FLOODING VELOCITIES OF GAS-LIQUID AND LIQUID-LIQUID CONTACTORS OF COLUMN TYPE*

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It has been reported by authors13) that the flooding velocities of packed columns and various types of plate columns without downcomer are well correlated by the following equation.

\[ Y = \exp \left( \frac{2.9}{\ln X} \right) \]  

where

\[ X = U_{LF}(P_x \cdot S_Y)^{0.5} \]
\[ Y = U_{GF}(P_y \cdot S_Y)^{0.5} \]

\( P_x, P_y \) and \( S_Y \) are shown in Table 1.

As a plate column with downcomer, a wetted wall column and a spray column are contactors of the column type in which gas and liquid or liquid and liquid flow countercurrently in the same way as in a packed column, it may be considered that the flooding phenomena of these contactors are similar.

In this work, the flooding velocities of plate columns with downcomer and wetted wall columns operated by gas-liquid systems, and of packed columns and spray columns operated by liquid-liquid systems were correlated by using the results of previous works1-7,9-11,14,15).

Gas-Liquid System

For plate columns with downcomer (bubble-cap and sieve trays), Fair et al.4,5) have correlated graphically the flooding velocities. These velocities are affected by the tray spacing. Hence the procedure for finding the correlation can be summarized as follows. From the results of the plate columns without downcomer13) and previous work, \( P_x \) and \( P_y \) can be determined as shown in Table 1. The flooding velocities and the physical properties of gas and liquid phases are substituted in Eq. (2). A value of the shape factor \( (S_Y) \) is assumed and substituted in Eq. (2), then Eq. (1) is calculated using the values of \( X \) and \( Y \) of Eq. (2). By repetition of this procedure, the value of \( S_Y \) that satisfies Eq. (1) is determined using a computer. Figure 1 shows the relation between \( S_Y \) obtained by the above procedure using Fair’s data4,5) and the tray spacing.

By using the dimensionless velocities of gas and liquid phases, Wallis14) has correlated the flooding velocities of wetted wall columns.

\[ V^*_{0.5} + V^*_{0.5} = C \]  

where \( C = 0.725 \) for the column with sharp flanges at both ends and 0.875 for smooth flanges. Koyanagi et al.7) have correlated the flooding velocities of wetted wall columns by using Sherwood’s coordinate12) in the packed columns. The flooding velocities are affected by the liquid viscosity, the column diameter and the structure of column ends. Figure 2 shows the relations between \( S_Y \) for the various gas-liquid systems obtained by the procedure for finding the correlation as mentioned above, and the column diameter. \( S_Y \) values are presented by \( 1.3/D_T \) for a column with sharp flanges at both ends4,14) and 0.75/D_T for smooth flanges4,15), and 2.5/D_T is obtained from Koyanagi’s data7).

From Figs. 1 and 2, the correlations of \( S_Y \) for plate columns with downcomer and wetted wall columns can be obtained, and have been shown in Table 1.

Liquid-Liquid System

Dell et al.3) have reported a correlation for the flooding velocities of packed columns operated by the various systems. Sakiadis et al.11) and Crawford et al.21) have also studied them. If the flooding veloci-

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Table 1 Correlations of \( P_X, P_Y \) and \( S_F \)

<table>
<thead>
<tr>
<th>Contactors</th>
<th>( P_X )</th>
<th>( P_Y )</th>
<th>( S_F )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas-liquid system</td>
<td>( \mu_{L}^2 g )</td>
<td>( \mu_{G}^2 g )</td>
<td>( a/\varepsilon )</td>
</tr>
<tr>
<td>Plate column</td>
<td>( (p_c/p_t)(\mu_{L}^2 g) )</td>
<td>( (p_c/p_t)(\mu_{G}^2 g) )</td>
<td>( \text{func}(A_{L}/A_{T}) )</td>
</tr>
<tr>
<td>Plate column with downcomer</td>
<td>( 1/g )</td>
<td>( 1/g )</td>
<td>( 1/0.12 D_T )</td>
</tr>
<tr>
<td>Wetted wall column</td>
<td>( \mu_{L}^2 g )</td>
<td>( \mu_{G}^2 g )</td>
<td>( (0.75 \sim 2.5)/D_T )</td>
</tr>
<tr>
<td>Liquid-liquid system</td>
<td>( \mu_{L}^2 g )</td>
<td>( \mu_{G}^2 g )</td>
<td>( 1.7a/\varepsilon )</td>
</tr>
<tr>
<td>Packed column</td>
<td>( (p_c/\rho_c)(\mu_{L}^2 g) )</td>
<td>( (p_c/\rho_c)(\mu_{G}^2 g) )</td>
<td>( 1.2/d_d )</td>
</tr>
</tbody>
</table>

Table 2 Comparisons of the measured and calculated flooding velocities in liquid-liquid packed columns (10 mm Raschig ring)

<table>
<thead>
<tr>
<th>System</th>
<th>( U_{LF} ) ([m^3/m^2 \cdot h])</th>
<th>Measured values(^{(3)})</th>
<th>Calculated values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene-water</td>
<td>1.66</td>
<td>43.6</td>
<td>38.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24.7</td>
<td>20.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.5</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.07</td>
<td>4.94</td>
</tr>
<tr>
<td>Methyl isobutyl ketone-water</td>
<td>14.8</td>
<td>28.8</td>
<td>24.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24.4</td>
<td>32.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>31.2</td>
<td>26.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.6</td>
<td>11.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24.2</td>
<td>23.7</td>
</tr>
<tr>
<td>Butyl acetate-water</td>
<td>15.0</td>
<td>4.94</td>
<td>6.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.4</td>
<td>17.7</td>
</tr>
<tr>
<td>Butyl acetate-47%aq. glycerin</td>
<td>14.5</td>
<td>8.61</td>
<td>22.3</td>
</tr>
</tbody>
</table>

Fig. 3 Effect of \( \alpha/\varepsilon \) on \( S_F \) in liquid-liquid packed columns

Fig. 4 Comparisons of measured and calculated flooding velocities in various contactors of column type

The measured flooding velocities in the various systems\(^{(3)}\) have been compared in Table 2 with the values calculated by the previous correlations\(^{(3)}\) and the present correlation.

For spray columns, Blanding et al.\(^{(1)}\), Price\(^{(3)}\), Johnson\(^{(6)}\) and Rosenthal\(^{(10)}\) have reported flooding velocities. \( S_F \) is the function of drop diameter of the dispersed phase (less dense liquid). If the flooding velocities\(^{(1,6,9,10)}\) are correlated with Eq. (1), \( P_X, P_Y \) and \( S_F \) can be represented as shown in Table 1.

Where \( U_{LF} \) and \( U_{GF} \) in Eq. (2) for the liquid-liquid systems show the flooding velocities of the continuous phase (denser liquid) and dispersed phase, respectively.

The measured values of the flooding velocities in these columns are presented in Fig. 4 by using Eqs. (1) and (2) and \( P_X, P_Y \) and \( S_F \) values in Table 1, and agree well with the correlation.

It is clear that the flooding velocities of the various gas-liquid and liquid-liquid contactors of column type can be correlated by Eqs. (1) and (2) and \( P_X, P_Y \) and \( S_F \) in Eq. (2) can be represented as shown in Table 1.

Nomenclature

- \( a \) = surface area of packing \([m^2/m^3]\)
- \( A_{L}/A_{T} \) = ratio of total hole area to tray area \([-]\)
- \( d_d \) = drop diameter \([m]\)
- \( D_T \) = column diameter \([m]\)
- \( h_s \) = tray spacing \([m]\)
- \( S_F \) = shape factor in flooding \([-]\)
- \( U_{LF} \) = flooding gas velocity \([m^3/m^2 \cdot h]\)
- \( U_{LF} \) = flooding liquid velocity \([m^3/m^2 \cdot h]\)
- \( V_L \) = \( U_{GF} \rho_G (D_T g d_p)^{0.5} \)
  - dimensionless gas velocity \([-]\)
NON-ISOTHERMAL ABSORPTION WITH CHEMICAL REACTION
— SURFACE TEMPERATURE AND ABSORPTION DATA
FOR THE SO₃-H₂SO₄ SYSTEM* —

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Most work which has been published for systems where gas absorption accompanied by chemical reaction occurs pertains to those systems where small heat effects are present. However, a number of industrially important reactions are strongly exothermic and substantial liquid surface temperature rises are present. Little information is available concerning the true interfacial temperature existing under such conditions, although attempts have been made to predict them²,³. An investigation is briefly described here in which interfacial temperatures and mass transfer rates have been measured for a system in which large heat releases occur, but which are not complicated by the additional factors such as solvent evaporation or interfacial turbulence effects. The absorption of sulphur trioxide into sulphuric acid was selected although the difficulties in handling these materials are considerable. To eliminate hydrodynamic disturbances, a remote form of thermometer was used which determines the liquid surface temperatures by measuring the amount of infra-red radiation emitted by the liquid surface. A short wetted-wall column, made of stainless-steel was designed, the film flowing down the outside of a 1 inch diameter column whose length could be adjusted to any value between 0 and 7 cm. A detailed diagram of the column is shown in Fig. 1.

A sketch of the apparatus is shown in Fig. 2. The acid supplied to the column was gravity fed from an elevated aspirator, J2. The liquid flowed from the aspirator through a constant temperature coil A1, the flow control valve B1, rotameter C, and then to the absorption column. The acid flowed up through the three radial holes and formed a liquid film at the aperture between the distributor and the column wall. The film flowed down the length of the column and was collected in the receiver in which the acid level was controlled by a constant head device, I, before discharging into the lower aspirator J1. Provision was made for liquid samples to be taken at the inlet line immediately prior to the absorber at D and the acid flow from the constant head could be diverted to attain a liquid exit sample at H. Mercury-in-glass thermometers capable of reading to 0.1°C were mounted immediately before and after the absorber to obtain liquid inlet and exit tempera-

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