H = circumference of pore
k = length of cross-sectional chord extending from an element of perimeter dx
L = pore length
N = molar flow rate through pore
P = gas pressure
r = radius of circular pore
r_h = hydraulic radius, ratio of area of conduit to wetted perimeter
R_o = universal gas constant
s = distance from cross-section area element dA to perimeter of pore
T = absolute temperature
$\bar{v}$ = mean molecular velocity
x = coordinate representing position on perimeter of pore
w = length of side of rhomboidal pore
θ = angle between cross-sectional chord k and the normal to pore wall
Φ = angle representing direction in which distance between area element dA and pore wall is measured

Subscripts

c = circular cross section
r = rectangular cross section
s = rhomboidal cross section
1 = entrance of pore
2 = exit of pore

LITERATURE CITED

Beck, R. E., "Restricted Diffusion of Nonelectrolytes through Artificial Mica Membranes with Known Pore Geometry," Ph.D. thesis, Univ. Mich., Ann Arbor (1969).

Beck, R. E., and J. S. Schultz, "Hindrance of Solute Diffusion within Membranes as Measured with Microporous Membranes of Known Pore Geometry," *Biochim. Biophys. Acta*, **255**, 273 (1972).

Clausing, P., "Über die Strömung sehr verdünnter Gase durch Röhren von beliebiger Länge," *Ann. Physik*, **12**, 961 (1932).

Dushman, S., *Scientific Foundations of Vacuum Technique*, 2 ed., pp. 87-90, Wiley, New York (1962).

Eldridge, B. D., and L. F. Brown, "The Effect of Cross Sectional Pore Shape on Knudsen Diffusion in Porous Materials," *AIChE J.*, **22**, 924 (1976).

Ho, W. S., "Model Membranes: Knudsen Flow Through Microcapillaries," Ph.D. thesis, Univ. Ill., Urbana (1971).

Jeans, J., *An Introduction to the Kinetic Theory of Gases*, pp. 167-170, Cambridge University Press, London, England (1940).

Kennard, E. H., *Kinetic Theory of Gases*, pp. 302-306, McGraw-Hill, New York (1938).

Knudsen, M., "Die Gesetze du Molekularströmung und der inneren Reibungsströmung der Gase durch Röhren," *Ann. Physik*, **28**, 75 (1909).

Loeb, L. B., *The Kinetic Theory of Gases*, 2 ed., pp. 290-294, McGraw-Hill, New York (1934).

Lyubitov, Y. N., *Molecular Flow in Vessels*, pp. 13-18, Plenum Press, New York (1967).

Petzny, W. J., and J. A. Quinn, "Calibrated Membranes with Coated Pore Walls," *Science*, **166**, 751 (1969).

Pollard, W. G., and R. D. Present, "On Gaseous Self-Diffusion in Long Capillary Tubes," *Phys. Rev.*, 73, 762 (1948).

Present, R. D., *Kinetic Theory of Gases*, pp. 55-61, McGraw-Hill, New York (1958).

Quinn, J. A., J. L. Anderson, W. S. Ho, and W. J. Petzny, "Model Pores of Molecular Dimension—The Preparation and Characterization of Track-Etched Membranes," *Biophys. J.*, **12**, 990 (1972).

Smoluchowski, M., "Zur Kinetischen Theorie der Transpiration und Diffusion verdünnter Gase," *Ann. Physik*, **33**, 1559 (1910).

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Predicted Comparisons of the Efficiency of Large Valve Trays and Large Sieve Trays

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Valve trays are proprietary devices, and as such the designs are usually provided by the supplier. However, there are times when a knowledge of the performance of such trays is desirable for preliminary studies. Recently, Bolles (1976) has considered the relationship between valve trays and sieve trays with a view to using the vast amount of data available for sieve trays. For tray efficiency, he recommends, in the absence of more detailed figures, that an efficiency similar to that of a sieve tray be assumed.

This approach appears to be reasonable based on the studies which have been reported by various authors comparing trays. However, these studies have been made in small to medium sized columns, and the question arises whether these similarities would still exist for very large trays. Recently, Garrett et al. (1977) have attempted to compare the scale-up of sieve tray and valve tray efficiencies. They have assumed similar mixing characteristics on the two types of trays.

During the course of a computer simulation of a 2.43 m diameter valve tray column separating benzene from a benzene/toluene/xylene mixture (Biddulph and Ashton, 1977), the mixing characteristics of a Koch valve tray have been established. This was achieved using a 0.69 m diameter air/water simulator which has been described

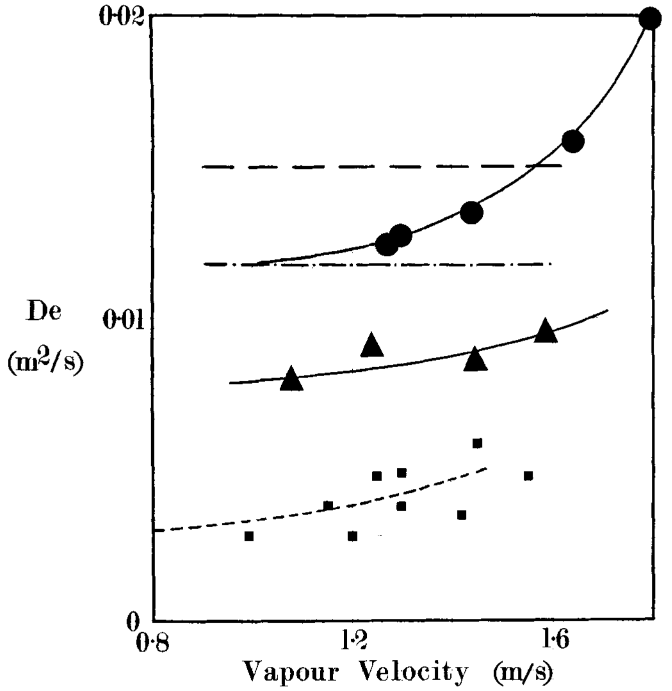

Fig. 1. Eddy diffusivity on valve trays and sieve trays.
—●— Valve tray. Liquid rate 460 l/min(m).
—▲— Valve tray. Liquid rate 317 l/min(m).
■ Sieve trays. Various conditions, same equipment.
— — — Valve tray. Welch (1964) equation. 460 l/min(m).
—·—·— Valve tray. Welch (1964) equation. 317 l/min(m).
----- Sieve tray. Barker (1962) experimental. 373 l/min(m).

elsewhere (Biddulph and Stephens, 1974). The values of eddy diffusivity measured by salt tracer injection are shown in Figure 1. Plotted on the same graph are the results of Welch, Durbin, and Holland (1964) on a Glitsch V-1 ballast tray. The magnitude of these results is somewhat higher. The eddy diffusivities measured in Nottingham do not completely confirm the dependence only on liquid rate found by Welch et al. (1964). Plotted on the same graph is an assortment of results from sieve trays, some from the Nottingham rig and some from Barker and Self (1962). It can be seen that at higher liquid loadings, the eddy diffusivity results on the valve trays are substantially greater than found on sieve trays. This indicates that the extent of mixing to be expected on valve trays is much greater than on sieve trays. This observation raises the question whether this could substantially alter the performance of large valve trays compared with sieve trays.

First, taking the conditions in the upper section of the benzene/toluene/xylene column referred to above, a Peclet number of 25 is indicated for a valve tray compared with a value of 82 if sieve trays had been used. Using simple backmixing theory as described previously (Biddulph, 1975), a point efficiency of 66% is required for each component, comparing quite well with measured (Carey et al., 1933) values of 69% for this system. In order to make a comparison, we should know whether valve trays and sieve trays might be expected to operate with similar point efficiencies.

Considering the results reported by Anderson, Garrett, and van Winkle (1976) on the system benzene/propanol in a 0.46 m diameter column, very similar tray efficiencies were established for two types of valve trays and a sieve tray. Calculations based on the conditions reported in their column, with its fairly low liquid rate, indicate very similar values for the Peclet number. Therefore, we may say that similar point efficiencies were probably operating. If we accept this, then we can rerun the simulation of the benzene/toluene/xylene column with a Peclet number of 82 and discover less than one tray difference in twenty one trays above the feed. This similarity is to be expected, since the value of $E_{OG}\lambda$ is low, about 0.32, and so valve trays and sieve trays would be expected to behave very similarly here.

In the lower section of the same column, where $E_{OG}\lambda$ is about 1.20 and the Peclet numbers for the split flow trays are 11 for valves and 36 for sieves, the efficiency of individual valve trays might be expected to be 10% less than sieve trays. This has been based on simple backmixing theory. The introduction of the stagnant zones model (Lockett et al., 1973) would tend to reduce the difference between single tray values of efficiency. The cumulative effect of stagnant zones being stacked above each other would be reduced by the improved mixing in the case of valve trays, and the results reported by Lockett (1973) indicate that under the prevailing conditions in the upper part of the benzene column, there could be a 15 to 20% tray efficiency advantage for valve trays over sieve trays.

CONCLUSIONS

The observation that valve trays appear to promote much improved mixing in the liquid phase compared with sieve trays indicates possible differences in large columns. This should be the subject of further study. The difference in mixing characteristics may influence the changeover diameter from single cross flow to split flow in the case of valve trays based on the stagnant zones effect.

NOTATION

E_{OG} = point efficiency
G = vapor rate (kg-mole/s)
L = liquid rate (kg-mole/s)
m = slope of equilibrium curve
λ = mG/L

LITERATURE CITED

Anderson, R. H., G. Garrett, and M. van Winkle, "Efficiency comparison of Valve and Sieve Trays in Distillation Columns," *Ind. Eng. Chem. Process Design. Develop.*, **15**, 96 (1976).

Barker, P. E., and M. F. Self, "The Evaluation of Liquid Mixing Effects on a Sieve Plate Using Unsteady and Steady State Tracer Techniques," *Chem. Eng. Sci.*, **17**, 541 (1962).

Biddulph, M. W., and D. J. Stephens, "Oscillating Behaviour on Distillation Trays," *AIChE J.*, **20**, 60 (1974).

Biddulph, M. W., "Multicomponent Distillation Simulation—Distillation of Air," *ibid.*, **21**, 327 (1975).

———, and N. Ashton, "Deducing Multicomponent Distillation Efficiencies from Industrial Data," *Chem. Eng. J.*, in press (1977).

Bolles, W. L., "Estimating Valve Tray Performance," *Chem. Eng. Progr.*, **72**, No. 9, 43 (1976).

Carey, J. S., J. Griswold, W. K. Lewis, and W. H. McAdams, "Plate Efficiencies in Rectification of Binary Mixtures," *Trans. Am. Inst. Chem. Engrs.*, **30**, 504 (1933-4).

Garrett, G. R., R. H. Anderson, and M. van Winkle, "Calculation of Sieve and Valve Tray Efficiencies in Column Scale-Up," *Ind. Eng. Chem. Process Design. Develop.*, **16**, 79 (1977).

Lockett, M. J., C. T. Lim, and K. E. Porter, "The Effect of Liquid Channelling on Distillation Column Efficiency in the Absence of Vapour Mixing," *Trans. Inst. Chem. Engrs.*, **51**, 61 (1973).

Welch, N. E., L. D. Durbin, and C. D. Holland, "Mixing on Valve Trays and in Downcomers of a Distillation Column," *AIChE J.*, **10**, 373 (1964).

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