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

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Gyula Vatai[a]; Miodrag N. Tekič[a]
[a] Faculty of Technology University of Novi Sad, Novi Sad, Yugoslavia

**To cite this Article** Vatai, Gyula and Tekič, Miodrag N.(1991) 'Membrane-Based Ethanol Extraction with Hollow-Fiber Module', Separation Science and Technology, 26: 7, 1005 — 1011
**To link to this Article: DOI:** 10.1080/01496399108050510
**URL:** http://dx.doi.org/10.1080/01496399108050510

SEPARATION SCIENCE AND TECHNOLOGY, 26(7), pp. 1005–1011, 1991

# NOTE

# Membrane-Based Ethanol Extraction with Hollow-Fiber Module

GYULA VATAI and MIODRAG N. TEKIĆ
FACULTY OF TECHNOLOGY
UNIVERSITY OF NOVI SAD
NOVI SAD, YUGOSLAVIA



## INTRODUCTION

The high energy requirements of the traditional separation of ethanol from fermentation liquors by distillation led us to seek a new energy-efficient separation method. Several alternatives, including absorption, molecular sieves, membrane separation processes, and liquid–liquid extraction processes, have been proposed and investigated (*1*). One of the most investigated separation techniques during the past few years has been membrane-aided solvent extraction (*2–5*). This dispersion-free solvent extraction process, which uses microporous membranes, overcomes such shortcomings of conventional liquid extraction as flooding and loadings. On the other hand, a technique with microporous hollow fibers may provide high mass transfer per unit volume since hollow-fiber modules contain an enormous surface area.

In this work, a hollow-fiber module for an artificial kidney was used as a permeable membrane, and the capacity to separate ethanol from water was examined by using a *sec*-octanol solvent.

## EXPERIMENTAL

The experiments were carried out with a commercial hollow-fiber module for an artificial kidney produced by Hemofarm, Vršac, Yugoslavia. Table 1 shows hollow-fiber membrane and module details. The extractant used in these experiments was reagent grade *sec*-octanol from Brixol, Vršac, with the physical properties given in Table 2.

TABLE 1
Hollow-Fiber Membrane and Module Details

| | |
|---|---|
| Contact area, $m^2$ | 1.25 |
| Module diameter, mm | 40 |
| Module length, mm | 230 |
| Fiber diameter, μm | 200 |
| Fiber number | 7200 |
| Fiber material | Polysulfone |
| Housing material | Polycarbonate |



All experiments were carried out at room temperature (20 ± 1°C) in a countercurrent flow of the feed (8.5 vol% ethanol solution in water) and extractant, with the feed flow on the tube side (extractant flow on the shell side) as well as with the feed flow on the shell side (extractant flow on the tube side). The membrane used in the experiments was hydrophobic, and the module was operated with the feed at a higher pressure than the extractant. As it can be seen from Fig. 1, the experimental apparatus was very simple. The flow rates of feed and extractant were regulated by needle valves and the vertical position of the storage tanks, i.e., the hydrostatic head of liquid. By using a measuring cylinder, the flow rates of both feed and extractant were determined.

Ethanol concentrations in the steady-state condition in water and the solvent were measured indirectly by assuming additivity of the liquid densities. The densities of water and the organic phase were measured by Anton Paar's digital density meter DMA 46. Following distillation of the organic phase, and on the basis of the density of both the distillate and the remaining material, the ethanol concentration was calculated.

TABLE 2
Physical Properties of Extractant, 2-Ethyl-1-hexanol (*sec*-octanol) at 20°C

| Distribution coefficient of ethanol (—) | Solubility of water in solvent (g/L) | Solubility of solvent in water (g/L) | Viscosity (mPa·s) | Diffusion coefficient of ethanol in extractant ($m^2/s$) |
|---|---|---|---|---|
| 0.43 | 31.5 | 0.65 | 7.79 | $0.24 \times 10^{-9}$ |

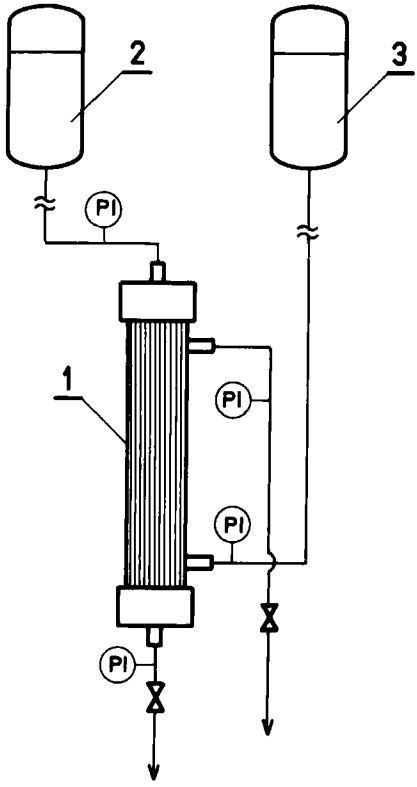


FIG. 1. Schematic diagram of experimental set-up. (1) Hollow-fiber module. (2) Tube-side storage tank. (3) Shell-side storage tank.



## RESULTS AND DISCUSSION

On the basis of the experimental data, the overall mass transfer coefficient was calculated by using the following relation:

$$Q_D C_{EO,out} = K_L \times \Delta C_{LM} \times \text{area of contact} \quad (1)$$

where

$$\Delta C_{LM} = (\Delta C_1 - \Delta C_2)/\ln(\Delta C_1/\Delta C_2)$$

$$\Delta C_1 = m_E C_{EW,in} - C_{EO,out}$$

$$\Delta C_2 = m_E C_{EW,out}$$

Experimental data are correlated by using Leveque's equation (*6*) for tube-side flow:

$$\frac{kd_i}{D} = 1.61\left(\frac{d_i^2 W}{LD}\right)^{1/3} \tag{2}$$

and the equation of Prasad and Sirkar (*5*) for shell-side flow:

$$\frac{kd_e}{D} = 5.8\left(\frac{d_e}{L}\right)\left(\frac{d_e W}{\nu}\right)^{0.6}\left(\frac{\nu}{D}\right)^{1/3} \tag{3}$$

As can be seen from Figs. 2 and 3, these equations fit the experimental data satisfactorily.

Wilson's plot (*7*), shown in Fig. 4, was applied to the determination of the mass transfer coefficient of the membrane on the basis of measured overall mass transfer coefficient, $K_L$, data and calculated values for mass transfer coefficient, $k_f$, in the feed. The mass transfer coefficient of the membrane, $k_m$ = 0.0109 m/h, was obtained from the intersection of the straight line experimental data and the vertical axis. From the membrane mass transfer coefficient, assuming molecular diffusion in membrane pores,

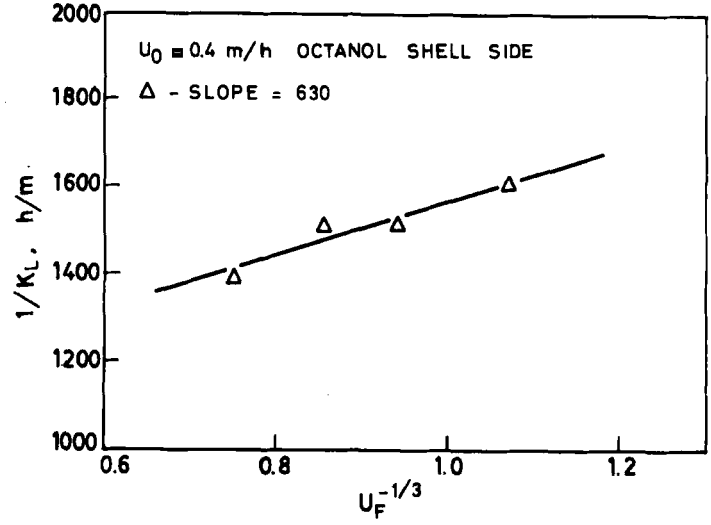


FIG. 2. Applicability of Leveque's equation on tube-side mass transfer.

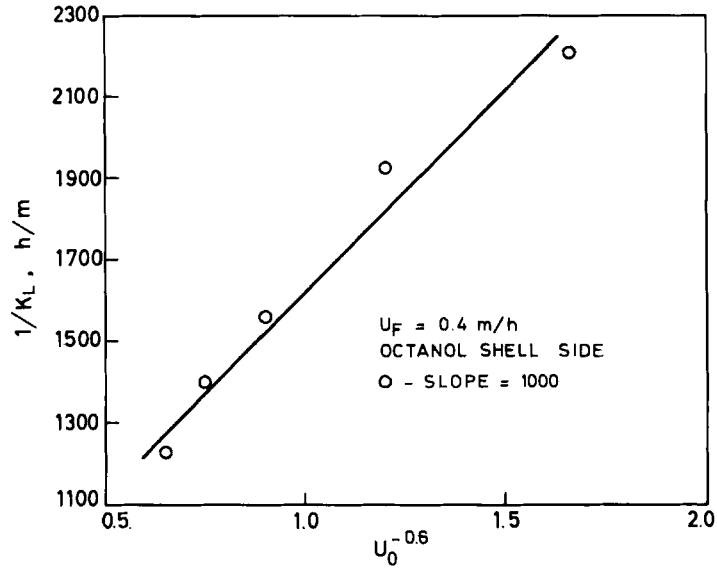


FIG. 3. Applicability of equation of Prasad and Sirkar on shell-side mass transfer.

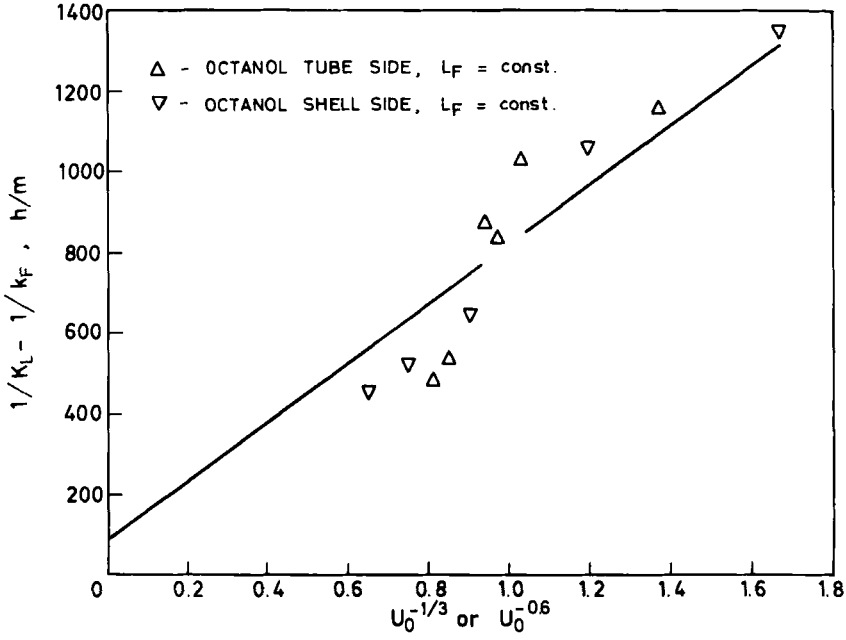


FIG. 4. Wilson's plot for determining mass transfer coefficient of the membrane.

and using the equation proposed by Prasad and Sirkar (*5*):

$$k_m = D_{EO}\epsilon_M \left[\tau_M \left(\frac{d_o - d_i}{2}\right)\right] \quad (4)$$

the tortuosity factor was found to be $\tau_M \approx 1$.

The results presented in this note show that ethanol extraction can be carried out efficiency by using a hollow-fiber membrane made of polysulfone. For the system investigated, the distribution coefficient, $m_i$, is close to 1, and as discussed in detail by Prasad and Sirkar (*5*), the moderate hydrophobicity of a polysulfone membrane does not have a dominant effect.

## NOTATION

| | |
|---|---|
| $C_{EO}$ | ethanol concentration in solvent |
| $C_{EW}$ | ethanol concentration in water |
| $d_i$ | fiber inner diameter |
| $d_e$ | equivalent diameter |
| $d_o$ | fiber outer diameter |
| $D$ | diffusion coefficient |
| $k_F$ | mass transfer coefficient in feed |
| $k_o$ | mass transfer coefficient in solvent |
| $k_m$ | mass transfer coefficient in membrane |
| $K_L$ | overall mass transfer coefficient |
| $L$ | module length |
| $m_E$ | distribution coefficient of ethanol |
| $U_F$ | superficial velocity of feed |
| $U_o$ | superficial velocity of solvent |
| $W$ | liquid velocity |
| $Q_o$ | solvent flow rate |

### Greek Letters

| | |
|---|---|
| $\epsilon_M$ | porosity of membrane |
| $\tau_M$ | tortuosity factor of membrane pores |
| $\nu$ | kinematic viscosity |

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*Received by editor May 29, 1990*