High-speed photography of stock transport in a disk refiner

ABSTRACT

Refining equipment has been constructed of clear plastic so that high-speed motion pictures can be made of a refining process. The photographic technique provides a means for viewing flow characteristics and making velocity measurements. The data demonstrate that the stock flow in the experimental disk refiner is three-dimensional and includes at least primary, secondary, and tertiary flows. The pulp fibers that are stapled to the tackle by fluid dynamic forces are subjected to the maximum refining action. The mechanism of release of Stapled fibers occurs predominately in the area of the refiner between the stock inlet and outlet.

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Little fundamental work on flows involving fiber suspensions has been done other than overall pressure drop measurements, largely because of the limited utility of conventional anemometry. The objectives of the present work were to ascertain the worth of high-speed photography as an experimental means of studying the fluid mechanics of such systems and to gain a preliminary understanding of the mechanics of the disk refiner. The disk refiner was chosen as the flow apparatus to be filmed because refining is an important industrial process about which little concrete knowledge is available.

The high-speed photographic technique, properly exploited, should yield insight into the mechanisms of drag reduction, flocculation, and fiber/water interaction in both laminar and turbulent flows, as well as provide a means of visualizing flows and making velocity measurements. There is mention in the literature of attempts to use high-speed photography (both motion and still pictures) to study fiber/fluid systems. The films were not sufficiently clear to allow projection and viewing, but some deductions were possible. Recent advances in this field, however, have led to a much broader use of photographic techniques, and application to fiber/water systems seems appropriate at this time.

For analysis, it is reasonable to divide the refining process into subunits, separating the refining morphology of the fiber from the transport of the stock to, through, and away from the refining zone. It is not certain that a complete description of the action of the disk refiner can be developed by a separation of this kind (treating refining completely separate from transport), but, in this research, transport is to receive the greater emphasis.

The visual refiner

An experimental refiner was constructed of clear plastic so that light might pass through it with ease. The 12-in. rotor/stator pair was modeled after
tackle used in a Sprout-Waldron refiner that was disassembled and measured. The experimental refiner was constructed roughly to scale; the dimensions of the tackle are a bit larger than on the Sprout-Waldron unit, but the relative sizes are the same and are of commercial dimensions. The angular offset in the plane of the tackle of the lands and grooves for the stator and for the rotor are 10° from the radial. There are 90 bars on the rotor and 90 bars on the stator, with the angular offset of the tackle for the rotor and for the stator opposed (Fig. 1).

The rotor turns with angular velocity $\omega$. The rotor/stator pair is enclosed in a housing. The flow geometry is a series of rectangular channels. There are multiple crossovers of rotor/stator bars over the radial length of the tackle as a result of the skewing of channels with respect to the radial direction (Fig. 2).

The first attempt to film the flow of fiber in the experimental refiner was successful, and the photographs are shown in Fig. 3. Note the clear definition of the tackle lands and grooves and the individual fibers stapled to the leading edge of the rotor bars. The image of the stock contained in the tackle grooves is blurred because the camera was focused on the land of the stator.

### Pulp flow characteristics

The fiber was bleached southern pine pulped by the kraft process. From the films, it was observed that the flow in the refiner can be divided into two main regions, one arbitrarily called the circulation region and the other the exit region. The flow inward, which takes place at the hub of the rotor, is designated as $Q_s$ and has two available paths through the grooves in either the rotor ($Q_{rs}$) or stator ($Q_o$) (Fig. 4).

Except in the exit region, the direction of flow in the stator is radially inward. Inward flow was not predicted in advance, but, in fact, a very strong radial flow inward in the stator was observed in the films. Reverse flow in the stator was, however, reported by Banks.

This is the situation observed for what has been called the circulation region. Because of the angular velocity of the rotor, fluid travels around the periphery of the rotor and stator ($Q_p$), and some of it is ultimately delivered to the discharge flow. The remainder is mixed with stock in the exit region and recirculated. It was observed that the flow in the rotor and stator are at least...
one order of magnitude greater than \( Q \) or \( Q_r \). This requires a large recycle stream within the refiner. Clearly, a tremendous acceleration exists in the flow loop out of the rotor and in the stator.

**Secondary and tertiary flows**

It can be expected from physical reasoning that primary, secondary, and tertiary flows will be present in the circulation region of the disk refiner. An outward radial flow in the rotor and an inward flow in the stator exist in the circulation region. In the exit region, the flow is radially outward in both the rotor and stator grooves (Fig. 4). A small circumferential flow is expected by virtue of the motion of the rotor. These three flows are arbitrarily called primary flows because they result from rather simplistic reasoning and have been confirmed by the visual studies.

If a cross section of a groove in the stator and the bar in the rotor is considered, then, by virtue of the rotor bar motion with respect to the fluid in the stator groove, a rotational force is imposed on the fluid in the stator. This force sets up a vortex flow in the stator. The fluid in the groove of the rotor is forced into a similar vortex motion as the bars of the stator move with respect to the fluid in the groove of the rotor (Fig. 5).

Note that the vortex flows in Fig. 5 are of the same rotational sense. Putting these secondary vortex motions together with the primary flow, it is apparent that the flow spirals outward in the rotor and inward in the groove of the stator. In addition, there are secondary vortex flows in the corner regions.

Consider a simplified flow model of one groove of the rotor and one groove of the stator. Since the flow in the rotor is greater than the flow in the stator, the velocity in the rotor is greater than the velocity in the stator, causing the pressure in the stator to be higher than the pressure in the rotor. Thus a pressure gradient exists in the direction across the cross section from the stator to the rotor. Although this pressure difference is small, it is very important as far as the refining mechanism is concerned and is the driving force creating a tertiary motion.

A small secondary vortex could exist in the corner of the stator but does not because of the pressure gradient that exists from stator to rotor. In fact, the flow comes all the way down the leading edge of the stator bar (shown by the dashed line in Fig. 6). This flow would be the source of the primary flow in the circumferential direction, \( Q_c \). This \( Q_c \) would further reduce the strength of \( Q \) and further strengthen the transverse pressure gradient. This tertiary flow is important since it prevents fiber from stapling over much of the stator. It is distinguished from the secondary motions because it is a result of the small pressure gradient between the stator and rotor.

**Conclusion**

Putting all of these complex motions together, the complete flow field is understood. There is (a) a primary circumferential motion, (b) a primary radial flow outward with a secondary vortex flow outward in the groove of the rotor, and (c) a primary flow inward in the groove of the stator with a secondary vortex flow of the same angular sense as that of the rotor. Secondary motions exist in the corners
of the grooves of both the rotor and stator. However, secondary motion in the stator is modified to a tertiary wiping flow at the stator leading edge. The wiping flow comes down and out of the stator and holds the pulp fibers against the bars of the rotor so that refining work can be done. The visual observations show that the fibers lie across the leading edge of the rotor. The heads of the fibers are held down by the secondary vortex flow in the groove of the rotor. One might expect the same thing to occur on the leading edge of the stator bars, but this was not observed in the films except at the tackle periphery. This does not happen because of the tertiary motion (Fig. 7).

At any particular radius, the fibers are stapled to the rotor or to the stator, but not to both. It is the conclusion of this work that it is mainly the stapled fibers that are refined. The fibers align themselves principally along the rotor bar in a circumferential direction. Periodically, they break loose and either (a) become a part of the inward stator flow (and may become stapled again), (b) become part of the outward rotor flow and are recycled to the stator at the periphery, as was often observed to happen, or (c) become part of the flow that eventually leaves the refiner through the outlet.

It is recognized that the refining action of plastic tackle may well be different from the action of commercial steel tackle. However, in the present work, the primary interest was not in refining action per se, but in the gross pulp transport phenomena.

Experimental

Visual observations have been made at pulp consistencies of up to 6% and at angular velocities of up to 1750 rpm. Plate clearances of up to 0.060 in. have been employed.

The photography was performed by focusing a high-speed camera on the desired portion of the refiner. Standard photographic techniques were employed using high-speed film.

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