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On hydrogeological calculations of flowing wells at abrupt decrease of their flow rates☆

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ABSTRACT

The article considers the method of hydro geological calculation of wells at abrupt decrease of their flow rates as a result of injecting in them additional hydraulic resistance. Based on the previously carried out individual investigations, the authors present the analytic relation for determining the value of the resistance that ensures the target value of the well flow rate.

The suggested relation enables staged automatic control of the flowing well operation.

The article ascertains the applicability of Theis equation for determining the value of partial recovery of the head after abrupt decrease of the well flow rate. At that it is accepted that at the given point there is concurrently operating virtual injection well with constant rate, at the value equal to the diminished one.

Introduction

As a result of disordered and inexpedient exploitation, the confined artesian aquifer of the Ararat valley is extremely depleted. This condition has mostly resulted due to the availability of widespread fishery pools in this region which are feeding from the flowing wells sunk in the aquifer of the basin. These wells are built up randomly, ignoring the adequate hydro geological design calculations and not taking into account their interaction with the other water sources. The flow rate of these wells usually exceeds the officially permissible one and rather often – the rate required for fish production in the pool.

It gets obvious that the measures that will be undertaken for saving the confined aquifer will also benefit the doomed-to-close fishery which directly depends on artesian basin condition. The RA government has already undertaken the first steps to it. The flow rates of flowing wells are being decreased to the officially permissible ones with the help of valves and the abandoned wells are being liquidated, etc. These activities have already had their payoff and need to be kept on.

Objectives and methods

To decrease abruptly the flow rate of the flowing wells and bring it closer to the permissible value, one should inject

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additional hydraulic resistance with the help of the valve. To achieve this aim, instead of gradual approximate method which besides being laborious is not quite exact, a new method should be elaborated which will give an opportunity to determine ahead, subject to the target value of the flow rate, the value of the local hydraulic resistance the injection of which will provide the required flow rate.

The assigned task has no theoretical solution because of the boundary condition rupture on the well bottom and the method of mathematical modelling used for this purpose is rather laborious and long [5,6,8]. We should give the problem solution by using N.L. Meliqyan's design formula for determining the flowing well yield [6,8]. To do the target transform of this formula we used digital data got from our research which we carried out on the hydrointegrator of the assigned task [2,7].

Results and analysis

In the research work [6,8] for determining the single flowing well yield N.L. Meliqyan gives the following dependence:

$$Q = \frac{\sqrt{F_o^2 + 64\pi^2(km)^2 H_o \eta} - F_o}{8\pi km\, \eta}, \quad (1)$$

where Q – well flow rate at any time point t, k – coefficient of water-bearing bed filtration, m – it thickness, H_o – initial positive pressure in the bed, η – total internal hydraulic resistance of the well, F_o – Fourier parameter which looks like as follows:

$$F_o = \ell n \frac{2{,}25at}{r_o^2} + 2\xi_{imp}, \quad (2)$$

where r_o – well radius, ξ_{imp} – well imperfection coefficient, $a = km/\mu^*$ – piezoconductivity of bed, μ^* – coefficient of elastic water yield.

The hydraulic resistances of well, including also the values of the injected there local additional ones, are determined by the dependences [2,6–8]:

$$\eta = \frac{1 + \lambda \frac{\ell}{2r_o} + \xi_{LR}}{2g\pi^2 r_o^4}, \quad (3)$$

where ℓ – well depth, λ – hydraulic friction coefficient, ξ_{LR}-coefficient of local hydraulic resistance, g – free fall acceleration factor in m/day^2 dimension.

By denominating $\eta_o = 1 + \lambda \frac{\ell}{2r_o}/2g\pi^2 r_o^4$, the eq. (3) gets the following look:

$$\eta = \eta_o + \frac{\xi_{LR}}{2g\pi^2 r_o^4}, \quad (4)$$

where η_o – initial, but undisturbed hydraulic resistance of the well.

By transforming the eq. (1), for Q we get [6,8]:

$$Q = \frac{4\pi km H_o}{F_o + 4\pi km\eta Q} \quad (5)$$

From eq. (5) for η we can write:

$$\eta = \frac{H}{Q^2} - \frac{F_o}{4\pi kmQ}. \quad (6)$$

By equating the eqs. (4) and (6), for ξ_{LR} we get the following design formula:

$$\xi_{LR} = 2g\pi^2 r_o^4 \left(\frac{H_o}{Q^2} - \frac{F_o}{4\pi kmQ} - \eta_o \right) \quad (7)$$

By using the results suggested in work [2,7] on the model investigations of the abrupt flow rate decrease of flowing wells, let us check the adequacy level of formula (6) for determining ξ_{LR} value.

In the mentioned model investigations for the problems the following initial parameters are accepted: conductivity of bed $T = km = 3000\, m^2/day$, $a = 3\cdot 10^5\, m^2/day$, $H_o = 13{,}5\, m$, $\eta_o = 7{,}59\cdot 10^{-9} day^2/m^5$, $r_o = 0{,}105\, m$.

Here we consider three periods of abrupt decrease of well yield. Without additional resistances the well operated 50 days, at which the yield made up 19,200 m^3/day (by formula (2) we got 18,800 m^3/day). After it there was a need to decrease abruptly the yield to 15,200 m^3/day. Let us determine the required for it ξ_{LR} value by formula (6), and we will have:

$$F_o = \ell n \frac{2{,}25\cdot 10^5 \cdot 50}{0.105^2} = 21{,}84$$

and

$$\xi_{LR_1} = 2\cdot 9{,}81\cdot 86400^2 \cdot 3{,}14^2 \cdot 0{,}105^4 \left(\frac{13{,}5}{15200^2} - \frac{21{,}85}{4\cdot 3{,}14\cdot 3000\cdot 15200} - 7{,}59\cdot 10^{-9} \right) = 2{,}25.$$

In simulation investigations we accepted that $\xi_{LR_1} = 2,24$.

Let us check the validity of the obtained value ξ_{LR_1}. On determining the new value of η by (5) we get:

$$\eta_1 = 7{,}59\cdot 10^{-9} + \frac{2{,}25}{2\cdot 9{,}81\cdot 86400^2\cdot 3{,}14^2\cdot 0{,}105^4} = 2{,}041\cdot 10^{-8} day^2/m^5,$$

to which, according formula (2), the following correspondents:

$$Q = \frac{\sqrt{21{,}84^2 + 64\cdot 3{,}14^2\cdot 3000^2\cdot 13{,}5\cdot 2{,}041\cdot 10^{-8}} - 21{,}84}{8\cdot 3{,}14\cdot 3000\cdot 2{,}041\cdot 10^{-8}} = 15180\, m^3/day.$$

In simulation investigations we got that Q = 15170 m^3/day.

The flowing well with resistance η_1 was operating 50 days more, after which, in the second period, its flowing rate should be reduced to 11,100 m^3/day.

Let us determine ξ_{LR_2} by formula (7) and we have:

$$\xi_{LR_2} = 2\cdot 9{,}81\cdot 86400^2\cdot 3{,}14^2\cdot 0{,}105^4 \left(\frac{13{,}5}{11100^2} - \frac{22{,}533}{4\cdot 3{,}14\cdot 3000\cdot 11100} - 7{,}59\cdot 10^{-9} \right) = 8{,}46,$$

to which the following corresponds:

$$\eta_2 = 7{,}59\cdot 10^{-9} + \frac{8{,}46}{2\cdot 9{,}81\cdot 86400^2\cdot 3{,}14^2\cdot 0{,}105^4} = 5{,}58\cdot 10^{-8} day^2/m^5.$$

For this case, by formula (2) we got that Q = 11,093 m^3/day. It means that ξ_{LR_2} provides the target yield. The duration of the second period makes up 50 days.

In simulation studies [2,7] for the third period the flow rate was reduced to 8200 m^3/day value, for which, by formula (7) we get that $\xi_{LR_2} = 20{,}16$ (opposite to the previously got