The New Small-Drillhole Minipermeameter Probe for In-Situ Permeability Measurement

Abstract

Laboratory measurement of permeability using a Hassler cell is the industry standard; however, consistently removing undisturbed rock samples from friable outcrops is difficult. Although conventional surface-sealing minipermeameters have been developed as an alternative for permeability measurement, these devices suffer from difficulties in maintaining optimal forces on the tip-seal when dealing with outcrop irregularities in the field; outcrop weathering is also problematic. Because a reliable field method is needed for outcrop studies, this paper presents an innovative technique for measuring permeability in situ. The design of a new small-drillhole minipermeameter probe is discussed, as well as the accompanying analytical technique and the size and shape of the instrument's averaging volume. Small diameter holes [i.e., 1.8 cm (0.7 in)] are drilled into an outcrop with a masonry drill, followed by drillhole vacuuming, probe insertion, seal expansion, gas injection, and calculation of the intrinsic permeability through measurement of the injection pressure, gas flow rate, and knowledge of the system geometry. Advantages of this approach are the elimination of questionable measurements from weathered outcrop surfaces, provision of a superior sealing mechanism around the air injection zone, and the potential for permeability measurement at multiple depths below an outcrop surface. To date, data have been collected from three diverse porous media: upper and lower shoreface sandstone (Escalante, Utah), saprolitic soils (Clemson, South Carolina), and nonwelded tuff (Bishop, California). The probe has proved durable and robust, with a single probe being sufficient to make thousands of measurements in a variety of environments. Data quality supports the conclusion that the drillhole probe is a practical field instrument.

Introduction

Small-scale permeability heterogeneity plays a substantial role in petroleum migration and reservoir performance; this parameter commonly ranges over many orders of magnitude (e.g., 0.01 mD to over 10,000 mD). Permeability heterogeneities on the meter-to-micrometer scale associated with beds, laminae, internal sedimentary structures and variations in pore morphology, are the source of most retrieval difficulties during enhanced oil recovery operations; thus, negatively affecting reservoir recovery efficiency. Considerable heterogeneity is evident when permeability measurements are made on small scales, either in the field or on field samples in a laboratory setting. Small-scale permeability measurements have traditionally been made by inducing one-dimensional gas flow through a cylindrical core plug in a Hassler sleeve or cell. Recently, such measurements have also commonly been made by inducing multidimensional gas flow through a sample with various configurations of the conventional surface-sealing gas minipermeameter.

Traditionally, cylindrical plugs are extracted from continuous core at 30-cm intervals for Hassler-cell permeability measurement, preserving a majority of the core while minimizing associated costs. Except for relatively homogeneous formations, this scale of permeability measurement is in an ill-defined geologic region, falling within the range of laminae and lamina sets. Furthermore, core plug samples tend to be biased toward the more consolidated, less permeable and less friable core sections. As an example, the effect of this arbitrary sampling density on Hassler-sleeve measurements for the case of tight gas sands is that magnitudes of permeability less than 100 mD frequently result, even when coarser-grained beds that would operate as preferential flow channels or “thief zones” are clearly present. Currently, the scale of sedimentary heterogeneity is best resolved by use of the minipermeameter, which allows investigation of permeability heterogeneity at much greater (and statistically significant) sampling densities and on much smaller scales than is possible with the traditional technique.
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Measurement of permeability in the case of isotropic media is usually performed on linear, mostly cylindrical shaped, "core" samples. Cores are cylinders with approximately 3.81 cm (1.5 inch) diameter and 5 cm (2 inch) length. Sometimes the permeability tests run on a whole core samples about 30-50 cm long. The experiment can be arranged so as to have horizontal or vertical flow through the sample. Since permeability is, in effect a measure of size opening in porous medium, it is found that \( b \) is a function of permeability. Jones (1972) studied the gas slip phenomena for a group of cores for which porosity, liquid permeability \( K_L \) (absolute permeability), and air permeability were determined. He correlated the parameter \( b \) with the liquid permeability by the following expression:

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