Optimization of filter washer operation and control

Yushan Han and Lou Edwards

To minimize total dissolved solids carryover from brownstock washing for a given shower flow, drum vacuum is the most important operating variable.

Washer models can be generally classified as descriptive or predictive. Descriptive models include the well known plot of displacement ratio against dilution factor. A descriptive model using the Norden (*1*) E-factor has proven useful. On the other hand, predictive models that involve filtration theory and flow in porous media are relatively few. Here, we will look at a new washer model (*2*) as it is applied to optimize filter washing operation and control.

New washer model

The mat formation in the new model is described using Ruth's equation and a variable specific resistance (i.e., a compressible mat). For a given drum speed and vacuum, the mat thickness and vat level are calculated from these filtration considerations.

After the mat emerges from the vat, dewatering, showering, and further dewatering take place. These actions are represented by equations that describe two-phase flow in a porous medium. The basic equation is:

$$\epsilon L(dS/dt) = q_i - k_r k(\Delta P/\mu L) \quad (1)$$

where

ϵ = void fraction, dimensionless
L = mat thickness, m
S = saturation (related to consistency), dimensionless
t = time, s
q_i = local shower flow (zero for dewatering), m/s
k_r = relative permeability, dimensionless
k = permeability, m^2
ΔP = effective pressure drop, N/m^2
μ = liquid viscosity, $N\text{-}s/m^2$

Yushan Han and Lou Edwards are research assistant and professor, respectively, with the Chemical Engineering Dept., University of Idaho, Moscow, Idaho 83843.

This equation is solved for dewatering portions of the drum with $q_i = 0$. Under the shower bars, q_i is equal to the shower flow rate. The major complication in Eq. 1 is that the relative permeability is a function of the mat saturation:

$$k_r = f(S) \quad (2)$$

This complication necessitates a numerical solution of the differential equation as the mat passes from the surface of the vat and over the drum to the doctor blade.

The removal of dissolved material from the mat is described by an axially dispersed plug flow model. It is the model published by Brenner (*3*) and is a one-parameter representation of washing. The single parameter is the Péclet number, P_e:

$$P_e = D/u\,L \quad (3)$$

where

L = mat thickness, m
D = axial dispersion coefficient, m^2/s
u = fluid velocity, m/s.

This model and other washing models have been discussed elsewhere (*4*). The Péclet number is a function of the mat thickness, and it is thus important to predict mat thickness in the calculations. Pellet (*5*) has shown that the quantity u/D in the Péclet number is approximately constant for a given pulp. Consequently, u/D is held constant here. Indicating that the Brenner solution is approximated well by the Norden equation, Edwards *et al.* (*4*) present a correlation between the Péclet number and the E-factor.

Single-filter washer, steady state

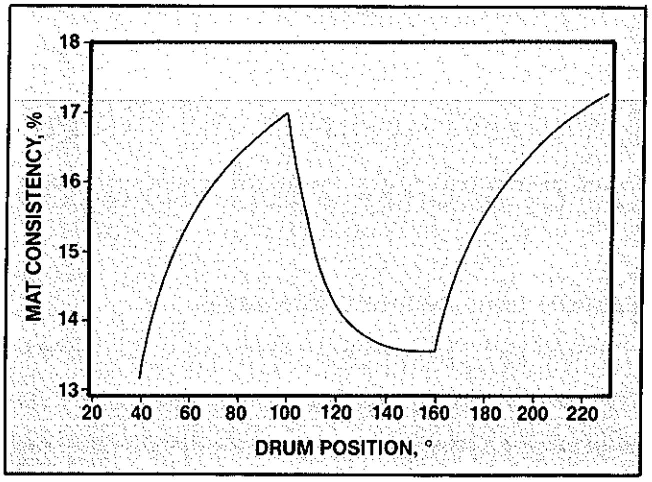
We studied a single-filter washer to answer the question, "How is washing affected by vacuum, drum speed, and vat consistency?" The base case is derived from the actual mill conditions and is shown in **Table I**.The simulated consistency for the mat from the vat liquid surface to the doctor blade is shown in **Fig. 1**. Wash shower addition

I. Mill data for the base case

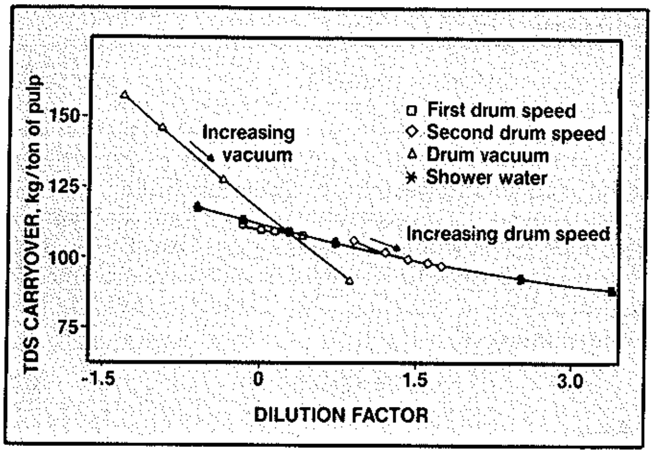
Washer speed, rpm	2.09
Stock flow rate, tons/h	446
Shower flow rate, tons/h	114
Vat consistency, %	2.58
Mat consistency, %	17.2
Stock consistency, %	4.8
Shower TDS concentration, g/L	15.0
Vat TDS concentration, g/L	38.0
Mat TDS concentration, g/L	22.5
Vacuum, cm Hg	33.0

Southern pine linerboard.

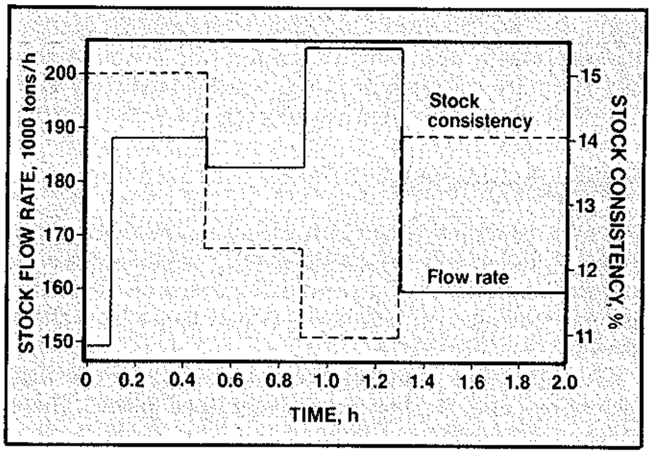
1. Profile of pulp mat consistency on a filter washer in the two-phase flow zones



2. The relationships between TDS carryover and dilution factor show the effects of changing operating conditions. (All points except those for shower water and the second drum speed use 114 tons/h of shower flow.)



3. The process disturbances used in the single-filter washer dynamics and control cases



occurs at a drum position of from 100° to 160°. The final mat consistency, 17.2%, matches the experimental value.

Figure 1 indicates that a large quantity of the shower flow is required to resaturate the sheet. In the washing model, this resaturation portion of the shower flow is assumed to mix with the mat liquor, and only the remaining shower flow is available for "displacement" washing using Brenner's model. The ratio u/D in the Péclet number is fixed at the average from several sets of mill data, where $u/D = 1.30\ cm^{-1}$). Pulp production is 537 o.d. tons/day in all cases.

The contribution of dewatering after the showers to the displacement washing is calculated in the new model using superposition as described by Edwards *et al.* (*4*).

Effect of drum vacuum

The drum vacuum has a major effect on the consistency of the mat formed on the washer. **Table II** shows five calculated cases with vacuum from 17.8 cm Hg to 43.2 cm Hg. Of course, drop-leg vacuum is not easy to adjust.

Effect of drum speed

Drum speed has an effect on the consistency of the mat formed on the washer. It also changes the mat thickness and Péclet number, as shown in Table II.

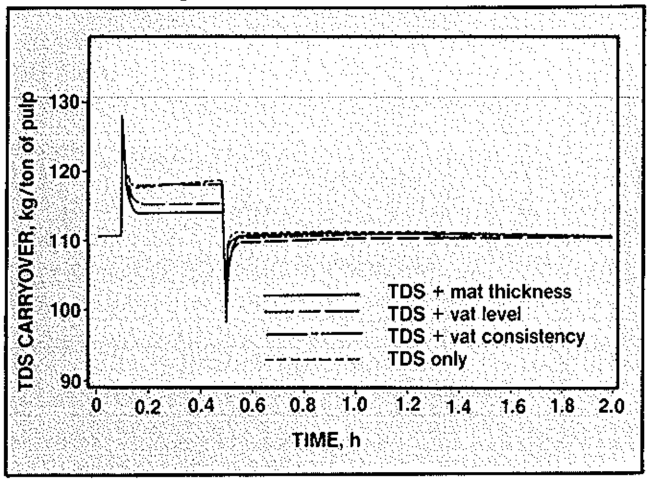
Total dissolved solids carryover

Total dissolved solids (TDS) carryover is the important economic measure of washing performance; therefore, it should be minimized for a fixed shower amount. **Figure 2** summarizes the results of varying operating conditions on filter washer TDS carryover. The figure shows that drum speed and vat consistency, or vat dilution, have little effect on TDS carryover. Vacuum is important mainly because dewatering is improved at high vacuum.

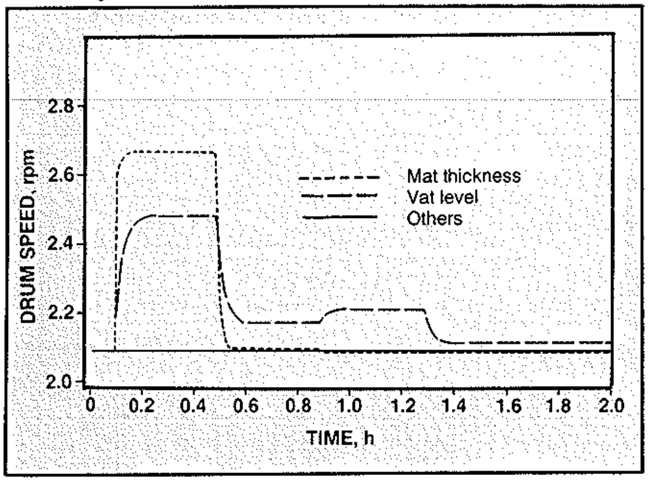
Single-filter washer, dynamics and control

The application of this new washer model to control of a single drum washer is illustrated in **Figs. 3-5.** Figure 3 shows the disturbances to which the single drum plus a seal tank are subjected. These production disturbances are based on actual mill measurements and are realistic in

4. TDS carryover can be stabilized by combining TDS control with other control strategies.



5. Drum speed changes corresponding to different control strategies for the single-filter washer



II. Impact of drum speed and drum vacuum on filter operation for Cases 1-9

	1*	2	3	4	5	6	7	8	9
Drum speed, rpm	2.09	2.09	2.09	2.09	2.09	2.50	1.70	1.5	1.35
Drum vacuum, cm Hg	33.0	43.2	25.4	20.3	17.8	33.0	33.0	33.0	33.0
Drum submerge angle, °	78.7	69.3	88.7	98.1	103.7	56.0	115.9	146.9	179.2
Mat thickness, cm	3.46	3.17	3.77	4.04	4.21	2.95	4.16	4.65	5.11
Discharge consistency, %	17.3	19.2	15.6	14.3	13.6	17.7	16.9	16.5	16.0
Discharge TDS, g/L	22.7	21.9	23.6	24.3	24.7	23.1	22.2	21.7	21.2
Displacement ratio	0.664	0.701	0.628	0.598	0.580	0.647	0.689	0.708	0.728
Dilution factor	0.287	0.871	-0.343	-0.930	-1.299	0.423	0.153	0.023	-0.156
Norden E-factor	2.692	2.676	2.713	2.740	2.757	2.505	2.981	3.270	3.706

Washer load = 14.4 o.d. tons/m²•day. Vat consistency = 2.58%. Flow rate of the shower water = 114 tons/h.
*Case No. 1 is the base case.

magnitude. Figure 4 shows the response of TDS carryover to the disturbances in Fig. 3, using various control schemes.

It is important to maintain a uniform pulp mat consistency to facilitate control of the seal tank level, and mat thickness control does this best. Figure 4 shows that TDS plus mat thickness control is superior to the other possibilities. Mat thickness control maintains the most uniform pulp mat consistency in the face of these upsets, though this control is not currently in widespread use.

Figure 5 shows the change in drum speed that is necessary to maintain a fixed mat thickness. The changes in drum speed are somewhat more severe than those required for simple vat level control.

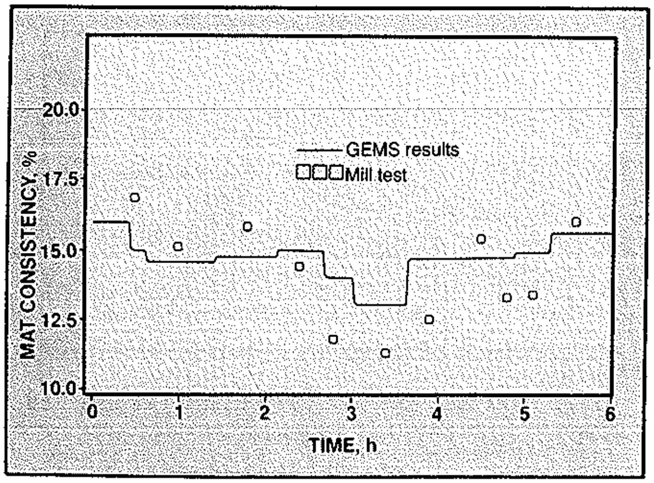
Four-stage filter washer system, dynamics

To simulate a complete brownstock washer system, the new model was incorporated into the GEMS modular simulation computer program (*6*). The GEMS dynamic simulation of a four-stage brownstock washing system is compared to mill mat consistency data in **Fig. 6**. The mill was operating with manual control only. Fourth-stage mat consistency varies from 11% to 17%, and carryover varies from 25 to 80 kg TDS/ton without control. Some automatic control would be beneficial.

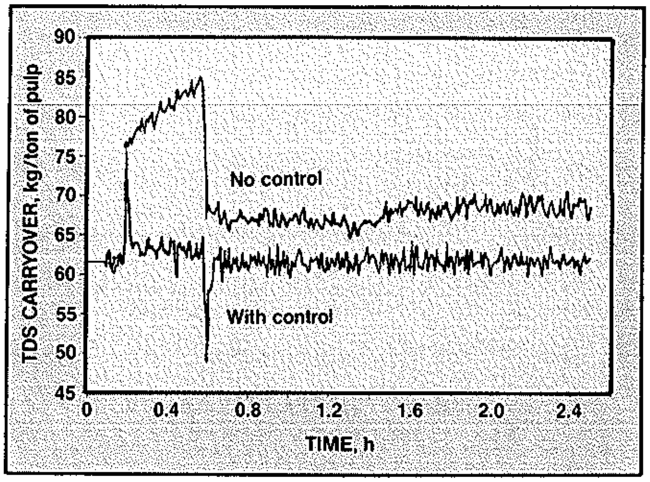
Based on results, a good control system should include:

1. Fourth-stage mat TDS control, using the fourth-stage shower flow
2. Simultaneous adjustment of all shower flows whenever the fourth stage shower is changed
3. Mat thickness control using drum speed on all stages
4. Conventional control of the seal tank level
5. Fixed vat dilution flow in all stages
6. Control of overall liquor and stock inventory, including control of the blow tank, high-density storage, and the weak black liquor tank.

The problem with this control scheme is sensors. Measurement of TDS in the mat liquor is a problem. Even using conductivity to estimate TDS requires separating fibers and liquor. Mat thickness sensing is not generally available yet, but vat level control is nearly as effective



6. The final mat consistency of a four-stage washer system



7. TDS carryover dynamics from the simulation of the four-stage brownstock washer

and is available technology.

The lower curve in **Fig. 7** results from a simulation run using this control scheme, subjecting the simulated four-stage brownstock washing system to the production upsets in Fig. 3, and adding instrument and process noise. The upper curve represents TDS carryover with no control.

Dynamic tank levels and tank contents are also included in the GEMS simulation so that inventories can be included as part of the control system evaluation. **Figure 8** shows the tank level dynamics corresponding to the curves in Fig. 7. The new model predicts the varying fourth stage mat consistency and includes this effect in accounting for liquor inventory.

Conclusions

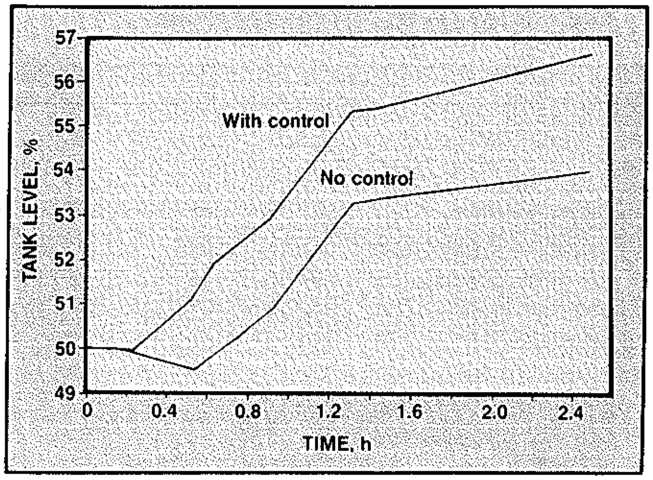
To minimize TDS carryover from brownstock washing for a fixed shower flow, drum vacuum is the most important operating variable. A low drum speed gives a higher displacement ratio but a lower exiting mat consistency, and these two offsetting effects result in a drum speed with little impact on TDS carryover. However, given a choice, high drum speeds are preferable to low drum speeds.

A good control scheme consists of (a) TDS control of the final brownstock washer using shower flow and (b) mat thickness control using drum speed. Vat level control is almost as effective as mat thickness control in minimizing variations in mat consistency.

Embedding the new washer model in the dynamic version of GEMS allows a complete system analysis including scheduling and inventory management.

Literature cited

1. Norden, H. V., Kemian Teollisuus 23(4): 343(1966).
2. Han, Y., Flow through porous media: impact of fluid flow on wood pulp washer performance, M.S. thesis, University of Idaho, Moscow, Idaho, 1985.
3. Brenner, H., Chem. Engr. Sci. 17: 229(1962).
4. Edwards, L., Peyron, M., and Minton, M., Pulp Paper Can. 87(1): T17(1986).
5. Pellet, G. L., Tappi 49(2): 75(1966).
6. Edwards, L. and Baldus, R., GEMS documentation manual, Idaho Research Foundation, Moscow, Idaho, 1983.



8. Tank level dynamics for weak black liquor in the simulation of the four-stage brownstock washer

The partial support of this work by the Weyerhaeuser Co., Mead Corp., and Quaker Computer Solutions is greatly appreciated.

Presented at the 1987 Pulp Washing Conference sponsored by the Finnish Pulp and Paper Research Institute (FPPRI) and Finnish Paper Engineers' Association, Helsinki.

Received for review July 15, 1987.

Accepted Nov. 11, 1987.