Sensitivity Analysis of A Three-Stage Cascade Screening System

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ABSTRACT

Pressure Screens are integral part of any approach flow system to paper Machine, as they help in removing contraries or impurities based on size and shape from the stock approaching the headbox. The screens, with holes or slots, are selected as per specific need of the process. Normally two to three screens are used in cascade to achieve the desired cleanliness level of the stock. Sensitivity analysis helps to optimize the system, and by the analysis given in this paper, Screening Quotient of the cascade system has been calculated to show the effect of primary, secondary and tertiary Screens Quotients. It is shown that the primary screen quotient has the dominant effect while the tertiary screen quotient has the least effect. The analysis also shows that there is no relationship between screening quotient of the cascade system and primary screen reject rate. However, the secondary and tertiary reject rates have some effect, but not significant, on the overall screening quotient.

INTRODUCTION

Screens are used primarily to remove debris particles, which are larger in at least one dimension than papermaking fibers, from an aqueous fiber slurry. The screens are normally used to remove particles of more than 100 μm size. The screens do not stand alone in the process. They are installed in a system, which is part of the overall pulp making process. Screening systems are installed to selectively remove certain constituents from the pulp feed, so that the accepted pulp is more suitable for the paper or board products in which it is used. The particles removed are concentrated in the system rejects so that they can be discarded with a minimum loss of good fibre or treated with the least amount of equipment and energy.

Pressure screens are by far the dominant type of screen in use today for removing debris from stock. In fact, fibers are generally screened at least 2 to 4 times with pressure screens between the digester and the headbox, and these are the one which are used in approach flow systems (1).

EXPERIMENTAL

Sensitivity analysis of a pulp screening system

In a sensitivity analysis we select some reasonable base design, and vary each design variable and input variable in turn by some fraction of the allowable range of variation.

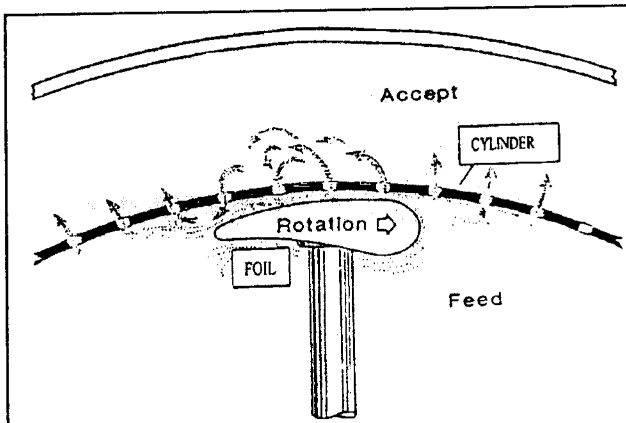

Fig. 1 Foil/cylinder interaction in a pressure screen

The resulting variations in the objective function and the output variables reveal the importance of each tested variable. The variables to which the system appears to be insensitive are fixed at reasonable values and attention is focused on the more important design variables (4).

In the following analysis, the Nelson's scrreening quotient (2) is used a an indicator of the performance of individual screens and the whole screening system.

A two stage (Fig. 4) cascade screening system sensitivity analysis (3) needs the following equations as obtained by the material balance in the system (5):

$$Q = Q_1 + (1 - R_2)(1 - Q_1) Q_2 \quad (1)$$

$$R = R_1 R_2 / [1 - R_1 (1 - R_2)] \quad (2)$$

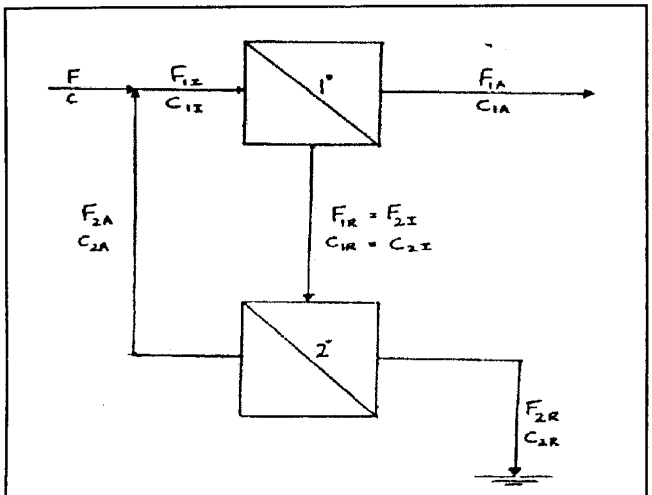

Fig. 4 Two - stage cascade screening system

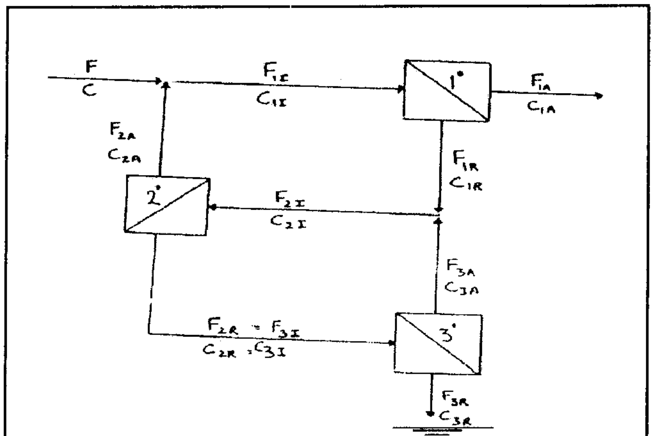

Fig. 5 Three - stage cascade screening system

$L_1 = 1 / [1 - R_1 (1-R_2)]$ (3)

$L_2 = R_1 / [1 - R_1 (1 - R_2)]$ (4)

Where -

Q_1 = Screening quotient of primary screen

$= 1 - \dfrac{\%\text{ debris in primary accept}}{\%\text{ debris in primary reject}}$

Q_2 = Screening quotient of secondary screen

$= 1 - \dfrac{\%\text{ debris in secondary accept}}{\%\text{ debris in secondary reject}}$

For the three - stage cascade screeing system as shown in Fig. 5, the relationships obtained from the material balance for the primary, secondary and tertiary screens are (5)-

$Q = 1 - [(1-Q_1)/\{1-R_2(1-R_3)\}]\ [\{(1-Q_2)(1-Q_3)(1-R_2)(1-R_3)\} + \{(1-Q_2)(1-R_2)R_3\} + \{R_2R_3\}]$ (1)

$R = R_1./R_2.R_3/[1-R_1(1-R_2)-R_2(1-R_3)]$ (2)

$L_1 = 1+[R(1-R_2)/(R_2R_3)]$ (3)

$L_2 = R/(R_2R_3)$ (4)

$L_3 = R/R_3$ (5)

Where -

Q_1 = Screening quotient of primary screen

Q_2 = Screening qutient of secndary screen

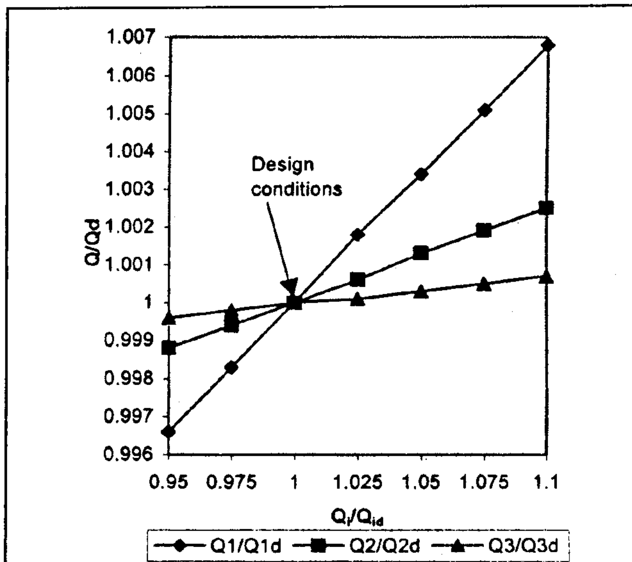

Fig. 6 Effect of individual screening quotients on the overall screening quotient

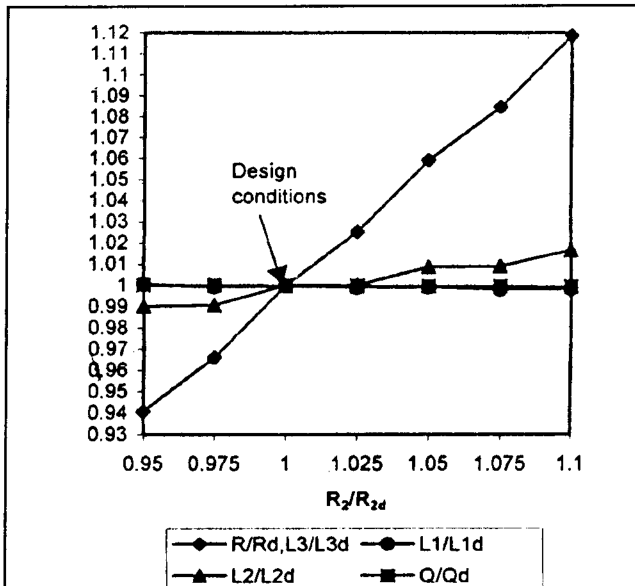

Fig. 7 Effect of R_1 on the performance and loading indicators

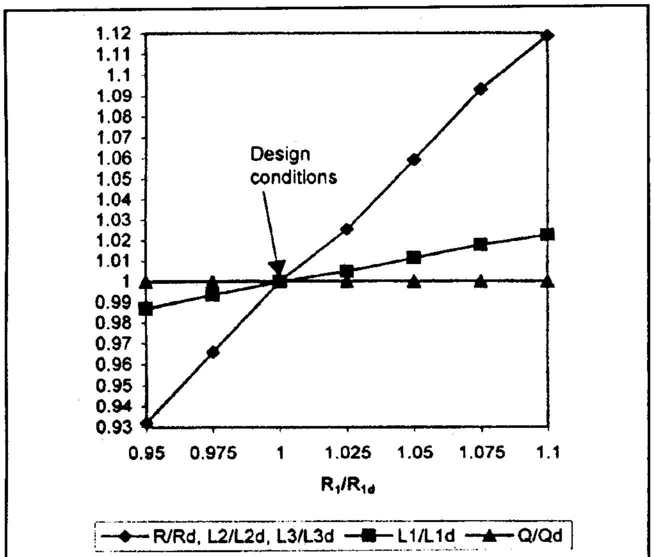

Fig. 8 Effect of R_2 on the performance and loading indicators

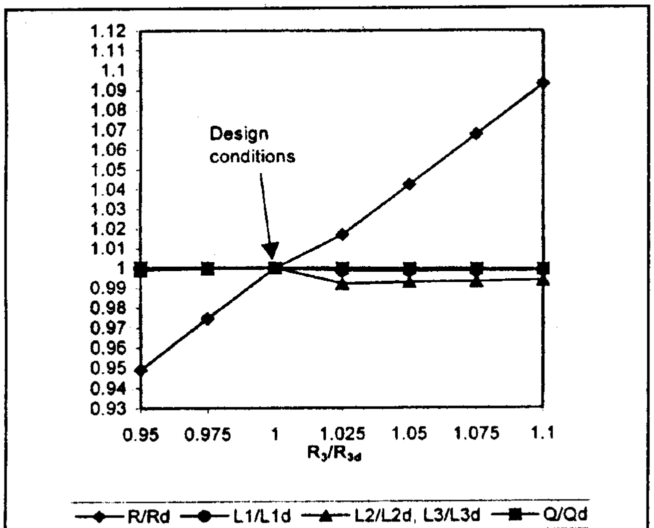

Fig. 9 Effect of R_3 on the performance and loading indicators

Tabe 1 The effect of controlling parameter, Q_1 on the performacne indicator, Q

Sl.	Q_1	Q_1/Q_{1d}	Q	Q/Q_d
1.	0.8519	0.95	0.9888	0.9966
2.	0.8743	0.975	0.9905	0.9983
3.	0.8967	1.00	0.9922	1.0000
4.	0.9191	1.025	0.9940	1.0018
5.	0.9415	1.05	0.9956	1.0051
6.	0.9640	1.075	0.9973	1.0034
7.	0.9864	1.1	0.9990	1.0068
The above results are shown in Fig. 6				

Tabe 2 The effect of controlling parameter, Q_2 on the performance indicator, Q

Sl.	Q_2	Q_2/Q_{2d}	Q	Q/Q_d
1.	0.8519	0.95	0.9910	0.9988
2.	0.8743	0.975	0.9916	0.9994
3.	0.8967	1.00	0.9922	1.0000
4.	0.9191	1.025	0.9928	1.0006
5.	0.9415	1.05	0.9935	1.0013
6.	0.9640	1.075	0.9941	1.0019
7.	0.9864	1.1	0.9947	1.0025
The above results are shown in Fig. 6				

Q_3 = Screening quoteint of tertiary screen

R_1 = Reject rate of primary screen

R_2 = Reject rate of secondary screen

R_3 = Reject rate of tertiary screen

R = Reject rate of the cascade system

Q = Screening quotient of the cascade system

L_1 = Load factor to primary screen

L_2 = Load factor to secondary screen

L_3 = Load factor to tertiary screen

The effects of the controlling parameters (Q_1, Q_2, Q_3, R_1, R_2, and R_3) on the performance and loading indicators (Q, L_1, l_2, L_3, and R) are analysed based on the above equations. The controlling parameters are treated as independent variables. The results from these equations are converted to a fraction of the design values and then plotted in (Fig. 6 to 9).

Desing values assumed for this analysis are as below, which are close to normal operating conditions:

Tabe 3 The effect of controlling parameter, Q_3 on the performance indicator, Q

Sl.	Q_3	Q_3/Q_{3d}	Q	Q/Q_d
1.	0.8519	0.95	0.9918	0.9996
2.	0.8743	0.975	0.9920	0.9998
3.	0.8967	1.00	0.9922	1.0000
4.	0.9191	1.025	0.9923	1.0001
5.	0.9415	1.05	0.9925	1.0003
6.	0.9640	1.075	0.9927	1.0005
7.	0.9864	1.1	0.9929	1.0007
The above results are shown in Fig. 6				

Tabe 4 The effect of controlling parameter, R_1 on the performance indicator, Q, L_1, L_2, L_3 and R

	R_1	R_1/R_{1d}	R	R/R_d	L_1	L_1/L_{1d}	L_2	L/L_{2d}	L_3	L_3/L_{3d}
1.	0.19	0.95	0.0110	0.9322	1.22	0.9870	0.275	0.9322	0.055	0.9322
2.	0.195	0.975	0.0114	0.9661	1.228	0.9935	0.295	0.9661	0.057	0.9661
3.	0.2	1.00	0.0118	1.0000	1.236	1.0000	0.285	1.0000	0.059	1.0000
4.	0.205	1.025	0.0121	1.0254	1.242	1.0048	0.3025	1.0254	0.0605	1.0254
5.	0.21	1.05	0.0125	1.0593	1.25	1.0113	0.3125	1.0593	0.0625	1.0593
6.	0.215	1.075	0.0129	1.0932	1.258	1.0178	0.3225	1.0932	0.0645	1.0932
7.	0.22	1.1	0.0132	1.1186	1.264	1.0226	0.33	1.1186	0.066	1.1186

Tabe 5 The effect of controlling parameter, R_2 on the performance indicator, Q, L_1, L_2, L_3 and R

R_2	R_2/R_{2d}	R	R/R_d	L_1	L_1/L_{1d}	L_2	L_2/L_{2d}	L_3	L_3/L_{3d}	Q	Q/Q_d
0.19	0.95	0.0111	0.9407	1.237	0.0008	0.2921	0.9902	0.0555	0.9407	0.9925	1.0003
0.195	0.975	0.0114	0.9661	1.235	0.9992	0.2923	0.9908	0.057	0.9661	0.9923	1.004
0.2	1.00	0.0118	1.0000	1.236	1.0000	0.295	1.0000	0.059	1.0000	0.9922	1.0000
0.205	1.025	0.0121	1.0254	1.2346	1.9989	0.2951	1.0003	0.0605	1.0254	0.9920	0.9998
0.21	1.05	0.0125	1.0593	1.2351	1.9993	0.2976	1.0088	0.0625	1.0593	0.9919	0.9997
0.215	1.075	0.0128	1.0847	1.2337	1.9981	0.2977	1.0091	0.064	1.0847	0.9918	0.9996
0.22	1.1	0.0132	1.1186	1.234	1.9984	0.3	1.0167	0.066	1.1186	0.9916	0.9994

1. % debris by weight in feed to the system (Si) 1.0%
2. % debris by weight in accept of primary screen (S_a) 0.4%
3. Reject rate of primary screen (R_{1d}) 0.2
4. Reject rate of primary screen (R_{2d}) 0.2
5. Reject rate of primary screen (R_{3d}) 0.2

From above design values, we obtain

R_d =0.0118

Q_d =0.9922

Assuming desing values of Q_1 and Q_2 to be same, we obtain

Q_{1d} =0.8967

Q_{2d} =0.8967

Q_{3d} =0.8967

Note: subscript "d" indicates design values.

Fig. 6 suggest that the screening quotients of all the screens have significant effects on the overall performance of the cascade. However it is apparent that the primary screening quotient has the dominant effect while the tertiary screening quotient has the least. Results from Tables 4-5 and 6 are shown in (Figs. 7 to 9). These figures suggest that loadings to the primary, secondary and tertiary screems increase with increased primary reject but loading to primary screen is not significant compared to other screens. Similarly loading to tertiary screen increase with increased secondary reject. The prediction shows no relationship between the screening quotient of the cascade and the primary screen reject. However, the secondary and tertiary reject does have some effect, but not significant, on the overall screening quotient.

CONCLUSION

Following conclusions can be drawn from the above detailed analysis : Screening quotients of all the screens have significant effects on the overall performance of the cascade. However it is apparent that the primary screening quotient has the dominant effect while the

Tabe 6 The effect of controlling parameter, R_3 on the performance indicator, Q, L_1, L_2, L_3 and R

R_2	R_2/R_{2d}	R	R/R_d	L_1	L_1/L_{1d}	L_2	L_2/L_{2d}	L_3	L_3/L_{3d}	Q	Q/Q_d
0.19	0.95	0.0112	0.9491	1.2358	0.9998	0.2947	0.9990	0.0589	0.9983	0.9926	1.0004
0.195	0.975	0.0115	0.9746	1.2359	0.9999	0.2949	0.9997	0.059	1.0000	0.9924	1.0002
0.2	1.00	0.0118	1.0000	1.236	1.0000	0.295	1.0000	0.059	1.0000	0.9922	1.0000
0.205	1.025	0.0120	1.0170	1.2341	1.9985	0.2927	1.9922	0.0585	0.9915	0.9921	0.9999
0.21	1.05	0.0123	1.0424	1.2343	1.9986	0.2929	1.9929	0.0586	0.9932	0.9919	0.9997
0.215	1.075	0.0126	1.0678	1.2344	1.9987	0.2930	1.9932	0.586	0.9932	0.9918	0.9995
0.22	1.1	0.0129	1.0932	1.2345	1.9988	0.2932	1.9939	0.586	0.9932	0.9916	0.9994

tertiary screening quoteient has the least. Loading to the primary, secondary and tertiary screns increase with increased primary reject but loading to primary screen is not significant compared to other screens. Similarly loading to tertiary screen increases with increased secondary reject. The prediction shows no relationship between the screening quoteint of the cascade and the primary screen reject. However the secondary and tertiary reject does have some effect, but not significant, on the overall screening quotient.

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