COMMUNICATIONS TO THE EDITOR

Flow Measurements with Ball Meters

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The communication from Shulman and van Wormer (*1*) on this subject appeared while a similar investigation was in progress in this department. Although the correlation equation (4) proposed by these authors is sound, the arguments leading to it are oversimplified. In its equilibrium position the ball comes to rest in contact with the outermost part of the wall of the tube; generally there will be a tangential frictional force acting on the ball at the point of contact.

When the ball is at equilibrium, the moments about its point of contact with the tube wall balance. The tangential component of gravitational force on the ball is ($W \sin \theta$) and acts through the center of the ball. The hydrodynamic force on the ball is f; its resultant will almost certainly be off-center, and so instead of acting through the center of the ball it acts through a point distant X from the wall (Figure 1). Assuming that the radius of curvature of the tube is irrelevant (this is justified by experiment), one finds that the quantities $(f/A_b\rho_f u^2)$ and (X/D_b) are functions of (D_b/D_t) and the Reynolds number only When one equates moments,

$$\frac{wD_b}{2}\cdot\sin\theta = fX = A_b D_b \rho_f u^2 \cdot F(Re,\ D_b/D_t) \qquad (1)$$

This can be reduced to a form identical with Equation (4) of Shulman and van Wormer, but their empirically determined coefficient C has a significance different from that which they assign to it, unless f acts through the center of the ball.

If f is off-center ($X \neq D_b/2$), the ball will spin at high values of θ because the frictional force required to stop it from spinning exceeds the limit imposed by the coefficient of friction, μ. This will occur when

$$\tan\theta \gtrless \left|\frac{\mu}{1 - D_b/2X}\right|, \qquad \left(\theta < \frac{\pi}{2}\right) \qquad (2)$$

Thereafter a different analysis must be applied. There is thus a *limit to the value* of θ to which the correlation equation (4) can be applied, and the limit depends on the coefficient of friction between the ball and the tube, which may in part be determined by the physical properties of the fluid.

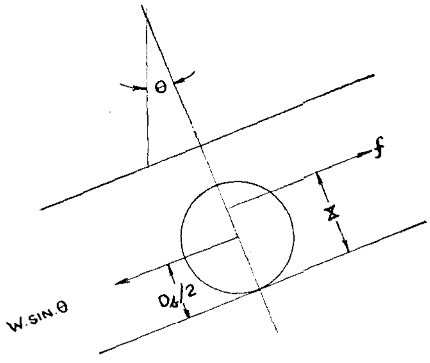

Fig. 1.

The direction of spin will be clockwise (Figure 1) if $X > D_b/2$ and counterclockwise if $X < D_b/2$. If the force f acts through the center of the ball ($X = D_b/2$), the ball will not spin at any value of θ. Observation shows that the ball actually spins clockwise.

LITERATURE CITED

1. Shulman, H. L., and K. A. van Wormer, *A.I.Ch.E. Journal*, 4, 380 (1958).

Reply

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Professor Danckwerts's rigorous treatment of the ball flow meter leads to an equation which is identical with our Equation (4), but it has the advantage of predicting the onset of spinning at high values of θ. We observed this phenomenon and found that at still higher values of θ the ball not only spins but tends to move to and away from the outer wall. When this occurred, the the meter reading θ did not remain constant for a constant flow rate. For this reason, we pointed out, readings were not taken above 60°, and we recommend that the meters be designed conservatively for a midscale reading of 25° to 30°.

The correlation presented applies only when the ball is at rest, that is when it is not spinning. Unfortunately Professor Danckwerts's Equation (2) cannot be used to predict the onset of spinning unless the coefficient of friction is known and a method developed to predict X. Until this information is available, the conservative design method is recommended, and the calculated calibration curve should not be used at values of θ above the observed onset of spinning.

ERRATUM

The caption for Figure 7 in "Heat Transfer to a Liquid Fluidized Bed" by Robert Lemlich and Isidoro Caldas, Jr., appearing on page 377 of the September, 1958, issue, should read: *Effect of flow rate and particle diameter on heat transfer, with methanol as the heating medium.* (*Symbols are identified in Figure 5.*)