HYDRODYNAMIC CHARACTERISTICS OF SIEVE TRAYS HAVING LARGE FREE AREAS WITHOUT DOWNCOMERS

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The sieve tray without downcomer is extensively used in industrial chemical processes such as distillation and absorption because it is the simplest and cheapest type of gas-liquid contacting device. Further, the importance of saving energy has recently increased the need for high-capacity gas-liquid contacting devices.

In the present study, following the previous work,[8,9] experiments were carried out with trays having large free areas for the purpose of clarifying the behavior and characteristics of froth. Pressure drop, liquid holdup and stable operating range were studied.

1. Apparatus and Procedure

The experimental apparatus and procedure used are the same as those described in previous papers[8,9] except for the method for measuring liquid holdup by using a level gauge, the difference between the liquid levels in the reservoir with and without blowing gas corresponding to the liquid holdup. **Tables 1** and **2** show details of trays and physical properties of liquids employed, respectively.

2. Results and Discussion

Figure 1 shows an example of liquid holdup H_l. As can be seen from this figure, the stable operating range is about 1–4 m/s, leading to the possibility of operation at higher gas velocities than in usual plate columns without downcomer. Also, the stable operating range seems to increase with increasing liquid velocity, while Kimura *et al.*[3] showed a decrease in stable operating range with liquid velocity.

On the basis of the method of correlation of flooding velocities for packed columns reported by Zenz *et al.*,[11] the authors[1,10] have obtained the following equation to predict loading and flooding points of sieve trays.

$$X^{0.5}+Y^{0.5}=0.832 \tag{1}$$

where

$$\left.\begin{aligned} &X=U_{lc}(P_X\cdot S)^{0.5},\quad Y=U_{gc}(P_Y\cdot S)^{0.5}\\ &P_X=1/g,\quad P_Y=(\rho_g/\rho_l)(1/g)\end{aligned}\right\} \tag{2}$$

$$\left.\begin{aligned} &S=22/(F_s^2\cdot d^{0.4}) && \text{Loading}\\ &S=23/F_s^2 && \text{Flooding}\end{aligned}\right\} \tag{3}$$

Figure 2 shows the correlation of loading and flooding points. Flooding points agree well with Eq. (1). For trays with holes of diameter larger than 5 mm, the loading points are also satisfactorily represented by Eq. (1), but for trays with holes of diameter less than

Table 1. Geometries of sieve trays employed

Plate	$t\times10^3$ [m]	$d\times10^3$ [m]	n [—]	$p\times10^3$ [m]	F_s [—]
T-1	1.03	4.21	199	10	0.1465
T-2	1.01	6.19	199	10	0.3136
T-3	1.01	8.02	199	10	0.5328
T-4	1.02	7.21	199	10	0.4311
T-5	1.01	11.08	85	15	0.4343
T-6	1.02	12.10	85	15	0.5180
T-7	0.995	4.54	499	6	0.4285
T-8	0.994	8.77	199	10	0.6371
T-9	8.03	7.05	199	10	0.4177
T-10	1.02	2.53	2299	3	0.6111
T-11	1.00	2.14	2348	3	0.4476
T-12	1.02	5.60	313	8	0.4086

Table 2. Physical properties of liquids used

Liquid	$\mu_1\times10^3$ [Pa·s]	ρ_1 [kg/m^3]	$\sigma\times10^3$ [N/m]
Distilled water	0.8	1000	72
Ethanol–water	2.08	962	36
Millet jelly–water	9.87	1180	62

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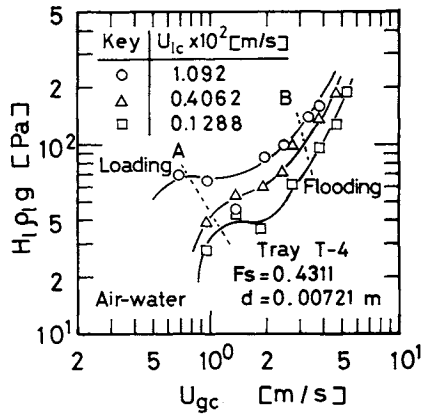


Fig. 1. Liquid holdup.

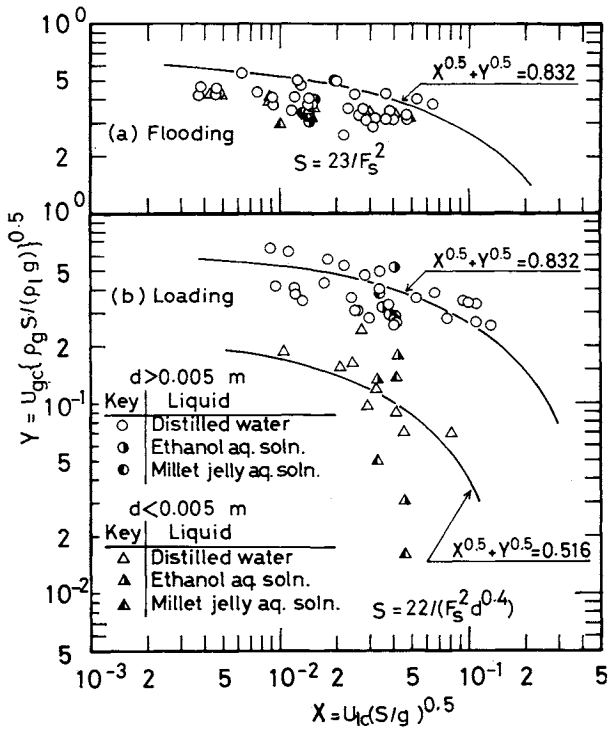


Fig. 2. Flooding and loading velocity.

5 mm the loading points shift to low gas velocities and are correlated as follows:

$$X^{0.5}+Y^{0.5}=0.516 \qquad d<0.005\,\mathrm{m} \tag{4}$$

In the previous works,[8,9] the authors divided the tray into two parts, and the ratio of hole area of weeping and of rising gas are given by τ and $(1-\tau)$. The following expression appears as an extension of the previous relation of the authors[8,9] by taking account of dry pressure drop ΔP_d and pressure drop due to bubble formation ΔP_σ resulting from high gas velocity and small liquid holdup.

$$P_o+\beta_2\rho_l g H_l+\rho_l U_{lc}^2/2+(\Delta P_d+\Delta P_\sigma)= P_i+\zeta_l(U_{lh}/\tau)^2\rho_l/2 \tag{5}$$

τ in Eq. (5) can be determined by applying the principle of minimum energy dissipation, leading to the minimum total pressure drop for the sieve tray. Using the results of ζ_d in ΔP_d,[4] ζ_σ in ΔP_σ[2] and ζ_l,[8,9] we obtain

$$k\rho_g U_{gh}^2\tau^3\{3-2.4F_s(1-\tau)\} -4.4\rho_l U_{lh}^2(1-\tau)^3=0 \tag{6}$$

Therefore, we can estimate total pressure drop ΔP_t from Eq. (5), determining aeration factor β_2 and liquid holdup H_l in advance. **Figure 3** shows the correlation of β_2. As gas velocity is increased, β_2 rises to maximum value and decreases. The maximum of aeration factor β_2 seems to correspond to the change of hydrodynamic regime, i.e., the transition from froth to spray regime. It can be anticipated that the maximum of β_2 results in neglecting residual pressure drop in Eq. (5) because Payne *et al.*[5,6] and Prince *et al.*[7] have demonstrated that the maximum in residual pressure drop corresponds to the transition. The prediction of total pressure drop from Eq. (5) also requires a knowledge of liquid holdup. From the experimental results, we propose the following equation for liquid holdup except for trays having holes less than 5 mm in diameter, which value is also the critical point for the correlation of loading points as shown in Fig. 2.

$$U_{gc}^2/(gH_l)=2.8(U_{gc}/U_{lc})^{1.5}(t/d)^{0.34}F_s^{1.8} \times(\rho_l g d^2/\sigma)^{0.42}\{U_{lc}^2/(gd)\}^{0.63}(dU_{lc}\rho_l/\mu_l)^{0.053} \tag{7}$$

The parity plot for total pressure drop using the correlation of aeration factor and Eq. (7) shows good agreement with the measurements.

Nomenclature

d	=	hole diameter	[m]
F_s	=	free area	[—]
g	=	gravitational acceleration	[m/s^2]
H_l	=	liquid holdup	[m]
k	=	coefficient given by McAllister *et al.*[4]	[—]
n	=	hole number	[—]
P_i	=	pressure of gas below a tray	[Pa]
P_o	=	pressure of gas above a tray	[Pa]
p	=	pitch	[m]
ΔP_d	=	dry pressure drop $=\zeta_d\{U_{gh}/(1-\tau)\}^2\rho_g/2$	[Pa]
ΔP_t	=	total pressure drop $=P_i-P_o$	[Pa]
ΔP_σ	=	pressure drop due to surface tension of liquid acting on hole $=\zeta_\sigma 4\sigma/d$	[Pa]
Re_g	=	Reynolds number $=dU_{gh}\rho_g/\{\mu_g(1-\tau)\}$	[—]
Re_l	=	Reynolds number $=dU_{lc}\rho_l/\mu_l$	[—]
S	=	shape factor	[l/m]
t	=	plate thickness	[m]
U_{gc}	=	superficial gas velocity	[m/s]
U_{gh}	=	gas velocity through hole	[m/s]
U_{lc}	=	superficial liquid velocity	[m/s]
U_{lh}	=	liquid velocity through hole	[m/s]
β_2	=	aeration factor defined by Eq. (5)	[—]

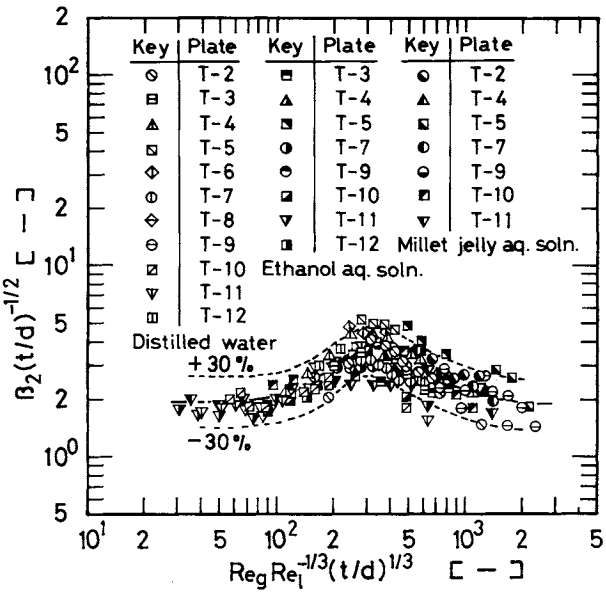


Fig. 3. Correlation of aeration factor.

ζ_d = resistance coefficient due to gas $=k[\{1-F_s(1-\tau)\}^2+0.4\{1.25-F_s(1-\tau)\}]$ [—]

ζ_l, ζ_σ = resistance coefficient due to liquid and surface tension [—]

μ_g, μ_l = viscosity of gas and liquid [Pa·s]

ρ_g, ρ_l = density of gas and liquid [kg/m^3]

σ = surface tension [N/m]

τ = ratio of hole area of dropping liquid flow per total hole area of a sieve tray [—]

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CRITICAL GAS VELOCITY REQUIRED FOR COMPLETE SUSPENSION OF MULTICOMPONENT SOLID PARTICLE MIXTURE IN SOLID-SUSPENDED BUBBLE COLUMNS WITH AND WITHOUT DRAUGHT TUBE

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Introduction

To design a solid-suspended bubble column for liquid-solid batch operation as a slurry reactor, the value of the critical gas velocity U_c required for complete suspension of solid particles should be known. A few research works on U_c for solid particles with a narrow size distribution (called here single-component particles) have been done by using a column with a draught tube[3,7,9] and without it.[1,2,4-6,10-12] However, no research work has been done on U_c for multicomponent solid particle mixtures, e.g., solid particles with a wide size distribution or a mixture of solid particles of different materials.

The purpose of this study is to clarify experimentally the effects of column dimensions, properties of the solid particles and composition of the solid mixture on the critical gas velocity required for complete suspension of the multicomponent solid particle mixture in solid-suspended bubble columns with and without a draught tube in liquid-solid batch

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