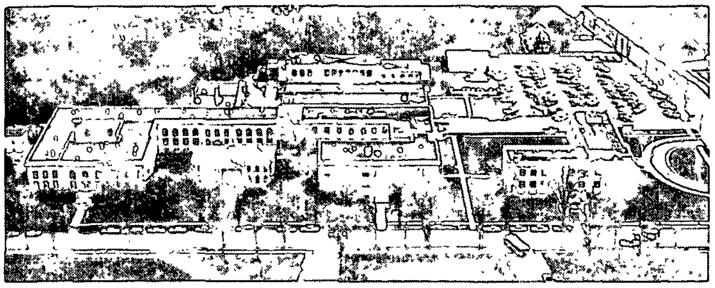

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

HIGH SPEED PHOTOGRAPHY OF THE DISK REFINING PROCESS

Project 2698
Report 5

To The

Technical Division

Fourdrinier Kraft Board Group

of the

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HIGH SPEED PHOTOGRAPHY OF THE DISK REFINING PROCESS

Introduction

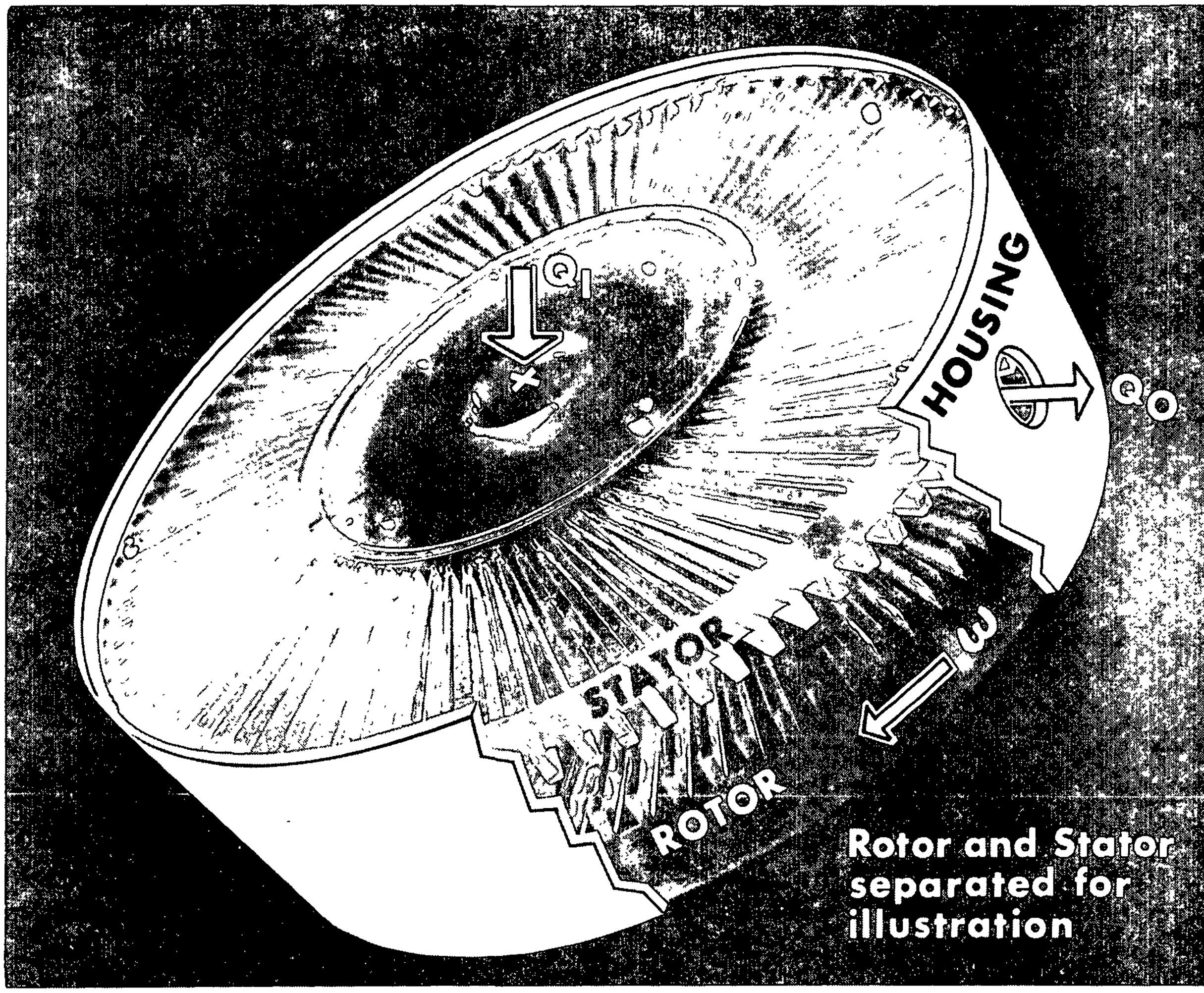
Little fundamental work on flows involving fiber suspensions has been accomplished other than overall pressure drop measurements, largely because of the limited utility of conventional anemometry. The objectives of the present effort were to ascertain the worth of high speed photography as an experimental means to study 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. Substantial conjecture has been put forth, however, by many authors.

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 to visualize flows and make velocity measurements. There is mention in the literature of past attempts to use high speed photography (both motion and still pictures) to study fiber/water systems (1-2). The films (1) were not sufficiently clear to allow projection and viewing, but some deductions were possible. Recent advances in this field (3), 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 clear 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.

Description of the visual refiner

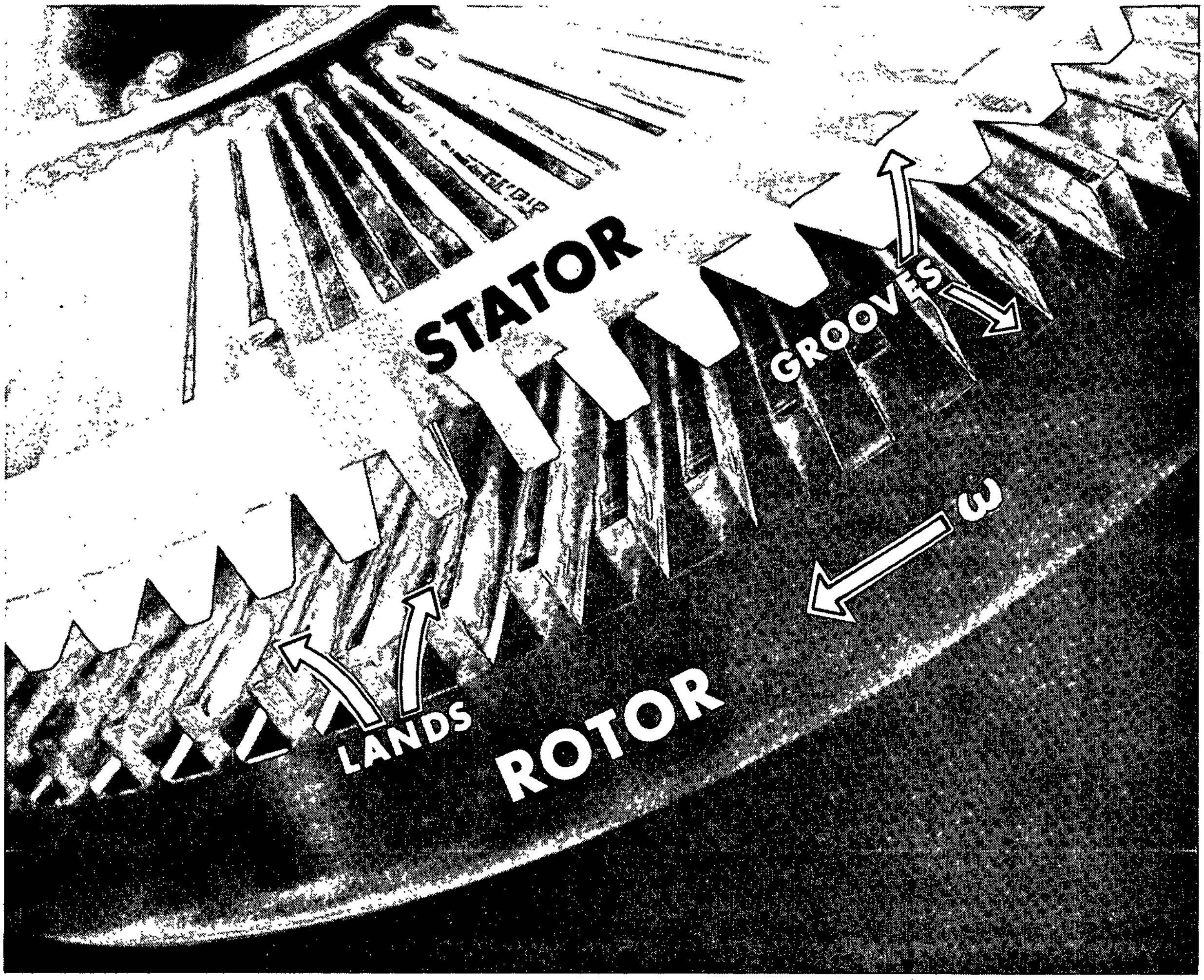
An experimental refiner was constructed of clear plastic so that light might pass through it with ease. The twelve-inch rotor/stator pair was modeled after tackle used in a Sprout-Waldron refiner that was disassembled and measured. The experimental refiner is constructed roughly to scale, the tackle is a bit larger in dimensions than that 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 degrees 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 oppositely opposed (Fig. 1).



EXPERIMENTAL REFINER

Figure 1

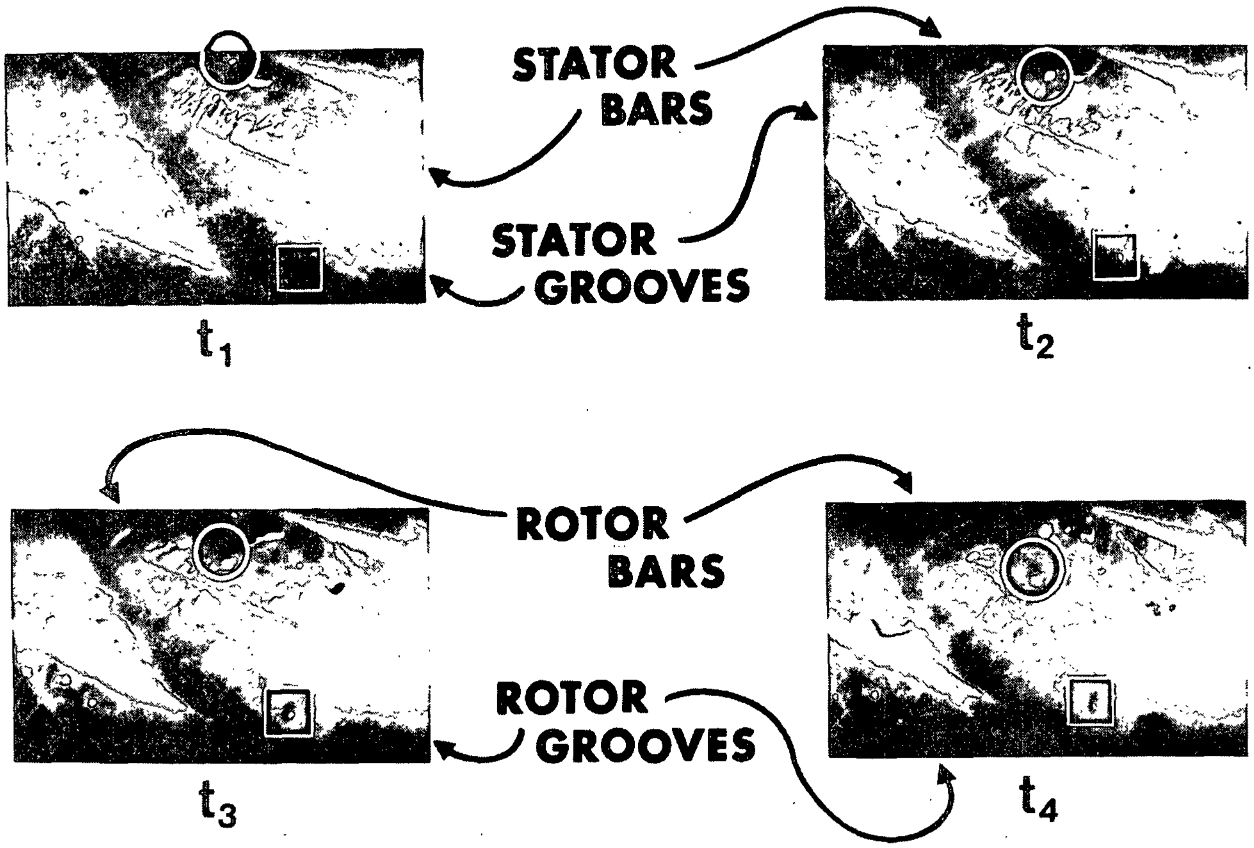
The rotor turns with angular velocity ω. The rotor/stator pair is enclosed in a housing. The flow geometry is a series of rectangular channels. There are multiple crossovers of rotor/stator bars over the radial length of the tackle as a result of the skewing of channels with respect to the radial direction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



CLOSE-UP OF ROTOR/STATOR GEOMETRY

Figure 2

The first attempt to film the flow of fiber in the experimental refiner was successful (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.



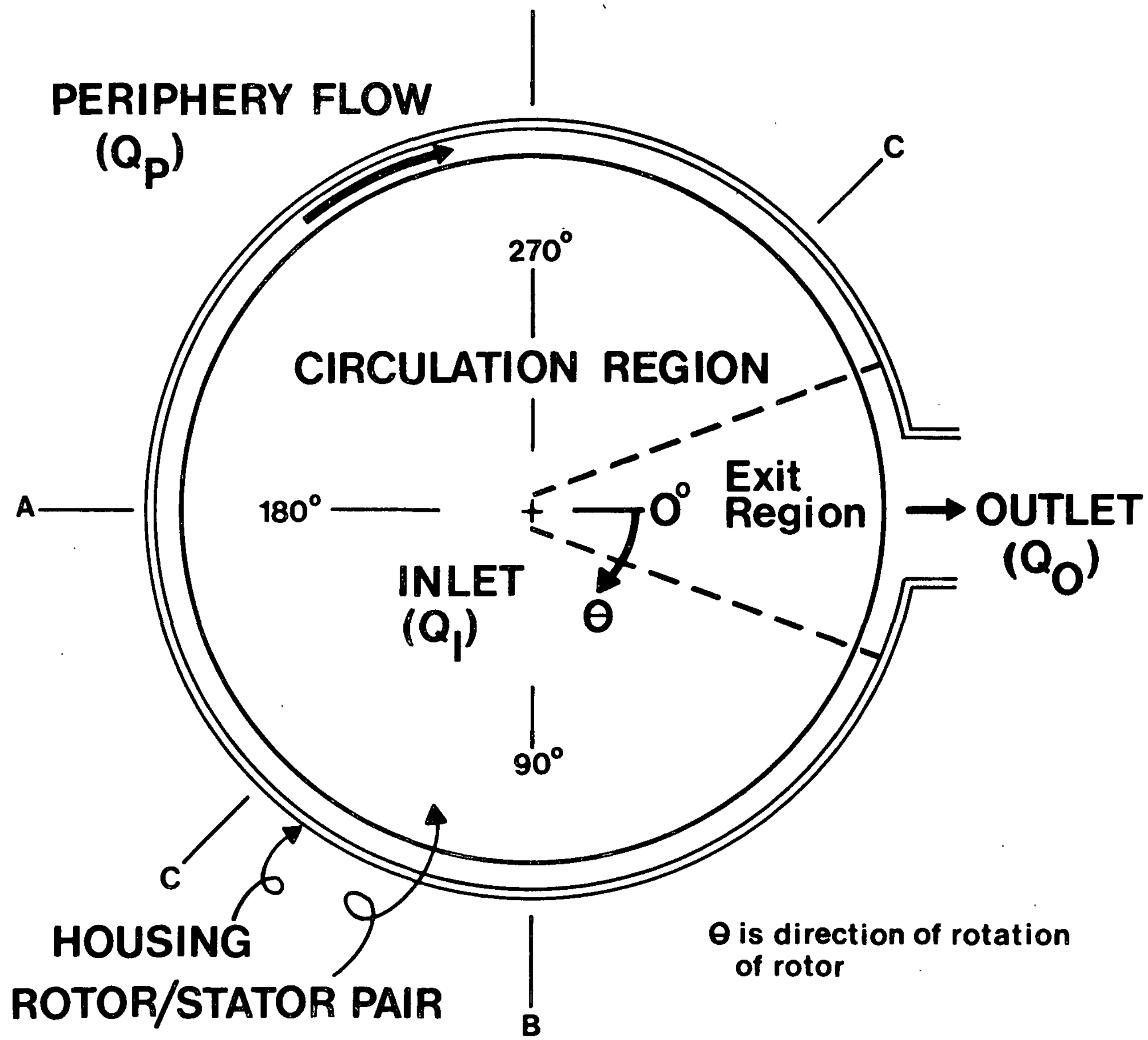
NOTES: THE CENTER OF THE REFINER IS BEYOND THE UPPER LEFT OF FRAMES.
; $\triangle$T BETWEEN FRAMES IS 1/3500 SECOND
; ① NOTE OUTWARD MOVEMENT OF AIR BUBBLE CONTAINED IN ROTOR GROOVE.
; [2] NOTE INWARD MOVEMENT OF AIR BUBBLE CONTAINED IN STATOR GROOVE.

ENLARGED 16 MM FILM OF EXPERIMENTAL REFINER (TOP VIEW).

FIGURE 3

Pulp flow characteristics

From the films, it has been observed that the flow in the refiner can be divided into two main regions, one which is 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_I, and has two available paths through the grooves in either the rotor (Q_R) or stator (Q_S) (Fig. 4).



REFINER FLOW PATTERN
SHOWING TWO MAIN REGIONS OF FLOW

Figure 4

The direction of the flow is radially inward in the stator except in the exit region. 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 (1). This is the situation observed for what has been called the circulation region. Due to 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_I or Q_O. This requires that a large recycle stream exists within the refiner. Clearly, a tremendous acceleration exists in the flow loop <u>out of the rotor</u> and <u>in the stator</u>.

Secondary and tertiary flows

<u>Circulation region</u>

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 exists 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).

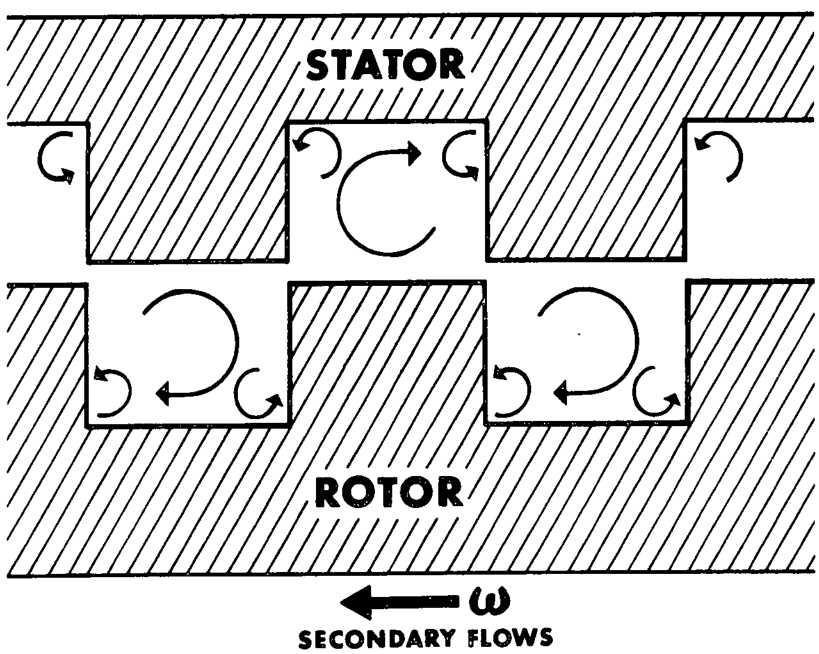


Figure 5

Note that these vortex flows are of the same rotational sense. Putting these secondary vortex motions together with the primary flow, it is apparent that the flow spirals outwards in the rotor and spirals inwards 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; the flow in the rotor is greater than the flow in the stator. Thus the velocity in the rotor is greater than the velocity in the stator and gives rise to the pressure in the stator being 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 is a small pressure difference, 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 this does not occur 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 as shown in Fig. 6 by the dashed line. This flow would be the source of the primary flow Q_C in the circumferential direction. This Q_C would further reduce the strength of Q_S and further strengthen the transverse pressure gradient. This tertiary flow is of importance since it prevents fiber from stapling over much of the stator and is distinguished from the secondary motions because it is a result of the small pressure gradient between the stator and rotor.

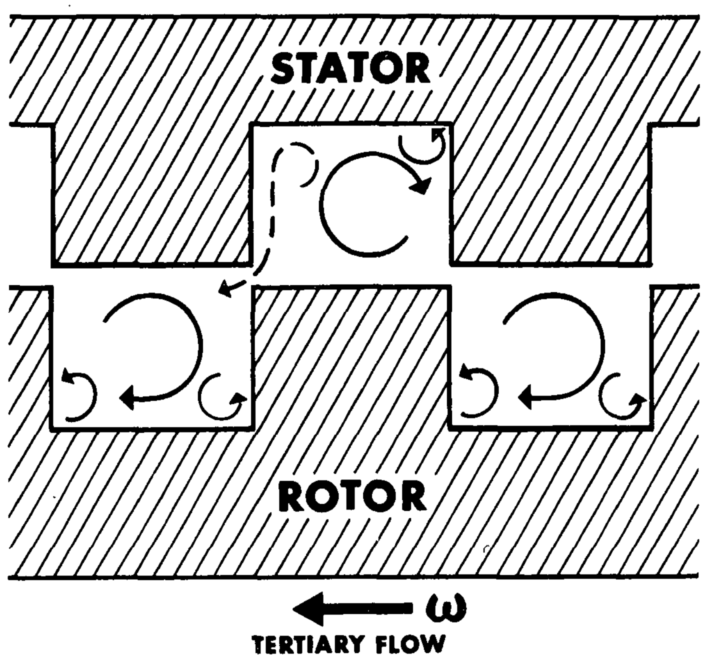


Figure 6

Putting all of these complex motions together, the complete flow field is understood. There is a primary circumferential motion; a primary radial flow outward with a secondary vortex flow outward in the groove of the rotor; and 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 corner 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).

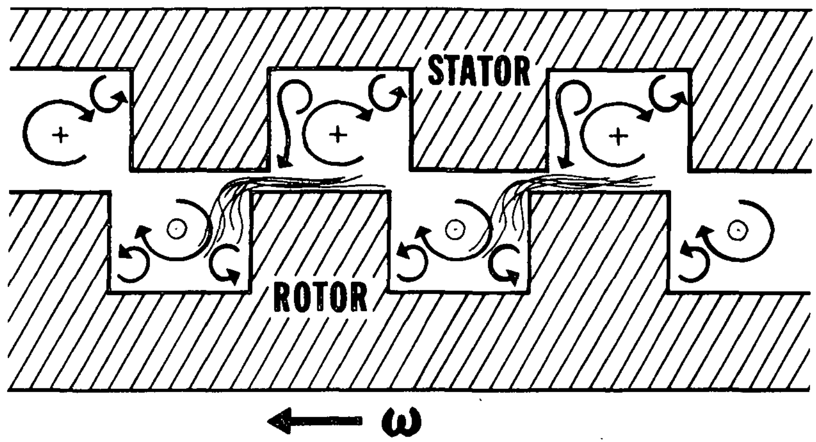


Figure 7

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

A more extensive paper dealing with the fluid mechanics of pulp transport in the disk refiner is in preparation and will be published early in 1979.

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