

Simple, Efficient Micro Mixing Device

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Thorough mixing of two streams of solution, A and B (Figure 1), is important in many kinetic measurements and in continuous assay procedures. Such mixing can be easily accomplished with high velocity (jet) streams, *i.e.*, those having velocities of the order of 100 cm/sec or more, where turbulence is readily achieved, as shown by Hartridge and Roughton (1). For low velocity streams, *i.e.*, those moving *ca.* 10 cm/sec or less, the combined solution C is frequently passed through a mixer M consisting of a coil of tubing. However, it is necessary that the time interval for flow of successive portions of solution from the point of mixing, Y, to the point of observation, O, be constant. To ensure that this constancy is not destroyed during the mixing process, the stream is frequently segmented by bubbles of air prior to entering M.

The mixing device described here required neither a mixing coil nor air, nor the peristaltic pump frequently used in such work. The mixing chamber consists simply of a Teflon (DuPont)-coated bar magnet about 2 mm in diameter \times 7 mm long enclosed in a glass tube *ca.* 4-mm i.d. (Figure 2). The bar is restricted to a section of tubing about 10 mm long. This can be accomplished by reducing the diameter of the glass tubing at one end, and inserting the bar magnet through the other end. An 8-mm length of tightly fitting plastic tubing is then inserted into the wider end of the tubing, to keep the magnet in place. The wider end of the glass tubing cannot be heated to reduce its diameter since this might melt the Teflon coating on the stirring bar.

When the mixing chamber is placed on a magnetic stirrer, the primary motion obtained is rotation of the bar about its cylindrical axis. In addition, the bar wobbles, and there is some movement to and fro in the direction of the axis of the tubing, both of which enhance the stirring action. End-over-end rotation about a vertical axis, the usual motion of a stirring bar, is, of course, impossible, since the i.d. of the glass tubing is less than the length of the bar. The mixing action is easily controlled by adjusting the rate of rotation of the driving magnet in the magnetic stirrer.

The volume of liquid in the central 10-mm section of the mixer is *ca.* 0.1 ml. There is thus little opportunity for unwanted mixing of portions of liquid of different age (age 0 being the instant of combination at point Y, Figure 1).

The efficiency of the mixing device was tested as follows. Two Y tubes made from 2.5 mm (internal diameter)

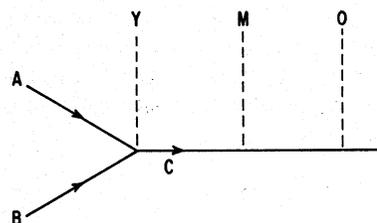


Figure 1. Arrangement for continuous assay procedures

Y is the point of confluence of the two streams, A and B, which contain the reactants. The resultant stream C flows through a mixer M before passing the point of observation O

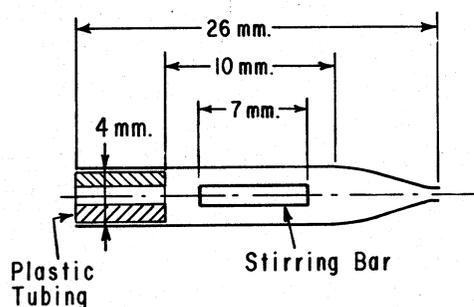


Figure 2. Micro mixing device. The direction of liquid flow is from right to left

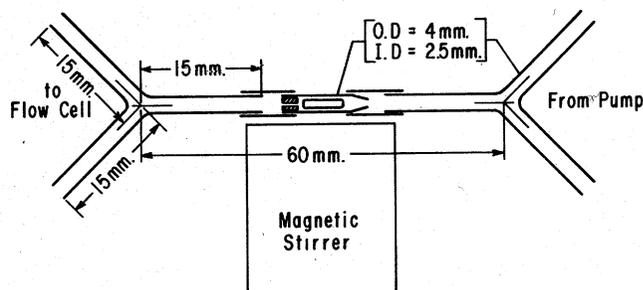


Figure 3. Experimental arrangement for testing the efficiency of mixing

Pyrex tubing were jointed either directly, by a piece of Tygon tubing, or via the mixing device, as shown (Figure 3). The arms of the Y tubes were *ca.* 1.5 cm in length. The Y tubes were positioned in a common vertical plane, with the connecting tube horizontal. When a mixer was used, a magnetic stirrer was placed below it. A solution of 0.1M NaOH containing sufficient phenolphthalein to give

(1) H. Hartridge and E. J. W. Roughton, *Proc. Roy. Soc., Ser. A*, **104**, 376 (1923).

Table I. Efficiency of Mixing with and without the Mixer

Flow rate, cm/sec	Efficiency, %	
	Without mixer	With mixer
0.02	35	99.6
0.41	6.3	100
1.31	4.0	99.9

an absorbance of 1-2 at 550 nm was introduced into the upper inlet arm at a volume flow rate of 0.001 to 0.065 cm³/sec, yielding a linear flow rate of 0.02 to 1.3 cm/sec. Into the lower inlet arm, a solution of 20% sucrose in 0.1M NaOH was introduced at the same flow rate. When not mixed, a clear line of demarcation could be seen, in the tube joining the two Y's, between the upper, light, colored solution and the lower, dense, colorless solution. The outlet arms were connected to two flow cells in a Gilford Model 2000 Multiple Sample Absorbance Recorder. Absorbance measurements were made at a wavelength of 550 nm.

Complete mixing corresponds to equality of the concentrations of dye in the two outlet arms. The efficiency of mixing, E , is given by the equation

$$E = 2A_2 / (A_1 + A_2) \quad (1)$$

this being the ratio of the concentration (absorbance), A_2 of dye in the lower outlet arm to the concentration, $\frac{1}{2}(A_1 + A_2)$, which would be obtained if mixing were perfect. The observed absorbance values were used as concentrations, proportionality being assumed.

Table I gives the efficiency for each of three flow rates, with and without the mixing device. Over the range in linear flow velocity of 0.02 to 1.3 cm/sec, the efficiency of mixing in the presence of the mixer is better than 99.5%.

The mixer simplifies substantially the apparatus required for continuous assay. Several mixers can be placed on one magnetic stirrer and all will perform in the same manner.