RESEARCH NOTE

The Effect of Hydrogen Bubbles on the Thymol Blue Velocity Measurement Technique

A. Bejan† and R. B. Yewell†

This note describes an experimental study of the damaging effect of hydrogen bubbles on the effectiveness of the thymol blue velocity measurement method. Specifically, we document the effect of flow velocity, cathode voltage, and cathode diameter on bubble formation and the quality of the thymol blue pattern. The time of bubble damage, i.e., the interval preceding the destruction of the blue pattern, was measured and reported as a function of flow velocity, cathode voltage, and cathode diameter.

INTRODUCTION

In a 1966 note, Baker (**1**) described the thymol blue (pH indicator) technique for flow visualization. This experimental method has since been adopted, having been used successfully in a number of investigations of slow flows such as buoyancy-driven thermal convection (see, for example, Sparrow *et al.* (**2**) and Eichhorn *et al.* (**3**)). Imberger (**4**) extended the usefulness of the technique to the measurement of local velocities in a flow field. The same velocity measurement technique was used in a recent study of natural circulation in horizontal ducts (**5**).

Perhaps one of the greatest advantages of the thymol blue technique is the fact that the convective medium is marked chemically without the introduction (injection) of a foreign substance. This makes it ideal for the study of natural convection where the weak density gradients driving the flow may be adversely affected by the dye injected to mark the flow. The thymol blue technique consists of using a pH-neutral (tea coloured) water/thymol blue solution as the convective medium. In this medium, at points where the flow has to be visualized or the local velocity has to be measured, one inserts a negatively charged electrode (cathode) positioned sufficiently far from a positively charged surface as anode. The colour of the fluid sweeping past the cathode turns deep blue (basic) due to the hydrogen released near the cathode through electrolysis. (Baker's paper (**1**) erroneously suggests that the blue streak is generated by the anode.)

Although the thymol blue technique is known to work satisfactorily in small-scale experiments (**2**, **3**) the technique has clear limitations when used in large systems. The difficulty stems from the fact that in a large experiment, due to the tea-coloured thymol blue solution, the cathode–observer distance is optically too 'thick'. Consequently, what may qualify as successful visualization in a water experiment of size comparable to that of the cathode, is not very useful when in a larger experiment the observe cannot 'see' the needed contrast in the blue patterns.

Received 13 May 1980 and accepted for publication on 19 June 1980.
† Department of Mechanical Engineering, University of Colorado, Boulder, CO 80309, USA.

Experience shows that measures aimed at enhancing the visibility of the thymol blue pattern often increase the formation of hydrogen bubbles on and near the cathode. Once formed and released, the bubbles rise in the fluid, disturbing the deep blue pattern needed for flow visualization and measurements. The objective of the present note is to illustrate the relationship between thymol blue visualization and hydrogen bubble formation. This relationship is not documented in the literature. We explored this relationship systematically, on the basis of a special experiment described below.

EXPERIMENT

We designed the experiment to simulate a uniform horizontal flow, by mounting a plexiglass tank filled with thymol blue/distilled water solution on the moving table of a quiet milling machine. The rectangular tank was 11·6 cm high, 49·4 cm long, and 2·4 cm wide. From the chuck (stationary) we suspended a plexiglass yoke supporting a vertical wire serving as cathode. The anode was immersed in the water against one end of the tank. Parts of the experimental set-up are visible in the close-up photographs reproduced in Figs 1–5. The cathode was coated intermittently with typist's correction fluid in order to generate a blue streak pattern instead of a uniform sheet. The streaks seen in Figs 1–5 do not all have the same length due to a weak clockwise circulation induced in the tank by heat received from the light source.

In the experiment we varied three parameters independently: (1) The flow velocity U, by changing the table speed of translation; (2) The voltage V between anode and cathode; (3) The cathode diameter D (the cathode wires were easily interchanged due to a snap-in mounting feature in the yoke). In an actual application of the thymol blue method, the flow velocity U and its range are fixed by the flow. However, the remaining parameters V and D can be adjusted in order to improve the quality of the visualization experiment. Below we discuss a number of effects associated with changing U, V, and D.

STRIATIONS

The first evidence of hydrogen bubble formation is the striations imposed on the blue streaks swept behind the

0142/727X/80/1200-0201$02.00 © MEP Ltd 1980

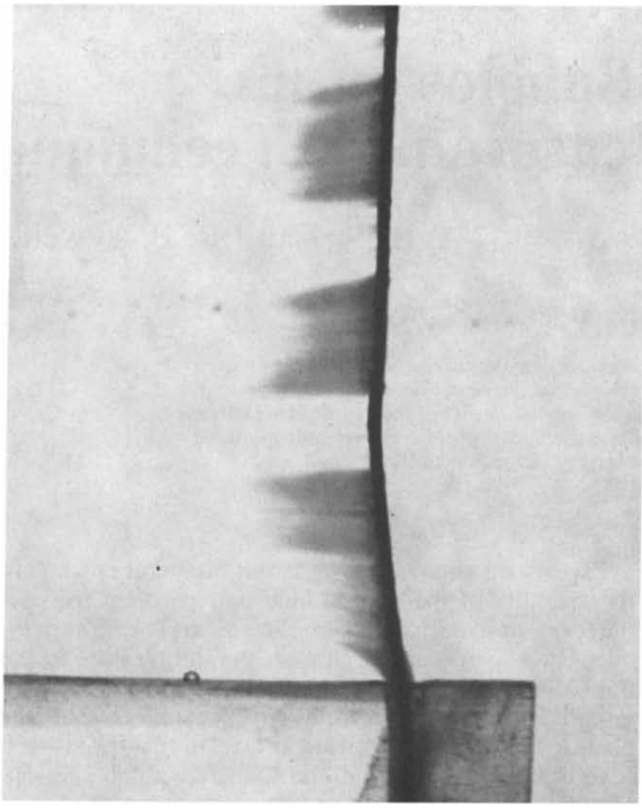

Fig. 1. Photograph taken after 11·6 s, showing striations caused by stationary bubbles; $U = 0{\cdot}9$ mm/s, $V = 6$ V, $D = 0{\cdot}51$ mm

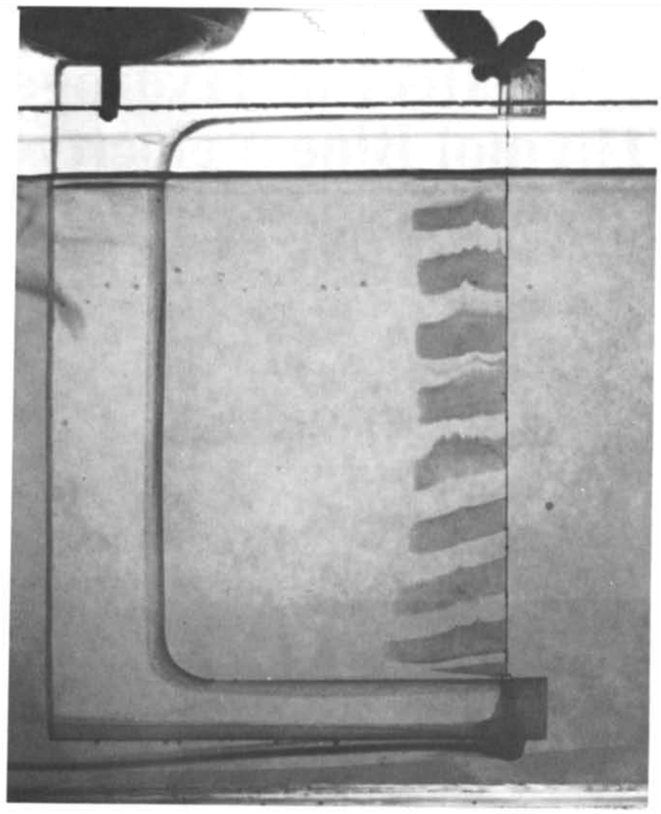

Fig. 2. Blue streak pattern after 7·1 s; $U = 3{\cdot}18$ mm/s, $V = 15$ V, $D = 0{\cdot}1$ mm

cathode. These striations are especially visible in Fig. 3. In a recent paper, Vehanayagam *et al.* (**6**) published a photograph showing striations in the blue sheet rising from a heated horizontal cylinder. These authors, however, were not able to explain the origin of these striations.

Figure 1 presents an enlarged view of the bottom portion of the cathode, showing a string of small bubbles lined up on the trailing side of the wire. The bubble diameter is considerably smaller than the wire diameter. The striations are a reflection of the fact that the wake flow immediately behind the wire is three-dimensional; the marked fluid sweeps around the wire and enters the wake through the voids created between adjacent bubbles.

EFFECT OF CATHODE VOLTAGE

Figure 2 shows the streak pattern generated with an anode–cathode voltage of 15 V. We see that after 7·1 seconds or less the pattern deteriorates sharply due to the buoyancy of the hydrogen bubbles. In taking this photograph we noted that the bubbles swept into the blue wake are very small in diameter and flow horizontally with the stream. In the wake, neighbouring bubbles coalesce. After exceeding a critical size, the aggregate bubbles take off vertically, distorting the upper edge of the blue streak. This distortion can be delayed at least for some time by decreasing the voltage. In Fig. 3 we show the pattern obtained after 15·6 s with a voltage of 7 V. The bubble formation is not eliminated, but its effect on the quality of the streak is considerably less pronounced. It should also be kept in mind that

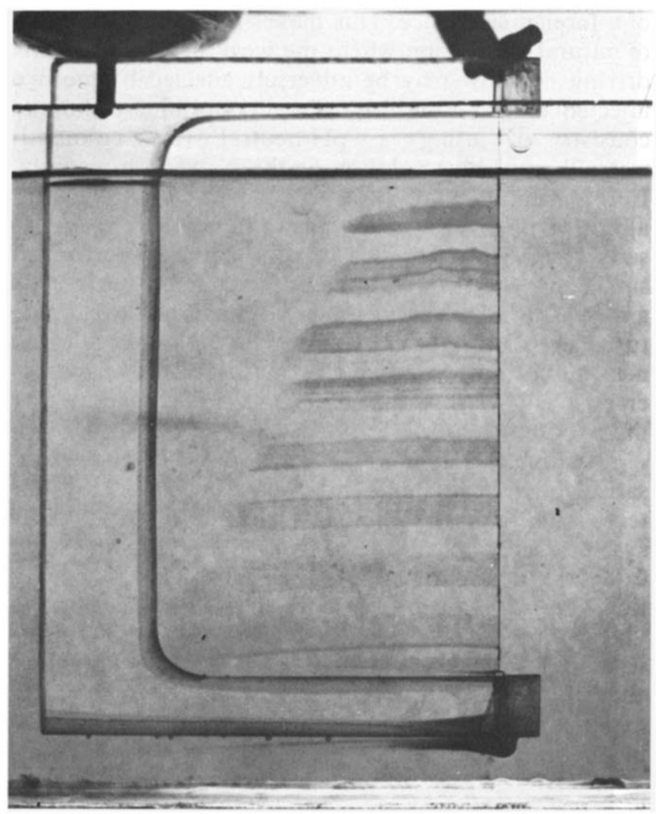

Fig. 3. Blue streak pattern after 15·6 s; $U = 3{\cdot}18$ mm/s, $V = 7$ V, $D = 0{\cdot}1$ mm

while decreasing the voltage to avoid hydrogen bubbles, one trades away some of the sharpness (visibility) of the blue streak.

EFFECT OF WIRE DIAMETER

When the cathode diameter increases, the cathode-water contact area increases and so does the rate at which blue is generated in the wake. Comparing Fig. 4 with Fig. 2 we see that, everything else being the same, the visibility of the pattern is improved when the cathode diameter increases. One negative aspect of a larger cathode diameter is that the wake region is longer, therefore one has to generate longer streaks for meaningful local velocity measurements (4, 5).

EFFECT OF FLOW VELOCITY

In an actual visualization experiment the flow velocity may vary along the cathode. Comparing Figs 4 and 5 we show the effect of decreasing the flow velocity from 3.18 mm/s to 1.91 mm/s. When the velocity is low, the hydrogen bubbles form earlier and their effect on the blue streak is more damaging. Fast flows, on the other hand, effectively cleanse the cathode of bubbles and prevent the bubbles from coalescing and rising.

TIME OF BUBBLE DAMAGE

We ran a series of tests to determine the effects of U, V, and D on the time interval (t) required for the formation of hydrogen bubbles and the subsequent destruction of the blue streak pattern. The results are summarized in the three-frame drawing of Fig. 6 where the cathode diameter D increases from frame to frame, downward. Each frame has the anode-cathode voltage V on the

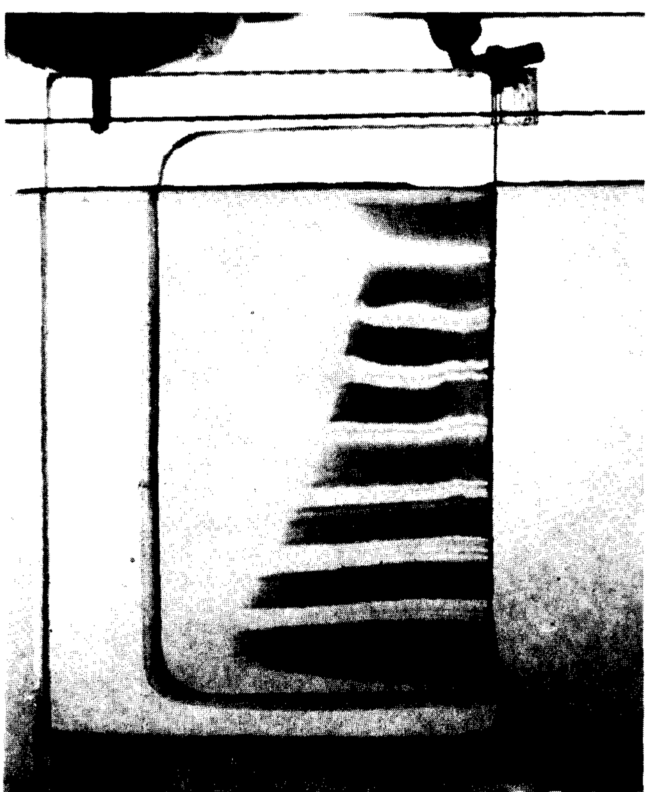

Fig. 4. Blue streak pattern after 14.2 s; U = 3.18 mm/s, V = 15 V, D = 0·51 mm

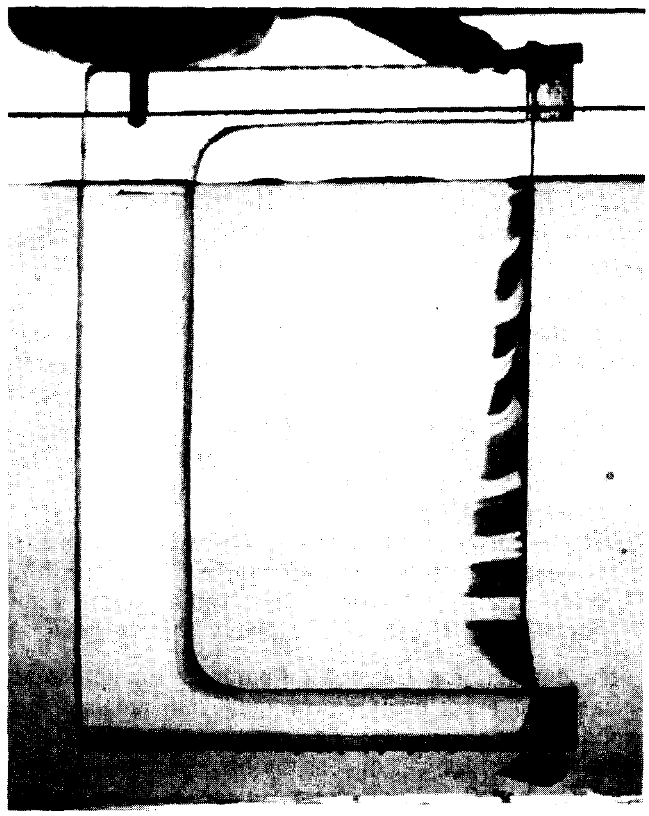

Fig. 5. Blue streak pattern after 8·5 s; U = 1·91 mm/s, V = 15 V, D = 0·51 mm

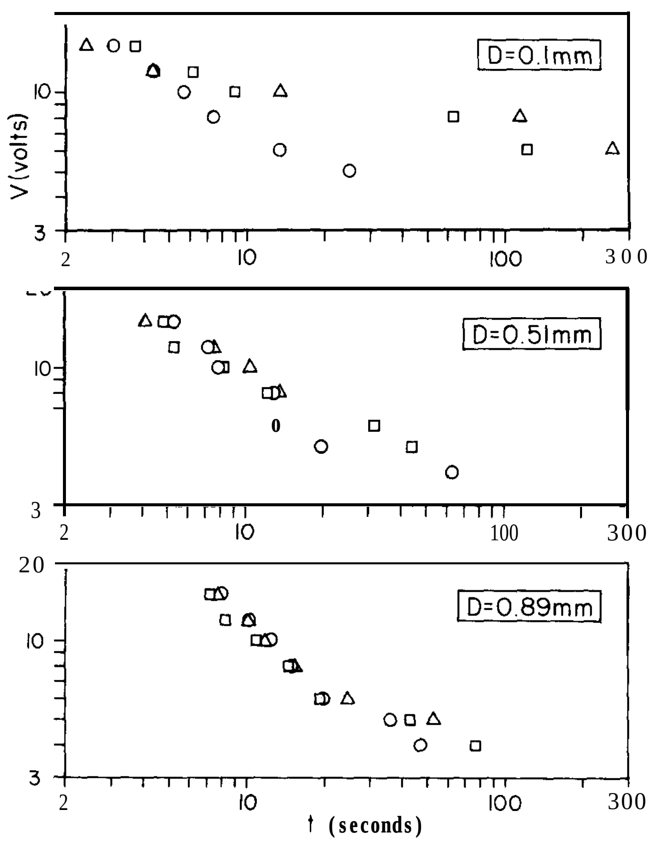

Fig. 6. Time of bubble damage as a function of cathode voltage V, cathode diameter D and flow velocity U (Δ = 3.23 mm/s, □ = 1·08 mm/s, ○ = 0·24 mm/s)

ordinate and the 'damage' time t on the abscissa. The points shown in Fig. 6 correspond to three flow velocities U.

The damage time t is the interval between switching on the current to a bubble-free wire and the appearance of the first upward spikes on the blue streaks. The fact that the flow velocity U was not truly constant along the cathode is responsible for the scatter in the data presented in Fig. 6. Despite the scatter, we can still draw the following conclusions:

(1) In the velocity and voltage ranges considered, the damage time is affected most strongly by changes in voltage. The flow velocity has a relatively weaker effect. This conclusion is important in velocity measurement applications where the velocity distribution may vary appreciably along the cathode (as in References **4**, **5**).
(2) If the voltage and the velocity are fixed, the damage is delayed if the cathode is thinner (as in the top frame of Fig. 6). Unfortunately, a thin cathode generates a blue streak with relatively poor contrast.

The damage time t is a useful parameter in an actual visualization experiment. Knowing the damage time, the experimenter can turn the voltage off before the hydrogen bubbles can distort the blue pattern. During the 'off' time the cathode region is depleted of hydrogen by fresh fluid so that after some time the voltage can be turned on again for a time shorter than t. It has been our experience that 'on' and 'off' periods of equal length yield reasonably good results, despite the fact that the darkness of each streak varies periodically. We conclude that *intermittent operation* will overcome the damage caused by the formation of hydrogen bubbles.

This research was carried out under the auspices of National Science Foundation Grant No. ENG 78-20957. We wish to acknowledge a number of valuable comments received from Dr Dale Perry, Lawrence Berkeley Laboratory, during the course of this study. We thank Mr. Karl Rupp and Mr. Richard Cowgill for constructing the apparatus and its instrumentation.

REFERENCES

(1) BAKER, D. J. 'A Technique for the Precise Measurement of Small Fluid Velocities,' *J. Fluid Mech.* 1966, **26**, 573.
(2) SPARROW, E. M., HUSAR, R. B., and GOLDSTEIN, R. J. 'Observations and Other Characteristics of Thermals', *J. Fluid Mech.* 1969, **41**, 793.
(3) EICHHORN, R., LIENHARD, J. H., and CHEN, C. C. 'Natural Convection from Isothermal Spheres and Cylinders Immersed in a Stratified Fluid', Paper NC 1.3, *Proc. Vth Int. Heat Transfer Conf.*, Tokyo, 1974
(4) IMBERGER, J. 'Natural Convection in a Shallow Cavity with Differentially Heated End-Walls. Part 3. Experimental Results', *J. Fluid Mech.* 1974, **65**, 247
(5) KIMURA, S. and BEJAN, A. 'Experimental Study of Natural Convection in a Horizontal Cylinder with Different End Temperatures', *Int. J. Heat Mass Transfer*, 1980, **23**, 1117–1126
(6) VEDHANAYAGAM, M., LIENHARD, J. H., and EICHHORN, R. 'Method for Visualizing High Prandtl Number Heat Convection', *J. Heat Transfer*, 1979, **101**, 571