A METHOD OF MAKING STREAM-LINES MOMENTARILY VISIBLE

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The classical colour-band method of Reynolds is in ordinary circumstances a satisfactory way of examining the stream-lines in flowing water. But, if the motion to be studied is oscillatory or if the flow is in a closed circuit, the method may break down because the concentration of colouring matter in the main stream continually increases as the experiment proceeds. To overcome this difficulty we have devised a means of making a stream-line visible for a short time only, and to test its feasibility Reynolds's pipe experiment was repeated in a modified form.

A glass pipe 5 ft. long and 0·385 in. in internal diameter was set up vertically and supplied with fluid through rubber tubing from a vessel of large cross-section. At the base of the pipe the fluid passed through a glass tap and rubber tubing to measuring vessels. The tap served to start and stop the flow, and a pinch-cock on the rubber tubing to control the velocity. The working fluid was made up with 'phosphorescent' or 'luminous' zinc sulphide, which is a highly purified form submitted to special heat treatment after the addition of 1 part in 10^4 of copper; 2 g. of this powder were shaken up with about 2 l. of tap water. A stirrer was inserted into the supply vessel, but the powder has a very high density, and only a small quantity of the finest particles remained suspended in the water. These were sufficient for the work described. The tests were carried out at night in subdued light with working fluid a fortnight old. (Zinc sulphide is stable towards water if this is free from acid, but the other phosphorescent sulphides of calcium, strontium and barium are hydrolysed slowly by cold water.)

About 50 in. (130 diameters) from the top, black paper was pasted round a 4 in. length of the glass pipe, and in this was cut a vertical slit about $2\frac{3}{4}$ in. long and $\frac{1}{25}$ in. wide. The slit was illuminated by a 500 W high-pressure quartz-mercury vapour lamp (Hanovia). This pattern of lamp provides a very intense and uniform source of light of cylindrical shape, and can be operated in any position. The horizontal beam from the lamp (placed with its axis vertical) passed first through a piece of Messrs Chance's black 'ultra-violet' glass, which cut off all visible radiations while transmitting the intense mercury line at 3650 A., and then through a cylindrical glass vessel filled with water, which

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roughly focussed the rays on the pipe. Thus a narrow vertical section of the liquid along the axis of the pipe was illuminated, and when the liquid was set into slow movement the phosphorescence of the particles could be seen defining the stream-line down the pipe.

After the supply vessel had been filled and the pinch-cock set, the tap was opened; and while one observer measured the flow, the other examined the stream-line in a region about 4 in. below the bottom of the slit. At a Reynolds number R of 1650 (formed with the pipe diameter and not with its radius), the stream-line was seen to be steady and sharply defined. Repetition of the test at higher velocities showed that at 1700 and 1770 the stream-line was occasionally disturbed by gusts of turbulence; at 1780 and 1940 it disappeared irregularly for about half the period of observation, being replaced by light of low intensity which filled the whole pipe; at 2130 the flow was mostly turbulent; at 2300 (corresponding to a mean velocity of almost exactly 1 ft./sec.) only a rare stream-line could be seen, while at 2500 no trace of it was visible, the entire pipe being continuously and uniformly illuminated. In brief, the familiar sequence of events observed in Reynolds's experiment was faithfully repeated. In the calculation of the above values of R the working fluid was taken to have the same kinematic viscosity as water. This assumption is reasonable in view of the very small quantity of powder used, but evidently it could not be satisfactorily checked by measurements with the usual capillary type of viscometer.

The experiments were then repeated with the lamp and slit raised to a level 2 ft. from the top of the tube, and it was found that the stream-line could be seen in the remaining 3 ft. of the pipe. Thus the decay of luminosity of this suspension would be too slow for many purposes. The commercial substance used had been prepared to bring out the longest possible phosphorescence period. The half-life of zinc sulphide phosphors, however, can be varied from minutes to fractions of a second by alterations in the mode of preparation; either by using greater proportions of copper, by using manganese as activator, or by the addition of certain impurities. If other phosphors also stable to water were used, such as zinc silicate (containing manganese) or calcium tungstate, the period could be brought down to 10^{-5} sec. or even less, but these materials need excitation by light of wave-length 2537 A., so that the apparatus described would require modification by the use of a mercury lamp producing this radiation and a fused silica tube instead of glass for the flowing liquid. It seems clear that suspensions can be made suitable for a wide range of experiments on pipe and two-dimensional flow.

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