

HYDRODYNAMICS OF PLATE COLUMNS. V.*

EFFECT OF GEOMETRY
OF A SIEVE PLATE WITH DOWNCOMER
ON STRUCTURE OF GAS-LIQUID MIXTURE
ON THE PLATE

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In one of the preceding papers of this series¹ we have dealt with the experimental verification of earlier^{2,3} obtained theoretical relationships, relating porosity and/or pressure in the gas-liquid mixture to the distance from the tray. The main aim of the mentioned work was to develop and verify an experimental technique on some types of plates which satisfied, to a sufficient extent, the condition of homogeneity in horizontal planes assumed in theory. From the condition of homogeneity it follows that all properties of the gas-liquid mixture are functions of the distance from the tray only, which reduces the problem to a one-dimensional one. The relationships obtained are

$$\frac{x}{h} = \frac{\varphi_H \varphi_0}{\varphi_H - \varphi_0} \left[\frac{\varphi - \varphi_0}{\varphi \varphi_0} + \ln \left(\frac{1 - \varphi_0}{\varphi_0} \cdot \frac{\varphi}{1 - \varphi} \right) \right] \quad (1)$$

for the dependence of porosity on the distance from the tray and

$$\frac{x}{h} = \frac{\varphi_H \varphi_0}{\varphi_H - \varphi_0} \left[\frac{p_0 - p_x}{p_0 - p_H} \cdot \frac{\varphi_H - \varphi_0}{\varphi_H \varphi_0} + \ln \frac{p_0 - p_H}{(p_0 - p_H) - (p_0 - p_x) \frac{\varphi_H - \varphi_0}{1 - \varphi_0} \cdot \frac{1}{\varphi_H}} \right] \quad (2)$$

for the dependence of pressure on the distance from the tray.

Since it was not realistic to measure the porosity of the mixture directly with our experimental means, we resorted to verification of the relationship (2) requiring pressure measurements only. The course of the dependence of porosity can be then calculated from Eq. (1) using values of φ_H and φ_0 determined from experimental data on the basis of Eq. (2).

The results obtained in the preceding paper have confirmed the justification of our theoretical conclusions. Since, however, the free cross-sectional area of a plate, given by the construction of the equipment, was used instead of the actual porosity at the tray level, it was necessary to introduce one empirical parameter.

With regard to the importance of the problem for a deeper knowledge of the studied system, it was desirable to carry out systematic measurements which would thoroughly verify chosen theoretical approach in a wide scope of variables, particularly the plate geometry. Sieve plates with downcomers, which in a wide range of flow rates of both phases fulfill the requirement of homogeneity of the gas-liquid mixture, seemed the most suitable for verification, provided that an appropriate distribution of downcomers over the area of the plate suppresses the lateral flow of liquid over the plate.

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Our experimental equipment and measuring technique have been thoroughly described in the cited paper¹. The construction parameters of the sixteen plates used are summarized in Table I of the preceding communication⁴.

RESULTS

The experiments were carried out using air-water system at 25°C. The flow rates of phases were varied in the range 0.4–2.2 m/s for air, and $5 \cdot 10^{-4}$ – $30 \cdot 10^{-4}$ m/s for liquid phase. The rates are related to the free cross-section of the column.

Similarly as in the preceding paper we found, particularly at high gas flow rates, that the value of the pressure drop across the whole gas-liquid mixture is smaller than the one corresponding to the course of pressure drop measured in different distances from the tray (see Fig. 1). An additional analysis have shown that these deviations are due to the fact that the moving pressure probe averages the value of pressure drop from the three different radii (the probe had three arms 0, 80 and 100 mm from the axis of the column), while the total pressure drop across the froth was measured by a fixed probe mounted in the center of the column. As can be seen from Figs 3 and 4 of the preceding paper⁵, an increasing gas velocity enhances the unevenness of the radial pressure profile. The pressure near the wall is higher than that in the center owing to the impacts of liquid on the wall, which gave rise to the mentioned deviations. Under these circumstances the values of the total pressure drop were discarded and only those, taken by the moving probe, were considered in the mathematical processing. The lowest position of the pressure probe was 10 mm above the plate. The obtained dependences are therefore valid from this distance up. The starting values of porosity and pressure were also calculated for this height and will be denoted as ϕ'_0 and p'_0 respectively, instead of ϕ_0 and p_0 reserved for respective quantities in the level of the tray.

The evaluation of the experimental data was carried out using Eq. (2) together with an acceptable assumption that $\varphi_H = 1$. As our experimental equipment did not allow to measure liquid

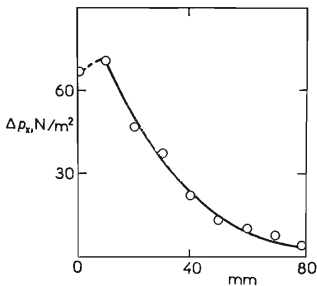


FIG. 1

Dependence of Pressure Drop Across Gas-Liquid Mixture on Distance from Tray ($\Delta p_x = p_x - p_H$)

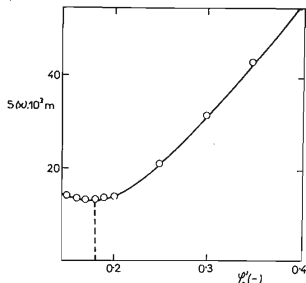


FIG. 2

Dependence of Sum of Square Deviations $S(x)$ on Porosity ϕ'_0

holdup on the plate with sufficient accuracy, the parameter h , necessary for calculation, was determined on the basis of the force and momentum balance

$$p_0 - p_H = h\gamma_1 - \frac{\rho_g v_g^2}{\varphi_0} (1 - \varphi_0) \quad (3)$$

which yields

$$x = \frac{1}{\gamma_1} \left[(p_0 - p_H) \frac{\varphi_0}{1 - \varphi_0} + \rho_g v_g^2 \right] \left[\frac{p_0 - p_x}{p_0 - p_H} \cdot \frac{1 - \varphi_0}{\varphi_0} + \ln \frac{p_0 - p_H}{p_x - p_H} \right], \quad (4)$$

or, for the starting values φ'_0 and p'_0 , 10^{-2} m above the tray

$$x = 10^{-2} + \frac{1}{\gamma_1} \left[(p'_0 - p_H) \frac{\varphi'_0}{1 - \varphi'_0} + \rho_g v_g^2 \right] \left[\frac{p'_0 - p_x}{p'_0 - p_H} \cdot \frac{1 - \varphi'_0}{\varphi'_0} + \ln \frac{p'_0 - p_H}{p_x - p_H} \right], \quad (5)$$

where x is expressed in metres and other quantities in corresponding units. The unknown parameter φ'_0 was calculated from the relation (5) by successive approximation so as to keep the sum of square deviations of the calculated and measured distances from the plate x , for given flow rates in the steady state, at minimum. The computational scheme is shown in Fig. 2. For a selected value φ'_0 , the sum of square deviations $S(x)$ is calculated and plotted in a graph. φ'_0 is then changed by a certain $\Delta\varphi'_0$ and the value of $S(x)$ is calculated anew. Thus the value of φ'_0 is gradually changed until $S(x)$ begins to rise. Then the value of the increment $\Delta\varphi'_0$ is reduced and the calculation repeated in the neighbourhood of the minimum. This sequence is continued until the calculated value of φ'_0 differs from the minimum by less than 1%.

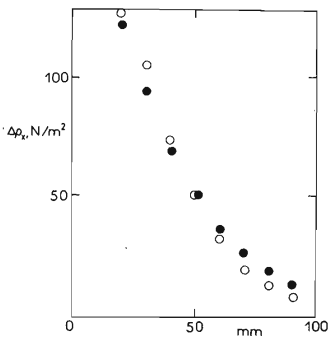


FIG. 3

Comparison of Measured and Calculated Values of $\Delta p_x = p_x - p_H$ in Dependence on Distance from Tray for Plate Number 8

○ Experimental values, ● calculated values.

By means of thus determined values of φ'_0 , reversed calculations of x from all 541 experimental points were performed (the experimental runs were paced by 10 mm as far as 100 mm, then we measured in the distance 120, 150 and 200 mm above the tray, *i.e.* 12 experimental points in the range between 10 and 200 mm).

The mean relative square deviation

$$\sigma(x) = \left[\sum_{i=1}^n \left(\frac{x_{\text{calc}} - x_{\text{exp}}}{x_{\text{exp}}} \right)^2 / n \right]^{1/2} \quad (6)$$

calculated for all 541 points is 11.23%.

The calculated values of φ'_0 , determined as described, were analyzed statistically and the following relation was obtained

$$\varphi'_0 = 1.457 - 0.384 \log(p'_0 - p_H) \quad (7)$$

with the mean square deviation ± 0.05 in the range $30 < (p'_0 - p_H) < 850$ N/m. The calculated and measured values of pressure for the plate number 8 are plotted in Fig. 3.

CONCLUSION

The experimental work has shown that the earlier derived theoretical relationship well describes the distribution of pressure in the gas-liquid mixture on a sieve plate with downcomer. It turns out that the values of φ'_0 , obtained by successive approximation, ensure a necessary accuracy of the calculation according to Eq. (5) without additional adjusting parameters. It is emphasized that φ'_0 is not an adjusting parameter, but it possess' a distinct physical meaning and an in advance known range of values ($0 < \varphi_0 < 1$) into which all our calculated values fell indeed. From Fig. 3 it is obvious that the calculated pressure drops well agree with those calculated from Eq. (5) and (7).

Considering that the froth is not quite homogeneous over the cross-section due to the above mentioned impacts of liquid on the wall, it can be expect that in an equipment of larger size, where this effect is considerably smaller, the theoretical conclusions will hold better than in our case.

LIST OF SYMBOLS

- h clear liquid height
- p pressure
- $S(x)$ sum of square deviations
- v velocity related to free cross section of column
- x distance above tray
- γ specific weight
- ρ density
- φ froth porosity (ratio of gas and liquid volumes in a unit of volume of mixture)
- σ mean relative square deviation

SUBSCRIPTS

- g gas
- l liquid
- o at $x = 0$ distance

H at $x = H$ distance
x at $x = x$ distance
calc calculated values
exp experimental values

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ÜBER DIE VANADYLREAKTION

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In den vorhergehenden Mitteilungen beschäftigten wir uns mit den Reaktionen des Hydroxylamins mit Vanadin(II)-, (III)- und (V)-ionen^{1,2} im Medium von Mineralsäuren oder in Gegenwart chelatbildender Reagentien. Als Endpunkt der Reaktion von Hydroxylammoniumsalzen mit Vanadinionen im sauren Medium ergaben sich Vanadylionen. Auf Grund von Literaturangaben sinkt durch pH-Erhöhung über den Wert 7 das formale Potential des Redoxsystems von +1,00 V im sauren Medium auf -0,75 V im alkalischen Medium und die Vanadylionen werden zu einem starken Reduktionsreagens. Wird dieses als Maßreagens verwendet, erfordert die Arbeit mit ihm eine inerte Atmosphäre³. Lingane und Meites⁴ stellten fest, daß Vanadylionen im Alkalicarbonatmedium das lösliche Salz VOCO_3 bilden, und sie fanden im pH-Bereich von 6,7–9,4 eine anodische Welle mit einem vom pH-Wert stark abhängigen Halbwellenpotential. Vor kurzem wurde von Sixta und Šulcek⁵ ein binärer Komplex des vierwertigen Vanadins mit Hydroxylamin beim pH-Wert 3–4 mit dem Absorptionsmaximum bei 220 nm beschrieben. In der vorliegenden Arbeit machten wir es uns zur Aufgabe, die Angaben, welche die gegenseitige Reaktion der Hydroxylammoniumsalze mit Vanadylionen im alkalischen Medium zum Gegenstand haben, zu ergänzen, da dieses System in der Literatur bisher nicht untersucht wurde.