Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

Filtration Behavior of Baker's Yeast Suspensions at Very High Concentrations

Dengxi Wu[a]; Robert Field[a]; John Howell[a]
[a] School of Chemical Engineering, University of Bath, Bath, U.K.

To cite this Article Wu, Dengxi , Field, Robert and Howell, John(1995) 'Filtration Behavior of Baker's Yeast Suspensions at Very High Concentrations', Separation Science and Technology, 30: 7, 1473 — 1490
To link to this Article: DOI: 10.1080/01496399508010358
URL: http://dx.doi.org/10.1080/01496399508010358

SEPARATION SCIENCE AND TECHNOLOGY, 30(7-9), pp. 1473-1490, 1995

FILTRATION BEHAVIOR OF BAKER'S YEAST SUSPENSIONS AT VERY HIGH CONCENTRATIONS

Dengxi Wu, Robert Field, and John Howell

School of Chemical Engineering
University of Bath
Bath, BA2 7AY, U.K.

ABSTRACT

Pritchard et al. observed the phenomenon that the flux began to rise when the baker's yeast suspension was concentrated to a very high concentration in a thin-channel membrane module under laminar conditions. A further investigation of this interesting finding through both filtration experiments and rheological measurements has been conducted using baker's yeast suspensions. The separate filtrations of the suspensions and their supernatants suggest that for baker's yeast suspensions at very high concentrations there might be no cake layer. On the basis of the above results, an alternative to the normal membrane concentration process is put forward. Using this novel approach, particularly in its batch mode, a low-concentration feed can be directly transferred into a high-concentration product at a much higher flux.

INTRODUCTION

Membrane filtration for the concentration of biomass and biofluids is complex. A recent review (1) has shown that much effort has been devoted to developing models to predict flux in cross-flow microfiltration. A common feature is the negative influence of bulk concentration on flux. For example, Zydney and Colton (2)

developed an expression of the following form for microfiltration:

$$J \propto \left(\frac{R_p^4}{L}\right)^{\frac{1}{3}} . \gamma_w . \ln\left(\frac{C_w}{C_b}\right) \quad (1)$$

The mechanism of bulk transport is ascribed to shear-induced diffusion of a particle suspension. From the above, it is very clear that the permeation flux would be expected to decrease with increases in bulk concentration.

The high viscosities resulting from the high concentrations that occur in the concentration boundary layer in macromolecular ultrafiltration have a detrimental effect on mass transfer. Although this might be generally accepted, there is no general appreciation in the literature that the bulk viscosity has an influence on flux. Pritchard et al. (3) found that the bulk viscosity affected mass transfer during the concentration of yeast suspensions by microfiltration. They observed that the flux began to rise dynamically when the yeast suspension of 50 g kg^{-1} (dry weight, the same below) was concentrated to about 180 g kg^{-1} under laminar conditions in a flat-sheet membrane module. The concentration runs at three cross-flow velocities in the flat-sheet module are shown in Fig.1. The rheological behaviour of yeast suspensions of various concentrations were measured with a capillary viscometer and the shear stress was then estimated. As shown in Fig. 1, the point of flux increase occurred at approximately the same value of wall shear stress, 50 Pa, for all three cross-flow velocities. They attributed the unusual flux increase to progressive removal of some upper layer of cell cake once a threshold shear stress had been reached. In their modeling work (4), Pritchard et al. thought that the only

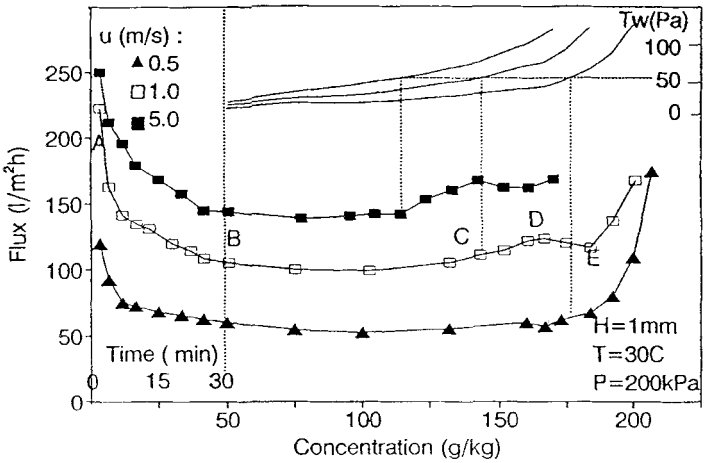

FIGURE 1. The concentration of baker's yeast suspension in the flat-sheet module: flux and wall shear-stress versus time then concentration (from M. Pritchard et al., 1990), at TMP of 2 bar, V of 0.5, 1.0 and 5.0 m s^{-1}.

information required to describe the impact of the bulk fuild upon laminar mass transfer is the wall shear stress. The main parameters that control the wall shear stress are the channel height, the cross-flow velocity, and the bulk viscosity. While the first two parameters are usually constant during a concentration process, the bulk viscosity will change considerably.

It is also recognized that biomass particulates are not only colloidal but adhesive. Also, biofluids are typically either adsorptive or prone to aggregate. A recent and siginificant finding was that the mechanism generating cake resistance and solute rejection depends on the extracellular matrix of organisms (5).

In the present paper, the filtration and rheological behavior of baker's yeast cell suspensions at very high concentrations is further investigated in order

to elucidate the mechanism for the extraordinary filtration performance. On the basis of these investigations, an alternative method to the normal concentration process with membrane filtration is put forward and verified.

EXPERIMENTAL

Membrane

A polysulphone membrane (Millipore, MWCO 100,000) was used in a flat-sheet module where there were 38 channels, each channel being 6 mm wide, 1 mm high, and 145 mm long.

Material

Fresh baker's yeast (*Saccharomyces cerevisiae*) was obtained from British Fermentation Products Ltd. as compressed cake of approximately 300 g kg^{-1} dry weight (at 105 °C for 12 h). The yeast was diluted for use with a solution of 10 mM phosphate buffer (pH = 7.0) and 1 g L^{-1} bacteriological peptone. The viability of the yeast cells, as determined microscopically by the uptake of methylene blue dye, was initially 98%, declining to 90% after a 3 h concentration (3).

The supernatant from a yeast suspension was obtained by centrifugation of the suspension at 2000 rpm and 10°C for 6 min with a Burkard Koolspin centrifuge (Biotech Instruments Ltd., Luton). No breakage of yeast cells was detected. The protein content (BSA equivalent) of the supernatant was estimated using the Bradford method (6).

Filtration Rig

The feed suspension was pumped via a rotary-lobe pump (AP125, SSP Ltd., Eastbourne, Sussex), which allowed

the flow rate to be maintained independently of discharged pressure.

The volumetric flow rate through the filtration module was monitored by an electromagnetic flowmeter (DN15 Magflo 1000/1100, Danfoss Instruments Ltd., Stonehouse, Glos.). This type of meter is independent of the viscosity or the shape of the velocity profile.

The inlet and outlet pressures were measured using PDCR 810 absolute pressure transducers (Druck Ltd., Leicester) interfaced to an OPUS PC via A to D interface (Linkon).

A temperature of 30°C was used for all runs. Temperature control was maintained by a coil situated in the feed tank.

The permeate was collected and weighted by an Avery model 1763 electronic balance (Sartorius) interfaced to a BBC computer.

Rheometer

Bohlin (Bohlin Reologi, Sweden) CS rheometer with PP40 measuring geometry (parallel disk of 40 mm diameter) was used for the rheological measurements (shear stress/ shear rate) of yeast suspensions at the same temperature as used for filtrations. A gap of 0.2 mm between the plates was set up. The system was calibrated with the standard oil (Viscosity Standard No. 4, Paint Research Association, Middlesex, U.K.).

RESULTS AND DISCUSSION

As mentioned above, Pritchard et al. observed that the flux steadily increased from about 180 g kg^{-1} to about 230 g kg^{-1} at V of 0.50 m s^{-1} during the continuous concentration of an yeast suspension. However, that was a dynamic process in which nearly all operating parameters, such as concentration, viscosity, and

pressure drop were also varying. An investigation to establish whether this extraordinary behavior was a transient pheomenon or a sustainable phenomenon, capable of exploitation, was undertaken. Experiments on the long-time filtration behavior of the yeast suspensions at constant concentrations were conducted. Figure 2 shows that the comparison of flux-time behaviors between two yeast suspensions of 50 g kg^{-1} and 200 g kg^{-1} at V of 0.45 m s^{-1} and transmembrane pressures (denoted as TMPs) of 0.96 and 1.75 bar under a constant-concentration operating mode. The flux for the 200 g kg^{-1} suspension was always much higher than that for the 50 g kg^{-1} during the 2.5 h run. The difference between the two fluxes at a TMP of 1.75 bar was even larger than that at a TMP of 0.96 bar. For the suspension of 200 g kg^{-1}, the flux data looked oscillatory when the sampling frequency for permeate was measured every 10 s. However, when the sampling frequency was decreased to a measurement every 20 s, the flux curve (not shown) was essentially smooth. This indicates that the frequency of the oscillation phenomenon was around 0.1-0.2 Hz. There was no such oscillation for the suspension of 50 g kg^{-1}, suggesting that for the 200 g kg^{-1} suspension, the cake layer was sheared off almost as soon as it formed.

The pressure drops across the membrane module were measured for the two suspensions at the same V of 0.45 m s^{-1} and found to be 0.26 bar and 0.63 bar, respectively. The power consumption for the 200 g kg^{-1} suspension was therefore higher than that for the low concentration suspension at the same cross-flow velocity, but not as high as one might anticipate from the very large increase in bulk viscosity. In part, this is due to the establishment of laminar flow at the higher viscosities, but it also could possibly indicate that the effective gap for flow was smaller at the lower concentration.

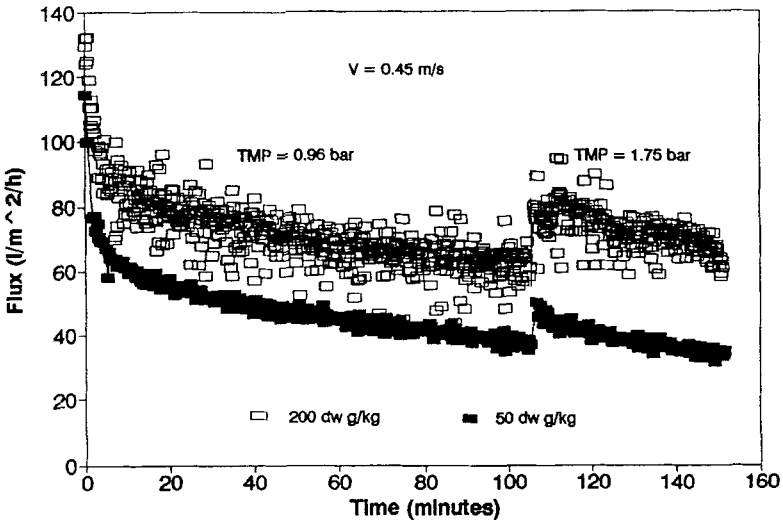

FIGURE 2. Comparison of flux-time curves for yeast suspensions with concentrations of 50 and 200 g kg^{-1} at TMPs of 0.96 and 1.75 bar using V of 0.45 m s^{-1}.

Furthermore, the tendency to form a "plasmatic" layer (1) increases as concentration increases, which reduces the resistance against flow. Figure 3 shows a comparison of two filtration runs at the same pressure drop of 0.63 bar across the module. The filtration of a 50 g kg^{-1} yeast suspension was performed at V of 0.84 m s^{-1}. As expected for the 50 g kg^{-1} suspension, the flux at 0.84 m s^{-1} was a little higher than that at 0.45 m s^{-1}. For example, at V of 0.45 m s^{-1}, the steady values of the flux at 0.97 bar (105 min) and 1.75 bar (150 min) were 36.5 and 34.6 L m^{-2} h^{-1}, respectively. The corresponding values at V of 0.84 m s^{-1} were 41.8 and 43.2 L m^{-2} h^{-1}, respectively. However, the flux for the 50-g kg^{-1} suspension at V of 0.84 m s^{-1} was still lower than that for the 200-g kg^{-1} suspension at 0.45 m s^{-1}, although the power consumption

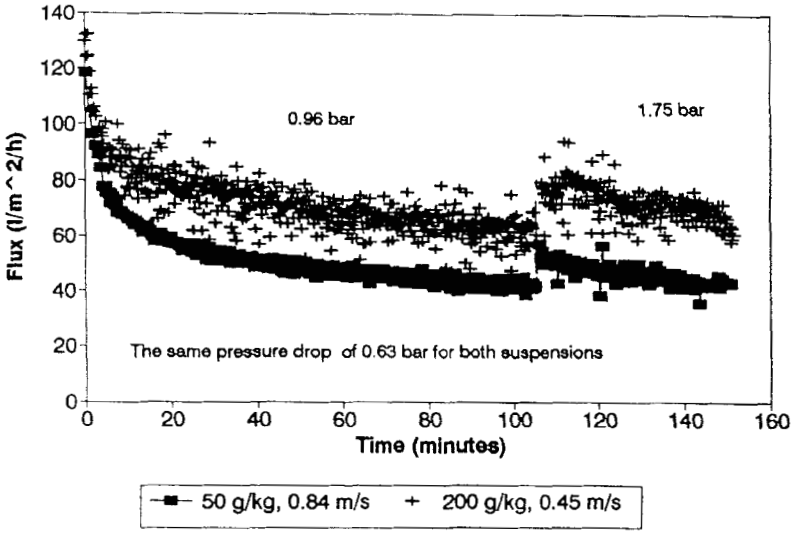

FIGURE 3. Comparison of flux-time curves for yeast suspensions with concentrations of 50 and 200 g kg^{-1} under the same pressure drop across the membrane module at TMPs of 0.96 and 1.75 bar, V of 0.45 m s^{-1} for a 200-g kg^{-1} suspension and V of 0.84 m s^{-1} for 50-g kg^{-1} suspension.

for the former was higher than that for the latter. Thus, for the same pressure drop, a better performance was obtained at the high concentration.

Although it was confirmed that a yeast suspension of very high concentration did result in a significant increase in flux, even for a longer running time, there still was a question to be answered: is there any cake layer adhering to the membrane surface? The results shown in Figs. 4 and 5 can be used to answer this question. Figure 4 shows the predictable result that the flux for the 50-g kg^{-1} suspension was obviously less than that for the corresponding supernatant at V of 0.45 m s^{-1}

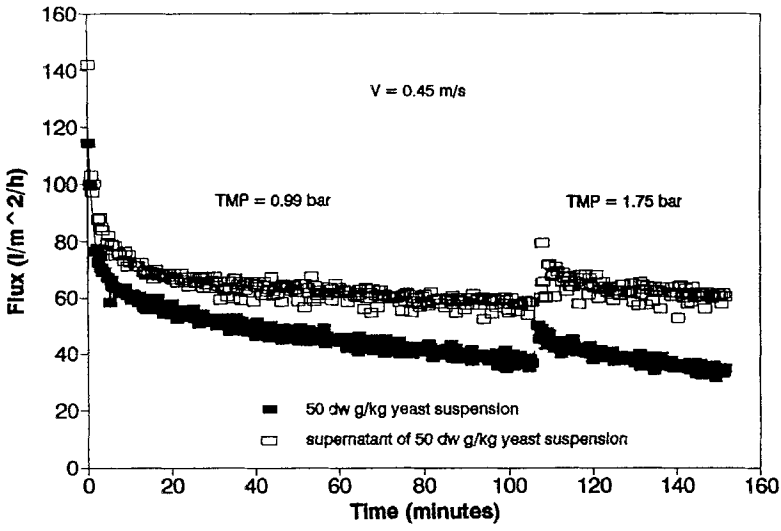

FIGURE 4. Comparison of flux-time curves between a 50-g kg^{-1} yeast suspension and its supernatant at TMPs of 0.96 and 1.75 bar, V of 0.45 m s^{-1}.

and TMPs of 1.0 and 1.75 bar. It may be reasonably presumed that the cake layer provided an additional resistance against the flux. Figure 5, however, shows completely contrary results: the flux for the 200-g kg^{-1} suspension was higher than that for the corresponding supernatant at the same operating parameter as in Fig. 4. Furthermore, this flux was even a little higher than that for the supernatant from a 50 g kg^{-1} suspension. These experimental results suggest that there might be no adherent yeast cake layer on the membrane surface at the very high concentrations.

Figure 6 demonstrates the relationship between viscosity and concentration of yeast at a shear rate of 2700 s^{-1}, which was equal to the nominal shear rate estimated using the formula (shear rate equals 6 x

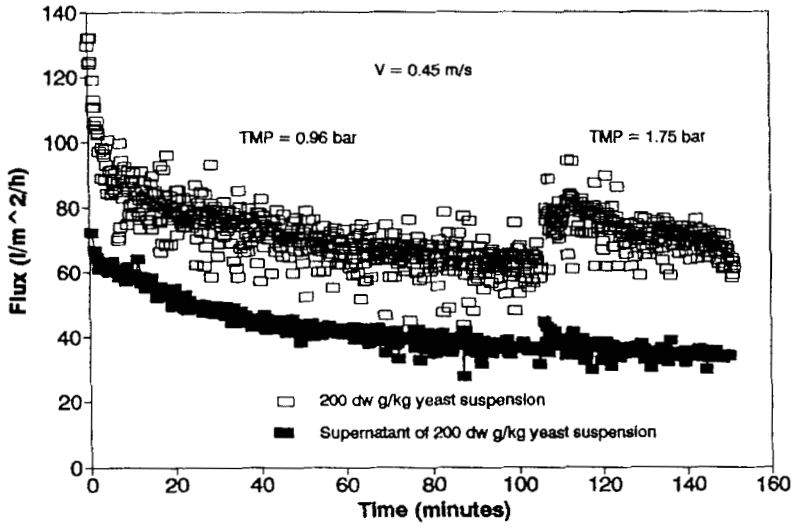

FIGURE 5. Comparison of flux-time curves between a 200-g kg^{-1} yeast suspension and its supernatant at TMPs of 0.96 and 1.75 bar, V of 0.45 m s^{-1}.

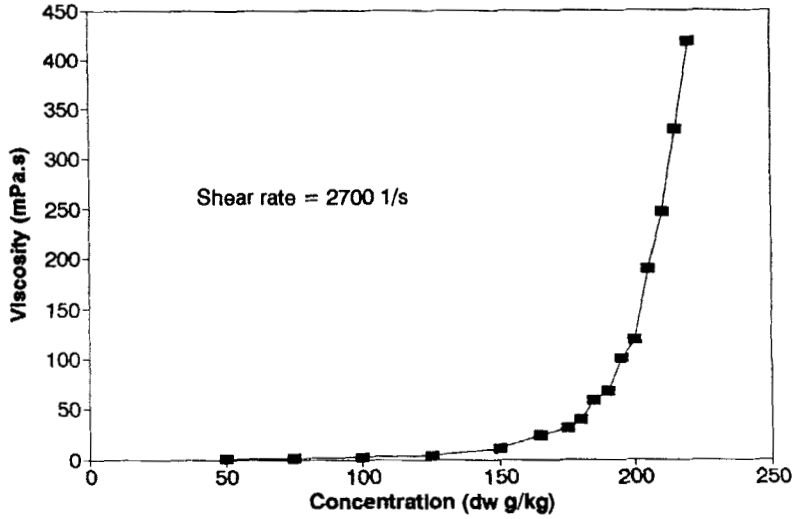

FIGURE 6. The variation of viscosity with concentration of the yeast suspension measured with Bohlin CS rheometer at a shear rate of 2700 s^{-1}.

velocity/channel height) for the filtration process operating at V of 0.45 m s^{-1}. According to the results shown in Fig. 6, the viscosity increased gradually with concentration below 150 g kg^{-1}, and afterwards rose very rapidly with concentration, especially above 190 g kg^{-1}. This viscosity – concentration curve is very similar to that obtained by Pritchard et al. (3) with a capillary tube viscometer at a nominal shear rate of 1000 s^{-1}. For the present data, it is noted that the viscosities of the 200- and the 220-g kg^{-1} suspensions were 119 and 418 mPa.s, respectively, which were 2 orders of magnitude higher than the value of a 50-g kg^{-1} suspension (1.36 mPa.s). Using Bohlin's procedure for yield-stress measurement, a yield-stress of 0.92 Pa was obtained for a 220-g kg^{-1} yeast suspension. Although the actual concentration of a cake layer on the membrane surface could not be known, it would be assumed that it would be larger than 220 g kg^{-1}. Therefore, the yield-stress for such a cake layer might be larger than 0.92 Pa. The shear stresses close to the surface for the 200- and the 220-g kg^{-1} suspensions were in excess of 100 Pa, while for the 50-g kg^{-1} suspension, the value was less than 4 Pa. Powell and Slater (7) reported that the detachment of bacterial cells adhered to glass surfaces occurred at shear stresses between 1 and 53 Pa. Hence, the collapse of the cake layer might occur in the case of filtration of a 200-g kg^{-1} suspension, but it might not happen for a 50-g kg^{-1} suspension. It is suggested that when the 200-g kg^{-1} suspension was used for filtration, the resistance against the flux resulted from what the corresponding supernatant provided. There are many macrosolutes, such as proteins and other excretions of yeast cells, in the solution environment for the case of yeast filtration. The resistance generated by the supernatant would thus consist of adsorption inside the

membrane pores and/or on the membrane surface, and an osmotic pressure effect due to the concentration polarization of the macrosolutes. For the high concentration suspension, the shear stress close to the membrane surface was very high, as mentioned above. The corresponding shear rate would be thus very high, which would reduce greatly the thickness of the concentration boundary layer and lead to an increase in the flux.

Table 1 gives the protein contents and color of the two supernatants. The protein content for the supernatant from the high-concentration suspension was nearly 4 times higher than that from the low concentration suspension. Thus, other macrosolutes in the high concentration supernatant might be 4 times higher too. Therefore, it would be expected that the flux for the low-concentration supernatant would be higher than that for the high-concentration supernatant, as shown in Figs. 4 and 5.

Figure 7 illustrates an interesting and beneficial property of the filtration of a 200-g kg^{-1} yeast suspension as three concentration runs were conducted, each of which started from 200 g kg^{-1} at V of 0.45 m s^{-1} and TMP of 0.98 bar. For the three consecutive runs (shown by open squares), the flux rose steadily with the increases in concentration. During each run, TMP increased automatically as a result of the increase in viscosity. The details at the ends of the three concentration runs are summarized in Table 2. It is worth noting from Fig. 7 that the flux, after the concentration run ended, was not lower than the flux in Fig. 5 which was obtained by the constant concentration filtration of a 200 g kg^{-1} suspension. This means that the increases in TMP and viscosity during the concentration run did not cause additionally irreversible fouling. If a yeast cake layer would have existed, the

TABLE 1. SOME COMPARISONS BETWEEN THE TWO SUPERNATANTS FROM 50-AND 200-g kg^{-1} SUSPENSIONS

Supernatant	Color	Proteins (g L^{-1})
200 g kg^{-1}	Brown	0.238
50 g kg^{-1}	Light yellow	0.06

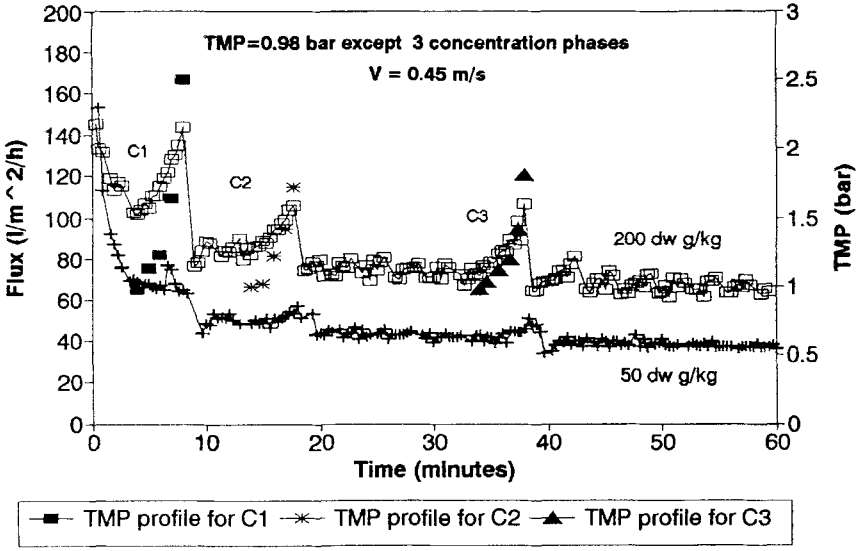

FIGURE 7. Comparison of flux-time curves between 50- and 200-g kg^{-1} yeast suspensions at V of 0.45 m s^{-1} and TMP of 0.98 bar except for the indicated concentration cycles where specific data are given.

TABLE 2. BATCH CONCENTRATION RUNS WITH INITIAL CONCENTRATION OF 200 g kg^{-1}

No. of Run	Final TMP (bar)	Final Concen.	Duration
1	2.50	230 g kg^{-1}	5 min
2	1.72	222 g kg^{-1}	5 min
3	1.81	224 g kg^{-1}	6 min

cake layer would be compressed, and the increased resistance produced by the more compact layer might have been maintained when the higher pressure was reduced. This is indeed what happened as the 50 g kg^{-1} yeast suspension was filtered at the same operating conditions. As shown in Fig. 7, when TMP was increased following the same TMP profiles as those for the 200 g kg^{-1} suspension, the flux did not respond much to the initial increase in TMP. It then increased slightly at a higher TMP and eventually declined to a lower value. Actually, a TMP of 1.0 bar was above the limiting pressure which was experimentally determined as about 0.66 bar at V of 0.45 m s^{-1} for the 50 g kg^{-1} yeast suspension. In contrast, the limiting pressure for the higher concentration suspensions of around 200 g kg^{-1} would appear to be in excess of 2.5 bar.

Alternative Concentration Process

A normal run for producing a yeast concentrate is conducted by continuously filtrating the suspension from the outset at a low concentration. It takes time to reach the target concentration, and the flux for the greater part of the concentration process is low, as shown in Fig. 1. The principle of the new method is schematically shown in Fig. 8. There are two operating modes (continuous and batch) for the new method. In a continuous-operation mode, according to mass balance,

$$\begin{aligned} Q_m &= Q_p + Q_c + Q_n \\ Q_i &= Q_p + Q_c \\ Q_i . C_i &= Q_c . C_c \ . \end{aligned} \qquad (2)$$

Using this new approach, a low-concentration yeast suspension is added to the filtration system; high-concentration product and permeate are withdrawn from the system. This means that a high-concentration product will be obtained directly from a low-concentration feed.

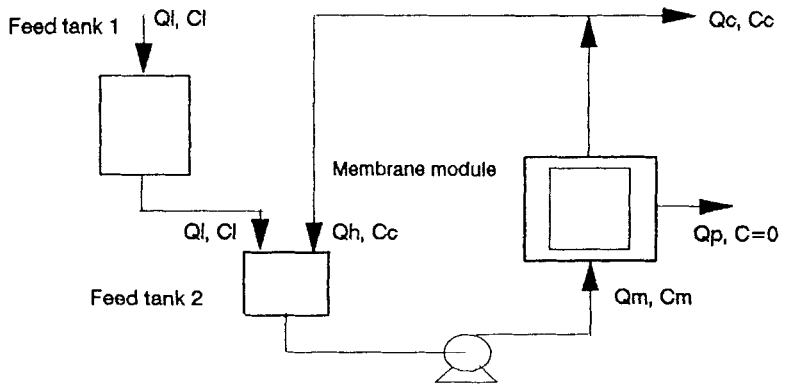

FIGURE 8. Schematic drawing of the method presented by the authors for exploitation of the high concentration–high flux phenomenon.

The filtration is thus carried out at high concentration and high flux, as shown in Fig. 2.

A variation of this method can also be carried out in batch mode. In batch mode, there is periodic addition of low-concentration feed into feed tank 2, and the withdrawal of concentrated product takes place in batches as well. As the filtration system is operated in batch mode, a series of small concentration runs is performed one by one. Adding of low-concentration feed and withdrawing concentrated product should be carried out at the end of a cycle according to mass balance. Probably higher product concentration can be obtained in this mode than with continuous operation. Figure 9 shows the results obtained using the batch version of the proposed method. The run was performed at V of 0.44-0.47 m s^{-1} with TMPs varying from 0.97 to 2.5 bar as viscosity increased. Feeding of low-concentration suspension of 50 g kg^{-1} and collecting the concentrate product of 222 to 228 g kg^{-1} were conducted in batches. The filtration

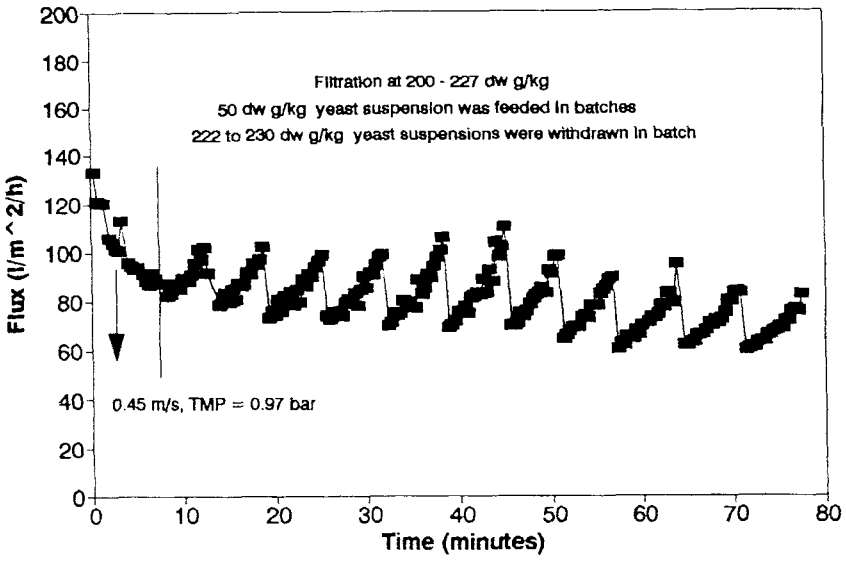

FIGURE 9. The concentration of yeast suspension using the batch mode of the authors' method with base TMP of 0.97 bar, V of 0.45 m s^{-1}, feed concentration of 50 g kg^{-1} and product concentration of 222-230 g kg^{-1}.

rate was much higher than with a normal concentration process.

Finally, it is worth pointing out that although the proposed approach was verified for baker's yeast suspensions, in principle, it should work for other fluids that have similar rheological behavior to that of yeast suspension provided the cells are not too shear-sensitive. The authors are investigating ultrafiltration and the rheological behavior of macromolecular solutions such as xanthan, pectin, and whey at very high concentrations. The main cross-flow velocity used in this paper was 0.45 m s^{-1}. This does not mean that using other velocities would violate the above results.

Actually, a filtration of a 200-g kg^{-1} yeast suspension was conducted at V of 1.0 m s^{-1} with a higher flux than that at 0.45 m s^{-1} (the data are not shown here). However, low cross-flow rates are preferred in order to avoid excessive power consumption.

CONCLUSIONS

In contrast to the filtration behaviour of the low-concentration yeast suspension, there appears to be no cake layer on the surface of the thin-channel flat-sheet membrane during the filtration of high-concentration yeast suspensions. This is the probable cause that produces higher flux for the filtration of high-concentration yeast suspensions. The mechanism is probably one of high viscosities resulting in high shear stresses leading to the removal of deposited yeast cells.

An alternative to the normal membrane concentration process is put forward for the concentration of the materials that are not damaged by high shear stress. Using this novel approach, particularly in its batch mode, a low-concentration feed can be directly transferred into a high-concentration product at a much higher flux.

NOMENCLATURE

C	concentration
L	length of module
R_p	radius of particle
J	permeate flux
V	cross-flow velocity
γ	shear rate

Subscripts

b	bulk
c	concentrate

h recycle of high concentration
l low-concentration feed
m feed to membrane module
p permeate
w membrane surface

ACKNOWLEDGMENTS

The authors are grateful for the support of the UK Science and Engineering Research Council (Grant No. GR/H 46930).

REFERENCES

1. M. H. Lojkine, R. W. Field, and J. A. Howell, Trans. IChemE, 70, Part C, 149 (1992).

2. A. L. Zydney and C. K. Colton, Chem. Eng. Comm., 47, 1 (1986).

3. M. Pritchard, J. A. Scott, and J. A. Howell, Separation for Biotechnology, D. L. Pyle, Ed., Elsevier Applied Science, London, 1990, p.65.

4. M. Pritchard, R. W. Field, and J. A. Howell, Presented at Int. Conf. on Engr. of Membrane Processes, Garmisch-Partenkirchen, Germany, May 13-15, 1992.

5. P. H. Hodgson, G. L. Leslie, R. P. Schneider, A. G. Fane, C. J. D. Fell, and K. C. Marshall, J. Mem. Sci., 79, 35 (1993).

6. N. M. Bradford, Anal. Biochem., 72, 249 (1976).

7. M. S. Powell and N. K. H. Slater, Biotech. Bioeng., 24, 2527 (1982).