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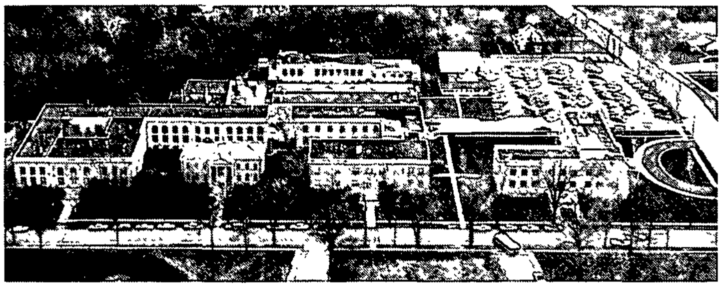

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EFFECTIVE SCREENING AND CLEANING OF SECONDARY FIBERS

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EFFECTIVE SCREENING AND CLEANING OF SECONDARY FIBERS

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ABSTRACT

Cascades of screens and cleaners in three or more stages are used to recover fibers. However, if the units in the secondary and tertiary stages are not very efficient, considerable amounts of contaminants will be recirculated. As a result, the overall cleaning efficiency of the system is reduced. Computer simulation of the system demonstrates the effect of reject ratios, contaminant recirculation and breakup, and forward flow arrangement.

INTRODUCTION

Screens and cleaners are used extensively in the paper industry. Reject streams from primary stage units contain considerable amounts of contaminants together with some good fibers. Therefore, rejects are further treated in one or more stages to recover fibers, and inevitably some contaminants also get accepted. As a result, in a large number of cases the loss of good fibers is reduced at the cost of cleanliness of the accepts from the system.

Usually two to four stages are used. A typical three-stage system is shown in Fig. 1. Here reject streams from the primary and secondary stages are treated, respectively, in the secondary and tertiary stages. Accept streams move countercurrent to the reject streams - from tertiary to secondary to primary stages.

There are several variations of this system. In some cases tertiary accepts are moved to the primary stage and/or secondary accepts are mixed with the primary accepts. These variations will have some effect on the overall capacity, contaminant removal efficiency and reject ratio of the system. Such variations could easily be considered, but in this paper we will focus on the most common countercurrent cascade system, shown in Fig. 1.

The objective of this paper is to show how reject ratio and contaminant removal efficiency of each unit affect the overall performance of the system. The computer simulation program, MAPPS, (Modular Analysis of Pulp and Paper Systems), developed specially at the Institute, will be used to determine mass flow rates of fibers and contaminants in the various streams. An advantage of such a simulation program is that the effect of a change in the system parameters - say reject ratio, or efficiency or mass flow rate of fibers - can be evaluated with relative ease (1,2,3).

Before presenting simulation results, definitions of reject ratio and efficiency will be useful.

3 STAGE CASCADE SYSTEM

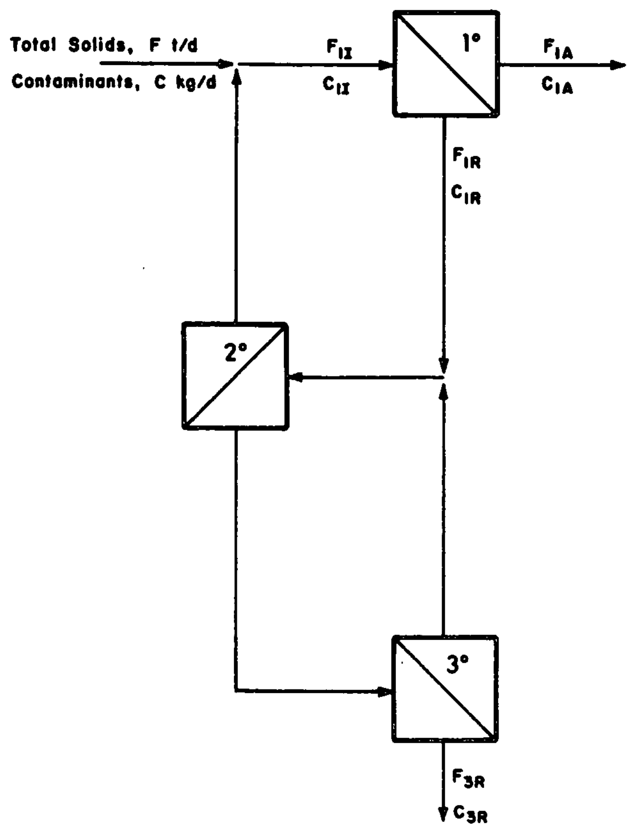

Fig. 1 A conventional 3-stage cascade system.

	Primary Stage	System (Fig. 1)
REJECT RATIO	$R = \frac{F_{1R}}{F_{1I}}$	$R = \frac{F_{3R}}{F}$
EFFICIENCY (Based on accepts)	$E = 1 - \frac{C_{1A} \cdot F_{1I}}{F_{1A} \cdot C_{1I}}$	$E = 1 - \frac{C_{1A} \cdot F}{F_{1A} \cdot C}$
EFFICIENCY (Based on rejects)	$E_R = \frac{C_{1R}}{C_{1I}}$	$E_R = \frac{C_{3R}}{C}$

Definitions for secondary and tertiary stages are analogous to those for the primary stage. The contaminant removal efficiency can be based on accepts (E) or rejects (E_R). In general, E will be somewhat lower than E_R. For our purposes, it does not matter which definition is used. MAPPS is equipped to handle either of the two definitions. When contaminant mass fraction, X (= C/F), in accepts and rejects is the same as that in the inlet stream, the efficiency should tend to be zero, as E does but E_R does not. That is why we prefer the definition based on accepts, E, and that is the one used here.

RESULTS AND DISCUSSION

All results are normalized with the inlet total mass flow rate, F = 100 t/d, and contaminant flow rate, C = 100 kg/d. So the percentage of contaminants in the inlet stream to the system is X = 100 • C/F = 0.1%. When three different sizes of contaminants (small, medium, and large) are considered - each one with a flow rate of 100 kg/d - total contaminant concentration will be 0.3%.

In reality, flow rates of water, consistency and the addition of dilution water, when required, should be considered. This can easily be handled by MAPPS. But to keep the discussion simple, only the flow rate of total mass and contaminants will be of concern here.

Several numerical experiments were conducted with the object of evaluating the overall system performance when parameters of individual units are varied. Results of these experiments are discussed below.

Case 1. Equal Reject Ratio and Efficiency for the Three Stages

Let us consider an example where all units in the primary, secondary, and tertiary stages have a reject ratio, R = 20%. Total mass flow rates for all streams as calculated by MAPPS are displayed in Fig. 2. Note that the primary accepts flow rate is 99 t/d and tertiary reject flow rate is 1 t/d, giving the system a reject ratio of 1%. It is clear that the three-stage countercurrent cascade system reduces the reject mass from 20% for single stage to only 1% for the system.

Calculated values of mass flow rates of contaminants are shown in Fig. 3 when the contaminant removal efficiency is assumed to be 50% for each stage. The percentage of contaminants in each stream is shown in parentheses. The tertiary reject stream is heavily loaded with contaminants and is usually discarded. The contaminant concentration reduces from 0.1% in the inlet stream to 0.06% in the primary accepts, giving the system efficiency, E = 40%. Thus, in an attempt to minimize the fiber loss from the system, the efficiency is sacrificed somewhat. This is a major drawback of the conventional systems.

Case 2. Contaminant Distribution

In screens and hydrocyclones contaminants are removed based on their size, shape, and density. Therefore, the efficiency could be high for some contaminants and low for others. In this numerical experiment, we arbitrarily divided contaminants into three classes, say, large, medium, and small, with corresponding efficiencies of 75, 50, and 25%, respectively. Computer results are shown in the form of the Shankey diagram in Fig. 4. The system contaminant removal efficiency for large, medium, and small particles is 75.0, 40.0, and 11.5%, respectively. The total contaminant removal efficiency for the system is 43.0%. Due to their differences in efficiency, small contaminants accumulate in primary accepts and large ones in tertiary rejects.

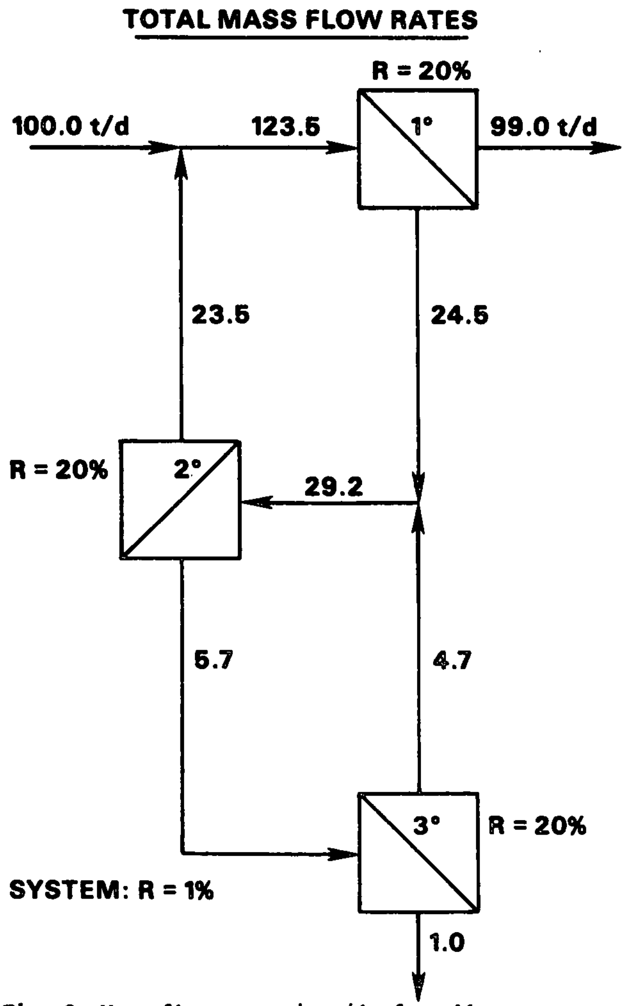

Fig. 2 Mass flow rates in t/d, for all streams, for Case 1 - Equal reject ratio (20%) and efficiency (50%) for all 3 stages.

It is not surprising that the proportion of large size contaminants is greatest in the stream entering the tertiary stage and lowest in that entering the primary stage. Numerical results of contaminant size distribution in the inlet stream of the three stages are shown in Table 1. Since the large size contaminants are removed with the highest efficiency, the overall contaminant removal efficiency of the tertiary stage (58%) is higher compared to 53 and 49% for the secondary and primary stages. Thus, two identical screens used in the primary and secondary stages could have a different contaminant removal efficiency due to the differences in the contaminant size distribution in the streams entering the two stages.

Case 3. Increasing/Decreasing Reject Ratios

So far, in all experiments reject ratio was assumed to be 20%. In reality, reject ratios could be different for each of the three stages. In most cases reject ratios could be adjusted easily by manipulation of valves. A question then is, should we operate the primary stage with the lowest reject ratio and the tertiary stage with the highest

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possible or vice versa - keeping the system reject ratio constant in either case?

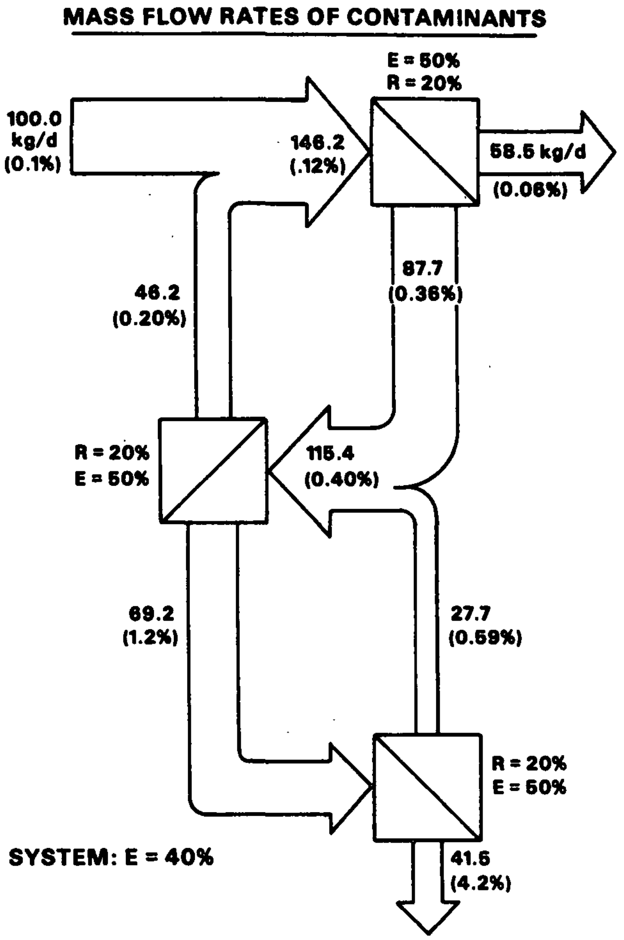

Fig. 3 Mass flow rates of contaminants, in kg/d, for all streams, for Case 1 - Equal reject ratio (20%) and efficiency (50%) for all 3 stages. Numbers in parentheses represent weight percent of contaminants.

Table 1 Contaminant distribution in the inlet stream of the three stages (Fig. 4) and its effect on E_T

Inlet Stream to	Weight Fraction of Contaminants Large	Medium	Small	E_T, %
Primary stage	0.10	0.12	0.12	49
Secondary stage	0.40	0.39	0.26	53
Tertiary stage	1.60	1.17	0.52	58

An example is considered in Fig. 5, where for the case of Increasing Reject Ratio, primary, secondary, and tertiary R values are selected as 20, 25, and 30%, respectively. Corresponding values for the case of Decreasing Reject Ratio, shown in parentheses, are 32.5, 25, and 15%. These values of reject ratios are selected so that the system reject ratio is 2.2% in both cases.

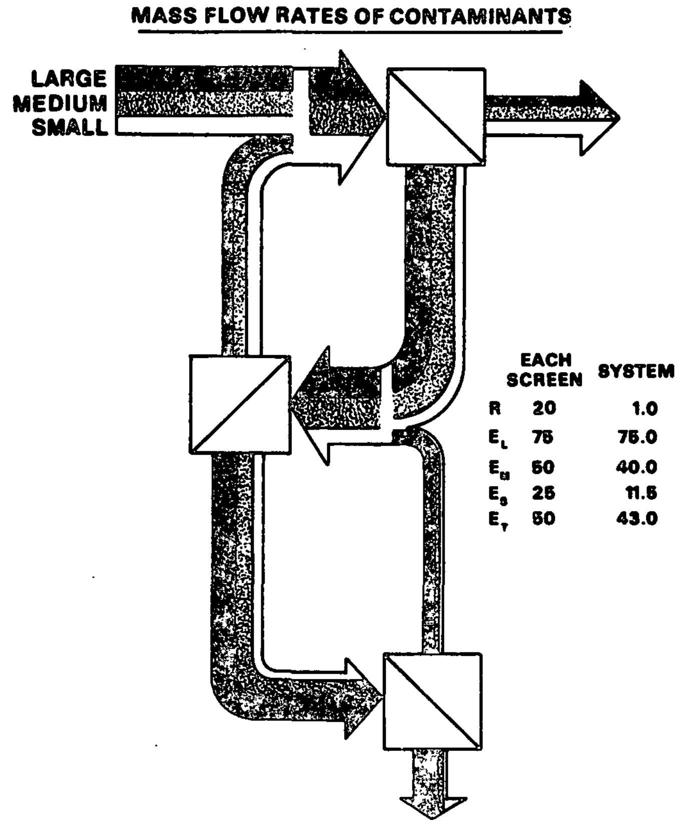

Fig. 4 Mass flow rates of large, medium, and small size contaminants for Case 2 - Contaminant distribution.

Mass flow rate of each of the three contaminants, large, medium, and small, is assumed to be 100 kg/d in the inlet to the system. As can be seen from the results of Fig. 6, the system efficiency is 43.7% for the Increasing Reject Ratio case and 47.3% for the Decreasing case. Total mass flow rates of contaminants in the primary accepts decreases from 165.2 kg/d to 154.5 kg/d by following the strategy of the highest reject ratio in the primary stage and the lowest one in the tertiary stage. However, the higher efficiency for the case of Decreasing Reject Ratio is achieved at the cost of requiring higher capacity for units in all three stages, as can be seen from Fig. 5.

It is interesting to note that most mills use vibrating or flat screens with relatively low reject ratios (3 to 5%) in the tertiary stage. Thus, the strategy of Decreasing Reject Ratio in cascades of screens and cleaners is followed in practice.

Case 4. Screening Quotient

It is known that as the reject ratio increases, the contaminant removal efficiency also increases. However, in the previous case the efficiency for large, medium, and small contaminants was assumed to be the same: 75, 50, and 25%, respectively, in all three stages, even when the reject ratios were quite different.

An appropriate mathematical model of a screen and a cleaner is needed to obtain a relationship

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between reject ratio and contaminant removal efficiency. One such model is based on the concept of screening quotient, introduced by Nelson (4). The screening quotient, Q, is defined as:

$$Q = \frac{E}{E_R}$$

or

$$q = 1 - Q = 1 - \frac{E}{E_R} = \frac{C_A F_R}{F_A C_R} = \frac{X_A}{X_R}$$

The relationship between the efficiency and reject ratio can then be derived as:

$$E = \frac{(1-q)R}{R + q(1-R)} = \frac{Q \cdot R}{1 - Q(1-R)}$$

and

$$E_R = \frac{R}{R = q(1-R)} = \frac{R}{1 - Q(1-R)}$$

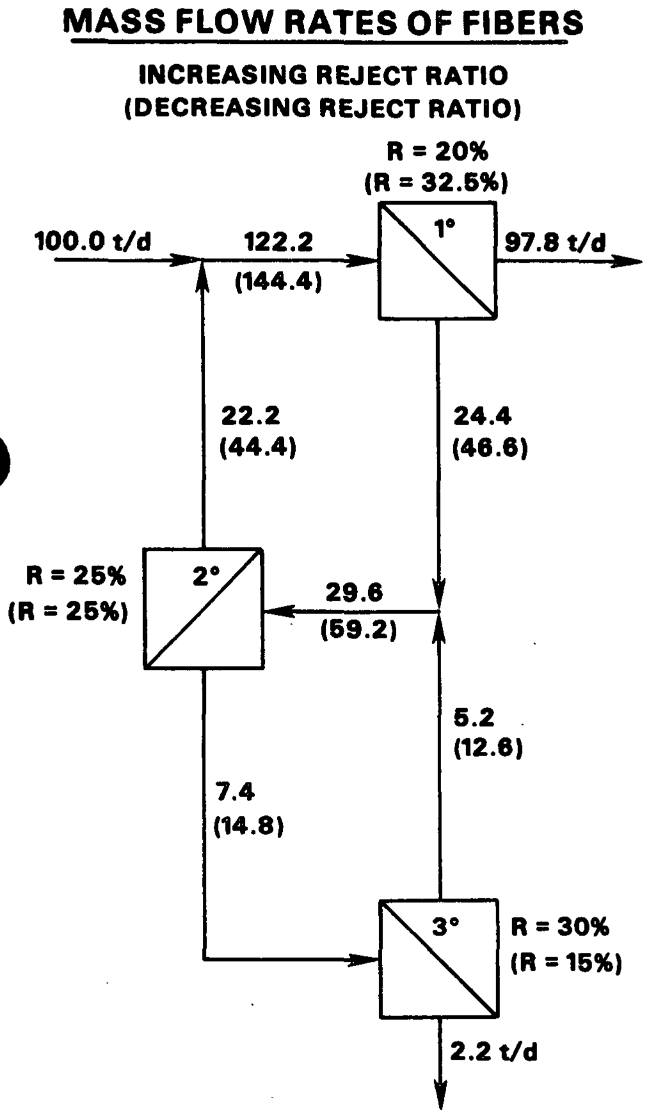

Fig. 5 Total flow rates for all streams for Case 3 - Increasing/Decreasing Reject Ratio. When two numbers are given, the top number corresponds to the case of Increasing Reject Ratio and the bottom one to the Decreasing Reject Ratio case. When both numbers are the same, only one number is stated.

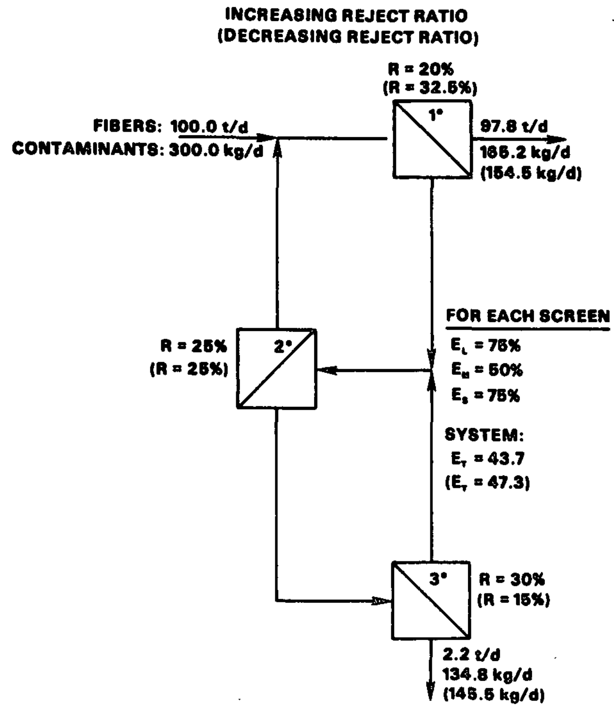

Fig. 6 Total flow rates of fibers (t/d) and contaminants (kg/d) for Case 3 - Increasing/Decreasing Reject Ratio.

Nelson assumes that the screening quotient, Q or q, is independent of reject ratio. This model has not been confirmed experimentally, but we will use it to show how it affects the results. MAPPS is capable of handling this model.

The above relationship between E_R and R is shown graphically in Fig. 7 for three different values of the screening quotient, q. It is clear that for a given reject ratio, the lower the value of q, the higher the efficiency.

Let us now consider the case of Increasing and Decreasing Reject Ratio considered earlier. The screening quotients, q, for large, medium, and small contaminants are assumed to be 0.0625, 0.167, and 0.375, repectively. Results shown in Fig. 8 indicate that, as before, the overall efficiency for the Decreasing Reject Ratio case is (54.6%) higher than that for the Increasing Reject Ratio case (45.8%). One can conclude that the strategy of Decreasing Reject Ratio should be adopted whenever possible.

Case 5. Recirculation and Disintegration of Contaminants

It is quite conceivable that some of the contaminants rejected in the primary stage can get accepted in the secondary stage. This cycle could continue and contaminants can possibly flow a number of times between stages. These recirculating contaminants could get disintegrated due to high shear forces in pumps, screens, cleaners or mixers and as a result leave the system via primary accepts. Certainly, such a recirculation and dis-

integration of contaminants could lead to reduction in the system efficiency.

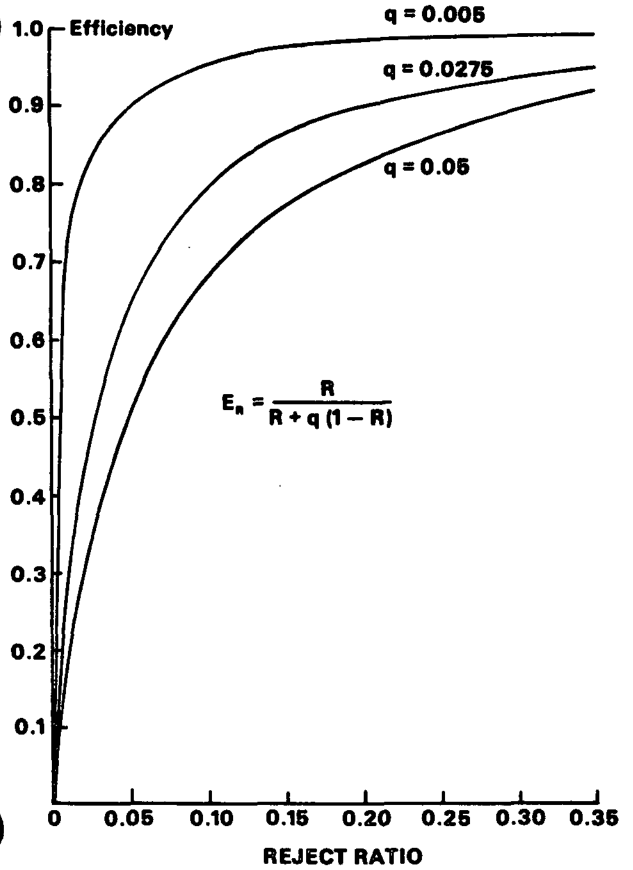

Fig. 7 Variation of efficiency with reject ratio based on the concept of screening quotient, q, Nelson (4).

A refiner module in the MAPPS library could be used to simulate disintegration of contaminants in the cascade system. One example of this computation is given in Fig. 9 for the case of Decreasing Reject Ratio, assuming efficiency to be 75, 50, and 25% for large, medium, and small contaminants, respectively. Refining energy consumed in each of the three refiners is assumed to be 1.0 kWh/ton. It was assumed that the energy consumed by the large size contaminants was 5 times that consumed by the medium size contaminants.

In Fig. 9, results with refining (WR) and without refining (WOR) are presented for comparison. The total flow of contaminants in the primary accepts increases from 154 kg/d to 207 kg/d due to disintegration of large and medium size contaminants. This 34% increase in the contaminants' flow rate results in the reduction in the total efficiency from 47.3% (WR) to 29.3% (WOR).

In this example, a relatively large portion of energy was consumed in disintegration. The variation of total system efficiency with the energy consumed in disintegration is shown in Fig. 10 for the Increasing/Decreasing Reject Ratio case. The cascade system with Decreasing Reject Ratio remained the most efficient irrespective of the amount of energy consumed in disintegration. Clearly, recirculation and associated disintegration of contaminants has a very detrimental effect on the overall performance of the system.

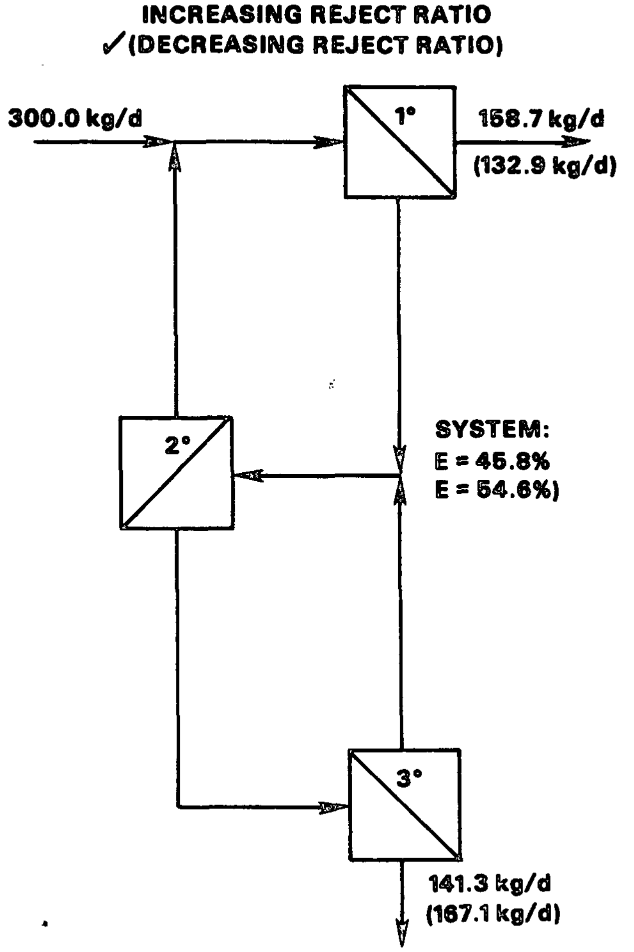

Fig. 8 Mass flow rates of contaminants for the case of Increasing/Decreasing Reject Ratio using the concept of screening quotient, q_L = 0.0625, q_m = 0.167, q_s = 0.375, for all units (Case 4).

Case 6. Forward Flow Arrangement

Several investigators have realized that further cleaning of tailing streams (secondary and tertiary stage accepts) could be quite beneficial. The recent trend is toward the application of fine screens, reverse cleaners, or other devices to clean up the tailing streams and thereby minimize the recirculation and disintegration of contaminants. As reported by Bennett and Koffinke (5), fine slotted screens in the reject system reduced the buildup of contaminants at the James River Corporation's mill in Kalamazoo, Michigan. Doshi et al. (1) have shown that by minimizing the recirculation of contaminants, the overall effectiveness of the stock preparation system at the Green Bay Packaging mill in Green Bay, Wisconsin, could be increased.

Another approach to avoid recirculation and minimize disintegration of contaminants is to use

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the forward flow arrangement, as shown in Fig. 11. One of the problems in the conventional cascade system is that when relatively dirty primary rejects and tertiary accepts are treated in the secondary stage, the resulting accept stream is not clean enough to be mixed with primary accepts. Therefore, this stream is further cleaned in the primary stage. But this gives rise to recirculation and concomitant disintegration of contaminants. In the forward flow arrangement this is avoided by providing series cleaning or screening in the secondary stage. Similarly, in the third stage series cleaning or screening is used so as to move the final accepts forward. As a result, contaminants do not get an exposure to excessive shear forces, and the detrimental recirculation and disintegration is avoided.

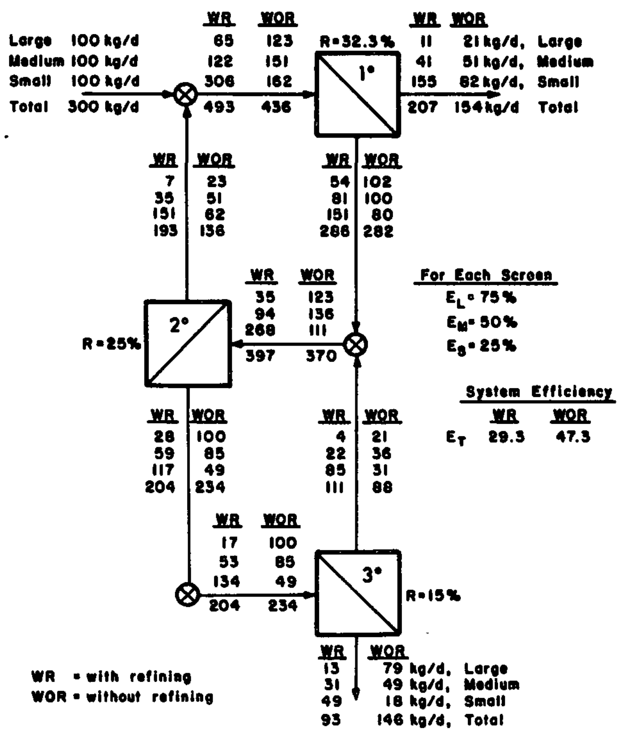

Fig. 9 The effect of recirculation and disintegration of contaminants, Case 5. The contaminant diminution occurs as streams go through refiners X which simulate the action of high shear forces in pumps, screens, cleaners, and mixers. Energy consumed in refiners is 1.0 kWh/ton and it is assumed that large size contaminants consume 5 times more energy than the medium size ones.

In the forward flow arrangement three reject streams leave the system, and also there are three accept streams. For meaningful comparison with the conventional cascade systems, reject ratios are chosen so that the overall system reject ratio is 2.2%, the same as that in the previous examples. The strategy of Decreasing Reject Ratio - found to be most effective - was considered in this example. As before, an efficiency of 75, 50, and 25% was assumed for large, medium, and small size contaminants, respectively, for all units.

Computer simulation results are displayed in Fig. 11, where the top and bottom numbers on each stream correspond to total mass flow rate (t/d) and total contaminants mass flow rate (kg/d). The overall system efficiency is 47.5%, close to that for the conventional cascade system (see Fig. 6). However, if recirculation and disintegration is taken into account, the efficiency of the conventional system could decrease substantially, as shown in Fig. 9 and 10.

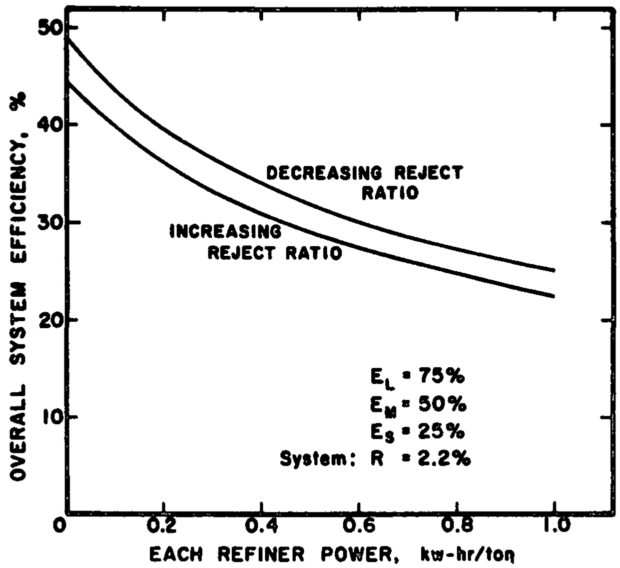

Fig. 10 The effect of contaminant disintegration on system efficiency, Case 5.

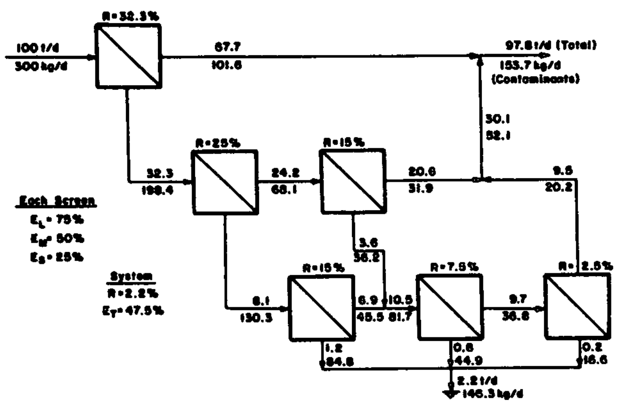

Fig. 11 Flow forward arrangement, Case 6. The top number on each stream corresponds to total mass flow rates (t/d) and the bottom one corresponds to mass flow rates of contaminants (large + medium + small).

It may appear at first glance that the capital cost of the forward flow arrangement could be substantially higher compared to that for the conventional arrangement. However, this is not necessar-

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ily the case if we look at the capacity requirements in each case. Total pulp treated in the conventional system is (144.4 + 59.2 + 14.8) 218.4 t/d, Fig. 5, as opposed to 15% less or only [100.0 + (32.3 + 24.2) + (8.1 + 10.5 + 9.7)] = 184.8 t/d in the flow forward arrangement, Fig. 11. Thus, the number of screens or cleaners required in the two systems may not be too different. The number of tanks and pumps needed in the forward flow system could be higher than those needed for the conventional system, but this should pay off in the long run by reducing the buildup of contami-nants, improving machine runnability, and improving product quality.

CONCLUSIONS

Computer simulation such as MAPPS, can be used to carry out numerical experiments to evaluate the performance of screening and cleaning systems. The following conclusions can be drawn from the results presented here:

1. A conventional three-stage cascade system of screens or cleaners is quite effective in reducing fiber loss but also lowers the contaminant removal efficiency of the system.

2. Due to differences in the contaminant size distributions, identical screens in different stages could have different efficiencies.

3. Whenever possible, the reject ratio of the primary stage should be as high as possible, while that of the tertiary stage should be as low as possible to increase the system contaminant removal efficiency without sacrificing fiber recovery.

4. An appropriate model relating reject ratio and efficiency, like the one used here based on screening quotient, can be used in the numerical experiments to obtain more meaningful results.

5. One of the problems with the conventional cascade system is the possible recirculation of contaminants between stages. This could have detrimental effects on the system contaminant removal efficiency.

6. The forward flow system (Fig. 11) is worth considering to avoid the recirculation of contaminants and thereby improve the system performance.

ACKNOWLEDGMENTS

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