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Retrofit Approach for the Reduction of Water and Energy Consumption in Pulp and Paper Production Processes

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1. Introduction

This chapter describes a comprehensive approach that allows a water and energy reduction in industrial processes. This technique is based on the retrofit concept. An analysis of retrofit has the feature to perform in a systematic way, a series of steps that guides practices and help to identify opportunities for saving water and energy.

Methodologies and techniques have been implemented independently in (pulp) industries in order to reduce water and energy consumption. At industry level and particularly in real pulp and pulp processes, methodologies and techniques to reduce independently water consumption as well as energy consumption have been implemented.

Pinch Technology began its application to this kind industry in 1990 (Calloway et at. 1990) to optimize energy using the traditional methodology introduced by Linnhoff et al. (1982). Subsequently, using the Pinch Analysis concept, Berglin et al. (1997) incorporated a mathematical programming work and an exergy analysis; they achieved the reduction of energy consumption in two pulp mills. Koufus et al. (2001), used sequentially Pinch Analysis and later on Water Pinch Analysis (WPA) methodology for these industries (Pulp and Paper), getting first of all an energy reduction and then a water reduction. In the paper of Rouzinuo et al. (2003) Pinch Technology proved to be a great tool for the integration of new equipment in processes for pulp and paper industry at an application in Albany (Oregon, USA) achieving the reduction of energy consumption significantly. Savulescu et al. (2005c), presented a processes integration technique based on Pinch Technology to reduce water (WPA) and energy (Pinch Analysis) in a Kraft process pulp mill; in the same way Towers (2007), applied Pinch Technology for water reduction.

The concept of energy reduction through the water reduction in the pulp and paper industry was applied by Wising et al. (2005). With the same concept, Nordam et al. (2006), presented a design for water and energy systems reducing energy consumption by reducing water use.

For water reduction (exclusively) in a pulp mill (Kraft process), Parthasarathy et al. (2001) used mass integration for effluent reuse and thereby reduce water consumption. Similarly Lovelady et. al (2007) reduced water consumption by optimizing the discharge effluent reuse water.

As it has been mentioned in the previous paragraphs, the application of technologies for the reduction of to reduce water and energy is performed independently, however, it has been established that water and energy are directly related. First these papers works analyze the opportunities for water minimization and later, an energy study is realized in order to conclude that reducing water, energy consumption also reduces.

The methodologies mentioned in previous paragraphs do not discuss the main characteristics concerning the operation of pulp and paper process; in fact, process conditions (stream flow rate, temperature, concentration, etc.) give the information to identify the objectives of the minimal use of water and energy.

Recently, Savulescu et al. (2008) published a work where heat is recovered through the mixing of streams and the dilutions that take place. However for this type of systems, they do not provide an integrated methodology where water and energy is reduced simultaneously.

The central premise of this work is that internal aspects of the process must be analyzed in order to look into opportunities that will change the operating conditions to achieve a more efficient use of water and energy. The internal aspects of the process that must be analyzed are: separation processes, reaction processes and equipment performance. The chemical operations involved are those used for the separation of (lignin), unwanted material that accompanies the final product (cellulose). Depending on the level of conversion in the reaction, the next step (washing) will require more or less amount of water. Therefore, by increasing the conversion, a decrease in the water consumption can be expected. By modifying the water streams, the energy requirements for the bleaching operation are also modified. Any change in the operating conditions, will have an effect on the equipment performance, and this should be evaluated.

This chapter presents a case study in a Kraft Pulp Mill (Fig. 1). The general process flowsheet is described in the following section.

2. Pulping process

Pulp is obtained from different types of cellulosic material sources, e.g. wood and other fibrous plants. The procedure for obtaining pulp from these materials is called pulping and its purpose is the purification and separation of cellulosic.

There are different categories of pulping processes: chemical and mechanical pulping. Chemical pulping methods rely on the effect of chemicals to separate fibers, whereas mechanical pulping methods rely completely on physical action. The two main chemical processes are: the Kraft process (alkaline) and the Sulfite process (acid). The mechanical process produces higher yields compared to the pulp process; Mechanical pulps are characterized by high yield, high bulk, high stiffness and low cost. They have low strength since the lignin interferes with hydrogen bonding between fibers when paper is made.

Wood is debarked and chipped, and the chips screened to eliminate fine material and over-sized chips. The "accepted" chips are fed to a pressure vessel, the digester. The chips are steamed with direct steam to eliminate as much of the air as possible. The cooking temperature is maintained until the desired degree of delignification is reached, after which the digester contents go to a blow tank. The pulp from the blow tank is then washed and screened. Residual lignin is removed from pulp by bleaching with chemical reagents. All bleaching treatments have certain common steps. The consistency of the pulp suspension is set in a washer or de-watering device to a target level; temperature and pH may be adjusted by controlling the wash water temperature and pH on the washer of a preceding stage. The suspension is pumped via one or several mixers to a co-current tubular reactor, which may be atmospheric or pressurised. The suspension is then transported to a washer for the removal of dissolved material. Finally, water is removed from the pulp through a drying process.

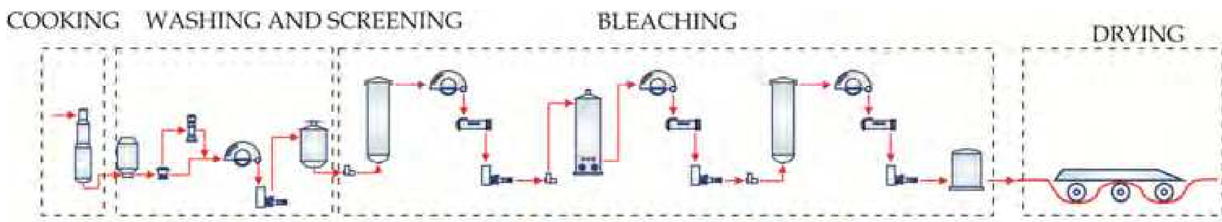

Fig. 1. Simplified diagram of a pulping process.

3. Overall retrofit strategy for the reduction of water and energy in pulp and paper processes

3.1 Hierarchical methodology

The guidelines set by Westerberg et al. (1979), the so-called strategy of the onion diagram (Linnhoff et al. 1982), (Shenoy, 1995) and the heuristic approach (Douglas, 1988), are examples of procedures for the design based on the decomposition of the process in stages. The philosophy behind each of these approaches is the basis for implementing the necessary strategies for the minimization of water and energy in real processes. In this work a hierarchical approach is developed for the retrofit of existing process aiming at the reduction of water and energy consumption.

Basic to this approach is a profound knowledge of the process; it continues then with the extraction of information and then the implementation of the heuristic rules and methodologies for analysis. A graphical diagram of the hierarchical approach is shown in Fig. 2 by means of an "onion diagram". The various steps are described below:

- Reaction:
  - Analysis of chemical reaction route
  - Reaction system (reactors)
- Water use system
- Water regeneration for reuse
- Heat recovery system

3.2 Reaction

The layer of reaction is **subdivided** into two levels: one is related to the analysis of the route of reaction and the other one is related to the system of reactors. In this stage, the type of chemical reaction, the kinetics and the reactor design are analyzed in detail.

3.2.1 Analysis of the chemical reaction route

The stage of bleaching is a section of the process for pulp production where chemical reactions take place. The purpose of the bleaching process is to withdraw the maximum amount of lignin contained within the pulp. In this stage, the type of reaction that is carried out in each of the different stages of the bleaching process is analyzed. The chemical compounds that are used in the bleaching stages are identified. In the case of an existing plant, the analysis of the route of reaction may trigger a series of actions allowing the implementation of technologies with greater reaction conversion while reducing the water consumption.

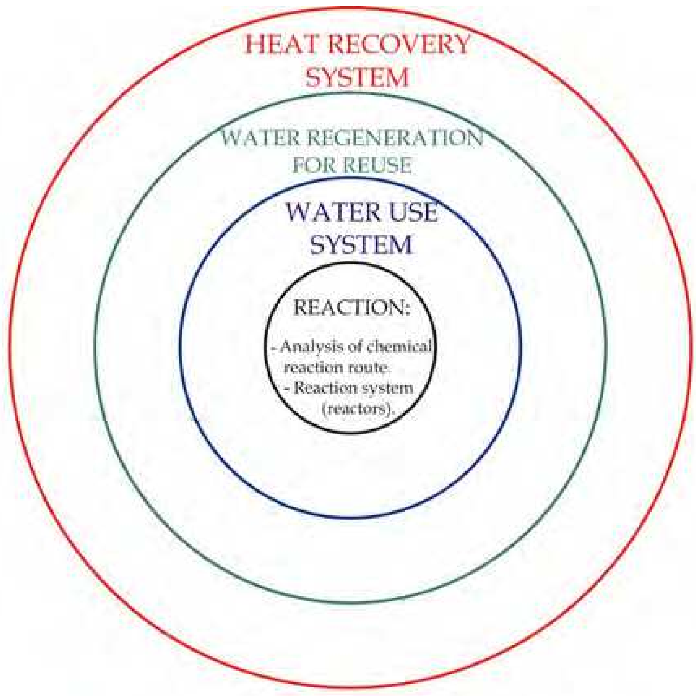

Fig. 2. Retrofit approach based on the concept of the "Onion Diagram ".

3.2.2 Reaction system (reactors)

Once the route of chemical transformation of the process is known, the reactor system design is then considered. This involves the examination of a three way trade-off between equipment, level of conversion and reduction in water consumption. In the case of the bleaching process, the lower the amount of solids product (pulp) at the outlet of the reactor; the lower is the amount of water that is needed to reach the required concentration in the filtering stage, as it is shown in the Fig. 3. Equation 1 (Walas, 1988) shows the relationship between mass flow rate, the volume of the reactor and concentrations.

$$\frac{V}{F} = \frac{x_e - x_F}{r_e} \qquad (1)$$

F = Flow rate
V = Volume of the reactor
x_e = Final conversion
x_F = Initial conversion
r_e = Conversion rate

Knowledge of the characteristics of the bleaching reaction and reactor volume, the actual reaction rate can be determined. This information is then used to determine the additional reactor volume needed for more lignin to react. The flow diagram of Fig. 3 shows the way fresh water consumption is linked to the level of lignin conversion in the reactor. Since fresh water is used to dilute the reactor outlet stream for it to be filtered downstream, as amount of lignin that reacts increases, the lower the amount of solids at the reactor outlet. This condition results in less fresh water being needed for dilution and therefore water savings are obtained. In addition, warm water is added into the filter for furthering the removal of impurities from the cellulose.

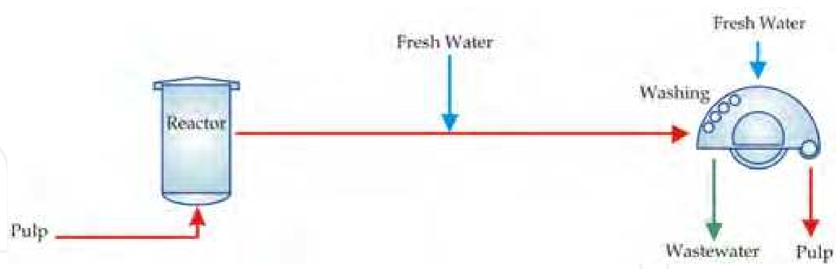

Fig. 3. Area of chemical reaction and filtering in the stage of bleaching.

3.3 Water use system

At this stage a water pinch analysis is carried out. Let us consider the washing section of the process that consists of a series of physical separations for the removal of impurities from the pulp coming out from the digester (Fig. 4). This pulp receives the name of raw flesh because it has not been bleached yet. At this stage, a large amount of water is used. It is therefore important the implementation of techniques that lead to the reduction of water. The large amounts of water used and the physical nature of the process are conducive for the implementation of the Water Pinch Analysis (WPA) technique which seeks to minimize the consumption of water. These conditions are also appropriate to pose an optimization problem by means of mathematical programming, seeking to reduce the total operation costs. Both techniques are effective for the analysis, synthesis and improvement of the water networks. Furthermore, they take into account the concepts of reuse and regeneration of water that have an impact on the generation of wastewater or effluents while minimizing the water consumption.

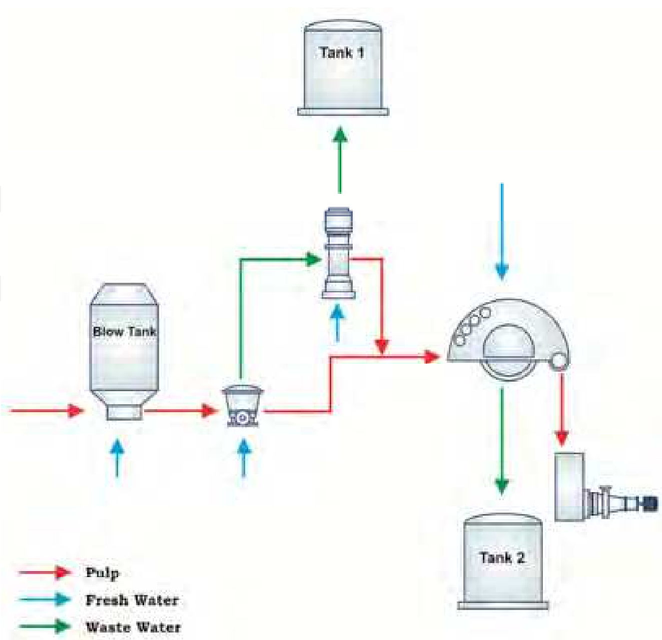

Fig. 4. Washing system.

3.4 Water regeneration for reuse

Once exploited and completed all the options for the reduction of water consumption through the measures implemented in the first two layers of the onion diagram, the next step consists in the application of water regeneration techniques. At this level, different techniques for feasible decentralized regeneration of the effluents for water reuse should be evaluated (Fig. 5). Among the typical regeneration technologies are those of physical, chemical and biological nature. The selection of the regeneration system should be based on a series of considerations such as: equipment cost, operating costs, ease of implementation, availability, etc.

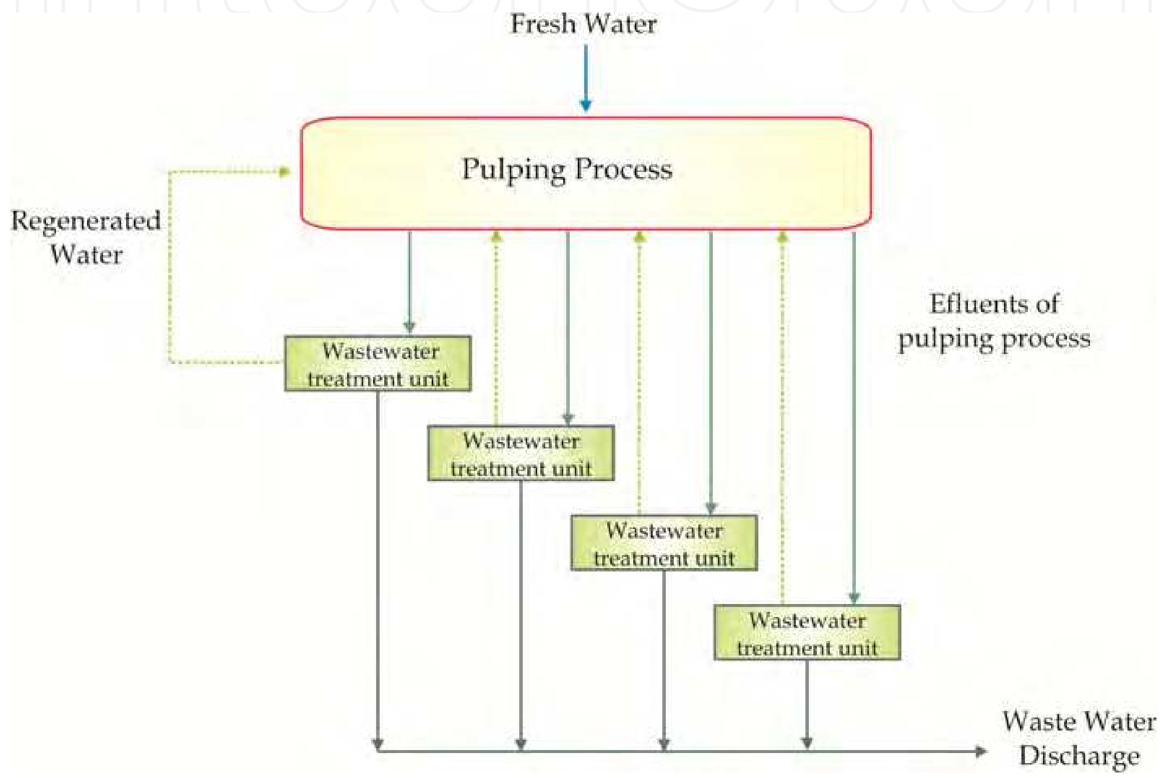

Fig. 5. Regeneration system for water reuse.

3.5 Heat recovery system

The last stage in the hierarchical strategy is to identify the options for reducing energy consumption through the maximization of the heat recovery and the quantification of direct savings generated by the simple reduction of the water consumption. In some cases, when the economic scenario is favorable, the savings of steam can be channeled to the production of electrical power in cases where the process plant is integrated with a cogeneration system.

4. Applications and case study

The case study in this section uses information from a real pulp plant. The methodology described in the previous section is implemented step by step with the aim of reducing energy and water consumption.

Knowledge of the various aspects of an existing plant allows us to identify particular situations that apart from theory lead us to incorporate certain considerations that make the application practical. For instance, the plant layout, the economic environment, the time required for the delivery of the projects which will require modifications and investment, the plant production rate and its fluctuations throughout the year, etc. The application is shown below.

4.1 Process description

The raw material used for the production of pulp is a short fiber wood from eucalyptus. The Kraft process is divided into four main stages, namely: cooking, screening and washing, bleaching and drying (see Fig. 1).

4.2 Application of the methodology

4.2.1 Analysis of the reaction stage in the bleaching process

As stated in the previous section, the first step consists in the analysis of the reaction route. In the case under consideration, chemical reactions take place during cooking and bleaching. The focus of the analysis will be around the former stage since it involves the consumption of fresh water.

The process proceeds by means of an Elemental Chlorine Free reaction (ECF) (Gullichsen et al., 1999) and takes place in three stages with three reactors arranged in series. The reactions are: D0 (oxygen delignification), EOP (Alkaline extraction reinforced with oxygen and hydrogen peroxide) and D1 (Chlorine dioxide). It is important to mention that the plant under consideration does not have an oxidizing stage previous to bleaching for the removal of lignin which implies that pulp reaches the process with a large Kappa number (the Kappa number that determines the weight percentaje of lignin in the pulp. This is: % lignin in pulp = 0.15 x Kappa number). It has been identified that as the lignin conversion increases in the reactor, the consumption of fresh water needed for effluent dilution for the filtering stage is reduced.

From equation 1 it is possible to calculate the rate of reaction (r_e) since the design parameters of the installed reactors are known. In the case of the D0 reactor, with a volume of 183.084 m^3, the volumetric feed (water and pulp mixture) is 216 m^3/hr. For the calculation of the reaction conversion as the kappa number moves from 28 to 8, the density of the mixture is needed. To this end, the pulp concentration of the feed is known to be 9.4% by weight; the density of the pulp is 1250 kg/m^3, so the overall density is determined below:

$$\delta_{DO} = (1250 \times 0.094) + (1000 \times 0.906) \left({kg}/{m^3} \right) \qquad (2)$$
$$\delta_{DO} = 1023.5 \quad \left({kg}/{m^3} \right)$$

Knowing the kappa number at the inlet and outlet of the reactor, the amount of lignin is calculated to be:

$$Lignin_{initial} = 0.15 \times KappaNo._{initial} \quad (\%) \qquad (3)$$
$$Lignin_{initial} = 0.15 \times 28 \quad = \quad 4.2 \ \%$$

$$Lignin_{final} = 0.15 \times KappaNo._{final} \quad (\%) \qquad (4)$$
$$Lignin_{final} = 0.15 \times 8 \quad = \quad 1.2 \ \%$$

The inlet and outlet lignin concentration is found to be:

$$L_o = (\delta_{DO}) \times (Concentration_{flow}) \times \left({Lignin_{initial}}/{100} \right)$$
$$L_o = \left(1023.5\, {kg}/{m^3} \right) \times (0.094) \times \left({4.2}/{100} \right) \tag{5}$$
$$L_o = 4.040778\, {kg}/{m^3}$$

$$L_f = (\delta_{DO}) \times (Concentration_{flow}) \times \left({Lignin_{final}}/{100} \right)$$
$$L_f = \left(1023.5\, {kg}/{m^3} \right) \times (0.094) \times \left({1.2}/{100} \right) \tag{6}$$
$$L_f = 1.154508\, {kg}/{m^3}$$

Once the lignin concentrations are known it is possible to determine the reaction conversion (X_F) from:

$$X_F = \frac{(L_o - L_F)}{L_o}$$
$$X_F = \frac{(4.040778 - 1.154508)}{4.040778} \tag{7}$$
$$X_F = 0.7143$$

Then, the rate of reaction can be calculate from:

$$\frac{V}{F} = \frac{x_e - x_F}{r_e}$$
$$\frac{183.084}{216/3600} = \frac{0.7143}{r_e}$$
$$r_e = -0.000234089 s^{-1}$$

Knowing the rate of reaction it is possible to determine the reactor volumen needed to take the kappa number form 8 to 4 (Gullichsen et al. 1999). This is, achiving higher conversion at the expense of investing in additional reaction volumne. Under the information so far obtained, it is determined that a volume of 219.7 m^3 is needed. Fig. 6 shows the process information and the water consumption that are required for the two scenarios, namely: a conversion corresponding to a kappa number of 8 (original) and a conversion correponding to a kappa number of 4 (new). From the results it can be concluded that the increase of the reactor volume by 36.61 m^3 allows more lignin to be removed from the pulp and consequently a mass reduction in the effluent is achieved; therefore, less fresh water is required to achieve a concentration of 1.2% which is required for an effective operation ofthe filter. In addition, the filter will consume less water for washing.

If the rector volumen was increased by 40 m^3, for a total volume of 223.084 m^3, calculations show that the fresh water consumption would be reduced by 11.511 m^3/hr. For an economical analysis, costs information is taken from Peters and Timmerhaus (1991). So, for the year 1990, the cost of a glass fiber linned reactor is approximately $ 190,000.00 USD. The cost is brought upto date by considering the the cost index according to:

$$f_{\theta} = \frac{Cost\ Index\ \ (August\ 2008)}{Cost\ Index\ \ (Reference\ year)} \tag{8}$$

Taking the cost indexes from Chemical: Engineering Plant Cost Index-USA (1990) and Economic Indicator, Chemical Engineering (August 2008), the following factor is obtained:

$$f_{\theta} = \frac{389}{660} = 1.6967$$

So, the approximate up-to-date cost is:

$$190000 \times 1.6967 = 322365 \ \ US\$$$

To determine the fresh water consumption, the cost of extraction per m3 of water is 1.2 US$ [Robin Smith, 2005]; considering a total of 8000 working hours, the water cost is

$$Cost_{Water} = \left(1.2 \, {}^{US\$}\!\!/_{m^3}\right) \times \left(11.511 \, {}^{m^3}\!\!/_{hr}\right) \times \left(8000 hrs\right)$$

$$Cost_{Water} = 110506 \ \ US\$ \ / \ year$$

From the information above, the payback period for the revamping of the bleaching reactor is approximately 3 years. For the second and third reaction stages, the lignin content is low enough to consider that the expected water saving would not justify the investment in reactor volume.

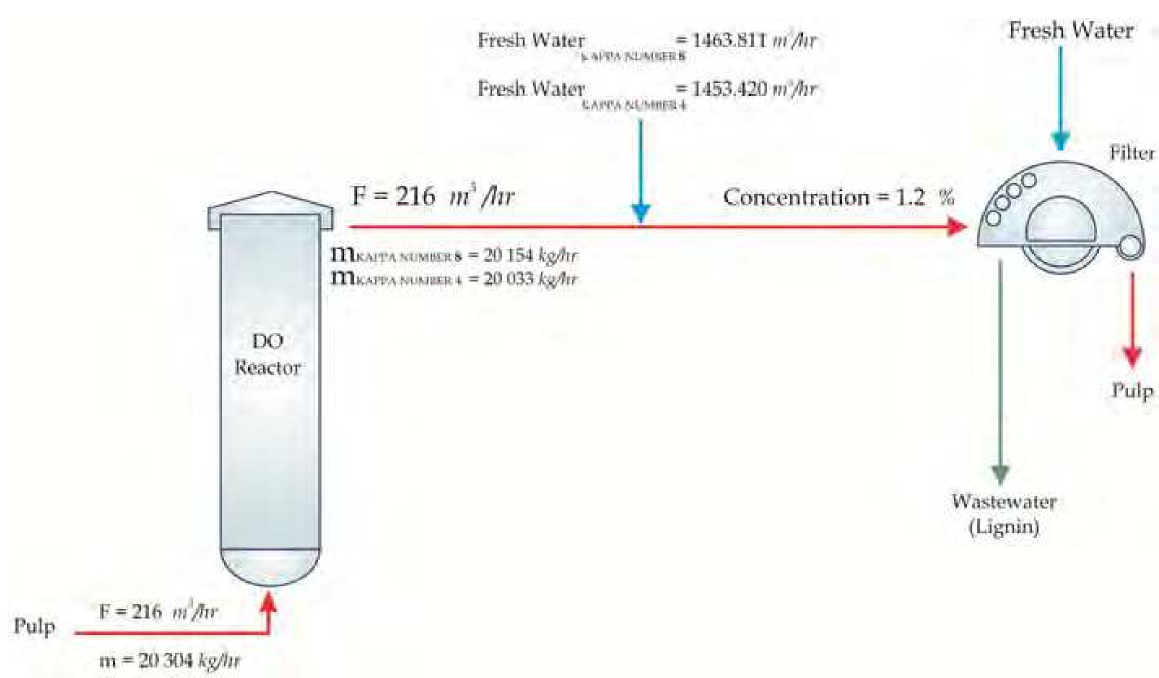

Fig. 6. Fash water consumption for different reactor volume (D0).

4.2.2 Water using system

Once the first hierarchical level has been covered, the second level is considered. This level corresponds to the pulp washing stage.

The purposes of the washing process are: a) the removal of un-reacted wood chips and non fibrous impurities from cellulose; b) the removal of soluble solids present in the fiber. The pulp washing step contains two filters that operate counter currently and a continuous rotary filter as shown in Fig. 4. Details of the operation of the equipment are shown in Fig. 7 and operating data are given in Table 1. The case is solved using a heuristic approach and the results are compared to those obtained a mathematical optimization.

No.	*Flowrate (ton/hr)*	*Concentration (%)*	*Mass Load (Kg)*	*No.*	*Flowrate (ton/hr)*	*Concentration (%)*	*Mass Load (Kg)*
1	72.250	12	8700	9	49.769	1.7	846
2	217.500	0	0	10	332.523	2.466	8223
3	290	3	8700	11	299.067	0	0
4	56.725	0	0	12	632.590	1.3	8223
5	62.971	2.1	1322.4	13	167.503	0	0
6	283.754	2.6	7377	14	732.134	0.009369	68.59
7	18.553	0	0	15	67.959	12	8155
8	31.755	1.5	476.3				

Table 1. Operating data of the washing step.

From Fig. 7 we see that the first filter removes the larger solids and its effluent is sent to filter 2 where smaller size solids are removed. The main stream from these two filters is sent to the rotary filter 3 where the pulp is finally washed for the bleaching step.

The total fresh water consumption in this process is of 759.348 ton/hr. As mentioned before, the effluent from the first filter (62.97 ton / hr) is processed again for further pulp recovery. Effluents reaching tanks 1 and 2 have different type of contaminant and different concentrations which imply that for water reuse, independent analysis must be conducted.

Total water usage is given by stream 2, 4, 7, 11 y 13 (759.348 kg / hr). Streams 2 and 11 give the pulp the required consistency whereas streams 4, 7 and 11 are used for washing. Table 1 shows the mass flow rates, concentrations and mass content of these streams.

In this part of the study, water pinch technology is applied (WPA). Some studies have been published on the application of this technology to total sites (Jacob et al., 2001; Koufus et al., 2001); however, in this work a local analysis is carried out. In a global study, one aspect that is ignored is the actual location of the water using operations; however, this aspect must be considered in a real plant application. Other aspects to be considered are: pulp recovery form water, the design of the piping network and the actual design and the operation of the equipment. For the case of filter 1, the operating data is:

$$f_1 = 56.712\left({}^{ton}\!/_{hr}\right)$$

$$C_{1,in} = 0 \quad (ppm)$$

$$\Delta m_1 = 1324 \left({}^{kg}\!/_{hr}\right)$$

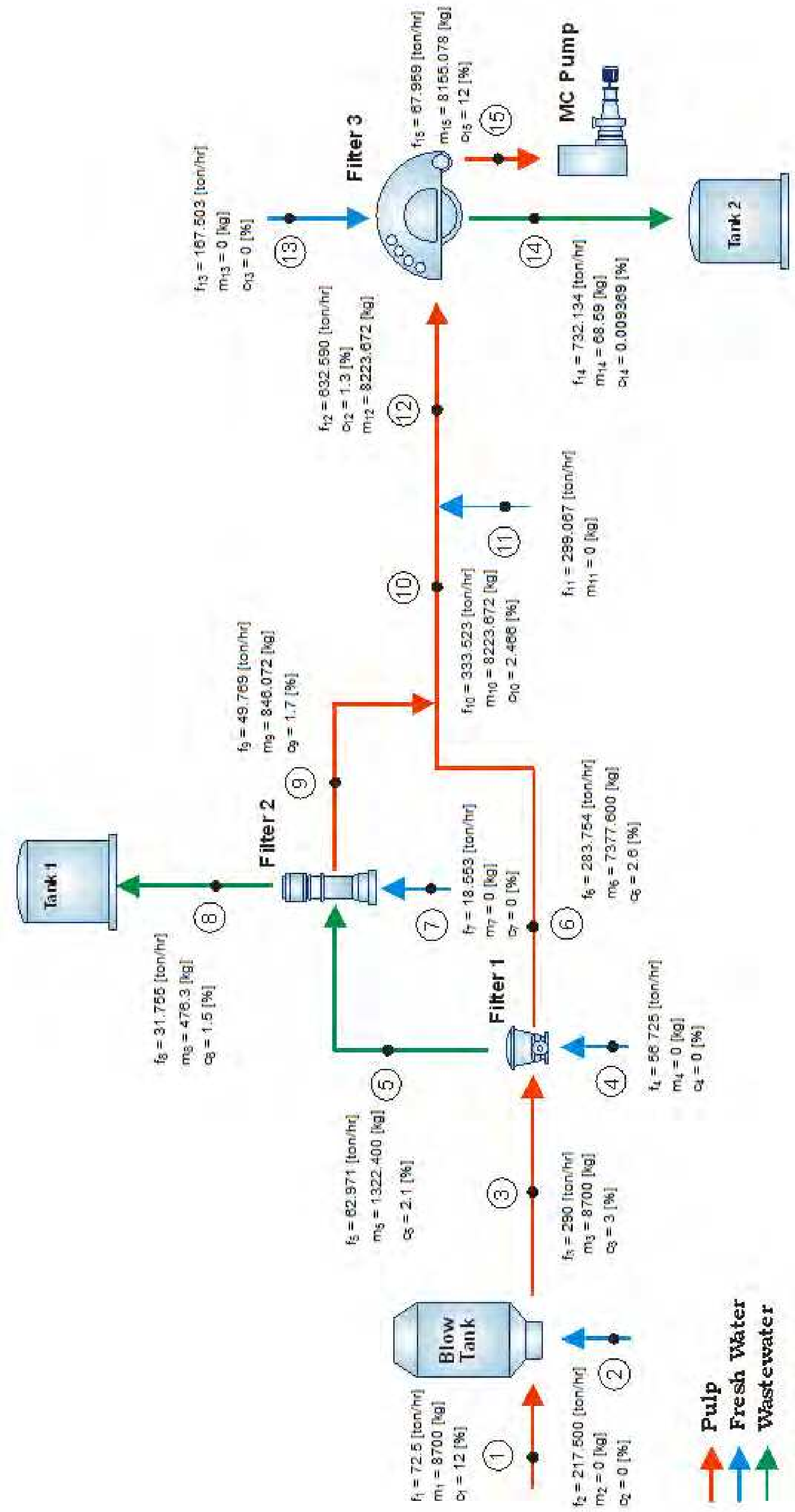

Fig. 7. Detail of streams and equipment in the washing process.

The outlet concentration limit, $C_{1,out,}$ is obtained from equation (9):

$$f_i^{\lim} = \frac{\Delta m_{i,total}}{[C_{i,out}^{\lim} - C_{i,in}^{\lim}]} x10^3 \quad (9)$$

$$56.712(ton/hr) = \frac{1324(kg/hr)}{[C_{i,out}^{\lim} - 0](ppm)} x10^3$$

$$C_{1,out} = 23346 \ (ppm)$$

Table 2 shows the limit concentrations of the stream that will be used to remove the mass of contaminant (Δm) with the minimum amount of fresh water (56.712 ton/hr). The inlet and outlet concentrations of contaminant to the filters are given in Table 3.
The information from Table 3 is used to construct the concentration-composite curve where the pinch point is obtained (424 ppm). This point represents the concentration limit of contaminant that can be used; it also shows the minimum fresh water consumption considering water reuse.

Filter (no.)	f_i *(ton/hr)*	C_{in} *(ppm)*	C_{out} *(ppm)*	Δm *(kg)*
1	56.712	0	23346	1324
2	18.546	0	25666	476
3	167.520	0	424	71

Table 2. Fresh water data in filters.

The amount of contaminant removed from each process and the total removal (1871 kg/hr) are shown in Fig. 8. The analysis indicates that fresh water is fed to operation 3; part of its effluent is reused in operation 1 and 2 as shown in Fig. 9.
The data form Table 3 is used to design the water network structure by means of mathematical programming. The final design is shown in Fig. 10. Although using both approaches the same minimum water consumption is obtained; however, the network structure is different.

Filter (no.)	f_i *(ton/hr)*	C_{in} *(ppm)*	C_{out} *(ppm)*	Δm *(kg)*
1	290.000	18780	23346	1324
2	62.952	18105	25666	476
3	632.400	311	424	71

Table 3. Process data of stream feeding the filters

Both the structures of Fig. 9 and 10 represent grass-root designs and they can be used to identify ways to improve o the existing structures. Now, there are some operating aspects that the former designs do not consider. For instance, none of the designs considers the start up and stabilization of the plant; besides, they do not allow residual water to be used to take the filter inlet to the required concentration. The actual operation of the various pieces of equipment is difficult to incorporate in the design such as the case of the filters and its efficiency in connection to the concentration load and the required flow rate that will remove the contaminant. An important issue in this process consists in the removal undesirable material such as stones, plastic and other pulp residues. It is also true that the pulp still contains un-reacted wood chips that can be re-circulated back to the main reactor in order to increase the production of pulp. Taking all these elements into consideration, the series of practical implementations to the washing stage that allow for the reduction of water consumption are described below.

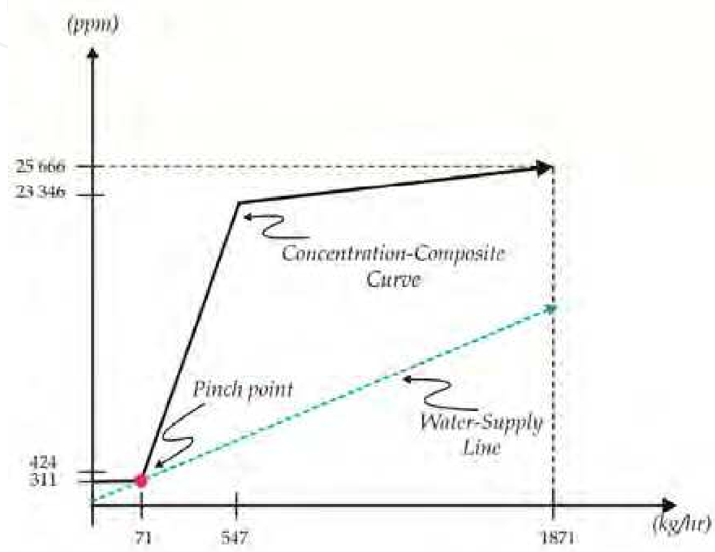

Fig. 8. Concentration composite curve for the washing process.

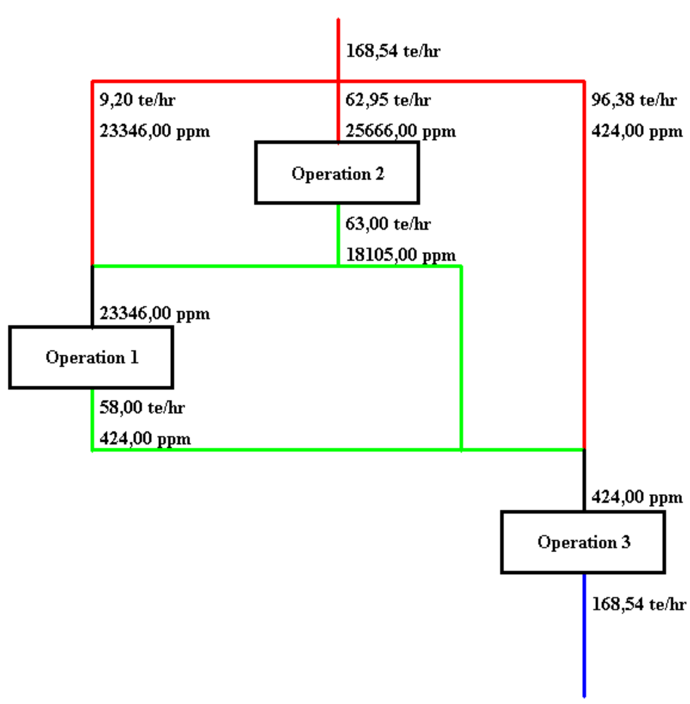

Fig. 9. Design of the water network structure using WPA.

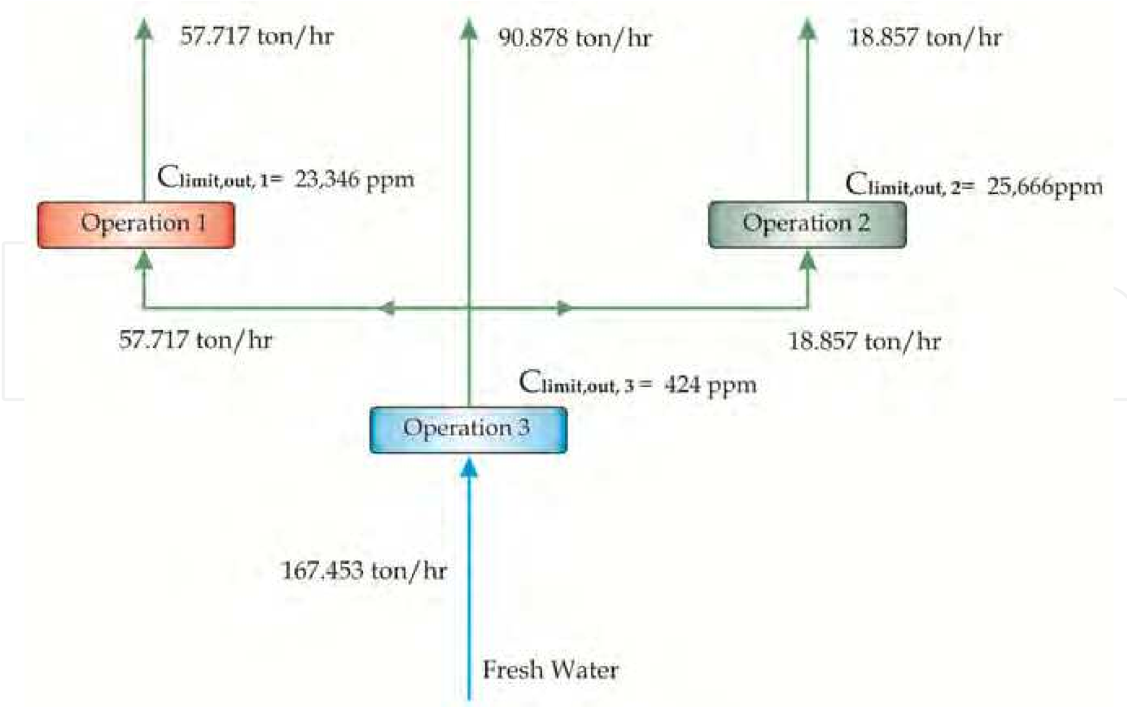

Fig. 10. Design of the water network structure using mathematical programming

Fig. 11, shows the washing process where two intermediate stages have been included. The first one removes non usable contaminants such as stones, plastic, etc., and those that can be reused in the process (i.e. pulp and wood chips). The effluent from this first stage passes through a second treatment where the pup is further cleaned prior to the bleaching stage.
In order to incorporate these aspects such as the plant start up and the way the operating conditions change as the steady state is reached. Table 4 shows the process information during the start up, on the other hand Fig. 11 and Table 5 present the operating data once the process has been stabilized.

No.	*Flowrate (ton/hr)*	*Concentration (%)*	*Mass Load (Kg)*	*No.*	*Flowrate (ton/hr)*	*Concentration (%)*	*Mass Load (Kg)*
1	72.500	12	8700	14	732.480	0.009369	68.6
2	217.440	0	0	15	67.920	12	8151
3	289.920	3	8700	16	591.678	0.009369	55.4
4	56.712	0	0	17	140.322	0.009369	13.2
5	62.940	2.1	1322	18	31.746	1.5	476
6	283.680	2.6	7376	19	5.589	2.316	129.5
7	18.546	0	0	20	26.157	1.326	346.9
8	31.746	1.5	476	21	26.157	1.326	346.9
9	49.758	1.7	846	22	26.157	1.326	346.9
10	334.020	2.466	8237	23	1.260	0.238	3
11	298.980	0	0	24	26.157	1.314	343.9
12	632.400	1.3	8222	25	1.260	0	0
13	167.520	0	0				

Table 4. Process information for the start up of the washing process.

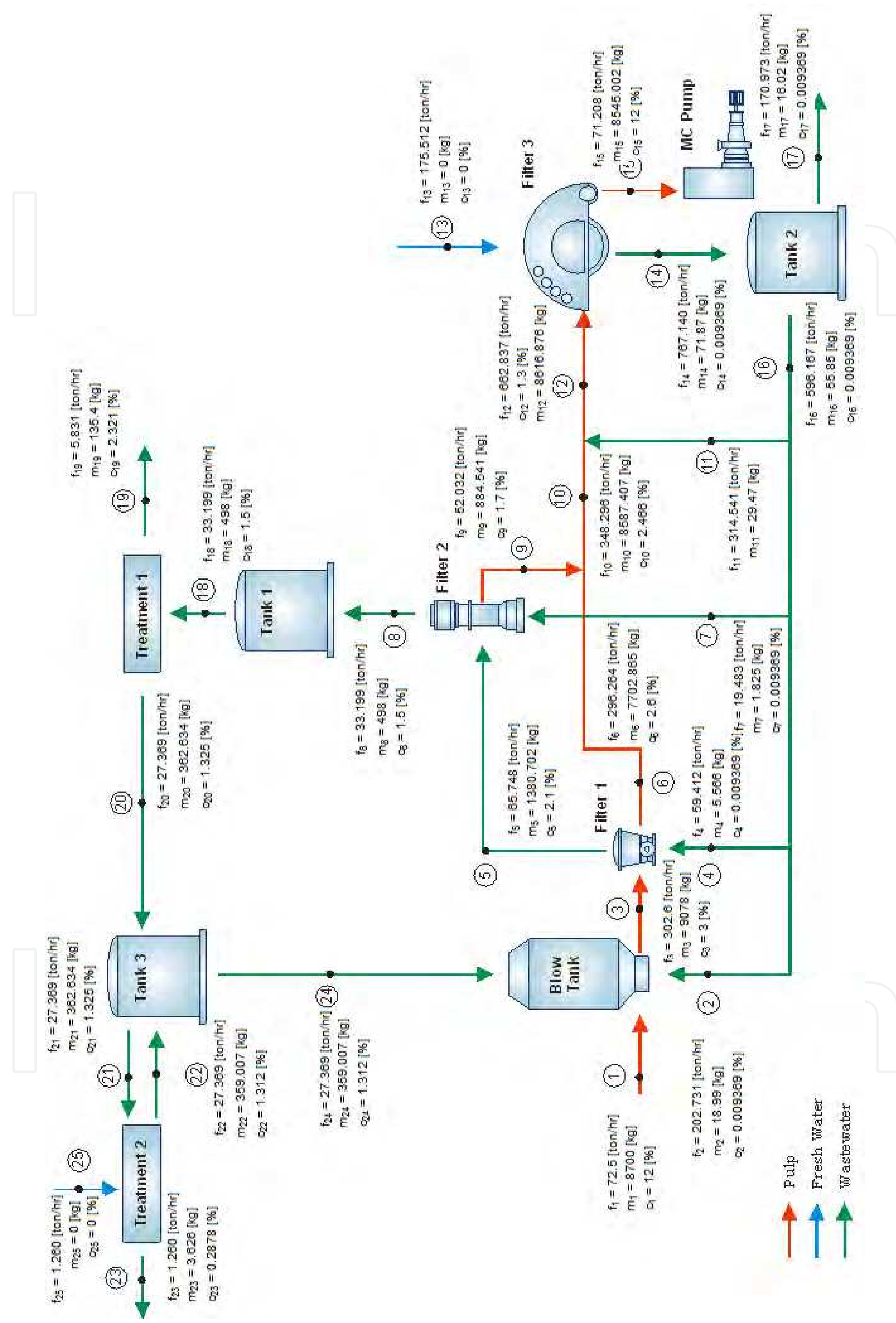

Fig. 11. Representation of the pulp production process after reduction of fresh water consumption.

No.	Flowrate (ton/hr)	Concentration (%)	Mass Load (Kg)	No.	Flowrate (ton/hr)	Concentration (%)	Mass Load (Kg)
1	72.500	12	8700	14	767.140	0.009369	71.87
2	202.731	0.009369	18.99	15	71.208	12	8545
3	302.600	3	9078	16	596.167	0.009369	55.85
4	54.412	0.009369	5.566	17	170.973	0.009369	16.02
5	65.748	2.1	1380.7	18	33.199	1.5	498
6	296.264	2.6	7702.9	19	5.831	2.321	135.4
7	19.483	0.009369	1.825	20	27.369	1.325	362.634
8	33.199	1.5	498	21	27.369	1.325	362.634
9	52.032	1.7	884.54	22	27.369	1.325	359.007
10	348.296	2.466	8547.4	23	1.260	0.2878	3.626
11	314.541	0.009369	29.47	24	27.369	1.312	359.007
12	662.837	1.3	8616.9	25	1.260	0	0
13	175.512	0	0				

Table 5. Process information for the stabilized process.

On the start up of the plant, 760.56 ton/hr of fresh water are needed. Of these, 168.78 ton/hr are sent to the washing stage while the rest, 591.678 ton/hr are used for dilution purposes before entering filter 3. Once the regeneration processes enter into operation and the reuse of effluent 3 is established, the fresh water consumption is reduced to 176.772 ton/hr. From the ongoing discussion it can be seen that regeneration and reuse considerable reduce the fresh water consumption by reducing the need of using fresh water to feed the filter at a concentration of 1.2%, thus achieving a saving of 582.626 ton/hr.
In the case under consideration there are various types of effluent stream with different contaminant concentrations, therefore it is important the adequate selection of the regeneration process for water reuse of recycling whatever the case. Regeneration processes are of the distributed type unlike the end of pipe treatment, which in the majority of cases is of centralized type. Fig. 12 shows the inlet and outlet process water flow rates.

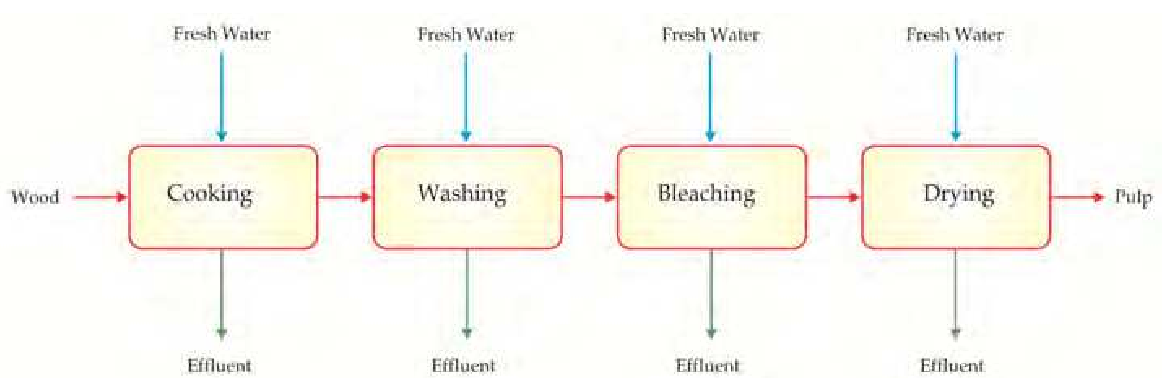

Fig. 12. Water effluent streams of the pulp production process.

4.2.3 Regeneration for water reuse

Fig. 13 shows the application of a specific treatment to each of the effluent streams in the pulp production process. Appropriate selection of each of these treatments is critical since given the different contaminant composition.

The characteristic of the effluents of the cooking processes as given by Sumathi and Hung (2006) are: high oxygen demand (BOD), color, it may have sulfur and resin reduced compounds. The effluent of the washing process, on the other hand, contains large amounts of suspended solids (SS), BOD and color. The effluent from the bleaching process contains organochloride compounds, BOD and resin. Now, the level of regeneration can be total or partial. The main types of regeneration processes can be divided in to physical-chemical and biological. Amidst the physical-chemical are: membrane separation techniques (inverse osmosis, ultrafiltration, nanofiltration, etc.), chemical flotation and precipitation and advanced oxidation processes. The biological processes are: activated sludge, anaerobic treatment, sequential anaerobic-aerobic system and fungi system for color and organo-halogenated derivatives.
It is important to emphasize that in the majority of cases 100% regeneration is not targeted; however, what is sought is the minimization of the fresh water consumption and the flow rate o the discharged effluent. In this part, no numerical results are presented since this is outside the scope of this work.

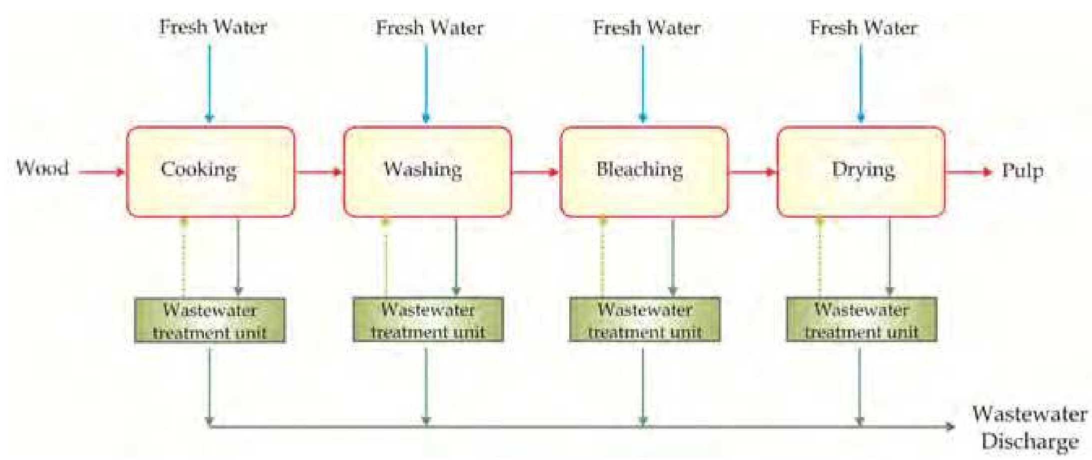

Fig. 13. Distributed treatment system for the effluents from each of the stages of the pulp production process.

4.2.4 Heat recovery system

The reduction of fresh water brings about important changes in the need of energy consumption since the pulp production process requires water streams at different temperatures. This stage of the analysis seeks to clearly identify the situations where energy is reduced as a result of a reduction in water consumption through the application of pinch analysis.
Fig. 14 shows the case where water consumption is reduced after increasing the conversion in one of the reactors if the bleaching stage. If fresh water is available at 40ºC and it has to be heated up to 60 ºC before been fed to the filter as shown in Fig. 15, the amount of energy saved is 52.1 kW . So, in order to take the temperature from 20 ºC to 40 ºC, the water and energy saving is 10.391 ton/hr and 242.45 kW, respectively.
Another type of sitations that arises is the one shown in Fig. 15, where stream 13 enters the process at 60 ºC and stream 12 reaches the filter at a temperature equal or larger than 35 ºC. After a water reuse scheme is applied, stream is reused 11 and since its temperature is above 35°C, an energy saving of 5,504 kW is achieved compared to the system where fresh water is used.

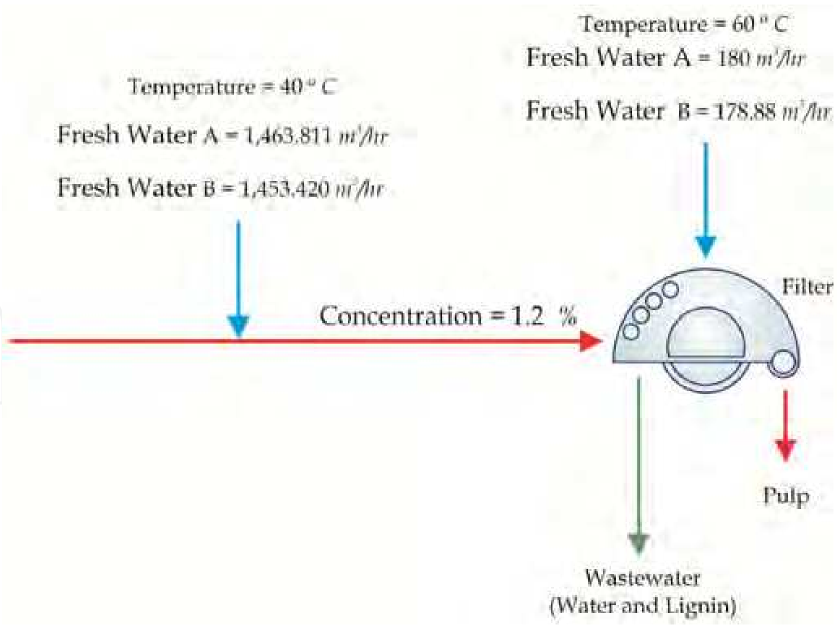

Fig. 14. Schematic of an energy saving application in the washing stage.

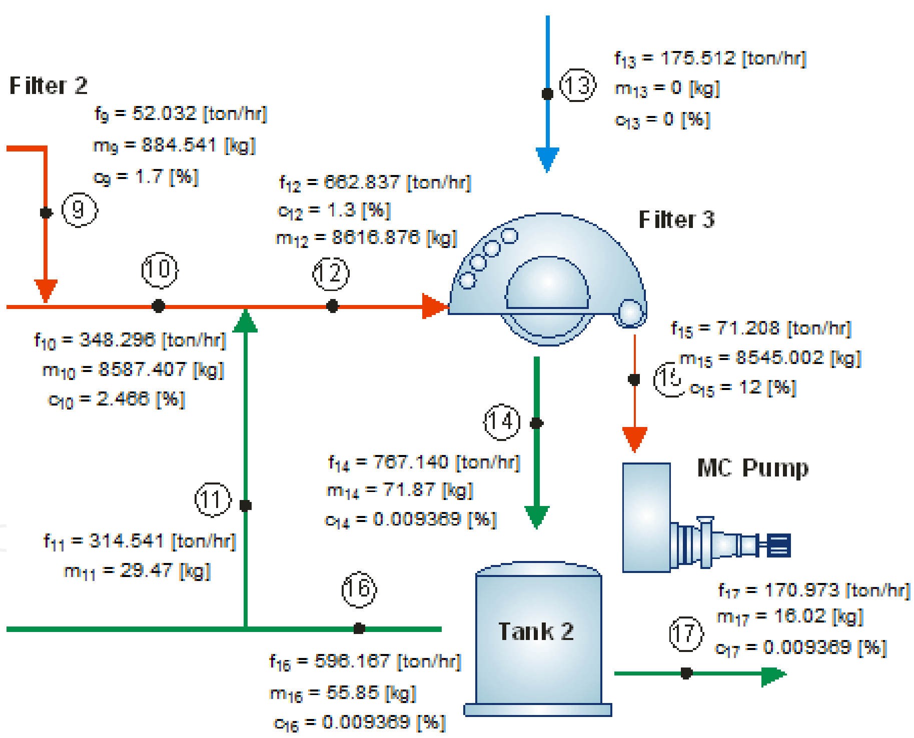

Fig. 15. Schematic of an energy saving process application.

In summary and putting together the results of the reviewed operations (washing and bleaching), the total amount of water saved is 582.626 ton/hr and an energy saving of 5504 kW is achieved. En el blanqueo se obtiene un ahorro de agua fresca de 11.511 ton/hr y un ahorro de energía de 294.55 kW. It is important to mention that water and energy savings have been achieved simultaneously by applying the methodology to particular unit operations.

5. Conclusions

This chapter has introduced a genera approach for the retrofit of existing processes for the reduction of water and energy consumption. The methodology introduced is based on a conceptual structured scheme with different hierarchical levels arranged in the following way:

Level 1. Analysis of the reaction system
Level 2. Analysis of the water using network
Level 3. Analysis and implementation of water regeneration schemes.
Level 4. Analysis of the heat recovery system.

This new approach direct us to determine the way changes to operating conditions affect the water and energy requirements in a process. In addition, these modifications can be viewed in the light of an economical analysis which shows the economical feasibility of the retrofit projects.

6. Acknowledgment

Thanks to Haydee Morales Razo. This work was supported by SEP-PROMEP (México) through grant PROMEP/103.5/11/0140.

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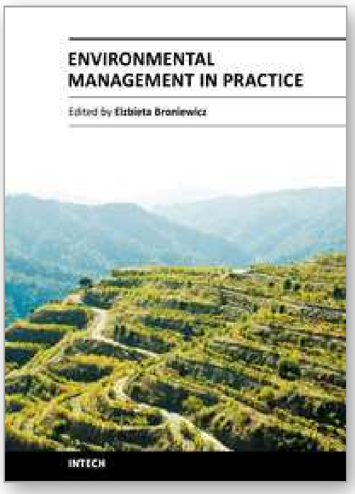

Environmental Management in Practice

Edited by Dr. Elzbieta Broniewicz

ISBN 978-953-307-358-3

Hard cover, 448 pages

Publisher InTech

Published online 21, June, 2011

Published in print edition June, 2011

In recent years the topic of environmental management has become very common. In sustainable development conditions, central and local governments much more often notice the need of acting in ways that diminish negative impact on environment. Environmental management may take place on many different levels - starting from global level, e.g. climate changes, through national and regional level (environmental policy) and ending on micro level. This publication shows many examples of environmental management. The diversity of presented aspects within environmental management and approaching the subject from the perspective of various countries contributes greatly to the development of environmental management field of research.