Concise Correlation of Sieve-Tray Heat and Mass Transfer

Thomas C. Young and Warren E. Stewart
Dept. of Chemical Engineering, University of Wisconsin-Madison, Madison, WI 53706

The purpose of this note is to simplify a correlation given by Young and Stewart (1992) for the hydrodynamic function a_{00} in their sieve-tray heat and mass transport model. They obtained the relation

$$a_{00} = (0.277 \pm 0.0112)\left(\frac{\rho_G \langle v_G \rangle h_w}{\mu_L}\right)^{0.648 \pm 0.075} \times \left(\frac{A_{\text{act}}^2}{A_{\text{open}}^2} - 1\right)^{0.344 \pm 0.138} \left(\frac{\rho_L \mu_G}{\rho_G \mu_L}\right)^{0.412 \pm 0.079} \quad (1)$$

with 95% probability intervals for the individual parameters. The first interval width (± 0.0112) in Eq. 1 is a corrected value.

The second dimensionless group in Eq. 1 is 50 or greater for the data used, and generally so in practice; hence, the -1 term can be neglected. Doing so, we find that the indicated power of this group is essentially the 0.688 ± 0.276 power of a ratio of characteristic gas velocities. Since the latter exponent range brackets that of the Reynolds number ($\rho_G \langle v_G \rangle h_w / \mu_L$), we can dispose of the second group by basing the gas velocity in the Reynolds number on the open area of the tray rather than on the total or the active projected area.

Fitting the resulting new model to the data by the procedure of Young and Stewart (1992), we obtain the simpler relation

$$a_{00} = (0.2753 \pm 0.0097)\left(\frac{\rho_G V_0 h_w}{\mu_L}\right)^{0.658 \pm 0.038} \times \left(\frac{\mu_G \rho_L}{\mu_L \rho_G}\right)^{0.420 \pm 0.046} \quad (2)$$

with more precise parameter estimates. This model is preferable to Eq. 1, since it fits the data comparably well with one parameter less.

The point transfer coefficients in a binary two-phase system on a sieve tray are computable from Eq. 2 and the relations

$$k_{A,G} = c_G \, \mathfrak{D}_{AB,G}^{1/2} a_{00} \sqrt{V_0 / h_w} \quad (3)$$

$$k_{A,L} = c_L \, \mathfrak{D}_{AB,L}^{1/2} a_{00} \sqrt{V_0 / h_w} \quad (4)$$

$$h_G = \rho_G \hat{C}_{p,G} \alpha_G^{1/2} a_{00} \sqrt{V_0 / h_w} \quad (5)$$

$$h_L = \rho_L \hat{C}_{p,L} \alpha_L^{1/2} a_{00} \sqrt{V_0 / h_w} \quad (6)$$

predicted by mobile-interface boundary layer theory at small net mass-transfer rates. Here h_G and h_L are heat-transfer coefficients, and α is the thermal diffusivity ($k/\rho \hat{C}_p$) of the given phase. Equations 2–6 summarize the effects of the main variables on the heat- and mass-transfer coefficients for each phase at flow conditions such that weeping and entrainment do not occur; surface-tension-driven flows (Marangoni effects) remain to be considered. Further boundary-layer relations are given for binary systems by Young and Stewart (1992), and for multicomponent nonisothermal systems by Young and Stewart (1990). The linearized boundary-layer approach used in these multicomponent calculations was tested by Young and Stewart (1986) against detailed solutions, and proved more reliable than multicomponent film mass-transfer models.

The notation a_{00} denotes the leading coefficient in an asymptotic expansion of the Nusselt or Sherwood number, given by Stewart (1987). This leading coefficient was evaluated formally by Stewart et al. (1970), and explicitly for simple interfacial motions. Data-based expressions like Eq. 2 allow direct application of the theory to complicated flows, since the calculations are straightforward once a_{00} is given.

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Notation

a_{00} = hydrodynamic function, dimensionless
A_{act} = active area of tray, m^2

Correspondence concerning this article should be addressed to W. E. Stewart.
Current address of T. C. Young: Dow Chemical Company, Pittsburgh, CA.

A_{open} = open area of tray, m^2
A_{tray} = total projected area of tray, m^2
c = total concentration, kmol/m^3
$\hat{C}_p$ = heat capacity at constant pressure, J/kg/K
$\mathfrak{D}_{AB}$ = binary diffusivity, m^2/s
h_G, h_L = heat-transfer coefficients based on A_{tray}, W/m^2/K
h_w = outlet weir height, m
k = thermal conductivity, W/m/K
$k_A = k_B$ = binary molar transfer coefficient based on A_{tray}, kmol/m^2/s
$\langle v_G \rangle = w_G/(\rho_G A_{\text{tray}})$, vapor velocity based on A_{tray}, m/s
$V_o = w_G/(\rho_G A_{\text{open}})$, vapor velocity based on A_{open}, m/s
w = mass-flow rate, kg/s

Greek letters

α = thermal, diffusivity, m^2/s
μ = viscosity, kg/m/s
ρ = density, kg/m^3

Subscripts

A, B = chemical species in a binary system
G = gas phase
L = liquid phase

Literature Cited

Stewart, W. E., J. B. Angelo, and E. N. Lightfoot, "Forced Convection in Three-Dimensional Flows: II. Asymptotic Solutions for Mobile Interfaces," *AIChE J.*, **16**, 771 (1970).

Stewart, W. E., "Forced Convection: IV. Asymptotic Forms for Laminar and Turbulent Transfer Rates," *AIChE J.*, **33**, 2008 (1987), Errata, **34**, 285 (1988).

Young, T. C., and W. E. Stewart, "Comparisons of Matrix Approximations for Multicomponent Transfer Calculations," *Ind. Eng. Chem. Fund.*, **25**, 476 (1986).

Young, T. C., and W. E. Stewart, "Collocation Analysis of a Boundary-Layer Model for Crossflow Fractionation Trays," *AIChE J.*, **36**, 655 (1990).

Young, T. C., and W. E. Stewart, "Correlation of Fractionation Tray Performance Via a Cross-Flow Boundary-Layer Model," *AIChE J.*, **38**, 592, Errata 1302 (1992).

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