*J. Fluid Mech.* (1966), *vol.* 26, *part* 3, *pp.* 573–575
*Printed in Great Britain*



# A technique for the precise measurement of small fluid velocities

By D. JAMES BAKER
Pierce Hall, Harvard University

(Received 24 March 1966)

A technique for the quantitative measurement of fluid velocities in the range 0–5 cm/sec is described. The technique uses a pH indicator, is applicable in aqueous solutions and permits visualization and measurement of three-dimensional flow fields.

---

This note presents a technique useful for the quantitative measurement of fluid velocities in the range 0–5 cm/sec. The technique uses a pH indicator, and is applicable in aqueous solutions. It permits visualization and measurement of three-dimensional flow fields. In brief, the method consists of placing two electrodes in a solution of thymol blue (thymolsulphonephthalein) which has been titrated to the end-point. A d.c. voltage is impressed between the electrodes, one (the positive) of which is a fine wire placed in the region of measurement. The resulting current flow induces a proton transfer reaction near the wire (Gold 1956; Noller 1957); as a consequence, the colour of the solution there changes, because the colour of the basic form of thymol blue (blue) is different from the acidic form (yellow). If the voltage is pulsed, a small cylinder of coloured solution will form around the wire, then move away from the wire with the fluid, forming a neutrally buoyant marker in the Lagrangian sense. A network of wires placed in the fluid and pulsed in this way permits visualization and measurement of the three-dimensional flow field.

The working fluid is prepared by adding enough thymol blue to 1000 ml. of distilled water to produce a 0·01 % by weight solution. This solution is titrated to the end-point (pH $\simeq$ 8·0) by adding 1 N-NaOH drop ($\sim$ 0·25 c.c.) by drop until it turns deep blue, then adding one drop 1 N-HCl to cause the solution to be on the acid (or yellow) side of the end-point.

Two types of electrode configuration prove convenient: a network of fine (0·002 in. or smaller diameter) platinum wires† may serve as one electrode, and a copper plate placed away from the region of interest as the other, or two electrically independent networks of the fine wires may be used as the two electrodes. A partially insulated wire allows marking at discrete points; a pair of wires at right angles provides a measurement of two components of velocity simultaneously. Figure 1 indicates how two grids of wires at right angles could be used to visualize three-dimensional flow. The proximity of the positive and negative electrodes in the latter method provides a more successful arrangement

† Available from Sigmund Cohn, Inc., Mt Vernon, New York.

for a large network. Voltages must be kept low in order to avoid the production of bubbles at the wire; a typical voltage for an electrode spacing of 0·5 cm is 5 V d.c. with a current flow of about 5 mA.

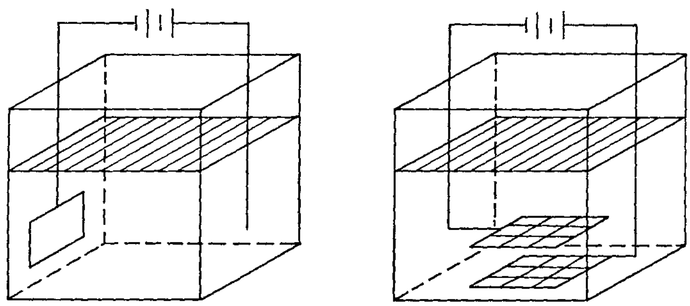

FIGURE 1. Possible electrode configurations: (*a*) large electrode, and a single fine wire to be placed in region of measurement; (*b*) a network of fine wires for three-dimensional visualization and measurement.

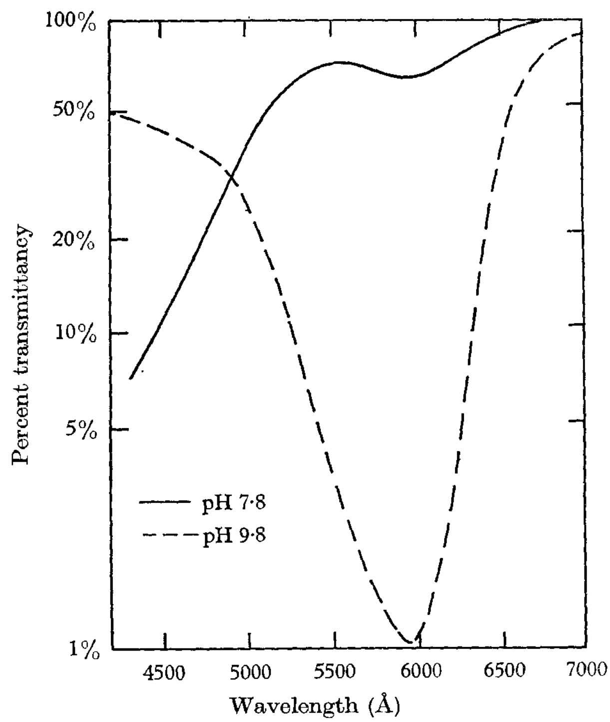


FIGURE 3. The effect of changing pH on a 0·008 % solution of thymol blue. (Data of Mellen & Ferner (1931).) ——, pH 7·8; – – –, pH 9·8.

Since the thymol blue molecule remains an ion in solution, density-difference effects (or centrifugal effects in rotating systems) are absent. This method is thus superior to the starch–iodine technique (Kolin 1953), where the greater density of the precipitated blue complex precludes the measurement of small velocities. The measurement of slow velocities in thermal convection experiments, where density gradients are present, is also facilitated by this technique, as the coloured fluid will have the local density. Figure 2 (plate 1) is a photograph of evaporation-driven thermal convection cells made visible by the vertical motion of a line of the coloured fluid. The upper wire is the positive electrode; the lower is the negative.

The change in absorption as a function of wavelength as the pH of a 0·008 % solution of thymol blue is changed is shown in figure 3. (These data were presented by Mellen & Ferner (1931) in a useful article which presents similar data for other indicators.) As light in the yellow region of the spectrum is most strongly absorbed by the basic (blue) solution, an improvement in photographic contrast is achieved by the use of yellow or orange filters, or by illumination with light in the 5800–6100 Ångström region. A sodium arc lamp is ideal for the latter.

Fluid velocities as low as 0·01 cm/sec can be conveniently measured with this technique; flows faster than about 5 cm/sec sweep the coloured fluid from the wire more rapidly than it can be formed in visible amounts. The closer the solution has been titrated to the end-point, the longer the coloured region will remain visible as it floats away from the wire. Eventually, however, the lower pH of the fluid far from the wire will cause the colour to disappear. The solution may thus be used indefinitely.

The author would like to thank Professor A. R. Robinson for his valuable criticism and interest in this work and Mr Bruce Ganem for assistance in laboratory tests. This research was supported by the Office of Naval Research under NONR Grant 1866(51) 44-709-7313-2 to Harvard University.

## REFERENCES

Gold, V. 1956 *pH Measurements*. New York: Wiley & Son.

Kolin, A. 1953 *Am. J. Phys.* **21**, 619.

Mellen, M. G. & Ferner, G. W. 1931 *J. Phys. Chem.* **35**, 1025.

Noller, C. R. 1957 *Chemistry of Organic Compounds*, p. 699. Philadelphia: W. B. Saunders.

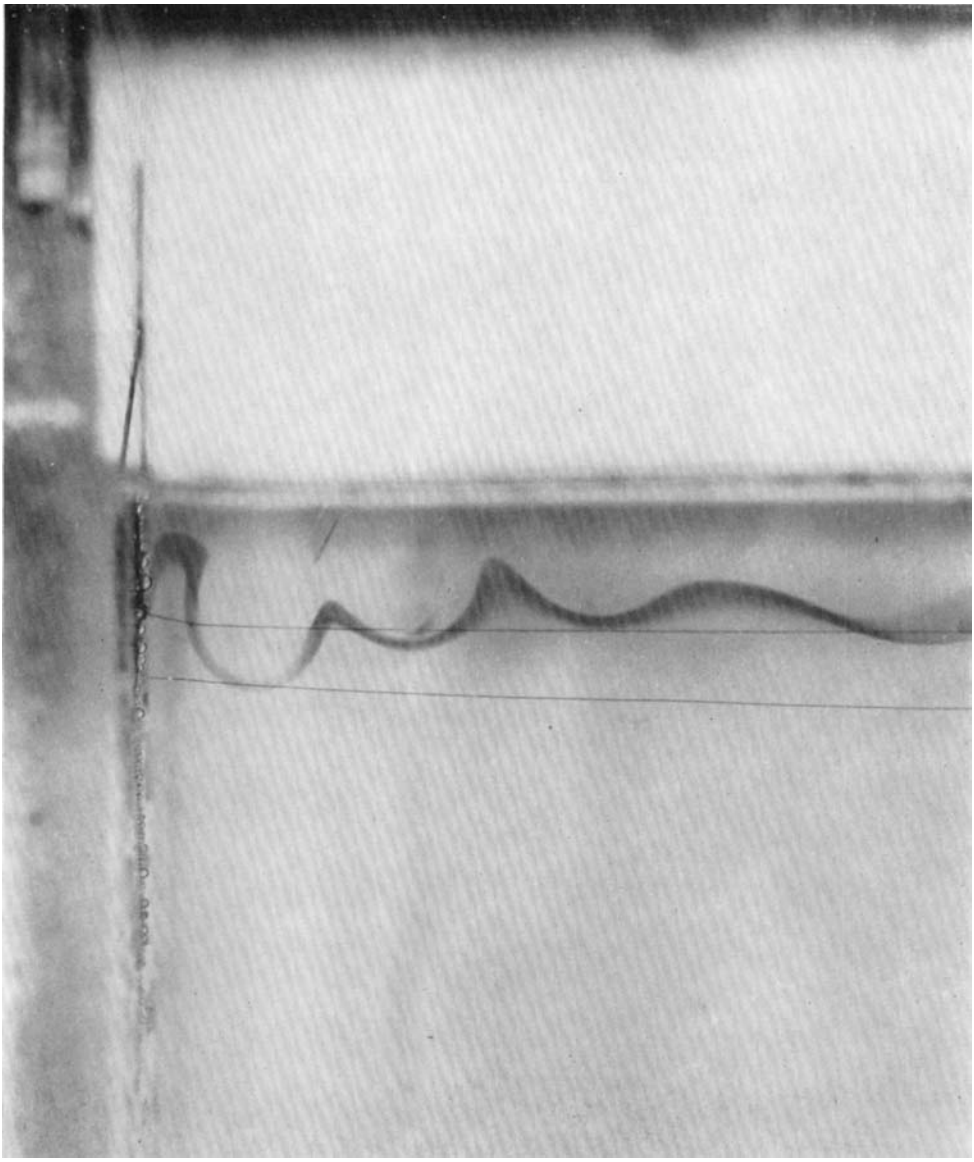

FIGURE 2. Vertical motion of fluid (evaporation-driven thermal convection) made visible by present technique. Upper wire is positive electrode; lower wire is negative.