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Estimation of the Limiting Current Density in Electrodialysis with Both Spacer and Space

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Abstract

The influence of "space" in the ion-exchange compartment (IEC) on limiting current density (LCD) during electrodialysis was investigated. A general equation to estimate LCD was derived for three types of electrodialytic equipment: 1) with the IEC filled with spacers, 2) without spacers, and 3) with spacers and space. The theoretical values of LCD calculated from the equation were in good agreement with the experimental values obtained by varying the space thickness and employing various kinds of spacers; it follows that the value of LCD in all three types of electrodialytic equipment can be estimated from the general equation derived here.

INTRODUCTION

When operating electrodialytic equipment with ion-exchange membranes, one is supposed to know its limiting current density (LCD) in order to extend the life of the membrane and to operate it effectively. Thus, many workers (*1–14*) have studied the estimation of LCD.

When a very thin commercial spacer is inserted into an ion-exchange compartment (IEC) in electrodialytic equipment of the filter press type, a frame of IEC is occasionally thicker than the spacer. An IEC in equipment of the unit cell type cannot be fixed completely in the electrodialytic stack. In either case, it is difficult to set the spacer close to the ion-exchange membrane, so there are small spaces on both sides of the spacer. Establishing a relationship between the space in the IEC of electrodialytic equipment and its LCD would be of use for improving spacers and equipment.

In this paper an equation for estimating the LCD in electrodialytic equipment with space on both sides of a spacer in an IEC is derived from two LCD estimating equations developed for equipment filled with spacers and for one without a spacer (*15*, *16*). The validity of this equation was tested experimentally.

ESTIMATING EQUATION OF LCD

The thickness (H) of a frame of IEC is often larger than that (t) of the spacer ($H > t$) as shown in Fig. 1. Thus, it is necessary to insert several sheets (n) of spacers into one IEC ($H > nt$).

On the other hand, it has been found that the flow distribution inside the spacer in an IEC with both a spacer and space could be represented by that of an IEC filled with spacers, and the flow distribution inside the space could be expressed by an IEC without a spacer (*17*). The mass transfer in an IEC ($H > nt$) with both a spacer and space employs the same concept as for flow distribution in an IEC. Therefore, a total mass transfer coefficient K_t can be represented by

$$\frac{H}{K_t} = \frac{H - nt}{K_0} + \frac{nt}{K_s} \tag{1}$$

where K_0 is a mass transfer coefficient inside the space (between the spacer and the ion-exchange membrane), and K_s is one inside the spacer.

Our previous work (*15*) revealed that LCD in electrodialytic equipment without a spacer can be estimated by

$$\mathrm{Sh}_0 = \frac{1.47}{\tau_m - \tau_s}\left(\frac{H}{L}\right)^{1/3}\mathrm{Re}^{1/3}\mathrm{Sc}^{1/3} \tag{2}$$

where Re is the Reynolds number ($= Hu_0/\nu$), Sc is the Schmidt number ($= \nu/D$), and Sh_0 is the Sherwood number ($= HK_0/D = HI_0/C_0DF$) which represents LCD (I_0).

In a succeeding work (*16*) it was found that Sh_s ($= HK_s/D = HI_s/C_0DF$),

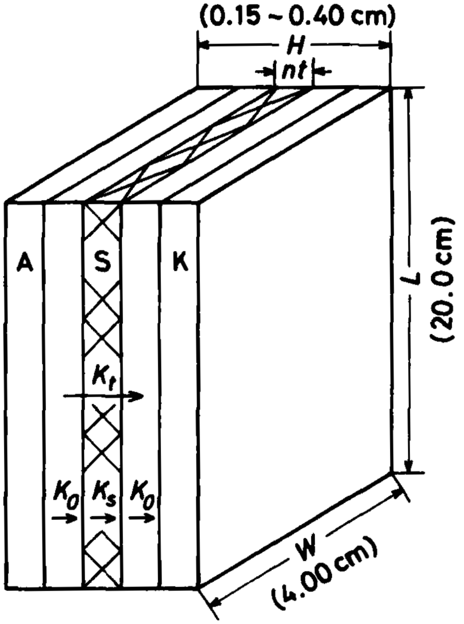

FIG. 1. Profile of an electrodialytic cell. A: anion-exchange membrane; *H*: channel thickness of IEC; *K*: cation-exchange membrane; K_t: total mass transfer coefficient in IEC; K_s: mass transfer coefficient inside the spacer; K_0: mass transfer coefficient inside space; *L*: height of IEC; *n*: numbers of spacers; *S*: spacer; *t*: apparent thickness of a spacer; *W*: width of IEC.

which represents LCD (I_s) in the equipment filled with spacers, is expressed by

$$\mathrm{Sh}_s = \frac{0.095}{\tau_m - \tau_s} \frac{1}{[n(t-d)]^{1/2}[(1-\varepsilon)^2/\varepsilon^3]^{1/5}} \left(\frac{H}{L}\right)^{1/3} M^{1/3}\mathrm{Re}^{1/2}\mathrm{Sc}^{1/3} \tag{3}$$

where t is the thickness of a spacer, d is the diameter of a fiber of the spacer, ε is the void fraction of the spacer, and M is a parameter represented by using the eddy viscosity (m) originated by the spacer as

$$M = \frac{m^3}{(m+1)^2 \ln(m+1) - 1.5m^2 - m} \tag{4}$$

Further, m is expressed by using the characteristic values of the spacer as in Eq. (5) (*18*):

$$m = 2.1 \times 10^5[n(t-d)]^{2.4}\left[\frac{(1-\varepsilon)^2}{\varepsilon^3}\right]^{0.8} \quad (5)$$

Therefore, the total Sherwood number Sh_t (= $HK_t/D = HI_t/C_0DF$) in a IEC with both a spacer and space can be represented by Eq. (6), which can be obtained by substituting Eqs. (2) and (3) into Eq. (1):

$$Sh_t = \frac{H Sh_0 Sh_s}{nt Sh_0 + (H - nt) Sh_s}$$

$$= \frac{1.47}{\tau_m - \tau_s} \frac{H(H/L)^{1/3} M^{1/3} Re^{1/2} Sc^{1/3}}{15.5nt[n(t-d)]^{1/2}[(1-\varepsilon)^2/\varepsilon^3]^{1/5} + (H - nt) M^{1/3} Re^{1/6}} \quad (6)$$

Equation (6) is applicable to all the cases: without spacer, filled with spacers, and with spacers and space.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The electrodialytic equipment used in this study was of the same filter press type as described in a previous paper (*16*).

The net area for the electric current in an IEC was 20.0 cm (L) × 4.00 cm (W), i.e., 80.0 cm^2. The value of H was changed from 0.15 to 0.40 cm by using two kinds of spacers. Three types of spacers, A, B, and C, were inserted into an IEC with n = 1–5. Table 1 shows the characteristics of these spacers. The values of n, H, and u_0 in each experiment are shown in Table 2.

The concentration C_0 of NaCl in the inlet solution was 0.05 × 10^{-3} g-eq/cm^3. The cation- and anion-exchange membranes used were Neosepta CL-25T and AV-4T from Tokuyama Soda Co., respectively.

TABLE 1
Characteristics of Spacers

Spacer	d (cm)	t (cm)	ε (-)	Textile
A	0.0238	0.30	0.940	Honeycomb
B	0.0568	0.15	0.727	Pointed twill
C	0.0294	0.08	0.600	Pointed twill

TABLE 2
Experimental Conditions

Spacer	n (-)	H (cm)	u_0 (cm/s)
A	1	0.30–0.40	0.208–13.9
B	1	0.15–0.40	0.208–27.8
C	1-5	0.40	0.208–10.4

Electric current density (I) and electric potential (V) were measured under each condition, and LCD (I_l) was determined from a plot of V/I vs $1/I$ (*2*, *15*).

All experiments were performed at 25.0 ± 0.1°C unless otherwise specified.

RESULTS AND DISCUSSION

1. Dependence of *n* on LCD

The values of LCD were measured for an IEC (H = 0.40 cm) in which spacers C (t = 0.08 cm) of 1-5 sheets ($H - nt$ = 0–0.32 cm, variable) were inserted.

Figure 2 shows the relation between Re and Sh_l obtained. The short-dash line represents Eq. (6) for an IEC without a spacer ($n = 0$; $H - nt$ = 0.40 cm), i.e., Eq. (2). The broken line represents Eq. (6) for IEC with one spacer ($n = 1$; $H - nt$ = 0.32 cm). The full line represents Eq. (6) for an IEC filled with spacers ($n = 5$; $H - nt$ = 0 cm), i.e., Eq. (3). Figure 2 shows that Eq. (6) satisfactorily reproduces the experimental plots obtained under each condition.

Further, LCD decreases with decreasing n (i.e., with increasing $H - nt$) and is asymptotic to that in the equipment without a spacer. Thus, it is concluded that an IEC operates best when filled with spacers.

2. Influence of *H* and Kind of Spacer on LCD

Equation (7) can be derived from Eq. (6):

$$Sh_m = \frac{1.47}{\tau_m - \tau_s}\left(\frac{H}{L}\right)^{1/3} Re^{1/3} Sc^{1/3} \tag{7}$$

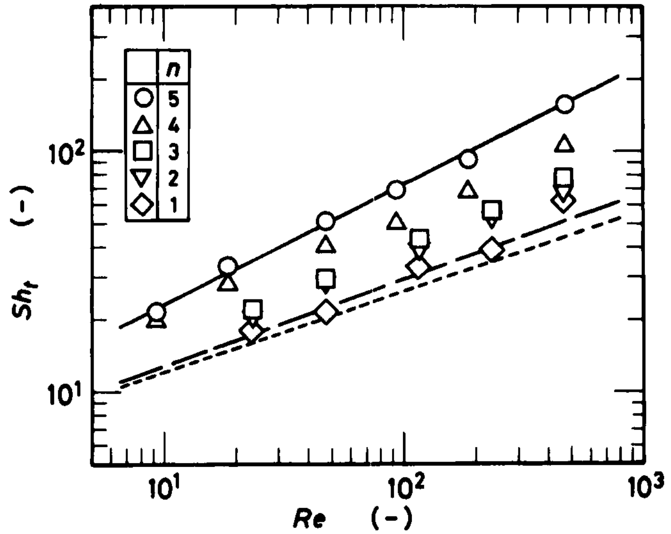

FIG. 2. Relation between Re and Sh_t with varying numbers (n) of spacers C in IEC. The short-dash line represents Eq. (6) at $n = 0$, which corresponds to Eq. (2). The long-dash line represents Eq. (6) at $n = 1$. The full line represents Eq. (6) at $n = 5$. This corresponds to Eq. (3) derived for IEC filled with spacers.

where Sh_m is the Sherwood number modified to allow for the presence of space in the IEC, and is defined by

$$Sh_m = \frac{I_t}{C_0DF} \frac{15.5nt[n(t-d)]^{1/2}[(1-\varepsilon)^2/\varepsilon^3]^{1/5} + (H-nt)M^{1/3}Re^{1/6}}{M^{1/3}Re^{1/6}}$$

$$= Sh_t \frac{15.5nt[n(t-d)]^{1/2}[(1-\varepsilon)^2/\varepsilon^3]^{1/5} + (H-nt)M^{1/3}Re^{1/6}}{HM^{1/3}Re^{1/6}} \quad (8)$$

Each value of LCD was measured for an IEC with a sheet of spacer A ($t = 0.30$ cm; $H = 0.30$–0.40 cm; $H - t = 0$–0.10 cm) or B ($t = 0.15$ cm; $H = 0.15$–0.40 cm; $H - t = 0$–0.25 cm). Figure 3 depicts the relationship between Re and Sh_m as calculated from Eq. (8). The full line represents Eq. (7).

Figure 3 shows that $Sh_m/(H/L)^{1/3}$ increases in proportion to the ⅓ power of Re, and that the theoretical values calculated from Eq. (7) coincide well with the experimental values under wide variation of H by using various

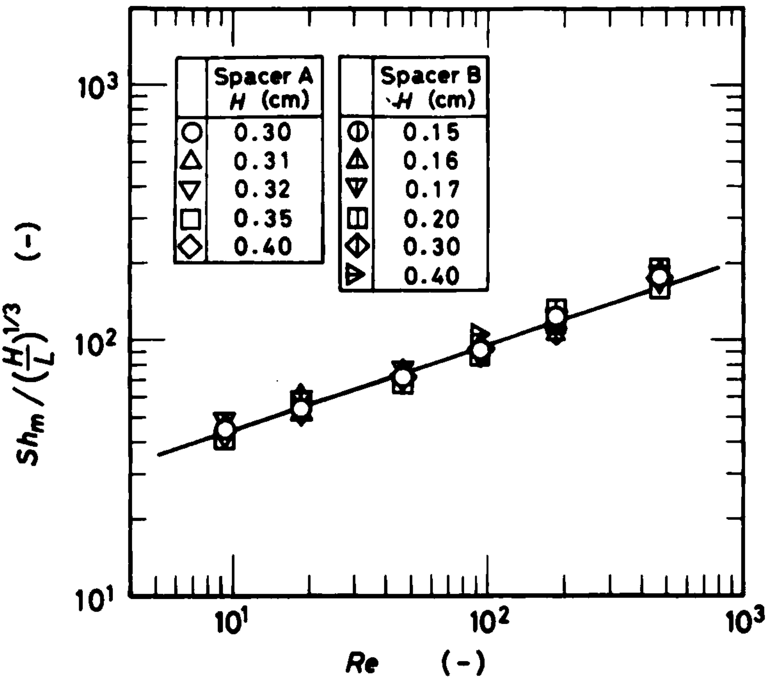

FIG. 3. Influence of Re on $Sh_m/(H/L)^{1/3}$ in IEC with spacer A or B. The full line represents Eq. (7).

kinds of spacers. Therefore, it is concluded that LCD can be estimated by Eq. (6) or Eq. (7), whether or not space exists in the IEC.

CONCLUSIONS

Equation (6) was derived in order to estimate the LCD in electrodialytic equipment with both a spacer and space in an IEC.

To examine the validity of Eq. (6), the values of LCD were measured for various sizes of space in an IEC and with various kinds of spacers. The theoretical value of LCD calculated from Eq. (6) was in good agreement with experiment. Therefore, it is evident that LCD can be estimated by Eq. (6) or Eq. (7).

It was also found that the LCD in electrodialytic equipment with both a spacer and space in the IEC is smaller than in equipment filled with spacers.

SYMBOLS

C_0 concentration of inlet solution in the ion-exchange compartment (IEC) (g-eq/cm^3)
D molecular diffusivity (cm^2/s)
d diameter of a fiber in spacer (cm)
F Faraday's constant (A s/g-eq)
H channel thickness of IEC (cm)
I electric current density (A/cm^2)
I_s limiting current density (LCD) in IEC filled with spacers (A/cm^2)
I_t total LCD in IEC with both spacer and space (A/cm^2)
I_0 LCD in IEC without spacer (A/cm^2)
K_t total mass transfer coefficient in IEC (cm/s)
K_s mass transfer coefficient inside spacer in IEC (cm/s)
K_0 mass transfer coefficient outside spacer in IEC (cm/s)
L height of IEC (cm)
M parameter as defined by Eq. (4) (-)
m parameter of the eddy viscosity due to spacer as defined by Eq. (5) (-)
n number of spacers in IEC (-)
Re Reynolds number ($= Hu_0/\nu$) (-)
Sc Schmidt number ($= \nu/D$) (-)
Sh_m modified Sherwood number as defined by Eq. (8) (-)
Sh_s Sherwood number in IEC filled with spacers ($= HK_s/D = HI_s/C_0DF$) (-)
Sh_t total Sherwood number in IEC with both spacer and space ($= HK_t/D = HI_t/C_0DF$) (-)
Sh_0 Sherwood number in IEC without spacer ($= HK_0/D = HI_0/C_0DF$) (-)
t apparent thickness of a spacer (cm)
u_0 superficial flow velocity (cm/s)
V electric potential (V)
W width of IEC (cm)

Greek Symbols

ε void fraction of spacer (-)
ν kinematic viscosity (cm^2/s)
τ_m transport number of ion in the ion-exchange membrane (-)
τ_s transport number of ion in the solution (-)

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REFERENCES

1. G. Belfort and G. A. Guter, *Desalination, 10,* 221 (1972).
2. D. A. Cowan and J. H. Brown, *Ind. Eng. Chem., 51,* 1445 (1959).
3. H. P. Gregor and M. A. Peterson, *J. Phys. Chem., 68,* 2201 (1964).
4. M. S. Isaacson and A. A. Sonin, *Ind. Eng. Chem., Process Des. Dev., 15,* 313 (1978).
5. A. Kitamoto and Y. Takashima, *Kagaku Kogaku, 31,* 1201 (1967); *32,* 74 (1968).
6. A. Kitamoto and Y. Takashima, *Desalination, 9,* 51 (1971).
7. W. G. B. Mandersloot and R. E. Hicks, *Ind. Eng. Chem., Process Des. Dev., 4,* 304 (1965).
8. N. W. Rosenberg and C. E. Tirrell, *Ind. Eng. Chem., 49,* 780 (1957).
9. R. F. Probstein, A. A. Sonin, and E. Gur-Arie, *Desalination, 11,* 165 (1972).
10. A. Solan and Y. Winograd, *Phys. Fluids, 12,* 1372 (1969).
11. A. A. Sonin and M. S. Isaacson, *Ind. Eng. Chem., Process Des. Dev., 13,* 241 (1974).
12. A. A. Sonin and R. Probstein, *Desalination, 5,* 293 (1968).
13. A. Storck and F. Coeuret, *Ind. Eng. Chem., Process Des. Dev., 17,* 99 (1978).
14. Y. Winograd, A. Solan, and M. Toren, *Desalination, 13,* 171 (1973).
15. H. Miyoshi, T. Fukumoto, and T. Kataoka, *Bull. Soc. Sea Water Sci., Jpn., 30,* 14 (1976).
16. H. Miyoshi, T. Fukumoto, and T. Kataoka, *Sep. Sci. Technol., 23,* 585 (1988).
17. H. Miyoshi, *Chem. Eng. J.,* Submitted for Publication.
18. H. Miyoshi, T. Fukumoto, and T. Kataoka, *Desalination, 42,* 47 (1982).

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