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Influence of the Vorticity at the Membrane Surface on the Performances of the Ultrafiltration Rotating Module

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Abstract

The performances of a rotating module during the ultrafiltration of oily emulsions have been studied and correlated with the vorticity at the membrane surface. Thus, a fully transparent module has been assembled and the size and shape of the vortices observed as functions of the rotational speed and the clearance of the annular gap around the membrane. The influence of the roughness and profile of the inner wall of the module has also been investigated. Photographs of the vortices have been correlated to the actual performances of a steel module. Evidence has been found relating the permeate flux and the size of the vortices.

INTRODUCTION

Many attempts have been made to utilize a rotating module for the ultrafiltration process (*1–4*). This type of module has some advantages in comparison with tubular and flat ones, as pointed out in an earlier paper (*5*).

A particular hydrodynamic regime takes place at the surface of the membrane: the so-called "Couette flow" which is mainly characterized by annular counterrotating vortices (Taylor's vortices) (*6, 7*).

The mass transport coefficient, and thus the resistance of the membrane to polarization, is dependent on these vortices through the Taylor number (*4*). In our study we tried to find evidence of a straightforward correlation between membrane performances and vortices by photo-

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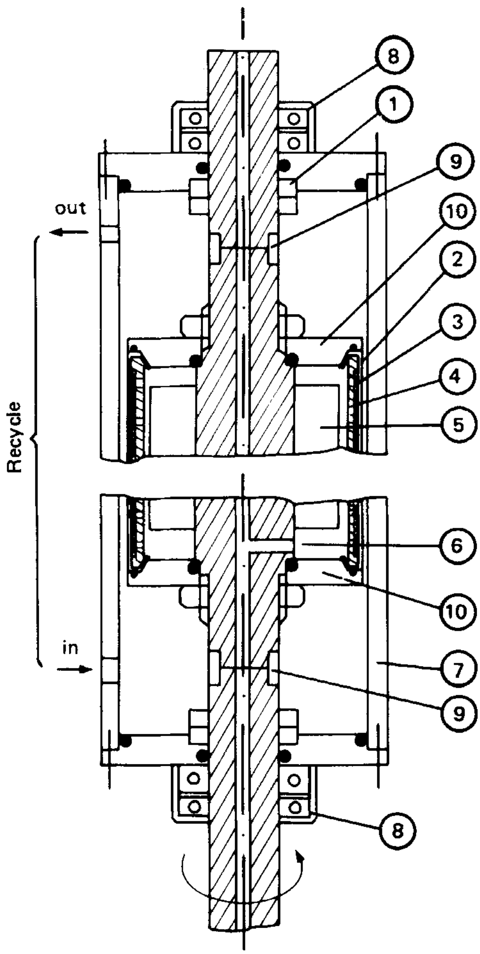


1	Mechanical seals
2	Membrane
3	Membrane support
4	Inner cylinder
5	Expanded polystyrene filling
6	Collection hole
7	Outer shell
8	Bearings
9	Fast couplings
10	Membrane sealing

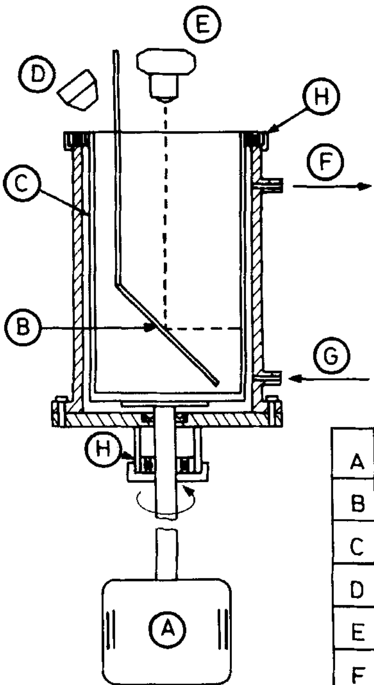
FIG. 1. Schematic section of the ultrafiltration rotating module.

graphically recording their number, size, and stability during ultrafiltration runs.

Our aim was to gather experimental data useful in optimizing the rotating module performances.

EXPERIMENTAL

The ultrafiltration (U.F.) performances were checked by means of a steel module (Fig. 1) working with a 20% cutting oil emulsion at the following conditions: temperature, 40°C; pressure, 300 kPa; recycle rate,



A	D.C. motor
B	Mirror
C	Rotating cylinder
D	Light flash
E	Camera
F	Recycle outlet
G	Recycle inlet
H	Bearings

FIG. 2. Schematic section of the Plexiglas model.

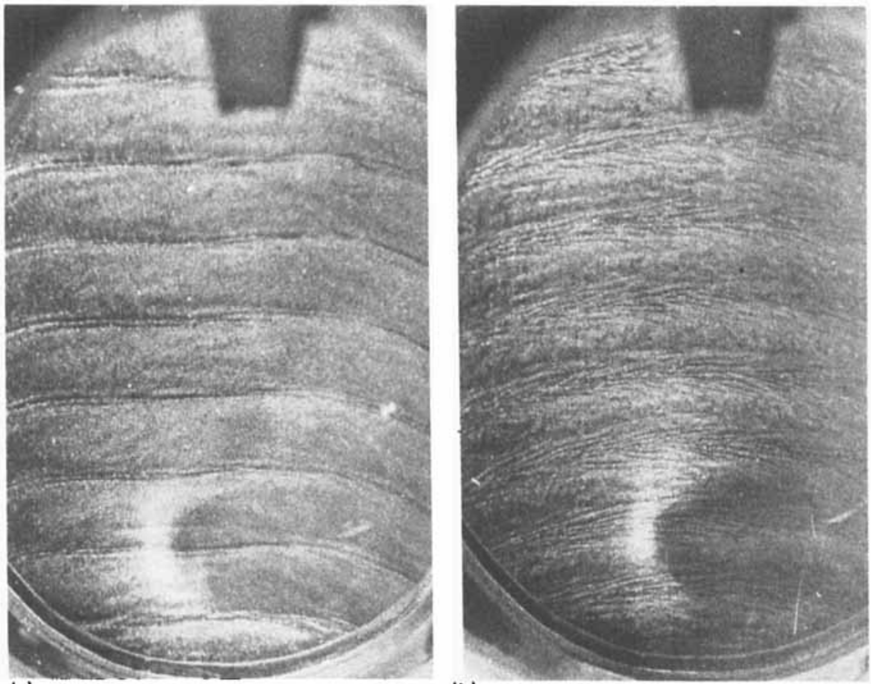
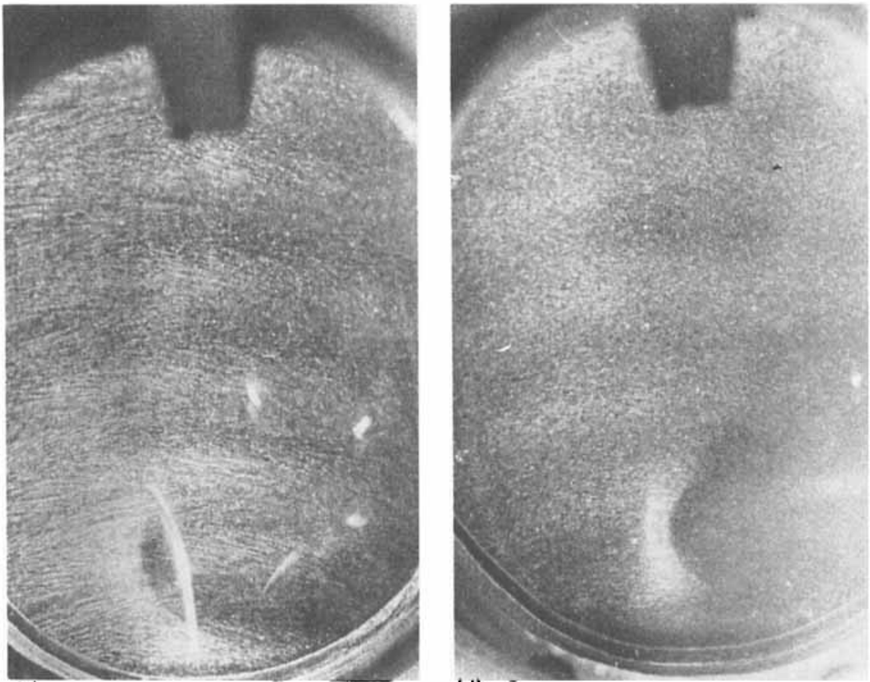


FIG. 3. Vortices as observed at different rotating speeds in an annular gap 3.3 mm wide.

10 L/min. A Celgard 3500 membrane made by Celanese was used in all experiments.

The photographic record of the vortices was made with a module quite similar to that used previously but completely built of transparent Plexiglas (Fig. 2). It was provided with all the devices necessary to simulate the operating conditions so that, as shown in Fig. 2, we were able to follow, by the use of a mirror, the formation and development of vortices on the membrane surface side. The photographs were taken with the aid of an electronic flash light at a 1/30,000 exposure time. The vorticity was revealed by aluminum powder suspended in water with a 0.5 g/L nonfoaming tensioactive agent. The suspension had a viscosity close to that of the oily emulsion.



(c) (d)

(a) 0.6 m/s, (b) 2 m/s, (c) 4 m/s, (d) 8 m/s.

RESULTS AND DISCUSSION

First, the influence of temperature, pressure, and the feed recycling ratio on the formation of the vortices was checked. In the range of values typical for the U.F. process, we did not find any appreciable variation. This result allowed us to continue the tests at room conditions with the Plexiglas module. The recycling ratio was kept constant at values largely higher than the predicted permeate flux.

Influence of the Rotational Speed

The appearance and the size of the vortices were photographically recorded between 3.5 and 42.5 rps, corresponding to a 1–12 m/s tangential

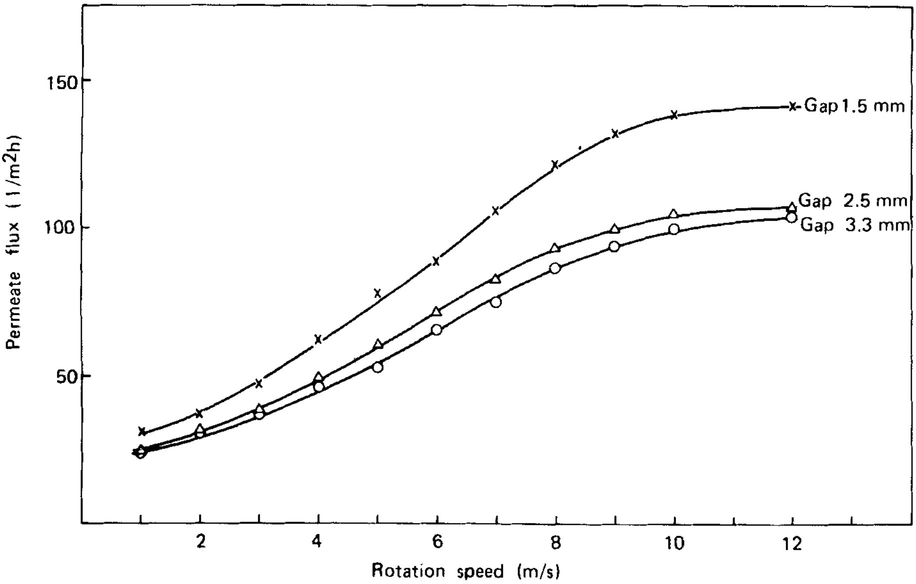


FIG. 4. Permeate flux at standard conditions as a function of the rotating speed.

speed over the membrane. We report in tangential speeds in order to allow for direct comparison with other kinds of modules.

Four photographs taken at different speed are shown in Fig. 3. From these pictures it can be seen that while the sizes of the vortices are fairly independent of speed, their appearances are greatly affected by it.

At higher speeds the vortices appear more confused and overlap. This is attributed to the formation of instability and to increased turbulence (*8*). In Fig. 4 the performances measured with the steel module are shown. This shows that the permeate flux increases with increasing instability, i.e., increasing turbulence.

Influence of the Annular Gap

The annular gap around the membrane was varied in both the steel and the Plexiglas module. Figure 5 photographs taken at three different gap sizes while keeping the tangential speed and other conditions constant. Here again, it is useful to make a comparison with the performances reported in Fig. 4; the permeate flux now appears to be a function of the size (density) of the vortices.

Influence of the Roughness

In order to check the influence of turbulence without affecting the size of the vortices, the inner wall of the module, opposite the membrane, was covered with nets of 270 and 140 meshes.

Photographs showing the overall effect on vorticity for the 270 mesh net are printed as Fig. 6.

Figure 7 records performances with oil emulsions both in the presence of the net ("rough wall") and without it ("smooth wall"). The gap over the membrane was kept at 2.5 mm in both cases. As expected, the net, acting as a turbulence promoter (*9*), lowers the polarization and increases the performances of the membrane.

Influence of the Profile of the Inner Wall

As shown by Figs. 4 and 5, performance is influenced by the size of the vortices, and the size variation is clearly related to the gap width. An attempt was made to obtain small vortices independent of the gap clearance.

To accomplish this, the inner wall of the module was shaped according to the profile shown in Fig. 8. The vortices were then observed as functions of the tangential speed. Some photographic records are shown in Fig. 9. A performance comparison is shown by the plots of Fig. 10.

From Fig. 9 it appears that this technique is successful; vortices having the same width as that of the groove are observed. At the same time, they look quite unstable, resulting in increased turbulence, especially at higher speeds.

CONCLUSIONS

The test runs allowed us to:

(1) Visualize and photographically record the vorticity close to the membrane surface in a rotating module

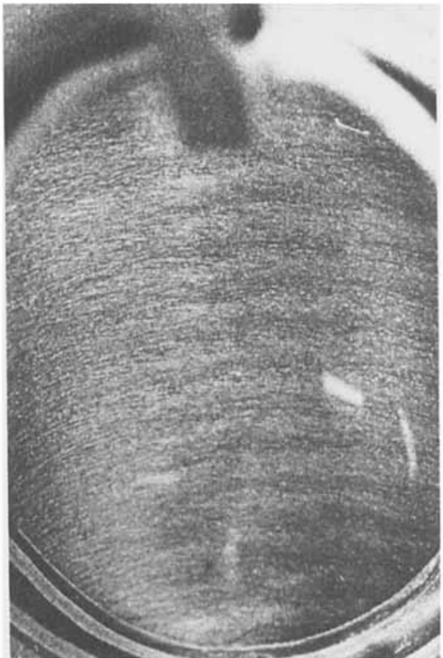
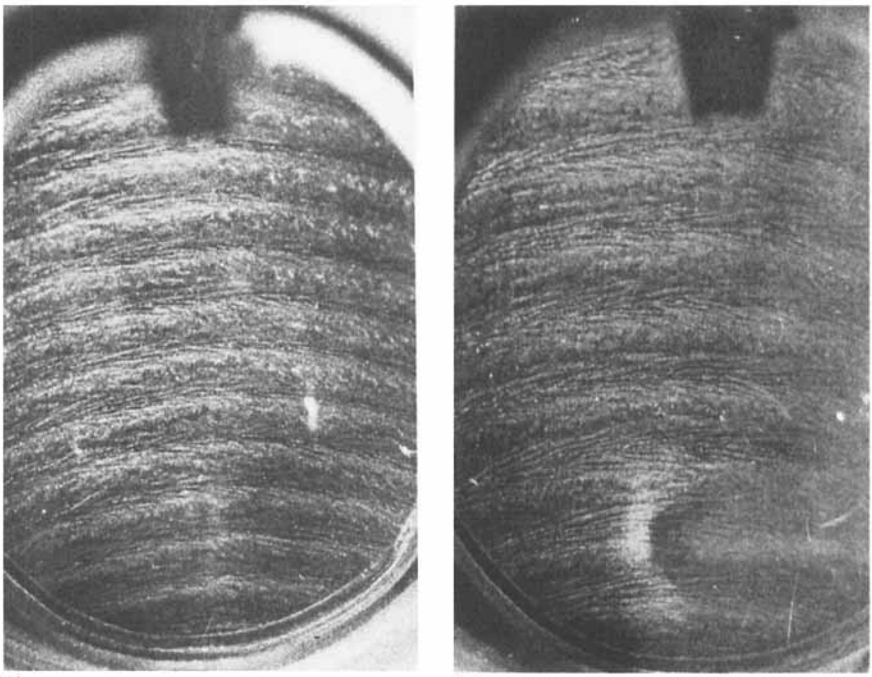
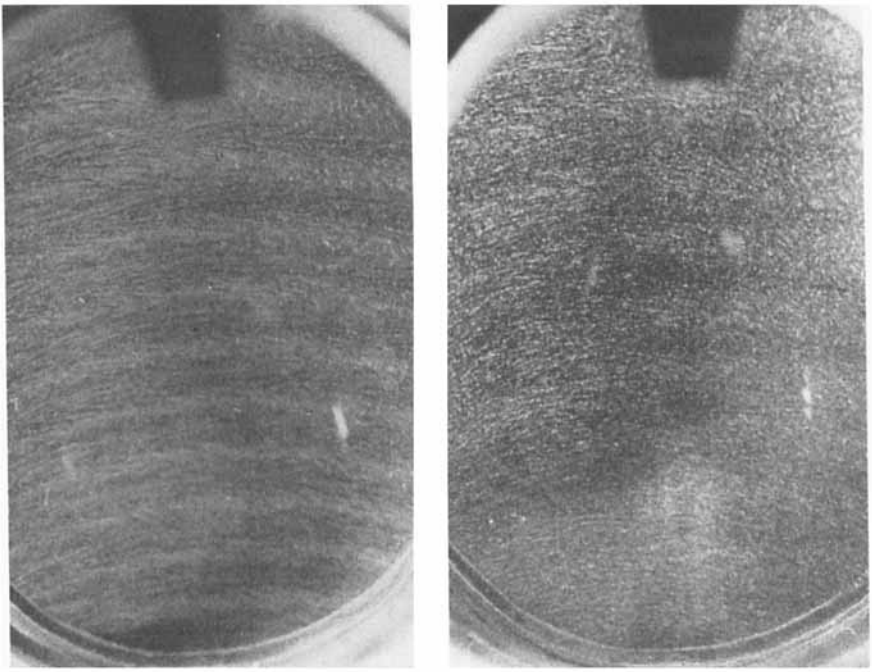

(a)

FIG. 5. Vortices as observed in different annular gap widths but at the same rotation



(b) (c)

speed (2 m/s). (a) 1.5 mm gap, (b) 2.5 mm gap, (c) 3.3 mm gap.



(a) (b)

FIG. 6. Influence of wall roughness on the vortices. (a) Smooth wall, (b) wall covered with a stainless steel net of 270 mesh. Conditions: rotation speed = 4 m/s, gap = 2.5 mm.

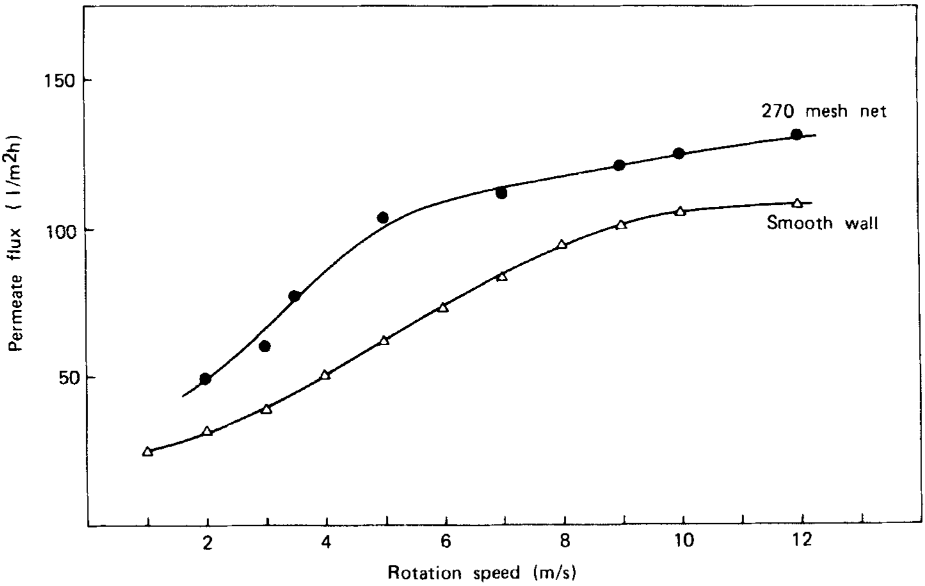
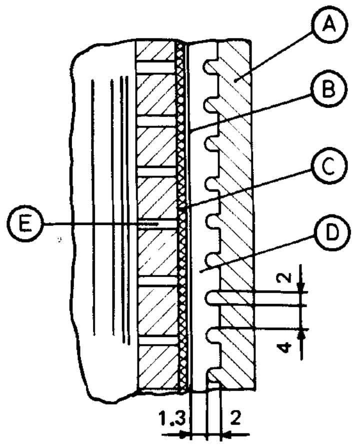
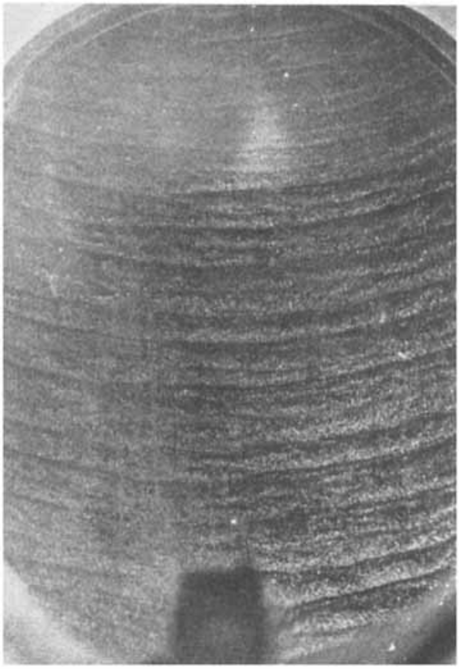


FIG. 7. Permeate flux at standard conditions (2.5 mm gap) as a function of the rotational speed.



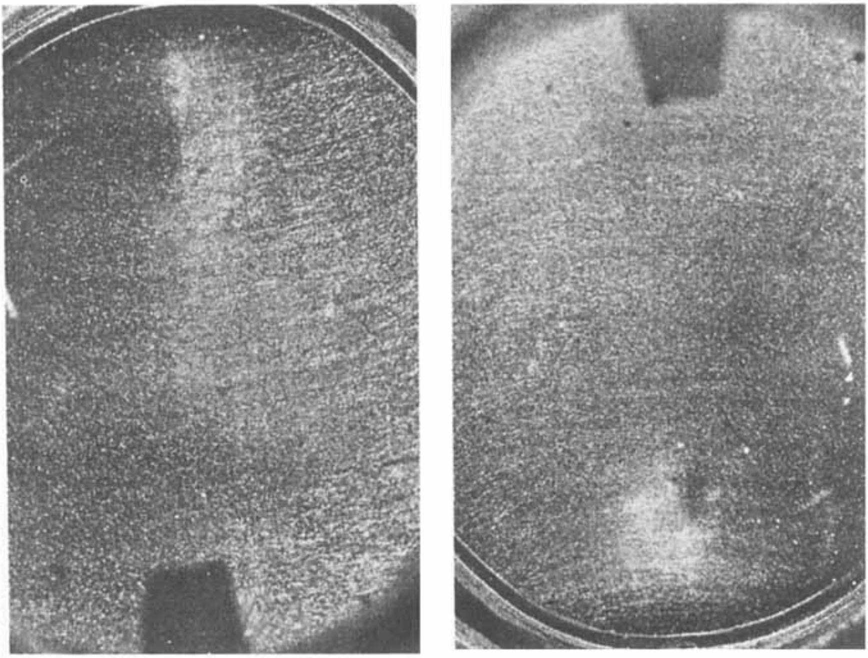
A	Inner wall
B	Membrane
C	M. support
D	Annular gap
E	Permeate drain

FIG. 8. Schematic section of the grooves on the inner wall.



(a)

FIG. 9. Vortices as observed in the case of regular grooves on the inner wall.



(b) (c)

Rotational speeds: (a) 1 m/s, (b) 4 m/s, (c) 6 m/s.

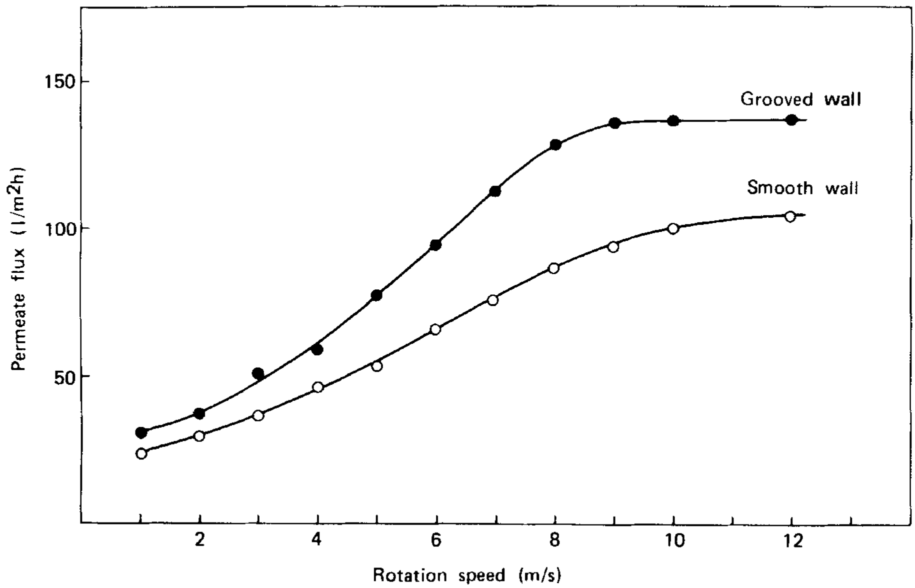


FIG. 10. Permeate flux at standard conditions (3.3 mm gap) as a function of the rotation speed.

(2) Follow the development of vortices and turbulence as functions of some physical and geometrical parameters
(3) Correlate several fluid dynamic situations with corresponding performances during ultrafiltration of oily emulsions

We thus conclude that the performance of a U.F. rotating module depends not only on the turbulence, as expected, but also on the size of the vortices. When the proper technology is applied, both these parameters can be exploited to enhance the efficiency of the U.F. process.

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