The Techno-Economic Factors of Brownstock Washing on Dorr-Oliver Brownstock Washers

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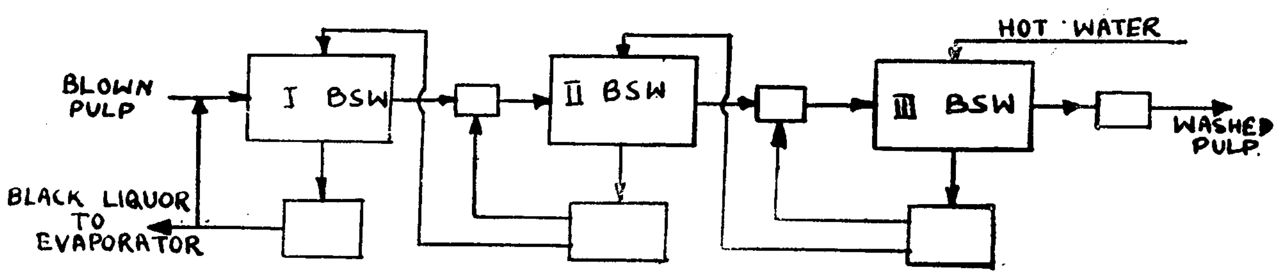
Introduction :

The Process Engineers connected with the production of pulp are familiar with the use of Rotary Vacuum Filters for the purpose of washing and thickening of pulp at various stages of processing in integrated pulp and paper mills all over the world. The Dorr-Oliver Brownstock Washers enjoy a very good reputation in this area, and the efficiency with which they perform, has been widely acknowledged. It is the purpose of this Paper to illustrate with the help of detailed calculations the techno-economic aspects of different systems formed by the variations in process variables and the number and type of washing filters. It is hoped that engineers connected with planning and expansion of pulp mills would find this paper of some use in evaluating their balancing equipment requirements.

The Underlying Principle of Displacement Washing :

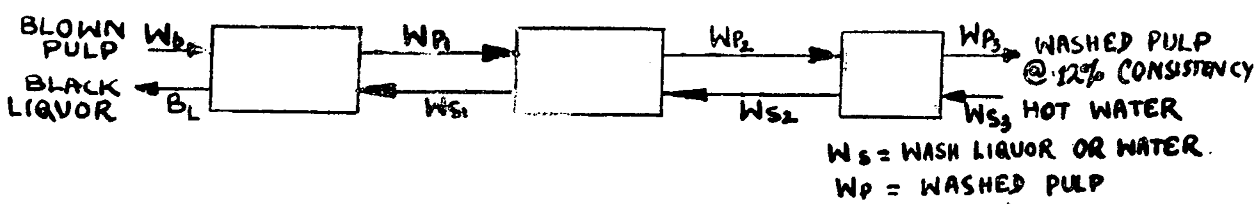
The washing of brown pulp as is normally practised on Dorr-Oliver Brownstock Washers is a continuous counter-current steady-state process with no accumulation of materials at any stage in the system. The main purpose of the Brownstock Washing equipment is to wash pulp free of dissolved solids and recover alkali charged to the digesters to the maximum possible extent. The concentration of the dissolved solids in the black liquor obtained from the subsequent stages decreases but the same remains constant over a period of time when the process variables are established and steady state has been attained. It is, therefore expected by the Net Flow Principle that the net transfer of materials for any stage is the same. This fundamental principle is further elucidated with the help of the following diagram :

Fig. 1



The above system can be simplified by ignoring recirculation strams as follows

Fig. 2



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From the above diagram the following facts emerge :—

[Pulp Balance]

(1) As the wash stream is free of pulp :
$W_h \times X_b = W_{p1} \times X_{p1} = W_{p2} \times X_{p2} = W_{p3} \times X_{p3}$
Now $X_{p1} = X_{p2} = X_{p3} = 0.12$ = Consistency of Pulp
Therefore $W_{p1} = W_{p2} = W_{p3}$ = Advancing Pulp Stream.

(2) By net flow priciple : [Liquor Balance].
$B_1 - W_b = W_{s1} - W_{p1} = W_{s2} - W_{p2} = W_{s3} - W_{p3}$
Or. $W_{s1} = W_{s2} = W_{s3}$ = Feedback Stream.

(3) By net flow principle : (Soluble Balance)

The difference in the amount of black liquor solids between the advancing and feedback streams is constant. Thus—

= Black liquor solids in W_{s3} + Black liquor solids in W_{p3}

= Black liquor solids in W_p − Black liquor solids in W_{s1}

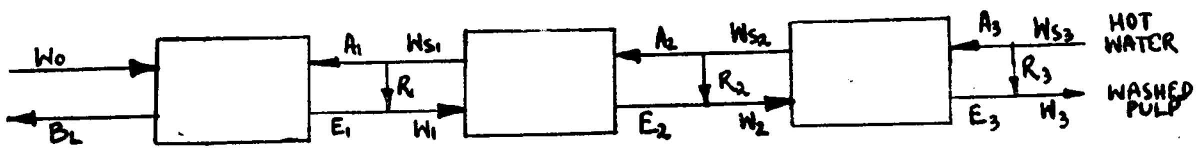
= Black liquor solids in W_{p1} − Black liquor solids in W_{s1}

= Black liquor solids in W_b − Black liquor solids in B_1

The Concept of Filter Entrainment :

The entrainment is the term used for the carry-over of Black Liquor of the same concentration as present in the Vat. in the Washed Pulp mat. By the application of wash on the filter drum, we are able to displace the entrained black liquor which passes out as a filtrate from each stage. However, the displacement of the liquor is never complete and there is always a certain amount of black liquor entrained in the pulp mat. This undisplaced black liquor of concentration identical to that in the vat is termed as the entrainment. Theoretically, by using 7.33 lbs. of wash water it should be possible to displace all the black liquor in the pulp mat (based on 12% consistency). However, due to inefficiencies inherent in the displacement washing, the washed pulp mat always contains some entrainment. It is difficult to estimate theoretically the amount to entrainment in the pulp, although data have been obtained from actual plant operations. As a result of entrainment, certain amount of wash liquor passes out as filtrate without displacing the Black Liquor. Further, the part of the wash liquor remains in the pulp mat and thus returns to the stage from which it originated. Thus, a part of the wash liquor (equivalent to the amount of black liquor displaced) is always recycled to the subsequent stage. For the purpose of calculations the process outlined in Fig. 2 can be further simplified as follows :—

Fig 3



Where, A_1, A_2. A_3 = Net Wash Liquor proceeding ahead from Stage N to Stage N − 1.

E_1, E_2, E_3 = Amount of Black Liquor entrained in the pulp mat.

R_1, R_2, R_3 = Recycled Wash Liquor.

W_1, W_2, W_3 = Amount of Liquor contained in the pulp mat.

The complete Brownstock Washing System can now be illustrated as follows :

It would be clear from the above, that,

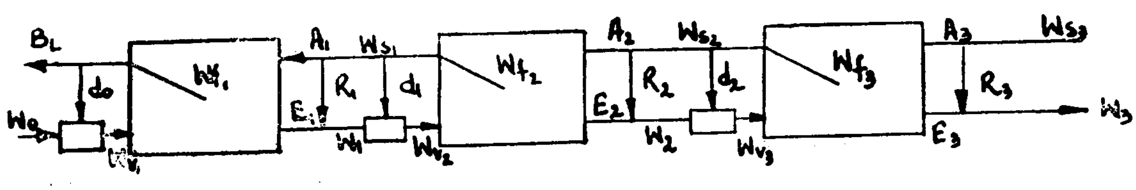
$Wsi = Ai + Ri$

$Wi = Ei + Ri$

But $Wsi - Wi = Ws3 - W3$ = Amount of Hot Water − amount of Water in the Pulp.
= Dilution Factor = D.

Therefore $Wsi - Wi = Ai + Ri - Ei - Ri = D$
or $Ai = Ei + D$

Fig. 4



Nomenclature :

BL = Black Liquor sent for recovery/lb. of pulp.

Wo = Blown pulp liquor/lb. of pulp (6.25 when consistency is 13.8%).

d_0, d_1, d_2, d_3 = Part of the filtrate used for dilution of pulp in feed box and repulpers.

Wv1, Wv2, Wv3 = Vat liquor/lb. of pulp (99 when consistency is 1%)

E1, E2, E3 = Amount of vat liquor entrained in pulp sheet/lb. of pulp.

Wf1, Wf2, Wf3 = Filtrate/lb of pulp.

A1, A2, A3 = Net wash liquor lb of A.D. Pulp.

R1, R2, R3 = Recycled wash lb of A.D. Pulp.

Ws_1, Ws_2, Ws_3 = Wash liquor/lb. of A.D. Pulp.

W_1, W_2, W3 = Total liquor in the pulp sheet/lb. of pulp (7.33 when consistency is 12%)

D = Dilution factor = lb. of wash water/lb of pulp.

By the net flow principle :

Assuming D = 3 ;

Wfi = Wvi + D = 99 + 3 = 102

Wsi = Wi + D = 7.33 + 3 = 10.33

Ai = Ei + D = Ei + 3.

B_1 = Wo + D = 6.25 + 3 = 9.25

Solubles Balance :

Having analysed the various streams and flow quantities, we are now in a position to determine the Soda Losses and the soluble concentrations in various streams. Let us define the soluble concentrations as follows :

S_b = Dissolved solids in blown pulp/lb. of A.D. Pulp.

S_{vi} = Dissolved solids/lb of A.D. Pulp in vat liquor (i = 1,2,3 for first, second and third stage resp.)

S_{Ai} = Dissolved solids/lb. of A.D. Pulp in wash stream.

Sfi = Dissolved solids/lb. of A.D. Pulp in filtrate stream.

Spi = Dissolved solids/lb. of A.D. Pulp in the washed pulp.

S_E i = Dissolved solids due to entrained black liquor in pulp sheet/lb. of A.D. Pulp.

Now $S_p 3 = S_E 3 = X$ lbs. of dissolved solids/lb of A.D. Pulp.

$S_A 3 = 0$

Therefore $S_E 3 - S_A 3 = X$ ...(1)

Hence by the net flow principle,

$-Sfi + Sri = X$ ...(2)

$S_E i - S_A i = X$ ...(3)

$S_b - S_{BL} = X$ ...(4)

The above equations are of great use in the analysis of the Brownstock Washing calculations.

Sample Calculation :

Data :

(1) $E_1 = E_2 = E_3 = 2.0$

(2) D = 4.0

(3) Wv = 99.0

(4) Wf = 99 + 4 = 103.0

(5) Wo = 6.25

(6) Wsi = Ws2 = Ws3 = 10.33

(7) A1 = A2 = A3 = 4 + 2 = 6.0

(8) $S_E 3 = X$

(9) N = No. of stages = 3.0

Starting from the third stage BSW ;

$S_E 3 = X$

$\therefore \frac{Sv3}{99.0}$ = Dissolved solids concentration in Vat liquor.

$\frac{SE3}{2.0}$ = Dissolved solids concentration in entrained vat liquor in the pulp sheet.

$$\therefore \frac{Sv3}{99} = \frac{S_{E3}}{2.0} = \frac{X}{2.0}$$

$$\therefore S_v 3 = \frac{99}{2.0} \times X = 49.5\,X$$

$$\therefore S_f 3 = S_v 3 - X = 48.5\,X$$

Again, for the second stage BSW ;

$\frac{S_A 2}{6.0}$ = dissolved solids concentration = $\frac{48.5\,X}{103}$

$$\therefore S_A 2 = \frac{6}{103} \times 48.5X = 2.83X$$

$$\therefore S_E 2 = S_A 2 + X - 3.83X$$

$$\therefore \frac{S_V 2}{99} = \frac{S_E 2}{2.0} = \frac{3.33X}{2.0}$$

$$\therefore S_V 2 = \frac{99}{2} \times 3.83X = 189X$$

$$\therefore S_f\ 2 = S_v\ 2 - X = 188X$$

Now for the First Stage BSW ;

$$S_A 1 = \frac{6.0}{103} \times \frac{188X}{1} \times 11X$$

$$S_E L = 11X + X = 82X$$

$$S_v\ 1 = \frac{99}{2} \times S_E 1 = \frac{99}{2} \times \frac{12X}{1} = 594X$$

$$S_f\ 1 = 593X$$

Now BL = 10.2s; and $\frac{SBL}{BL} = \frac{S_f 1}{103}$

$$\therefore SBL = \frac{10.25}{103} \times \frac{593X}{1} = 59.3X$$

$$\therefore SB = 59.3X + X = 60.3X$$

Thus the amount of dissolved solids entering the Brownstock Washing System is 60.3X. while the amount of solids leaving System is X.

Hence % loss $= \frac{X}{60.3X} \times 100 = 1.66\%$

The logical arguments used in the above calculations can be extended further for any member of stages and these calculations have been carried out for different values of N, D and E. The charts indicating the % losses for different values of N, D and E are given below :—

TABLE A

Dilution Factor :			% Losses 2	3	3	5
E	=	1.0				
N	=	2.0	3 05%	2.25%	1.74%	1.49%
N	=	3.0	0.97%	0.54%	0.355%	0.236%
N	=	4.0	0.325%	0.142%	0.0735%	0.0415%
N	=	5.0	0.111%	0.037%	0.0152%	0.0072%

TABLE B

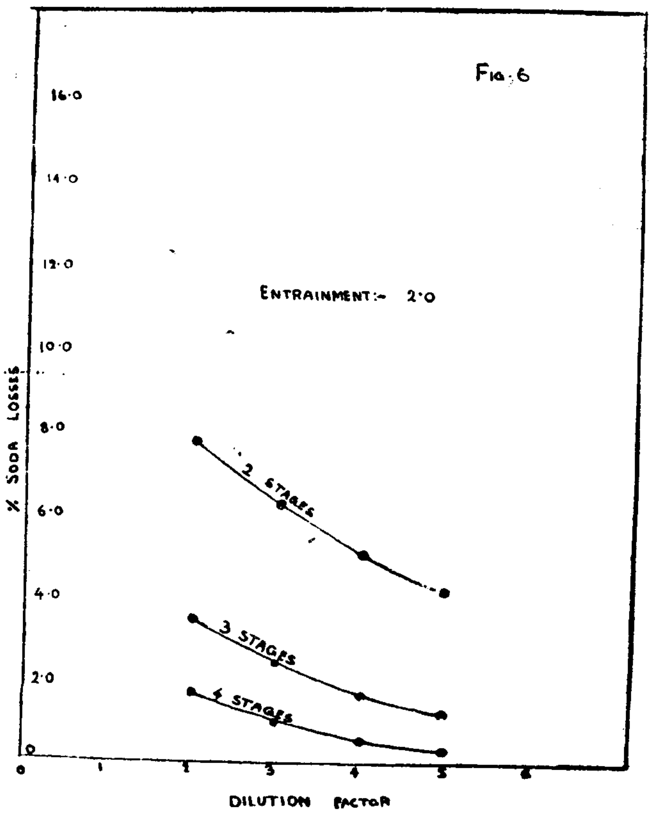
E	=	1.35				
N	=	2.0	4.65%	3.95%	2.8%	2.26%
N	=	3.0	1.74%	1.18%	0.72%	0.495%
N	=	4.0	0.68%	0.375%	1.87%	0.109%
N	=	5.0	0.28%	0.120%	0.049%	0.024%

TABLE C

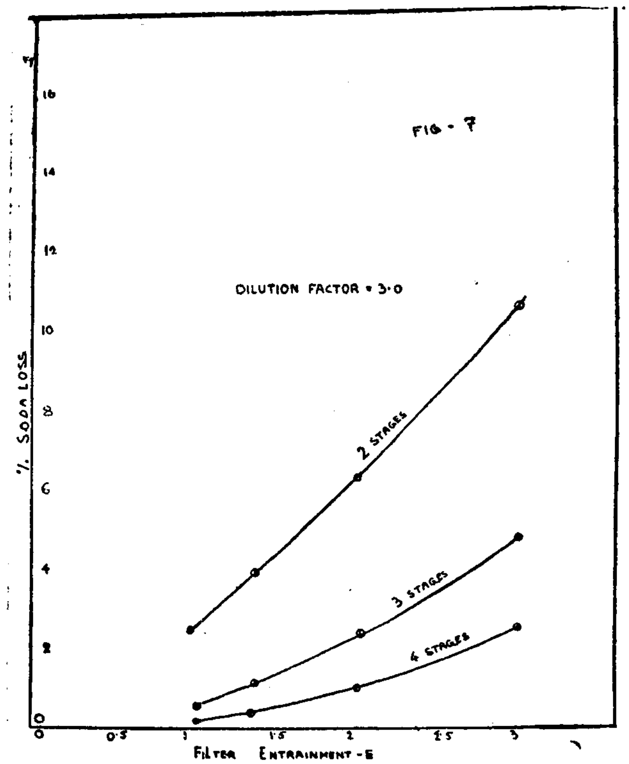
E	=	2.0				
N	=	2.0	7.8%	6.25%	5.50%	4.2%
N	=	3.0	3.52%.	2.40%	1.66%	1.22%
N	=	4.0	1.70%	0.96%	0.57%	0.361%
N	=	5.0	0.85%	0.39%	0.196%	0.11%

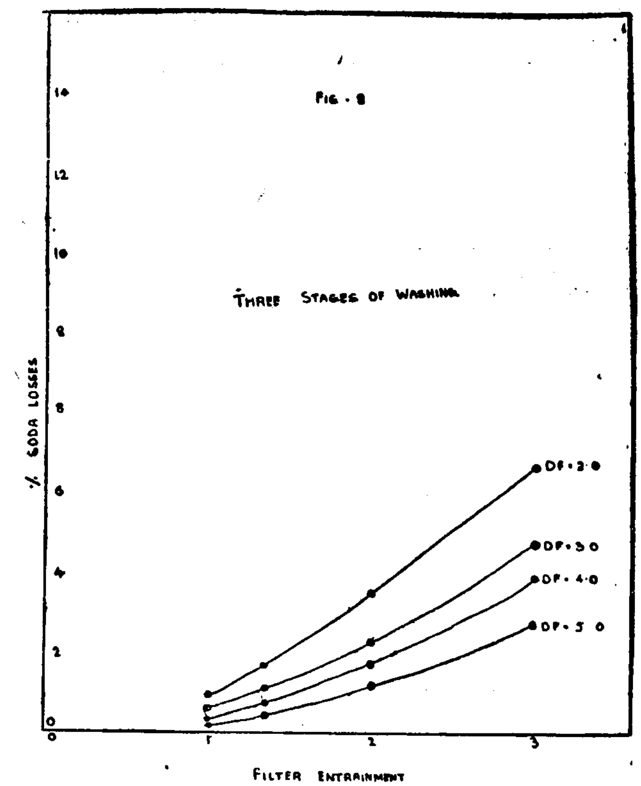
TABLE D

E	=	3.0				
N	=	2.0	[illegible]	[illegible]	8.8%	7.45%
N	=	3.0	6.6%	4.76%	3.95%	2.78%
N	=	4.0	3.69%	2.88%	1.70%	1.08%
N	=	5.0	2.16%	1.21%	0.75%	0.42%



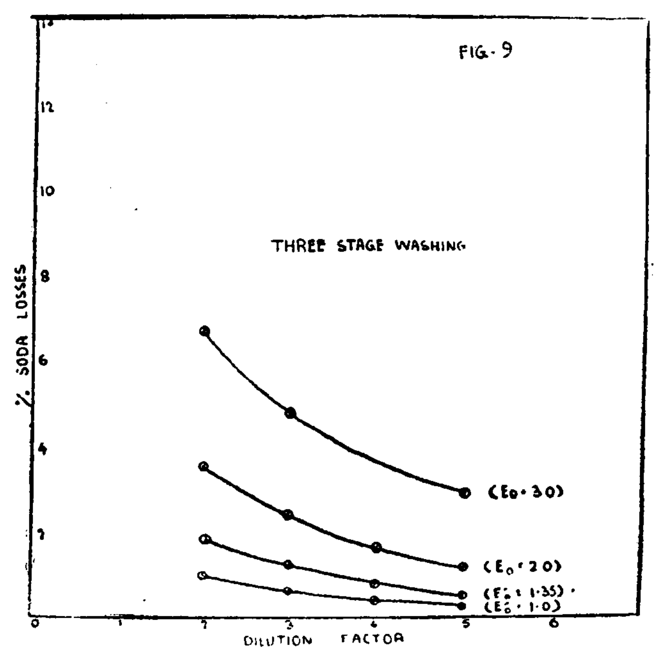
Soda losses as indicated in the above chart could be reduced by reducing entrainment or by increasing number of stages and/or dilution factor.





The entrainment however is a characteristic property of the Rotary Vacuum Filter for a definite raw material and as much it may not be possible to reduce E. Consequently we can improve the performance of the Brownstock Washing System either by increasing the number of stages or by increasing the dilution factor. It may however be noted that by increasing the value of D, we invariably end up with a dilute black liquor which means an increased load on the Evaporators and ultimately an increase in the operating cost. Further the savings resulting from the increase in dilution factor beyond a certain value are negligible and do not justify the increased operating costs resulting from the increase in steam consumption.

Another look at the chart given above would immediately indicate the substantial savings resulting from the decreased soda losses for the same value of dilution factor and entrainment by installing an additional Brownstock Washer e.g. the overall efficiency increase from 93.75% to 97.6% by adding one Brownstock Washer to a two stage Washing System, when E = 2.0 and D = 3.0.



For a 100 MTD Pulp Mill, this would mean a gross savings of,

$$\therefore Y = \frac{(6.25 - 2.40)}{100} \times \frac{(\text{Tons of } Na_2SO_4 \text{ in cooking liquor}) \times 100}{\text{Tons of A. D. Pulp}}$$

Assuming that the amount of alkali charged is equivalent to 1.19 M Ton of Na_2SO_4 per A.D. ton of pulp

$$\therefore Y = \frac{3.85}{100} \times \frac{1.19}{1} \times 100 = 4.55 \text{ MTD of } Na_2SO_4$$

$\therefore$ Money saved per year = 4.55 × 330 × 600 = Rs. 900,000/-.

It would be therefore, obvious from the above example that the savings resulting from the increase in number of stage could be substantial.

Optimization of Performance:

A. Balancing Savings against Capital Cost:

Although the increase in number of stages would always fetch more and more grosssavings, one has to also consider the additional capital investment and the losses resulting from depreciation, maintenance and repairs on machinery and such other expenses. Depending on the plant capacity and the cost of the machinery and utilities one can always arrive at the most profitable system which would give an optimum performance. An attempt in this direction has already been made and the results are given in the chart below. The results are obtained on the basis of the following data :—

(1) 330 working days in a year

(2) Price of Na_2SO_4 = Rs. 600/ton.

(3) Depreciation @ 15% on the installed capital cost.

(4) Maintenance & Repairs @ 10% on the installed capital cost.

(5) Insurance & Taxes @ 5% on the installed capital cost.

(6) Electricity @ Rs. 4.0/100 H.P. Hours.

(7) Steam @ Rs. 5/ton.

(8) Capital expenditure for an additional stage as follows :—

No.	Pulp Mill Capacity	Capaital Expenditure in Rs. for one Stage
1	100 MTD	395,000/-
2	75 MTD	360,000/-
3	50 MTD	330,000/-
4	30 NTD	300,000/-

*These figures are given for a Bamboo Pulp Mill.

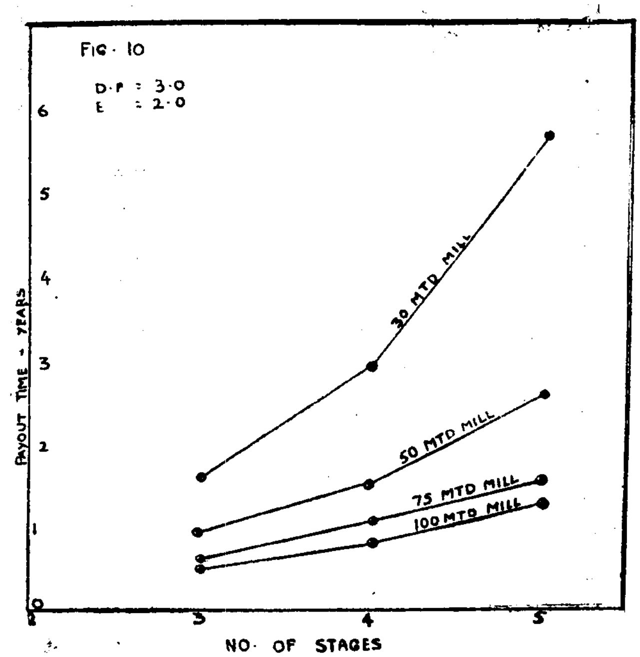
Payout Time (the number of years required to realise the cost of additional Brownstock Washing Stages) for Pulp Mills of different capacity :—

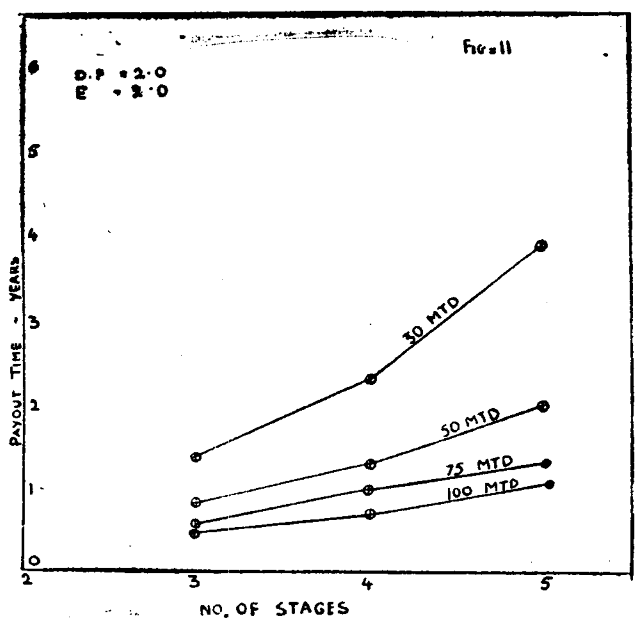
No.	Plant Capacity	*Payout Time (Years)		
		†3 Stage Washing	4 Stage Washing	5 Stage Washing
1	100 MTD	0.525	0.84	1.28
2	75 MTD	0.645	1.06	1.58
3	50 MTD	0.940	1.54	2.55
4	30 MTD	1.620	2.95	5.70

*D. F. =3.0 & E=2.0
†Existing no. of Stages - 2.0.

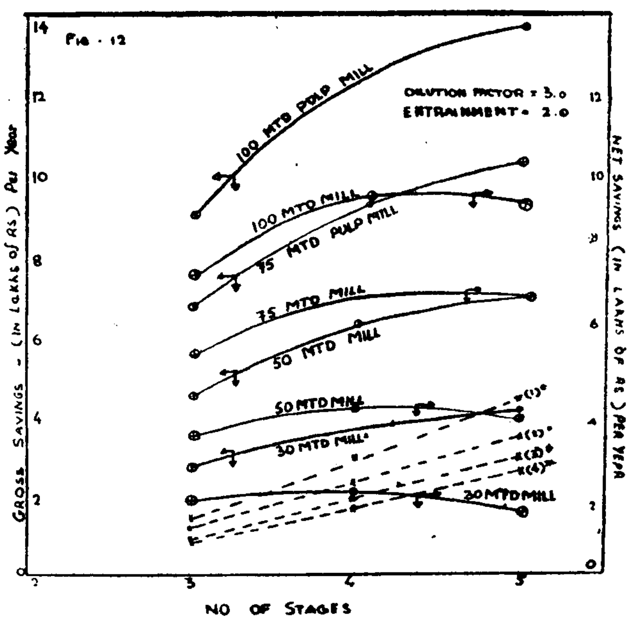
No.	Plant Capacity	*Payment Time (Years)		
		†3 Stage Washing	4 Stage Washing	5 Stage Washing
1	100 MTD	0.461	0.695	1.010
2	75 MTD	0.571	0.975	1.240
3	50 MTD	0.820	1.280	1.930
4	30 MTD	1.380	2.275	3.850

*D.F.=2.0 & E= 2.0.
† Existing no. of Stages = 2.0.





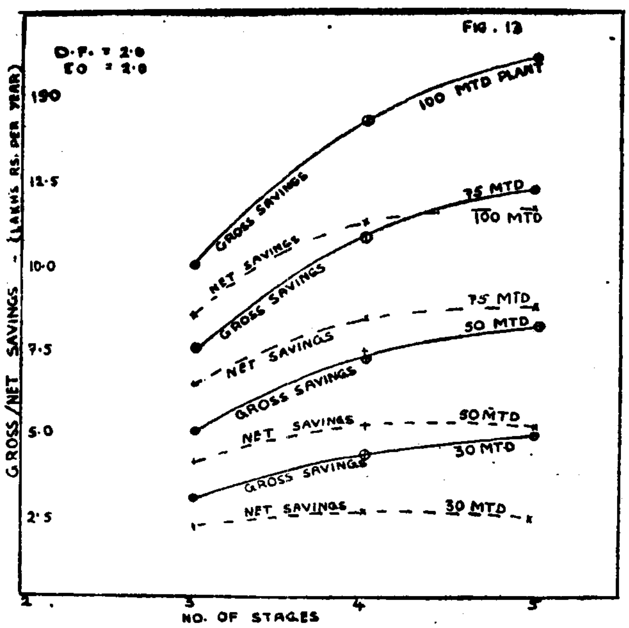
It would be clear from the above that the installation of an additional Brownstock washer to the existing 2 stage Brownstock Washing System is by far the most profitable proposal, as the payout time is as low as 7 months, for a 100 MTD plant. From the considerations of the payout time, even the installation of two additional stages appear highly profitable, as the payout time is again as low as 10-11 months. Another interesting fact emerging from the above figures is that variation of payout-time with respect to the plant capacity. The installation of an additional stage is much more profitable when the plant capacity is 100 MTD or higher. Thus the capacity of a plan has a great influence on the machinery requirements. The influence of the plant capacity and the number of washing stages on the overall profitability of the System has been clearly indicated in Fig. 11 and 12. It is of interest to note that the savings are optimum when the total number of stages are four.

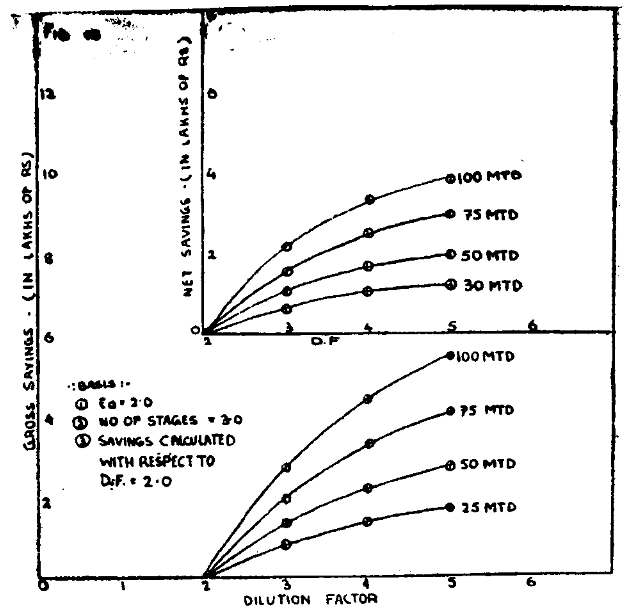


* CURVES (1) TO (4) GIVE TOTAL ADDITIONAL EXPENSES FOR 100, 75, 50 AND 30 MTD PULP MILLS.

B. Balancing Savings against Evaporation Costs:

It has already been pointed out earlier that higher dilution factor yields higher savings, other things remaining constant. There is however a limit beyond which one cannot increase the value of dilution factor because of the following two factors:—





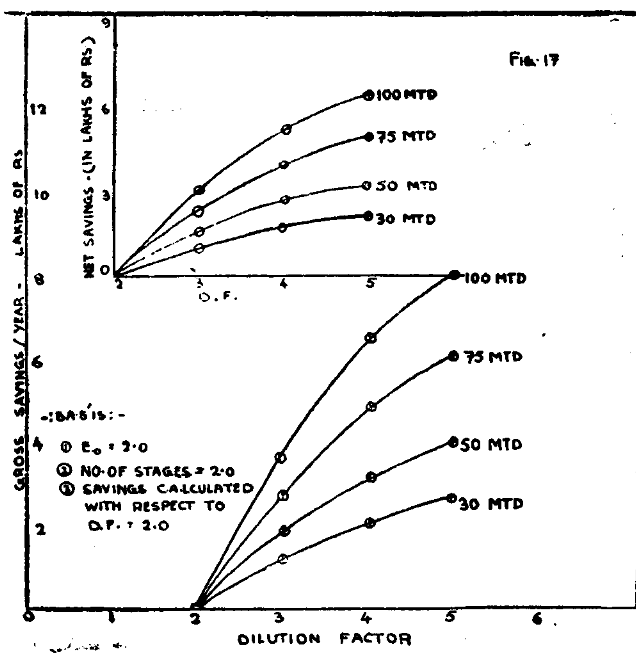
(1) The limited capacity of the evaporators.

(2) The increase in the operating costs due to higher steam consumption

The effect of dilution factors on the "Savings" has been clearly indicated in Fig. 13 and Fig. 14 and the following Chart once again makes it obvious that at the D.F. of 4.0 Savings are optimum and the increase in savings by increase in the D.F. beyond 4.0 would be negligible.

No. of Stages	Dilution Factor	* Not Savings per Year			
		100 MTD	75 MTD	50 MTD	30 MTD
Two	2	—	—	—	—
	3	3.10	2.34	1.5	0.93
	4	5.41	4.06	2.70	1.62
	5	6.37	4.76	3.18	1.91
Three	2	—	—	—	—
	3	2.10	1.57	1.05	0.63
	4	3.31	2.50	1.65	1.00
	5	3.80	2.85	1.90	1.14

* Calculated over a D. F. of 2.0 in lakhs of Rs.



Two Stage Washing on a Brownstock Washer :

It has been found advantageous to use multiple displacement on a single Brownstock Washer by collecting filtrate separately through the Automatic

Valve. Figure 15 represents the flow diagram for a two stage Washing System on a single Brownstock Washer :

Fig. 15

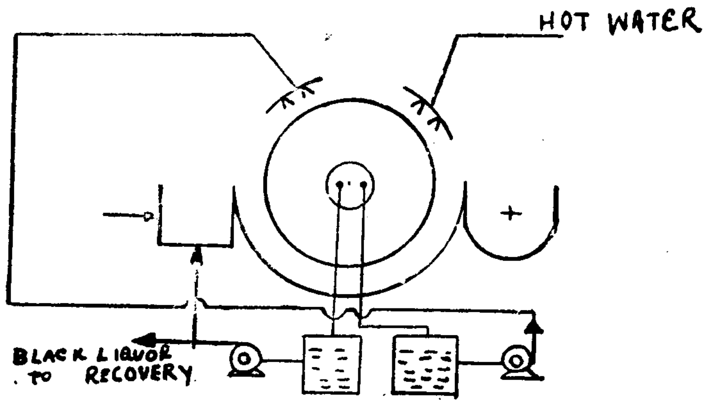
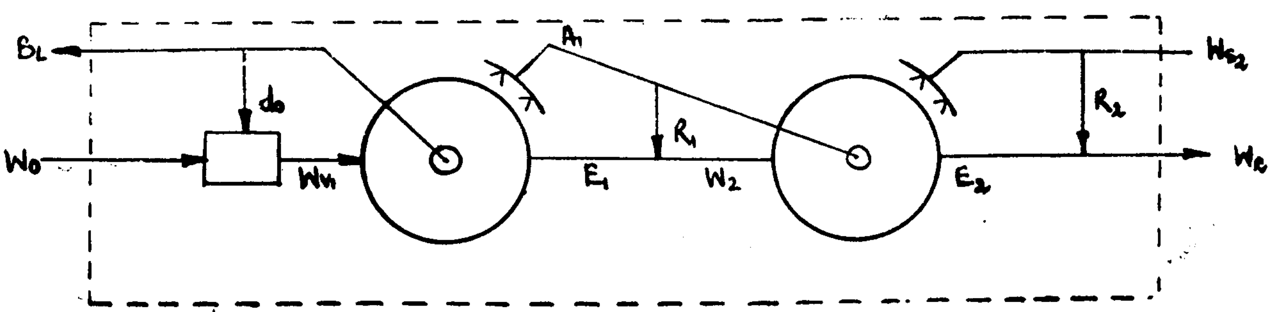


TABLE E

No.	Dilution Factor	% Losses 2	3	4
	System :			
(a)	2-Stage on a single BSW.	8 33%	7.60%	6.96%
(b)	3-Stage on one single stage & one two-BSW	3.76%	2.84%	2.22%
(c)	4-Stage on two two-stage BSW	1.90%	1.37%	1.00%
(d)	5-Stage on two 2-Stage & one 1-Stage BSW	0.95%	0.55%	0.367%

Fig. 16



The pulp mat is washed with the filtrate and hot water as indicated above. The automatic valve has two outlets and the filtrate obtained from the stage wash. The net flows and soluble balances can be easily calculated from the following diagram which is the equivalent of Fig. 4 for a two stage filter.

Two Stage Washing on a Single BSW :

Two stage displacement Wash on a Single Washer is not the equal of two conventional Washer Stages as there is no dilution between the two washers. Although it is difficult to estimate the efficiency of a two stage washer, attempts have been made to predict the overall entrainment in the pulp sheet, assuming entrainment values for individual washes (1), the average value for an overall entrainment Eo is 0.73 (2). Based on this value Soda loss calculations have been made and the results are indicated in the following Table :

Soda losses as indicated in the above Chart, again indicate the general trend that with higher dilution factors there is a gradual decrease in the Soda losses. Further, with more number of Stages, at a certain dilution factor, losses are considerably reduced. Comparing the values of Table E with those given in Table C (values are representative of a Dorr-Oliver Single Stage Washer) following conclusions are arrived at :—

(1) The overall performance of the Brownstock Washing System having single stage washers is better than the washing system consisting of multistage washers having the same number of washing stages, e.g. soda losses with 3 stage washing on 3 single stage washers is 2.4% (when D=3.0 & E=2.0) as against 2.84% with one two stage washer followed

by a single stage washer. Similarly the soda losses are 0.96% as against 1.37% for four stage washing, and 0.39% as against 0.55% for five stage, washing.

(2) The effect of dilution factor is felt more on Single Stage Washers than two-stage washers ; 'e.g. the percentage increase in washing efficiency for 2-stage washing by increasing the D.F. from 2 to 3 is 1.68% on single-stage washers, whereas the same on a two-stage washer is 0.80%.

The other values are given below for different stages when the dilution factor is increased from 2.0 to 3.0 :

TABLE F

No.	No. of stages	% increase in efficiency	
		Single Stage Washers	2-Stage & Single Stage
1	Two	1.68	0.80
2	Three	1.22	0.95
3	Four	0.75	0.54
4	Five	0.50	0.40

The Location of the Multistage Washer in the Brownstock Washing :

Theoretical calculations have revealed an interesting aspect regarding the variation in overall performance of the Brownstock Washing System with respect to the location of a two-stage Brownstock Washer in a **mixed** Brownstock Washing System. As a rule two stage Brownstock Washer has better efficiency than a single-stage Brownstock Washer and consequently is always better to install 2-stage washer ahead of the Single stage Brownstock Washer. Soda losses on a three-stage washing system (comprising of one single-stage and one two-stage washer) would depend to a great extent whether the two stage washer precedes or follows the single stage washer, e.g. the soda losses for a 3 stage washing system in which the two stage washer precedes the single stage washer is approximately (D.F. = 30) 2.84% whereas the same is approximately as high as 7.9% when the two-stage washer is preceded by the single-stage washer.

The same argument also applies to the relative locatoin of two washers—one more efficient and the other less efficient—in a Brownstock washing system. It is always profitable to install a better washer ahead of the less efficient washer, to attain higher washing efficiencies.

Conclusion :

It can be concluded from the foregoing discussions that the Brownstock Washing performance charts given above could be used for the following purposes :—

(1) It is possible to evaluate the performance of a single Brownstock Washer in the Multi-stage Brownstock Washing System by analysing the following data :—

(a) Dilution Factor

(b) Concentration of solubles in Vat Liquor

(c) Total solubles in the washed pulp mat

(d) Concentration of solubles in the Wash Liquor.

(2) It is possible to determine upto what extent the pulp mill capacity can be increased without overloading the evaporators and keeping the soda losses to an optimum value. This statement can be further elucidated with the help of the following illustration :—

Data :

(a) Existing Plant Capacity = 75 MTD of B.D. Pulp

(b) Dilution Factor = 3.0

(c) Percent Soda Losses = 2.4%

(d) Evaporator Capacity = 1,000 M^3/day of Black Liquor maximum
Existing Load = 8.75 M^3/day of Black Liquor

Let us assume that the plant capacity could be increased by 100%. Hence the actual capacity $= 75 + 75 \frac{(100X)}{100} = 75(1+X)$ MTD.

The increase in the volume of black liquor amount to evaporator $= 875 \times M^3$/day, at the D.F. of 3.0

The reduction in black liquor volume due to a reduction in Dilution Factor from 3 to D^1 is :

$$(3 - D^1) \times [75(1+X)_6)M^3/day$$

By the extrapolation of the Dilution factor Chart (Fig. 6) it is apparent that with a dilution factor of 1.3 on this three-stage Brownstock Washing System, it is possible to contain the soda losses to a value of about 5%.

Thus, substituting 1.3 for D^1,
Overall increase in Black Liquor Volume $=$
$875X - (3-1.3)(75)(1+X) = 1000 - 875$
Therefore, $875X - 128 - 128X = 1000 - 875$
Therefore, $X = 0.34$
Or the actual plant capacity after expansion $=$
$75(1.34) = 100$ MTD

If, however we decide to run the Washing System at a D.F. of 3.0 the plant capacity would be obtained by balancing the black liquor quantities as illustrated below :—

$$875X = 125$$

$$\therefore \quad X = \frac{125}{875} = 0.143$$

Or actual capacity $= 1.143 \quad (75) = 86$ MTD.

It may, however, be noted that the increase in the Plant capacity is possible only if the Washers are big enough to handle the increased load.

(3) The calculations and the procedure for determining the soda losses established above could be used with great success in comparing the performance of different Brownstock Washing Systems and as such it would help in arriving at the optimum system.

Reference :

1. Fifth Fitch B. and Pitkin W. H., Tappi, 47, (10), Page 179A, of October 1964
2. Fitch B. and Pitkin W. H., Tappi, 47, (10), Page 130A, of October 1964.