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Flow Interference Effects at Fracture Intersections

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A series of laboratory experiments were conducted to determine the magnitude of laminar flow interference effects at fracture intersections. Circular conduits were used in these experiments to maintain strict dimensional tolerance, and the intersection head loss, if expressed in terms of equivalent length of straight conduit, should be the same order of magnitude for a circular pipe as for a parallel plate fracture model. The results indicate that interference effects at intersections are negligibly small in most fracture systems when flow is in the laminar regime.

The bulk of groundwater seepage in most natural rock masses occurs through small but relatively permeable fractures rather than through the less permeable pores of the rock itself. Our recent efforts to mathematically model flow in networks of fractures [*Wilson and Witherspoon*, 1974] have led to a laboratory investigation of the magnitude of flow interference and head loss effects at the point where two conducting fractures cross.

Intersection head loss in a conduit of any shape can be normalized by being expressed in terms of an equivalent length of straight conduit. A constant proportionality exists between laminar hydraulic conductivity in parallel plates, which are often used to model fractures, and in circular pipes. Because of this proportionality, intersection head losses, when expressed in terms of equivalent length of straight conduit, should be of the same order of magnitude in circular pipes as in parallel plates. In our experiments, two perpendicular intersecting circular pipes with identical diameters were used to model two small intersecting fractures.

A schematic drawing of the laboratory equipment is shown in Figure 1. The intersection element was made by drilling and reaming two identical 4.724 ± 0.025 mm diameter holes into a small block of clear plastic approximately 7.6 × 7.6 cm^2 and 2.5 cm thick. Copper pipe with the same interior diameter was used to conduct flow into the intersection with a minimum of disturbance. The remaining conduit was of flexible plastic

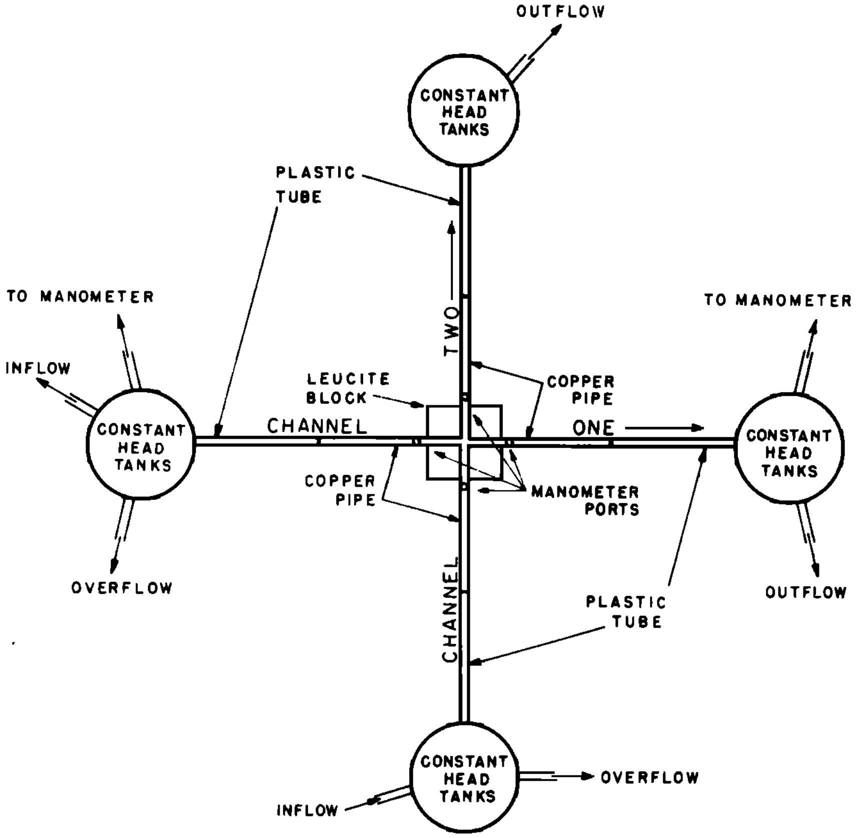

Fig. 1. A schematic drawing of the laboratory equipment.

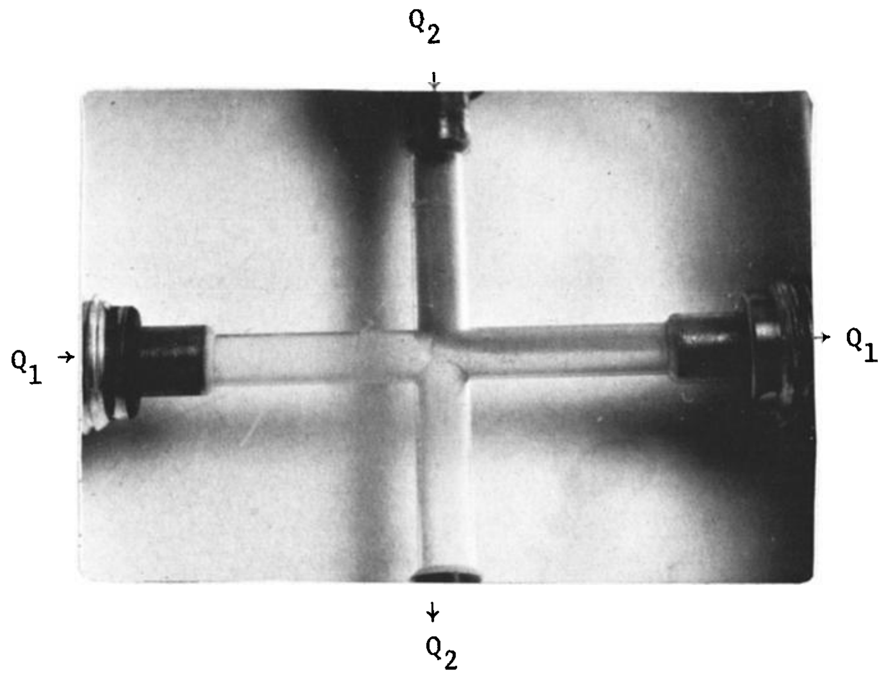

Fig. 2. A photograph of an intersection with $Q_2 \approx 0.6Q_1$ and $Re_1 \approx 1000$. The incoming water in channel 2 is dyed and exits the intersection as a narrow band in channel 1.

tubing to allow the head tanks to be raised and lowered. Deaired water was used in all tests, and temperatures were closely monitored.

The experimental technique followed was to determine total flow in the system both with and without cross flow in the intersection while maintaining constant entrance and exit heads. In reference to Figure 1, flow was initiated in channel 1 alone, no flow being in channel 2. The flow rate and the head at the intersection were measured. Flow was then stopped in channel 1 without changing the head or moving the flexible tubing and was initiated in channel 2 alone. First, heads in channel 2 were adjusted to give the same head at the intersection as was measured when channel 1 was flowing alone, and second, the flow rate in channel 2 was made approximately the same as that in channel 1. The sum of the flow rates measured when each channel was flowing alone gave the total flow rate without cross flow. Then without changing the heads or flexible tubing, both channels were opened simultaneously, and flow rates were measured for each channel. The sum of these last two flow rates gave the total rate with cross flow.

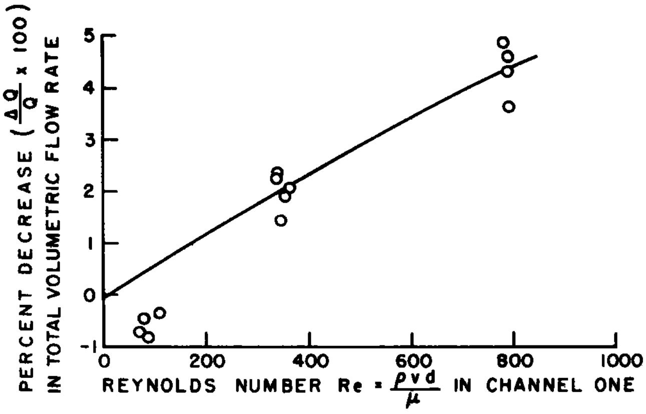

Fig. 3. Percent decrease in total volumetric flow rate due to intersection interference.

All tests were run on a symmetric network, channel 1 being the same length as channel 2. The results show a definite net reduction of flow in the system during simultaneous operation except at very low flow rates, where the Reynolds number was less than 100 and errors attained significant magnitudes. For the range of discharges studied, the amount of head loss at the intersection appears to be only slightly dependent on the relative discharges Q_1 and Q_2 in the intersecting channels (Q_2/Q_1 ratios ranged from 0.5 to 1.2) but was greatly dependent upon the magnitude of the discharges.

The selection of clear plastic for the intersection element permitted direct observation of the flow paths of the dyed waters. Little or no mixing was evident in the intersection at the relatively low flow rates used, and the individual flow paths of the dyed waters appeared as quite distinct bands of color. A photograph of one such experiment (Figure 2) shows the state of flow in the intersection when the discharge of dark water in channel 2 is about 60% of the discharge of clear water in channel 1. The flow paths do not cross, and the dark water in channel 2 turns at right angles and exits the intersection as a banded portion of the flow in channel 1. Although it cannot be seen, a similar portion of the clear water entering the intersection in channel 1 is turned at right angles and leaves the intersection as the total downstream flow in channel 2. The rate at which the banded waters leaving the intersection in channel 1 eventually intermingle and lose their separate identities depends on the velocity of flow in that channel.

Experimental results are presented in Figure 3. The percent reduction in discharge due to intersection interference is plotted as a function of the Reynolds number. The measured decrease attained a value of about 4% at a Reynolds number of 800, which represented the threshold of turbulent flow in the test network. As the flow rate approaches zero, intersection losses become negligibly small.

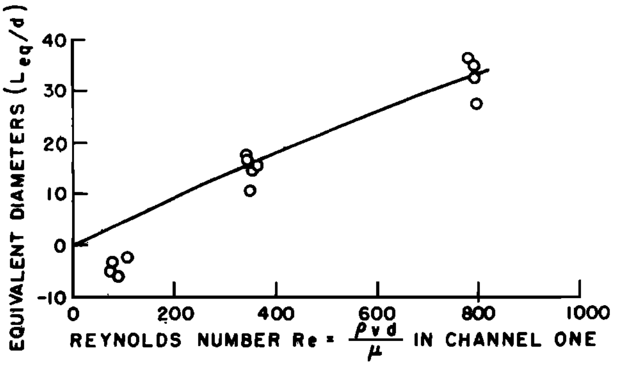

Fig. 4. Equivalent length of pipe, in terms of pipe diameter, necessary to produce the same head loss as one intersection.

The equivalent length of conduit necessary to produce the same head loss as one intersection is shown as a function of Reynolds number in Figure 4. These data were computed from the experimental results plotted in Figure 3 and give equivalent lengths for the smooth copper pipe used in the experiments. The friction factor for this pipe was only about 10% greater than the theoretical value for ideally smooth pipe. Head loss at the intersection was found to be equivalent to a length of about five pipe diameters, flow being at a Reynolds number of 100. As the discharge was increased, the head loss approached approximately 30 diameters at the threshold of turbulent flow.

If flow interference effects are of the same order of magnitude for platelike fractures as for circular conduits, the head loss at a fracture intersection would be equivalent to a length of about five apertures for flow rates with Reynolds numbers of about 100. In the case of a 0.01-cm fracture with similar fractures intersecting perpendicularly every 10 cm, the error involved in ignoring the intersection would be approximately one half of 1%. This error is very low, and in cases where the flow rate is small, interference effects at fracture intersections can be ignored safely.

REFERENCE

Wilson, C. R., and P. A. Witherspoon, Steady state flow in rigid networks of fractures, *Water Resour. Res., 10*(2), 328–335, 1974.

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