$$U = \left[\frac{2g_c \, \Delta P_{av}}{\rho\left(1 - \frac{r^2}{R^2}\right)} - \overline{U'^2} \right]^{1/2} \quad (6)$$

Values of $\overline{U'^2}$ were taken from hot-wire anemometer data *(10, 11)*.

Equation (3) applies directly in the center portion of the pipe for laminar flow of low-viscosity fluids. For turbulent flow the corrections for pressure variation over the impact area and for turbulent fluctuations have a compensating effect as illustrated by Equation (6).

ACKNOWLEDGMENT

The work reported here is part of a project supported by the National Science Foundation.

NOTATION

g_c = gravitation constant
ΔP = difference between impact pressure at any point on the impact area and the static pressure
ΔP_{ave} = average pressure difference over the impact area
r = radius of the impact area
R = radius of the impact tube
ρ = density of the fluid
θ = angle between a point on the impact area and the front stagnation line
U = velocity of the fluid at the impact point
x = axial distance on the cylinder from the center of the impact area
y = radial distance on the cylinder from the center of the impact area

LITERATURE CITED

1. Knudsen, J. G., and D. L. Katz, "Fluid Dynamics and Heat Transfer," p. 216, McGraw-Hill, New York (1958).
2. Barker, Muriel, *Proc. Royal Soc.*, **A101**, 435 (1922).
3. Miller, D. R., and E. W. Comings, *J. Fluid Mech.*, **3**, 1 (1957).
4. Rosler, R. S., and S. G. Bankoff, *A.I.Ch.E. Journal*, **9**, 672 (1963).
5. Rothfus, R. R., J. E. Walker, and G. A. Whan, *A.I.Ch.E. Journal*, **4**, 240 (1958).
6. Senecal, V. E., and R. R. Rothfus, *Chem. Eng. Progr.*, **49**, 533 (1953).
7. Bogue, D. C., and A. B. Metzner, *Ind. Eng. Chem. Fundamentals*, **2**, 143 (1963).
8. Callighan, M. J., and D. M. Mason, *A.I.Ch.E. Journal*, **10**, 52 (1964).
9. Knudsen, J. G., and D. L. Katz, "Fluid Dynamics and Heat Transfer," p. 62, McGraw-Hill, New York (1958).
10. Deissler, R. G., *Trans. Am. Soc. Mech. Engrs.*, **73**, 101 (1951).
11. Schlichting, Hermann, *Boundary Layer Theory*, p. 466, McGraw-Hill, New York (1960).

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Fluidised Particles, J. F. Davidson and D. Harrison, Cambridge University Press, New York (1963). 155 pages. $6.50.

This book is an interesting attempt to present a mathematical picture of the complicated phenomena of fluidization through an analytical treatment of the mechanism of fluidization, including incipient fluidization velocity, the formation of bubbles, the rise and coalescence of bubbles, the exchange between phases, and the stability of bubbles.

The analysis is heavily based on experimental work from the authors' laboratory, and these observations and measurements differ in many cases from those of other investigators. This lessens the value of the mathematical models. For example, the book states in several places that in aggregate fluidization "with still greater flows, the bubbles grow and appear more frequently until their frontal diameters are equal to the diameter of the containing apparatus," and again, "for a gas fluidised bed of one to two inch diameter, the bubble size becomes equal to the bed diameter when the height is more than one to two feet." This is not in agreement with the observations of other investigators who have found that with many aggregate systems the solid is blown out of the bed long before the bubble size is equal to the column diameter. These statements also appear to contradict later discussions in the book. Perhaps this is due to a different interpretation of aggregate fluidization.

The mathematical models used are, in general, very idealized and appear to neglect many important factors such as the presence of solid particles within the bubbles and the effects of radial velocity gradients in the column which other data indicate are of prime importance in the scale-up of fluidized-solid beds. The section on the velocity of bubbles neglects other studies which indicate that much higher velocities than the superficial velocity plus the idealized velocity of bubbles in a liquid are present. The use of the "stationary bubble-moving fluid" analog is not a good approximation of actual conditions.

The section on the fluidized bed as a catalytical reactor does not give an adequate analysis of the advantages and disadvantages of these units as compared to other types of reactors or of the real problems of scaling-up from laboratory units. This section also ne-

(Continued on page 785)

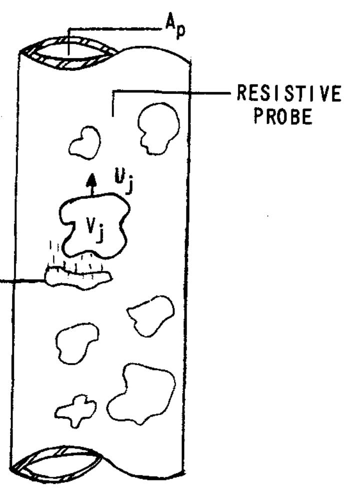

Fig. 1. Irregularly shaped bubbles in a pipe.

An idealized analysis indicates the effects of the bubble size distribution on the gas contact time and on the volumetric void fraction. For the purpose of illustration, the actual behavior of bubbles moving in a liquid is approximated by an infinite-medium solution. Influence of pipe wall on all aspects of bubble size and motion is neglected, bubbles are uniformly distributed across the area perpendicular to flow, and all bubbles of the same radius move at the same velocity. For these conditions, the average bubble chord pierced by the probe has a length of $(4/3)r$. The variance or standard deviation of the chord about the average is $(\sqrt{2}/3)r$, or roughly half the radius. This variance is large enough to create difficulties in obtaining bubble size directly from the traces.

The bubble size distribution function, $B(\zeta)$, discussed by Bankoff and Neal [their Equation (2.2)] is reiterated here:

$$B(\zeta) = \int_0^\zeta b(Z)\, dZ \qquad (4)$$

where $Z = r/R$ and $B(\zeta)$ is the probability that the nondimensionalized radius of a bubble striking the probe is less than ζ. The density function, $b(\zeta)$, is the derivative of $B(\zeta)$ with respect to ζ.

To obtain a simple expression for void fraction in terms of the bubble size distribution, a few assumptions will be made. The assumptions are not crucial to the analysis but illustrate the procedure of obtaining void fraction for a simple case. For an infinite flow field, velocity and size of the bubble are independent of the bubble position relative to the probe. If the bubbles are noninteracting, bubble velocity should be a function of radius only (Figure 2). The average bubble transit time for a bubble of radius r is then

$$\bar{\theta}(r) = \frac{\bar{\delta}(r)}{U(r)} \qquad (5)$$

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glects consideration of the movement of the solid in the bed which is important in the chemical reactions in many cases.

The reader will find the material and presentation interesting and provocative, but the state of the art appears to be more appropriate for journal articles and symposia than for a book.

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Process Control, Peter Harriott, McGraw-Hill, New York (1964). 374 pp. $13.50.

This book has arrived on the scene just in time to fill a vital need for the professor of chemical process dynamics and control and for his student. It provides an intermediate level text which combines, in an integrated fashion, both automatic control theory and the dynamic response of chemical plant apparatus and its associated control system.

Previously one could choose only from the elementary texts in the field, such as those of N. H. Ceaglske, G. D. Shilling, or T. J. Williams and V. A. Lauher, or from the quite advanced and specialized texts such as Campbell's *Process Dynamics*. Many thus chose one of the many excellent texts of the mechanical or electrical engineering fields at the sacrifice of applications and examples from the chemical field. Therefore Professor Harriott's text should find a welcome reception at our universities and colleges.

This book further justifies its choice as a textbook by a natural breakdown into three progressively more comprehensive and more difficult areas of discussion; by a wide choice of problems at the end of each chapter; by the use of excellent illustrative examples and figures, and by a quite complete author and subject index and table of nomenclature and symbols.

Chapters 1 through 7 of the book can be considered as a review of the basic concepts of automatic control with attention focused on the mathematics of automatic control and on the use and the dynamic response of typical automatic control equipment. While similar to the treatment given in any good text on automatic control, regardless of the field of engineering involved, this section does correlate the theory quite well to the field of chemical engineering through the use of examples taken from the chemical process area.

A second section comprised of Chapters 8 through 13, less 11, and Chapter 16 presents a comprehensive view of several of the specialized areas of the chemical process control field such as control valves and their use, level control, flow control, pH control, theory and use of complex control schemes such as cascade control and feedforward control, and methods of obtaining optimum controller settings.

The third section, Chapters 11, 14, and 15, gives excellent reviews and discussions of the three major areas of chemical process dynamics and control investigation today—heat exchangers, distillation columns, and chemical reactors.

Despite its overall excellence, the book does have some drawbacks which perhaps should be called to the reader's attention for his evaluation of their importance. Foremost of these concerns the problems following each chapter. Many of them might be difficult for the student at the level of knowledge he will presumably have when he encounters them. Several others call for the use of data from the literature or the reference to other independent textbooks, some of which are relatively old. Second of this reviewer's concerns relates to the author's choice of subject matter. It would be a major aid to the student if the subject of temperature control in general could have been treated to the extent of level control, flow control, etc. This is particularly important since such systems tend to have an entirely different level of time constants, etc. The subject of heat exchangers is well covered but is only a part of the temperature control field. Likewise, the subject of analytical instrumentation application and response, which is becoming so vital to chemical process control, is effectively limited to the discussion of pH control in Chapter 16. Perhaps both of these important subjects will be greatly expanded if and when a second edition is prepared.

The textbook *Process Control* is thus one which is highly recommended for any two-semester senior level or beginning graduate student course in chemical process dynamics and control.

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Advances in Heat Transfer—Vol. 1, Edited by Thomas F. Irvine, Jr., and James P. Hartnett, Academic Press, New York (1964). 459 pages. $18.00.

The publishing industry provides a useful service to the scientific community and earns a significant income by marketing collections of review articles which are variously entitled "Progress In . . .," "Annual Reviews of . . .," "Modern Developments In

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