

LOWER CRITICAL GAS AND LIQUID VELOCITIES OF GRID TRAYS

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A simple method for calculation of the lower critical gas and liquid velocities of grid trays of different geometrical parameters for several systems with different physico-chemical properties is presented.

For the design of plate columns used as separation units or reactors for gas-liquid systems it is necessary to determine the limiting phase velocities at which the considered plate begins to operate. As the lower critical velocities of the grid tray are considered such gaseous and liquid velocities at which the first liquid holdup is formed on the tray. This moment is visually represented by liquid covering the tray slots in such a way that through their part below the liquid layer liquid flows while through another part the gas flows. The formation of the first liquid holdup is accompanied by a sudden increase of over-all pressure drop of the tray. On basis of the analysis of the countercurrent gas and liquid flows through the slots of the grid plate has been earlier¹ derived an equation relating the lower critical velocities

$$(\xi)^{n/2} (\rho_g/\rho_L)^{n/2} v_0^n = K_1 + K_2 w_0^n \quad (I)$$

On basis of the experimental results obtained with several systems of different physico-chemical properties was evaluated the value of the exponent n ; the dependence (I) is at best represented by the value $n = 1/2$. In the above cited paper the coefficients K_1 and K_2 were further expressed empirically as linear functions of the basical physico-chemical parameters of the systems employed (ρ_g , ρ_L , σ , μ_L) and geometrical tray parameters (T , d). As a disadvantage of this approach we consider the fact that both coefficients of the resulting relation (I) are simultaneously functions of the geometrical tray parameters and the physical properties of the system which among others resulted in the impossibility to correlate by one dependence results obtained for one chosen system on different trays and further the relation did not represent data obtained for other systems. Here an effort has been made to overcome these shortcomings. Experimental data for 3 gas-liquid systems (water-air, glycerol-air and kerosene-air) measured on a hydraulic model of cross sectional area 0.105 m^2 (see^{1,3}) and data obtained at vacuum distillation of the mixture phenol-*o*-cresol in a column of 200 mm diameter were used. The geometrical parameters of the trays employed and physical properties of the liquids used are given in Tables I and II.

RESULTS AND DISCUSSION

In agreement with the theoretically derived Eq. (I) and with the empirically determined exponent $n = 1/2$, the dependence of $\xi^{1/4} (\rho_g/\rho_L)^{1/4}$ on $w_0^{1/2}$ is linear. For expressing the effect of the slot

width we have introduced, with the liquid velocity, the empirical coefficient $(2d/T)^{1/2}$. The effect of different tray geometry is by this coefficient uniquely expressed. The results of evaluation of the experimental data are given in Fig. 1. The final form of the proposed relation may be then given as

$$(\xi)^{1/4} (\rho_g/\rho_L)^{1/4} v_0^{1/2} = K_1 + K_2 w_0^{1/2}, \quad (2)$$

where

$$K_2 = K_3(2d/T)^{1/2}. \quad (3)$$

The experimental points are situated in the chosen coordinates for the given gas-liquid system on straight lines where the coefficients K_1 and K_3 are only functions of physical properties of the system and are independent on geometrical tray parameters.

Dependence of the Coefficient K_1 on Physico-Chemical Properties of the System

For $w_0 \rightarrow 0$ the value v_0 ($w_0 \rightarrow 0$) represents such gaseous velocity in slots which at an infinitesimal liquid flow rate suffices for formation of the initial foam bed which is stable. It is possible to expect this limiting gaseous velocity to be different for various systems in dependence on the

TABLE I

Dimensions of Trays Employed

Hydraulic section plates No I—III, V and IX, distillation column trays No A—E.

Plate	ϕ , %	d , mm	T , mm	Plate	ϕ , %	d , mm	T , mm
I	8.93	4	2	A	23.6	4.15	4
II	16.25	4	2	B	14.7	4.5	4
III	22.03	4	2	C	10.5	4.7	4
V	17.07	8	2	D	14.0	8	4
IX	16.12	2	2	E	18.2	4	4

TABLE II

Properties of Measured Systems

System	ρ_L kg m^{-3}	ρ_G kg m^{-3}	μ_L cP	σ dyn cm^{-1}
Water-air	1 000	1.14	1.0	70.7
Glycerol-air	1 174	1.14	15.3	56.9
Kerosene-air	808	1.14	1.8	26.3
Phenol- <i>o</i> -cresol	978	0.4	0.78	28.5
Methanol-water	780	1.0	0.43	23.0

ability of the considered system to form a stable foam. The quantitative expression of stability of the foam bed does not yet exist. In engineering practice is introduced as one possibility for expressing this ability the "system factor" by which *e.g.* data on the capacity of absorption and distillation columns are corrected. These factors are for some typical systems tabulated in literature¹.

But it is known that the properties of foam systems are mostly affected by the physical parameters of the liquid phase. It is usually assumed that the foam bed is the more stable the greater is the viscosity and the lesser the surface tension of liquid. We have made an attempt to correlate the values v_0 ($w_0 \rightarrow 0$) by the parameter (σ/μ^2) ; the lesser is the value of this parameter the lesser should be the limiting value v_0 ($w_0 \rightarrow 0$) necessary for forming a stable liquid holdup on the plate. The systems correlated are the non-foaming liquid with large surface tension (water), with great viscosity and liquid density (glycerol) and a system with low surface tension and low density (kerosene). For the coefficient K_1 was obtained the empirical relation

$$K_1 = 0.267(\sigma/\mu^2)^{0.36} \cdot 0.1885 \quad (4)$$

Dependence of the Coefficient K_2 on Physico-Chemical Properties

The constant K_2 is, on basis of the theoretical analysis¹, beside being a function of geometrical tray parameters (d) also a function of surface tension and liquid density. As the effect of geometrical tray parameters is by the parameter $(2d/T)^{1/2}$ in the coefficient K_2 uniquely expressed, the new value of coefficient K_3 is expressed in agreement with the theoretical assumptions as a function of surface tension and liquid density only. The dependence of the coefficient K_3 on value of the ratio (σ/γ_L) determined empirically has the form

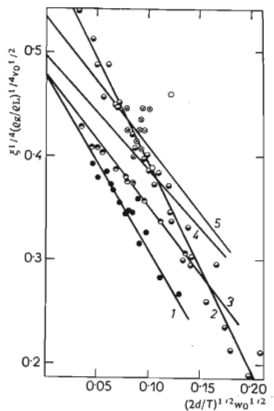
$$K_3 = -[\ln(\sigma/\gamma_L) - 2.258] \quad (5)$$

Relation (2) together with the coefficients K_1 and K_2 calculated according to relations (3) to (5) is for individual studied systems presented in a graphical form in Fig. 1. It is obvious from this figure that the linear dependence (2) represents the experimental points of the all three systems studied on the hydraulic section with a very good agreement. According to the relations (2)–(5) is also plotted in the figure the corresponding linear dependence for the system phenol-*o*-cresol.

FIG. 1

Limiting Gas and Liquid Velocities

Lines with numbers represent the calculated dependences, points the experiments. 1 ● Glycerol-air, 2 ○ water-air, 3 ● kerosene-air, 4 ○ methanol-water, 5 ○ phenol-*o*-cresol.



Though the experimental points for this systems were measured in a very narrow interval of liquid flow rates and further the scatter of the points (the lowest point in the graph is not consistent with the other experimentally determined points) due to very severely limited accuracy of determination of limiting velocities with distillation columns is greater than the scatter of experimental data from the hydraulic model, the determined dependence is passing through the region of experimental points and the limiting velocities may be determined with a good accuracy according to the relations (2) to (5). In Fig. 1 are also plotted two points obtained with rectification of the mixture methanol-water in a column of 1 m diameter at the conditions of total reflux⁴. But in this case were not directly determined the lower limiting velocities and the both points represent experiments with the lowest chosen vapour velocity, *i.e.* situations when the visually estimated foam height on the plate was about 1 cm. In the case of the tray with a small free plate area the correlated point is obviously not in agreement with the limiting velocity and the difference from the value calculated according to relation (2) is great; for the plate with a large free plate area the experimental point is in a good agreement with the calculated value.

For verification of validity of the empirical relations for the coefficients K_1 and K_2 for systems with substantially different physico-chemical characteristics not enough experimental data were available. However, on basis of this study it is possible in the range of here considered parameters of the liquids employed to determine for grid plates of arbitrary geometrical parameters the lower limiting velocities of both phases and to determine in this way the starting point of operation of these trays. The method enables the determination of lower critical velocities in the whole range of flow rates of both phases from two pairs of experimental points (vapour and gas velocities) obtained with various systems on model units of arbitrary geometrical parameters. With its application for columns of larger diameters a careful judgement is necessary as data used for its evaluation were measured on units of 0.3 and 0.4 m diameter and only two points on a unit of 1 m diameter.

LIST OF SYMBOLS

d	slot width (mm)	ρ	density (kg m^{-3})
$K_{1,2,3}$	empirical coefficients	γ	liquid density (g cm^{-3})
T	plate thickness (mm)	ξ	friction factor of dry plate
v_0	linear gas velocity in slots (m s^{-1})	σ	surface tension (dyn cm^{-1})
w_0	linear liquid velocity in slots (m s^{-1})	μ	viscosity (cP)
		ϕ	free plate area

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