FIBER SEPARATION WITH A VANELESS SPINNING DISK: DETERMINATION OF MECHANISM

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ABSTRACT

Present pulp cleaning and screening processes are restricted in their effectiveness, especially at medium and high solids content. Pulp fractionation with a spinning disk is an alternate method that has potential for cleaning and upgrading pulp furnishes. In the present study, the mechanisms involved in spinning disk fractionation were investigated in order to determine disk designs which might be more appropriate for pulp separations.

Disks designed to atomize liquids for spray drying were found to be inappropriate for efficient fiber fractionation. Specially designed wide-lip disks were used to examine separations of different rayon fiber slurries. The results indicated that fiber separation occurs primarily at the leading edge of the lip (disk shoulder) with the fibers detaching themselves from the liquid film. Detachment occurs when centrifugal and inertial forces, which tend to free the fibers from the film, overcome the surface force which tends to retain the fibers in the film.

The results indicated that further evaluations are needed to optimize both disk design and operating conditions for more efficient use of wood fiber raw materials.

Keywords: Centrifugal force, corrugated containers, design criteria, disks, inertia, interfacial tension, mechanisms, rayon fibers, recycling, separation, waste papers.

INTRODUCTION

Upgrading wood fiber raw materials by separation, as practiced in the United States, is typically based on size (screening) and density (centrifugal cleaning). Both methods limit the use of low-quality raw materials because of their inability to remove certain substances. They also require large volumes of water for operations which results in high energy consumption. A new method, which has shown some success, for separating paper-making fibers has been reported (1-2).

In these reported separations, conventional industrial vaneless spinning disks designed specifically to atomize liquids for spray drying apparently were used. We initially used similar disks with an old corrugated container furnish and achieved some measure of success in separating the components (Table 1).

Table 1. Separation of old corrugated container by conventional bottom-fed disk.

<table>
<thead>
<tr>
<th>Fraction number</th>
<th>Solids distribution of total solids</th>
<th>Canadian average fiber length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>14.0</td>
</tr>
<tr>
<td>2</td>
<td>1.6</td>
<td>19.1</td>
</tr>
<tr>
<td>3</td>
<td>1.7</td>
<td>14.9</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>11.0</td>
</tr>
<tr>
<td>5</td>
<td>1.3</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Disk diameter: 203 mm; disk speed: 9400 rpm. Feed rate: 1.5 l/min.

-Numbered consecutively from top of spray pattern.

It was felt that disk design as well as operating conditions would have to be improved significantly to effect acceptable separations in pulp furnishes. The purpose of this study was to:
1. Understand better the mechanisms involved in fiber separation with a vaneless spinning disk and
2. Suggest disk design changes which might improve the potential of disk separation for processing wood fiber furnishes for papermaking.

The investigation was conducted cooperatively between the Chemical Engineering Department of the University of Wisconsin and the Forest Products Laboratory.

RESULTS AND DISCUSSION

Deficiencies in Prior Proposed Mechanisms

Mechanisms governing the separation have been proposed by Felsvang et al. (1) and Holler et al. (2) to manifest themselves in the thin liquid film on the disk surface (Fig. 1) and are described as
follows: The high shear field, caused by the centrifugal force imparted to the liquid film by the disk, causes fibers to migrate to preferred locations in the film. The larger the particle the more it tends to migrate from regions of high shear (i.e., near the wheel surface) to regions of low shear (i.e., towards the free surface of the film). At the same time, the denser particles tend to migrate preferentially towards the concave wheel surface because of centrifugal force. A combination of the two forces produces a distribution of suspended particles according to size and density across the film thickness. This distribution is assumed to be maintained to the disk edge, where the film is atomized, and to result in the observed separations.

However, preliminary experiments tend to refute portions of these early proposals for curved disks. For example, fiber separations occurred with flat disks which indicate that disk curvature is not important. Also, in dilute fiber concentration the theoretical film thickness at the disk edge is the same order of magnitude as the fiber diameters. Under these conditions any distribution of fibers within the film near the disk center would be lost at the disk shoulder.

Fiber Alignment

Rayon fibers in water slurries fed to the center of a rotating disk surface tend to separate from each other and align radially as they move within the liquid film toward the disk shoulder. At the leading edge of the disk lip, fibers can be released with radial orientation. This has been recorded photographically. It is believed that the radial alignment is a result of the intense shear field existing within the flowing liquid film.

Lip Wetting

Application of a hydrophobic silicone lubricant to the lips of wide-lip top-fed disks allowed study of the effects of lip wettability. Figure 2 is a schematic representation illustrating the experimental results where various degrees of separation for two different diameter fibers were attained as a function of lip length covered with silicone lubricant. Lip surface wettability is required to promote adherence of the liquid film to the lip surface as fractionation occurs when the liquid film turns the corner at the disk shoulder and flows along the lip. If the entire lip is nonwettable, DO liquid film forms on the lip and no fiber separation occurs. As the fraction of upstream lip surface not covered with the lubricant increases, both the length of lip wetted by the liquid film and quality of fiber separation increase.

Lip Angle

Increasing the lip angle aids fiber separation. For example, a 67.5° lip angle produced complete separation of fibers at 4200 rpm, as shown in Fig. 3, but no separation resulted with a 22.5° lip angle at the same disk speed. With both lip angles the liquid film wetted the lip surface, turned the corner, and travelled the entire 51-mm lip length. The 54-µm-diameter fibers detached themselves from the film when the lip angle was 67.5° but did not when the lip angle was 22.5°. In both cases the 18.2-µm-diameter fibers remained in the liquid film all the way to the lip edge.

Fiber Length

All previous separations were conducted with fibers that differed in diameter only. Experiments with mixtures of fibers differing in both diameter and length showed that separations seemed to correlate with diameter and not with length. Experiments were conducted with disks having 45° and 67.5° lip angles, and mixtures of four sizes of rayon fiber with diameters of 18.2 and 54 µm and lengths of 3.2 and 6.4 mm with each fiber size dyed a separate color. The results are shown in Fig. 4.
Fig. 3. Fractionation of fibers with disks having lip angles of 67.5° and 22.5°. Dirk speed = 4200 rpm, fiber length = 3.2 mm; flow rate = 3 l/min; disk diameter = 152 mm.

Fig. 4. Effect of fiber length versus fiber diameter on fractionation of dyed rayon fibers. Disk speed = 4200 rpm; lip angle = 45° and 67.5°; flow rate = 3 l/min; disk diameter = 152 mm.

The 18.2-µm-diameter fibers (green and red) separated from 54-µm-diameter fibers (yellow and black) and even collected in two distinct groups. Each group contained the two fiber lengths but only one fiber diameter. In all cases the 18.2-µm-diameter fibers remained in the liquid film all the way to the lip edge, while the 54-µm-diameter fibers started detaching themselves from the liquid at the disk shoulder.

Dirk Speed

Dirk speed, as well as lip angle, is important in detachment of fibers from the liquid film. Table 2 shows the results of fiber separation for four disk speeds and lip angles of 22.5°, 45°, and 67.5° with fiber mixtures of 18.2-, 26-, and 54-µm-diameter. In these experiments the flow rate was kept at 3 l/min to maintain film integrity over the entire lip surface.

At 6000 rpm, detachment of the 54-µm-diameter fibers occurred at all three lip angles. At lower dirk speeds a larger lip angle was needed to detach the fibers. For example, at 2740 rpm detachment occurred only with the 67.5° lip angle. But at 1920 rpm no detachment occurred at any of the three angles investigated. Observation showed the 26-µm-diameter fibers detaching themselves from the film at a dirk speed of 6000 rpm and a lip angle of 67.5°. Again, in all cases the 18.2-µm-diameter fibers remained in the liquid film all the way to the lip edge. This was true for both the mixtures of fibers 3.2- and 6-mm-long.

Flow Rate

Increasing flow rates as well as lip angles and disk speeds caused disengagement of a part of the liquid film at the disk shoulder and the lip surface because of liquid film instabilities. Table 3 summarizes the results of experiments conducted to determine the critical flow rate above which instabilities form for different lip angles and operating speeds.

For example, with a disk having a 67.5° lip angle, rotating at 4200 rpm and processing a mixture of 54- and 18.2-µm-diameter fibers of 3.2-mm-length, the flow rate was progressively increased. A critical flow rate was established as the point at which the upper spray zone containing 54-µm fibers began to show tracer of 18.2-µm fibers. The liquid film flowing over the lip surface at this flow rate was no longer stable. This instability caused ligaments and drops to form and break off the surface of the film. These liquid particles carried the 18.2-µm fibers with them and reduced the quality of the 54-µm fiber fraction.
Table 3. Critical flow rates

<table>
<thead>
<tr>
<th>Lip angle degree</th>
<th>Disk speed (rpm)</th>
<th>Flow rates (g/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.5</td>
<td>1920</td>
<td>7.3</td>
</tr>
<tr>
<td>45</td>
<td>2740</td>
<td>6.0</td>
</tr>
<tr>
<td>67.5</td>
<td>4200</td>
<td>4.8</td>
</tr>
</tbody>
</table>

*From fiber mixtures 18.2, 26 and 54 µm in diameter, both 3.2-mm and 6-mm long.

Apart from the formation of ligaments and drops on the lip surface, the liquid film also began to show instabilities of the leading edge of the lip. At a flow rate of about 4 g/min, a fraction of the liquid started to detach itself from the film at this point.

Amendment to Separation Mechanism

Earlier investigators (1-4) proposed that fiber separation occurred because of particle migration within the liquid film flowing on the disk surface. The particle size and density distribution across the film thickness was considered to be maintained after the suspension was dispersed at the disk edge. The experiments suggest that other phenomena which occur at the disk shoulder and on the surface of the disk lip are critical factors in producing particle separations. Separation occurs because of: (1) the interaction of three forces acting primarily at the disk shoulder, and (2) the ability of the disk lip to be wetted by the liquid. These factors cause a sudden change in the direction of the liquid with respect to the solid particles. In addition, the lip length should be sufficient to allow adequate separation of the fibers and sprays ejected respectively from the shoulder and trailing edge of the disk lip.

CONCLUSIONS

1. Fiber separation from a liquid suspension fed to a vaneless spinning disk occurs primarily at the disk shoulder. When a liquid suspension is fed to the center of a rotating disk, the fibers tend to align in the radial direction as the entire suspension travels radially toward the outer circumference of the disk.

The at disk shoulder the liquid film adheres to the disk surface and turns the corner to follow the shoulder. As a result, the solid fibers are subjected to three forces. Centrifugal force resulting from the rotation of the disk, and inertial force resulting from the change in direction of the liquid suspension act at the disk shoulder to eject the fibers from the liquid film (Fig. 5). These forces are opposed by the surface force which tends to retain the particle within the film.

2. Disk characteristics and operating conditions are critical to the interaction of these forces. The net force at the disk shoulder can be partially controlled by the shoulder design for optimum removal of selected fibers in a partially dewatered state.

The lip beyond the disk shoulder should be wide to direct the liquid film away from the fibers separated at the disk shoulder. This allows the separated fibers and sprays to be collected separately before their dispersion patterns merge and mix as in the case of conventional short-lip disks.

Further investigations are needed to determine how disk design, together with operating conditions, can aid in optimizing pulp separation processes.

MATERIALS AND EXPERIMENTAL PROCEDURES

Equipment

Specially designed flat, aluminum disks with wide lips were fabricated to study the effect of lip angle and width. These disks had:

- 152-mm-diameter flat surfaces
- 51-mm-wide outer lips
- Lip angles measured from the horizontal of 22.5°, 45° and 62.5°.
Conventional bottom-fed disks obstruct observation of the liquid flow from below. To enhance the view, equipment for top-feeding the disks was assembled. This apparatus allowed the operator to vary disk speeds up to 6000 rpm by changing the pulley arrangements between the motor and driveshaft.

Materials

Experiments were simplified by using commercial rayon fibers of uniform sizes for accurate control of fiber dimensions. Feed was prepared with appropriate portions from batches of fibers of uniform dimension. Each batch of fibers was dyed a separate color so separation efficiency could be seen immediately.

Procedure

Solids, at about 0.2% by weight, fed to the disk center resulted in a spray which was collected on a pad covered with cheesecloth at a distance of 150 mm from the edge of the disk. Vertical variations in colors of the fiber mat retained on the cheesecloth, recorded by color photographs, determined the degree of separation.

LITERATURE CITED