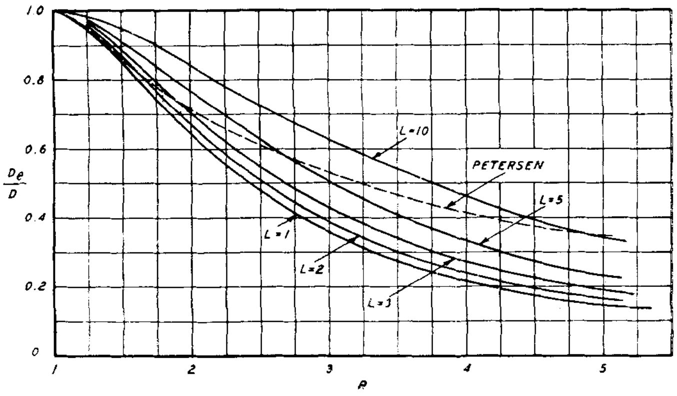

Fig. 1.

where $L = 2R$, the values are virtually identical with Petersen's.

Equation (5) has certain unusual properties which merit comment. The function $L/(L + 1)^2$ is relatively insensitive to the value of L, varying only about threefold as L increases from 1 to 10; this means that the convergence factor is much more sensitive to the degree of change of pore cross section (or R) than it is to the relative lengths of the bulges or constrictions. Also $L/(1 + L)^2$ is a maximum at $L = 1$ and has the same value for $1/L$ as it does for L; that is to say, the convergence factor will be the same whether the pore constrictions occupy a given fraction of the pore length of the pore bulges occupy that fraction, and it will be smallest when the bulges and constrictions occupy equal fractions of the pore length.

Failure to consider entrance and exit effects in the preceding derivation amounts to assuming that all flux lines are parallel to the pore walls at all points. Clearly however there will be parts of the pore where this is not the case, and thus a certain fraction of the pore volume will not contribute to the flux. Consequently the convergence factor calculated from Equation (5) will be greater than the true convergence factor for the corresponding irregular pore, or, conversely, pore dimensional ratios calculated from a measured convergence factor via Equation (5) will always be larger than the actual values. It should however be pointed out that the actual diffusional flow process through a porous solid is an impressively complex matter involving convergence effects, flow splitting, and multidirectional flow paths, of which the individual contributions to the flow resistance are unknown. One may lump all these effects into either a tortuosity factor or a convergence factor; both are calculational conveniences, but in the absence of a detailed knowledge of the geometry of a porous solid, neither throws any direct light on the flow mechanism. In view, therefore, of the limitations attendant upon employing any parallel capillaric model to describe a random porous medium, further refinement of the irregular pore model hardly seems profitable.

NOTATION

c_i = constant upstream concentration
c_0 = constant downstream concentration
D = diffusion coefficient
D_e = effective diffusivity
L = ratio of length of pore bulges to pore constrictions
R = ratio of maximum to minimum pore diameter

Slot Capacity of Bubble Caps

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In setting up their differential equations Rogers and Thiele (*1*) overlooked the directional property of the differential slot height and did not put in a necessary minus sign. Later they reversed the integration limits without changing the sign. The final equation for rectangular slots happens to be correct, because the slot width does not vary with the slot height, and two negatives make a positive. However their equations for trapezoidal and triangular slots are incorrect; the capacities of trapezoidal and triangular slots are underestimated by 14.3 and 50%, respectively.

DERIVATION OF EQUATION

For the convenience of comparison the notation used here is the same as that used by Bolles (*2*), except that the slot-height variable and the slot opening start from the top of a slot, as illustrated in Figure 1.

Trapezoidal slots

Application of the orifice equation to a differential element of slot area gives the vapor velocity through the differential area

$$u = K_s \sqrt{2g\left(\frac{\rho_L - \rho_V}{\rho_V}\right)\frac{h}{12}} \quad (1)$$

The vapor flow rate through the differential area is given by

$$dV_s = u\,dA$$
$$= K_s \sqrt{2g\left(\frac{\rho_L - \rho_V}{\rho_V}\right)\frac{h}{12}}\,\frac{w\,dh}{144} \quad (2)$$

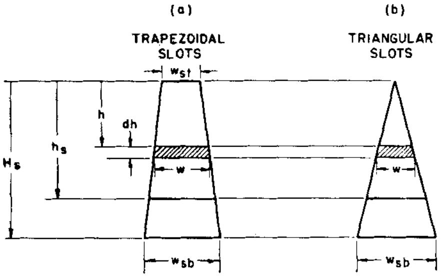

Fig. 1. Slot-opening formula-derivation diagram.

The width of the differential area may be obtained as

$$w = w_{st} + (w_{sb} - w_{st}) \frac{h}{H_s} \tag{3}$$

Combining, rearranging, and integrating Equations (2) and (3) one obtains

$$V_s = \frac{K_s}{144} \sqrt{\frac{2g}{12} \left(\frac{\rho_L - \rho_V}{\rho_V} \right)} \left[w_{st} \int_0^{h_s} h^{1/2}\, dh + \frac{w_{sb} - w_{st}}{H_s} \int_0^{h_s} h^{3/2}\, dh \right] \tag{4}$$

Introducing $K_s = 0.51$ and applying to the whole tray one gets

$$V = 0.00820 N_c N_s \sqrt{\frac{\rho_L - \rho_V}{\rho_V}} \cdot \left[\frac{2}{3} w_{st} h_s^{3/2} + \frac{5}{2} \left(\frac{w_{sb} - w_{st}}{H_s} \right) h^{5/2} \right] \tag{5}$$

The total slot area per tray may be expressed as

$$A_s = N_c N_s H_s (w_{sb} + w_{st})/(2 \times 144) \tag{6}$$

Combining

$$R_s = w_{st}/w_{sb}$$

with Equations (5) and (6) one gets

$$V = 2.36 \frac{A_s}{H_s} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}} \cdot \left[\frac{2}{3} \left(\frac{R_s}{1 + R_s} \right) h_s^{3/2} + \frac{5}{2} \left(\frac{1 - R_s}{1 + R_s} \right) \frac{h_s^{5/2}}{H_s} \right] \tag{7}$$

Maximum slot capacity is obtained by the substitution of H_s for h_s, which results in

$$V_m = 236 A_s \left[\frac{2}{3} \left(\frac{R_s}{1 + R_s} \right) + \frac{2}{5} \left(\frac{1 - R_s}{1 + R_s} \right) \right] \sqrt{H_s \left(\frac{\rho_L - \rho_V}{\rho_V} \right)} \tag{8}$$

Rectangular slots

This is an extreme case of trapezoidal slots of which $R_s = 1$. From Equations (7) and (8)

$$V = 0.787 \frac{A_s}{H_s} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}\, h_s^{3/2} \tag{9}$$

and

$$V_m = 0.787 A_s \sqrt{H_s \left(\frac{\rho_L - \rho_V}{\rho_V} \right)} \tag{10}$$

Triangular slots

This is another extreme case of trapezoidal slots of which $R_s = 0$. From Equations (7) and (8)

$$V = 0.944 \frac{A_s}{H_s} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}\, h_s^{5/2} \tag{11}$$

and

$$V_m = 0.944 A_s \sqrt{H_s \left(\frac{\rho_L - \rho_V}{\rho_V} \right)} \tag{12}$$

COMPARISON OF TOTAL VAPOR LOAD

Rectangular slots ($R_s = 1$)

In this case Rogers-Thiele equations are correct and agree with the author's Equations (7) and (8).

Trapezoidal slots (for the case $R_s = 0.5$)

The Rogers-Thiele equation is

$$V_{mR} = 0.734 A_s \sqrt{H_s \left(\frac{\rho_L - \rho_V}{\rho_V} \right)}$$

The author's equation is

$$V_{mT} = 0.839 A_s \sqrt{H_s \left(\frac{\rho_L - \rho_V}{\rho_V} \right)}$$

$$V_{mT}/V_{mR} = 0.839/0.734 = 1.143$$

The correct vapor capacity calculated from the author's equation is 14.3% higher than that calculated from the Rogers-Thiele equation.

Triangular slots ($R_s = 0$)

Similarly

$$V_{mT}/V_{mR} = 0.944/0.630 = 1.500$$

The corrected vapor capacity calculated from the author's equation is 50.0% higher than that calculated from the Rogers-Thiele equation.

SELECTION OF SLOT DESIGN

To provide a basis for the selection of slot shapes the performance of bubble caps with different slot shapes is compared. This comparison is based on 4-in. caps, used by Bolles in his comparison, with a slot height of 1.25 in. The mean slot width is held constant at 0.25 in. to maintain equal area per slot. The slot designs of the three different 4-in. caps are as follows:

Slot	R_s	Number of slots per cap	Slot area per cap sq. in.
Rectangular	1	25	7.82
Trapezoidal	0.5	26	8.12
Triangular	0	19	5.94

The author, as Bolles did, chose the distillation of benzene at atmospheric pressure to compare the slot performance of these bubble caps. In this system the temperature is 176°F., and liquid density equals 50.5 lb./cu. ft.

The calculation of the slot performance was based on the correct equations given in this paper. The calculated slot openings for various vapor loads are presented in Figure 2. This chart shows that the cap with trapezoidal slots provides the greatest capacity at maximum slot open-

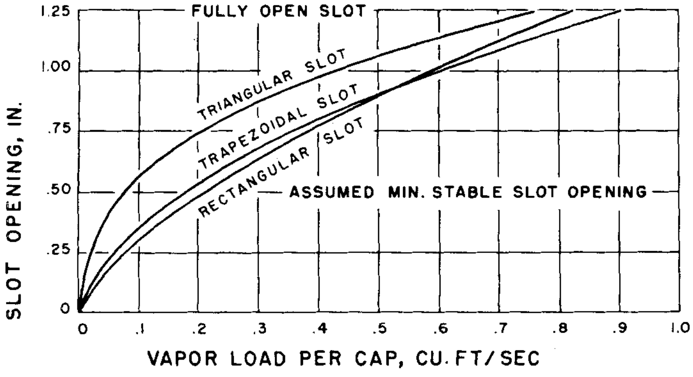

Fig. 2. Performance comparison for common slot shapes with 4-in. bubble caps with 1.25-in. slot height used; system is benzene at atmospheric pressure.

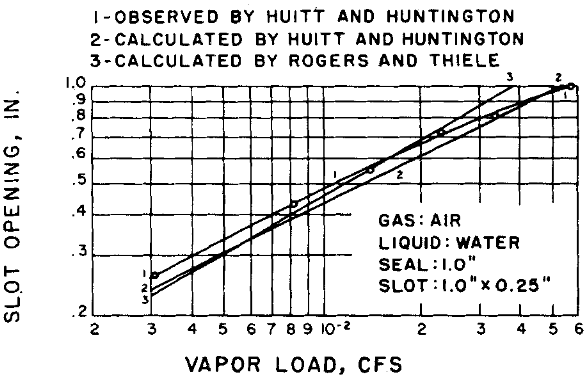

Fig. 3. Calculated and observed slot opening.

ing of the three types. This bears out the popular preference of trapezoidal slots. In either capacity or flexibility trapezoidal slots are better than rectangular slots. This is in disagreement with Bolles' study based upon Rogers-Thiele equations which indicated that the cap with rectangular slots would provide the greatest capacity at maximum slot opening.

It is to be noted that triangular slots are not as undesirable as the Rogers-Thiele equations would show. The maximum capacity of the cap with triangular slots is actually not much lower than that of rectangular or even trapezoidal slots. On the other hand if a column is to be designed to meet the widest range of operation in throughput, caps with triangular slots actually are the best choice and the most stable of the three types (when one assumes a minimum stable slot opening of 0.5 in.). Caps with triangular slots probably can be operated at a throughput of 9.8% of maximum capacity, while caps with rectangular slots probably cannot be operated satisfactorily under 25% of maximum capacity. Since the maximum slot capacity of cap with triangular slots is actually as high as 85 and 93% of the maximum capacity of caps with trapezoidal and rectangular slots respectively, it properly deserves more attention in future applications.

Slot of 4-in. cap	Maximum capacity/cap		Minimum capacity/cap	
	cfs	% trapezoidal	cfs	% maximum
Triangular	.765	84.5	.075	9.80
Trapezoidal (R_s = 0.5)	.905	100	.176	19.46
Rectangular	.825	91.2	.208	25.2

DISCUSSION

Huitt and Huntington (*3*) compared their observed slot openings of a rectangular slot with their equation and also with Rogers-Thiele equation. Figure 3 shows that both equations agree with their data fairly well. However vapor loads predicted by the Huitt-Huntington equation are about 20% higher than their observed values, except when the slot is fully open. Rogers-Thiele equation is on the conservative side when the slot is more than 60% open. Therefore the latter equation is preferable in design calculations to the first. In this comparison a slot orifice coefficient of 0.51 was used. This confirms that 0.51 is a proper and conservative coefficient for rectangular slots.

Simkin *et al.* (*4*) used the Rogers-Thiele equation with the coefficient modified to fit the experimental data of Griswold (*5*) for trapezoidal slots. They proposed to use 0.70 in Rogers-Thiele equation instead of 0.51 for trapezoidal slots. This bears out the finding of this paper that Rogers-Thiele equation for trapezoidal slots is about 14% too low. Therefore if equations in this paper are used in design, the same coefficient of 0.51 can be used in general for all types of slots.

CONCLUSION

Slot capacities of trapezoidal and triangular slots in a bubble cap column calculated by Rogers-Thiele equations are underestimated by 14.3 and 50.0%, respectively.

The correct equations given in this paper show that:

1. Caps with trapezoidal slots are better than caps with rectangular slots in either capacity or flexibility.
2. Caps with trapezoidal slots are the best for distillation columns of high vapor/liquid ratios, and caps with triangular slots the best for columns of low vapor/liquid ratios.
3. Triangular slots provide the highest flexibility. Although the maximum capacity of caps with triangular slots is somewhat lower than that of caps with the other two types of slots, it is much higher than indicated by Rogers-Thiele equation; therefore it deserves more attention in the future, especially for distillation and absorption columns with high liquid loadings or widely variable vapor loadings. These occur for instance in batch columns in which fine chemicals in small quantities are produced and in which products are often switched from one to another.

NOTATION

A = slot area, sq. ft.
A_s = total slot area per tray, sq. ft.
g = acceleration of gravity, 32.2 ft./sec./sec.
h = slot opening variable, in.
h_s = slot opening, in.
H_s = slot height, in.
K_s = slot orifice coefficient
N_c = number of caps per tray
N_s = number of slots per cap
R_s = trapezoidal slot shape factor, w_{st}/w_{sb}
u = vapor velocity through an element of slot area, ft./sec.
V = total vapor load per tray, cu. ft./sec.
V_m = maximum vapor load per tray, cu. ft./sec.
V_{mR} = Maximum vapor load per tray calculated from Rogers and Thiele's equation, cu. ft./sec.
V_{mT} = maximum vapor load per tray, calculated from the author's equation, cu. ft./sec.
V_s = vapor load per slot, cu. ft./sec.
w = slot width, in.
w_{sb} = slot width at bottom, in.
w_{st} = slot width at top, in.
ρ_L = liquid density, lb./cu. ft.
ρ_V = vapor density, lb./cu. ft.

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4. Simkin, D. J., C. P. Strand, and R. B. Olney, *Chem. Eng. Progr.*, **50**, 565 (1954).
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BOOKS

Management for Engineers, Roger C. Heimer. McGraw-Hill Book Company, Inc., New York (1958). 453 pages. $6.75.

The purpose of this textbook is to acquaint "the young engineer with the business firm's decision-making process." It is written with the premise that the reader has little knowledge of the workings of a business firm.

For the novice in the business world Chapter 2, "The Legal Forms of Business Organization," and Chapter 3, which analyzes the finances of a mythical business firm, should be particularly helpful. The major portion of the book is concerned with daily operational problems: profit, cost, interest, depreciation, insurance, and inventory.

A basic understanding of organizational structure and operation will be gleaned from the last four chapters, which deal with over-all managerial problems, and really differentiate this book from the usual economics textbook. The young engineer should find these chapters most helpful in understanding managerial decisions.

The best use of this book would be as a supplement to the usual undergraduate economics course.

J. M. Ruder

Engineering Materials Handbook. Charles L. Mantell, Editor. McGraw-Hill Book Company, Inc., New York (1957). 1936 pages. $21.50.

The field of engineering materials is a broad one, and it seems almost impossible that any one book could cover the whole subject completely. The "Engineering Materials Handbook" does, however, cover the field with a remarkable degree of