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RESEARCH PAPER

Analyses of Storage Coefficient for a Production Well

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A B S T R A C T:

In case of Production or (single) well pumping tests the Storativities are overestimated, it depends on radial distance between effective well bore radius in single well test. The objective of the paper proposed to drive the diffusion equation to find out the effective radial distance. Applying AQTISOLVE and Aquifer win 32 software via Jacob method for well testing , we can obtain the Storativity value and the Transimissivity using specific capacity data to check the Transimissivity value . The advantage of this method reducing the cost by having single well test (production well) without observation well. Justification the parameters of aquifer is require because turbulent velocity and the screen of well (aquifer losses and well losses). Application of single well test lead to understand aquifer layer and the management of reservoir.

KEY WORDS: Diffusion equation, Single well test, Aquifer parameters, Effective radius.
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INTRODUCTION :

Groundwater plays a major role in water supply and irrigation worldwide. With the growth of the population, the abstracting water increases and the water level decreases, these may lead to effect on the groundwater management, and change the characteristics of the aquifer. The withdrawal water from the aquifer required to testing of the aquifer in order to estimate the capacity of the well and determine the accurate aquifer properties. The test data were analyses through many methods according to the situation of each location.

Estimating the accurate values of aquifer parameters required conducting pumping test on the production well and measuring drawdown in the monitoring well .but it needed high cost of economy, so in order to decrease cost of other well ,it is regarded to used many methods for that test which is known as single well test.

Single-well aquifer tests consist of monitoring water-level changes in a well before, during, and after a known volume of water is either injected or removed from a formation open to the well. Single-well aquifer tests are described in this report, including pumping and slug tests. Water is typically removed from the well (pumped) at a constant rate during pumping tests (Kruseman et al., 1970).

The first scientist was (Theim, 1906) that developed a method for both confined and unconfined aquifer according to the Dupuit assumptions in 1863, who governed the equation for flow in water table aquifer for steady state

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(equilibrium conditions). Later, (Theis, 1935) based on heat transfer derived a method for transient groundwater flow in confined aquifer, then (Cooper Jr and Jacob, 1946) simplified Theis solution for long time of pumping test and small radial distance, both previous equations are applicable for unconfined aquifer type, if the drawdown is very small compared to the saturated thickness of the aquifer. Since the last decade there are many experiences that are tried to discover a method to estimate the aquifer parameters through analyzing single well test data such as by using single well test with the Cooper-Jacob method shows overestimate of transmissivity for unconfined aquifer while, for confined aquifer near to the known value (Keith J. Halford, et al, 2006). Moreover, (Anomohanran & serhien-Emekeme , 2014) performed a pumping test data to estimate aquifer parameters using Cooper-Jacob straight line method. and the method of (P. N. Ballukraya, et al,1991) it derived an equation to estimate Storativity by recovery test, Also (M. Razack, et al, 1991) tried to determine Transmissivity through specific capacity data, then aquifer Parameters and Well Efficiency Estimation for Selected Site in Erbil Governorate (Mawlood and Mustafa, 2017).

Now, Aquifer Test, AQTISOLVE and Aquifer win 32 software which calculates the parameters of the pumping test by computer, these software's are specifically used for the analysis of data of pumping test, data processing, analysis and research of obtaining parameters graphically. It can be applied to calculate the data of the pumping test and complete the display and printing of the process and get the result of parameters.

2. METHOLOGY

2.1.1 Derivation of Diffusion Equation for x-axis:

Storativity for a single well test, such as effective well bore storage (Choi, 2007), Recovery test (Ballukraya and Sharma, 1991), slug test, etc. In this case due to the absence of the observation well the application of diffusion equation is selected for ground water flow in the vicinity of the well. The pumping test is conducted by pumping water from the well itself at a constant rate and measuring the drawdown in the well as a function of time. The test data are used to understand how water.

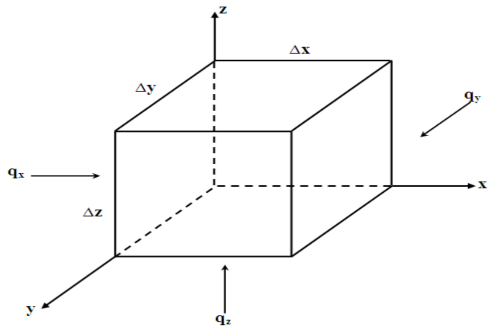

Figure 1 : Representative control volume (RCV)

The difference between inflow and outflow=change of storage

Flow in-flow out=change of storage

qin-qout=Δs

$$qin - \left(qin + \frac{dq}{dx}dx\right) = \Delta s \qquad (1)$$

since:

By substituting Darcy equation in terms of x-direction obtain the equation below:

$$-\frac{dq}{dx}dxA = \mathrm{SA}\frac{\mathrm{dh}}{\mathrm{dt}} \qquad (2)$$

$$-\frac{d\left(-K\frac{dh}{dx}\right)}{dx}dx(dydz) = S(dxdy)\frac{dh}{dt} \qquad (3)$$

horizontal area vertical area

$$dzK\frac{d^2h}{dx^2} = S\frac{dh}{dt} \qquad (4)$$

where:

dz is equal to the aquifer thickness T=Kb=Kdz, So:

$$T\frac{d^2h}{dx^2} = S\frac{dh}{dt} \qquad (5)$$

$$\frac{T}{S}\frac{d^2h}{dx^2} = \frac{dh}{dt} \qquad (6)$$

$$\eta\frac{d^2h}{dx^2} = \frac{dh}{dt} \qquad (7)$$

The above equation is 1D diffusion equation in x-direction.

2.1.2 Derivation of Diffusion Equation for y-axis:

$$qin - \left(qin + \frac{dq}{dy}dy\right) = \Delta s \qquad (8)$$

$$-\frac{dq}{dy}dyA = \mathrm{SA}\frac{\mathrm{dh}}{\mathrm{dt}} \qquad (9)$$

Then replacing Darcy's equation for y-direction

$$-\frac{d\left(-K\frac{dh}{dy}\right)}{dy}dy(dxdz) = S(dxdy)\frac{dh}{dt} \qquad (10)$$

$$dzK\frac{d^2h}{dy^2} = S\frac{dh}{dt} \qquad (11)$$

$$T\frac{d^2h}{dy^2} = S\frac{dh}{dt} \qquad (12)$$

$$\frac{T}{S}\frac{d^2h}{dy^2} = \frac{dh}{dt} \qquad (13)$$

$$\eta\frac{d^2h}{dy^2} = \frac{dh}{dt} \qquad (14)$$

The above equation is diffusion equation for y-direction.

2.1.3 Derivation of Diffusion Equation for z-axis:

$$qin - \left(qin + \frac{dq}{dz}dz\right) = \Delta s \qquad (15)$$

$$-\frac{dq}{dz}dzA = \mathrm{SA}\frac{\mathrm{dh}}{\mathrm{dt}} \qquad (16)$$

Then replacing Darcy's equation for z-axis, it will be:

$$-\frac{d\left(-K\frac{dh}{dz}\right)}{dz}dz(dxdy) = S(dxdy)\frac{dh}{dt} \qquad (17)$$

$$dzK\frac{d^2h}{dz^2} = S\frac{dh}{dt} \qquad (18)$$

$$T\frac{d^2h}{dz^2} = S\frac{dh}{dt} \qquad (19)$$

$$\frac{T}{S}\frac{d^2h}{dz^2} = \frac{dh}{dt} \qquad (20)$$

$$\eta\frac{d^2h}{dz^2} = \frac{dh}{dt} \qquad (21)$$

The above equation is diffusion equation for z-direction, And for 3D diffusion equation the it will be:

$$\eta\frac{d^2h}{dx^2} + \eta\frac{d^2h}{dy^2} + \eta\frac{d^2h}{dz^2} = \frac{dh}{dt} \qquad (22)$$

$$\eta\left\{\frac{d^2h}{dx^2} + \frac{d^2h}{dy^2} + \frac{d^2h}{dz^2}\right\} = \frac{dh}{dt} \qquad (23)$$

The above equation 3D Transient Groundwater flow for isotropic homogeneous confined aquifer ,and it can be written in other form such as:

$$\eta\nabla^2h = \frac{dh}{dt} \qquad (24)$$

Where:

q : is Darcy flux(L/T).
K : is Hydraulic conductivity(L/T)
s : is aquifer storage (unitless)
T : is Transmissivity (L^2/T).
S : is Storativity(unit less).
η : is diffusivity (L^2/T).
x,y,z : is axis in the direction of x, y and z respectively.
t: is time (T).

∇:is lamda or lacplacian
By using the dimension of the equations:

η length/length²=length/time
(25)

Simplify the equation:
$\eta\ 1/l^2=1/T$ (26)
$l^2=4\eta\tau$ (27)
$L=2\sqrt{\eta\tau}$ (28)
Where:

L: is radial distance from pumping well to monitoring well (L).
$\mathcal{T}$: is time (T).
2: Geometric term.
η: is aquifer diffusivity(L^2/T) which is equal to :

$$\eta = \frac{T}{S} = \frac{Kb}{Ssb} \quad (29)$$

The equation of (27) can be used to find out the radial distance at time of pumping, then substituting this distance as a radial distance from cooper-Jacob's time -drawdown equation to estimate Storativity (S).

2.2 Cooper-Jacob Straight Line Equation

Jacob (1946) derived a method based on Theis (1935) equation for large values of time (t) and small value of u and for time versus drawdown after considering Jacob's assumptions:

$$s = \frac{2.3Q}{4\pi T}\log_{10}\frac{2.25Tt_{\circ}}{r^2S} \quad (30)$$

To calculate the value of Transmissivity through Jacob's equation:

$$T = \frac{2.3Q}{4\pi\Delta s} \quad (31)$$

The above equation is used to estimate Transmissivity ,the slope of the line(Δs) on the semi logarithmic plot are taken by measuring the difference between two drawdown per one log cycle ,and the intercept of the straight line at zero drawdown determines the initial pumping test time($t_{\circ}$) ,then using it to estimate storage coefficient(S) in the equation below:

$$S = \frac{2.25Tt_{\circ}}{r^2} \quad (32)$$

Where:

r: radial distance from pumping well to observation well (calculated from diffusion equation) (L).

2.3Application of Diffusion Equation:

The first step to finding the values of diffusivity by dividing equivalent hydraulic conductivity (K) on specific storage (Ss):
η=Kb/Ssb
η=k/Ss
$\eta=0.1m^2/s$
[The value of aquifer diffusivity (η) determined according to the geological formation in the vicinity of the well during borehole test and sampling Fig.2and Table 1]. For soils and unconsolidated materials, the skeleton compressibility dominates fluid compressibility .Fracture wespecially have very small storage and potentially very high T, hence fractured rocks.

$L=2\sqrt{0.1*0.4*60}$
L=60m

After taking out the value of radial distance within diffusivity equation and estimating the value of Storativity, then the test data Table2 should be plot on semi-log paper. To determine the values of Δs and $t_{\circ}$ on plot, see Fig.3
Although the following steps should be taken into account during the calculation in order to get the values of both Transmissivity and Storativity as the following calculations:

$$T = \frac{2.3*0.029}{4*\pi(0.4)} = 0.013m^2/s$$

And Storativity:

$$S = \frac{2.25 * 0.013 * 0.4 * 60}{60^2} = 0.0001$$

The value of Storativity for confined aquifer type is within the range of (0.001-0.00001) according to (Michael et al.,2006)

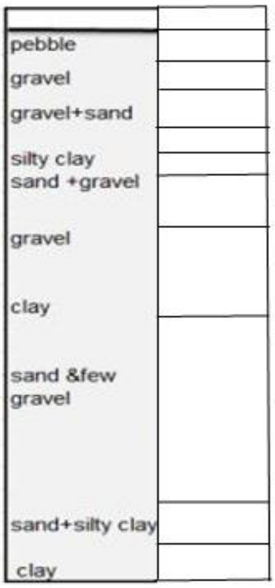

Figure 2: Geological profile taken from borehole test.

Table 1 Ranges of storitivity and diffusivity according to geological information

	∝	β	n	k	Ss	η
	1/pa			m/s	1/m	m^2/s
Clay	1.00e-07	4.40E-10	0.25	1.00E-10	9.81E-04	1.0E-07
Silt	5.00E-07	4.40E-10	0.25	1.00E-07	4.90E-03	2.0E-05
Sand	1.00E-08	4.40E-10	0.25	1.00E-05	9.91E-05	1.0E-01
Gravel	1.00E-08	4.40E-10	0.25	1.00E-03	9.91E-05	1.0E+01
Jointed Garnite	1.00E-11	4.40E-10	0.0001	1.00E-07	9.84E-08	1.0E+00
Facture Zone	1.00E-11	4.40E-10	0.001	1.00E-05	1.02E-07	9.8E+01

$Ss=\rho g(\propto+n\,_{\beta})(1/L)$

$\propto$= Solid skeleton compressibility (1/pressure)

$_{\beta}$= fluid compressibility

n=porosit

2.4 Transmissivity from specific capacity data

We can also fine Transmissivity by

- Specific capacity = yield/drawdown.
- $T = Q/ (h_0-h)\ 2.3/4\pi \log (2.25Tt/ (r^2S))$.
- $T = 15.3\ [Q/(h_0-h)]^{0.67}$ [m,d]
- $T = 0.76\ [Q/(h_0-h)]^{1.08}$ [m,d]

Study Area

Salah al-Din district is one of the districts of Shaqlawa district in Erbil province in Iraq, with a total area of 796 km 2, while the villages belonging to it have 56 villages and 25% lands, 35% hills and 40% mountains.

The pumping test exercise was carried out on a single well within the Salahaddin area, with a constant discharge of 177 Gpm (1146.96 m^3/day). The pumping well has a depth of 150 m. The aquifer saturated thickness is 138 m and the original static water level is 12 m, coordination number 38s0423770, UTM 4033138 with elevation :756m.

Figure 2: Satellite image of salahaddin area

Well depth: 150 m	**Length of pipe test:** 120 m
Static water level: 12 m	**Radius of pipe test:** 3 in
Dynamic water level: 18 m	**Type of test equipment:** 30-SP46 4 in
Discharge: 177(gal/min), 1146.96 (m^3/day)	**Inside raduis of pipes:** 8 in

Table(2) Pumping test data results from Directorate of Erbil Groundwater

Time (min)	**Depth to water level (meter)**	**Drawdown (meter)**	**Time (minute)**	**Depth to water level (meter)**	**Drawdown (meter)**	**Time (minute)**	**Recovery (meter)**
0	12	0	60	18	6	0.5	18
0.5	16.5	4.5	80	18	6	1	18
1	16.8	4.8	100	18	6	1.5	18
1.5	17.2	5.2	120	18	6	2	18
2	17.4	5.4	140	18	6	3	18
3	17.6	5.6	160			4	18
4	17.8	5.8	200			5	18
5	17.9	5.9	280			6	18
6	18	6	300			7	18
7	18	6	360			8	18
8	18	6	420			9	18
9	18	6	480			10	18
10	18	6	540			15	18
15	18	6	600			20	18
20	18	6	660			25	18
25	18	6	780			30	18
30	18	6	900			40	18
40	18	6	1020			50	18
50	18	6	1140			60	18
			24 hours				

3. RESULTS AND DISCUSSION

Table 3 presents aquifer parameters results from Salahaddin area by Jacob method. During the comparison between the calculated and standard range of Transmissivity, The calculated value of Transmissivity of Salahaddin well which can be classified according to (Table 3) from high to intermediate.

Figure 3 : Cooper-Jacob solutions by AQTISOLVE program

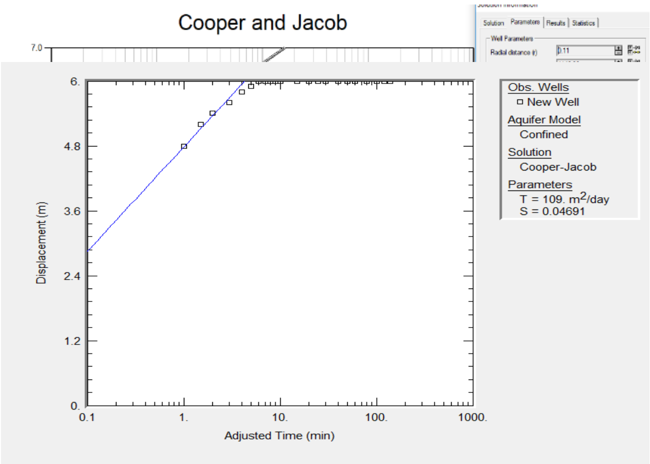

Figure 4: Cooper-Jacob solutions by aquifer test program

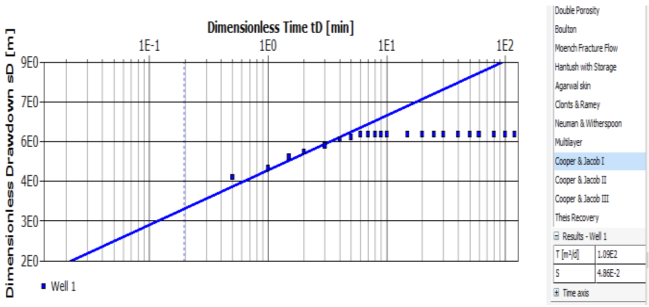

Figure 5 : Cooper-Jacob solutions by aquifer win 32 program

Table 3 Result of Transmissivity and Storativity by Jacob (1946) method

Jacob (1946) method	Transmissivity (m^2/day)	Storativity
AQTESOLVE program	109	0.04691
Aquifer test program	109	0.0486
Aquifer win 32 program	112.59	0.0410
Transmissivity from specific capacity data	221	-

Table 4 Transmissivity classification (Jirikrasny et al., 1993).

Coefficient of Transmissivity (m^2/day)	class of Transmissivity magnitude	Designation of Transmissivity magnitude
>1000	I	very high
100 to 1000	II	High
10 to 100	III	Intermediate
1 to 10	V	Low
0.1 to 1	IV	Very low
<0.1	VI	Imperceptible

CONCLUSION

The presented method can be used to analyses Storativity , according to the results ,the value of the Storativity is within the standard range for confined aquifer type which is between 0.001 to 0.00001, thus the paper satisfied that the values of the aquifer parameters especially Storativity can be find out from single well test by finding the radial distance through diffusivity equation and using this distance to calculate Storativity without existing monitoring well, however , it is obvious that the values of Storage coefficient cannot be accurate in case of have a single-well test because of two reasons first : it depends on radial distance between pumping well to point of measuring drawdown, we need observation well, second: Have a well loss and aquifer loss, which give inaccurate data of storativity. Monitoring well has no screen and the velocity of screen wells laminar by single well which have a submerging pump lead to turbulent velocity in the vicinity of the well, but this article proved that the suggested method succeeded in providing radial distance. This may lead to reduce the cost of drilling of observation well as well. Aquifer Test, AQTISOLVE and Aquifer win 32 software have been used for determine confined aquifer parameters. Using specific capacity data in order to obtain the Transimissivity to be compared with all programs that applied in research

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