

# Fundamental study of screening hydraulics

## Part 2: Fiber orientation in the feed side of a screen basket

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**ABSTRACT:** *This study examines fiber motion at the feed-side surface of smooth and contoured screen baskets. Fiber orientation was strongly dependent on flow velocity and distance from the basket surface. Fiber trajectory toward a screen opening was very sensitive to the height of the contours at the basket surface. The degree of fiber stapling/hanging strongly affected throughput for the contoured baskets and was dependent on (a) the position of the contour relative to the screen opening and (b) the size and intensity of the eddy at the wake zone. Stapling can be reduced by using screens with hole patterns or slot distances exceeding the average length of the fiber in the furnish. Optimum throughput can be obtained by selecting a screen with appropriate spacing for a given application, bearing in mind that throughput is increased by sacrificing efficiency.*

**KEYWORDS:** *Baskets, containers, curves, fibers, flow, fluid mechanics, fractionation, hydraulics, mechanics, orientation, screening, separation, trajectories.*

This is part 2 of a three-part work investigating the fundamental hydraulics of screening. Part 1 examined the flow patterns around different screen baskets, described how fiber mats are formed on basket surfaces, and explained how fiber mats are remixed and rediluted during

screening (1). Part 2 presents the results of experiments studying the trajectory of fibers as they approach apertures on different types of screen baskets. The paths of fibers approaching screen apertures were observed with the aid of a high-speed video camera. Fiber speeds were

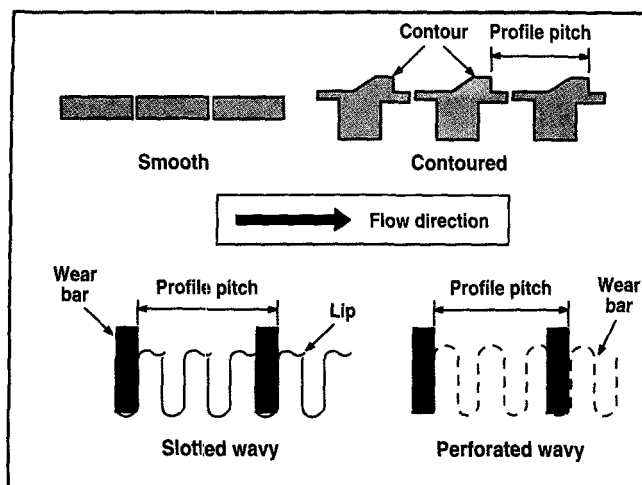
determined from the video images. In part 3 of this report [presented elsewhere in this issue (2)], a preliminary model is proposed for estimating the effective open area available for fiber to pass through a screen based on rotor characteristics, furnish type, and basket design. This model takes into account the results of our earlier work examining the mechanism of fiber-mat formation (1), fiber behavior at screen apertures (2), and the pulsation mechanism inside a screen (3).

### Experimental work

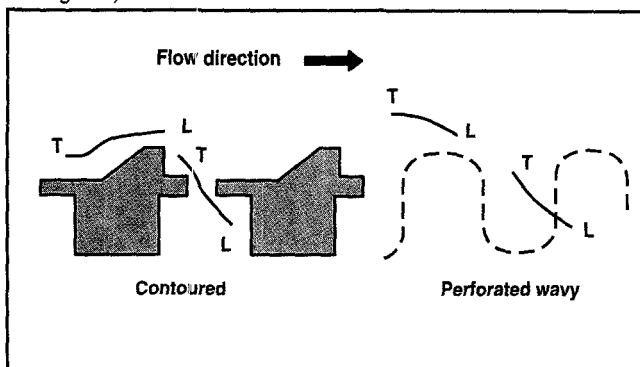
Four screen-basket designs were modeled using samples from four different baskets: perforated smooth, slotted smooth, slotted wavy, and perforated wavy baskets. **Figure 1** shows cross sections of these models. The laboratory apparatus used to study flow patterns is shown in **Fig. 2**. The laboratory device was installed on the top of a tank, with the flow entering from the left-hand side. Some pulp slurry flows out of the device from the openings of the basket model (i.e., the accept flow); the rest flows back to the tank from the right-hand side of the model (i.e., the rejects). Flow rates were varied from 1 m/s to 9 m/s.

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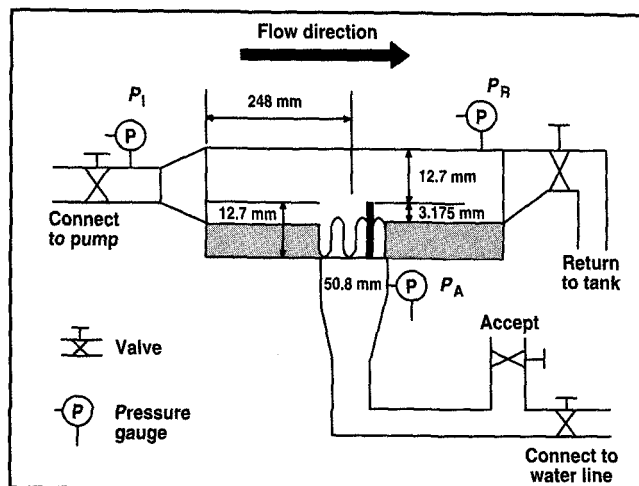
## 1. Basket models



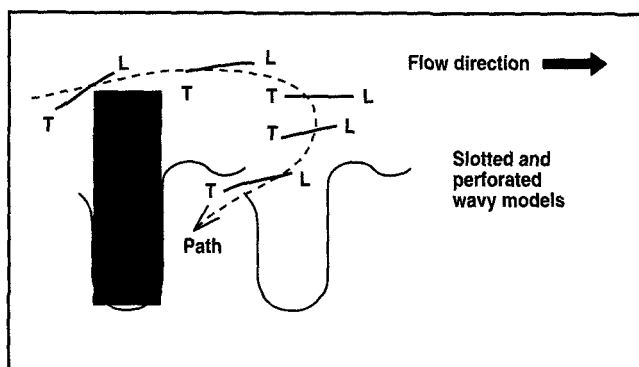
3. Leading end of fiber passing through openings in two types of screens via the flow-reattachment mechanism (L = leading end; T = trailing end)



## 2. Laboratory apparatus for study of flow patterns



4. Trailing end of fiber passing through an opening in a wavy basket via the vortex flow mechanism (L = leading end; T = trailing end)



The tank—40 in. long, 20 in. wide, and 24 in. high—was about 80% full during the experiments. In order to track the movement of individual fibers, only about 200 mL of bleached softwood kraft pulp at 3% consistency was added to the tank. The resulting consistency was about 0.0024%, and the average fiber length was 2.45 mm. A Nac HSV-400 high-speed video camera was used to record the fiber motion. The camera was placed in front of the laboratory apparatus, which was constructed of transparent plexiglass. A strobe light was set up on the back side of the model.

Results for the four basket models are presented and discussed. The figures depicting fiber motions are direct copies of the recorded video images.

## Discussion

### How fiber passes through an aperture

There are three ways for a fiber to pass through an aperture during the positive pulse period

1. The leading end of a fiber goes first.
2. The trailing end of a fiber goes first.
3. The central portion of a fiber goes first.

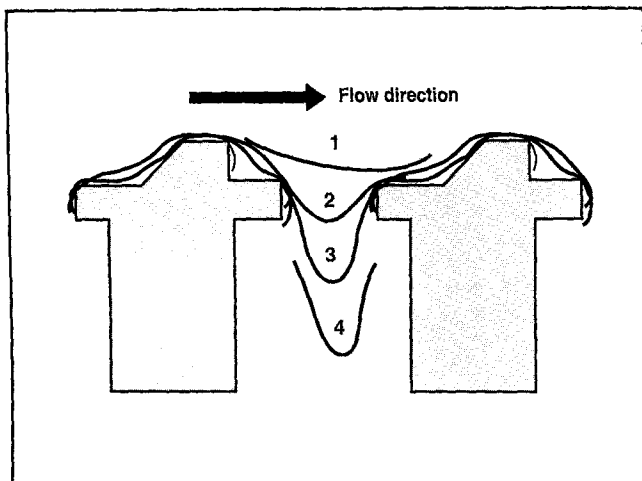
The dominant factors determining the way a fiber passes through an aperture were (a) the flow pattern at the screen surface, (b) the flexibility of the fiber, and (c) the

radial distance between the fiber and the basket surface.

**Leading end.** If the leading end of the fiber is to pass through an aperture, the flow-reattachment mechanism is essential (1). **Figure 3** shows the leading end of a fiber passing through openings in two different types of screens. This phenomenon was observed in smooth, perforated wavy, and contoured screen baskets.

**Trailing end.** For the trailing end of a fiber to pass through an aperture first, the vortex flow mechanism (1) is needed. As shown in **Fig. 4**, the fiber aligns itself along the streamline as it approaches the profile (wear bar). However, the presence of a vortex to the right of the profile causes

5. Center of fiber passing through opening in a contoured basket



the streamline to turn sharply before it eventually passes through an aperture. Figure 4 clearly shows that the fiber does not have enough time to adjust its orientation to realign with the streamline, and while the streamline sees the opening, the trailing end of the fiber is being dragged through the opening. This phenomenon was observed only in the wavy models (slotted or perforated).

**Central portion.** A fiber that is very close to the basket surface can span the opening like a free-end beam, as seen in Fig. 5. The flow through the opening causes the fiber to deform and bend, eventually folding so that the center of the fiber passes through the opening first. This phenomenon was observed in smooth and contoured baskets.

### Fiber orientation

**Perforated wavy basket.** An individual fiber in three consecutive video frames is shown in Fig. 6. The numbers in Fig. 6 indicate elapsed time from the beginning of the particular videotaped sequence. (Similar notation is also used in Figs. 7–11.) The actual length of the view inside this frame is about 15 mm. Accordingly, the length of the fiber in this figure is about 2.8 mm, and its velocity is about 0.98 m/s, which is very close to the mean velocity of 1 m/s. This indi-

cates that the speed of a fiber passing through an aperture is similar to the mean velocity of stock between rotor and basket. Thus fiber speed is determined by the rotor's rotational speed, clearance, and design (3).

The angle between the fiber and the horizontal flow direction increased when the fiber approached the wear bar. This indicates that flow is turning upward, as expected. In the recorded videotape, a clear vortex is also seen prior to the wear bar.

The fiber motion above the wear bar is depicted in Fig. 7, which shows two types of fiber orientation. The fiber can either align itself perpendicular to the streamline of flow (Orientation I), or it can align parallel to the streamline of flow (Orientation II). This phenomenon can be explained as follows: If a fiber approaches the wear bar at a position less than 90° from the flow direction, the flow acceleration before the wear bar causes the fiber to stretch out and align onto the streamline. Fibers that are close to an angle of 90° from the flow direction are not affected by the flow acceleration. For fibers in this position, the flow at one end is not appreciably faster than the flow at the other end, so they maintain their original orientation. This observation agrees with the work done by Moss and Bryant (4).

6. Fiber motion before the wear bar on a perforated wavy basket (Numbers in Figs. 6–11 indicate elapsed time.)

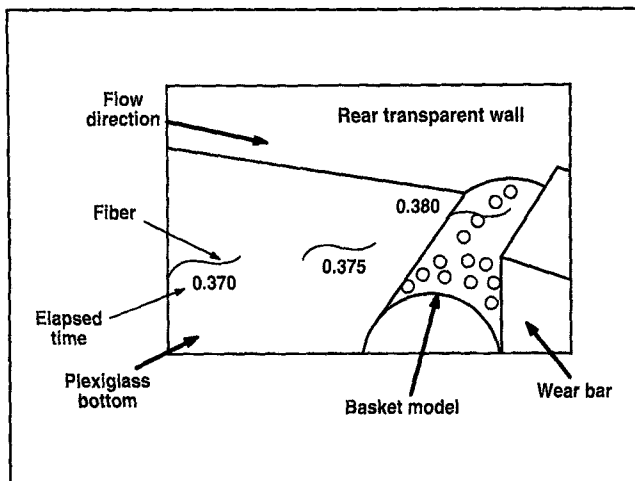
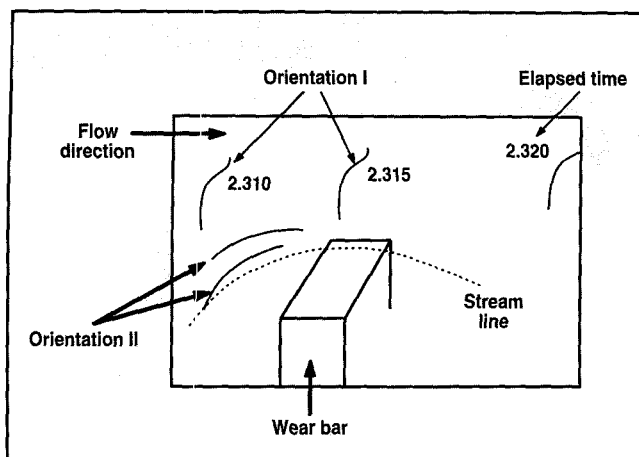


Figure 8 shows one type of fiber motion between wear bars. Flow direction is perpendicular to the wear bar and moves from left to right. From the time sequence in Fig. 8, it is apparent that the fiber is moving in the opposite direction of flow. In other words, the fiber is carried by a vortex. Moreover, the fiber changes its orientation dramatically from its position at 0.815 s to its position at 0.820 s. This indicates that the fiber's trailing end may be in the path of outward flow (i.e., the flow through the basket openings) while the leading end is dominated by the vortex, causing the fiber to rotate. Another type of fiber motion between the wear bars is shown in Fig. 9. In this case, there is no sign of rotational motion.

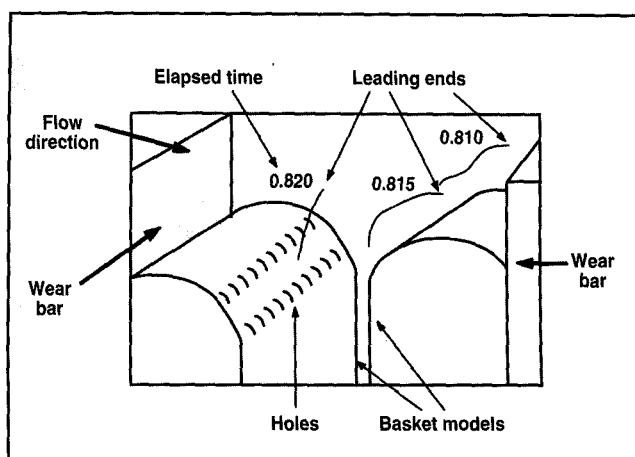
The fiber marked 0.815 in Fig. 8 and the fiber marked 0.835 in Fig. 9 are almost in the same position, but their orientations in that particular position are different. The fiber in Fig. 9 is straight, while the fiber in Fig. 8 is curved. The successive positions and orientations of these fibers are also dramatically different. The fiber in Fig. 8 shows a clear sign of rotational motion. This rotational motion is not seen in Fig. 9. This comparison implies that the fiber motion is very sensitive not only to its position, but to its orientation or angle from the flow direction.

## Screening

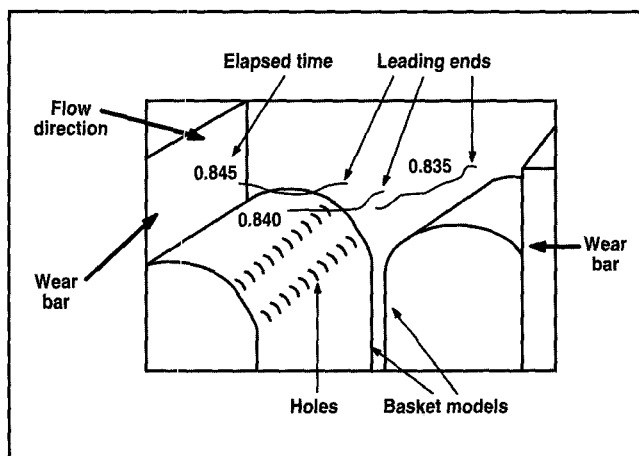
7. Fiber motion above the wear bar on a perforated wavy basket



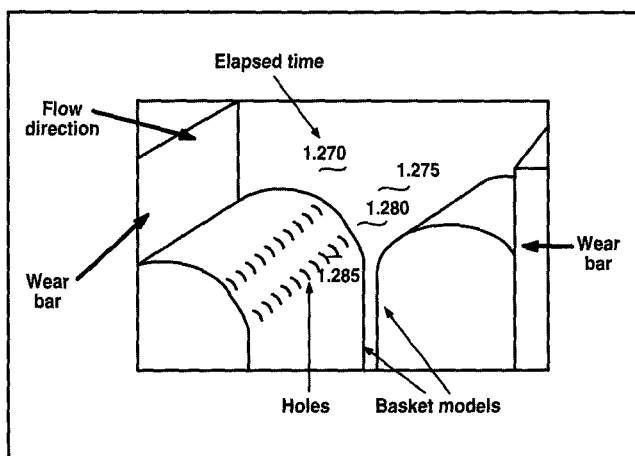
8. Fiber motion between the wear bars on a perforated wavy basket (fiber rotation)



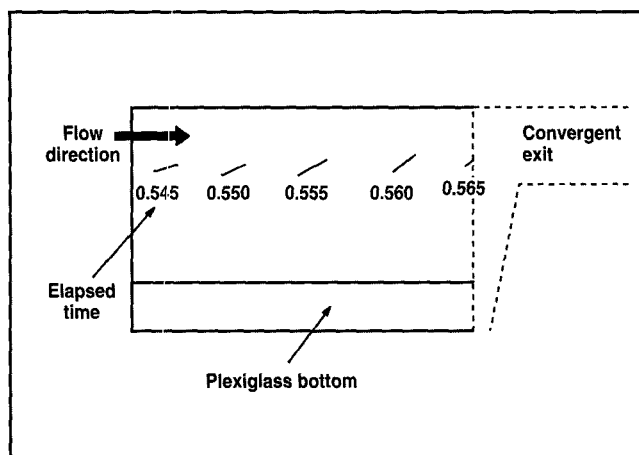
9. Fiber motion between the wear bars on a perforated wavy basket (no fiber rotation)



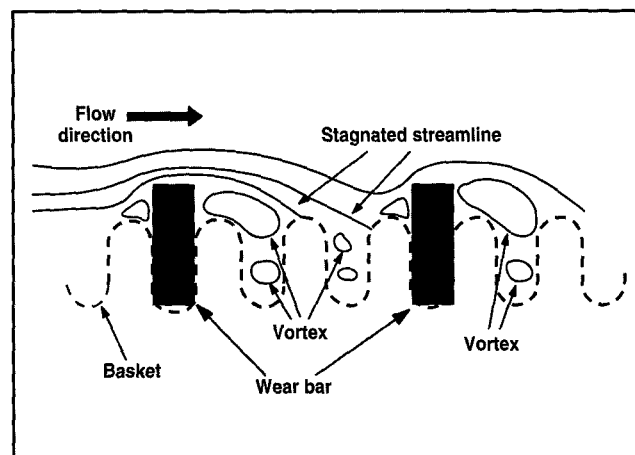
10. Fiber approaching an opening on a perforated wavy basket



11. Fiber approaching the exit of the laboratory apparatus



12. Streamline flow at the feed side of a perforated wavy basket



13. Streamline flow at the feed side of a perforated smooth basket, with fiber flocs hanging at edge of each hole

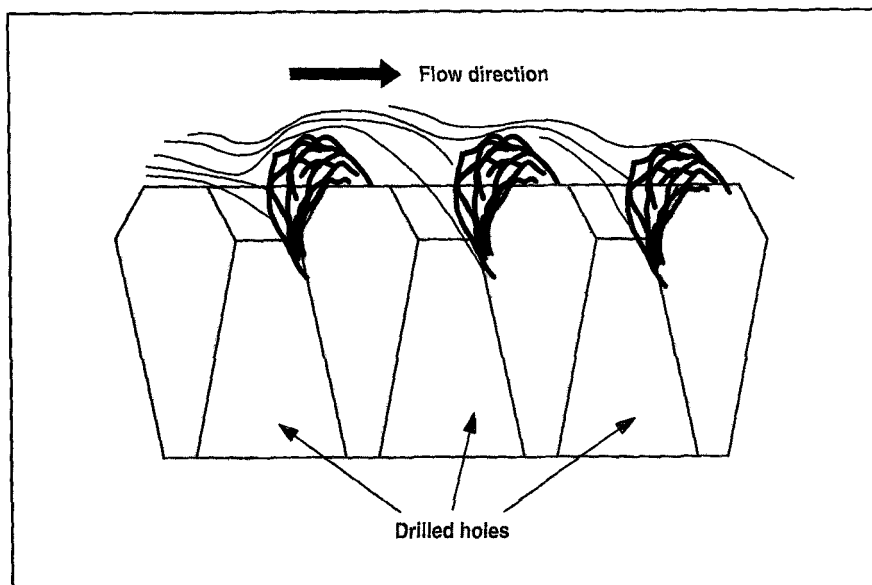


Figure 10 shows a series of four positions for a fiber approaching a basket opening. The time sequence shows that the fiber follows a curved path before passing through the opening. The curved path apparently is from the rotational motion of an eddy. Figure 10 explicitly shows the trailing end of the fiber passing through the opening first, not the leading end. This phenomenon is not seen in other basket models and is a distinguishable characteristic of wavy baskets, both perforated and slotted.

The flow approaching the exit of the laboratory apparatus is shown in Fig. 11. The exit of this flow model is a square-to-circle reduction, and the exit is on the top of the model. The decrease in the cross section causes the velocity of the flow to increase as it approaches the exit. Figure 11 shows that the angle of the fiber increases from the horizontal as the fiber approaches the exit. The increasing angle indicates that the streamline of the flow is going up, and the fiber orients itself on the streamline, as in Orientation II (Fig. 7).

By studying the videotaped sequences of fiber motion, it was pos-

sible to plot the streamlines around the perforated wavy basket model. The streamline contour plot for the wavy basket model is shown in Fig. 12. This figure clearly shows that the wake length after the wear bar is about the width of two undulations. Therefore, for the perforated wavy basket, some fibers are carried through the opening through vortices, and some are carried through flow reattachment.

**Slotted wavy basket.** The streamlines for the slotted wavy basket model were the same as for the perforated wavy model. However, all of the outward flow from the slotted basket is from vortices, with no outward flow from flow reattachment. Since the fiber is being carried out by the vortex, the trailing end of the fiber goes through the opening first.

On the other hand, because the open area for the slotted basket is less than for the perforated basket, the intensity of the vortex should be stronger. There was almost no fiber stapling/hanging observed on the screen openings, apparently the result of strong shear forces. Moreover, the distance between slots for

the slotted wavy model is 7.5 mm, much longer than the normal fiber length. As discussed later in this report, fiber stapling seldom occurs on baskets where the slot or hole spacing exceeds the average length of the fiber in the furnish.

**Perforated smooth basket.** No significant stapling was observed for the perforated smooth basket. However, severe fiber hanging occurred very quickly in this experiment. Large fiber balls were observed hanging on the edge of each hole. The diameter of the fiber balls was about the same as the diameter of the hole, 1.5 mm. This phenomenon is illustrated in Fig. 13.

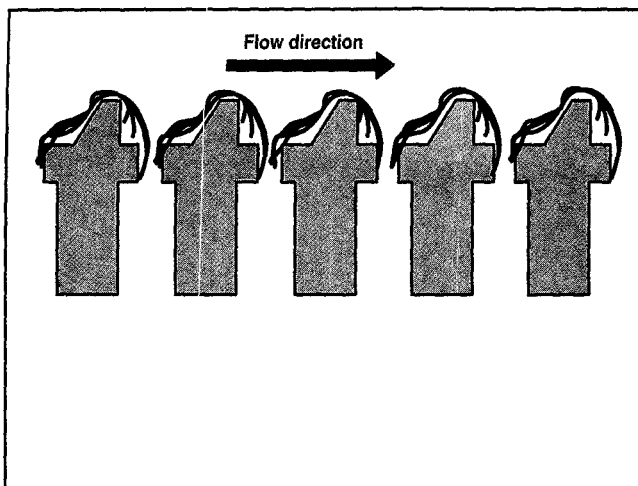
**Slotted contoured basket.** Fiber stapling in the slotted contoured basket model was severe, in contrast to the perforated smooth model. This event is shown in Fig. 14. Fiber stapling can occur in two ways.

1. For a fiber at sufficiently high attitude, the leading end enters a slot, contacting the edge/side of the opening. The continuous motion of flow drives the trailing end downstream, where it eventually enters the next slot (or hole).
2. For a fiber at a lower attitude, the leading end does not enter a slot. However, as the fiber skims over the surface of the profile, both ends of the fiber are positioned above two consecutive slots, and the outward flow forces both ends into the openings, completing the stapling process.

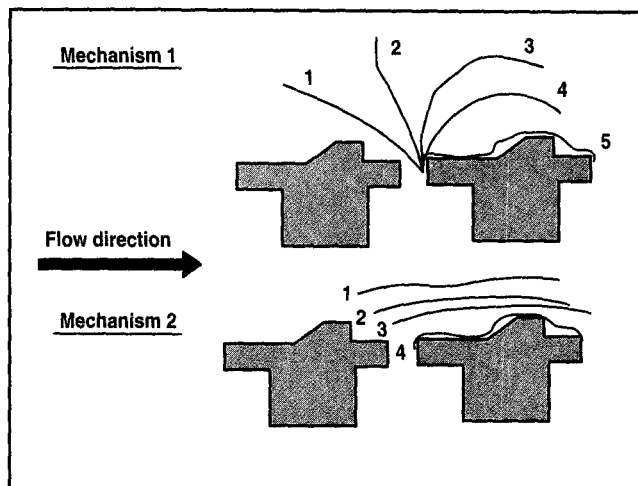
Both mechanisms are illustrated in Fig. 15.

Fiber stapling/hanging reduces the overall open area, thus decreasing throughput. Given the two fiber-stapling mechanisms presented here, it is reasonable to conclude that fiber stapling can be reduced by increasing the distance between slots or holes so that it exceeds the average fiber length. If the fiber length is shorter than the opening spacing, no fiber stapling can occur, and throughput will increase. This ex-

14. Fiber stapling at the feed side of a slotted contoured basket



15. Two mechanisms for fiber stapling at the feed side of a slotted contoured basket



plains why a basket with less open area can have greater throughput than a basket with more slots or openings.

## Conclusion

Fiber behavior at the feed-side surface of a screen basket is the primary factor affecting throughput and efficiency. Basket design governs the motion of fibers at the screen interface. A study of fiber trajectory and orientation around the openings of different types of screen baskets provided valuable insights into the phenomena affecting screening throughput and efficiency.

At flow speeds of 1 m/s, fibers in the slurry maintain their original form. When the flow speed increases to about 6 m/s, fibers assume the form of changing curves and start to rotate in the flow. Fiber orientation is randomly distributed at constant velocity. In areas where the flow accelerates—convergent areas or in the area before a profile or wear bar—the fibers tend to align with the streamline.

For baskets with contours or wear bars, there are two ways for the fiber to go through the screen openings:

- Fiber is carried out of the open-

ing by vortex flow. This mechanism occurs only in wavy baskets, either slotted or perforated.

- Fiber is carried out of the opening by flow reattachment. This mechanism occurs in contoured baskets and in the perforated wavy basket.

If a vortex guides a fiber through a screen opening, the trailing end of the fiber passes through the opening first. If the vortex intensity is high enough, no fiber mat forms on the basket. When the fiber is carried through the opening by the flow-reattachment mechanism, the situation is more complicated. Either the leading end of the fiber goes through the opening first, or both ends of the fiber span the opening, with the flow through the opening forcing the central portion of the fiber to pass through the hole.

Vortex flow is an effective means of preventing fibers from residing on basket openings or stapling between two openings. When stapling occurs, the blockage of the openings reduces the total open area. The result of this filtration effect is a decrease in throughput and an increase in efficiency. Stapling occurs only when the fiber is longer than the distance between openings. Therefore, stapling can be reduced by us-

ing screens with appropriate hole patterns or slot distances, depending on the average length of the fiber in the furnish. It is important to select a screen with appropriate spacing for a given application, bearing in mind that throughput is increased by sacrificing efficiency. **□**

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