Dynamics of white water networks during web breaks

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ABSTRACT

A model representing a white water network has been developed to characterize its dynamic behavior. This study focuses on key process modeling issues: the process flow sheet, steady-state mass and energy balances, and a dynamic model and its control system. The system was disturbed by web breaks in the paper machine. During simulations, the manipulated variable used to manage broke inventories was the broke reuse rate. The results emphasize the importance of the process and control design in reducing the impact of perturbations.

Application:

Dynamics modeling is a process-design tool for characterizing the transient behavior and selecting the best control structure to reject disturbances. In existing mills, this tool can be used to develop policies dealing with perturbations to improve performance, to save energy, and to minimize the impact on the environment.

Control of the wet-end white water network in a highly closed integrated newsprint mill is a difficult task. The complex configuration of the network promotes interactions between the large number of variables involved. Furthermore, the process operation is subject to frequent perturbations. The most frequent and most important perturbation is the break of the web on the paper machine. Repulping of broke consumes large amounts of white water, thus creating sudden variations in the white water and broke inventories. When several breaks occur in close sequence, it may be necessary to add fresh water.

The rate of broke recycling that can be achieved without causing additional perturbations is a constraint, as is the broke tank capacity. In highly closed mills, where there is little room for maneuvering, the management of water inventories may become particularly difficult. Characterizing the dynamics of white water networks under high- closure conditions is paramount to equipment sizing (for new designs or implementation of closure strategies), white water management, and integrated process control.

The objectives of this work were (a) to develop a dynamic model of a generic but representative newsprint wet-end flow sheet to study the transient response of the white water network and the variations of the broke and white water stocks in response to web breaks and (b) to evaluate the performance of a pre-established design (white water network and its control system) when dealing with major disturbances in a mill working under high-closure conditions.

OVERVIEW OF THE SHEET BREAK PROBLEM

Web breaks occur when adhesion of the sheet to contacting surfaces is greater than its cohesiveness. This happens when two conditions are simultaneously present: high load and low strength *(1)*. A sequence of breaks may be characterized by their average duration and frequency. *Break duration* is the time elapsed between the moment when the sheet is ruptured and the moment when its continuity is restored in the paper machine. This duration, varying from a few minutes to hours, depends on the break type (generally wet breaks have longer duration than dry breaks) and the severity of the problem (difficulty to restore the sheet or eventual failure of a piece of equipment). The *break frequency* seems to depend on the basis weight; the average interval between two breaks increases at higher basis weights *(2)*. As breaks occur in the open draws where the sheet is not supported, great efforts have been devoted to developing means to reduce or to close the open draws, not only in new machines but also by equipment retrofit in existing machines. The ultimate goal would be to provide uninterrupted web support from the headbox to the calender *(3)*.

The most frequent causes of breaks in the wet end of a machine have been identified as stock quality variations, low web strength, low dryness, lumps, slime, and water drops *(4)*. However, there is no physically based predictive model to forecast break occurrence for given operating conditions, and despite recent developments on these subjects, anticipating or preventing the triggering event (e.g., jagged edge) remains an elusive goal. Sheet breaks continue to be a frustrating problem that affects paper machine performance. For the present time, web breaks can only be treated as random phenomena. A probabilistic model using Markov chains has recently been proposed *(5)* on the basis of correlations between paper break characteristics, machine speed, and broke reuse rate, derived from a large set of actual mill data.

During a break, the paper sheet is

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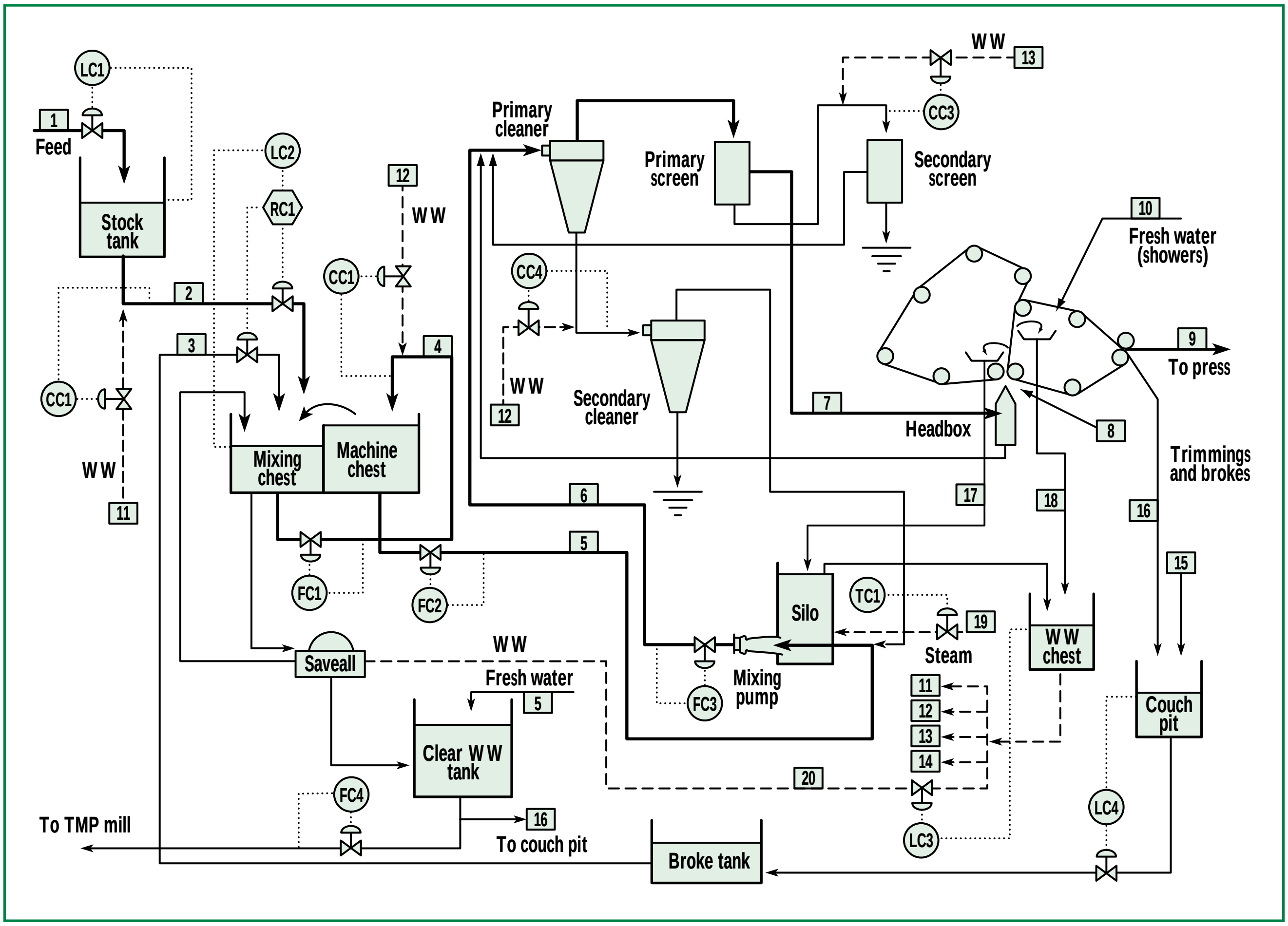
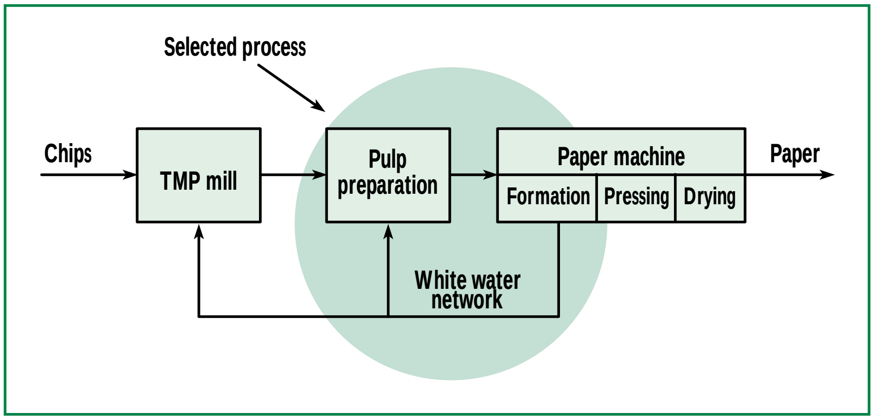


2. Simulated wet-end flow sheet



1. Section of the newsprint mill process studied

diverted to a pit under the machine, where it is dispersed in white water. This repulped broke is then pumped and stored in the broke tank, and from there it is progressively reinjected in the main pulp stream. Repulping of the broke requires large amounts of water. This large and sudden consumption of water modifies the white water inventory and creates cascading effects throughout the network. When there are frequent breaks, the management of broke and white water inventories becomes a delicate task. Broke inventories may require higher recirculation rates to avoid broke tank overflow, thus affecting pulp composition and eventually paper machine retention. It is well accepted that the stability of the white water system *(6, 7)*, defined here as the capacity to keep the process close to an equilibrium value, is a key factor in the operation of the paper machine. Other major causes for upsets in a white water system are excessive fresh water addition, poor mixing or lack of agitation in white water tanks (causing tank stratification), insufficient white water tank capacity, and poor control of broke stock *(4)*.

The wet end is a complex network that interconnects all the pulp preparation equipment and the forming section of the paper machine. The study of this network during transient conditions requires an accurate and

Stream	Flow rate, L/min	Consistency, %	Temperature °C
1	5,154	8.00	60.0
2	14,849	3.00	59.1
3	358	3.50	58.9
4	20,193	2.97	59.1
5	17,271	2.80	59.0
6	100,484	1.00	59.7
7	105,500	0.90	59.6
8	94,950	0.90	59.6
9	2,193	18.00	59.1
10	4,167	0.00	55.0
11	9,695	0.31	58.7
12	1,396	0.31	58.7
13	1,241	0.31	58.7
14	12,616	0.31	58.7
15	290	0.03	58.8
16	68	18.00	59.1
17	67,951	0.52	59.5
18	28,905	0.29	58.5
19	75[a]	-	-
20	7,358	0.31	58.7
21	0[b]	0	15.0

[a]Saturated steam at 690 kPa (tons/day)
[b]Fresh water is not required in steady-state conditions.

I. Main steady-state conditions

reliable dynamic model. Dynamic simulation is being used increasingly in the pulp and paper industry. Previous studies *(8, 9)* have mainly focused on the transient behavior of a white water network in response to breaks and on the development of broke and white water management policies. Dynamic modeling has also been used to simulate a white water network to test control strategies *(10)* and to compare solution algorithms and computational structures such as differential equation solvers (Parode), types of process simulation software (Simulink and Extend), and discrete time modeling (Markov series) *(11).* In our study, we have used dynamic simulation to characterize the wet-end behavior in response to sheet breaks in the paper machine and to evaluate the ability of the design (process and its control system) to reject perturbations.

PROCESS MODELING AND SIMULATION

Developing a dynamic model of a white water network and of its broke recirculation system that is simple and general yet representative of actual situations involved the following steps:

1. An appropriate process flow sheet and a control system were chosen.
2. Detailed steady-state mass and heat balances were performed on the basis of representative data.
3. The results of the steady-state balances were used as initial values for the set of differential and algebraic equations representing the dynamic model. Those steps are summarized as follows.

Process flow sheet

The portion of the newsprint mill considered in this work is shown in **Fig. 1**, while the detailed simulated process flow sheet is shown in **Fig. 2**. The flowsheet corresponds to the wet end of a typical but generic single-line newsprint mill of 600-tons/day production capacity and includes the following: the paper machine forming zone, the stock preparation area, the machine white water network, and the broke repulping system. Feedstock to the preparation area is fresh thermomechanical pulp (TMP) at 8% consistency. The fresh pulp is stored in the high-consistency tank and then diluted by using white water from the white water chest (stream 11). The pulp is subsequently mixed in the mixing chest with repulped trimmings, broke, and fibers recovered from the saveall. This mixed pulp is then conditioned for papermaking, i.e., homogenized, cleaned, and screened. It is also further diluted at this stage with white water from the machine white water chest (streams 12, 13, and 14) and with white water from the machine directly collected in the silo. The main pulp stream is at 0.9% consistency when it is delivered to the headbox.

During normal machine operation, only the wet trimmings, representing approximately 3% of the total paper production, are collected in the couch pit. When a break occurs, the paper sheet is diverted to the couch pit, and clear white water is then added for dilution (stream 15). The repulped broke is returned to the mixing chest via the broke storage tank.

Two disruptions may occur after prolonged or repeated breaks: (a) a broke tank overflow because its storage capacity is insufficient or because of constraints on the allowable amount of recycled broke and (b) an interruption of clear white water availability to dilute broke, which requires the addition of fresh water.

Steady-state balances

This phase required collecting basic wet-end operating data such as consistencies, flow rates, and temperatures; the data are selected values taken from an actual newsprint mill mass balance *(12).* Preliminary partial balances were used to check the initial process flow sheet before performing the complete mass and energy balances. *Steady- state* was defined as those periods with no web break and when the recycled broke is composed exclusively of the trimmings. Detailed steady-state mass and energy balances of this process flow sheet were initially obtained by using a spreadsheet *(13).* The main hypotheses when establishing steady-state balances were as follows:

Description	Capacity, m^3	Height, m	Res. time,[a] min	Target level, %
Stock tank	900	12	90	50
Mixing chest	240	5	7.5	50
Machine chest	265	5	15	100
Silo	50	7	1	100
WW chest	200	5	3	50
Couch pit	90	3	2.5[b]	33
Clear WW tank	3000	17	450	-[c]
Broke tank	1900	15	160[b]	-[c]

[a]Based on target levels during normal steady-state operation
[b]Residence time calculated at break conditions
[c]For simulation purposes, these levels were allowed to vary freely.

II. Reservoir dimensions

- The pulp is composed of water and fibers; no length classification was considered in this work.
- Pulp physical properties, such as density and heat capacity, were estimated at different consistencies assuming the additivity of water and fiber properties.
- In energy balances, no heat exchanges were considered between any equipment and its surroundings except at the paper machine. To estimate those heat losses, we assumed a fixed temperature drop (approx. 0.5°C) between the feed coming from the headbox and the white water streams leaving the machine.
- Fresh water consumption in the paper machine showers was fixed at 10 m^3/metric ton of paper produced.

The main results obtained from the steady-state balances of the selected flow sheet are shown in **Table I**. Fresh water addition to the clear white water tank is not required during steady-state operation.

Dynamic modeling

For the purpose of dynamic modeling, the following new information was necessary concerning the geometry of the reservoirs (height and cross-sectional area), the control system, and the establishment of additional hypotheses about the process

- The wet end contains two types of equipment: (a) the equipment that has a strong dynamic impact on the white water network (essentially the reservoirs) and (b) the equipment with very short residence time (cleaners, screens, headbox, and the formation zone of the paper machine) compared to the reservoirs, which have fast dynamics.
- Properties in the reservoirs (consistencies and temperature) were considered as homogeneous, and the reservoirs were represented by the classical continuous stirred tank (CST) model. Note that the perfect mixing assumption may not apply to the reservoirs with large residence times and a high elevation difference between inlet and outlet, such as the stock tank **(Fig. 2)**. Nevertheless, a CST model was used for this tank, because its dynamics have no effects on the perturbation studied, i.e., the recycling system.
- Delays introduced by the piping system, valves, and instrumentation (sensors and controllers) were neglected.

The capacities and dimensions of all reservoirs used in the simulations are given in **Table II**. Residence times were calculated at target volume except for the couch pit and broke tank, for which they were estimated on the basis of flow rates at break conditions.

Control system

The main objectives of the proposed control system indicated in the flow diagram of **Fig. 2** were (a) to assure the uniformity of the stock supply to the paper machine, i.e., the amount of pulp at the conditions required for papermaking (0.9% pulp consistency and 60°C in the headbox) and (b) to manage broke and clear white water inventories by preventing broke overflows or the need for fresh water addition. To achieve these objectives, we have incorporated control loops for tank levels, consistencies, flow rates, and temperatures. Each controller was independently tuned by considering its control loop as a single-input/single-output (SISO) system. All controllers are conventional proportional and integral (PI) controllers. The description of each control loop is summarized in **Table III**.

The control of the main process variables such as consistency, temperature, and flow rate was considered at the following selected locations in the wet end:

- Pulp consistency is controlled at the mixing chest. The dual-mixing machine chest configuration should ensure good uniformity of the main pulp stream. Mixing the fresh pulp, broke, recovered fibers from the saveall, and overflow from the machine chest is carried out in the mixing chest, and the final adjustment in pulp consistency is achieved by further dilution in the machine chest. The pulp is further diluted with white water from the short recirculation loop before it is delivered to the paper machine.
- Temperature is regulated in the silo (short recirculation loop) by direct steam addition, which is an indirect way to keep the pulp headbox temperature within acceptable operational limits. The purpose of this control loop is to reduce the effect of temperature changes in the white water network that may be caused by the excessive addition of fresh water.

Controller	Controlled variable	Manipulated variable
LC1	Stock tank level	Process feed flow rate
LC2	Mixing chest level	TMP pulp & repulped broke flow rates
LC3	WW chest level	Excess WW flow rate
LC4	Couch pit level	Repulped broke to broke tank
CC1	TMP pulp consistency	Dilution WW flow rate (stream 1)
CC2	Machine chest feed consistency	Dilution WW flow rate (stream 2)
CC3	Secondary screen feed consistency	Dilution WW flow rate (stream 3)
CC4	Secondary cleaner feed consistency	Dilution WW flow rate (stream 4)
FC1	Pulp flow rate to machine chest	Outlet flow rate from mixing chest
FC2	Pulp flow rate to silo	Outlet flow rate from machine chest
FC3	Pulp flow rate to primary cleaner	Exit from mixing pump
FC4	Water flow rate to TMP	Exit from clear WW tank
TC1	Silo temperature	Steam flow rate to silo
RC1	Broke fraction to mixing chest	Fresh pulp and broke flow rates

III. Process control loops

Controller	Equipment	ΔF_{MAX}, m^3/min	Δh_{MAX}, m	K_c, m3/min·m	T_i, min
LC_1	Stock tank	3	0.25	8.8	34
LC_2	Mixing chest	5	0.10	37	5.2
LC_3	WW chest	10	0.25	–30	5.3
LC_4	Couch pit	12	0.25	–35	3.4

IV. Level controllers parameters

- Thick-stock flow rate in commercial newsprint mills is controlled by the basis-weight gauge at the reel. In our study, this control loop was always kept in open loop mode, since the main objective was to characterize the dynamics of the network, especially those of the broke and clear water inventories.
- Broke reuse rate is controlled at the mixing chest, and the level of this chest is adjusted by manipulating the fresh pulp and broke inlet streams. The broke reuse rate is fixed manually. The selected value depends on how broke inventories evolve and how frequent breaks occur. In many mills, this value is selected by operators, and it usually varies from 5% to 20%.

Tuning of controllers

Considering that the dynamics of the white water network model are determined by the response of the reservoirs, special care was given to the level control loops. These loops were specified by using the analytical method for level and inventory control described by Marlin *(14)* in which two cases are considered. In the first case, or *tight level control,* the level is the critical parameter while large variations in the manipulated flow rate can be tolerated. The second situation, called *averaging level control,* occurs when level variations are not critical as long as the level remains within specified limits. In this case, the manipulated flow rate does not experience rapid changes of significant importance. The tight level control was selected for the level control loops, because the objective was to keep levels close to a target by manipulating some inlet or outlet flow rates. The parameters for a PI controller, the gain K_c, and the reset time T_i, are then given by the following equations:

$$K_C = -\frac{2}{e}\left(\frac{\Delta F_{MAX}}{\Delta h_{MAX}}\right) \qquad (1)$$

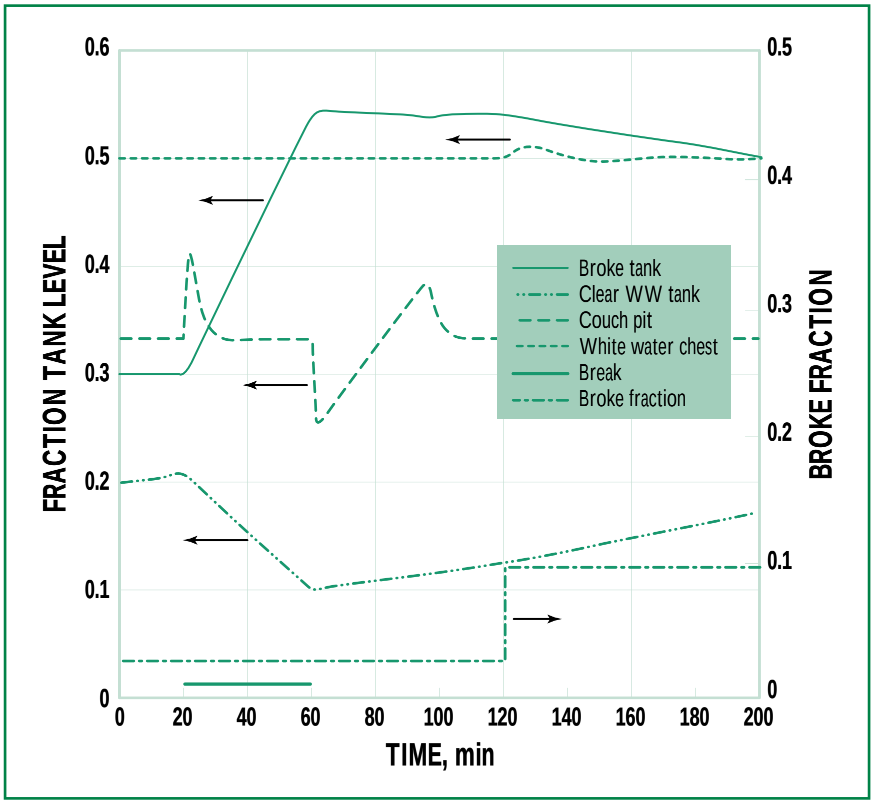
$$T_i = \frac{4\,\xi^2 A}{-K_C} \qquad (2)$$

In Eq. 1, "e" is the base of the natural logarithms (2.7183). These equations imply that the variation in the level response will reach a maximum allowable value, Δh_{MAX}, when the maximum variation in the stream perturbation is ΔF_{MAX}. This allowable level variation must be specified for each tank, and it becomes a design criterion for controller tuning. In Eq. 2, A is the cross-sectional area of the reservoir, and the damping factor, ξ, is usually set equal to 1.

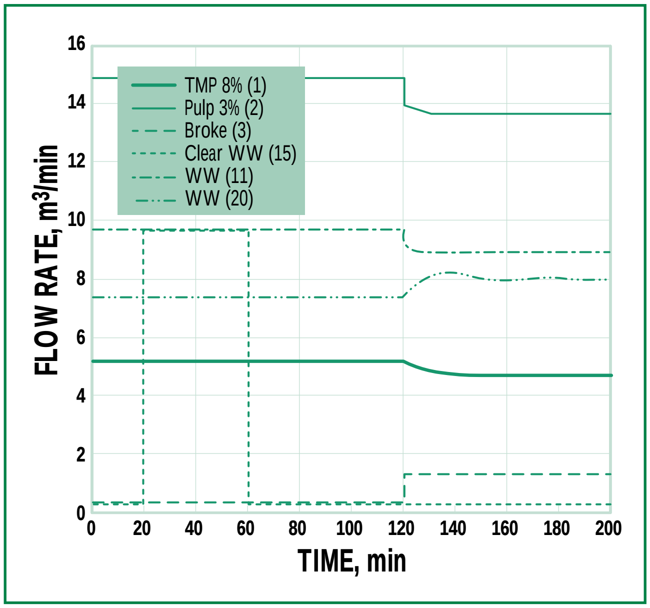
In Eqs. 1 and 2, the negative signs associated with the gain implies that the tank level is controlled by manipulating the outlet flow (assuming an air-to-open valve); those signs would be positive if the manipulated flow was the inlet. The values of the PI parameters obtained after using Eqs. 1 and 2 are given in **Table IV**. The selected criterion to obtain the PI parameters for consistency and temperature control loops was the settling time: less than 30 seconds and 3 min for the consistency and temperature loops, respectively. In the case of flow controllers, the settling time was short enough when compared to other control loops. For this reason, we have considered instantaneous setpoint tracking.

Simulation

Dynamic simulations were carried out by using SPEEDUP *(15),* a multipurpose equation-oriented package for process and control-system simulations. SPEEDUP is a simultaneous solver in which all equipment is represented by a set of mixed ordinary differential equations (ODEs) and



3. Variation of tank levels (single-break case)



4. Main flow rates (single-break case)

algebraic equations (AEs). The simulation of the process consists of solving the system of differential and algebraic equations (DAEs) for given initial conditions. Early methods for solving DAE systems were in the following common semiexplicit forms:

$$f(\dot{x}, x, y, t) = 0 \qquad [3(a)]$$

$$g(x, y, t) = 0 \qquad [3(b)]$$

These forms relied on solving the algebraic equations [Eq. 3(b)] numerically to obtain the algebraic variables y in terms of the differential variables x. The algebraic variables can then be substituted into the differential equations [Eq. 3(a)], thus effectively converting them to a set of implicit ordinary differential equations. The main limitation of this approach is that the solution of complicated ODE systems requires multiple evaluations of the residuals of the differential equations, each evaluation itself being performed by an iterative solution of the algebraic equations. Gear's method *(16)* overcomes this problem by solving the differential and algebraic equations simultaneously. A detailed overview of equation-oriented dynamic models has been presented by Pantelides and Barton *(17)*. SPEEDUP provides numerical routines for the solution of dynamic simulation problems. Among several possibilities available, the default integration algorithm is a modified Gear's method. The integration step is automatically varied, and the estimated integration error is kept within a prespecified tolerance.

The process diagram of **Fig. 2**, which includes 45 process streams, 15 process units, and 13 control loops, was represented by approximately 500 differential and algebraic equations. The SPEEDUP software was installed on an IBM RISC 6000 platform. The execution time was approximately 2 min for a real-time period of 500 min.

RESULTS

Single-break case

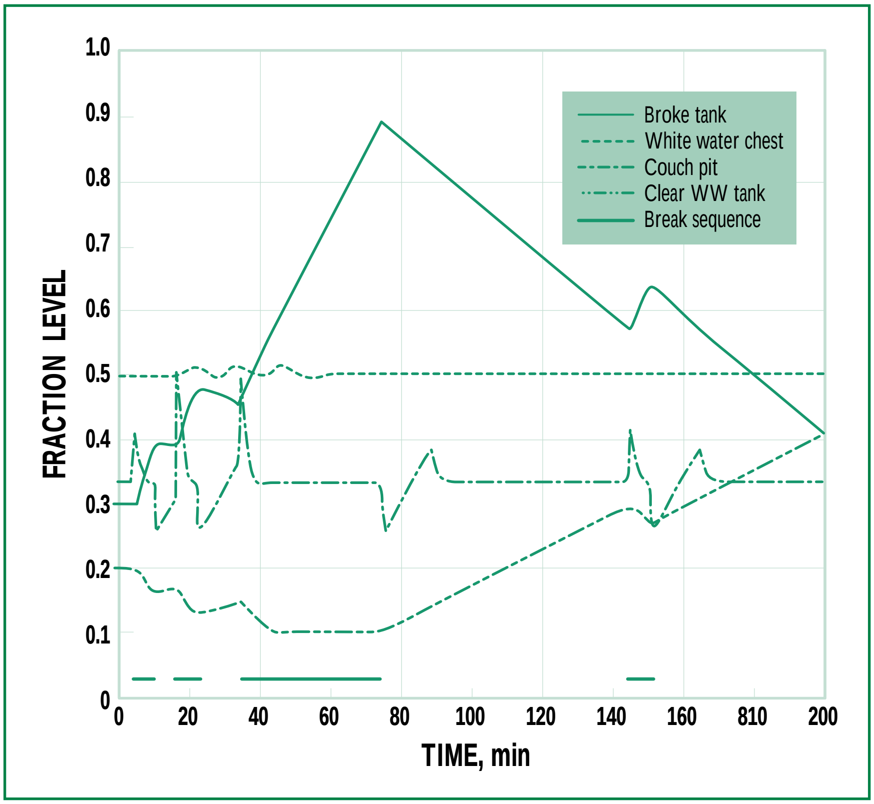
To illustrate the wet-end dynamic behavior of the process and its control system, the wet end's transient response to a single break was first simulated. The sequence of events is as follows:

- The system is originally at steady-state with 3% of broke recirculation rate (trimmings from the paper machine).
- At time 20 min, a break occurs, and it lasts 40 min.
- At time 120 min, the broke reuse rate is increased to 10%.

The broke reuse rate increase was purposefully applied with a substantial delay to observe separately the direct effect of broke repulping on white water inventories and the effect of broke reuse.

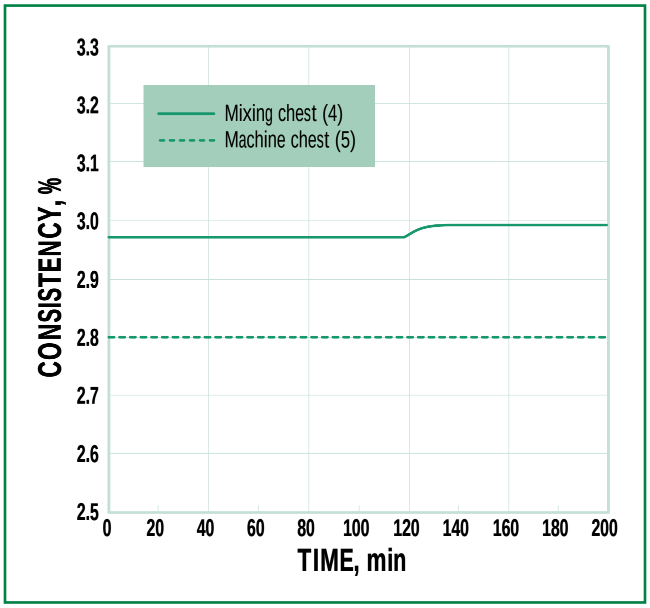
As shown in **Fig. 3**, before the break occurs, the water level is rising in the clear white water tank, since the surplus of water generated in the wet end is stored in that tank. During the break, the broke tank level increases rapidly; the level evens out at the end of the break and starts to decrease again when the broke recycling rate to the main pulp stream is increased. The couch pit experiences sharp variations. Its level first increases when the break occurs. Then, as the level controller LC_4 takes action and increases the flow rate of repulped broke to the broke tank, the couch pit level returns to its setpoint value. Finally, when the web is again restored and the paper production resumed, there is a sudden imbalance as the incoming flow of dilution water is immediately stopped after the break, causing a temporary reduction in the level followed by a slow return to the target level because the inlet stream resumes its initial value.

The white water chest collects the white water from the paper machine; the water is then redistributed through the network to dilute the fresh pulp before it is supplied to the paper machine. During breaks, there are no important changes in this chest, but when the broke recirculation ratio is increased, the white water distribution within the network is altered. As the rate of broke reuse is increased, the flow rate of fresh pulp from the stock tank to the mixing chest is reduced, as indicated in **Fig. 4**. This immediately causes a reduction of the required amounts of white water for dilution (stream 11). As the total white water produced at the paper machine and the other white water flow rates remain essentially constant, the ultimate effect of the sheet break is an increase of the white water excess in the wet end.



6. Variations of tank levels (multiple-break case)

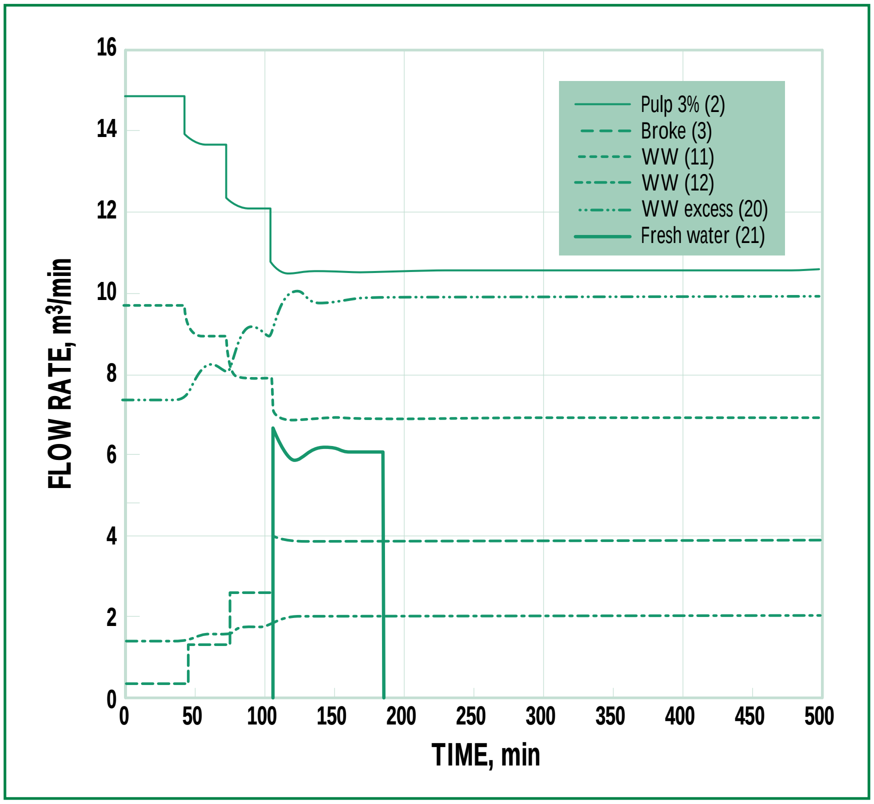
As shown in **Fig. 5**, machine chest consistency is maintained constant at 2.8%, but the mixing chest consistency increases slightly when the broke recirculation rate is increased because the broke is at 3.5% consistency while the fresh pulp supply is at 3.0%. This effect causes a slight increase of the white water flow to dilute the main pulp stream at the machine chest (stream 12). The flow rate variations of the clear white water used to diluted trimmings and breaks are indicated in **Fig. 4** (stream 15).



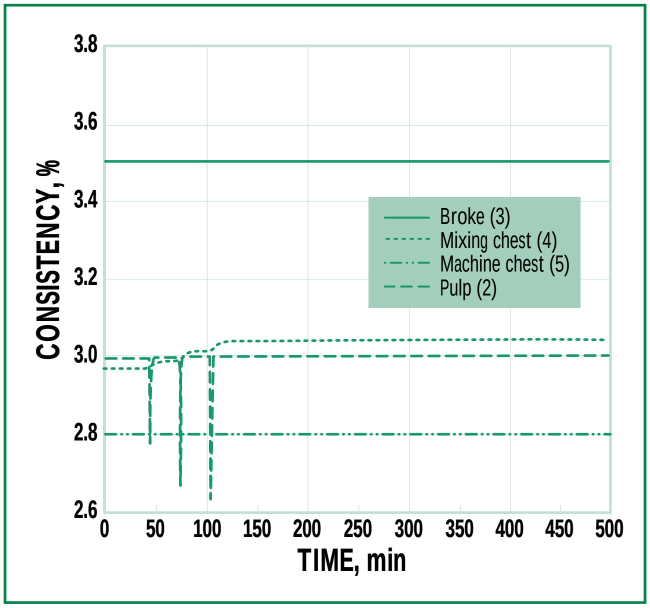
5. Consistency in the mixing and machine chest (single-break case)

Multiple-break case

Following the characterization of the process by the single-break simulation, the process robustness was tested by simulating a severe sequence of breaks taken from actual mill data. The data consists of four wet breaks during a



7. Main flow rates (multiple-break case)



8. Consistencies of major streams around the mixing chest (multiple-break case)

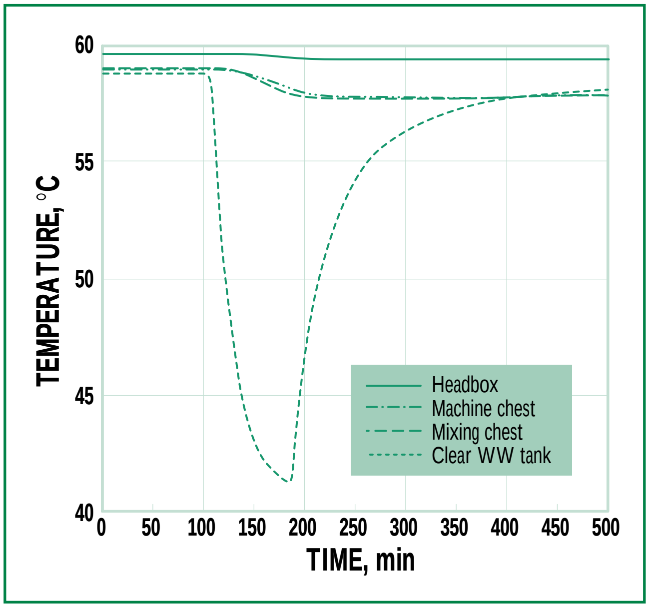
KEYWORDS

Broke, control systems, design, dynamics, flow charts, models, networks, newsprint mills, performance evaluation, process control, simulation, test methods, web breaks, variables, wet ends, white water.

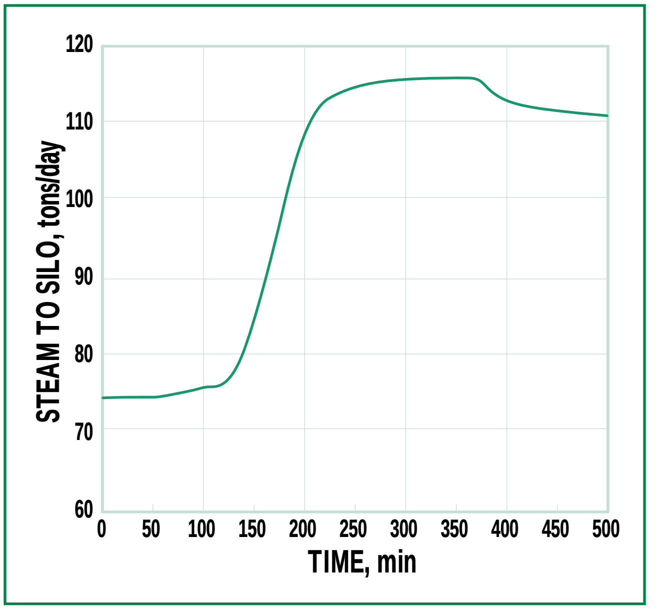
500-min period with the following time distribution: 10(15), 40(15), 85(100), and 360(15). The initial numbers are the times in minutes at which breaks occur, and the numbers in parentheses are the corresponding break durations. To avoid overflow of the broke tank, the broke recirculation ratio was increased. Fresh water is added to the clear white water tank as soon as its level reaches 10%. The initial levels were 30% and 20% in the broke and clear water tanks, respectively **(Fig. 6)**. As expected, the broke tank level increased rapidly with each break while the clear water tank level decreased. At time 105 min, this level dropped to 10%, requiring the addition of fresh water.

The couch pit level shows higher peaks than in the single-break case. This is explained by cumulative effects: Second and third breaks occurred before the effect of the precedent break had completely vanished. (This may be verified by comparing couch pit level profiles in **Figs. 3 and 6**.) To avoid broke tank overflows, the broke recirculation ratio was increased successively up to 30%. Increasing broke content in the pulp implies a lower amount of fresh pulp, thus reducing the need for dilution and increasing the excess of white water to the saveall. **Figure 7** shows the changes in main flow rates to the mixing chest (fresh pulp and broke) and the variations in main white water streams as a consequence of the changes in the broke reuse ratio. The final result of all these changes is an increment of the white water surplus (stream 20). In **Fig. 8**, the slight increase in the mixing chest consistency was a result of the higher broke consistency compared to the fresh diluted pulp (3.5% and 3.0%, respectively). The variations in consistency in the diluted pulp are the result of the change in broke reuse; this temporarily affects the loop CC_1.

Thermal changes caused by the fresh water addition to the clear water tank were also illustrated by this simulation. As described earlier, fresh water addition at 15°C causes rapid temperature drops in the clear water tank **(Fig. 9)**. Despite this large temperature change, the temperature variation through the network was damped by the successive dilutions of the broke and its mixing with other process streams during the recirculation. The target temperature in the silo was 60°C. This temperature was satisfactorily maintained because no constraints on the steam supply were specified. The headbox temperature remained quite constant, close to 59.5°C, but the



9. Main temperatures in the wet end (multiple-break case)



10. Steam consumption (multiple-break case)

steam requirement in the silo was increased from 75 to 110 tons/day, as shown in **Fig. 10**.

DISCUSSION

Reservoir dimensions used in this study were taken from actual cases and are similar to those currently found in the newsprint industry. The clear white water and broke tanks are the largest ones in the wet end of a paper mill. Usually the dimensioning of these reservoirs is based on holding time criteria. Two main parameters should be considered when sizing a broke tank: the expected break frequency and the broke reuse rate. These parameters affect broke inventories in opposite directions. The broke tank capacity (1900 m^3) is equivalent to 1.6 times the longest sustained trouble period considered (100 min) when storing broke at 3.5% consistency.

The mass balances around the wet end indicate that there is a water surplus that is the result of two factors: (a) the higher consistency of the wet web leaving the forming zone when compared to the fresh feed and (b) the fresh water added to the showers of the machine. This surplus causes the clear water tank to be in continuous overflow. A design objective for this tank is to stock enough water to dilute the broke. The capacity of this unit should match the broke tank size, thus avoiding the addition of fresh water. The clear water tank capacity is 3000 m^3, which corresponds to approximately 450 min retention time. A consequence of this is the fresh water requirement, which happens only when there is a long-duration break (more than 1 hour) and the initial tank level is below 30%. This low- level condition should be considered as an extreme situation and is not likely to occur on a frequent basis.

The fresh high-consistency pulp at 8% is stored in the stock tank. The 900 m^3 capacity of this tank enables the paper machine to run up to 3 hours without fresh pulp supply from the TMP mill. This tank also reduces the effect of perturbances caused by high-frequency variability in the fresh pulp.

The pulp and white water streams have been modeled by a two-component system: fibers and water. This simplified system was chosen to characterize the dynamic behavior of the wet end during breaks. Interactions between broke and clear water inventories underline the importance of dynamic characterization when designing broke and clear water tanks. Appropriate capacity choice may diminish the impact of perturbations by reducing changes during broke reuse and avoid the use of fresh water for broke dilution.

When characterizing wet-end dynamic behavior in response to web breaks, two aspects should be considered. First, breaks will increase inventories in the broke tank and will reduce those in the clear water tank. This first aspect is not controlled or predicted; it simply happens: Broke must be diluted, repulped, and stocked. The second aspect is the need for broke recycling. The amount of broke to be recycled is a decision generally made by the operator on the basis of broke inventories and is largely influenced by his experience. Broke reuse affects the process by changing the pulp composition and the white water distribution in the network.

Dynamic modeling results may be used in two ways: (a) during the design of new mills, to determine, from historical data in similar plants (break duration and frequency), the optimum tank size without overflow for a certain broke recirculation ratio and (b) for existing mills, to find a compromise between the broke recycling rate and the broke content of the pulp without affecting paper properties and machine performance. From the standpoint of break impact, the process configuration studied has shown good performance. The single-break case did not seriously affect the broke and clear water inventories. Its duration (40 min) may be considered as a good approximation of a daily average break time in a newsprint mill. By considering trimmings and an average daily break time, a constant broke reuse rate would have been enough to manage broke inventory. When the system is occasionally disturbed by multiple breaks, the fast increase in the broke tank level requires an increase in the broke reuse rate of up to 30%.

Fresh water addition to dilute broke causes some changes in temperature throughout the wet end. These variations indicate long-term dynamics, and transient responses are felt during many hours. The sequence of reservoirs acts as a buffer: The effect of the perturbation is softened through the reservoirs. This is a typical behavior observed on intensives properties such as temperature and concentration.

The focus of this work was on modeling and characterizing the dynamics of a white water network. Further work in progress considers the controllability of the paper machine and its white water network. Fiber length distribution (i.e., the fibers-to-fines ratio) and the total dissolved solids content should also be included as process variables. The addition of fines as a new component implies that the machine forming zone cannot be considered as an elementary separation unit. The effect of the headbox fines content on the first-pass retention should be considered.

CONCLUSIONS

The simulation presented here illustrates the use of a dynamic model to show the most significant time-dependent characteristics of a typical white water network during a sequence of wet breaks. Changes in variables such as tank levels, consistencies, flow rates, and temperatures have been computed in response to this perturbation. Though average daily breaks are, in most cases, of lower frequency, the break sequence analyzed made it possible to test the process design during severe perturbations. The white water networks have long-term dynamics. The effect of perturbations may continue through the system for hours and sometimes days. The steady-state behavior represents a hypothetical situation that is never fully reached. For the simulated model, the process configuration and its control system dealt effectively with breaks by keeping the main variables under control. **TJ**

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This work was supported by a PAPRICAN scholarship through the Carl Winkler Memorial Foundation and a strategic grant of the Natural Sciences and Engineering Research Council of Canada. The SPEEDUP software was used under an academic license from Aspen Technology Inc. These contributions are gratefully acknowledged.

Received for review Nov. 8, 1996.

Accepted April 18, 1997.

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