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Standard Practice for Determining Specific Capacity and Estimating Transmissivity at the Control Well[1]

This standard is issued under the fixed designation D5472/D5472M; 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 practice describes a procedure for conducting a specific capacity test, computing the specific capacity of a control well, and estimating the transmissivity in the vicinity of the control well. Specific capacity is the well yield per unit drawdown at an identified time after pumping started.

1.2 This practice is used in conjunction with Test Method D4050 for conducting withdrawal and injection well tests.

1.3 The method of determining transmissivity from specific capacity is a variation of the nonequilibrium method of Theis (**1**)[2] for determining transmissivity and storage coefficient of an aquifer. The Theis nonequilibrium method is given in Practice D4106.

1.4 *Limitations*—The limitations of the technique for determining transmissivity are primarily related to the correspondence between the field situation and the simplifying assumptions of the Theis method.

1.5 The scope of this practice is limited by the capabilities of the apparatus.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.6.1 The procedures used to specify how data are collected/recorded and calculated in this practice are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to commensurate with these considerations. It is beyond the scope of this practice to consider significant digits used in analysis methods for engineering design.

1.7 *Units*—The values stated in SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values for the two systems may result in nonconformance with the standard. Reporting of results in units other than SI shall not be regarded as noncompliance with this standard.

1.8 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of the practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without the consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)

D3740 Practice for Minimum Requirements for Agencies

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

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

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4050 Test Method for (Field Procedure) for Withdrawal and Injection Well Testing for Determining Hydraulic Properties of Aquifer Systems
D4106 Practice for (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Theis Nonequilibrium Method
D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 For common definitions of common technical terms used in this practice, refer to Terminology D653.

3.2 *Symbols and Dimensions:*
3.2.1 *K*—hydraulic conductivity $[LT^{-1}]$
3.2.2 *m*—saturated thickness [L]
3.2.3 *Q*—discharge $[L^3T^{-1}]$
3.2.4 *Q/s*—specific capacity $[(L^3T^{-1})L^{-1}]$
3.2.5 *r*—well radius [L]
3.2.6 *s*—drawdown [L]
3.2.7 *S*—storage coefficient [dimensionless]
3.2.8 *T*—transmissivity $[L^2T^{-1}]$
3.2.9 *T'*—provisional value of transmissivity $[L^2T^{-1}]$
3.2.10 *t*—elapsed time of pumping [T]
3.2.11 *u*—$r^2S/4Tt$ [dimensionless]
3.2.12 *W(u)*—well function of "u" [dimensionless]
3.2.13 c_1—$[W(u)/4\pi]$

4. Summary of Practice

4.1 A control well is equipped with an accumulated water meter or other well yield measuring device and the static water level determined after conditioning.

4.2 After a conditioning pumpdown, the well is pumped continuously and measurements collected. Determination of the specific capacity and an estimate of the transmissivity of the well is then calculated.

5. Significance and Use

5.1 Assumptions of the Theis (**1**) equation affect specific capacity and transmissivity estimated from specific capacity. These assumptions are given below:
5.1.1 Aquifer is homogeneous and isotropic.
5.1.2 Aquifer is horizontal, of uniform thickness, and infinite in areal extent.
5.1.3 Aquifer is confined by impermeable strata on its upper and lower boundaries.
5.1.4 Density gradient in the flowing fluid must be negligible and the viscous resistance to flow must obey Darcy's Law.
5.1.5 Control well penetrates and receives water equally from the entire thickness of the aquifer.
5.1.6 Control well has an infinitesimal diameter.
5.1.7 Control well discharges at a constant rate.
5.1.8 Control well operates at 100 percent efficiency.
5.1.9 Aquifer remains saturated throughout the duration of pumping.

5.2 *Implications of Assumptions and Limitations of Method.*
5.2.1 The simplifying assumptions necessary for solution of the Theis equation and application of the method are never fully met in a field situation. The satisfactory use of the method may depend upon the application of one or more empirical correction factors being applied to the field data.

5.2.2 Generally the values of transmissivity derived from specific capacity vary from those values determined from aquifer tests utilizing observation wells. These differences may reflect *1*) that specific-capacity represents the response of a small part of the aquifer near the well and may be greatly influenced by conditions near the well such as a gravel pack or graded material resulting from well development, and *2*) effects of well efficiency and partial penetration.

5.2.3 The values of transmissivity estimated from specific capacity data are considered less accurate than values obtained from analysis of drawdowns that are observed some distance from the pumped well.

NOTE 1—The quality of the result produced by this practice is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this practice are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5.3 Withdrawal well test field procedures are used with appropriate analytical procedures in appropriate hydrogeological sites to determine transmissivity and storage coefficient of aquifers and hydraulic conductivity of confining beds.

6. Apparatus

6.1 Various types of equipment can be used to withdraw or inject water into the control well, measure withdrawal and injection rates, and measure water levels. The practice procedure may be conducted with different types of equipment to achieve similar results. The objectives to be achieved by the use of the equipment are given in this section and in Sections 7 and 8. The selection of equipment and measuring apparatus will be evaluated to ensure that sufficient accuracy and sensitivity will be provided for the later evaluation of data by Practice D4106.

6.2 *Control Well*—Discharge or injection well test methods require that water be withdrawn from or injected into a single well. This well, known as the control well, must be drilled and completed such that it transmits water to or from the aquifer (usually the entire thickness of the aquifer) at rates such that a measurable water level change will occur at observation wells. The control well should be as efficient as possible, to reduce the head loss between the aquifer and the well. Well development should be as complete as possible to eliminate additional production of sand or silt and consequent changes in well efficiency and pumping water levels during the field testing. The cuttings from the control well (if available) should be described and recorded according to Practice D2488. The analytical method selected for analysis of the data may specify certain dimensions of the control well such as screen length and depth of screen placement. Specific requirements for control wells may be given in standards for specific analytical methods (see, for example, Practice D4106).

6.3 *Observation Wells or Piezometers*—Numbers of observation wells and their distance from the control well and their screened interval may be dependent upon the method to be employed. Refer to the analytical practice to be used for specifications of observation wells (see, for example, Practice D4106).

6.4 *Control Well Pump*—A pump capable of withdrawal of a constant or predetermined variable rate of water from the control well. The pump and motor should be adequately sized for the designed pumping rate and lift. The pump or motor must be equipped with a control mechanism to adjust discharge rate. In the case of diesel-, gasoline-, or natural-gas-fueled engines, throttle settings should allow for small adjustments in pumping rates. Pumps equipped with electric motors are usually controlled by adjusting back pressure on the pump through a gate valve in the discharge line. Take care to select a discharge rate small enough such that the rate can be maintained throughout the field test without fully opening the gate valve. If neither method of control is practical, split the discharge and route part of the discharge back to the well through a separate discharge line. If water is withdrawn, the discharge should be at a distance sufficiently away from the area to prevent recharging back into the aquifer being tested.

6.5 Many aquifer tests are made at "sites of opportunity," that is, using existing production or monitoring wells as the control well and using other existing wells for observation of water level. In such cases the locations and screened intervals of the wells should be compatible with the requirements of the method of test analysis.

6.6 *Water-Level Measurement Equipment*—Manual measurements can be made with a steel tape or electric tape, with a mechanical recorder linked to a float, or combination of pressure transducer and electronic data logger.

6.6.1 *Mechanical Recorders*—Mechanical recorders employ a float in the well to produce a graphic record of water level changes. Early in the test, it may be difficult to distinguish small increments of time on the recorder chart, therefore the recorder should be supplemented with additional early time measurements or by marking the trace of an automatic water-level recorder chart and recording the time by the mark. Check the mechanical recorder periodically throughout the field test using the steel tape.

6.6.2 *Pressure Transducers and Electronic Data Loggers*—A combination of a pressure transducer and electronic data logger can provide rapid measurements of water level change, and can be programmed to sample at reduced frequency late in the test. Select the pressure transducer to measure pressure changes equivalent to the range of expected water level changes. Check the transducer in the field by raising and lowering the transducer a measured distance in the well. Also check the transducer readings periodically with a steel tape.

6.6.3 Equipment used for measuring flows, and water levels should have calibration records, or be calibrated for the field test.

6.7 *Sand Content Measurement Device*—Apparatus to measure the sand content in discharged water. Cone Types (for example, Imhoff) can be used for higher concentrations of sand in the discharge water and centrifugal sand separators (for example, Rossum) can be used for lower levels and are commercially available and commonly used.

7. Conditioning Procedures

7.1 Conditioning procedures are conducted before the field test (Test Method D4050) to ensure that the control well is properly equipped and that the well discharge and water-level measuring equipment is operational.

7.1.1 Equip the control well with a calibrated accumulating water meter or another type of calibrated well yield measuring device.

7.1.2 Provide the control well with a system for maintaining a constant discharge.

7.1.3 Equip control well for measuring the pretest water level (prepumping water level) and pumping water levels during the specific capacity test.

7.1.4 Measure static water level immediately before starting the pump.

7.1.5 Start pump and simultaneously measure elapsed time with a stop watch or data recorder. After 3 to 5 minutes well yield and drawdown should be measured and recorded.

7.1.6 If all the equipment is working properly, drawdown measurements can be obtained, and constant discharge maintained, the equipment check can be ended.

7.1.7 Cease pumping and allow the water level to recover to its prepumping level before the specific capacity test procedure is initiated.

8. Procedure

8.1 The general procedure consists of conducting the field procedure for withdrawal or injection well test (Test Method D4050) and analyzing the field data with this practice.

8.2 Initiate well discharge.

8.3 Measure the well yield and pumping water level in the control well at predetermined time intervals, for example, 2-, 5-, 10-, 20-, 30-, minutes after discharge is initiated. Adjust the discharge rate during the field test to maintain discharge within 5 % of the rate planned. Discharge waters should be at a distance sufficiently away from the area to prevent recharging back into the aquifer being tested.

8.4 While field testing continues make the following calculations:

8.4.1 Adjust drawdown for effects of desaturation of the aquifer, if applicable (see Section 9).

8.4.2 Determine the specific capacity (see Section 11) and estimate transmissivity (see Section 12). If well bore storage effects are negligible (see Section 10), compare the new value of T to the value used to calculate c_1, if the value is within 10 %, the test can be terminated.

8.4.3 If control well is not screened through the entire thickness of the aquifer, estimate the transmissivity of the aquifer following procedure in Sections 12 and 13.

NOTE 2—The withdrawal of water from a well with contamination may be problematic by the generation of contaminated water that will have to be handled and disposed of in accordance with applicable regulations.

NOTE 3—The use of a sand content measurement device can be used when a well is pumped to assess the well condition, determining a pumping rate, and avoiding damage to the well.

NOTE 4—The addition of water to a well should be fully evaluated prior to the field test. The water quality should be known, and may be subject to regulatory approval. The additional of water may change the chemistry of the well water for subsequent monitoring, and the rapid injection may damage the well pack and surrounding natural soils. The withdrawal of water from a well with contamination may be problematic by the generation of contaminated water that will have to be handled and disposed of in accordance with applicable regulations.

9. Correction of Drawdown in an Unconfined Aquifer

9.1 The Theis equation is directly applicable to confined aquifers and is suitable for use with limitations in unconfined aquifers. If the aquifer is unconfined and drawdown is less than 10 percent of the prepumping saturated thickness, little error will be introduced. If drawdown exceeds 25 percent of the prepumping saturated thickness, this practice should not be used to estimate transmissivity. For unconfined aquifers with drawdown equal to 10 to 25 percent of the original saturated thickness, correct the drawdown for the effects of reduced saturated thickness by the following formula given by Jacob (**2**):

$$s' = s - \frac{(s^2)}{2m} \tag{1}$$

where:

s = measured drawdown in the control well,
s' = corrected drawdown, and
m' = saturated thickness of the aquifer prior to pumping.

10. Well Bore Storage Effects

10.1 Evaluate the time criterion to determine if well-bore storage affects drawdown at the current duration of the test. Weeks (**3**) gives a time criterion modified after Papadopulos and Cooper (**4**) of $t > 25\ r^2/T$ after which drawdown in the control well is not affected by well-bore storage.

NOTE 5—Commercial software is available for performing the following calculations. The users should verify the correctness of the software used and the results.

Examples: a well with a radius of 305 mm and a T of 9.2903 m^2/day has a time criterion of $t > 25\ r^2/T = t > 25$ days $= t > 32.8$ min [a well with a radius of 1 foot and a T of 1000 ft^2/day has a time criterion of $t > 25\ r^2/T = t > 25\ (1)^2/1000 = 0.025$ days $= t > 36$ min].

11. Computation of Specific Capacity

11.1 Record the drawdown and the time since pumping started.

11.2 Compute the specific capacity of the control well from the average well yield (Q) and the drawdown (s):

$$\text{Specific Capacity} = Q/s\left[(L^3T^{-1})L^{-1}\right] \tag{2}$$

11.2.1 An example of a specific capacity where discharge is given in m^3, (4.546 m^3/min) and a drawdown of 15 m:

Specific Capacity = 4.546 m^3/min (1440 min/day)/15 m = 109 m^3/day

11.2.2 An example of specific capacity where discharge is given in inch/pound units (1000 gallons per minute) and drawdown in feet (50):

Specific Capacity =
[1000 gpm (1440 min/day/7.48 gal/ft^3)]/50 ft =
3850 [(ft^3/day)]ft

12. Estimate Transmissivity from Specific Capacity

12.1 A modification of the Theis (**1**) nonequilibrium equation is used to evaluate transmissivity data derived from specific capacity as follows:

$$T = [W(u)/4\pi]Q/s \tag{3}$$

12.1.1 A general form of the equation is:

$$T' = c_1 Q/s \tag{4}$$

where:

c_1 = $W(u)/4\pi$.

12.1.2 Calculate the value of c_1 from a provisional value of transmissivity, T', estimated storage coefficient, S, well radius, r, and duration of the test, t. An example of the computation of c_1 using field values of discharge in SI units [inch/pound] units is as follows:

where:

T' = 1022 m^2/day [11 000 ft^2/day],
S = 2×10^{-5}
r = 200 mm [0.67 ft (16-in. Id diameter pipe)],
t = 0.50 days

$C_1 = W(u)/4\pi$
$W(u) = (-0.5772 - Ln[u])$

where:

u = $(r^2S)/(4Tt) = 4.0809 \times 10^{-10}$
C_1 = $(-0.5772 - Ln\ [4.0809 \times 10^{-10}])/4\pi]$
C_1 = $(-0.5772 - Ln[4.0809 \times 10^{-10}])/12.5664$
C_1 = $(-0.5772 - [-21.6195])/12.5664$
C_1 = $21.0423/12.5664 = 1.6745$

12.1.3 Calculate transmissivity from Eq 4;

$T = c_1Q/s$,
Assume Q/s = 109 m^3/day/ft
$T = 1.6745 \times 109$ m^3/day/m = 1163.52 m^3/day
Assume Q/s = 3850 [(ft^3/day)/ft]
$T = 1.6745 \times 3850 = 6450$ ft^2/day (rounded)

12.1.4 If transmissivity calculated in 12.1.3 is not within 10 % of the provisional transmissivity, T, recalculate c_1 from the new value of transmissivity and recalculate transmissivity by formula. In the example, because 1163.52 m^3/day [6450 ft^2/day] is approximately 59 percent of the initial T value of the 1022 m^2/day [11 000 ft^2/day], a more accurate c_1 can be computed to match the new T value.

T' = 1022 m^2/day [6450 ft^2/day]
$S = 2 \times 10^{-5}$
$c_1 = W(u)/4\pi$
$W(u) = (-0.5772 - Ln[u])$