Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 8 (14): 2640-2643, 2008
ISSN 1812-5654

A Simple Method to Estimate Transmissibility and Storativity of Aquifer Using Specific Capacity of Wells

[1]Ismail Chenini, [2]Silvain Rafini and [1]Abdallah Ben Mammou
[1]Mineral Resources and Environmental Laboratory, Department of Geology,
Faculty of Sciences of Tunis, 2092 Tunis El Manar, Tunisia
[2]Planetology and Geodynamic (UMR 6112), Nantes University, BP 92208, 44322 Nantes Cedex 3, France

Abstract: Drawdown data collected during a pumping test are used to assess hydrologic properties of the aquifer. The application of the Theis and Theis-Jacob non-steady state method are used to determine the coefficient of transmissibility (T) and the coefficient of storage (S). But, due to the variation of specific capacity of wells with time during the earliest period of the pumping test, the values of T and S did not remain constant with the time of pumping. A simple method is proposed in this study using graphical method to estimate the transmissibility and storativity of aquifer. In the projected method which is based on Theis'formula, no assumptions for the hydrologic parameters are required and the values of T and S are determined simultaneously.

Key words: Pumping test, Theis'formula, hydrologic properties, transmissibility, storativity

INTRODUCTION

The pumping test data analyses and interpretations are used as a method for estimating the hydrologic properties of the aquifer (Week, 2005; Stefan and Vitaly, 2005). The principle of existing formulas in this subject (Theis, 1935; Xaviez *et al.*, 1999) is to determine the specific capacity after constant period of pumping assuming the value of the coefficient of storage to get the corresponding value of T and S (Singhal and Gupta, 1966; Vincent and Joshi, 1986).

The specific capacity of the well, which is the discharge per unit drawdown, decreases with time (Norman and James, 1971). If the discharge during the pumping test is constant, then the specific capacity should vary with time.

The estimation of the aquifer parameters (transmissibility, storativity) is of great importance for hydrogeological studies, as it constitutes an indicator of the hydrodynamic functioning. The pumping data set interpretations methods are developed taking in consideration time factor, to determine the coefficient of transmissibility, with the assumption of the value of storage coefficient.

In this study, a simple graphical method to estimate the transmissibility and storativity of aquifer is presented. The pumping data set are analyzed whilst the variation of specific capacity with time is taken in consideration and without assumption of the value of storage coefficient.

THEORY AND SIGNIFICANCE

In an artesian well that is pumped, the drawdown is equal to the difference between the pumping water level and the static water level (Forkasiewicz, 1972). It has two components. The first arising from the resistance of the formation and is proportional to the discharge. The second represent the loss of head that accompanies the flow; this well loss is proportional to the square of the discharge.

If S_w designs the drawdown inside the well in meter, F the formation resistance, c well loss and Q the discharge (m^3 day^{-1}) we can write:

$$S_w = FQ+CQ^2 \quad (1)$$

The ratio of discharge to the drawdown (specific capacity) is equal to:

$$Q/S_w = \frac{1}{F + cQ} \quad (2)$$

If the discharge Q is constant during pumping period, the specific capacity must decrease with time. Thus, due to the reality that the formation resistance F increases with time same as the everwinding area of influence of well expands.

For small values of well loss c which is usually ranges from 0.2×10^{-6} to 6×10^{-6}, then cQ in Eq. 2 shall be very small if it is added to F and can be neglected without any serious error. Eq. 2 will be:

Corresponding Author: Ismail Chenini, Mineral Resources and Environmental Laboratory, Department of Geology, Faculty of Sciences of Tunis, 2092 Tunis El Manar, Tunisia Tel: 0021697282335

$$\frac{Q}{S_w} = \frac{1}{F} \tag{3}$$

For the non steady radial flow, Theis developed the following equation:

$$S_w = \frac{Q}{4\pi T} W(u) \tag{4}$$

$$W(u) = (-0.5772 - Ln.u + u - \frac{u^2}{2\times 21} + \frac{u^3}{3\times 31} ....)$$

W(u) is the well function and Sw is the drawdown inside the well (Stanley and Roger, 1966).

$$u = \frac{r_w^2 S}{4 T t}$$

Where:
S = Coefficient of storage
T = Coefficient of transmissibility in m^2 day^{-1}
t = Time in days since pumping began
r_w = Effective radius of the pumped well in meter

For sufficiently large values of t, the well function W(u) may be approximated by a simple logarithmic expression. Thus, the drawdown after sufficient time has onwards and values of u less then 0.02 is given by:

$$S_w = \frac{Q}{4\pi T}(Ln. \frac{4 T t}{r_w^2 S} - 0.5772) \tag{5}$$

When the well loss is appreciable the drawdown in the well is:

$$S_w = \frac{Q}{4\pi T}(Ln. \frac{4 T t}{r_w^2 S} - 0.5772) CQ^2 \tag{6}$$

$$S_w = \frac{Q}{4\pi T}(2.303 \text{ Log } \frac{4 T t}{r_w^2 S} - 0.5772) + CQ^2 \tag{7}$$

Comparing Eq. 7 with Eq. 1 therefore:

$$F = \frac{Q}{4\pi T}(2.303 \text{ Log } \frac{4 T t}{r_w^2 S} - 0.5772) \tag{8}$$

in the other hand, according to Theis formula:

$$F = \frac{1}{T}(0.183 \text{ Log } \frac{4 T t}{r_w^2 S} - 0.046) \tag{9}$$

In Eq. 9, the value of T/S is usually defined as the diffusivity. In this study, calculations of this parameter run in the range of 10^4 to 10^9. r_w is considered to be 0.1 m which is a practical value for well diameter. We considered t as variable between 0.01 day to 100 days.

If x (t) is equal to $(0.183 \text{ Log } \frac{4 T t}{r_w^2 S} - 0.046)$ in Eq. 9, then $F = \frac{x(t)}{T}$

RESULTS AND DISCUSSION

Graphical method estimating transmissibility and the coefficient of storage: Table 1 shows some computed values of F for T/S equals to 0.5×10^6.

From Table 1 it is clear that the value of specific capacity is the arithmetic reciprocal for value of F-values of given transmissibility and the corresponding values of specific capacities are plotted on square grid. It gives a straight line for each time interval. It gives radial group of straight lines distributed from the origin. A set of graphs similar for Fig. 1 are plotted for values of T/S from 1×10^4 to 1×10^9. These graphics gave a clear variation in its divergent and slope. The divergence between two radiated lines decreases as time increase and as T/S value increase. The slope of the radiated group decreases as T/S values are increases.

The value of the well loss coefficient c is determined from step discharge test. During pumping test which is running with constant discharge test, the measured drawdown and time are tabulated. From each drawdown, we subtract the value of CQ^2 which equals the well loss constant during the test. Then, we can obtain the net Drawdown (DD) of the aquifer. After that we divide the value of the constant discharge Q by each value of net drawdown to obtain the variant values of specific capacity. We plot the obtained values and corresponding time where t in minutes as X axis and specific capacity values as Y axis. A straight line will be obtained. From this

Table 1: Calculated values of F and specific capacities (Sp.C.) which is the reciprocal of F at T/S equal to 0.5×10^6

t (days)	x(t)/T		200	400	600	800	1000	1200	1400	1600	1800	2000
0.01	1.10/T	F	5.50	2.750	1.83	1.370	1.10	0.916	0.785	0.687	0.6110	0.550
		Sp.C.	181.81	363.630	546.44	729.920	909.10	1091.700	1273.880	1455.600	16.36.66	1818.180
0.1	1.29/T		6.45	3.220	2.15	1.610	1.29	1.070	0.921	0.806	0.716	0.645
			155.04	310.080	465.11	620.150	775.19	930.230	1085.270	1240.310	1395.340	1550.380
1	1.47/T		7.35	3.675	2.45	1.830	1.47	1.220	1.050	0.910	0.816	0.735
			136.05	272.190	408.16	544.210	680.27	816.320	952.380	1088.430	1224.480	1360.540
10	1.65/T		8.25	4.125	2.75	2.062	1.65	1.375	1.178	1.031	0.916	0.825
			121.21	242.420	363.63	484.840	606.06	727.270	848.480	969.690	1090.900	1212.120
100	1.83/T		9.15	4.575	3.05	2.287	1.83	1.525	1.307	1.140	1.016	0.915
			109.28	218.570	327.86	437.150	546.44	655.730	765.027	874.316	983.600	1092.890

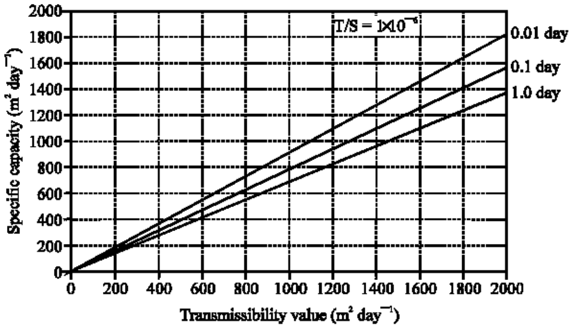

Fig. 1: Values of given transmissibility and calculated Sp.C. plotted at time in min

Table 2: Well characteristics test data in PL1 well in Maknassy basin

Elapsed time since yield	Drawdown (m)	Specific capacity ($m^2\ day^{-1}$)
1	7.10	734
10	7.72	651
14	7.89	631
20	7.95	621
30	8.14	607
60	8.41	569
90	8.55	561
120	8.65	554
180	8.82	540
240	8.85	535
300	8.96	530
360	8.95	525
420	9.10	522
480	9.00	520
540	9.12	518
600	9.15	515
660	9.14	513
720	9.14	511

C: 0.10×10^{-6}, CQ^2: 2.4

straight line, we determine the value of specific capacities at time 0.01 day (14.4 min) and at time 0.1 day (144 min), respectively. From the difference between these two values, the values of T and S can be obtained as shown in the example below.

The following table shows the observed data for one of wells in Maknassy basin (Central Tunisia).

Well loss is 0.2×10^{-6} determined from measured drawdown. Specific capacity values plotted against time as shown in Fig. 2.

At time 14.4 min the specific capacity is 632 $m^2\ day^{-1}$. This value is 552 $m^2\ day^{-1}$ at 144 min. Therefore, the difference equals 80 $m^2\ day^{-1}$. It is the difference as shown in Fig. 3 between specific capacities. 632-552 = 80 is only found in the sheet of $T/S = 4\times10^6$. Drop a vertical line on x axis, we will get the value of T = 800 $m^2\ day^{-1}$. So, $S = (800/4*10^6) = 2\times10^{-4}$. Jacob method gives a value of transmissibility equal to 792 $m^2\ day^{-1}$ and a coefficient of storage equal to 7.3×10^{-4}.

Proposed method is based on the Thies non-equilibrium formula and its modification made by Jacob (Stanley and Roger, 1966). In the mathematical process to

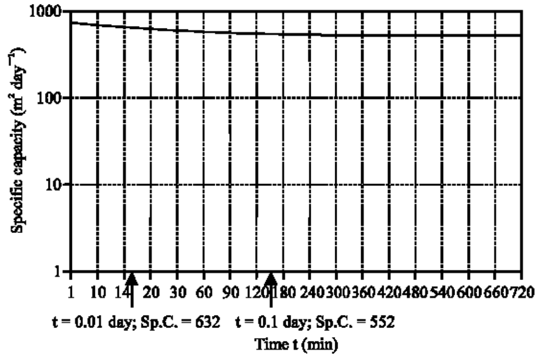

Fig. 2: Specific capacity, time curve for well

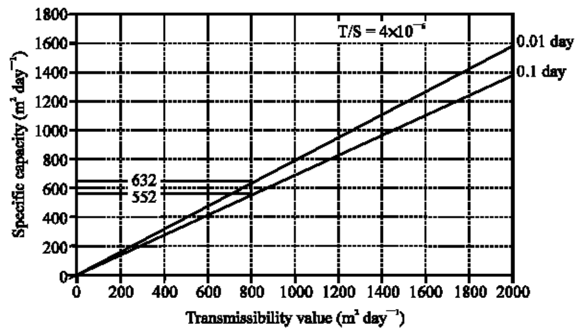

Fig. 3: The relation between specific capacity and transmissibility at $T/S = 4\times10^6$

produce Theis'Formula, there are several assumptions. First, the aquifer is supposed homogenous, isotropic, with constant thickness and an infinite areal extent. Second, the well loss is negligible or must be taken in consideration if it is valuable. Third, the effective radius of the well has not been affected by the drilling and is equal to the nominal radius of the well. Fourth, the discharge, coefficient of transmissibility and storativity are supposed constant during the period of the pumping test.

CONCLUSION AND RECOMMENDATIONS

This graphical method as described and illustrated before is rapid and easy to assess T and S simultaneously, while being based on Theis'Fomula and its modification, without serious errors. For well diameter more then 0.1 meter other sets of calculations and T/S sheets must be prepared. Like Theis non-equilibrium formula, some assumptions, limit the field of application of this method. It is possible to correct values of transmissibility and storativity by using the well-known Hantush modification (Hantush, 1961) of the Theis method or Boonstra method that consists of a matching procedure between the drawdown observed in the field and the theoretical drawdown found from the analysis (Boonstra, 1992).

REFERENCES

Boonstra, J., 1992. Aquifer tests with partially penetrating wells: Theory and practice. J. Hydrol., 137: 165-179.

Forkasiewicz, J., 1972. Interprétation des données de pompage d'essai pour l'évaluation des paramètres des aquifères. Doc. B.R.G.M., Orléans, pp: 31.

Hantush, M.S., 1961. Aquifer tests on partially-penetrating wells. J. Hydraul. Div., Proc. ASCE, 87: 171-195.

Norman, S.B. and M.A.P. James, 1971. An extended theory of delayed yield from storage applied to pumping tests in unconfined anisotropic aquifers. J. Hydrol., 14: 53-65.

Singhal, B.B.S. and B.L. Gupta, 1966. Analysis of pumping test data from a well in the Indo-Gangetic of India and its bearing on the aquifer characteristics. J. Hydrol., 4: 121-140.

Stanley, N.D. and J.M.D. Roger 1966. Hydrogeology. 1st Edn. John Wiley and Sons, New York, pp: 463.

Stefan, J.K. and A.Z. Vitaly, 2004. Influence of aquifer heterogeneity and return flow on pumping test data interpretation. J. Hydrol., 300: 267-285.

Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. Trans. Am. Geophys. Union, 16: 519-524.

Vincent, W.U.H.L. and V.G. Joshi, 1986. Result of pumping tests in the Beccan trap basalts of central India. J. Hydrol., 86: 47-168.

Week, E.P., 2005. Hydrologic properties of coal-beds in the Powder River Basin, Montana II. Aquifer test analysis. J. Hydrol., 308: 242-257.

Xaviez, S., M.M. Peter and C. Jesús, 1999. Pumping tests in heterogeneous aquifers: An analytical study of what can be obtained from their interpretation using Jacob's method. Water Resour. Res., 35: 943-952.