Operational evaluation of rotary drum vacuum filters for brownstock washing using basic filtration parameters

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ABSTRACT: A calculation procedure was developed for a rotary drum vacuum filter used in brownstock washing. In the model of a rotary drum vacuum filter, brownstock washing is split into a set of basic unit operations. These operations are described, combining mass balance equations with constant-pressure filtration equations. This set of equations is solved using the system/engineering methodology. The results for a typical rotary drum vacuum filter are presented.

Application: A computer program using these calculations will facilitate the management of brownstock washing operations.

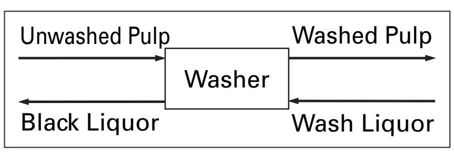
Brownstock washing is the pulping process operation in which the organic and inorganic substances dissolved in the black liquor are removed from the cellulose pulp. The pulp is decontaminated of those substances, the valuable inorganic chemicals are recovered, and the organic material is burned in the recovery steam boiler.

Brownstock washing is one of the most important operations in the pulping process [1]. Efficient washing requires accurate control of the amount of washing fluid. Greater quantities of washing fluid result in cleaner pulp but lead to higher steam consumption in the evaporator system. Lower quantities of washing fluid result in lower energy consumption in the black liquor concentration but entail a greater expenditure of bleaching chemicals. In short, efficient brownstock washing contributes to greater energy conservation, decreased water usage, and lower expenditure of chemicals. It also helps to limit the discharge of polluting effluents.

A brownstock washing set uses a series of filters through which the filtrate flows countercurrent to the brownstock being washed. The rotary drum vacuum filter (RDVF) is one of the earliest filtering systems and is still in use in many pulping plants. In brief, a perforated drum rotates partially immersed in the pulp suspension. Its surface is covered with a filter medium, over which the cake is formed by the effect of a vacuum applied within the drum. A set of sprinklers disperse the washing fluid over the cake surface to wash the pulp. The cake is finally discharged when the vacuum is interrupted.

Several studies have dealt with the scientific fundamentals of brownstock washing [2–9]. The knowledge developed in these examples has enabled engineers to design improved filtering equipment. However, there have been very few studies aimed at aiding process managers in their daily routine. In Brazil, which is a major producer of pulp and paper, this type of knowledge is essential to improving operational efficiency, a requirement for maintaining competitiveness in this market.

Our objective was to develop a practical calculation procedure in the form of a computer program. This program would furnish brownstock washing managers with information complementary to that available on the instrument panel and to that obtained through chemical analysis.



1. The main streams of a rotary drum vacuum filter.

METHODOLOGY

Overview

In early studies [7–9], the brownstock washing operation was described using a mass balance approach to correlate brownstock washing variables. Our study complements those earlier studies by including the variables and equations that describe the macroscopic behavior of the RDVF. In a subsequent step, microscopic aspects related to mass transport phenomena could be introduced as suggested by Cullinan [7].

The RDVF process was split into a set of basic unit operations, as proposed by Edwards [8]. Mass balances and specific RDVF equations were applied to these unit operations, providing a set of equations that describe the entire RDVF operation.

We treated this set of equations by the system/engineering analysis as proposed by Barton [10,11]. The purpose was to set the values of all variables available to the brownstock washing manager for performing the operational RDVF diagnostic.

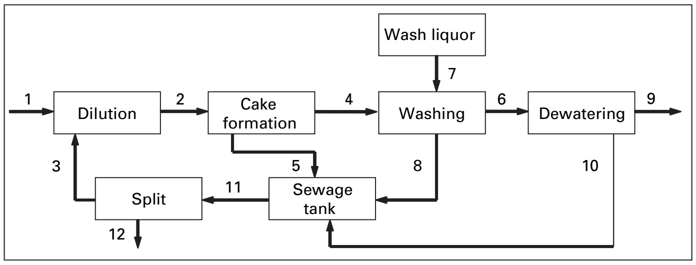
Basic unit operations for RDVF

Figure 1 is a diagram of the main streams of an RDVF. The entering streams are unwashed pulp and wash liquor, and the exiting streams are washed pulp and black liquor.

Figure 2 illustrates the division of the RDVF process into six basic unit operations. The feed suspension (1) is diluted in a mixing tank that feeds (2) the suspension trough of the RDVF with pulp of a specific consistency.

In the cake formation zone, the liquid phase (5) is separated from the cake (4). In the washing zone, the washing fluid (7) is sprayed over the cake, resulting in a washed cake (6) and contaminated washing fluid (8).

In the cake dewatering zone, the washed cake is dried into a dried cake (9). The liquid removed (10) is drained into the sewage tank, where two of the other streams (5 and 8) are also collected. At the split, Stream 11 is divided into a recycling stream (3) and an outlet stream (12).



2. Basic unit operations for the rotary drum vacuum filter.

Basic equations

Each stream, identified by index i in Fig. 2, can be characterized by the following parameters:

- Mass flow rate of pulp, M_{Pi}
- Mass flow rate of water, M_{Wi}
- Consistency of the brownstock, S_{SPi}
- Ratio between the mass of water and the mass of pulp, W_{Pi}
- Ratio between the mass of (pulp free) soluble solids and the mass of water, X_{Si}.

W_{Pi}, S_{SPi}, and X_{Si} are related by Eq. 1:

$$W_{Pi} = \frac{1 - S_{SPi}}{\left[S_{SPi}\left(1 + X_{Si}\right) - X_{Si}\right]} \quad (1)$$

Table I shows the mass balances for each of the basic unit operations in steady-state flow.

Table II shows the parametric equations for the cake formation zone of the RDVF operating under constant pressure [12].

Table III lists the equations for the washing zone [12]. In the calculation of washing time, the conditions of the fluid flow are assumed to be the same as those at the end of the cake formation. This means that the cake structure is unaffected when the washing fluid displaces the liquid originally inside the cake.

Washing efficiency

The performance of the washing system is usually described by the dilution factor DF and the displacement ratio DR [13,14]:

$$DF = \left(\frac{M_{W7}}{M_{P2}}\right) - W_{P9} \quad (31)$$

$$DR = \left(\frac{X_{S2} - X_{S9}}{X_{S2} - X_{S7}}\right) \quad (32)$$

In addition, the concept of overall washing system efficiency, Y, expresses the fraction of dissolved solids removed in the system:

$$Y = \frac{M_{W12}X_{S12} - M_{W7}X_{S7}}{M_{P1}W_{P1}X_{S1}} \quad (33)$$

The local washing efficiency, Y_L, expresses the fraction of dissolved solids removed in the washing zone:

$$Y_L = \frac{M_{P4}W_{P4}X_{S4} + M_{W7}X_{S7} - M_{P6}W_{P6}X_{S6}}{M_{P4}W_{P4}X_{S4} + M_{W7}X_{S7}} \quad (34)$$

Using Eq. 10 in Eq. 34 allows Y_L to be expressed as

$$Y_L = \frac{M_{W8}X_{S8}}{M_{P6}W_{P6}X_{S6} + M_{W8}X_{S8}} \quad (35)$$

Unit Operation	Mass Balance Equation	No.
Dilution tank		
Cellulose pulp	$M_{P2} = (1\text{-}f_1)M_{P1}$	(2)
Water	$M_{P1}W_{P1} + M_{W3} = M_{P2}W_{P2}X_{S2}$	(3)
Solids	$M_{P1}W_{P1}X_{S1} + M_{W3}X_{S3} = M_{P2}W_{P2}X_{S2}$	(4)
Cake formation zone		
Cellulose pulp	$M_{P4} = (1\text{-}f_2)M_{P2}$	(5)
Water	$M_{P2}W_{P2} = M_{P4}W_{P4} + M_{W5}$	(6)
Solids	$M_{P2}W_{P2}X_{S2} = M_{P4}W_{P4}X_{S4} + M_{W5}X_{S5}$	(7)
Washing zone		
Cellulose pulp	$M_{P6} = (1\text{-}f_3)M_{P4}$	(8)
Water	$M_{P4}W_{P4} + M_{W7} = M_{P6}W_{P6}M_{W8}$	(9)
Solids	$M_{P4}W_{P4}X_{S4} + M_{W7}X_{S7} = M_{P6}W_{P6}X_{S6} + M_{W8}X_{S8}$	(10)
Cake drying zone		
Cellulose pulp	$M_{P9} = (1\text{-}f_4)M_{P6}$	(11)
Water	$M_{P6}W_{P6} = M_{P9}W_{P9} + M_{W10}$	(12)
Solids	$M_{P6}W_{P6}X_{S6} = M_{P9}W_{P9}X_{S9} + M_{W10}X_{S10}$	(13)
Sewage tank		
Water	$M_{W5} + M_{W8} + M_{W10} = M_{W11}$	(14)
Solids	$M_{W5}X_{S5} + M_{W8}X_{S8} + M_{W10}X_{S10} = M_{W11}X_{S11}$	(15)
Split		
Water	$M_{W3} + M_{W12} = M_{W11}$	(16)
Solids	$M_{W3}X_{S3} + M_{W12}X_{S12} = M_{W11}$	(17)

I. Mass balances for rotary drum vacuum filter.

The low limit for Y_L is Y_{Li}, presuming that there is a perfect mixture between the washing fluid and the brownstock liquor. Therefore, the perfect mixture model is $X_{S6} = X_{S8}$, and Eq. 35 becomes Eq. 36:

$$Y_{Li} = \frac{M_{W8}}{M_{P6}W_{P6} + M_{W8}} \quad (36)$$

The upper limit for Y_L is Y_{LS}, presuming that there is plug flow of the washing fluid and total displacement of the brownstock liquor. So, $X_{S6} = X_{S7}$, and Eq. 35 becomes Eq. 37:

$$Y_{Ls} = 1 - \frac{M_{P6}W_{P6}X_{S7}}{M_{P4}W_{P4}X_{S4} + M_{W7}X_{S7}} \quad (37)$$

In conclusion, it is possible to combine these two limit conditions to express the washing efficiency Y_L with a parameter x_F, where $0 \leq x_F \leq 1$ as Eq. 38:

$$Y_L = Y_{Ls}x_f + (1 - x_f)Y_{Li} \quad (38)$$

where $x_F = 0$ indicates the perfect mixture model and $x_F = 1$ indicates the plug flow model. This concept will be used in the calculation procedure.

Norden proposed the parameter of the Norden efficiency factor to evaluate the washing system performance [13]. For the "black box" composed of all of the unit operations evaluated in this study, Norden efficiency, E, is expressed as:

$$E = \frac{\log\left(\frac{W_{P1}}{W_{P9}}\left(\frac{X_{S1} - X_{S12}}{X_{S9} - X_{S7}}\right)\right)}{\log\left(\frac{M_{W7}}{M_{P9}W_{P9}}\right)} \quad (39)$$

$$t_F = \frac{K_C V_F^2}{2\Delta P_F} + \frac{K_{MF} V_F}{\Delta P_F} \quad (18)$$

$$K_C = \frac{\alpha S_{SP2} \rho_5 \mu_5}{(1 - S_{SP2} F_{WS}) A_F^2} \quad (19)$$

$$K_{MF} = \frac{R_{MF} \mu_5}{A_F} \quad (20)$$

$$t_F = \frac{\theta_F}{\omega} \quad (21)$$

$$M_{W5}(1 + X_{S5}) = \rho_5 \frac{V_F}{t_F} \quad (22)$$

$$M_{P4}(1 + W_{P4} X_{S4}) = \frac{S_{SP2} \rho_5}{(1 - S_{SP2} F_{WS})} \frac{V_F}{t_F} \quad (23)$$

$$W_{P4} = \frac{F_{WS} - 1}{(1 - X_{S4}) - F_{WS} X_{S4}} \quad (24)$$

Eqs. 22 and 23 connect cake formation zone parameters with mass balances variables. Eq. 24 connects W_{P4} with the ratio of wet cake mass to dry cake mass (F_{WS}).

II. Equations for the cake formation zone.

$$t_L = \frac{\theta_L}{\omega} \quad (25)$$

$$A_L = A_F \left(\frac{\theta_L}{\theta_F} \right) \quad (26)$$

$$t_L = \frac{(K_{CL} V_F + K_{MFL}) V_L}{\Delta P_L} \quad (27)$$

$$K_{CL} = K_C \left(\frac{\theta_L}{\theta_F} \right) \quad (28)$$

$$K_{MFL} = K_{MF} \left(\frac{\theta_L}{\theta_F} \right) \quad (29)$$

$$M_{W8}(1 + X_{S8}) = \rho_8 \frac{V_L}{t_L} \quad (30)$$

In the RDVF, the washing area A_L is different from cake formation area A_F, requiring that the coefficients K_{CL} and K_{MFL} be adjusted for this in Eqs. 28 and 29. Eq. 30 connects the washing time and washing fluid volume with mass balance variables.

III. Equations for the washing zone.

Operational Conditions
- Dilution factor, DF
- Fiber consistency at system inlet, S_{SP1}
- Fiber consistency at system outlet, S_{SP9}
- Solids at system inlet, X_{S1}
- Solids at washing fluid inlet, X_{S7}
- Angular velocity of the filter's drum, ω

Cake Formation Zone
- Cake humidity, F_{WS}
- Pressure drop, ΔP_C
- Filter media resistance, R_{MF}
- Fiber consistency in the suspension trough, S_{SP2}
- Specific cake resistance, α
- Filtrate viscosity in Stream 5, μ_5
- Filtrate density in Stream 5, ρ_5

Washing Zone
- Fluid density in Stream 8, ρ_8

RDVF Geometry
- Filtration area, A_F
- Filtration sector angle, θ_F
- Washing sector angle, θ_L

Local Washing Efficiency
- x_F factor

IV. Subcategories for the five major categories.

where $E = \infty$ corresponds to the plug flow model applied to the black box, and $E = 1$ corresponds to the perfect mixture model applied to the black box.

Note that RD, Y, and E are parameters defined for the overall system and that Y_L and x_F are defined for the washing unit only.

Assumptions of the calculation procedure

A number of assumptions were made in this version of the calculation procedure.

First, we assume there is no loss of cellulose pulp in the basic RDVF unit operations. Therefore, the fraction of pulp lost in each case is equal to zero, or $f_1 = f_2 = f_3 = f_4 = 0$.

Second, the pressure drop in the washing zone (ΔP_L) is assumed to be the same as that in the cake formation zone (ΔP_F):

$$\Delta P_L = \Delta P_F \quad (40)$$

Third, the amount of solids in Stream 4 ($M_{P4} W_{P4} X_{S4}$) is considered negligible when compared with the amount of cellulose pulp (M_{P4}). Therefore, Eq. 23 can be simplified to Eq. 41:

$$M_{P4} = \frac{S_{SP2} \rho_5}{(1 - S_{SP2} F_{WS})} \frac{V_F}{t_F} \quad (41)$$

Fourth, the quantity of solids ($M_{W5} X_{S5}$ and $M_{W8} X_{S8}$) in Streams 5 and 8 is considered negligible when compared with the amount of water (M_{W5} and M_{W8}). Therefore, Eqs. 22 and 30 can be simplified to Eq. 42 and 43:

$$M_{W5} = \rho_5 \frac{V_F}{t_F} \quad (42)$$

$$M_{W8} = \rho_8 \frac{V_L}{t_L} \quad (43)$$

Fifth, the following equalities hold:

$$X_{S4} = X_{S2} \quad (44)$$

$$X_{S5} = X_{S2} \quad (45)$$

$$X_{S9} = X_{S6} \quad (46)$$

$$X_{S10} = X_{S6} \quad (47)$$

$$X_{S11} = X_{S3} \quad (48)$$

$$X_{S12} = X_{S3} \quad (49)$$

Sixth, since the value of X_{Si} is very small in comparison to the value of W_{Pi}, Eqs. 1 and 24 can be simplified to Eq. 50 and 51:

$$W_{Pi} = \frac{1 - S_{SPi}}{S_{SPi}} \quad (50)$$

$$W_{P4} = F_{WS} - 1 \quad (51)$$

Finally, the specific cake resistance (α) is assumed to be determined experimentally by the Leaf Test Procedure [15]. For compressible cellulose pulp cakes, this value could be estimated for several filtering pressures using the equation proposed by Reynol [16]:

$$\alpha = 7.76 \cdot 10^5 \, \Delta P_C^{0.77} \quad (52)$$

SYSTEM/ENGINEERING ANALYSIS

The set of equations can be managed using the system/engineering analysis method [10,11] to obtain the desired calculation procedure. The procedure is obtained through the following steps.

1. Determine the degrees of freedom. Number of variables at the set of equations = 61. Number of independent equations = 43. Degrees of freedom = 61 – 43 = 18 (design variables).

2. Select the design variables. These 18 variables were chosen by the following major categories: operational conditions, cake formation zone, washing zone, RDVF geometry, and local washing efficiency. Subcategories are listed in **Table IV**.

Step	Eq.	Calc.	Comments
1	21	t_F	—
2	25	t_L	—
3	19	K_C	—
4	20	K_{MF}	—
5	26	A_L	—
6	28	K_{CL}	take K_C
7	29	K_{MFL}	take K_{MF}
8	40	ΔP_L	—
9	18	V_F	take K_C, K_{MF}, t_F
10	27	V_L	take K_{CL}, K_{MFL}, t_L, ΔP_L, V_F
11	41	M_{P4}	take V_F, t_F
12	2	M_{P2}	take M_{P4}
13	5	M_{P1}	take M_{P2}
14	8	M_{P6}	take M_{P4}
15	11	M_{P9}	take M_{P6}
16	42	M_{W5}	take V_F, t_F
17	43	M_{W8}	take V_L, t_L
18	50	W_{P1}	$i = 1$
19	50	W_{P2}	$i = 2$
20	50	W_{P9}	$i = 9$
21	51	W_{P4}	M_{P2}
22	31	M_{W7}	take M_{P2}, W_{P9}
23	9	W_{P6}	take M_{P4}, W_{P4}, M_{W7}, M_{P6}, M_{W8}
24	12	M_{W10}	take M_{P6}, W_{P6}, M_{P9}, W_{P9}
25	14	M_{W11}	take M_{W5}, M_{W8}, M_{W10}
26	3	M_{W3}	take M_{P1}, W_{P1}, M_{P2}, W_{P2}
27	16	M_{W12}	take M_{W11}, M_{W3}
28	—	X_{S4}	assumed initial value
29	—	X_{S8}	assumed initial value
30	—	—	start of the calculation loop for X_{S8}
31	—	—	start of the calculation loop for X_{S4}
32	36	Y_{Li}	take M_{P6}, W_{P6}, M_{W8}
33	37	Y_{Ls}	take M_{P4}, W_{P4}, X_{S4}, M_{P6}, W_{P6}, M_{W7}
34	38	Y_L	take Y_{Li}, Y_{Ls}
35	34	X_{S6}	take M_{P4}, W_{P4}, X_{S4}, M_{P6}, W_{P6}, M_{W7}, Y_L
36	46	X_{S9}	take X_{S6}
37	47	X_{S10}	take X_{S6}
38	10	X_{S4C}	take M_{P4}, W_{P4}, M_{P6}, W_{P6}, X_{S6}, M_{W7}, M_{W8}, X_{S8}
39	—	X_{S4}	take X_{S4} assumed value and X_{S4C} and[a]
40	44	X_{S2}	take X_{S4}
41	45	X_{S5}	take X_{S2}
42	4	X_{S3}	take M_{P1}, W_{P1}, M_{P2}, W_{P2}, X_{S2}, M_{W3}
43	48	X_{S11}	take X_{S3}
44	49	X_{S12}	take X_{S3}
45	15	X_{S8C}	take M_{W5}, X_{S5}, M_{W8}, M_{W10}, X_{S10}, M_{W11}, X_{S11}
46	—	X_{S8}	take X_{S8} assumed value and X_{S8C} and[b]
47	32	RD	take X_{S2}, X_{S9}
48	33	Y	take M_{P1}, W_{P1}, M_{W7}, M_{W12}, X_{S12}
49	39	E	take M_{P9}, W_{P2}, X_{S2}, M_{W7}, X_{S9}

[a]Using the convergence subroutine for the new value of X_{S4}, repeat Step 31 until convergence is attained. After the first convergence calculation, the assumed value at Step 28 is no longer used. [b]Using the convergence subroutine for the new value of X_{S8}, repeat Step 30 until convergence is attained. After the first convergence calculation, the assumed value at step 29 is no longer used.

V. Calculation procedure.

The other 43 state variables are calculated by solving the nonlinear algebraic system composed of the 43 equations presented.

3. Construct the structural array. One line is used for each equation, and one column is used for each variable. An "X" in a variable column indicates that the variable belongs to that equation.

4. Construct of the precedence diagram. From the structural array, equations are chosen for calculating specific variables. A block is drawn around the equation number. Arrows pointing to the block represent the variables that must be supplied to calculate the chosen variable, which is represented by an arrow exiting the block. The line for the equation is removed from the structural array, together with the column for the variable.

This step is repeated until the remaining structural array has been removed. The result is a diagram connecting all variables. It would be practically impossible to solve the system directly using only the input data for the 18 design variables.

5. Identify the recycles. Recycles within the precedence diagram are identified, and the variables whose initial values must be assumed in order to solve the system are selected.

6. Calculate values. All values are calculated, and the assumed values are checked for agreement with the results of the calculation. If the calculated values are not equal to the assumed values, the convergence subroutine is used to generate new initial values until the entire system converges.

Calculation procedure. Performing these steps results in the calculation procedure shown in **Table V**.

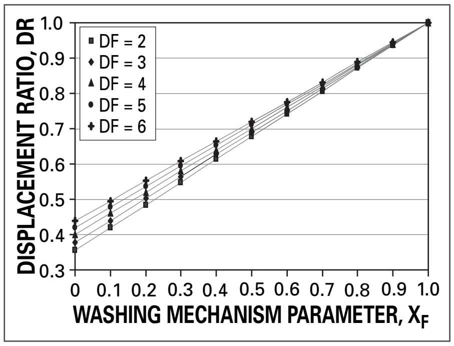
RESULTS

The results of a sample calculation procedure for conditions typical of industrial brownstock washing indicated a fiber production of 0.13 kg/(s•m²). This outcome is similar to the results obtained by Kukreja [17], considering the different conditions of rotation, pressure, and the compressibility of the cake.

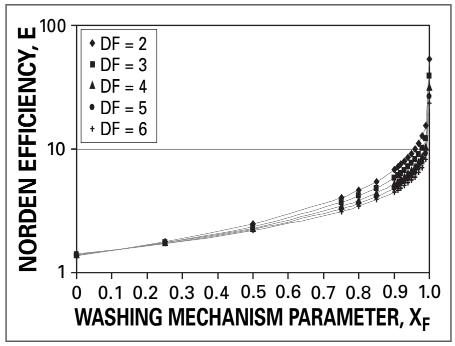
DISCUSSION

Figure 3 shows the correlation, for typical *DF* values, between the traditional *DR* parameter and the x_F parameter proposed in this study. The plug flow model is evaluated under ideal washing conditions ($DF \geq 1$), so $x_F = 1$, and $DR = 1$. However, because of the heterogeneity of the fiber bed under typical operational conditions, plug flow may never occur. Therefore, efficient washing requires a volume of washing liquid much higher than the ideal, and the practical dilution factor may range from 2 to 4.

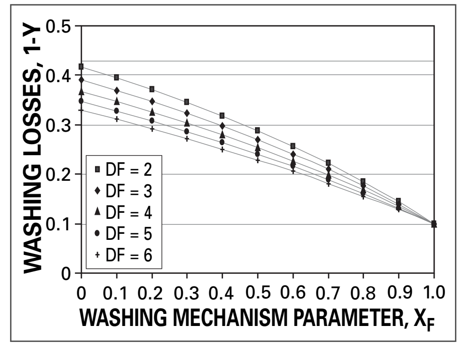
Figure 4 illustrates the relationship between Norden *E* (usually thought to evaluate washing system performance) and the x_F factor at various *DF* values. The Norden *E* value increases in parallel with the x_F factor. For the plug flow model, $x_F = 1$, and $E \rightarrow \infty$. For the perfect mixture model, taking into consideration the washing unit only, $x_F = 0$ and $E = 1.39$.



3. Displacement ratio in relation to the washing mechanism parameter at different dilution factors.



4. Norden efficiency in relation to the washing mechanism parameter at different dilution factors.



5. Washing losses in relation to the washing mechanism parameter at different dilution factors.

E is defined for the entire system, and x_F is defined for the washing unit alone. For this reason, *E* does not take on the value of 1 for the perfect mixture model when applied only to the washing unit.

As **Fig. 5** shows, the loss in washing (1 – *Y*) is related strongly to the x_F factor. At $x_F = 1$, washing system efficiency is high but limited by the concentration of washing liquid used. In our case, X_{S7} = 0.0005. For the perfect mixture model ($x_F = 0$), washing system efficiency is lower and depends on the *DF*.

Figure 6 presents the concentration of solids (X_{Si}) in the pulp stream in the different steps of the system, assuming $x_F = 0.7$, $X_{S1} = 0.005$, and $X_{S7} = 0.0005$. The results illustrate that the dilution unit is as important as the washing unit in determining the system efficiency.

CONCLUSIONS

A calculation procedure is presented for rotary drum vacuum filters used in brownstock washing. The RDVF operation is split into basic steps that represent unit operations. These unit operations are modeled by the mass balances and the fundamental equations of the classical filtration theory. This set of equations was solved using the system/engineering analysis methodology. By providing insight about each unit operation, the procedure enables the macroscopic analyses of the overall system operation.

The x_F parameter is useful in defining the efficiency of the washing operation in isolation, independent of the other operations. There are correlations between x_F and the commonly used parameters (*DF*, *DR*, 1 – *Y*, and Norden *E*). The relationships between x_F and microscopic aspects of mass transport phenomena in the washing operation constitute an important topic for future study.

This study was aimed at developing a practical calculation procedure in the form of a computer program that could be a useful tool in the management of the brownstock washing operation. We plan to present a detailed application of this calculation procedure in the near future. **TJ**

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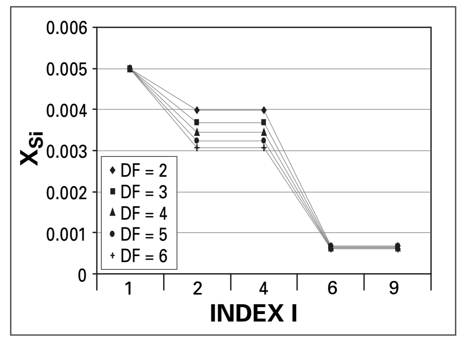

6. Ratio between the mass of soluble solids and the mass of water in the suspension (X_{Si}), by dilution factor, for the pulp stream for the system depicted in Fig. 2. (The index I corresponds to the stream number.)

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NOMENCLATURE

A_F = filtration zone area, m^2
A_L = washing zone area, m^2
C_{SP} = concentration of solids in suspension, kg/m^3
DF = dilution factor, kg/kg
DR = displacement ratio
E = Norden efficiency
f_i = fraction of pulp lost
F_{WS} = ratio between wet cake mass and dry cake mass, kg/kg
K_C = characteristic coefficient of the filtration zone, N•s/m^8
K_{CL} = characteristic coefficient of the washing zone, N•s/m^8
K_{MF} = characteristic coefficient of filter media in the filtration zone, N•s/m^5
K_{MFL} = characteristic coefficient of filter media in the washing zone, N•s/m^5
M_{Pi} = mass flow rate of pulp, kg/s
M_{Wi} = mass flow rate of water, kg/s
ΔP_C = pressure drop of cake, Pa
ΔP_F = pressure drop of filtering zone, Pa
ΔP_L = pressure drop of washing zone, Pa
R_{MF} = Filter medium resistance, m^{-1}
S_{SP} = consistency of the brownstock, kg/kg
t_F = filtration time, s
t_L = washing time, s
v_F = filtrate volume collected during filtration time, m^3
v_L = washing liquid volume collected during washing time, m^3
x_F = washing parameter
X_{Si} = ratio between mass of soluble solids and mass of water in the suspension, kg/kg
W_{Pi} = ratio between mass of water and mass of pulp in the suspension, kg/kg
Y = overall washing system efficiency
Y_L = local washing efficiency
Y_{Li} = lower limit of local washing efficiency
Y_{LS} = upper limit of local washing efficiency
α = average specific cake resistance, m/kg
μ_5 = filtrate viscosity in Stream 5, kg/(m•s)
ω = RDVF angular velocity, radians/s
ρ_5 = filtrate density in Stream 5, kg/m^3
ρ_8 = filtrate density in Stream 8, kg/m^3
ρ_{10} = filtrate density in Stream 10, kg/m^3
θ_F = filtration zone angle, radians
θ_L = washing zone angle, radians

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INSIGHTS FROM THE AUTHORS

Several studies have been published that deal with the scientific fundamentals of brownstock washing. However, there have been very few studies on brownstock washing that are aimed at aiding process managers in their daily routines.

In early studies the brownstock washing operation was described using a mass balance approach to correlate the variables. Our research complements those earlier studies by including the variables and equations that describe the macroscopic behavior of the rotary drum vacuum filter and the x_F parameter that defines the efficiency of the washing operation. In addition, the equations are solved in our study by the system/engineering analysis methodology.

We discovered that the washing parameter x_F is useful in defining the efficiency of the washing operation. It was correlated to the commonly used parameters of dilution factor, displacement ratio, and Norden efficiency. An interesting point is that the dilution unit is as important as the washing unit with regard to system efficiency.

Our next step is to present a detailed application of this calculation procedure in terms of a parametric analysis of the rotary drum vacuum filter.

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