Analysis of A Pulp Cleaning System - A Case Study

Ashok Kumar

ABSTRACT: The cleanliness requirement of pulp depends on the end product for which pulp is used. If a mill decides to produce pulp of higher cleanliness, the existing screening and cleaning system should be properly examined. Depending on the cleanliness requirement, the existing system may require slight modifications or more efficient equipments may have to be installed. A case study of a pulp cleaning system is presented in which a mill proposes to modify its cleaning system to produce pulp of higher cleanliness. The easiest option is to purchase "new improved cleaners" from a supplier who guarantees the desired shive level in the accepts from the primary stage of the 3-stage cleaning system. This option is compared with another proposal is given by an experienced process engineer of the mill. The process engineer's proposal is thoroughly examined and it is shown that the detailed analysis of the existing system based on theoretical considerations and the experiences of operating personnel may result in a considerable saving of capital expenditure.

INTRODUCTION

Screening and cleaning are the mechanical operations used to remove the undesirable constituents (knots, debris, shives, chop, dirt, plastic particles etc.) from pulp. These operations affect the quality of finished product decisively but are, in general, not given the attention they deserve. If the contaminants are not removed effectively during screening and cleaning operations, the operational and quality problems will be experienced in further processing of pulp. Contaminants such as shives, if not removed by screening, have to be bleached in order to achieve the desired cleanliness. This requires higher consumption of bleaching chemicals which result in higher effluent load from bleach plant.

The performance of an individual screen depends on the properties of fibres and contaminants to be removed, type of screen plate used, operating consistency, reject rate, and a number of other factors. To maintain high efficiencies, high reject rates must be used. The rejected stream then passes to the secondary and tertiary screens/ cleaners to reclaim the good fibre. Thus, a system configuration is to be used in order to produce the pulp of desired quality.

Many different pulp screening and cleaning systems are operating in the industry. Experiences show that these screening and cleaning systems do not always remove the contaminants as efficiently as we would like. Optimizing the performance of a system is a key to obtain the desired pulp quality. To get a better understanding of the system, it is important to analyze the process by carrying out mass balances and using

Institute of Paper Technology
Saharanpur-247001 (U.P.)

the theoretical considerations and the practical experiences of persons operating the system.

GENERALIZED EXPRESSIONS OF CLEANER SYSTEM MASS BLANCE

It is a simple matter to develop a generalized screen or cleaner system mass balance. One has to use only simple algebra and the calculations are such that they can be done by hand calculators. The use of a programmable calculator will speed up the analysis and for more elaborate massaging, the use of the simplest computers will be more than adequate.

Consider a 3-stage cleaner system as shown in Figure-1. The feed to each stage is made up of the rejects from the previous stage and the accepts from the next stage. The cascade is said to be broken if the accepts from the next stage combine with the accepts from the stage in question. For example, the cascade would be broken at the tertiary stage if the tertiary accepts are combined with the secondary stage accepts instead of the primary stage rejects.

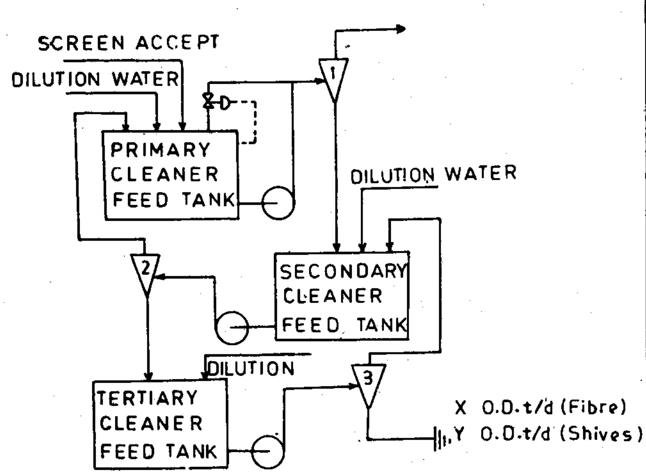

Fig.-1 3-STAGE CLEANING SYSTEM

To develop expressions for the cleaning system, the expressions for each flow at each point of the system should be developed first. One can start from the last stage and proceed towards the first stage. These expressions will be good for both fibre content and debris content when the correct values are substituted i.e. reject rates for calculating fibre flow and cleaner efficiency for debris values.

To develop expressions for the system shown in Figure-1, let

- tertiary reject stream contain X o.d. t/d (oven dry tonnes/day) fibre and Y o.d. t/d debris (slivers or contaminants).
- primary, secondary, and tertiary rejects rates be R_1, R_2 and R_3 respectively.
- Z be the fraction of primary accepts returned to the feed.

Now let us start at the third stage for simplicity. Assume that the effects of dilution water are either negligible with respect to the overall objective or do not enter into the steady state considerations.

Tertiary stage

Feed $= X/R_3$ (2.1)

Accepts $= (1-R_3)\,X/R_3$ (2.2)

Secondary stage

Feed $= X/R_2R_3$ (2.3)

Accepts $= (1-R_2)\,x\,/\,R_2R_3$ (2.4)

Rejects $=$ Tertiary feed $= X/R_3$ (2.5)

Primary Stage

Feed $= X[1-R_2(1-R_3)]/R_1R_2R_3$ (2.6)

Accepts $= X(1-R_1)[1-R_2(1-R_3)]/R_1R_2R_3$ (2.7)

Rejects $= X[1-R_2(1-R_3)]/R_2R_3$ (2.8)

Overall System

Accepts $= X(1-Z)(1-R_1)[1-R_2(1-R_3)]/R_1R_2R_3$ (2.9)

Feed $= X\{(1-Z)(1-R_1)[1-R_2(1-R_3)] + R_1R_2R_3\}/R_1R_2R_3$ (2.10)

Overall reject rate = Tertiary rejects/System feed

$= R_1R_2R_3/\{(1-Z)(1-R_1)[1-R_2(1-R_3)] + R_1R_2R_3\}$ (2.11)

The above expressions are summarized in Table-1. Similarly, one can write generalized mass balance equations for a portion of the fibrous flow (e.g. debris) by replacing the R terms (reject rates) with E terms (debris removal efficiency). If primary, secondary and tertiary stage efficiencies be E_1, E_2 and E_3 respectively, all the above equations will give shive content and shive removal efficiencies if Y is substituted for X and E_n for R_n.

Table-1

Expressions for calculating fibre flow at various stages.

Stream		Fibrous balance
Tertiary	- Feed	X/R_3
	- Accepts	$(1-R_3)\ X/R_3$
	- Rejects	X
Secondary	- Feed	X/R_2R_3
	- Accepts	$(1-R_2)\ X/R_2R_3$
	- Rejects	X/R_3
Primary	- Feed	$X[1-R_2(1-R_3)]/R_1R_2R_3$
	- Accepts	$X(1-R_1)[1-R_2(1-R_3)]/R_1R_2R_3$
	- Rejects	$X[1-R_2(1-R_3)]/R_2R_3$
Overall System		
	- Accepts	$X(1-Z)(1-R_1)[1-R_2(1-R_3)]/R_1R_2R_3$
	- Feed	$X\{(1-Z)(1-R_1)[1-R_2(1-R_3)]+R_1R_2R_3\}/R_1R_2R_3$
	- Reject rate	$R_1R_2R_3/\{(1-Z)(1-R_1)[1-R_2(1-R_3)]+R_1R_2R_3\}$

CASE STUDY

A pulp mill used to produce 120 o.d. tonnes per day (t/d) of newsprint grade pulp as measured at the point of screen accepts. This pulp was cleaned in 3-stage centricleaning system as shown in Figure-2. The primary cleaners were made up of 4 banks, each being separable by valves. The pulp mill started producing 90 o.d. t/d of light weight coating raw stock pulp and one of the four primary cleaner banks was shut down to match the decreased production rate. No other changes were made to the cleaner system.

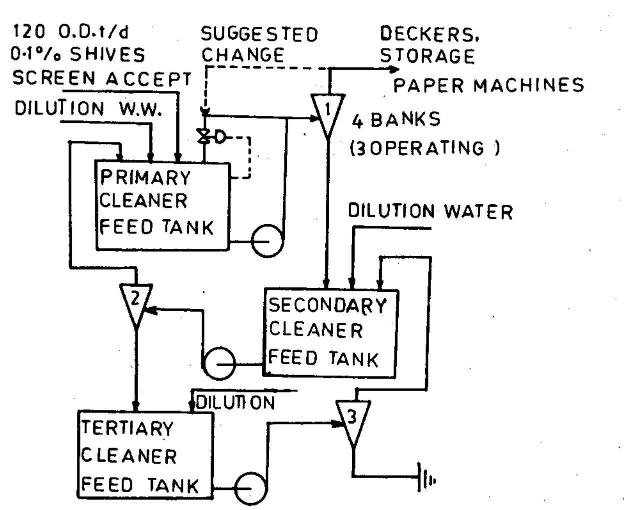

Fig.2 3 STAGE CLEANING SYSTEM WITH A SUGGESTED CHANGE

The shive content of the screen accepts stream is 0.1% of the o.d. fibre. Though the cleaners improved this property to a satisfactory level for news grade pulp but it is too high for light weight coated raw stock. A supplier of the cleaner system has suggested to install "New Improved Cleaners" in the primary position at a substantial cost and guarantees that the finished pulp shive content will be reduced by 30% from its present value.

A process engineer of the mill has also made a proposal which, in his opinion, would make a significant improvement in finished pulp shive content for a very moderate cost. He suggests to reactivate the fourth primary cleaner bank and convert the primary cleaner feed tank level control in order to recirculate the cleaner feed stock. This means that a significant portion of the pulp will be cleaned twice which will improve the overall cleaner accepts.

Following reliable test data exists for the shive removal efficiency of each cleaner stage, although all tests were carried out at the maximum rejects rate for the stage in question.

Stage	Rejects fraction by weight			Efficiency at maximum reject rate
	minimum	nominal	maximum	
Primary	0.08	0.10	0.13	0.80
Secondary	0.15	0.18	0.25	0.92
Tertiary	0.20	0.25	0.30	0.95

The past operating experience shows that although the three cleaner stages operate at the nominal reject rates shown, they can be made to reject any rate between the maximum/minimum values mentioned above.

Let us critically analyze the proposal of process engineer from the following points of view.

1. What will be the shive content of the finished pulp if the proposal is accepted?
2. Would operating cost (pumping energy and fibre loss to the sewer) increase, decrease or stay essentially the same as at present if his proposal was adopted?

3. What additional suggestions can be made to improve the shive content of the finished pulp?

SPECIFIC STAGE BEHAVIOUR

Nelson's Equation is used to study the behaviour of specific stage by relating reject rate (R) with shive removal efficiency (E)

$$E = R/[1-Q(1-R)] \quad (4.1)$$

Where Q is the screening quotient.

Based on the efficiency given at maximum reject rate for a given stage earlier, Q can be calculated using Eq. (4.1). This value of Q is then used for calculating E at any R.

Primary stage

$R_1 = 0.13$ and $E_1 = 0.80$, Thus $Q_1 = 0.9626$
Thus when $R_1 = 0.08$, $E_1 = 0.08/[1-0.9626\,(1-0.08)] = 0.6993$
and When $R_1 = 0.10$, $E_1 = 0.10/[1-0.9626(1-0.10)] = 0.7482$

Secondary Stage

$R_2 = 0.25$ and $E_2 = 0.90$, Thus $Q_2 = 0.9630$
Thus when $R_2 = 0.15$, $E_2 = 0.8267$
and when $R_2 = 0.18$, $E_2 = 0.8558$

Tertiary Stage

$R_3 = 0.30$ and $E_3 = 0.93$, Thus $Q_3 = 0.9677$
Thus when $R_3 = 0.20$, $E_3 = 0.8856$
and When $R_3 = 0.25$, $E_3 = 0.9117$

EXISTING SITUATION

System feed = 90 o.d. t/d fibre

Shives = 90 o.d. kg/day (0.1% of feed)

No recirculation i.e. Z = 0

Nominal conditions apply i.e.

$R_1 = 0.10$ $\quad E_1 = 0.7482$

$R_2 = 0.18$ $\quad E_2 = 0.8558$

$R_3 = 0.25$ $\quad E_3 = 0.9117$

overall rejects fibre: (use Eq. 2.11)

$$\frac{(0.10)\,(0.18)\,(0.25)\,(90t/d) \times 1000}{\{(1-0)(1-0.10)[1-0.18(1-0.25)]+(0.10)(0.18)(0.25)\}} = 517.24 \text{ o.d. kg/day}$$

overall rejects shives: (use Eq. 2.11 replacing R by E)

$$\frac{(0.7482)(0.8558)(0.9117)(90t/d)(0.001)(1000)}{\{(1-0)(1-0.7482)[1-0.8558(1-0.9117)]+(0.7482)(0.8558)(0.9117)\}}$$

= 64.30 o.d. kg/day

overall accepts shives:
(90 x 0.001 x 1000) -64.30 = 25.70 o.d. kg/day

CLAIM OF THE SUPPLIER OF "NEW IMPROVED CLEANER"

A 30% reduction in finished pulp shives i.e.

25.70-0.30(25.70)=17.99 o.d. kg/day.

PROCESS ENGINEER'S PROPOSAL

The proposal of process engineer was to activate the fourth primary bank. It means that the primary feed would increase by one third meaning that one quarter of the higher accepts flow would have to be recirculated to maintain 90 o.d. t/d accepts to deckers. It means Z=0.25

Substituting Z=0.25 into the equations developed earlier and keeping all other data same, we get

overall reject fibre = 688.34 o.d. kg/day
overall reject shives = 69.28 o.d. kg/day
overall accept shives = 90-69.28 = 20.72 o.d. kg/day

ANALYSIS OF ENGINEER'S PROPOSAL

Shive content of finished pulp

If the engineer's proposal was adopted, the shive content of the finished pulp will be reduced from 25.7 to 20.72 o.d. kg/day. This is not as good as the 17.99 o.d. kg/day promised by the supplier of "new improved cleaners"

Operating cost

The operating cost component in terms of fibre loss would increase as overall rejects fibre would increase from 517.24 o.d. kg/ day to 688.34 o.d. kg/ day.

As regards to pumping energy cost component, nothing is mentioned for changing cleaner feed pumps and motors. It means the primary feed pump energy will be more productively used for feeding an extra bank of primary feed cleaners. The volume pumped to secondary and tertiary stages will not change, however, the feed consistency will only increase slightly. It means, pumping energy will neither increase nor decrease if the engineer's proposal was adopted.

Additional Suggestions

The engineer basically had a good idea but it was not fully developed to the best potential. By using the equations given in Table-1, it is possible to construct Figure - 3. The maximum recycle of primary accepts which will use up all the spare primary cleaner bank capacity is 25%. This maximum should be used because it will mean that one quarter of the primary feed stock will in effect be double cleaned. Point A results if rejects rate from all stages is pushed to the minimum level. Though this obviously represents the best overall reject rate but the efficiency is the poorest. On the other hand, the reverse is true if the highest reject rates are chosen i.e. best efficiency but poorest reject rate as represented by point B.

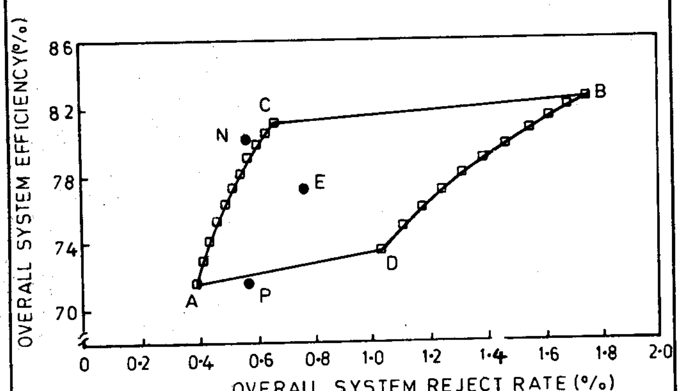

Fig.3 Overall System Efficiency vs Overall System Reject Rate

A = Minimum rejects rate of all stages
B = Maximum rejects rate of all stages
C = Variable primary, minimum secondary and tertiary
D = Variable primary, maximum secondary and tertiary
P = Present condition
E = Engineer's proposal
N = New Improved Cleaners
Note: 25 % recycle of primary accepts assumed for all points except "present condition" and "new improved cleaners".

If the primary reject rate is varied from minimum to maximum keeping the secondary and tertiary stage reject rates at minimum, line AC is generated. Similarly, line DB is obtained when primary reject rate is varied but secondary and tertiary stage reject rates are kept at maximum level. Therefore, one can choose any combination of reject rates between minimum and maximum and the overall efficiency and reject rate will lie within the boundaries of ACBD. The points representing the present condition, the supplier's proposal, and the engineer's proposal are also shown in Figure-3.

The value of theoretical maximum system efficiency can be calculated by substituting $E_1=0.80$ (i.e. maximum) and $E_2=E_3=1.00$ (i.e. perfection) in equations of Table - 1. Although this maximum system efficiency is practically unacceptable, it is useful as various proposals can be measured against this.

SUMMARY

Based on the above analysis, the following points may be noted.

1. Figure-3 shows that it is possible to find a combination of reject rates which will give as good an overall efficiency and reject rate as that promised by the supplier of "new improved cleaners".
2. If the proposal of engineer is accepted, it will save substantial capital spending and will result in no increase in the operating cost.
3. The system efficiency can be further improved by choosing the operating conditions of point C in Figure-3. There will be slight increase in the sewered rejects.
4. A further improvement in efficiency could be obtained by choosing the operating conditions of point B but the cost in sewered rejects would increase substantially. However, the cost of lost pulp may still be much less than the capital expenditure required for installing new cleaners.

CONCLUSION

Screening and cleaning operations in pulp and paper industry are normally the neglected area of the pulp and paper making process and do not, in general, receive the attention they deserve. It is not uncommon that due to inefficient working of screening/ cleaning system, the contaminants such as shives are not removed effectively and in order to achieve the desired pulp cleanliness, these shives have to be bleached meaning higher consumption of bleaching chemicals and thus increased effluent load from the bleach plant. Efforts are not made by mill personnel to analyze their existing systems and the data about the performance of equipments with respect to the changes in furnish, process conditions, and hardware are not available. The instrumentation and control systems are generally inadequate and the facilities for evaluating performance of screens and cleaners with changes in operating parameters do not exist. The suppliers of screening and cleaning system also do not provide the detailed information about the performance of their equipments to take advantage of the maximum potential of the system.

The present study has shown that it is very important to make a detailed analysis of the existing system based on the theoretical considerations and the practical experiences of mill personnel. The claim of any supplier should always be properly examined in the light of suggestions made by mill personnel. It the exercise is done properly, a considerable saving of capital expenditure may be realised.