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

Ismail Chenini, Silvain Rafini and Abdallah Ben Mammou

1 Mineral Resources and Environmental Laboratory, Department of Geology, Faculty of Sciences of Tunis, 2092 Tunis El Manar, Tunisia
2 Planctology 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 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:

$$S_w = FQ + cQ^2$$  (1)

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

$$\frac{Q}{S_w} = \frac{1}{F + cQ}$$  (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 $0.2 \times 10^{-4}$ to $6 \times 10^{-5}$, 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

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\[
\frac{Q}{S_w} = \frac{1}{F} \quad (3)
\]

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

\[
S_w = \frac{Q}{4\pi T} \left[ -\ln u + \frac{u}{2} + \frac{u^2}{2} \right] \quad (4)
\]

\[
W(u) = (-0.5772 - \ln u + \frac{u}{2} + \frac{u^2}{3}) \ldots
\]

\[W(u)\] is the well function and \(S_w\) 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 m² 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:

\[
S_w = \frac{Q}{4\pi T} \left( \ln \frac{4 T t}{r_w^2 S} - 0.5772 \right) \quad (5)
\]

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

\[
S_w = \frac{Q}{4\pi T} \left( \ln \frac{4 T t}{r_w^2 S} - 0.5772 \right) + CQ^2 \quad (6)
\]

\[
\frac{Q}{r_w^2 S} = \frac{Q}{4\pi T} \left( 2.303 \ln \frac{4 T t}{r_w^2 S} - 0.5772 \right) + CQ^2 \quad (7)
\]

Comparing Eq. 7 with Eq. 1 therefore:

\[
F = \frac{Q}{4\pi T} \left( 2.303 \ln \frac{4 T t}{r_w^2 S} - 0.5772 \right) \quad (8)
\]

in the other hand, according to Theis formula:

\[
F = \frac{1}{T} \left( 0.183 \ln \frac{4 T t}{r_w^2 S} - 0.046 \right) \quad (9)
\]

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 10⁴ to 10⁶. \(r_w\) 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 \(0.183 \ln \frac{4 T t}{r_w^2 S} - 0.046\) 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 \(T/S\) equal to 0.5 × 10⁶.

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 × 10⁴ to 1 × 10⁶. 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 raditated 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 plot the time vs. the aquifer. After that we divide the value of the constant discharge \(Q\) by each value of net drawdown to obtain the yield 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
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 $0.2 \times 10^{-4}$ 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$^3$ day$^{-1}$. This value is 552 m$^3$ day$^{-1}$ at 144 min. Therefore, the difference equals 80 m$^3$ day$^{-1}$. It is the difference as shown in Fig. 3 between specific capacities. 632-552 = 80 is only found in the sheet of $T/S = 4 \times 10^6$. Drop a vertical line on x axis, we will get the value of $T = 800$ m$^3$ day$^{-1}$.

So, $S = (800/4 \times 10^6) = 2 \times 10^{-4}$. Jacob method gives a value of transmissibility equal to 792 m$^3$ day$^{-1}$ and a coefficient of storage equal to 7.3 $\times 10^{-4}$.

Proposed method is based on the Theis non-equilibrium formula and its modification made by Jacob (Stanley and Roger, 1966). In the mathematical process to 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 Formula and its modification, without serious errors. For well diameter more than 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