EVALUATION OF STORATIVITY AND SKIN FACTOR FROM AQUIFER TEST

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Determination of aquifer hydraulic properties is a basic component of most groundwater supply and contaminant transport investigation. Unsteady flow to a single well fully penetrating confined aquifer is analysed. The well is assumed to be located in an infinite system. Procedure for determination of the skin factor and storativity from pumping test data at a single well (no observation well is available) dominated skin effect is presented This method can be used for the case if skin effect dominated and wellbore storage tends to zero.

groundwater; pumping test; storativity; skin factor

INTRODUCTION

One of the first solutions to the diffusivity equation (if wellbore storage and skin effect are taken into account) was presented by Agarwal (Agarwal et al., 1970). Since then many authors derived various methods analysing these effects (Batu, 1998; Raghavan, 1993; Moench, 1995, 1997; Pech, 2003). In this contribution method for determination skin factor, W and storativity, S from pumping test data affected only by skin effect (the volume of a wellbore is neglected) is derived. Pumpimg test must be conducted long enough for semilogarithmic analysis (transmissivity, T is evaluated from the late-portion of pumping test by means of the Jacob's semilogarithmic approximation).

MATERIAL AND METHODS

Dimensionless parameters

The following dimensionless parameters are used:
Dimensionless drawdown at a well

$$s_{WD}(t_D) = \frac{2\pi T}{Q}\left(s_W(t)\right) \tag{1}$$

where: T – transmissivity
t – time
s_W – drawdown at a pumping well
Q – well discharge

Dimensionless time

$$t_D = \frac{T_t}{r_w^2 S} \tag{2}$$

where: r_W – well radius
S – storativity

Dimensionless radius

$$r_D = \frac{r}{r_W} \tag{3}$$

where: r – radial distance

Dimensionless skin factor

$$W = \frac{2\pi T s_W}{Q} \tag{4}$$

where: s_W – drawdown caused by additional resistance at a well

SKIN EFFECT

Skin effect is a concept to characterize a production well that is surrounded by a local region with transmissivity that is different from the aquifer transmissivity. This can occur when the aquifer material next to the well is "damaged" by invasion of drilling mud, in which the transmissivity next to the well is lower than the transmissivity of the aquifer, or if the well is surrounded by a gravel pack, in which the transmissivity next to the well is higher than the transmissivity of the aquifer. The zone of altered transmissivity is often called a "skin". This notion was first introduced in the petroleum literature by van Everdingen (1953).

The mathematical problem describing flow to a well surrounded by a skin of infinitesimal thickness is described by the partial differential equation for radial flow to a well fully penetrating confined aquifer expressed in dimensionless form :

$$\frac{\partial^2 s_D}{\partial r_D^2} + \frac{1}{r_D}\frac{\partial s_D}{\partial r_D} = \frac{\partial s_D}{\partial t_D} \tag{5}$$

The following assumptions are considered:

- the aquifer is homogeneous, of infinite lateral extent, horizontal and of uniform thickness
- aquifer is isotropic
- the porous medium and fluid are slightly compressible and have constant physical properties
- before pumping the piezometric surface is horizontal
- the pumped well is infinitesimal in diameter
- skin effect is constant during time

As was shown by Agarwal (1970), the complete solution to the problem under consideration may be obtained by the application of the Laplace transformation technique. The Laplace transform is inverted numerically using the Stehfest algorithm 368 (Stehfest, 1970).

SOLUTION

Dimensionless drawdown at a well (from Agarwal's drawdown in Laplace space) was obtained by applying the Stehfest inversion algorithm. By means of program STEHF a dimensionless drawdown at a well for the range of values of skin factor $W = 0, 2, 4, 6, \ldots, 26, 28, 30$ was evaluated. Example of evaluation is shown in Fig. 1.

As can be seen in Fig.1 two semilogarithmic straight lines are obtained. It is in accordance with Garcia-Rivera and Raghavan (1979). The second straight line represents the part which can be evaluated by means of Jacob's semilogarithmic method.

Equation of the first straight line is written in the following form:

$$s_D = i_D \cdot \log(t_D) + k_D \qquad (6)$$

where: i_D – the slope of the first straight line

Coefficients k_D for all values of skin factor, W were evaluated. Results of these evaluation are given in Table 1. The graph k_D vs. W (Fig. 2) proves that linear relationship is an acceptable approximation.

Thus, we can write for k_D

$$k_D = a_0 + a_1 W \qquad (7)$$

where: a_0 and a_1 – coefficients

By means of least square method a_0 and a_1 were evaluated

$a_0 = -6.34981$; $a_1 = 1.00212$

For $s_D = 0$ from eq. 7 follows:

$$0 = i_D \log(t_{DP}) + k_D \Rightarrow t_{DP} = 10^{-k_D/i_D} \qquad (8)$$

where: t_{DP} – intersection time (where the first straight line intersects the horizontal axis)

These intersection times, t_{DP} for all values W are in Table 2.

The relationship between intersection time t_{DP} and W (Fig. 3) can be approximated by a polynomial of the 3rd degree:

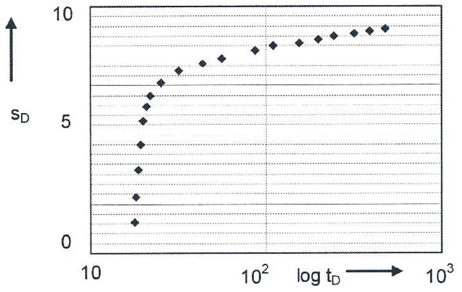

Fig. 1. Semilogarithmic graph s_D vs. log t_D

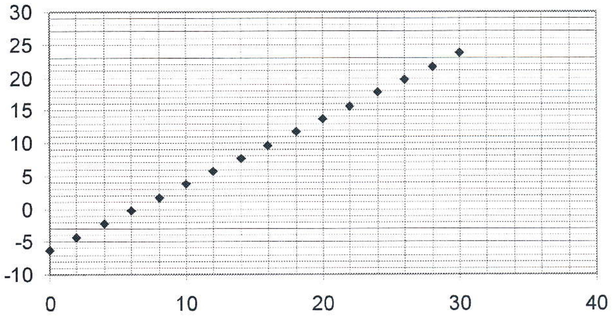

Fig. 2. Graph k_D vs. W

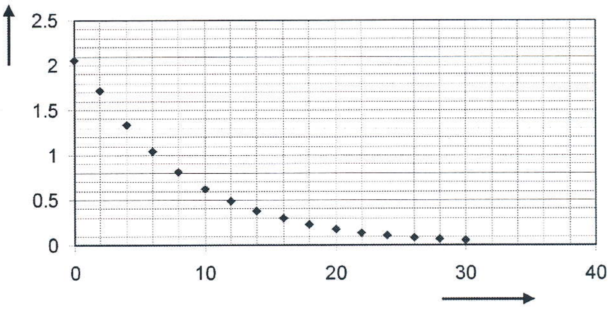

Fig. 3. Graph t_{DP} vs. W

$$t_{DP} = b_0 + b_1 W + b_2 W^2 + b_3 W^3 \qquad (9)$$

By means of least square method, b_0, b_1, b_2 and b_3

$b_0 = 1.928145$; $b_1 = -0.154089$;

$b_2 = 3.1516 \cdot 10^{-3}$; $b_3 = 2.8772 \cdot 10^{-7}$

were evaluated and b_3 can be neglected.

Table 1. Coefficients k_D

W	k_D	W	k_D	W	k_D
0	–6.304	12	5.694	24	17.694
2	–4.304	14	7.694	26	19.694
4	–2.304	16	9.694	28	21.694
6	–0.304	18	11.694	30	23.694
8	1.694	20	13.694		
10	3.694	22	15.694		

Table 2. Intersection times, t_{DP}

W	t_{DP}	W	t_{DP}	W	t_{DP}
0	1.410	12	0.487	24	0.107
2	1.722	14	0.379	26	0.083
4	1.338	16	0.294	28	0.065
6	1.039	18	0.229	30	0.050
8	0.807	20	0.178		
10	0.627	22	0.138		

RESULTS AND DISCUSSION

We have a complete pumping test data (Fig. 4). For determination of transmissivity, T storativity, S and skin factor, W from pumping test influenced only by skin effect, the following procedure is suggested:

- from the slope of the second straight line i we can calculate transmissivity, T (by using Jacob's semilogarithmic approximation):

  $$T = 0.183Q/i$$

- from the first straight line coefficient k_D is calculated

  $$k_D = 2\pi T K/Q$$

- by using eq. (7) skin factor is

  $$W = (k_D - a_0)/a_1$$

- for the drawdown at the well $s = 0$ from the first straight line we obtain intersection time t_P and then from eq. (9) it follows

  $$t_{DP} = b_0 + b_1W + b_2W^2 + b_3W^3$$

- and the storativity

  $$S = Tt/r_V^2 \cdot t_{DP}$$

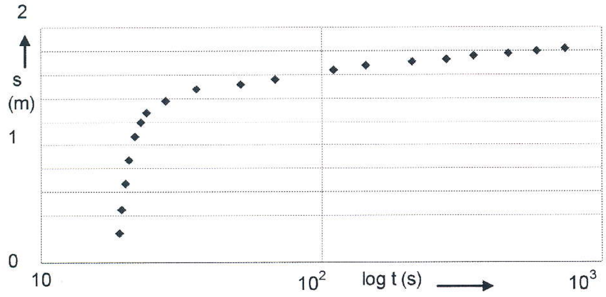

Fig. 4. Semilogarithmic graph s vs. log (t)

Presented method suggests evaluation of the skin factor, W and storativity, S from pumping test data influenced by skin effect (if no observation is available). Pumping test must be long enough to get two straight lines where the second straight line is the right line for Jacob's semilogarithmic approximation. Then the derived procedure can be used.

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Vyhodnocení storativity a skinového faktoru z čerpací zkoušky.

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V práci je odvozen postup určení základních hydraulických parametrů zvodnělého prostředí, tj. storativity a koeficientu dodatečných odporů, tzv. skinového faktoru, pro případ hydrodynamické zkoušky na odčerpávaném vrtu, není-li k dispozici pozorovací vrt. Na odčerpávaném vrtu je uvažován vliv dodatečných odporů. Neuvažuje se s vlivem objemu vrtu na průběh počátečního úseku hydrodynamické zkoušky, tj. poloměr vrtu je zanedbatelně malý.

Při odvození nové metody stanovení storativity a skinového faktoru bylo vycházeno z řešení základní parciální diferenciální rovnice axiálně-symetrického přítoku vody k vrtu. Rovnice je řešena v bezrozměrných parametrech pomocí Laplaceovy transformace. K inverzi byl použit Stehfestův algoritmus 368 (Stehfest, 1970). Pro nulové hodnoty storativity vrtu byly pomocí programu STEHF vyhodnoceny sklony prvního přímkového úseku grafu čerpací zkoušky a jeho průsečíky s vodorovnou osou log *t* pro koeficienty dodatečných odporů v rozsahu 0 až 30 (tab. 1 a 2). V příspěvku je navržen postup určení transmisivity, storativity i koeficientu dodatečných odporů z údajů čerpací zkoušky na odběrovém vrtu pro případ, kdy není k dispozici pozorovací vrt. Je nezbytné, aby čerpací zkouška trvala dostatečně dlouho a byl zachycen i úsek vyhodnotitelný Jacobovou semilogaritmickou aproximací.

vrt; hydrodynamická zkouška; dodatečné odpory

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