Different Approaches to Evaluate Brownstock Washer Efficiency

Kukreja V.K., Ray A.K., Singh V.P. & Rao N.J.

ABSTRACT:-- Brownstock washing has manifold effects in the pulp and paper industry. On one hand it produces clean pulp for paper making and on the other hand it separates black liquor solids (Na-salts and Lignin based solutes) from the pulp. Various type of expressions are available in the literature to assess the performance of a brownstock washer. These expressions are somewhat complex. Therefore these are not commonly practiced by the industry particularly the Indian pulp and paper industry. In this investigation some efficiency parameters are discussed. These parameters have been expressed in terms of simpler terms which can be readily measured like, porosity, inlet and outlet consistency, dissolved solids of various streams, fibre production rate and density. Some interrelations between various efficiency parameters have been established. A sample calculation based on industry data is given. Some common factors affecting the performance of a brown stock washer are also listed.

KEY-WORDS:-- *Dilution factor, Displacement ratio, Efficiency, Entrainment ratio, Equivalent displacement ratio, Modified Norden's efficiency factor, Norden's efficiency factors, Thickening factor, Wash ratio, Wash yield, Weight liquor ratio.*

INTRODUCTION

Removal of soluble impurities from the pulp by water/weak wash liquor is known as pulp washing. Pulp is washed mainly due to the following reasons:

(a) to obtain clean pulp for further processing,

(b) to recover expensive inorganic Na-salts in recovery section,

(c) to recover lignin based organic solutes for their heating values,

(d) to reduce consumption of bleaching chemicals in bleach plant,

(e) strict pollution regulations forbid the sewering of chemicals.

Ideally, there should be no overflow of black liquor solutes with the washed pulp and no overflow of fibres with the filtrate leaving the washing plant. Certainly these ideal stipulations can not be met in the industry. Hence, it is desirable that the pulp should be washed optimally, i.e., using minimum amount of water and with maximum removal of black liquor solutes.

Various equipments are used to wash the pulp namely, rotary vacuum washer, belt washer, pressure washer, fibrefuge washer, diffusion washer, screw press, pressure diffusion washer, wash press etc. A rotary vacuum multistage brownstock washer

Institute of Paper Technology (University of Roorkee)
SAHARANPUR (U.P.) 247001 INDIA

containing 3 to 4 stages is overwhelmingly preferred in India and abroad because of its simplicity in design and flexibility in operation.

Basic mechanism of brownstock washer consists of dilution, agitation, extraction and displacement. It is not possible to displace one volume of black liquor with one volume of water/weak wash liquor because the phenomenon of diffusion also takes place simultaneously. Hence, thorough cleaning can not be achieved in any industrial operation.

To predict the performance of a brownstock washer various mathematical expressions are available, which can be divided into two groups namely, macroscopic or qualitative and microscopic or quan-

Table-1.

Some filter washer performance parameters

Wash liquor usage parameters

Dilution factor (DF)	=	(Wash liquor entering-Liquor in washed pulp) / (O.D. ton of washed pulp)
Wash liquor ratio (WR)	=	(Wash liquor entering) / (Wash liquor leaving with washed pulp)
Weight liquor ratio (W)	=	(Filtrate liquor leaving the washer) / (Liquor entering with unwashed pulp)
Filter entrainment (FE)	=	((Feed liquor in washed pulp) (Dryness of pulp)) / (O.D. ton of washed pulp)

Solute removal parameters

Wash yield (Y)	=	(Dissolved solids removed) / (Dissolved solids entering)
Displacement ratio (DR)	=	(Actual reduction of dissolved solids) / (Maximum possible reduction of dissolved solids)
Thickening factor (TF)	=	(Liquor in stock entering – Liquor in washed pulp) / (Liquor in stock entering)
Solid reduction ratio (SR)	=	(Solid contents in the liquor of the washed pulp) / (Solid contents in the liquor in the blown pulp)

Efficiency parameters

Efficiency (%E)	=	Percentage of black liquor solids removed
Norden's efficiency factor (E)	=	Number of ideal (hypothetical) stages in series required to achieve same departing stream flows and concentrations as in the case of actual washing system or single washer
Modified Norden's efficiency factor (E_{st})	=	Number of ideal countercurrent mixing stages equivalent to a washing system operating at standardized discharge consistency (10-12%).
Equivalent displacement ratio (EDR)	=	Displacement ratio of actual washer is compared with a hypothetical one operating at standard inlet consistency of 1% and outlet of 12%.

titative and the third is semi quantitative approach. Complete mathematical models of various zones have been reported by Kukreja et al. [1, 2].

According to Smook [3], washing efficiency of 99% is usually equivalent to carry over of about 6 to 9 kg/BDT of washable equivalent salt cake. If total salt cake losses are to be calculated, then chemically bound salt cake must also be considered. It has been reported that at least 1 kg of Chlorine is consumed for each 1-2 kg of black liquor solids. Thus a 35 kg loss (app. 20 kg of Na_2SO_4/Ton of pulp) would use up at least a similar amount of Cl_2 per year in a 500 TPD bleach plant. Cullinan [5] has shown that soda loss (as Na_2SO_4) is a linear function of COD.

It is important to mention here that previous investigators have put forward different type of definition for a particular parameter and therefore same results can not be obtained even for same input and output conditions of a washer. Therefore it is very much necessary to identify the parameters and to have the interrelation among different parameters defined by previous investigators. In this paper an attempt is made to correlate various input and output parameters and to find out some sort of interrelationship between them.

PERFORMANCE PARAMETERS

The expressions suggested by previous investigators to predict the brownstock washer efficiency range from very simple to rather complex equations. These can be classified as follows,

(a) wash liquor usage parameters
(b) solute removal parameters
(c) efficiency parameters

These parameters are categorized and defined in TABLE 1. To understand the basic definition of different terms various streams entering and leaving a stage of a brownstock washer are shown in Figure 1.

The parameters of TABLE 1 are explained in terms of symbols in this section. Value of any parameter for any stage can be found out by giving different values to j (j=1,2,3,).

Dilution factor :

$$DF_j = [L_s-L_d]_j = [1+V_w\rho/P_f)-100/C_{yd})]_j \quad (1)$$

$$= [(C_i-C_d)\ \varepsilon_t\rho/\{(\overline{C}-C_s)\ (1-\varepsilon_t)\rho_{fib}\}+(C_{yd}-100)/C_{yd}]_j \quad (2)$$

Where,

$$\overline{C}=C_s+(1/t_w)\left[\int_0^{L/u}(C_i-C_s)\ Idt + \int_{L/u}^{t_w}(C_i-C_s)\ Idt\right]$$

for $0<t<L/u$, $I=1$

for $L/u<t<tw$,

$$I=(1/2)\ [1+erf(\sqrt{\xi}-\sqrt{\tau})]-e^{-}(\xi+\tau)\ Io(2\sqrt{\xi\tau})/\ [1+(\xi/\tau)^{1/8}]$$

$\xi = k\varepsilon_sL/\varepsilon_du$, $\tau= (k/u)\ (ut-L)$, erf= Error function

Wash liquor ratio:

$$WR_j =[L_s/L_d]_j =[V_w\rho\ C_{yd}/\ \{P_f\ (100-C_{yd})\}]_j \quad (3)$$

$$=[\{(C_i-C_d)\ \varepsilon_tC_{yd}\rho\}/\{(\overline{C}-C_s)\ (1-\varepsilon_t)\ (100-C_{yd})\ \rho_{fib}\}]_j \quad (4)$$

Weight liquor ratio:

$$W_j= [L_f/\ L_i]_j \quad (5)$$

Where $L_i = \{(100-C_{yi})\ /\ C_{yi}$, $L_f=L_i+DF$

Filter Entrainment:

$$FE_j = [L_d\ (1-DR)\ m]_j \quad (6)$$

where $L_d = \{(100-C_{yd})/C_{yd}\}$

Wash yield:

$$Y_j = \{L_f\ X_f\ /\ L_i\ X_i]_j \quad (7)$$

Displacement ratio:

$$DR_j = [(X_i-X_d)/\ (X_i-X_s)]_j \quad (8)$$

$$= [\{(C_i/\rho_i) - (C_d/\rho_d)\}\ /\ \{(C_i/\rho_i) - (C_s/\rho_s)\}]_j \quad (9)$$

By assuming that the density of all streams is same, i.e.,

$$\rho_i = \rho_s = \rho_d$$

$$DR_j = [(C_i-C_d)/\ (C_i-C_s)]_j \quad (10)$$

$$= [1-(\varepsilon_s/\varepsilon_d)\ exp\ [(k\eta\varepsilon_tL^2/\ K\Delta P)\ \{1-(V_w/\varepsilon_dNAL)\}]]_j \quad (11)$$

Thickening factor:

$$TF_j = [(L_p-L_d)/\ L_p]_j \quad (12)$$

Solid reduction ratio:

$$SR_j = [X_d/X_p]_j \quad (13)$$

Solid reduction ratio of the whole system can be found as,

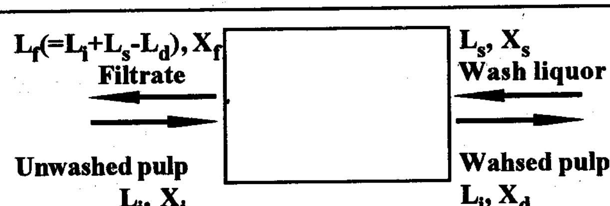

Figure 1 : A single stage brownstock washer

$$SR = X_c / X_b \tag{14}$$

Efficiency:

$$\%E_j = [1-\{(C_d-C_s)/(C_i-C_s)\}(\rho_i/\rho_s)\{(100-C_{yd})/(100-C_{yi})\}]_j \, 100 \tag{15}$$

By assuming that $\rho_i = \rho_s = \rho_d$,

$$\%\,E_j = [1-\{(C_d-C_s)/\,(C_i-C_s)\}\,\{100-C_{yd})/\,(100-C_{yi})\}]_j \, 100 \tag{16}$$

According to Smook [3], $\%\,Ej = [TF+(1-TF)\,DR]_j 100$ (17)

According to Luthi [4], $\%\,Ej = [(L_pX_p-L_dX_d)/\,L_pX_p]_j 100$ (18)

% efficiency of the whole system ($\%E_0$) can be calculated as,

$$\%\,E_0 = [(L_bX_b-L_cX_c)/\,L_bX_b]100 \tag{19}$$

Alternatively it can also be found as,

$$\%\,E_0 = [1-(1-DR_1)\,(1-DR_2)\,(1-DR_3)]\,100 \tag{20}$$

The suffix 1, 2, 3 indicates the DR of that stage.

Norden's efficiency factor:

$$E_j = [\log\,\{L_i\,(X_i-X_f)/\,L_d\,(X_d-X_s)\}/\,\log\,(L_s/L_d)]_j \tag{21}$$

Norden efficiency factor (NEF) of the entire system can be found by adding NEF of the each individual stage.

Modified Norden's efficiency factor:

$$[E_{st}]_j = [\log\,\{L_i\,(X_i-X_f)/\,L_d(X_d-X_s)\}/\,\log\,\{1+(DF/L_{st})\}]_j \tag{22}$$

where, $L_{st} = (100-C_{yst})/\,C_{yst}$

Total Modified Norden's efficiency factor of the whole washing system is the sum of the E_{st} value of each individual stage.

Equivalent displacement ratio:

$$(1-EDR)_j = [(1-DR)\,(DCF)\,(ICF)]_j \tag{23}$$

where, $DCF = L_d/\,7.333$

$ICF = [99\,(L_i+DF)]/\,[L_i(99+DF)-L_d(99-L_i)(1-DR)]$

for dilution extraction washers $ICF = 99/(99+DF+L_d)$

The above definition or terms can be used for either a single stage of a multistage washer. However, for multistage, material balance calculations are prerequisite for evaluation of different parameters, The general material balance equations and the procedure for estimation are discussed below.

Material Balances :

This method is widely practiced by the industry people around the globe to determine the amount of soda loss during the washing operation. This method serves well despite being an approximate one. The quantity of the solutes adsorbed on the fibres, i.e., chemically bound solute can not be found by this method. Material balances around three washers are explained with the help of Figure 2.

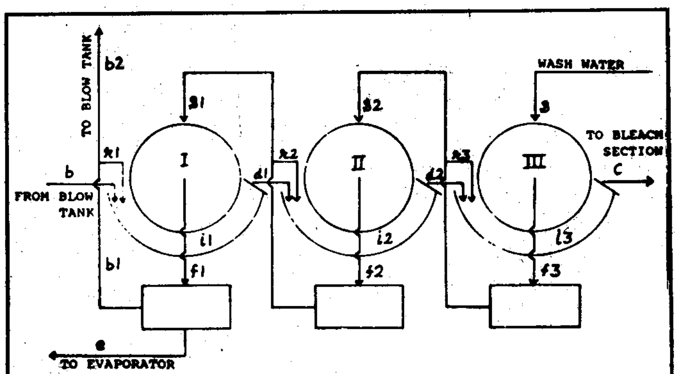

Figure 2 : A brownstock washing system

First washer mass balance

Liquor : $L_b+L_{r1}+L_{s1} = L_{f1}+L_{d1}$,

$L_{f1} = L_{b1}+L_e$, $L_{b1} = L_{b2}+L_{r1}$, $L_{i1} = L_{r1}+L_b$

Solids : $L_bX_b+L_{r1}X_{r1}+L_{s1}X_{s1} = L_{f1}X_{f1}+L_{d1}X_{d1}$

$L_{f1}X_{f1} = L_{b1}X_{b1}+L_eX_e$, $L_{b1}X_{b1} = L_{b2}X_{b2}+L_{r1}X_{r1}$,

$L_{i1}\,X_{i1} = L_{r1}X_{r1} + L_bX_b$

Fibre : $L_bC_{yb} = L_{d1}C_{yd1}$

Water : $L_b(1-C_{yb})\,(1-X_b)+L_{r1}\,(1-X_{r1})+L_{s1}(1-X_{s1})$

$= L_{f1}(1-X_{f1})+L_{d1}(1-C_{yd1})\,(1-X_{d1})$

Second washer mass balance

Liquor : $L_{r2}+L_{d1}+L_{s2} = L_{f2}+L_{d2}$,

$L_{f2} = L_{r2}+L_{s1}$, $L_{i2} = L_{r2} + L_{d1}$

Solids : $L_{r2}X_{r2}+L_{d1}X_{d1}+L_{s2}X_{s2} = L_{f2}X_{f2}+L_{d2}X_{d2}$,

$L_{f2}X_{f2} = L_{r2}X_{r2}+L_{s1}X_{s1}$, $L_{i2}X_{i2} = L_{r2}X_{r2}+L_{d1}X_{d1}$

Fibre : $L_{d1}C_{yd1} = L_{d2}C_{yd2}$

Water : $L_{d1}\,(1-C_{yd1})\,(1-X_{d1})+L_{r2}\,(1-X_{r2})+L_{s2}\,(1-X_{s2})$

$= L_{f2}\,(1-X_{f2})+L_{d2}\,(1-C_{yd2})\,(1-X_{d2})$

Third washer mass balance

Liquor : $L_{r3}+L_{d2}+L_s = L_{f3}+L_c$,

$L_{f3} = L_{r3}+L_{s2}$, $L_{i3} = L_{r3}+L_{d2}$

Solids : $L_{r3}X_{r3}+L_{d2}X_{d2}+L_sX_s = L_{f3}X_{f3}+L_cX_c$,

$L_{f3}X_{f3} = L_{r3}X_{r3}+L_{s2}X_{s2}$, $L_{i3}X_{i3} = L_{r3}X_{r3}+L_{d2}X_{d2}$

Fibre : $L_{d2}C_{yd2} = L_cC_{yc}$

Water : $L_{d2}\,(1-C_{yd2})\,(1-X_{d2})+L_{r3}\,(1-X_{r3})+L_s\,(1-X_s)$

$= L_{f3}\,(1-X_{f3})+L_c\,(1-C_{yc})\,(1-X_c)$

RELATIONSHIP BETWEEN EFFICIENCY PARAMETERS

Relation between DF and WR:

$$DF=\{(100-C_{yd})/C_{yd}\}\,(WR-1)$$

If volume of the shower liquor is equal to the volume of the liquor leaving with washed pulp, i.e., when WR=1, DF=0.

Relation between DR and %E :

$$\%E=[1-(1-DR)\ \{(100-C_{yd})/(100-C_{yi})\}]100$$

When the actual reduction of dissolved solids is equal to the maximum possible reduction of dissolved solids, i.e., when DR=1 then %E=100%. But. this is an ideal condition only.

Relation between %E and WR :

$$\%E=\left[1-\left[1-\frac{(\bar{C}-C_s)\ (1-\varepsilon_t)\ (100-C_{yd})\ \rho_{fib}}{(C_f-C_s)\ \varepsilon_t C_{yd}\rho}\ WR\right]\frac{\rho_f\ (100-C_{yd})}{\rho_s\ (100-C_{yi})}\right]100$$

Relation between W and WR :

Weight liquor ratio relates the filtrate flow rate to the liquor entering with unwashed pulp. When the discharge consistency is same through the washers. W and WR are approximately equal. provided the changes in the liquor densities are small.

Relation between EDR, WR and E_{st} :

For displacement washing EDR and E_{st} can be related as (Luthi[4]),

$$EDR=1-[(WR-1)/\{WR(E_{st}+1)-1\}]$$

SIMULATION OF THE MODEL

Efficiency parameters of this investigation have been simulated by using the data of Luthi [4]. In Table 2 the data of a typical 3 stage countercurrent brownstock washing system is given. By using this ~~data the value of different paremeters for each~~ washer is calculated and then the overall % efficiency, NEF and MNEF of the system is obtained. Output data is given in Table 3.

Table-2.

Data for estimation of efficiency parameters

Input parameters		Washer 1	Washer 2	Washer 3
Vat consistency	(%)	1.500	4.000	1.000
Discharge consistency	(%)	13.000	14.000	11.000
Solids in vat	(%)	13.986	4.352	0.911
solids in shower liquor	(%)	3.801	0.866	0.000
Solids in filtrate	(%)	13.348	3.801	0.866
solids in discharged pulp	(%)	5.932	1.587	0.226
solids in recycled liquor	(%)	13.348	3.801	0.866
Amount of vat liquor	(Kg/Kg)	65.667	24.000	99.000
Amount of shower liquor	(Kg/Kg)	9.692	9.143	11.091
Amount of filtrate liquor	(Kg/Kg)	68.667	27.000	102.000
Liquor in discharged pulp	(Kg/Kg)	6.692	6.143	8.091
Amount of recycled liquor	(Kg/Kg)	56.667	17.308	92.857

Blow consistency = 10%. Solids in blow liquor = 18%
Amount of liquor in the blow = 9 Kg/Kg
Standardized consistency C_{yst} = 12%

Table-3.

Value of some efficiency parameters

Parameters	Washer 1	Washer 2	Washer 3	Eq
Dilution factor	3.000	3.000	3.000	1
Wash liquor ratio	1.448	1.488	1.371	3
Weight liquor ratio	1.046	1.125	1.030	5
Entrainment ratio	1.399	1.272	2.006	6
Wash yield	0.998	0.983	0.979	7
Displacement ratio	0.791	0.793	0.752	8
Thickening factor	0.256	0.082	-0.317	12
Solid reduction ratio	0.329	0.268	0.142	13
% Efficiency	84.450	84.848	67.338	17
% Efficiency	75.496	75.442	81.243	18
NEF	2.911	2.752	2.822	21
MNEF	3.142	3.189	2.597	22
EDR	0.805	0.802	0.726	23
% Efficiency of the entire system	= 98.871			19
% Efficiency of the entire system	= 98.927			20
NEF of the entire system	= 8.485			
MNEF of the entire system	= 8.928			

CONCLUSIONS

An attempt has been made to list performance parameters proposed by various investigators. In some cases corresponding quantitative expressions have also been reported (Kukreja et al.[2]). These expressions are developed in terms of simple variables and can also take into account the parameters like. dispersion. diffusion. porosity and permeability. which are influenced by the nature of pulp fibres.

Simulation of the model has been carried out by taking the actual mill data reported by Luthi [4] of 3 counter current brownstock washers. First of all the efficiency of each individual brownstock washer is calculated and then the efficiency of a battery of 3 washers is calculated. Parameters like NEF and MNEF are also calculated for the entire system consisting of 3 washers.

The present model can be used to measure the change in the efficiency parameters by changing the amount of dilution factor. wash water and input & output consistency of pulp. Thus the model can be gainfully utilized for the control and evaluation of washing losses. which are of ultimate importance to the industry.

These efficiency parameters can be used to evaluate the brownstock washing performance parameters for industry and also to design a battery of washers for a new plant.