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# Modeling of Transport Phenomena Based on the Velocity Distribution in a Hollow-Fiber Dialyzer

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Abstract

The relation between mass transport phenomena and flow characteristics in the shell side of a hollow-fiber dialyzer has not been investigated sufficiently because of the tangled flow path. In this study, the effect of the radial convection was investigated. Radial components of flow velocity in the shell side were estimated based on the axial components which were measured. In addition, a model which characterizes the mass transport phenomena considering the effect of radial convection was established and the local concentration distributions were also estimated. As a result, a new knowledge, which is useful for the design of dialyzers was obtained.

Keywords: Dialyzer, Hollow-Fiber, Velocity Distribution, Mass Transport Phenomena

## 1 Introduction

A hollow-fiber dialyzer has been usually used for hemodialysis. During the cure of the hemodialysis, human blood is fed into lumens of hollow-fibers while dialysate is fed to the shell side of the dialyzer countercurrently from the lateral side. The shell side or dialysate side means the outside of the hollow-fibers and blood side means the lumens of the hollow-fibers. Mass transport phenomena in a hollow-fiber dialyzer are transfer through the liquid film in lumens and in the shell side, and permeation through membranes. A mass transfer coefficient in a liquid film in a lumen is estimated considering that the flow in the lumen is a circular pipe laminar flow. On the other hand, in the shell side, dialysate flows among a lot of hollow-fibers and the flow path is complicated. It is, therefore, difficult to estimate a mass transfer coefficient in a liquid film in the shell side.

In the previous studies on the flow in the shell side, it was pointed out that the effects of the flow characteristics on the performance of the dialyzer were not negligible. The axial velocity distribution in the axial and the radial directions was investigated experimentally. In the center region, the values of the velocity were small. On the other hand, the values in the outer region were much larger than those in the center region. Though the values of the velocity in the center region were much smaller than those in the outer region in the upstream region, the difference of the values between center region and outer region become smaller in the downstream region. This suggests that there exists radial convection from outer region to the center region and it is expected that the effect of it is not negligible.

In this study, the effect of the radial convection was investigated. In addition, a model which characterizes the mass transport phenomena considering the effect of radial convection was established and local concentration distribution was also estimated.

## 2 Radial Convection in the Shell Side

As mentioned above, in the previous study, the axial components of velocity in the shell side were measured. The local axial components of velocity at arbitrary radial and axial positions can be calculated with the regression curves, which correlate the experimental results. The shell side of the cylindrical dialyzer is divided into 100 divisions in axial

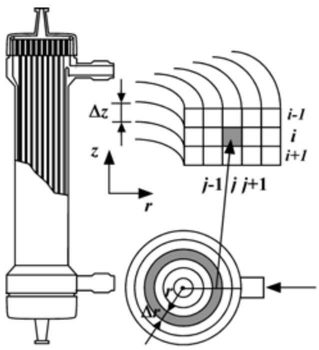


Figure 1 Schematic illustration of a dialyzer and control volumes

direction and also 100 divisions in radial direction as shown in the Fig.1. Each division is considered as a control volume. Radial components of velocity in the shell side are calculated sequentially according to the following equation, which is the mass balance equation around a control volume:

$$\left(u_r S_r\right)\big|_{i,j} = \left(u_r S_r\right)\big|_{i,j+1} + \left(u_z S_z\right)\big|_{i+1,j} - \left(u_z S_z\right)\big|_{i,j} \quad (1)$$

where $u_z$[m・s$^{-1}$] is axial component of velocity in the shell side and $u_r$[m・s$^{-1}$] is radial component of velocity in the shell side, $S_z$ and $S_r$[m$^2$] are areas of the surfaces of the control volume in the shell side normal to the *r*-axis and *z*-axis. Subscripts *i* and *j* indicate that the control volume is *i*-th in axial direction and *j*-th in radial direction.

Figure 2 shows the radial volume flow rate distribution in the radial direction. $Q_r$[ml・min$^{-1}$] is the sum of radial flow rate through the surfaces of control volumes at each radial position over the whole axial region except for the regions close to the both ends of the dialyzer, where the effects of outlet and inlet flow of dialysate is significant. $Q_D$[ml・min$^{-1}$] is flow rate in the dialysate side. $Q_r$ takes the maximum around $r/R$=0.6, in the middle region between the wall of the shell and the center. The average value of $Q_r$ is about 10% of axial convection and it becomes clear that the effect of radial convection is not negligible.

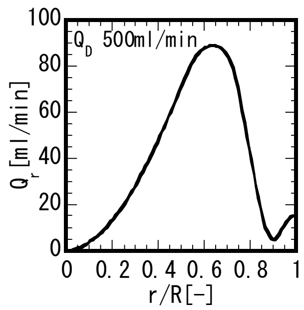


Figure 2 Radial flow rate at each radial position

3 Concentration Distribution in the Dialyzer

Local concentration distributions in both blood side and dialysate side are calculated by solving the following simultaneous equations, which are balance equations of mass transfer of solute in blood side and dialysate side around a control volume considering the effect of radial convection in the shell side:

blood side:

$$\left(C_B \frac{Q_B n_f}{N_f}\right)\Bigg|_{i-1,j} - \left(C_B \frac{Q_B n_f}{N_f}\right)\Bigg|_{i,j} - \left(K(C_B - C_D)\pi d_{lm}\Delta z n_f\right)\big|_{i,j} = 0 \quad (2)$$

dialysate side:

$$\left(C_D u_z S_z\right)\big|_{i+1,j} - \left(C_D u_z S_z\right)\big|_{i,j} + \left(C_D u_r S_r\right)\big|_{i,j+1} - \left(C_D u_r S_r\right)\big|_{i,j} + \left(K(C_B - C_D)\pi d_{lm}\Delta z n_f\right)\big|_{i,j} = 0 \quad (3)$$

where $C_B$ and $C_D$[mol・m$^{-3}$] are concentrations in the blood side and dialysate side, $Q_B$[m$^3$・s$^{-1}$] is flow rate in the blood side, $N_f$ and $n_f$ are numbers of hollow-fibers in the dialyzer and in a control volume, $d_{lm}$[m] is logarithmic average diameter of a hollow fiber, $\Delta z$[m] is axial height of a control volume, and $K$[m・s$^{-1}$] is the local overall mass transfer coefficient, which was calculated according to the correlating equation about Sh and Re of the blood side and that of the dialysate side, which were proposed by Yoshikawa et al. (2003). Local axial velocity in the shell side was used as the representative velocity of Re in order to calculate the mass transfer coefficient of shell side film at each local position.

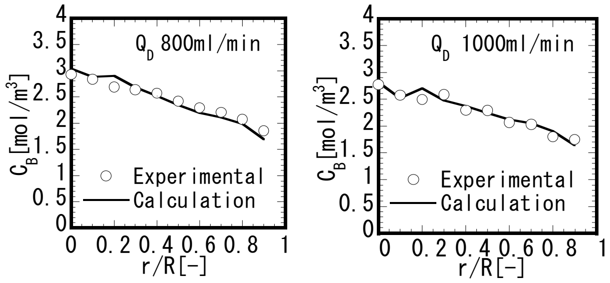


Figure 3 Comparison of concentration at the outlet of lumens between experiment and calculation

Comparison of concentration distribution in radial direction of hollow-fibers at the outlet of blood side between experimental and calculation results is shown in Fig.3. The experimental results are correlated with the calculated results well. From this result, it is confirmed that the model is appropriate for the calculation of concentration distributions in a dialyzer.

4 Conclusions

It was verified that the radial convection in the shell side is not negligible. In addition, a model which characterizes the mass transport phenomena considering the radial convection in the shell side was proposed and it has become possible to estimate the local concentration distribution by means of the model.

Reference


[1] Yoshikawa,S., *J.Chem.Eng.Japan*,36,1076-1084 (2003)