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INCREASED DISK SEPARATOR THROUGHPUT

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ABSTRACT

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

INTRODUCTION

At present, no single satisfactory industrial process exists for recovering fiber from recycling mill tailing streams *(1)*. This is because 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 disk separation can remove significant levels of hot-melt adhesive (WMA) 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 disk separation can separate not only by particle diameter and density differences, but by differences in contact (wetting) angle as well *(3)*.

A study involving industrial tailing samples from a newsprint recycling mill showed disk separation can effectively reclaim fiber while separating contaminants *(4)*. Disk separation removed 93% of total contaminants, including 98% of stickies, in three passes. This separation reduced the total contaminant and sticky level of the recovered fiber to about that of pulp fed forward to the papermill system. Approximately 70% of the original fiber was recovered. 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.

Capacity of the present experimental 152-mm-diameter separator is 0.23 metric tons per day at optimum operating conditions *(2)*. Scale-up to between 2 and 3 metric tons per day is needed to permit disk separation application on an industrial scale. The strategy of our study, therefore, was to increase the capacity of the separator by *(1)* determining how contaminant removal (HMA in a simulated OCC furnish) and fiber loss of the disk separator are affected by increasing the diameter of the disk from 152 to 305 mm diameter, and *(2)* based on the previous information, determining what combinations of disks are required to achieve a 2 to 3 ton per day throughput with sufficient contaminant removal (98%) to feed reclaimed fiber forward.

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- and 305-mm-diameter disks. Second, disk diameters and operating conditions were selected for processing 2 to 3 metric tons per day with 98% contaminant removal.

Determination of Optimum Operating Conditions

Optimum operating conditions were verified by experiments removing HMA 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 drive the disk, expressed as dollars per ton of feed.
2. Vnet(p), Vnet with a penalty applied for operating conditions requiring excessive material handling, expressed as dollars per ton of feed.
3. Vday(p), Vnet multiplied by tons of feed per day and also penalized for operating conditions that require excessive material handling. This value is expressed as dollars per day.

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

Selection of Disk Diameters and Operating Conditions for Optimal Processing

The second step involved selecting disk diameters] combinations of number of disks, and operating conditions to process

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2 to 3 metric tons per day with 98% contaminant removal. The predicted combinations were based on experimental results at optimum conditions for individual disks, which were obtained in the first step. Operating conditions and separation predictions for disks between 152 and 305 mm diameter were obtained by interpolating the separation conditions of the 152- and 305-mm-diameter disks.

RESULTS AND DISCUSSION

Effect of Disk Diameter

At the best experimental conditions found for all three cleaning values—Vnet,Vnet(p), and Vday(p)–disk diameter did not greatly affect the contaminant removal efficiency (E) (Table 1). Optimized Vnet and Vnet(p) cleaning values were within 2% of each other based on differences in disk diameter. However, fiber recovery, as indicated by the accepts-to-feed ratio (A/F), was about 9% higher for the 152-mni-diameter disk than for the 305-mm-diameter disk. The penalty value for excessive material handling did not affect the Vnet values for either diameter disk (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 disk was shown to be about twice that of the 152-mm-diameter disk because, of the larger throughput of the larger disk.

Table 1. Predicted and Experimental Cleaning Values for 152- and 305-mm-Diameter Disk Separators

Disk size and cleaning value	Predicted net value[a]		Experimental net value		Experimental operating conditions					
	$/t	$/da	$/t	$/da	Feed rate (m^3/h)	Disk speed (r/s)	Feed solids (%)	A/F ratio[b] (%)	E[c] (%)	Throughput (t/da)
152-mm-diameter										
Vnet	71	NA[d]	79	NA	2.32	100.0	0.5	93.2	86.1	0.28
Vnet(p)	72	NA	79	NA	2.32	100.0	0.5	93.2	86.1	0.28
Vday(p)	NA	27	NA	39	2.48	100.0	1.1	84.6	77.0	0.65
305-mm-diameter										
Vnet	68	NA	75	NA	3.52	45.0	0.7	84.4	85.0	0.59
Vnet(p)	67	NA	75	NA	3.52	45.0	0.7	84.4	85.0	0.59
Vday(p)	NA	66	NA	90	5.68	43.9	1.4	75.4	78.8	1.90

[a]$/t, dollars per metric ton of feed $/da, dollars per day.
[b]Accepts-to-feed ratio.
[c]Contaminant removal efficiency.
[d]Not applicable.

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

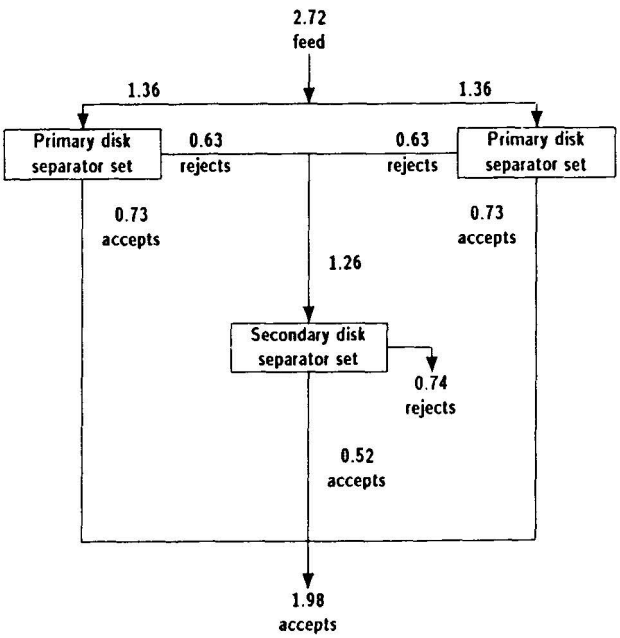
Net cleaning value, with penalty (Vnet(p)). For the 152-mm-diameter disk, applying a penalty for conditions requiring excessive material handling, i.e., high fiber loss and low contaminant removal, resulted in a predicted value of $72 per ton of pulp feed compared to $79 per ton for the experimental value. These values are the same or very close to those obtained for the corresponding Vnet values. The 305-mm-diameter disk 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 due, with penalty (Vday(p)). A maximum Vday(p) value could be achieved only by applying a penalty for excessive material handling. Otherwise, conditions with very large volumes of material being passed over the disk appear good even with low fiber recovery. The dollar values for this separation were greater for the 305-mm-diameter disk than for the 152-mm-diametcr disk. The A/F ratio was 84.6% for the 152-mm-diameter disk compared to 75.4% for the 305 mm diameter and the E values were within 2% for the two disks, but the 305-mm-diameter disk processed much greater amounts of fiber per day (1.90 compared to 0.65 t/da). This accounts for the $90 per day value for the large disk compared to the $39 per day for the 152-mm-diameter disk. The operating conditions for this optimum cleaning value differed greatly from that for the other two cleaning values.

Disk Coinbinations Required

Two 305-mm-diameter disks can be used in parallel to process 2.72 metric tons of pulp per day (Figure 1). Feed solids at 1.0% and feed rate of 5.63 m^3/h give each disk a capacity of 1.36 metric tons per day, for a total of 2.72 metric tons per day. (The percentage of 1.0% solids is probably satisfactory for both the 305-mmn- and 153-mm-diameter disks; see Table 2.) To achieve a 98% contaminant removal rate, which we assumed was required for feeding accepts forward to a papermaking process, requires three disks in series. The disks must be sequentially scaled down in diameter. as listed in Table 2, to give predicted optimum performance based on interpolating results for the 305- and 152-mm-diameter disks. The aggregate fiber recovery for the two primary disk sets was estimated as 1.16 metric tons per day.

Rejects from the two primary sets of disks can be fed to a secondary set of disks. By interpolation, the secondary set of disks requires four disks with an accepts rate of 0.52 metric tons per day. The entire system consisting of two parallel sets of disk separators and one secondary set of disk 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 application of this system on an industrial scale, such as recovery of fiber from a tailing stream, also require use of a specific furnish.



Schematic of predicted fiber recovery using disk separator sets. Values in metric tons per day. All flows at 1.0% solids. Each separator set in series.
Primary set: 305-, 252-, and 215-mm-diameter disks.
Secondary set: 286-, 216-, 185-, and 163-mm-diameter disks.

Figure 1.

Table 2. Predicted Values for Primary and Secondary Disk Separator Sets[a]

Separator type and disk number	Feed rate[b] (t/da)	Feed rate[b] 7(m/h)	Disk diameter (mm)	Disk speed (r/s)	A/F ratio[c] (%)	E[d] (%)	Contaminant concentration (%)
Primary[e]							
No. 1 disk	1.36	5.68	305	36.7	79.8	70.5	0.50
No. 2 disk	1.08	4.53	252	58.3	81.4	72.5	0.19
No. 3 disk	0.89	3.69	215	73.3	82.6	74.2	0.06
Secondary[f]							
No. 1 disk	1.26	5.26	286	44.2	80.3	70.9	1.06
No. 2 disk	1.02	3.73	216	73.3	82.6	74.2	0.38
No. 3 disk	0.74	3.08	185	85.0	83.5	75.5	0.14
No. 4 disk	0.62	2.57	163	95.0	84.3	76.6	0.01

[a]Accepts from primary separator sets, 0.735(2) = 1.47 t/da. Accepts from secondary separator set, 0.52 t/da. Overall fiber recovery, 73.2%.
[b]Metric tons of feed per day (t/da). Feed, 1.0% solids old corrugated container (OCC) with 0.5% hot-melt adhesive (HMA) contaminant (0.02% target).
[c]Accepts-to-feed ratio.
[d]Contaminant removal efficiency.
[e]Two separators fed with fiber waste stream. Accepts concentration was 0.019% and contaminant removal, 97.9%.
[f]One separator fed with rejects from primary separator. Accepts concentration was 0.009% and contaminant removal, 99.6%.

Conclusions

When removing hot-melt adhesive from a simulated OCC furnish, contaminant removal efficiency is not greatly affected by increasing disk 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 disks. Contaminant removal efficiencies were all within 2% of each other for the two sizes of disks for all three cleaning values investigated. However, the accepts-to-feed ratio was about 9% lower for the 305-mm-diameter disk. Based on this information, two primary disk separator sets, each with three disks in series that decrease in diameter, are required for desired capacity and contaminant removal. The rejects of the primary disk separator sets can be fed to a secondary disk separator set with four disks in series. The predicted designed system ratings are capacity of 2.7 metric tons per day, contaminant removal 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 disks of different diameters: 152 and 305 mm. Both disks had 152-mm-diameter-wide lips (skirts) at 22.5° to the horizontal. The radius of the disk shoulder for both disks 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 per metric ton.

Cleaning Values

The problem was to develop realistic equations that measure the economic impact of changes in disk operating conditions and allow one to optimize the operating conditions of the disk separator. First, some initial notation needs to be defined. Let Vi be the value of clean fiber ($100 per metric ton) and Ve. the cost of energy, based on $0.06 per KWH, required to disk-separate 1 metric ton of feed solids. The net value of a single-pass separation in dollars per metric ton of feed solids may then be expressed as

$$\text{Vnet} = [\text{Vi} - \text{Vi}(1 - \text{E})](\text{A/F}) - \text{Ve} \qquad (1)$$

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 disk. At optimum disk separator operating conditions, Vnet is maximized.

However, several additional factors must also be considered. First, equation (1) does not consider 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 Vnet by the process rate giving a cleaning value as the value of the separation in dollars per day.

$$\text{Vday} = \text{Vnet}(\text{metric tons of pulp/day}) \tag{2}$$

A final factor that must be considered is the cost of handling the material. The disk 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 where the separation falls below either of the target efficiencies.

$$\begin{aligned}\text{Penalty value} = {} & (\text{Value of fiber/metric ton})(\text{Target} - \text{Actual}) \\ & \times (\text{Metric tons of fiber fed})\end{aligned}$$

This penalty is applied to the appropriate value being considered. Note that the value should not increase if above target. Equations can now be developed for each type of dollar value considered.

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

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

For cleaning value based on one day of production,

$$\begin{aligned}\text{Vday}(p) &= \text{Vday} && \text{if } E > E_t \text{ and } A/F > A/F_t \\ &= \text{Vday} - \text{Vi}(E_t - E) \quad t/da && \text{if } E < E_t \text{ and } A/F > A/F_t \\ &= \text{Vday} - \text{Vi}(A/F_t \\ &\qquad - A/F) \quad t/da && \text{if } E > E_t \text{ and } A/F < A/F_t \\ &= \text{Vday} - (A/F_t - A/F) \\ &\quad - (E_t - E) \quad t/da && \text{if } E < E_t \text{ and } A/F < A/F_t\end{aligned}$$

The above equations were used in selecting optimum operating conditions for the 152- and 305-mm-diameter disks described in Table 1.

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 (disk 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 1. Experimental verification of the predicted cleaning values is also listed.

Disk Diameters and Combinations

Plots of disk diameter compared to optimum disk speed, optimum feed rate, contaminant removal efficiency, and accepts-to-feed ratio were constructed. The accepts flow rate from the first disk to the second disk was known from experiments. The flow rate compared to disk diameter plot then established the diameter of the second disk. Similarly, the optimum disk speed, contaminant removal efficiency, and accepts-to-feed ratio could be estimated. The criteria for the third disk were estimated similarly.

The volume of combined rejects predicted from the two primary sets of disk separators was then used as a criterion for selecting the diameter and disk speed of the first disk separator in a secondary series of disk separators. Disk speeds and diameters were again selected by the method given above. Four disks were required to reach the target contaminant removal. The results of these interpolations are listed in Table 2.

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