Designing Water Reuse in a Paper Mill by Means of Computer Modelling

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With an increasing water loop closure, the papermaking industry must implement different process changes. Computer simulation can be used as a very useful and cost-effective tool for prediction of consequences associated with such changes. In the case study presented, a computer model of papermaking process stock preparation and wet end has been created with help of WinGEMS modelling software. The process equipment change and possibilities for water reuse in terms of water quality, fresh water demand, and wastewater generation were studied by means of a computer model. The results predicted by the computer model were also verified by measurements after the equipment change had actually been made.

Key words:
Papermaking, computer modelling & simulation, waste water, water reuse

Introduction

In paper production, water represents one of the key components of the process. It is used as a transport medium, as a diluter of paper stock, as a solvent for process chemicals, as steam for energy transfer, and as cleaning medium for all kinds of washing and cleaning operations. Although a typical paper mill's water consumption has been drastically reduced in the last 100 years (from over 300 $l\ kg^{-1}$ of paper to ~ 20 $l\ kg^{-1}$), the amount of fresh water used by a paper mill is still quite large. However, the main problem remains not the need for fresh water, but rather the fact that every cubic meter of fresh water produces almost the same amount of wastewater. Therefore, several measures for reducing the wastewater amount have been implemented. The majority of them represent various techniques for process water and wastewater treatment: fibre recovery systems, chemomechanical treatment, flotation, filtration, biological treatment. After the treatment there is purified process water (wastewater) ready for reuse, whereas on the other hand there is some material (recovered stock, sludge) that can be used again in papermaking or other industrial processes, or just deposited as waste. Despite its ecological efficiency, this approach has one major drawback. After treatment, there are still some substances present in the process water. At an increased level of process water loop closure, these substances accumulate and can cause serious problems in papermaking process.[1,2]

There are several possibilities to find the most appropriate treatment techniques and operating practices for a specific paper mill. One of them is computer modelling and simulation. It represents a useful tool for evaluation of possible process (new equipment, different operating practices), material (raw materials, process chemicals) or end product changes. In addition, the simulation is very cost-effective because possible future process changes are virtual, and there are no costs arising if some design proves to be false.[3,4] Today, there are several modelling and simulation software tools available. One of them is WinGEMS, which has been used in our research for predicting the changes in process water and wastewater quality as a consequence of water loop closure in a paper mill.

The investigated paper mill produces approximately 9.6 tons (oven dried) of label paper per hour. The production raw materials are short fibre cellulose, long fibre cellulose and broke produced at paper cutting or during process failures. Broke currently represents approximately 32 % of total amount of raw materials. A research was made into the question of how process water quality is affected by the amount of broke used. In addition, the wish of the previously mentioned paper mill was to substitute the existing internal flotation water treatment system with a poly-discfilter. By means of a computer model we tried to determine if this change is justified from the process water recycling point of view. Also an investigation was made into what impact this change would have on the efforts for establishing production in accordance with the IPPC Directive.[5] The research was focused on the wet end of paper machine (before drying), where a major part of process water in question is produced.

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Materials and methods

The first stage of the research included data collecting and creating of a computer (WinGEMS) model of the wet end part of papermaking process. The quantities (variables) applied were flow rate, total suspended solids concentration (referred to as consistency in papermaking), and chemical oxygen demand (COD) which was at the same time the parameter taken as a measure for "pollution" of process water.

Measurements and analyses

Flow rate measurements were performed on all points in the process where flow rate or concentration changes are present. Thus, eighteen measuring points were identified. Flow rate measurements were performed with two ultrasound flow measuring devices: NIVUS PCM II was used for process water flow rate measurements, whereas Krohne UFM 610P was used for fresh water flow rate measurements.

On the same eighteen measuring points samples of pulp or process water were taken. Firstly, the total suspended solids concentration was determined by a standardized method.[6] After filtration through 100 μm screen and 20 min of centrifugation (3000 rpm),[7] the COD value in centrifugate was determined. The COD was determined by the ISO standardized method. [8]

Creating a WinGEMS model

On the basis of measurements and analyses results a steady state model of the stock preparation and wet end of the papermaking process was created by means of the WinGEMS software, designed especially for modelling of pulping and papermaking processes. WinGEMS contains several designed process blocks for modelling various process operations such as mixing and dilution of streams, separation of material … Each of these blocks also contains various individual adjustable quantities (flow rate, suspended solids concentration, temperature, COD, displacement ratio…). The model was created on the basis of input streams and input process quantities measurements. Then, the calculated output values were compared to the measured values of output streams. After some model adjustments we were able to predict the output values with an error in the range of experimental error of measurements (analyses). However, it should be noted that every model represents a simplification of the real process, which automatically allows for a certain level of error. The WinGEMS model of stock preparation and paper machine wet end is represented schematically in Figure 1.

Results and discussion

Modelling of broke reuse

Currently reused broke represents 32 % of raw material. By means of the model, a research was made into how the COD of different process water streams changes with the broke portion increasing from 10 to 60 %. The results are shown in Table 1 where the COD is presented, both, as an absolute

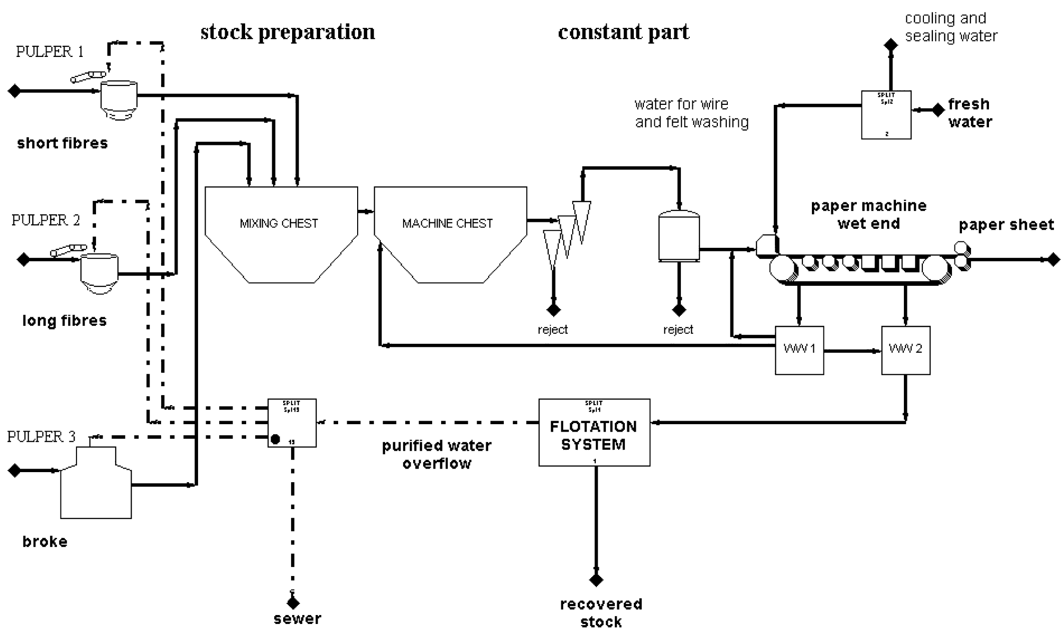

Fig. 1 – *Schematic representation of stock preparation and paper machine wet end with flotation system*

value in wastewater and as specific COD load per ton of paper produced.

As presented in Table 1, broke reused in the stock preparation can cause relatively high COD loads in paper machine wastewater. From our model, the linear dependence between broke reused and COD load can be inferred. The current use of broke as 32 % of raw materials causes the COD load to be more than two times higher than if no broke is used. The results imply that increasing the broke portion in stock preparation could result in a high COD load in wastewater, and in the case of its potential reuse, in a higher COD load of process waters. Consequently, this can cause production problems and affect the end product (paper) quality. Production without broke reuse is suggested as a possible solution to current and potential future problems. Thus, the COD load of process and wastewater would be lowered to the minimal possible value, which would result in better possibilities for process/wastewater reuse. The broke should be used separately or, if there is no other option, reused in the smallest portion possible.

Table 1 – *Influence of broke reuse on COD load of wastewater*

Broke %	COD of waste water γCOD/ mg l^{-1}	Mass fraction COD load wCOD/kg^{-1} paper produced
0	196	5.25
10	273	7.31
20	349	9.43
30	423	11.32
40	497	13.31
50	569	15.23
60	641	17.16

Modelling of equipment change

When the WinGEMS model was created, the paper mill was using an internal flotation water treatment system for fibre recovery from white water 2 (WW 2). Recovered stock was returned back to the stock preparation, and the major part (80 %) of the resulting 262 m^3 h^{-1} of purified water was discharged to the chemomechanical water treatment plant, due to its being useless for reuse. To improve water quality, the wish of the paper mill management was to substitute the flotation system with a poly-discfilter. However, we tried to identify benefits and problems associated with such a change by means of the computer model before the actual substitution.

The model is based on the model with flotation system except that the flotation system is now substituted by a poly-discfilter (Figure 2). The poly-discfilter operating parameters determined by the manufacturer are:

– maximum capacity (wastewater flow rate): 300 m^3 h^{-1},

– input mass fraction of suspended solids (for efficient formation of filtering mat): 0.34 %,

– relative amounts of filtrates (portions of input flow rate): 35 % – cloudy filtrate, 40 % – clear filtrate, 25 % – super-clear filtrate,

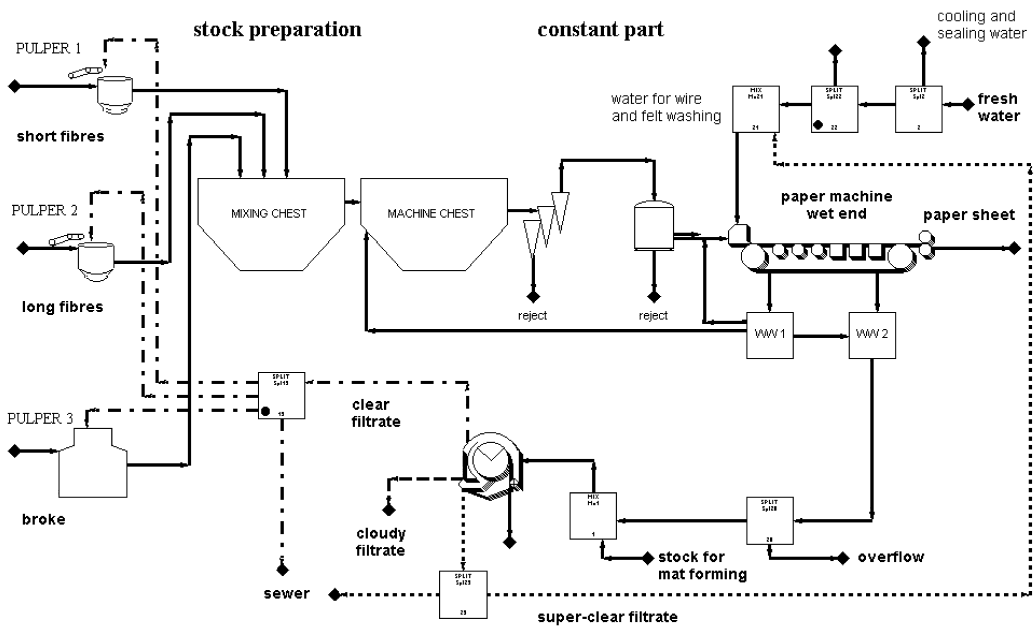

Fig. 2 – *Schematic representation of stock preparation and paper machine wet end with poly-discfilter*

– suspended solids mass concentrations: < 100 mg L^{-1} – cloudy filtrate, < 20 mg L^{-1}- clear filtrate, < 10 mg L^{-1} – super-clear filtrate.

If the cloudy filtrate (77.4 m^3 h^{-1}, predicted by the model) is not exposed to further treatment, it is not suitable for reuse as washing or dilution water because it does not meet the process requirements. The clear filtrate can be used as a dilution water in stock preparation whereas the super-clear filtrate can be used for machine wire (sieve) and felt washing. According to the model, there is approx. 111.6 m^3 h^{-1} of clear filtrate available for returning to stock preparation, and approx. 70 m^3 h^{-1} of super-clear filtrate available for cleaning duties. In comparison to the flotation system, in which the majority of water flow to the sewer after flotation (and finally to the central water treatment plant), approximately 65 % of water is now available for reuse.

Reuse of clear filtrate would not affect process and wastewater quality significantly. Even if the total amount of fresh water for dilution in stock preparation is substituted by a clear filtrate, the COD value of process waters (WW 1 and WW 2) and of the paper machine wastewater would almost not change. The main reason for such behaviour is the fact that the clear filtrate represents only $^1/_{20}$ of the entire water volume in the system. Thus, every change in the dilution water properties is dampened through the volume of the system (buffering effect). Also, the quality of clear filtrate, used for dilution in stock preparation of the original system, is better than the quality of water purified by flotation. The absence of variations between the COD value of headbox suspension and the COD value of white water 1 (WW 1) can be explained by the fact that only the little of the dissolved organic matter is retained in the paper sheet and consequently, COD value does not change.

The simulation of super-clear filtrate reuse represents a rather different situation. When used for machine wire and felt washing, it virtually all ends as white water 2 (WW 2), which is again purified on the poly-discfilter. Then, one portion returns to machine wire and felt washing. The COD value of process waters (WW 1 and WW 2) and paper machine wastewater increases together with the super-clear filtrate returned. The highest increase is obtained by the COD value of white water 2 and of the paper machine wastewater. White water 2 circulates through the system in a relatively "short" loop – from machine wire washing through the poly-discfilter and, having been mixed with fresh water, back to washing. During each cycle, some suspended and dissolved material is "picked up". The suspended material is effectively removed by the poly-discfilter. However, the dissolved material remains and accumulates in the water. Eventually, a

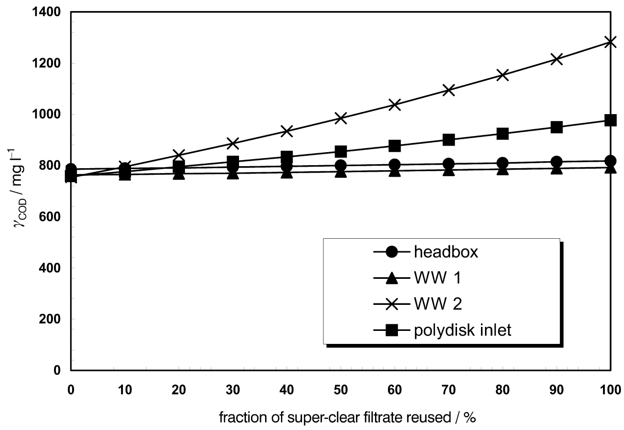

Fig. 3 – *Dependence of COD value of various process streams on portion of super-clear filtrate reused*

new steady state (for each level of super-clear filtrate reuse), containing higher COD values of process waters, is established (Figure 3). The increase in the COD value of wastewater is due to the fact that, with the super-clear filtrate reuse, the amounts of fresh water needed and wastewater generated, have decreased. Consequently, with the same suspended and dissolved material input, this would result in a higher COD value of wastewater. Because the main source of wastewater is the cloudy filtrate originating in the filtration of white water 2, the accumulation of dissolved matter in white water 2 increases the COD value of wastewater.

The general conclusion is that the substitution of flotation system by the poly-discfilter would positively affect the water management of the paper mill. The demand for fresh water could be lowered by the amount equal to that of the super-clear filtrate reused, which is in best case by approximately 8 m^3 per ton of paper produced. Consequently, the wastewater amount decreases for approximately 8 m^3 per ton (Table 2).

Therefore, the need for fresh water decreases by almost 50 % at unchanged production rate, and the production of wastewater by 20 %. At this point it should be noted that the wastewater volume in the paper mill observed also includes cooling and sealing waters. According to simulation results, combined with separation of water streams (cooling and sealing waters should be treated and reused separately from wastewater), the paper mill could meet the IPPC recommendations regarding fresh water usage and amount of wastewater discharged.[5] However, there is a drawback to this benefit. A lower fresh water demand, and consequently also a lower wastewater discharge causes a higher COD load in process water and wastewater, which could negatively affect the process conditions (slime formation) and product quality. In addition, the wastewater quality at higher degrees of super-clear

Table 2 – *Dependence of fresh water use and wastewater generation on portion of super-clear filtrate reused*

Fraction of super-clear filtrate reused %	Fresh water specific volume m^3 t^{-1} of paper produced		Waste water	
	total	for washing	specific volume m^3 t^{-1} of paper produced	γ_{COD} / mg l^{-1}
10	20.43	8.98	25.6	671
20	19.59	8.14	24.8	690
30	18.74	7.28	23.9	711
40	17.88	6.42	23.1	733
50	17.03	5.57	22.2	755
60	16.17	4.72	21.4	781
70	15.32	3.87	20.5	808
80	14.47	3.01	19.7	836
90	13.61	2.16	18.8	867
100	12.76	1.31	18.0	901

filtrate recycling would no longer meet (legislative) obligatory values. Combined with the assumptions of some researchers[9] who suppose an exponential dependence between specific wastewater volume and COD value of wastewater, the results of the simulation predict a further increase of the waste water COD load with an increasing system closure (Figure 4).

Figure 4 clearly confirms that the COD value of wastewater does not meet the IPPC recommendations already at a low level of recycling (high specific wastewater discharge) which is also the position of the results predicted by the model. As a long term solution to this problem, a (biological) wastewater treatment plant is required.

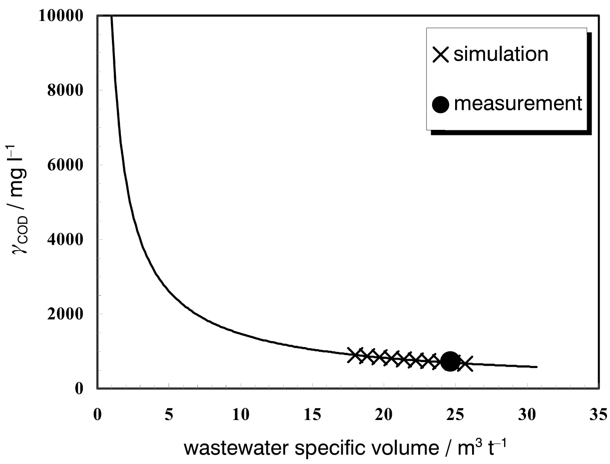

Fig. 4 – *Predicted rise of wastewater load in connection with reduction of specific volume of wastewater*

Reuse of process water also has a beneficial impact on the energy balance of a paper mill. With the maximum possible reduction of fresh water demand of approximately 8 m^3 per ton of paper produced, heat savings of around 220 kW per ton of paper produced could be achieved based on estimations of average temperatures of fresh water (~ 15 °C) and discharged waste water (~ 40 °C). This amount of heat can either be used for preheating the fresh water to the operating temperature level, or it can simply be returned into the system with the reused super-clear filtrate. In the first case, a system for heat exchange is needed, but consequently less fuel is consumed for energy generation. The second case does not need any changes of equipment. The result of a simple reuse of warm super-clear filtrate is a rise in process temperature. The reuse of clear filtrate for the dilution in the stock preparation stage causes the same effect. Generally, a conclusion can be drawn that although an operating temperature around 35 °C in the wet end of the paper machine was for a long time desirable in papermaking, nowadays, with the increasing closure of water system, temperatures between 50 an 60 °C are not uncommon either. Higher temperatures are desired in the web forming section of the paper machine because of improved drainage and for shower waters used for wire and felt washing. Nevertheless, regarding the mill described in this article, the temperature rise in the system due to proposed water reuse possibilities would not be very significant.

Beside energy management, there is another very important issue regarding temperature – the microbial activity. Due to the fact that papermaking process water contains great amounts of organic material, it is an ideal environment for microorganisms. Temperature is one of the key factors that influence the type and the extent of microbial activity. If, as in the case described, water is recycled without biological treatment, the majority of dissolved organic material remains in process water. With elevated temperature, the microbial activity increases and the probability of biological contamination of the product is higher. Along with the increased activity, the type of microflora also changes from mezophylic to thermophylic. Especially in the case of higher-quality paper grades, this represents a problem regarding paper properties (lower strength, lower whiteness, spots in paper). The most common solutions, also used in the paper mill described, are the use of biocides and regular washes of the system. Thus, the level of microbial activity is kept on a reasonably low level so that it has no impact on the quality of the final product. Another safety factor which reduces the possibility of the final product being contaminated by microorganisms is paper drying. The temperatures in the drying section of the paper machine are high enough (up to 120 °C in the end) to reduce the amount of vegetative microbes. Nevertheless, there is higher probability for contamination of paper with sporeforming microorganisms, because the contact time in the drying section is too short to destroy the spores.

Implementation of results

At the final stage of the research, the paper mill in question actually substituted the flotation system by a poly-discfilter. Since then, $^1/_3$ of the super-clear filtrate has also been reused for machine wire and felt washing. After this process change, the flow of fresh water and wastewater was measured and COD values of process waters and wastewater were determined. Compared to the flotation system, less fresh water is needed and less wastewater is produced (Table 3).

The model-predicted values and the measured values are in quite an acceptable agreement (Figure 4). The main reasons for deviations are probably measurement inaccuracies and simplifications in the model. There are two exceptions – fresh water (for wire and felt washing) flow rate and the COD of wastewater – where deviations between measured and predicted values are higher and can not be explained by analytical or measurement error. The reason for these somewhat erroneous predictions lies in some uncertainties about the white water 2 loop. Especially in the section between poly-discfilter and paper machine, it is not quite clear whether or not the whole recycled part of the super-clear filtrate actually ends in the white water 2. In spite of the deviations, it can be concluded that the model successfully predicts the influence of process changes on process water quality.

Conclusions

Computer modelling and simulation is a very efficient tool for designing process changes in the papermaking process. The aim of the research was to show how the substitution of flotation system with a poly-discfilter would influence the process water and wastewater quality. The substitution itself does cause water quality to improve, but in such case, some of the purified water streams are also appropriate for reuse. Such streams are the clear and the super-clear filtrate. The former can be used

Table 3 – *Comparison between influence of flotation system and poly-discfilter (with $^1/3$ of super-clear filtrate reused) on fresh water use and wastewater generation*

	Type of wastewater γ_{KPK} / mg l^{-1}	Wastewater flow Q / l min^{-1}	Mass fraction wastewater load w_{KPK} / kg t^{-1}	Flow rate paper machine fresh water use Q / l min^{-1}	Specific volume fresh water use m^3 t^{-1} paper*
flotation system	purified water after flotation	3360 l min^{-1} 777 mg/l	19,1	1340	21,2
poly-discfilter	cloudy filtrate	1294 l min^{-1} 777 mg l^{-1}			
	residual clear filtrate	1154 l min^{-1} 733 mg l^{-1}			
	residual super-clear filtrate	778 l min^{-1} 594 mg l^{-1}			
	sum	3226 l min^{-1} 717 mg l^{-1}	16,9	957	18,4

*specific fresh water use also includes 1560 l min^{-1} of cooling and sealing waters as dilution water in stock preparation, and the latter as washing water for felt and machine wire washing. The effects of the reuse are reduction of fresh water use, reduction of the generated wastewater volume, and an increase in process water and wastewater COD value. According to our model, the fresh water use can be reduced by almost a half and the wastewater generation by approx. 20 % at an unchanged production rate. The structure of fresh water usage would also change. Namely, the model predicts that if all of the super-clear filtrate would be reused, that washing water would represent only 10 % of fresh water used (compared to the 65 % before super-clear filtrate reuse). The model also predicts an over 30 % increase in the COD value of paper machine wastewater. According to the simulation results, the fresh water use and wastewater generation would thus meet the IPPC recommendations, although at the expense of an increase in COD value. Thus, it is concluded that a further closing of water loop (more than 50 % of super-clear filtrate reused, reuse of cloudy filtrate) without additional water treatment system would not bear the desired results.

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