Possible mechanism for stapling on bars of disc refiners

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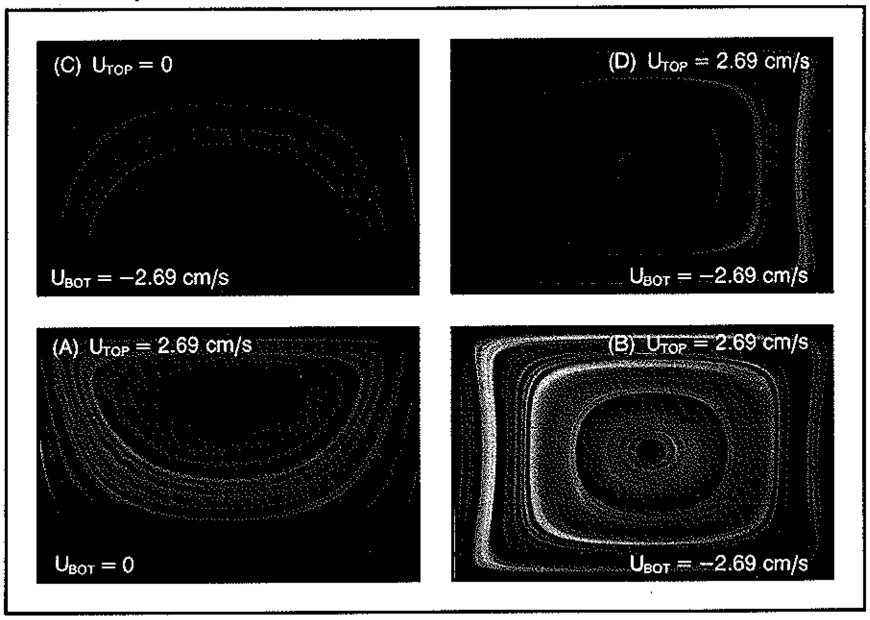
On a visit by Terry Fox, then of The Institute of Paper Chemistry, and Robert Brodkey, of Ohio State University, to the Covington Research Center of Westvaco in 1978, I put forward the conjecture that the flow of stock in the grooves of a disc refiner would be a rich field of study in fluid mechanics. The impulsive and periodic drag of the moving bars on the open surface of the stock in a stationary groove and, symmetrically, the drag of the stationary bars on the open surface of the stock in a moving groove must result in a form of vortical motion. This motion, coupled with the axial motions caused by pumping and centrifugal forces, would add up to complicated helicoidal flows with certain other secondary flows.

The two academic guests were so intrigued with these possibilities that within three weeks a 12-in. disc refiner with transparent discs was built and the first of high-speed cine-pictures were taken. The results of this research were published in 1979–82 (*1–3*). They showed helicoidal and other secondary flows and strongly held, persistent bundles of fibers stapled to the leading edges of moving bars.

A paper by Ottino, Leong, Rising, and Swanson (*4*) on chaotic flows shows an even richer picture than envisioned in my simplistic conjecture. Their Figure 1 is reproduced here as **Fig. 1.** I believe that in it lies an explanation of the flows in disc refiner grooves and for the stapling observed on the bars.

1. Instantaneous pictures of streamlines in cavities with movable belts on top and bottom and stationary sidewalls. Maximum values shown.



Periodic vs. continuous motions

Each of the four pictures shows a cavity with two stationary vertical sides and two horizontal sides consisting of movable belts. In Frame A, the top belt moves while the bottom is stationary. In Frame B, both belts move but in opposite directions. In Frame C, the bottom belt moves while the top side is stationary. In Frame D again, both belts move but in opposite directions.

In the experiments reported, two classes of time-dependent motions were studied. The motion of the moving belts was either (a) discontinuous, moving with velocity U for a half period, $T/2$, and remaining stationary for a half period $T/2$, or (b) moving periodically with the motion being proportional to $[\sin^2(\pi t/T)]$ and $[-\sin^2(\pi t/T+\pi/2)]$ for the top and bottom belts, respectively. The fluid used was glycerine, and passive indicator-particles were used to aid in observing the streamlines.

Figures 1A and 1C closely represent events in the grooves of disc refiners. In both moving and stationary grooves, the impulses of discontinuous or periodic drag applied to the free surfaces of the stock correspond to the discontinuous or periodic motions of the belts. As the authors explain, there is a deep-seated difference between the two types of periodic motions, represented by Fig. 1, and that of continuous motions.

In the class of continuous motions, the velocity fields and their stream functions are stationary—that is, time-independent. Hence, the velocity fields are integrable and cannot lead to chaotic flow. In the periodic flows of Fig. 1, the velocity fields are time-dependent and hence can lead to chaotic flows. This time-dependence is the case for flows in refiner grooves—a much more complicated picture than previously envisioned.

One rotating and one stationary disc

Concentrating on the refiner with one rotating and one stationary disc, the following points emerge from a study of Frames A and C. Actually, the flows will be more complex—"chaotic" in hydrodynamic terms—as later pictures of Ottino's paper demonstrate; but to simplify the events we will study just these initial visualizations.

Chaotic flow

The flows, in cross sections, are not simple vortices—either natural or induced. They represent chaotic flows which develop into complex patterns with time. The streamlines crowd near the moving surfaces and open up near the stationary surfaces. Furthermore, the crowding of the streamlines into a small space near the moving surfaces and the incompressibility of liquids imply that the flows in the regions near the moving surfaces will be more rapid than those near the stationary surfaces.

Centrifugal forces

Along the diagonals, the streamlines are curved. Hence, centrifugal forces will be enhanced at the diagonals. But the crowding of the streamlines results in smaller radii of curvatures as they approach the corners, much more so near the moving surfaces than near the stationary surfaces. This fact implies that the centrifugal forces along the diagonals are increasing as we move towards the corners.

Homogeneity

In these pictures, the liquid was homogenous glycerine. In a refiner, it is a suspension of fibers in water. The fibers are denser than water. Therefore, the centrifugal forces will tend to diminish the consistency of the stock near the eccentric axis of circulation and thicken the stock near the periphery.

But this thickening will be further complicated because it is not homogenous. Consequently, most thickening will occur near the corners of the cavities at the moving surface side.

Motion of stock in the grooves

Let us visualize the groove in Frame A as the stationary groove and, above it, that in Frame C as the moving groove approaching the stationary groove from the left and moving to the right. We'll call these Grooves A and C, for simplicity.

The bottom surface of stock in Groove C will be moving from right to left, and the top surface of stock in Groove A will be moving from left to right as a result of the previous impulsive actions of the bars. At the same time, centrifugal forces behind the right vertical face of Groove C (the trailing edge of a bar) would tend to shoot out a sheet of a bundle of fibers diagonally to the right and bottom (i.e., in the southeast direction). The same forces in Frame A would counter with a bundle of fibers to the left and top (or in the northwest direction).

The two bundles will be subject to shear and possibly turbulence and will thus entangle with each other. As Groove C moves further to the right, the bundles will lose velocity because of their opposing motions and hence will move to the left, relative to the sides of the Groove C. This operation continues until the left side of Groove C is over the stationary Groove A, when the fiber bundle will crowd around the leading edge of the succeeding bar. Hence, a stapling of fiber bundles ensues in the leading edges of the moving bars, with little or no stapling on the stationary bars, just as observed by Fox *et al.*

Variations in stock consistency

On average, the consistency of the stock in the grooves will be less than the stock at the entry and exit of the refiner. The consistency between the bars will be higher.

Conclusions

As the paper by Ottino *et al.* shows, the flows in their experiments and hence in refiner grooves are much richer and more complex than the situation as summarized here. Other factors affecting the flows include velocity, pressure, and consistency fields. Further studies of the flows in the grooves of disc refiners for different aspect ratios, throughputs, rotational speeds, and bar-and-groove geometries should be rewarding to fluid mechanics of chaotic flows.

The grooves prepare the fiber bundles for refining by the bars.

Such studies could lead to improved refining efficiencies. □

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The photographs in Fig. 1 were printed in the wrong order when this article was first published in the January issue (p. 132). The journal staff regrets any inconvenience this may have caused.