



Designation: D 4630 – 96 (Reapproved 2002)

Standard Test Method for Determining Transmissivity and Storage Coefficient of Low- Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test¹

This standard is issued under the fixed designation D 4630; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a field procedure for determining the transmissivity and storativity of geological formations having permeabilities lower than $10^{-3}\mu\text{m}^2$ (1 millidarcy) using constant head injection.

1.2 The transmissivity and storativity values determined by this test method provide a good approximation of the capacity of the zone of interest to transmit water, if the test intervals are representative of the entire zone and the surrounding rock is fully water-saturated.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 Definitions of Terms Specific to This Standard:

2.1.1 *transmissivity, T* —the transmissivity of a formation of thickness, b , is defined as follows:

$$T = K \cdot b \quad (1)$$

where:

K = hydraulic conductivity.

The hydraulic conductivity, K , is related to the permeability, k , as follows:

$$K = k\rho g/\mu \quad (2)$$

where:

ρ = fluid density,

μ = fluid viscosity, and

g = acceleration due to gravity.

2.1.2 *storage coefficient, S* —the storage coefficient of a formation of thickness, b , is defined as follows:

$$S = S_s \cdot b \quad (3)$$

where:

S_s = specific storage.

The S_s is the specific storage of a material if it were homogeneous and porous over the entire interval. The specific storage is given as follows:

$$S_s = \rho g (C_b + nC_w) \quad (4)$$

where:

C_b = bulk rock compressibility,

C_w = fluid compressibility, and

n = formation porosity.

2.2 Symbols:

2.2.1 C_b —bulk rock compressibility (M^{-1}LT^2).

2.2.2 C_w —compressibility of water (M^{-1}LT^2).

2.2.3 G —dimensionless function.

2.2.4 K —hydraulic conductivity (LT^{-1}).

2.2.4.1 *Discussion*—The use of symbol K for the term hydraulic conductivity is the predominant usage in ground water literature by hydrogeologists, whereas the symbol k is commonly used for this term in the rock and soil mechanics and soil science literature.

2.2.5 P —excess test hole pressure ($\text{ML}^{-1}\text{T}^{-2}$).

2.2.6 Q —excess water flow rate (L^3T^{-1}).

2.2.7 Q_o —maximum excess water flow rate (L^3T^{-1}).

2.2.8 S —storativity (or storage coefficient) (dimensionless).

2.2.9 S_s —specific storage (L^{-1}).

2.2.10 T —transmissivity (L^2T^{-1}).

2.2.11 b —formation thickness (L).

2.2.12 e —fracture aperture (L).

2.2.13 g —acceleration due to gravity (LT^{-2}).

2.2.14 k —permeability (L^2).

2.2.15 n —porosity (dimensionless).

2.2.16 r_w —radius of test hole (L).

2.2.17 t —time elapsed from start of test (T).

2.2.18 α —dimensionless parameter.

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

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2.2.19 μ —viscosity of water ($\text{ML}^{-1}\text{T}^{-1}$).

2.2.20 ρ —density of water (ML^{-3}).

3. Summary of Test Method

3.1 A borehole is first drilled into the rock mass, intersecting the geological formations for which the transmissivity and storativity are desired. The borehole is cored through potential zones of interest, and is later subjected to geophysical borehole logging over these intervals. During the test, each interval of interest is packed off at top and bottom with inflatable rubber packers attached to high-pressure steel tubing.

3.2 The test itself involves rapidly applying a constant pressure to the water in the packed-off interval and tubing string, and recording the resulting changes in water flow rate. The water flow rate is measured by one of a series of flow meters of different sensitivities located at the surface. The initial transient water flow rate is dependent on the transmissivity and storativity of the rock surrounding the test interval and on the volume of water contained in the packed-off interval and tubing string.

4. Significance and Use

4.1 *Test Method*—The constant pressure injection test method is used to determine the transmissivity and storativity of low-permeability formations surrounding packed-off intervals. Advantages of the method are: (a) it avoids the effect of well-bore storage, (b) it may be employed over a wide range of rock mass permeabilities, and (c) it is considerably shorter in duration than the conventional pump and slug tests used in more permeable rocks.

4.2 *Analysis*—The transient water flow rate data obtained using the suggested test method are evaluated by the curve-matching technique described by Jacob and Lohman (1)² and extended to analysis of single fractures by Doe *et al.* (2). If the water flow rate attains steady state, it may be used to calculate the transmissivity of the test interval (3).

4.3 Units:

4.3.1 *Conversions*—The permeability of a formation is often expressed in terms of the unit darcy. A porous medium has a permeability of 1 darcy when a fluid of viscosity 1 cp (1 mPa·s) flows through it at a rate of 1 cm³/s (10^{−6} m³/s)/1 cm² (10^{−4} m²) cross-sectional area at a pressure differential of 1 atm (101.4 kPa)/1 cm (10 mm) of length. One darcy corresponds to 0.987 μm². For water as the flowing fluid at 20°C, a hydraulic conductivity of 9.66 μm/s corresponds to a permeability of 1 darcy.

5. Apparatus

NOTE 1—A schematic of the test equipment is shown in Fig. 1.

5.1 *Source of Constant Pressure*—A pump or pressure intensifier shall be capable of providing an additional amount of water to the water-filled tubing string and packed-off test interval to produce a constant pressure of up to 1 MPA (145 psi) in magnitude, preferably with a rise time of less than 1 % of one half of the flow rate decay ($Q/Q_0 = 0.5$).

² The boldface numbers in parentheses refer to the list of references at the end of this standard.

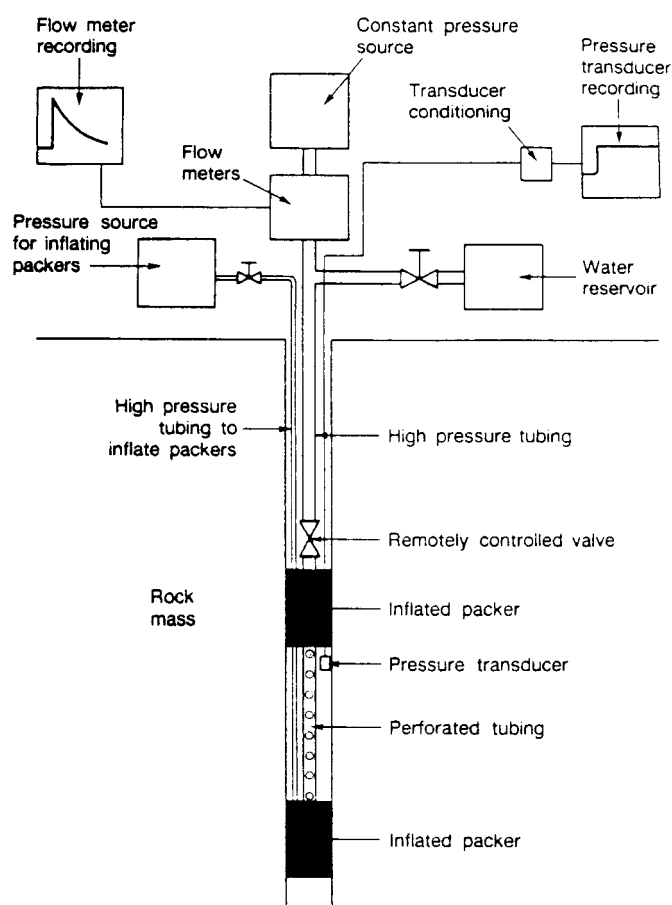


FIG. 1 Equipment Schematic

5.2 *Packers*—Hydraulically actuated packers are recommended because they produce a positive seal on the borehole wall and because of the low compressibility of water they are also comparatively rigid. Each packer shall seal a portion of the borehole wall at least 0.5 m in length, with an applied pressure at least equal to the excess constant pressure to be applied to the packed-off interval and less than the formation fracture pressure at that depth.

5.3 *Pressure Transducers*—The pressure shall be measured as a function of time, with the transducer located in the packed-off test interval. The pressure transducer shall have an accuracy of at least ± 3 kPa (± 0.4 psi), including errors introduced by the recording system, and a resolution of at least 1 kPa (0.15 psi).

5.4 *Flow Meters*—Suitable flow meters shall be provided for measuring water flow rates in the range from 10³ cm³/s to 10^{−3} cm³/s. Commercially available flow meters are capable of measuring flow rates as low as 10² cm³/s with an accuracy of ± 1 % and with a resolution of 10^{−5} cm³/s; these can test permeabilities to 10^{−3} md based on a 10-m packer spacing. Positive displacement flow meters of either the tank type (Haimson and Doe (4) or bubble-type (Wilson *et al.* (3) are capable of measuring flow rates as low as 10^{−3} cm³/s; these can test permeabilities to 10^{−4} md based on a 10-m packer spacing.

5.5 *Hydraulic Systems*—The inflatable rubber packers shall be attached to high-pressure steel tubing reaching to the surface. The packers themselves shall be connected to the