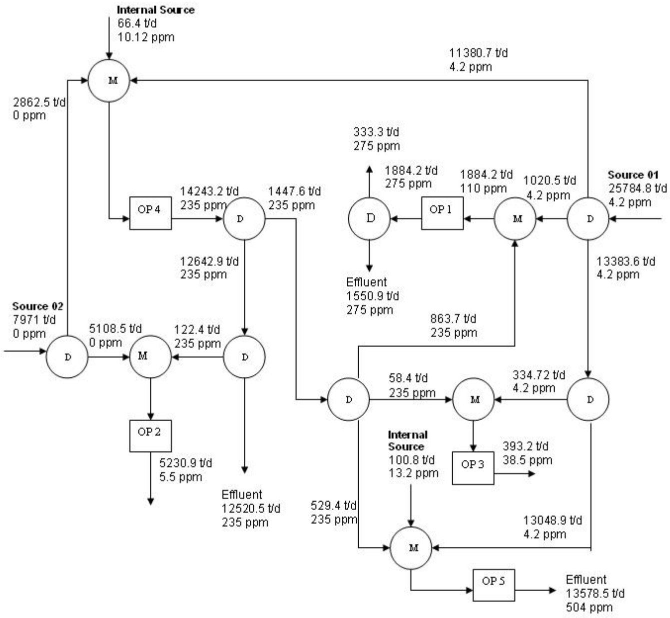

Figure 3: Mass exchange network for maximum reuse. The unit of contaminant Cl^- is in ppm.

Assuming the existence of a regenerator which regenerates streams to the concentration of 6.2 ppm of chloride, Figure 4 shows the new WSD, where there is a new source of water at 6.2 ppm, coming from regeneration of the acid stage (operation 4) effluent. In the procedure, this new water source is considered as an external source.

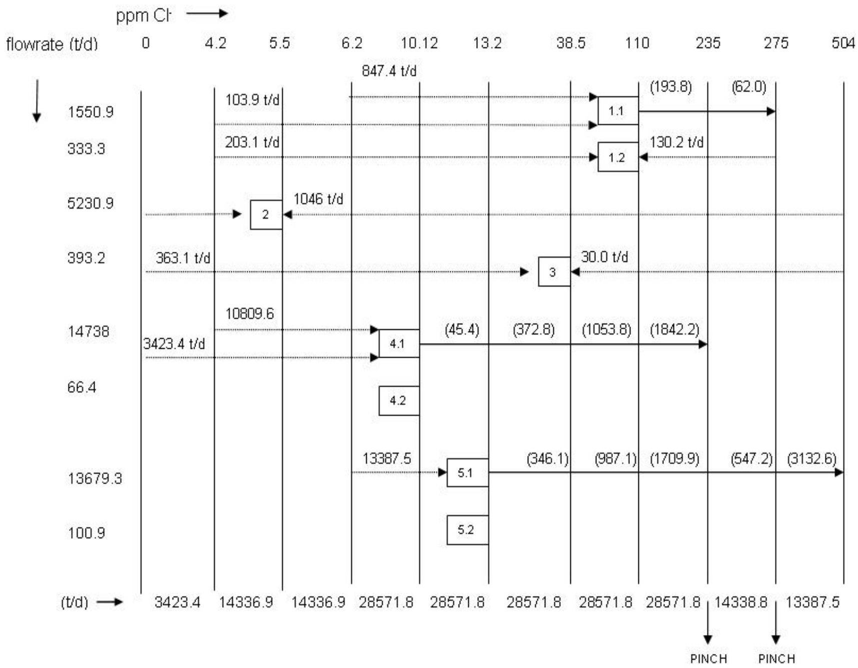

Figure 4: WSD with fixed regeneration at 6.2 ppm and reuse.

Figure 5 shows the mass exchange network for regeneration and reuse with operations arranged according to WSD in Figure 4. Observe in Figure 5 that with regeneration to 6.2 ppm and reuse of the regenerated stream, the minimum consumption of external water at 4.2 ppm is reduced to 11116.6 t/d. The regeneration of the acid effluent, for example by ionic exchange, reduces the chloride concentration from 235 ppm to around 6.2 ppm.

Thus, the chloride removal rate by ionic exchange is about 97% and is a feasible operation.

The consumptions determined using WSD procedure are lower than the ones reached using the mathematical optimization procedure of Parthasarathy and Krishnagopalan (2001).

The case study demonstrates the application of the WSD algorithm in cases with regeneration and reuse of effluents.

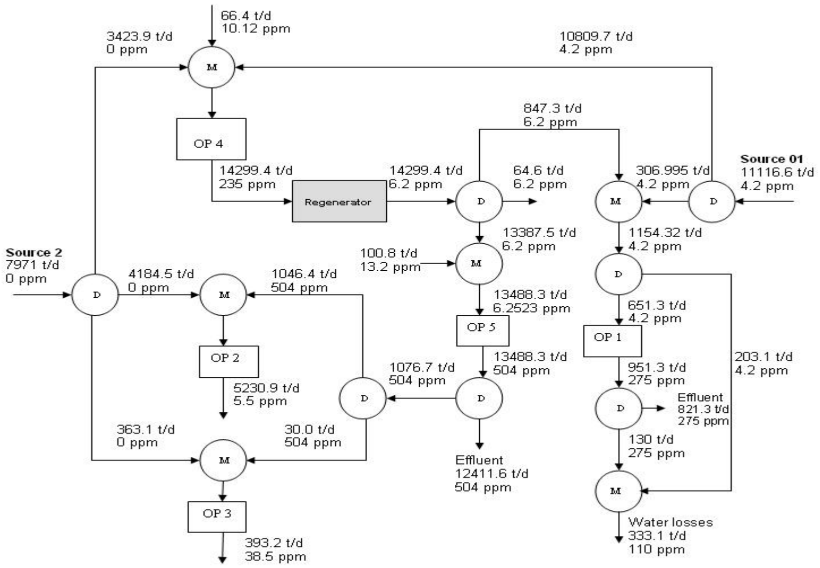

Figure 5: Mass exchange network with regeneration at 6.2 ppm and reuse.

4. Conclusion

For the two options considered: maximum reuse and regeneration with reuse, the results of WSD procedure were better than the proposed by other authors using mathematical programming. Besides, the case study demonstrated that the application of WSD procedure can also be easily used in cases involving maximum reuse and regeneration and reuse through hand calculations.

5. References

Castro P., H. Matos, M.C. Fernandes and C.D. Nunes, 1999, Improvements for mass-exchange networks design. Chemical Engineering Science, 54: 1649-65.

Gomes J.F.S., E.M. Queiroz and F.L.P. Pessoa, 2007, Design Procedure for Water/Wastewater Minimization: single contaminant. Journal of Cleaner Production, 15: 474-485.

Gomez J., M. Salvelski and M. Bagajewicz, 2000, On a systematic design procedure for water utilization systems in refineries and process plants. Chem Eng Commum.

Wang Y.P. and R. Smith, 1994, Wastewater minimization. Chemical Engineering Science, 49: 981-1006.

Wang Y.P. and R. Smith, 1995, Wastewater Minimization with Flowrate Constrains. Trans I Chem, 73(a): 889-904.

Parthasarathy G. and G. Krishnagopalan, 2001, Systematic reallocation of aqueous resources using mass integration in a typical pulp mill. Advances in Environmental Research, 5: 61-79.