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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Theis Nonequilibrium Method[1]

This standard is issued under the fixed designation D 4106; 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 an analytical procedure for determining the transmissivity and storage coefficient of a nonleaky confined aquifer. It is used to analyze data on water-level response collected during radial flow to or from a well of constant discharge or injection.

1.2 This analytical procedure is used in conjunction with the field procedure given in Test Method D 4050.

1.3 *Limitations*—The limitations of this test method for determination of hydraulic properties of aquifers are primarily related to the correspondence between the field situation and the simplifying assumptions of this test method (see 5.1).

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

1.5 *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. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 4043 Guide for Selection of Aquifer Test Method in Determining of Hydraulic Properties by Well Techniques[2]

D 4050 Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *aquifer, confined*—an aquifer bounded above and below by confining beds and in which the static head is above the top of the aquifer.

3.1.2 *confining bed*—a hydrogeologic unit of less permeable material bounding one or more aquifers.

3.1.3 *control well*—well by which the head and flow in the aquifer is changed, for example, by pumping, injection, or imposing a constant change of head.

3.1.4 *drawdown*—vertical distance the static head is lowered due to the removal of water.

3.1.5 *head*—see *head, static*.

3.1.6 *head, static*—the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point.

3.1.7 *hydraulic conductivity (field aquifer tests)*—the volume of water at the existing kinematic viscosity that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

3.1.8 *observation well*—a well open to all or part of an aquifer.

3.1.9 *piezometer*—a device so constructed and sealed as to measure hydraulic head at a point in the subsurface.

3.1.10 *specific storage*—the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head.

3.1.11 *storage coefficient*—the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. For an unconfined aquifer, the storage coefficient is approximately equal to the specific yield.

3.1.12 *transmissivity*—the volume of water at the existing kinematic viscosity that will move in a unit time under a unit hydraulic gradient through a unit width of the aquifer.

3.1.13 *unconfined aquifer*—an aquifer that has a water table.

3.1.14 For definitions of other terms used in this test method, see Terminology D 653.

3.2 *Symbols:Symbols and Dimensions:*

3.2.1 K [LT^{-1}]—hydraulic conductivity.

3.2.2 K_{xy}—hydraulic conductivity in the horizontal plane, radially from the control well.

3.2.3 K_z—hydraulic conductivity in the vertical direction.

3.2.4 Q [L^3T^{-1}]—discharge.

3.2.5 S [nd]—storage coefficient.

3.2.6 S_s[L^{-1}]—specific storage.

3.2.7 T [L^2T^{-1}]—transmissivity.

3.2.8 $W(u)$ [nd]—well function of u.

[1] This test method is under the jurisdiction of ASTM Committee D-18 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] *Annual Book of ASTM Standards*, Vol 04.08.

3.2.9 b [L]—thickness of aquifer.

3.2.10 r [L]—radial distance from control well.

3.2.11 s [L]—drawdown.

4. Summary of Test Method

4.1 This test method describes an analytical procedure for analyzing data collected during a withdrawal or injection well test. The field procedure (see Test Method D 4050) involves pumping a control well at a constant rate and measuring the water level response in one or more observation wells or piezometers. The water-level response in the aquifer is a function of the transmissivity and storage coefficient of the aquifer. Alternatively, this test method can be performed by injecting water at a constant rate into the aquifer through the control well. Analysis of buildup of water level in response to injection is similar to analysis of drawdown of water level in response to withdrawal in a confined aquifer. Drawdown of water level is analyzed by plotting drawdown against factors incorporating either time or distance from the control well, or both, and matching the drawdown response with a type curve.

4.2 *Solution*—The solution given by Theis **(1)**[3] may be expressed as follows:

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-y}}{y}\,dy \tag{1}$$

where:

$$u = \frac{r^2 S}{4Tt} \tag{2}$$

$$\int_u^\infty \frac{e^{-y}}{y}\,dy = W(u)$$

$$= -0.577216 - \log_e u + u - \frac{u^2}{2!2} + \frac{u^3}{3!3} - \frac{u^4}{4!4} + \ldots \tag{3}$$

5. Significance and Use

5.1 *Assumptions*:

5.1.1 Well discharges at a constant rate, Q.

5.1.2 Well is of infinitesimal diameter and fully penetrates the aquifer.

5.1.3 The nonleaky aquifer is homogeneous, isotropic, and aerially extensive. A nonleaky aquifer receives insignificant contribution of water from confining beds.

5.1.4 Discharge from the well is derived exclusively from storage in the aquifer.

5.1.5 The geometry of the assumed aquifer and well conditions are shown in Fig. 1.

5.2 *Implications of Assumptions*:

5.2.1 Implicit in the assumptions are the conditions of radial flow. Vertical flow components are induced by a control well that partially penetrates the aquifer, that is, the well is not open to the aquifer through its full thickness. If the control well does not fully penetrate the aquifer, the nearest piezometer or partially penetrating observation well should be located at a distance, r, beyond which vertical flow components are negligible, where according to Reed **(2)**:

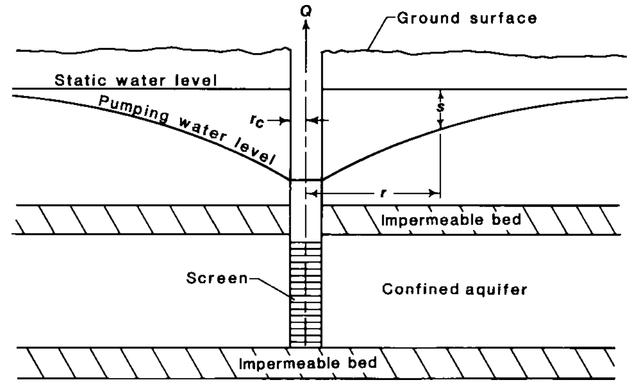

FIG. 1 Cross Section Through a Discharging Well in a Nonleaky Confined Aquifer

$$r = 1.5\frac{b}{\sqrt{\frac{K_z}{K_{xy}}}} \tag{4}$$

This section applies to distance-drawdown calculations of transmissivity and storage coefficient and time-drawdown calculations of storage coefficient. If possible, compute transmissivity from time-drawdown data from wells located within a distance, r, of the pumped well using data measured after the effects of partial penetration have become constant. The time at which this occurs is given by Hantush **(3)** by:

$$t = b^2 s/2T\,(K_z/K_r) \tag{5}$$

Fully penetrating observation wells may be placed at less than distance r from the control well. Observation wells may be on the same or on various radial lines from the control well.

5.2.2 The Theis method assumes the control well is of infinitesimal diameter. Also, it assumes that the water level in the control well is the same as in the aquifer contiguous to the well. In practice these assumptions may cause a difference between the theoretical drawdown and field measurements of drawdown in the early part of the test and in and near the control well. Control well storage is negligible after a time, t, given by the Eq 6 after Weeks **(4)**.

$$t = 25 \times \frac{r_c^2}{T} \tag{6}$$

where:

r_c = the radius of the control well in the interval in which the water level changes.

5.2.3 *Application of Theis Method to Unconfined Aquifers*:

5.2.3.1 Although the assumptions are applicable to artesian or confined conditions, the Theis solution may be applied to unconfined aquifers if drawdown is small compared with the saturated thickness of the aquifer or if the drawdown is corrected for reduction in thickness of the aquifer, and the effects of delayed gravity yield are small.

5.2.3.2 *Reduction in Aquifer Thickness*—In an unconfined aquifer dewatering occurs when the water levels decline in the vicinity of a pumping well. Corrections in drawdown need to be made when the drawdown is a significant fraction of the aquifer thickness as shown by Jacob **(5)**. The drawdown, s, needs to be replaced by s', the drawdown that would occur in an equivalent confined aquifer, where:

[3] The boldface numbers in parentheses refer to a list of references at the end of the text.