PROCESSING OF EXPERIMENTAL DATA DERIVED FROM PUMPING THE PERFECT WELLS IN COMPLEX AQUIFERS

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Abstract

In this paper, the correct interpretation of experimental data derived from pumping the perfect wells in complex aquifers was drawn up a mathematical model of computing and automatic data processing which is facilitated by computer program Filtrate Coefficients m. Thus filtration coefficients by each filtrate aquifer and the coefficient of proportionality of the Kusakin formula for the radius of drilling influence a_R were determined. The proposed model was applied to case study of the Miercurea Ciuc area.
According to the mathematical model proposed a data processing was found that permeability of the aquifer under pressure is about four times higher than the groundwater aquifer, but for the constant a_R obtained a value closer to the one proposed by Kusakin, which is a validation of the algorithm calculation.

Key words: confined aquiferous, unconfined aquiferous, filtration coefficients, pumping test

In this work, a mathematical model of computing was drawn up in order to facilitate the correct interpretation of experimental data derived from pumping the perfect wells in complex aquifers, coordinated by a computer program Filtrate Coefficients of Matlab automatic data processing.

MATERIAL AND METHOD

There were considered that complex aquifers can be equated with a phreatic aquifer (free level) overlapped on the aquifer under pressure.

We propose, on the basis of the trial of drilling pumping, to assess factors including filtrate coefficients equivalents for the phreatic aquifer, k_p, and for aquifer under pressure, k_p, as well as the coefficient of proportionality of the Kusakin formula type for the radius of influence of drilling, a_R.

The total flow pumped from drilling, Q_T, corresponding to the dishevelment, is equal to the amount of flow captured from phreatic aquifer, Q_f, and those captured from the aquifer under pressure, Q_p.

These flows are evaluated with the formulas for perfect wells Bartha I., Javgureanu V , 1998) in the aquifer with free level(1) and, respectively, in the aquifer under pressure (2).

$$Q_f = \frac{\pi k_f \, s\left(2H_f - s\right)}{\ln \frac{R}{r}} \quad (1)$$

$$Q_p = \frac{2\pi \, k_p \, sM}{\ln \frac{R}{r}} \quad (2)$$

for the Q_T flow resulting the equation (3)

$$Q_T = \frac{\pi}{\ln R - \ln r}\left[k_f\left(2H_f - s\right) + k_p \, M\right]s \quad (3)$$

where:
M – thickness of layer (when opening) the aquifer under pressure, [m];
k_f – filtrate coefficient (permeability) equivalent of the phreatic aquifer, [m/s];
k_p – filtrate coefficient of aquifer under pressure aquivalent, [m/s];
H_f – water depth phreatic aquifer layer (above the base layer of this aquifer) as natural, [m];
H_f – piezometric load layer of the aquifer under pressure (calculated on the base layer of aquifer under pressure), naturaly (without pumping), [m];
r – the radius of the well, [m];
R – radius of influence of the well (addicted by the hydraulic characteristics of the aquifer, **k** and **H**, as well as of the dichevelment of **s**).
Considering the range R of a relationchip type Kusakin:

$$R = a_R \, s\sqrt{k_f \, H_f} \quad (4)$$

where $\mathbf{a_R}$ is a coefficient of proportionality (acording to Kusakin, a_R=575) the aquation *(3)* becomes:

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$$Q_T = \frac{\pi \cdot \left[k_f \left(2H_f - s \right) + 2k_p M \right] \cdot s}{\ln(a_R) + \frac{1}{2}\ln(k_f) + \ln(s) + \frac{1}{2}\ln(H_f) - \ln(r)} \quad (5)$$

Performing pumping essays with $N_T \geq 3$ steps,

$$\left(s_i, Q_{Ti}\right), i = 1, \cdots, N_T, \quad (6)$$

$s_i < H_f$ it gets a N_T system of aquations, with 3 variables : a_R, k_f si kp.

In a particular case, N_T=3, the above system was transcribed in the form of :

$$\begin{cases} B_{s1}k_f - \frac{1}{2}\ln\left(k_f\right) + 2\pi M \frac{s_1}{\left(Q_T\right)_1} k_p - C_{s1} = \ln\left(a_R\right) \\ B_{s2}k_f - \frac{1}{2}\ln\left(k_f\right) + 2\pi M \frac{s_2}{\left(Q_T\right)_2} k_p - C_{s2} = \ln\left(a_R\right) \\ B_{s3}k_f - \frac{1}{2}\ln\left(k_f\right) + 2\pi M \frac{s_3}{\left(Q_T\right)_3} k_p - C_{s3} = \ln\left(a_R\right) \end{cases} \quad (7)$$

where the notation introduced:

$$B_{si} = \pi \frac{2H_f - s_i}{\left(Q_T\right)_i} s_i ,$$

$$C_{si} = \ln\left(s_i\right) + \frac{1}{2}\ln\left(H_f\right) - \ln r, \text{ cu } \left(i{=}1,2,3\right) \quad (8)$$

For the above system, dividing each member with the second member of the second and third equation, the variable a_R from the first equation can be removed, which, taking into account the realtions (8), can be led to the following system of two equations of variables k_f and k_p:

$$\begin{cases} 2\pi M A_{s2} k_p = \left(B_{s1} - B_{s2}\right) k_f + \ln s_2 - \ln s_1 \\ 2\pi M A_{s3} k_p = \left(B_{s1} - B_{s3}\right) k_f + \ln s_3 - \ln s_1 \end{cases} \quad (9)$$

where the notation introduced below

$$A_{s2} = \left[\frac{s_2}{\left(Q_T\right)_2} - \frac{s_1}{\left(Q_T\right)_1} \right], A_{s3} = \left[\frac{s_3}{\left(Q_T\right)_3} - \frac{s_1}{\left(Q_T\right)_1} \right] \quad (10)$$

Removing the variable k_p from the system above, resulted a first degree equation on variable k_f, which represent the following solution:

$$k_f = \frac{A_{s3}\left(\ln s_2 - \ln s_1\right) - A_{s2}\left(\ln s_3 - \ln s_1\right)}{A_{s2}\left(B_{s1} - B_{s3}\right) - A_{s3}\left(B_{s1} - B_{s2}\right)} \quad (11)$$

Moving ahead, from each equation of the system (9), have resulted a solution for variable k_p:

$$\left.\begin{aligned} \left(k_p\right)_1 &= \frac{\left(B_{s1} - B_{s2}\right) k_f + \left[\ln\left(s_2\right) - \ln\left(s_1\right)\right]}{2\pi M A_{s2}} \\ \left(k_p\right)_2 &= \frac{\left(B_{s1} - B_{s3}\right) k_f + \left[\ln\left(s_3\right) - \ln\left(s_1\right)\right]}{2\pi M A_{s3}} \end{aligned}\right\} \quad (12)$$

In order to verify the analytical and numerical calculations, the condition $\left(k_p\right)_1 \cong \left(k_p\right)_2$, must be satisfied , then, the following arithmetic average should be adopted for the k_p :

$$k_p = \frac{1}{2}\left[\left(k_p\right)_1 + \left(k_p\right)_2\right] \quad (13)$$

Moving forward, from each equation of the system (7), have resulted a solution for variable a_R:

$$\left.\begin{aligned} \left(a_R\right)_1 &= \exp\left[B_{s1}k_f - \frac{1}{2}\ln\left(k_f\right) + 2\pi M \frac{s_1}{\left(Q_T\right)_1} k_p - C_{s1} \right] \\ \left(a_R\right)_2 &= \exp\left[B_{s2}k_f - \frac{1}{2}\ln\left(k_f\right) + 2\pi M \frac{s_2}{\left(Q_T\right)_2} k_p - C_{s2} \right] \\ \left(a_R\right)_3 &= \exp\left[B_{s3}k_f - \frac{1}{2}\ln\left(k_f\right) + 2\pi M \frac{s_3}{\left(Q_T\right)_3} k_p - C_{s3} \right] \end{aligned}\right\} \quad (14)$$

In order to verify the analytical and numerical calculations, the condition : $\left(a_R\right)_1 \cong \left(a_R\right)_2 \cong \left(a_R\right)_3$, must be satisfied , then, at the final stage, the following arithmetic average should be adopted for the a_R:

$$a_R = \frac{1}{3}\left[\left(a_R\right)_1 + \left(a_R\right)_2 + \left(a_R\right)_3\right] \quad (15)$$

The input data as well as output data are described in the Program List, on DATA SECTION.

INPUT DATA

Geometrical characteristics of phreatic and under pressure aquifers

b - the depth of the track, *b,* of the first waterproof layer (the base layer of phreatic aquifer, which is the same as the waterproof ceiling of aquifer under pressure), [m];

a - thickness, *a*, of the waterproof ceiling of aquifer under pressure, [m];

MC - thickness, *M*, of the layer of aquifer under pressure, [m];

Geometrical characteristics of drillings and pumping parameters essays (pumping test)

r_C - inner radius of drilling, *r*, [m]

N_T- number of pumping steps, N_T;

s- vector that includes values of drilling dishevelment, s_i, (*i*=1,2,3), corresponding to each stage of pumping, [m];

Q - variables $(Q_T)_i$, (i=1,2,3), of the total flow extracted from drilling, Q_T, corresponding to each stage of pumping, $[m^3d^{-1}]$.

Hydrogeological characteristics of the phreatic aquifers and under pressure
dLt - depth,δ, at the level of hydrostatic, NHS, [m].

OUTPUT DATA
Values of secondary size (auxiliary)

H_f –water depth of the phreatic aquifer layer, H_f, (above the base layer of this aquifer), naturaly, [m];

H_p – piezometric load layer of the aquifer under pressure, H_f, (calculated on the base layer of aquifer under pressure), naturally (without pumping), [m];

Bs1, Bs2 , Bs3 ,Cs1, Cs2, Cs3 - expresions B_{si} and C_{si},(i=1,2,3) given by relations (8)

As2, As3= expresions A_{s2} and A_{s3} given by relations (10)

K_p1, K_p2= variables $(kp)_1$ and $(kp)_2$ for the filtrate coefficient of aquifer under pressure, evaluated by the relation (12);

a_R1, a_R2, a_R3=values $(a_R)_1$, $(a_R)_2$ and $(a_R)_3$ for the coefficient of proportionality of the equation type Kusakin for the radius of influence R of the well (drilling), evaluated by the relation (14);

The values of the main measures

K_f - filtrate coefficient of phreatic aquifer, k_f, evaluated by the relation (11);

K_p - filtrate coefficient of aquifer under pressure, k_p, evaluated by the relation (13);

a_R - coefficient of proportionality of the equation type Kusakin for the radius of influence R of the well (drilling), evaluated by the relation (15).

Testing program filtrate coefficients.m

RESULTS AND DISCUSSIONS

The Program **Filtrate Coefficients.m** has been tested for a case study adapted to the conceptual model on the behalf of the mathematical model proposed. There was considered, in this case, that the drilling F3, situated at the North of the Miercurea Ciuc region, on the distance of 1527 m from the left side of the shore of the Olt River and from the distance of 41 m towards to Ciceu railway.

The geometrical parameters of drilling F3 and hydrogeological layers of aquifer are as following: b=1.6 m, a=0.4 m, M=4.0 m, r=0.1 m, H_f=1.20 m, H_p=5.60 m. Pumping test analysis was performed on 23.07.2008 and data are summarized in (table 1).

Applying the relations (7) şi (10) following values was determined for the additional constants:

B_{s1} = 1214.3, B_{s2} = 1256.0, B_{s3} = 1315.0

C_{s1} = 0.9666, C_{s2} = 1.1208, C_{s3} = 1.3995.

A_{s2} = 9.6454, A_{s3} = 27.2498

From the relation (11) was resulted the filtrate coefficient k_f,

$k_f = 1.5269\cdot10^{-4}$ m/s = 13.1924 m/day

From the equations (12) and (13) were obtained:

$k_{p1} = k_{p2} = k_p = 6.0959\cdot10^{-4}$ m/s = 52.6686 m/day

From the equations (14) and (15) resulted:

$a_{R1} = a_{R2} = a_{R3} = a_R$ = 574.6816 m.

Table 1

Experimental data

Pumping step	1		2		3	
Parameters	s (m)	Q (dm, c/s)	s (m)	Q (dm, c/s)	s (m)	Q (dm, c/s)
	0,24	1,34	0,28	1,48	0,37	1,79

CONCLUSIONS

For the case study analyzed, has been observed that the permeability of aquifer under pressure is about 4 times higher than that of the phreatic aquifer, which leads to the need for considering the different filtrate coefficients for each of the two types of aquifers, but for the constant a_R we obtained a value close to that proposed by Kusakin.

The conception and numerical solution of this mathematical model generalized for the processing experimental data from pumping perfect wells in complex aquifers constitute the challenge of obtaining satisfactory results, with sufficient precision for these types of wells, which are commonly used in hydraulic engineering practice.

The mathematical model serves to correct interpretation of the test pumping of wells – in order to establish the appropriate technical measures and solutions, but differentiated for each of the two types of aquifers.

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