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Dilute Polymer Solution Pressure Hole Errors in Turbulent Boundary Layers

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The errors in the use of a pressure tap to measure the static pressure or normal stress on the wall of a flow channel are well known for Newtonian fluids when the ratio of the length l to diameter d of the hole is greater than 2.5. Summaries of previous work can be found in the experimental investigation of Franklin and Wallace (1970). For smaller l/d ratios the results are not so clear and small imperfections at the hole become important. Ray (1956) reports that the error, which is normally positive (the hole pressure is larger than the true static pressure), can be negative for l/d of 0.1.

In viscoelastic solutions, measurements have only been made in laminar flow. Errors can be large when the first normal stress difference N_1 is large, but in very dilute polymer solutions N_1 is small. When the streamlines bend into the hole and there is no flow into the hole, the error for viscoelastic fluids has been theoretically shown to be negative and equal to $-0.25\,N_1$ (Tanner and Pipkin, 1969). This effect has been verified by Broadbent and Lodge (1971) and Novotny and Eckert (1973). At very high flow rates Novotny and Eckert find a positive error using l/d of 0.144. They erroneously compare their results to Newtonian fluids for high l/d and conclude that viscoelastic fluids give large errors. Novotny and Eckert attribute the error to the diverging of the streamlines out of the hole when an eddy is present in the hole. Ray (1956) has shown that this occurs in Newtonian fluids also.

It is clear that this problem merits careful experimental evaluation to determine the static pressure tap errors for both Newtonian and viscoelastic fluids under turbulent flow conditions. A preliminary study is presented in this note. The results show little difference in the errors for water or 100 ppm of Polyox WSR 301, and large errors are present in both cases for small l/d.

EXPERIMENTAL PROCEDURE

Six pressure tap holes and a one-quarter-in. flush mount type pressure transducer (Sensotec Model TAH-6H(W), 0.1-0.2 MN/m^2 (0-15 psig), G Type flange mounted, with welded diaphragm) were mounted in the center of the rectangular test section of a 0.305 m water tunnel at the Garfield Thomas Water Tunnel Facility. The holes were patterned after those of Franklin and Wallace with d, the hole diameter l the hole depth and d_t, the diameter of the tube from the hole to the pressure transducer, held at fixed ratios. Hole sizes used in this work were 6.35, 3.175, and 1.5875 mm, l/d was approximately 15.5, and d_t/d was 2. A Statham $\pm$ 35 kN/m^2 ($\pm$5 lb./sq.in.abs.) pressure transducer was used to measure the pressure hole static pressure with reference to a column of water whose surface was at the tunnel centerline. Since the flush mounted transducer was at this same location, all measurements were referenced to the atmospheric pressure at the tunnel centerline.

The holes were drilled in brass cylinders which were pressed in a brass plate. After plugs were placed in the holes, the surface was milled and then hand finished. The plugs were removed before installation of the plate in the tunnel. The holes under 20 power magnification appeared sharp.

The flush mounted transducer was mounted in the middle 3.175-mm hole and held in place by screws on an outside flange. The location of the flush mount could be changed with respect to the tunnel wall by using shims between the outside flange and the outside of the brass plate. The reference for this transducer was atmospheric pressure on the outside of the tunnel.

To make a measurement the zero of the flush mounted transducer was found with no flow in the tunnel. One major source of error found by Franklin and Wallace was zero drift and we encountered it also. Only by recalibrating the zero for each measurement was it possible to obtain reasonable results. After the 1.5875-mm hole and the flush mounted transducer were compared with no flow, the tunnel was brought up to speed and the pressures at the holes and the transducer were read at the same time.

For this test one second integration times were used on two digital voltmeters and readings were taken when the pressure was constant on both for two or more seconds. The pressure in the tunnel was kept at about 7 kN/m^2 (one lb./sq.in.) above atmospheric pressure. After reading the 1.5875-mm hole, the other holes were read in a similar manner. Then the tunnel flow was stopped and the zero checked.

The polymer was aspirated into water to make about one m^3 (300 gal.) of a 0.1% solution which was allowed to stand overnight. The next day this solution was mixed with the fill water to the tunnel to form the final 100 ppm solution. The flow rate versus pressure drop in a 6.35-mm diameter pipe was monitored during the course of the water tunnel tests to check degradation. Degradation did occur, of course; however, the polymer solution was always greater than 50% drag reducing at the shear rate at the point of measurement. The rectangular test section of the water tunnel was 0.114 by 0.546 m and measurements were made approximately 0.36 m after the start of the boundary layer development.

To determine the wall shear stress a 4-hole-pitot-tube mouse was placed in the center hole instead of the transducer. Approximate values of wall shear versus tunnel test section velocities were determined for water in a separate run. The wall shear values for polymer solution were estimated from the water measurements and the measured drag reduction in the 6.35-mm pipe. The wall shear was used to calculate the hole Reynolds number du_*/ν. Although the 100 ppm Polyox WSR 301 had a viscosity about 10% greater than water, it was within experimental error to use the water value.

TABLE 1. DIFFERENCES BETWEEN THE TRANSDUCER AND THE HOLES

U_∞ m/sec	N_{Re}	e_{meas} kN/m^2	e_{calc} kN/m^2
10.7 polymer	290	−0.3	+0.1
	580	−0.2	+0.1
	1,150	−0.2	+0.1
10.8 water	670	+0.35	+0.35
	1,340	+0.3	+0.5
	2,680	+0.15	+0.55
16.9 polymer	500	+1.1	+0.2
	1,000	+1.3	+0.3
	2,000	+1.45	+0.35
17 water	1,000	+1.0	+1.0
	2,030	+1.45	+1.2
	4,060	+2.0	+1.3
20.7 polymer	630	+2.2	+0.4
	1,260	+2.8	+0.55
	2,520	+3.1	+0.6

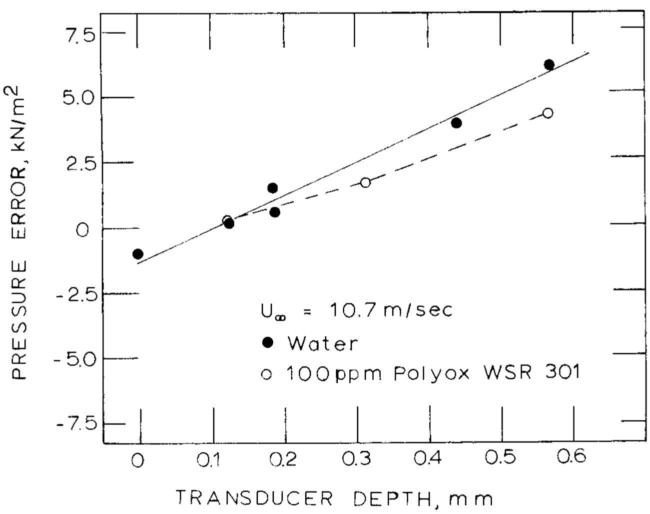

Fig. 1. Pressure error as a function of transducer depth.

RESULTS

To determine the effect of the location of the transducer, or of small l/d, measurements were taken using several different shims. The results are shown in Figure 1. The comparison is against the 1.5875-mm hole which should have an error of + 0.35 kN/m^2. Thus the transducer appears flush at a location of 0.102 mm. Figure 1 shows that the error can be large for small l/d for water as well as polymer solution. For large l/d the differences between the transducer (at a location of 0.127 mm on Figure 1) and the holes are compared in Table 1. In Table 1 N_{Re} is du_*/ν, the free stream velocity is U_∞, and the errors are e_{meas}. The last column e_{calc} is calculated from the curves given by Franklin and Wallace.

DISCUSSION

The results show agreement between results in turbulent boundary layer pressure measurements using large l/d taps for water and polymer solutions. Since the wall shear is less in the polymer solution case, it is not clear why the errors are the same. If we accept the analysis of Franklin and Wallace that the shear stress should determine the error, we could conclude that stretching of the polymer over an eddy in the hole leads to an additional error which makes the errors for polymers and water comparable.

Another possible explanation is that the wall shear is not the governing parameter at all. If a pitot tube effect due to the termination of streamlines on the wall of the hole is largely responsible for the error, this explanation may be reasonable.

Our measurements have shown that the large errors found by Novotny and Eckert are also found in water under the same conditions. Care must be taken when using flush mounted transducers to ensure that the transducer is flush and smooth. Small irregularities can lead to large errors, and large errors are present for small l/d when presumably there is flow into the hole.

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