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HYDROGEN-BUBBLE FLOW-VISUALIZATION: LIMITATIONS IN DRAG REDUCING POLYMER SOLUTIONS

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ABSTRACT

Hydrogen-bubble flow-visualization experiments have demonstrated that distinct bubble pulses cannot be obtained in water solutions of polyacrylamide of high enough molecular weight to cause drag reduction at low shear stresses. Good bubble pulses were obtained in poly(ethylene oxide) and in surfactant solutions, but they did not cause drag reduction at feasible shear stresses.

INTRODUCTION

The original objectives of this study were to obtain detailed instantaneous normal and spanwise velocity profiles in the near wall region of a drag reducing turbulent boundary layer. This program was motivated by the results of a previous study (1) in which the presence of 140 ppm of poly(ethylene oxide) ($MW \sim 7 \times 10^6$) produced dramatic changes in the near-wall turbulent structure (visualized by dye injection). A pulsed hydrogen-bubble experimental program was subsequently established that was able to produce satisfactory results in water flows. It was observed, however, that the hydrogen-bubble flow-visualization technique was severely limited in the drag-reducing polymer solutions. The experimental difficulty and its origin are described in this paper.

Figures 1 and 2 show near-wall low-speed streaks of a fully developed turbulent channel flow visualized by dye carefully inserted at the wall. The flow is from left to right and the

scale at the right represents 10 divisions to the inch. These photographs represent equal volume flow rates before and after the addition of 140 ppm poly(ethylene oxide) (see reference (1) for a complete discussion). It is clear that the presence of the drag-reducing polymer has significantly altered the flow structure of the near-wall region. Unfortunately, this dye flow visualization technique provides only a qualitative picture of what is happening. In order to gain a more quantitative insight into this phenomenon one needs to use a technique such as the pulsed hydrogen-bubble scheme described by Kline, et al. (2).

RESULTS

Figure 3 shows instantaneous velocity profiles during the formation of a low speed streak. Again, the flow is from left to right. Both rotational and axisymmetric spanwise strain rates may be estimated from a series of such velocity profiles. This velocity profile was obtained in a turbulent boundary layer developed over a flat plate aligned in the flow direction of the Naval Undersea Center's 12-inch-diameter, open-jet, vertical water tunnel. A 0.005-inch-diameter platinum wire was aligned spanwise to the flow and positioned on the surface of the wall. 100 VDC was supplied to the wire from a DC power supply and the pulsing was controlled by a General Radio Model 1340 pulse generator. The pulses were 1 ms in duration with

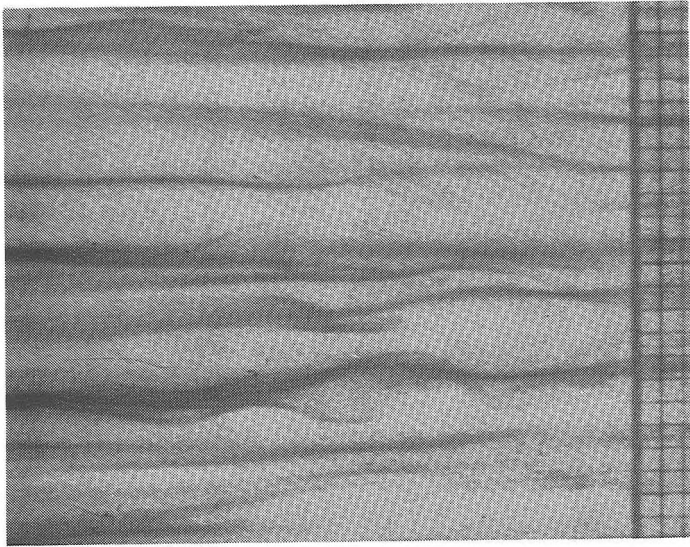


Figure 1. Dye visualized low speed streaks. Water only, $U = 0.43$ ft/sec.

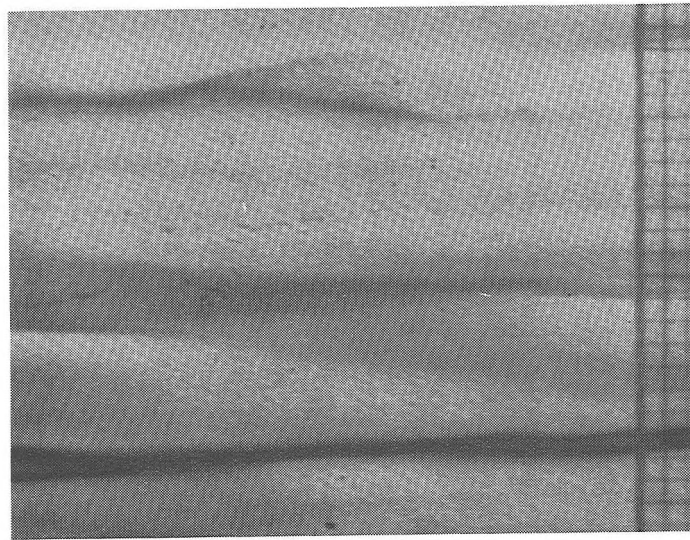


Figure 2. Dye visualized low speed streaks. 139 ppm Polyox, $U = 0.43$ ft/sec, 16% drag reduction.

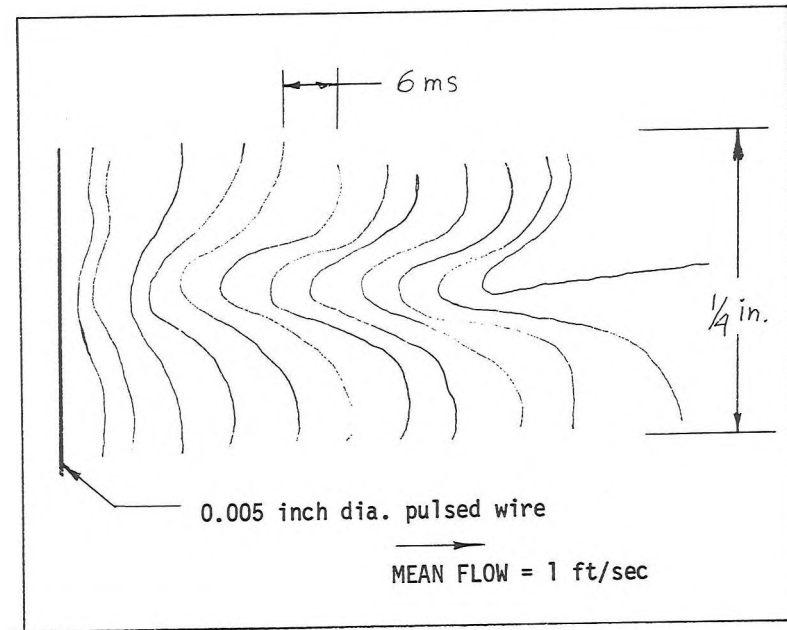


Figure 3. Spanwise velocity profile of a developing low speed streak.

a 6 ms period. The free stream velocity was 1 ft/sec and the wire was 15 inches back from the plate's leading edge. It is clear from Figures 1 and 2 that the polymers significantly alter the strain rates visualized in Figure 3.

The same techniques used to obtain the instantaneous velocity profiles shown in Figure 3 failed to produce any usable data in a polymer filled boundary layer. A 1500 ppm Magnafloc 905N (a high molecular weight polyacrylamide^{*}) solution was injected into the flat plate's boundary layer upstream of the hydrogen bubble wire locations. The resultant polymer concentration in the boundary layer was approximately 50 ppm. A pulsed wire, normal to both the flow direction and the surface of the plate, showed a sheath of gas on the platinum wire in the polymer filled boundary layer while outside of the boundary layer rows of hydrogen gas bubbles produced good velocity profiles. A small scale experiment was subsequently designed in order to determine if this failure was due to equipment malfunction or to a natural phenomenon peculiar to these polymer solutions.

Five different experiments were performed using solutions of (a) tap water; (b) 50 ppm AP 273 (a high molecular weight polyacrylamide^{**}) in tap water; (c) 50 ppm AP 273 and 150 ppm sodium sulfate in filtered, deionized water; (d) 50 ppm Polyox Coagulant^{***}, a poly(ethylene oxide) (MW~4.5 x 10⁶), in tap water, and (e) 60 ppm Tergitol NP-40^{***}, a nonionic surfactant, in tap water. Photographs were taken of a 0.005-inch diameter platinum wire horizontally suspended in a one liter glass beaker filled with the solutions. The same electronics that were used for the water tunnel experiments were used for these tests. The pulsing rates were greatly decreased (0.15 sec pulses with a period of 2.3 sec) since only the buoyant force caused the bubbles to rise off

the wire. Since the buoyant force was the only motive force acting on the bubbles in this flow situation, the pulsed time lines did not remain coherent. All of the bubbles that were shed from the wire were not the same size and thus not all of the bubbles rose at exactly the same rate.

Figure 4 shows a row of hydrogen bubbles leaving the platinum wire in a tap water solution. Notice that the leading edge (composed of the larger bubbles) is very bright and distinct. Also note that the wire has a fairly dull appearance. Figure 5 shows the hydrogen bubbles leaving the platinum wire in a 50 ppm polyacrylamide and tap water solution. There were no pulses observable at any time in this solution. Notice that large bubbles are formed on the wire and that the wire itself had a bright appearance indicating that there was a sheath of gas formed around the wire. In addition, conglomerates of gas bubbles were observed attached to each other and rising together. When this same experiment was performed in the filtered deionized polyacrylamide solution, a slight pulsing was observed but the bubble quality was still not as good as that found in water only. The test was repeated again in the 50 ppm Polyox and 60 ppm Tergitol NP-40 solutions. In these cases the bubble quality was as good as in tap water. Thus, the failure to produce coherent hydrogen bubble pulse lines is due neither to alteration of the hydrodynamics nor to reduction of surface tension by polymer molecules but must be peculiar to the polyacrylamide solutions.

CONCLUSIONS

An important characteristic of polyacrylamide polymers is that they are used commercially as flocculents. All of the data point to the conclusion that the polyacrylamide polymers are, in some manner, causing aggregation of the hydrogen bubbles. Since the poly(ethylene oxide) solution showed no effect, it could be used for these flow visualization experiments. Unfortunately, the presently available poly(ethylene oxide) polymers

* American Cyanamid Corp.

** Dow Chemical Company

*** Union Carbide Corp.

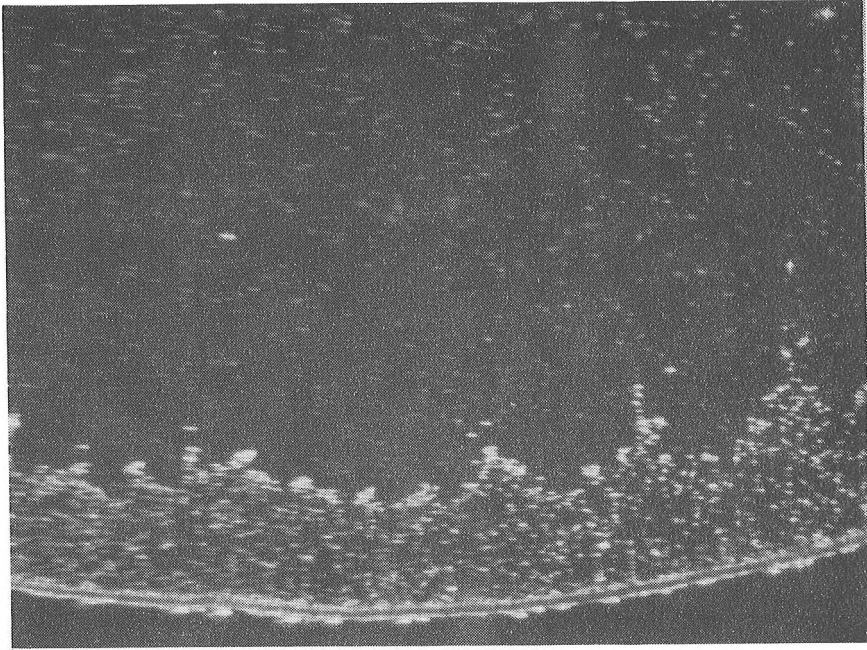


Figure 4. Pulsed platinum wire in water only.

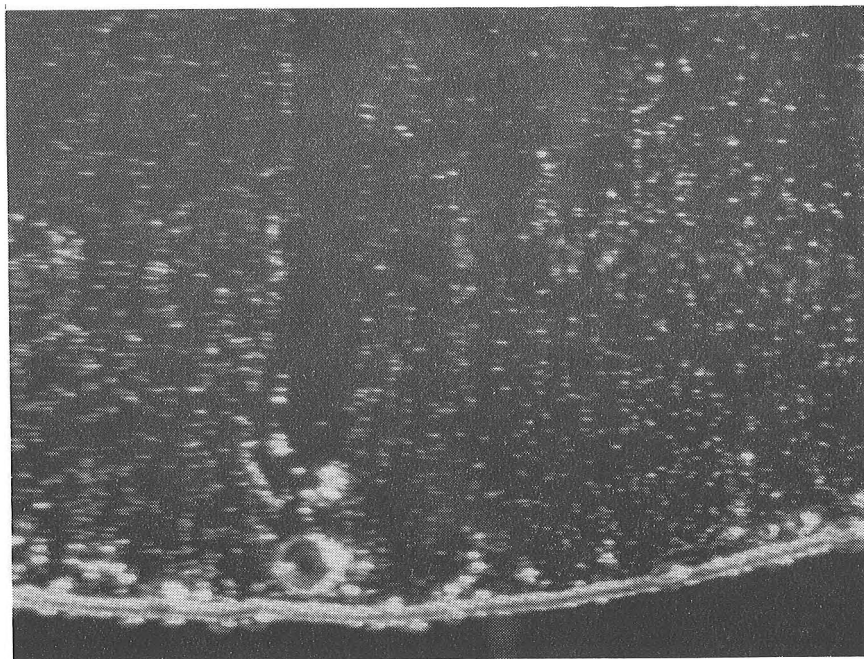


Figure 5. Pulsed platinum wire in 50 ppm AP 273.

are not of high enough molecular weight to produce good drag reduction at the low shear stresses required for good flow visualization. It is clear that the pulsed hydrogen bubble technique cannot be used in polyacrylamide polymer drag reduction studies. Until a different flow visualization scheme is devised or until larger poly(ethylene oxide) polymers again become available, these important experiments must be postponed.

ACKNOWLEDGEMENT

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REFERENCES

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2. Kline, S. J., W. C. Reynolds, F. A. Schraub, and P. W. Runstadler, "The Structure of Turbulent Boundary Layers", *J. Fluid Mech.*, 30, 741 (1967).

DISCUSSION

C. A. Sleicher, University of Washington: One bit of hope--sometimes aggregation is very sensitive to pH and if you systematically change the pH you might have some luck.

Donohue: That's a thought, I didn't change pH.

S. J. Kline, Stanford University: Of course, what you're after in the combined time-streak marker method is to get marking in time and space. So if the dye works and the bubble doesn't work you could do at least part of this by making say an array of little holes through which you can inject dye and then put a oscillator on your inlet tube as Dick Schramm did some years ago and chop it and play around with it a little bit. You might be able to get what you want a little easier that way than to try to de-coagulate.