NOTATIONS

A = coefficient in Equation (1)
a = exponent in Equation (1)
a_g = specific surface area of the packing
D = column diameter
d = particle diameter
Eo = Eotvos number, $(\rho_L g_c d^2)/(\sigma_L)$
G = superficial gas flow rate
g_c = conversion constant
h_k, h_B = constants in Equation (5)
L = superficial liquid flow rate
P, Q, R = coefficients in Equation (5)
u_G = gas superficial velocity
Z = height of packed bed

Greek Letters

$\beta, \beta_{nc}, \beta_c$ = total, noncapillary and capillary holdup expressed in percentage of interparticle void $\beta = \beta_{nc} + \beta_c$
ΔP = pressure loss; ΔP_L for single phase liquid, ΔP_G for single phase flow
ϵ = porosity (interparticle)
λ = flow parameter, $\lambda = \left[\frac{\rho_G}{\rho_{\text{air}}} \cdot \frac{\rho_L}{\rho_{\text{wat}}}\right]^{0.5}$
$\mu_G, \mu_L, \mu_{\text{wat}}$ = gas, liquid viscosity, and water viscosity
$\rho_G, \rho_L, \rho_{\text{wat}}, \rho_m$ = gas, liquid, water, manometric fluid density
$\sigma_L, \sigma_{\text{wat}}$ = liquid, water surface tension
ψ = flow parameter,

$$\psi = \frac{\sigma_{\text{wat}}}{\sigma_L}\left[\frac{\mu_L}{\mu_{\text{wat}}}\left[\frac{\rho_{\text{wat}}}{\rho_L}\right]^2\right]^{0.33}$$

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Prediction of the Pressure Drop Across Sieve Trays

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Generally, the total pressure drop across a sieve tray operating in the froth regime is calculated as the sum of a number of terms representing additive resistances to vapor flow:

$$P = h_{DT} + h_v$$

Although it is generally recognized that the pressure drop across the tray itself is not the same with and without liquid, in nearly all cases this assumption is made, and any variations due to the presence of liquid on the tray are incorporated in an additional term such that $h_v = h_L + h_R$.

Many suggestions have been made regarding the value of h_R (Hunt et al., 1955; Mayfield et al., 1952; and Brambilla et al., 1969). However, it will be contended that this approach is unsound, since vapor flow through the holes on the tray is fundamentally modified owing to the presence of liquid for the following reasons:

1. Not all the holes have an equal, instantaneous vapor flow rate. Owing to the irregular movement of liquid across the floor of the tray, some holes, or groups of holes, may be discharging rapidly at a given instant, while others may be temporarily inactive.
2. The rate of flow through an individual hole is oscillatory as bubbles grow and then detach.
3. Liquid may penetrate into the holes, effectively reducing the area available for vapor flow. At high vapor velocities, this penetration may depend on surface tension forces, but as the vapor velocity through the holes decreases, the liquid penetration can rapidly increase owing to gravity. This is the situation when the tray is weeping.
4. There is a venturi effect produced by the cone of liquid around the gas stream at the outlet of each hole which will tend to decrease the pressure drop and could give rise to pressure recovery. This is likely to be most noticeable at high hole velocities when the gas emerges from the holes nearly continuously rather than as distinct bubbles.

Steiner and Kolar (1969) have recognized that any equation for dry tray pressure drop must be modified for

TABLE 1. DATA USED IN CORRELATION OF BUBBLING FACTOR

System	Reference	Tray hole size, mm	Free area, %
Air-water	Davy (1974)	4.8 and 12.7	8.15 and 15.5
n pentane-iso pentane	Sargent et al. (1964)	1.6 and 3.2	10.1 and 22.6
Methanol-ethanol	Davy (1974)	12.7	15.5
Methylcyclo-hexane-toluene	Davy (1974)	12.7	15.5

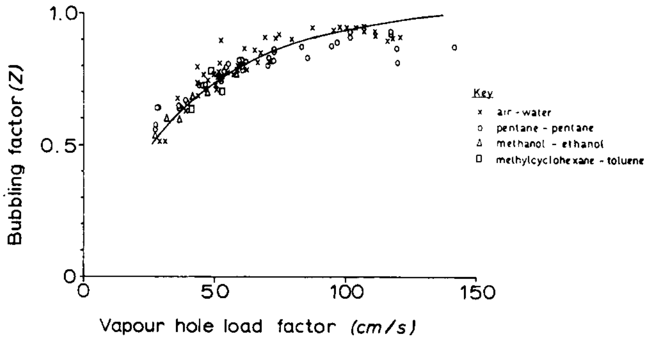

Fig. 1. Correlation of bubbling factor.

the wet tray situation. They consider that the effect of the liquid on the tray is to alter the effective free area of the tray, and they have derived theoretical relationships for the variation of free area with superficial vapor velocity, tray thickness, hole diameter, and downcomer free area. This method was tested on a number of different trays by using the air-water system; however, Steiner and Kolar (1969) failed to take account of system properties in their correlation for free area, and, in fact, their method has not been found to give good results for organic systems.

In the present work an alternative approach is proposed.

THEORY

Define

$$P = h_{WT} + h_L \qquad (1)$$

where h_{WT} is the head loss through the tray with liquid present, including the loss due to bubble formation.

Assume that h_{WT} can be correlated by an orifice type of equation:

$$h_{WT} = \frac{1}{2g} \frac{\rho_v}{\rho_L} \left(\frac{V_H}{C_W}\right)^2 \qquad (2)$$

where $C_W = Z\ Co$. This is an adaptation of one of the most comprehensive dry tray, pressure drop correlations (Kolodzie and van Winkle, 1957):

$$h_{DT} = \frac{1}{2g} \frac{1}{Y^2} (1 - F^2) \frac{\rho_v}{\rho_L} \left(\frac{V_H}{Co}\right)^2 \qquad (3)$$

As Y is close to, but less than 1, $1/Y^2$ is slightly greater than 1. The free area of the tray (or fraction of the active area occupied by perforations) is nearly always less than 0.2, so that the term $1 - F^2$ is close to unity but slightly less than it. As stated above, the free area will decrease with liquid present on the tray; hence, $1 - F^2$ becomes closer to 1, but still less than it. Therefore, $1/Y^2$ and $1 - F^2$ have been neglected. This simplification leads to a corresponding dry tray pressure drop equation of the form proposed by Kamei (1954) which is identical to Equation (2) with $C_W = Co$; that is, $Z = 1$ for the dry tray.

In order to be able to calculate Z, experimental values of P, h_L, and V_H must be substituted into the equation

$$P = \frac{1}{2g} \frac{\rho_v}{\rho_L} \left(\frac{V_H}{Z\ Co}\right)^2 + h_L \qquad (4)$$

EXPERIMENTAL RESULTS

The experimental data used, and the range of variables which they cover, are shown in Table 1.

In all cases, the value of Co was calculated from experimental dry tray runs by using Equation (3).

The bubbling factor has been plotted (Figure 1) against the vapor load factor, based on the hole velocity:

$$Z = \frac{V_s}{F} [\rho_v/(\rho_L - \rho_v)]^{1/2} \qquad (5)$$

This has been used to bring the results for the different systems onto a single line, which is given by

$$Z = 1 - \exp [-0.0265\ (V_s/F)\ (\rho_v/(\rho_L - \rho_v)]^{1/2} \qquad (6)$$

Although the plotted points show a slight divergence from this line at high values of load factor, further results obtained by the authors on a small air-water rig follow this line up to load factors of 170, which was the highest for which results were available.

DISCUSSION

Although the bubbling factor is an empirical concept, Equation (6) has some physical meaning, as Z is likely to be a function of vapor rate, tray geometry, and system properties. It decreases rapidly at low vapor rates and tends to unity at high values, as discussed in the introduction. It was expected that surface tension would be a significant variable; however, on the basis of these results, no trend has emerged despite the large surface tension difference between the aqueous and organic mixtures.

The predicted pressure drop from using Equations (4) and (6) is compared with the experimental values in Figure 2. These are to within 10% for most values, although the error already noted at high load factors is again apparent. Further work should be directed towards deter-

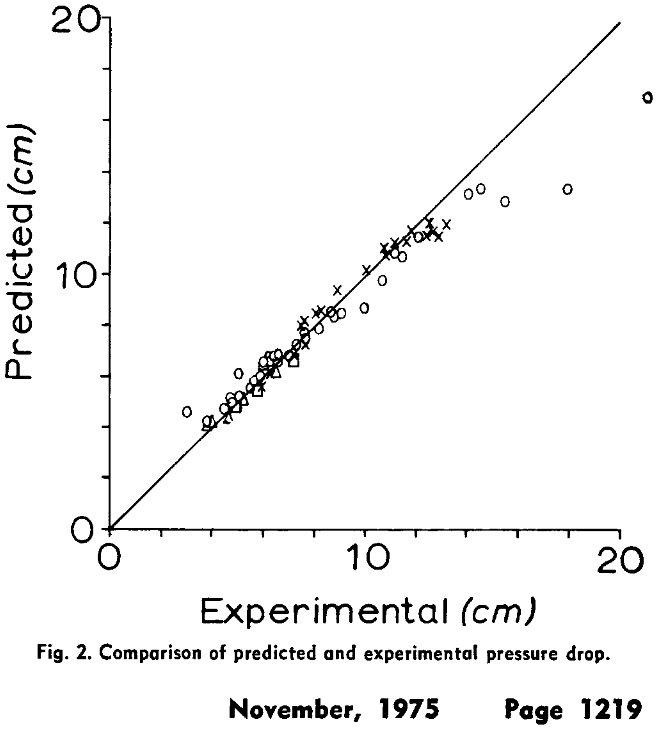

Fig. 2. Comparison of predicted and experimental pressure drop.

mining the upper limit of the applicability of this correlation; however, it is thought that it will apply at all vapor velocities where the tray is operating in the froth regime from below the point at which the tray commences weeping, up to the point of transition from the froth to spray regimes.

At hole load factors greater than 0.9 m/s, Z is between 0.9 and 1.0, and so in this range the correction to the dry tray correlation is of only small significance. However, below 0.9 m/s the correction becomes more important, particularly as this is the more likely operating range for modern large hole trays with high free areas.

CONCLUSIONS

Use of a correction to the dry tray orifice equation provides a useful design correlation for pressure drop in terms of the liquid head on the tray, superficial vapor velocity, system properties, and tray geometry. This correction is most significant at values of hole load factor below 0.9 m/s.

NOTATION

Co = dry tray orifice coefficient
Cw = wet tray orifice coefficient
F = tray free area (that is, fraction of the perforated tray area occupied by holes)
g = gravitational acceleration, cm/s
h_L = static liquid head, cm
h_R = residual head, cm
h_v = head loss by vapor passing through the liquid, cm
h_{DT} = head loss across dry tray, cm
h_{WT} = head loss across tray with froth present, cm
P = pressure drop across operating tray, cm
V_s = superficial vapor velocity, cm/s
V_H = vapor velocity through perforations, cm/s
Y = expansion factor
Z = bubbling factor
ρ_L = liquid density
ρ_v = vapor density

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An Approach to Mechanism Discrimination in Free-Radical Reactions

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There has been considerable interest over the past 10 yr. in the treatment of kinetic mechanisms involving active intermediates which may be experimentally unobservable for all or part of the reaction time. Examples of such reaction systems include free radicals in homogeneous pyrolysis and oxidation reactions, active surface compounds in catalytic systems, and enzymes in biochemical systems.

By their nature, such sets of reactions involving active intermediates have two different time scales, and the dynamic behavior of such systems leads invariably to a stiff set of differential equations with widely differing eigenvalues. A significant amount of attention has been focused on methods of solving such equations numerically (Seinfeld et al., 1970; Gear, 1971; Sena and Kershenbaum, 1975; Denis and Daubert, 1974), and several generally successful algorithms are available.

However, in the absence of any good estimates of the rate constants involved or even of the viability of a proposed reaction mechanism, it is often more important to test some preliminary experimental data on such systems to see if they are consistent with the proposed mechanism. A usual procedure in this direction is to invoke the well-known quasi steady state approximation (QSSA). This reduces some of the differential equations to algebraic ones and often allows the remaining differential equations to be solved analytically. Bowen et al. (1963) showed that, in fact, the QSSA was generally the first term in a singular perturbation solution of the complete problem, and Aiken and Lapidus (1974) have recently devised an effective numerical integration method based on that principle.

In this work, a systematic approach has been outlined for the study of systems of chemical reactions involving active intermediates. By utilizing existing theory with some small extensions, it has been possible to show that such systems have built into them a set of constraints which must be satisfied by any proposed mechanism seeking to explain the kinetics of the system.

THEORY

The singular perturbation approach to the solution of problems in kinetics seeks to put the differential equations describing the system in the form

$$\frac{dx}{dt} = \mathbf{f}(t, \mathbf{x}, \mathbf{y}, \epsilon) \quad \epsilon \frac{dy}{dt} = \mathbf{g}(t, \mathbf{x}, \mathbf{y}, \epsilon) \qquad (1)$$

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