- Des. Dev.*, **21**, 706 (1982).
- 13) Ueyama, K., S. Morooka, K. Koide, H. Kaji and T. Miyauchi: *Ind. Eng. Chem., Process Des. Dev.*, **19**, 592 (1980).
 - 14) Wallis, G. B.: "One-dimensional Two-phase Flow," McGraw-Hill, New York (1969).
 - 15) Yasunishi, A., M. Fukuma and K. Muroyama: *Kagaku Kogaku Ronbunshu*, **12**, 420 (1986).
 - 16) Yasunishi, A., M. Fukuma and K. Muroyama: *J. Chem. Eng. Japan*, **19**, 444 (1986).

PARAMETER ESTIMATION IN A COOLING TOWER PROCESS

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In the previous paper,¹⁾ the solution to the packed tower process problem was proposed in the form of sequential cell flowgraph representation. There, the design problem of determining the tower height subject to the known input-output conditions data and the known parameter values (volumetric coefficients of heat and mass transfer) was treated. Alternatively, the parameter estimation subject to the known tower height and the known input-output conditions data is important for cases where a process is in operation.

In this report, a computational technique for parameter estimation in a packed tower process is proposed with the aim of eliminating the troublesome graphical routine, and an application to a cooling tower process is shown.

1. Proposed Method

The following algorithm for the parameter estimation in a packed tower process is proposed, where sequential cell flowgraph representation is used:

1) The height of tower Z is divided into N equal parts, and fundamental equations for the n -th part (called the n -th cell) from the tower bottom are arranged, using a model with gas phase, liquid phase, and interface.

2) Individual fundamental equation is converted to flowgraph unit and all units are combined to form an n -th cell flowgraph. A sequential cell flowgraph is constructed by arranging the n -th cell flowgraph simplified in boxed cell from $n=1$ to N .

3) Using the multi-variable searching technique in the sequential cell flowgraph, the value of the parameter is estimated as a limit when Δz goes to zero.

2. Application to a Cooling Tower Process Problem

A problem is proposed for estimating the values of the volumetric coefficients of heat and mass transfer in a cooling tower process, subject to the following data: temperature of air and water at tower top and bottom t_{GT} , t_{GB} , t_{LT} , t_{LB} , humidity of air at tower top and bottom H_T , H_B , dry air flow rate G , flow rate of water at tower top L_T , specific heat of water C_{PL} , and tower height Z .

As for steps 1 and 2, the model, the fundamental equations of the n -th cell and the n -th cell flowgraph are shown in the literature.¹⁾ Since the volumetric coefficient of heat transfer $h_{Gn}a$ in the Lewis equation depends on the cell number, its value should be determined as the average value between the tower top and bottom. A sequential cell flowgraph is shown in Fig. 1, where the following equations are used:

$$N = Z/\Delta Z \quad (1)$$

$$dv2 = dvH + dvL + dv t_L + dv t_G \quad (2)$$

Calculation will be commenced in the first cell with left-hand side variables t_{GB} , H_B , L_B , t_{LB} , Z and ΔZ , together with h_La and k_Ha . Cell-by-cell calculation must be continued to the N -th cell, where N is an integer determined by Eq. (1).

Since there is one-to-one correspondence between two parameters and $dv2$ in Eq. (2), we can determine h_La and k_Ha so as to minimize $dv2$ for a small value of ΔZ , using the multi-variable searching technique. This problem is denoted as follows:

$$h_La, k_Ha: dv2 = \min.$$

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Fig. 1. Sequential cell flowgraph.

A numerical example problem¹⁾ of determining the parameter values h_{Ga} , h_{La} and k_{Ha} subject to the following data will be treated: $Z=0.724$, $t_{LB}=20.1$, $t_{LT}=36$, $t_{GB}=35$, $t_{GT}=27.6$, $H_B=0.006$, $H_T=0.0223$, $L_T=0.5$, $G=1.0278$, $C_{PL}=4.184$. The value of L_B is calculated from $L_B=L_T-G(H_T-H_B)$ as 0.4832.

The two-variable searching problem was solved by the Simplex method with starting values of $h_{La}=50$ and $k_{Ha}=10$. As a result, the plots of h_{La} and k_{Ha} vs. ΔZ are shown in Figs. 2 and 3, respectively.

As step 3, we adopt $h_{La}=59.0$ by curve approximation and $k_{Ha}=3.69$ by line approximation, and these values are comparable with $h_{La}=60.42$ and $k_{Ha}=3.611$, which are used in the design problem. This discrepancy is probably attributed to the convergence technique in the method used.

Finally, the Lewis equation gives the value of h_{Ga} :

$$h_{Ga} = C_{Hav} \cdot k_{Ha} = (1.0306) \cdot (3.69) = 3.80$$

where C_{Hav} is the averaged value of C_H between tower top and bottom.

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Nomenclature

C_H	= humid heat of air	[kJ/kg·K]
C_{PL}	= specific heat of liquid	[kJ/kg·K]
dv	= deviation	[—]
G	= dry air flow rate	[kg/m ² ·s]
H	= humidity of air	[kg/kg]
h_{Ga}	= volumetric heat transfer coefficient in gas phase	[kW/m ³ ·K]
h_{La}	= volumetric heat transfer coefficient in liquid phase	[kW/m ³ ·K]
k_{Ha}	= volumetric mass transfer coefficient	[kg/m ³ ·s]
L	= liquid flow rate	[kg/m ² ·s]
N	= number of divisions	[—]
Z	= height of tower	[m]
ΔZ	= height of cell	[m]

Fig. 2. Relationship between h_{La} and ΔZ .

Fig. 3. Relationship between k_{Ha} and ΔZ .

<Subscripts>

B	= tower bottom
n	= number of cell from tower bottom
T	= tower top

Literature Cited

- 1) Yoshifuku, I.: *J. Chem. Eng. Japan*, **18**, 137 (1985).