

Increased disc separator throughput

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ABSTRACT *At present, there is no single satisfactory industrial process for recovering fiber from tailing streams of recycling mills. This study was undertaken to increase the throughput of a disc separator with a 152-mm-diameter disc from the present 0.23 metric tons/day at optimum conditions to the 2-3 metric tons/day required for use on an industrial scale. Practical fiber recovery also requires 98% contaminant removal. Experiments were performed to predict and verify the optimum operating conditions for 305-mm-diameter and 152-mm-diameter discs. The two types of discs had contaminant removal efficiencies within 2% of each other. (The contaminant was hot-melt adhesive in a simulated old corrugated furnish.) Accepts-to-feed ratios were about 9% lower for the 305-mm-diameter disc than for the 152-mm-diameter disc. Based on the optimized conditions, two primary disc separator sets in parallel, each set with three discs in series, would be needed to achieve 2.7 metric tons/day throughput, with the rejects of the primary disc separator sets fed to a secondary disc separator set. With this system, projected contaminant removal is 98%, and projected fiber recovery is 73%.*

KEYWORDS

Cleaning
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Fiber
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Separators

At present, there is no single industrial process that is satisfactory for recovering fiber from the tailing streams of mills that use recycled fiber (1). The problem is that the separation processes used by industry for recycling wastepaper have not been totally effective in removing contaminants. The problem contaminants are usually about the same size and density as wetted pulp fibers. Thus, screens and centrifugal cleaners that separate on the basis of size and density differences are not effective in removing such contaminants.

Experimental laboratory studies showed that disc separation can remove significant amounts of hot-melt adhesive (HMA) and pressure-sensitive adhesive from a simulated old corrugated container (OCC) furnish with low levels of fiber loss (2). Experiments with synthetic fiber showed that disc separation can separate not only by particle diameter and density differences but also by differ-

ences in contact (wetting) angle (3).

A study involving industrial tailing samples from a newsprint recycling mill showed that disc separation can effectively reclaim fiber while separating contaminants (4). Disc separation removed 93% of total contaminants, including 98% of stickies, in three passes. This separation reduced the total contaminant and stickies level of the recovered fiber to about that of pulp initially fed to the paper mill system. The fiber length of the recovered fiber was nearly twice the length of the fiber normally sent to the paper machine system, with only about a quarter of the fines.

The capacity of our experimental 152-mm-diameter separator is 0.23 metric tons/day at optimum operating conditions (2). We need to scale up to 2-3 metric tons/day to be able to apply disc separation on an industrial scale. The strategy of our study, therefore, was to increase the capacity of the separator. First, we would have

to determine how contaminant removal (HMA in a simulated OCC furnish) and fiber loss of the disc separator are affected by increasing the diameter of the disc from 152 mm to 305 mm. Second, based on this previous information, we would have to determine what combinations of discs are required to achieve a 2-3 ton/day throughput with sufficient contaminant removal (98%) to feed reclaimed fiber back to the mill.

Strategy to increase the capacity

Our strategy consisted of two steps. First, statistically designed experiments were performed from which models were developed to predict optimum operating conditions for the 152-mm- and 305-mm-diameter discs. Second, disc diameters and operating conditions were selected for processing 2-3 metric tons/day with 98% contaminant removal.

I. Predicted and experimental cleaning values for 152-mm- and 305-mm-diameter disc separators

Disc size and cleaning value	Predicted net value		Experimental net value		Experimental operating conditions					
	\$/t*	\$/day	\$/t*	\$/day	Feed rate, m ³ /h	Disc speed, rev/s	Feed solids, %	A/F ratio, %	E, %	Throughput, metric tons/day
152-mm-diameter										
Vnet	71	n.a.	79	n.a.	2.32	100.0	0.5	93.2	86.1	0.28
Vnet(p)	72	n.a.	79	n.a.	2.32	100.0	0.5	93.2	86.1	0.28
Vday(p)	n.a.	27	n.a.	39	2.48	100.0	1.1	84.6	77.0	0.65
305-mm-diameter										
Vnet	68	n.a.	75	n.a.	3.52	45.0	0.7	84.4	85.0	0.59
Vnet(p)	57	n.a.	75	n.a.	3.52	45.0	0.7	84.4	0.59	0.59
Vday(p)	n.a.	66	n.a.	90	5.68	43.9	1.4	75.4	78.8	1.90

n.a. = not applicable.
 *\$/t = dollars/metric ton.

Determination of optimum operating conditions

Optimum operating conditions were verified by experiments in which HMA was removed from a simulated OCC furnish. Optimum operating conditions were those that gave the maximum for each of three cleaning values, each of which was designed to stress different aspects of the separation:

1. *Vnet*: the value of the clean fiber corrected for fiber loss and cleaning efficiency minus the cost of energy needed to run the disc separator, expressed as dollars/ton of feed
2. *Vnet(p)*: *Vnet* with a penalty applied for operating conditions requiring excessive material handling, expressed as dollars/ton of feed
3. *Vday(p)*: *Vnet* multiplied by tons of feed/day and also penalized for operating conditions that require excessive material handling. This value is expressed as dollars/day.

These different cleaning values were designed to permit us to select operating conditions for the second step of our strategy.

Selection of disc diameters and operating conditions for optimal processing

The second step involved selecting disc diameters, combinations of number of discs, and operating conditions to process 2–3 metric tons/day with 98% contaminant removal. The predicted combinations were based on

experimental results at optimum conditions for individual discs, which were obtained in the first step. Operating conditions and separation predictions for discs between 152 mm and 305 mm in diameter were obtained by interpolating the separation conditions of the 152-mm- and 305-mm-diameter discs.

Results and discussion

Effect of disc diameter

At the best experimental conditions found for all three cleaning values, the disc diameter did not greatly affect the contaminant removal efficiency, *E*, as shown in Table I. Optimized *Vnet* and *Vnet(p)* cleaning values were within 2% of each other, based on differences in disc diameter. However, fiber recovery, as indicated by the accepts-to-feed ratio (*A/F*), was about 9% higher for the 152-mm-diameter disc than for the 305-mm-diameter disc. The penalty value for excessive material handling did not affect the *Vnet* values for either disc (*Vnet* ≈ *Vnet(p)*). Nor did it affect optimum feed rate, percentage of solids, *A/F*, *E*, or throughput. However, a penalty for excessive handling was required to capture an optimum for the *Vday* values. The cleaning value, *Vday*, of operating with a 305-mm-diameter disc was shown to be about twice that of the 152-mm-diameter disc because of the larger throughput of the larger disc.

Net cleaning value, *Vnet*. The *Vnet* predicted for the 152-mm-

diameter disc gave a value of \$71/ton of pulp feed. The experimental *Vnet* at about the same operating conditions resulted in a reasonably close value of \$79/ton of pulp feed, indicating the model was reasonably accurate. Lower values were obtained for the 305-mm-diameter disc, but these were reached with about the same dollar difference between the predicted and experimental values. The lower dollar values for the 305-mm-diameter disc resulted from greater fiber loss, and thus poorer separation was achieved with the 305-mm-diameter disc. This difference is indicated by the *A/F* ratio of 84.4% for the 305-mm-diameter disc compared to 93.2% for the smaller disc. The *E* value was 85.0% for the 305-mm-diameter disc, compared to 86.1% for the 152-mm-diameter disc.

Net cleaning value, with penalty, *Vnet(p)*. For the 152-mm-diameter disc, applying a penalty for conditions requiring excessive material handling, i.e., high fiber loss and low contaminant removal, resulted in a predicted value of \$72/ton of pulp feed compared to \$79/ton for the experimental value. These values are the same or very close to those obtained for the corresponding *Vnet* values. The 305-mm-diameter disc gave a similar correlation between *Vnet(p)* and *Vnet*. Thus, applying a penalty to *Vnet* for increased material handling had little effect on the predicted or experimental results.

Net cleaning production value, with penalty, *Vday(p)*. A maximum

II. Predicted values for primary and secondary disc separator sets^a

Separator type and disc number	Feed rate ^b		Disc diameter, mm	Disc speed, rev/s	A/F ratio, %	E, %	Contam- inant conc., %
	t/day ^b	m ³ /h					
Primary ^c							
No. 1 disc	1.36	5.68	305	36.7	79.8	70.5	0.500
No. 2 disc	1.08	4.53	252	58.3	81.4	72.5	0.19
No. 3 disc	0.89	3.69	215	73.3	82.6	74.2	0.06
Secondary ^d							
No. 1 disc	1.26	5.26	286	44.2	80.3	70.9	1.06
No. 2 disc	1.02	3.73	216	73.3	82.6	74.2	0.38
No. 3 disc	0.74	3.08	185	85.0	83.5	75.5	0.14
No. 4 disc	0.62	2.57	163	95.0	84.3	76.6	0.04

^a Accepts from primary separator sets: 0.735 × 2 = 1.47 metric tons/day. Accepts from secondary separator sets: 0.52 metric tons/day. Overall fiber recovery: 73.2%.

^b t/day = metric tons of feed per day. Feed: 1.0% OCC with 0.5% HMA contaminant (0.02% target).

^c Two separators fed with the fiber waste stream. Accepts concentration was 0.019%, and contaminant removal was 97.9%.

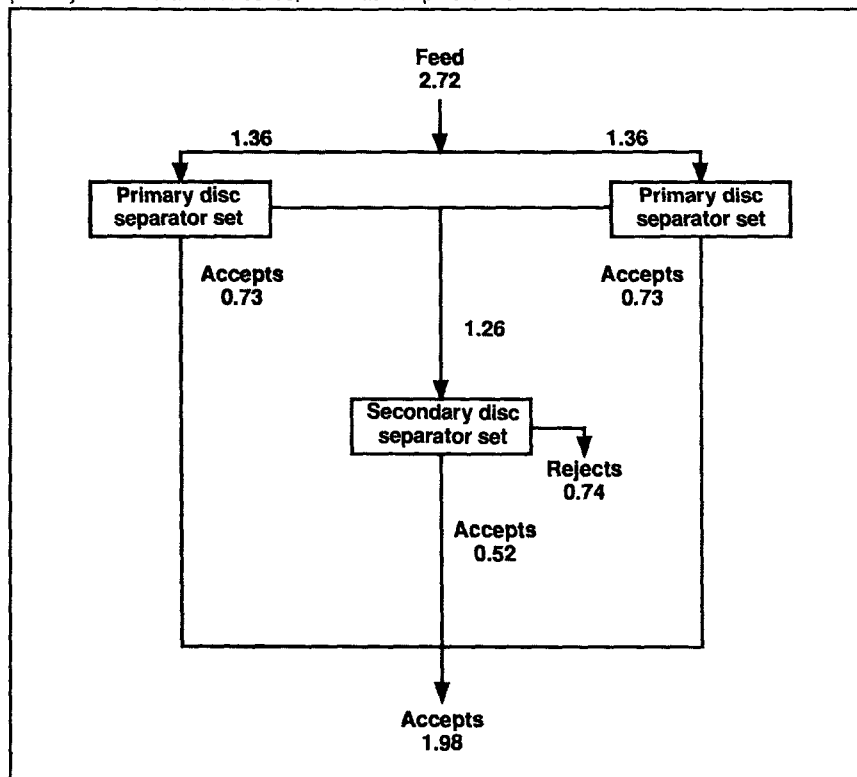
^d One separator fed with rejects from the primary separator. Accepts concentration was 0.009%, and contaminant removal was 99.6%.

$V_{day(p)}$ value could be achieved only by applying a penalty for excessive material handling. Otherwise, conditions with large volumes of material being passed over the disc appear good, even with low fiber recovery. The dollar values for this separation were greater for the 305-mm-diameter disc than for the 152-mm-diameter disc. The A/F ratio was 84.6% for the 152-mm-diameter disc compared to 75.4% for the 305-mm diameter. The E values were within 2% for the two discs, but the 305-mm-diameter disc processed much greater amounts of fiber per day (1.90 metric tons/day compared to 0.65 metric tons/day). This difference in the amount of fiber processed accounts for the \$90/day value for the large disc compared to the \$39/day for the 152-mm-diameter disc. The operating conditions for this optimum cleaning value differed greatly from that for the other two cleaning values.

Disc combinations required

Two 305-mm-diameter discs can be used in parallel to process 2.72 metric tons of pulp/day (Fig. 1). Feed solids at 1.0% and a feed rate of 5.63 m³/h give each disc a capacity of 1.36 metric tons/day, for a total of 2.72 metric tons/day. (The percentage of 1.0% solids is probably satisfactory for both the 305-mm- and 152-mm-diameter discs, as indicated in Table II.) To achieve a 98% contaminant removal rate, which we assumed was required for feeding accepts forward to a papermaking process, requires three

1. Schematic of predicted fiber recovery using disc separator sets. Values are in metric tons per day. All flows at 1.0% solids, with each separator set in series.



discs in series. The discs must be sequentially scaled down in diameter, as listed in Table II, to give predicted optimum performance based on interpolating results for the 305-mm- and 152-mm-diameter discs. The aggregate fiber recovery for the two primary disc sets was estimated as 1.46 metric tons/day.

Rejects from the two primary sets of discs can be fed to a secondary set

of discs. By interpolation, the secondary set of discs requires four discs with an accepts rate of 0.52 metric tons/day. The entire system consisting of two parallel sets of disc separators and one secondary set of disc separators will result in a predicted recovery rate of 73.2%. However, experiments are needed to verify the throughput and fiber recovery rates. In addition, experiments to verify the

application of this system on an industrial scale, such as recovery of fiber from a tailing stream, also require the use of a specific furnish.

Conclusions

When removing hot-melt adhesive from a simulated OCC furnish, contaminant removal efficiency is not greatly affected by increasing the disc diameter from 152 mm to 305 mm, as shown by comparing contaminant removal at three cleaning values at optimum operating conditions for 152-mm- and 305-mm-diameter discs. Contaminant removal efficiencies were all within 2% of each other for the two sizes of discs for all three cleaning values studied. However, the accepts-to-feed ratio was about 9% lower for the 305-mm-diameter disc.

Based on this information, two primary disc separator sets, each with three discs in series that decrease in diameter, are required for the desired capacity and contaminant removal efficiency. The rejects of the primary disc separator sets can be fed to a secondary disc separator set with four discs in series. The predicted designed system ratings are a capacity of 2.7 metric tons/day, a contaminant removal efficiency of 98%, and fiber recovery of 73%.

Materials and experimental conditions

Experimental procedure

Pulp slurries were prepared from HMA-contaminated corrugated fiberboard sheets, which were used to simulate OCC furnish contaminated with HMA (1). Separation of HMA from the fiber was optimized using two discs of different diameters: 152 mm and 305 mm. Both discs had 152-mm-diameter-wide lips (skirts) at 22.5° to the horizontal. The radius of the disc shoulder for both discs was 2.0 mm. Operating procedures, visual contaminant measurements, A/F ratio calculations, and energy measurements were performed as described earlier (1). Fiber costs were given a nominal value of \$100/metric ton.

Cleaning values

The problem was to develop realistic equations that measure the economic impact of changes in disc operating conditions and allow one to optimize

III. Equations for the different dollar values

For net value based on 1 metric ton of fiber feed:

$$\begin{aligned} V_{net}(p) &= V_{net} && \text{if } E > E_t \text{ and } A/F < A/F_t \\ &= V_{net} - V_i (E_t - E) && \text{if } E < E_t \text{ and } A/F > A/F_t \\ &= V_{net} - V_i (A/F_t - A/F) && \text{if } E > E_t \text{ and } A/F < A/F_t \\ &= V_{net} - (A/F_t - A/F) - (E_t - E) && \text{if } E < E_t \text{ and } A/F < A/F_t \end{aligned}$$

For cleaning value based on one day of production (metric tons/day):

$$\begin{aligned} V_{day}(p) &= V_{day} && \text{if } E > E_t \text{ and } A/F > A/F_t \\ &= V_{day} - V_i (E_t - E) && \text{if } E < E_t \text{ and } A/F > A/F_t \\ &= V_{day} - V_i (A/F_t - A/F) && \text{if } E > E_t \text{ and } A/F < A/F_t \\ &= V_{day} - (A/F_t - A/F) - (E_t - E) && \text{if } E < E_t \text{ and } A/F < A/F_t \end{aligned}$$

the operating conditions of the disc separator. First, some initial notation needs to be defined. Let V_i be the value of clean fiber (\$100/metric ton), and let V_e be the cost of energy, based on \$0.06/(kW·h), required to disc-separate 1 metric ton of feed solids. The net value of a single-pass separation in dollars/ton of feed solids may then be expressed as

$$V_{net} = [V_i - V_i(1 - E)](A/F) - V_e \quad (1)$$

The equation states the value of the separation is the value of clean fiber corrected for fiber loss and cleaning efficiency minus the cost of energy needed to drive the disc separator. At optimum operating conditions, V_{net} is at a maximum.

However, several additional factors must also be considered. First, Eq. 1 does not include a factor for the rate of separation. That is, the separation may take a long time to perform and may thus be impractical. This can be accounted for by multiplying V_{net} by the process rate, giving a cleaning value as the value of the separation in dollars per day.

$$V_{day} = V_{net} \text{ (metric tons of pulp/day)} \quad (2)$$

A final factor that must be considered is the cost of handling the material. The disc separator can be expected to operate at an A/F ratio of >0.85 . Also, an E value of 0.8 can be achieved. Operating conditions that do not reach both these target values, A/F_t and E_t , will result in excessive material handling. Thus, some sort of penalty is required for those cases in which the separation falls below either of the target efficiencies.

$$\text{Penalty value} = (\text{value of fiber/metric ton}) \\ (\text{target} - \text{actual}) \times (\text{metric tons of fiber fed})$$

This penalty is applied to the appropriate value being considered. Note that the value should not increase if the efficiency is above the target value. Equations can now be developed for each type of dollar value considered, and these are given in Table III. These equations in Table III were used in selecting optimum operating conditions for the 152-mm- and 305-mm-diameter discs described in Table I.

Experimental design

Optimum operating conditions were obtained by maximizing the cleaning values. A central composite experimental design was used to construct a three-dimensional model (disc speed, percentage of feed solids, and feed rate) of cleaning values. From this model, optimum conditions were predicted (5). The optimum operating conditions and predicted cleaning values are listed in Table I. The experimental verification of the predicted cleaning values is also listed.

Disc diameters and combinations

Plots of disc diameter compared to optimum disc speed, optimum feed rate, contaminant removal efficiency, and accepts-to-feed ratio were constructed. The accepts flow rate from the first disc to the second disc was known from experiments.

The plot of the flow rate compared to disc diameter was then used to establish the diameter of the second disc. Similarly, the optimum disc

speed, contaminant removal efficiency, and accepts-to-feed ratio could be estimated. The criteria for the third disc were estimated similarly.

The volume of combined rejects predicted from the two primary sets of disc separators was then used as a criterion for selecting the diameter and disc speed of the first disc separator in a secondary series of disc separators. Disc speeds and diameters were again selected by the method given above. Four discs were required to reach the target contaminant removal. The results of these interpolations are listed in Table II.□

Literature cited

1. Doshi, M. R., Secondary fibers: procurement, processing, properties, and products, Institute of Paper Chemistry, Appleton, Wis., 1983, p. 11-1.
2. Klungness, J. H., Tappi J. 70(3): 131(1987).
3. Klungness, J. H., Tappi J. 70(7): 125(1987).
4. Klungness, J. H., 1987 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 729.
5. Myers, R. H., Response, Surface Methodology, Allyn and Bacon, Boston, 1971, Ch. 5-7.

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