LETTERS TO THE EDITORS

PHYSICS

Vortex Shedding from the End of a Tube as a Result of Buoyancy Effects

ONE of the most interesting phenomena observed in fluid flow is that of vortex shedding, the best known example of which is the von Kármán vortex street behind a cylinder or similar obstacles normal to the flowing stream. For such two-dimensional systems, there is considerable information available. However, for axially symmetric systems, there appears to be little more than the recent results of Magarvey and Bishop[1] on spheres. Therefore, a study of vortex shedding in axially symmetric systems was initiated under Battelle sponsorship. In one system, vortices as shown in Fig. 1 were observed in alkaline water (containing amounts of sodium carbonate neutralized by up to 1·24 c.c. nitric acid/litre) discharging from a long vertical tube into a large plenum chamber. The chamber contained slightly acidic water (up to 7·65 c.c. nitric acid/litre). Reynolds numbers down to the experimental limit of above 200 were investigated. The flow pattern was revealed by phenolphthalein added to the inlet water supply.

The Strouhal number, $\nu D/V$, which characterizes in a dimensionless manner the vortex shedding frequency, varied from about 0·3 to 1·4 in the experiments. The Strouhal number was observed to increase with increasing acidity, with increasing alkalinity, and with decreasing Froude number. Reynolds number did not appear to be an important variable. It would appear that the buoyancy effects produced by the small release of heat at the reaction interface causes the vortex shedding in an otherwise stable flow. This supposition is supported by the observation of similar vortex shedding when a charged platinum ring at the tube exit was used to generate hydrogen bubbles, and when the density of the inflow was reduced slightly by use of a small addition of alcohol.

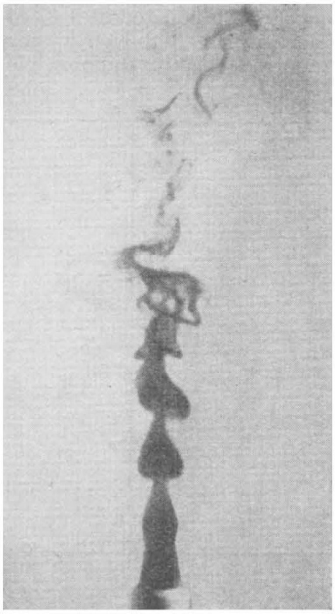

Fig. 1. Vortex formation at discharge of ½ in. diameter tube

One other observation should be reported. Tritton[2] observed, in an investigation of vortex shedding from rods, that at certain combinations of the independent parameters two alternative frequencies rather than one frequency could occur. Sato[3], in work on the instability of two-dimensional jets, made a similar observation. In my system, quite dissimilar to the previous two, we also observed that there were certain combinations of independent variables which led to two alternative frequencies, and, consequently, two alternative Strouhal numbers. In fact, the shifting from one frequency to the other, which often occurred in these instances, led to difficulties in obtaining accurate counts of frequency of vortex formation.

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[1] Magarvey, R. H., and Bishop, Roy L., *The Physics of Fluids*, **4**, 800 (1961).

[2] Tritton, D. J., *J. Fluid Mechanics*, **6**, 547 (1959).

[3] Sato, Hiroshi, *J. Fluid Mechanics*, **7**, 53 (1960).

Distribution of Pressure for Flow of Gas through Porous Media

THE permeability coefficient K for flow of gas through a porous medium is defined by the equation[1]:

$$G = -K\frac{\partial c}{\partial x} \qquad (1)$$

where G is the flowing flux in moles through unit cross-sectional area of the medium in unit time, and $\frac{\partial c}{\partial x}$ is the concentration gradient. When the concentration of the gas is expressed in terms of the pressure p, equation (1) becomes:

$$G = -\frac{K}{RT}\frac{\partial p}{\partial x} \qquad (2)$$

If K is a linear function of pressure:

$$K = a + bp \qquad (3)$$

where a and b are constants, equation (2) may be integrated using the boundary conditions: $p = p_i$ (inlet pressure) at $x = L$; $p = p_0$ (outlet pressure) at $x = 0$; $p = f(x)$ $0 < x < L$ for all time.

The solution is:

$$p^2 + \frac{2a}{b}p - \left(\frac{a}{b} + p_m\right) 2\Delta p\frac{x}{L} - p_0{}^2 - \frac{2a}{b}p_0 = 0 \quad (4)$$

where $\Delta p = p_i - p_0$ = pressure difference, $p_m = (p_i + p_0)/2$ = mean pressure, and L is the length of the medium. This is the general equation for a parabola.

We have measured the pressure at three points inside a split specimen for steady-state flow of nitrogen, carbon dioxide and freon-12 (CF_2Cl_2) through Acheson '*A*' and Morgan '*EY*9' graphites. The experimental pressure distributions approximate to