ESTIMATION OF A WELL DAMAGE OR STIMULATION

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Unsteady flow to a single well fully penetrating confined aquifer (nonhomogeneous and isotropic) is analysed. The well is assumed to be located in an infinite system; that is, the effect of boundaries is not considered. The additional resistances and finite volume of a wellbore are the two main factors which influence pumping test data measured at a well. If skin effect and wellbore storage dominate pumping test data and testing has been conducted long enough, two semilog straight lines normally are obtained. On a semilog graph, the first straight line can be identified readily as the line of maximum slope. Procedure for determination of the skin factor from pumping test data at a single well (no observation well is available) dominated by wellbore storage and skin effect is presented. Correlation of the slope of the first straight line as a function of the dimensionless wellbore-storage C_D and the skin factor W is shown.

well; aquifer test; skin effect; well damage

INTRODUCTION

The additional resistances and finite volume of a wellbore are the two main factors which influence pumping test data measured at a well. The drawdown caused by additional resistance (the skin effect) was noted for the first time by (van Everdingen, 1953). Since then many authors in petroleum engineering and groundwater hydraulics have published articles giving their attention to the problem of the influence of skin effect and wellbore storage on the measured value of the real drawdown at a well (Dawson, Istok, 1991; Moench, 1995; Moench, 1997; Earlougher, 1977; Raghavan, 1993). Agarwal et al. (1970) introduced the idea of a log-log type curve matching to analyze pressure data at a well dominated by wellbore storage and skin effect. A new method for evaluation of the skin factor W from the early time portion of pumping test data was published by Garcia-Rivera, Raghavan (1979) and Raghavan (1993).

Here we derive a method for the evaluation of skin factor W on a single well fully penetrating a confined aquifer (no observation well is available) from the early time portion of a pumping test. This method can be applied if the Jacob semi logarithmic part of pumping test is not achieved. The solution of the general partial differential equation of liquid flow through porous media in Laplace space was used. The Laplace transform was inverted in terms of algorithm 368 of Stehfest (Stehfest, 1970). Here we derive a correlation of the dimensionless intersection time as a function of the dimensionless wellbore-storage constant and skin factor.

MATERIAL AND METHODS

Theory

The problem to be considered is the classic of flow of a slightly compressible fluid in an ideal radial flow system. That is, flow is perfectly radial to a well of radius r_V in an isotropic medium, and gravitional forces are neglected (Theis, 1935; Batu, 1998). We will consider that the medium is infinite in extent, since interest is focused on times short enough for outer boundary effects not to be felt at the well. The initial condition is taken as constant head H for radii greater than or equal to r_V. The inner boundary condition will be taken as production at constant surface rate from a wellbore of finite volume, and it will be assumed that a steady-state skin effect exists at the sand face.

Dimensionless parameters

The following dimensionless parameters are used:
Dimensionless drawdown

$$s_D(r_D, t_D) = \frac{2\pi T}{Q}(s(r, t)) \tag{1}$$

where: T – transmissivity
t – time
s – drawdown
Q – well discharge

Dimensionless drawdown at a well

$$s_{VD}(t_D) = \frac{2\pi T}{Q}(s_W(t)) \tag{2}$$

Dimensionless time

$$t_D = \frac{T\,t}{r_V^2 S} \tag{3}$$

where: r_V – well radius
S – storativity

Dimensionless radius

$$r_D = \frac{r}{r_V} \tag{4}$$

where: r – radial location

Dimensionless wellbore storage constant

$$C_D = \frac{C}{2\pi\, r_V^2\, S} \tag{5}$$

where: C – unit storage factor (Ramey, 1970)

Dimensionless skin factor

$$W = \frac{2\pi\, T\, s_W}{Q} \tag{6}$$

Dimensionless intersection time

$$t'_D = \frac{T\, t'}{r_V^2\, S} \tag{7}$$

where: t' – intersection time (see Fig. 2)

The skin effect

Skin effect is a concept to characterize a production well that is surrounded by a local region with a transmissivity that is different from the aquifer transmissivity.

The drawdown at a well depends on the resistance of the formation, the viscosity of the fluid and the additional resistance concentrated in an infinitesimally thin skin zone around the well. The additional resistance is due to hydromechanical, chemical, and biological factors that occur during drilling or completion operations, and during the exploitation of a well. These include such things as well perforations, partial penetration, fractures of various types, non-Darcy flow, and so on. This additional resistance causes an additional" drawdown at a "real" well (here denoted s_{SK}). More details about the skin effect and its influence on pumping test data evaluation can be found in van Everdingen (1953) and Agarwal et al. (1970).

If the additional drawdown s_{SK} is taken into account then the total drawdown at a "real" well can be written in the following form (Fig. 1).

$$s_W = s_{te} + s_{skin} \tag{8}$$

where: s_W – measured drawdown at a "real" well
s_{te} – drawdown at an "ideal" well ($W = 0$)
s_{skin} – additional drawdown at a well caused by additional resistance

Fig. 1 shows the drawdown in the vicinity of a production well surrounded by a zone of altered (reduced) transmissivity that extends from the well radius r_v to the skin radius r_{skin}. The reduced transmissivity of the skin causes an additional drawdown in the well. Because the skin region is usually relatively thin, the skin is often assumed to have infinity.

Equation (2) indicates that the drawdown at a "real" well differs from drawdown at an "ideal" one by an additive amount (van Everdingen, 1953):

$$s_{SK} = \frac{Q}{2\pi\, T} W \tag{9}$$

where: Q – pumping rate
T – transmissivity
W – skin factor

Wellbore storage

Wellbore storage, also called wellbore loading or unloading, has long been recognized as affecting short-time transient hydraulic head behavior. Ramey (1970) discussed this problem in detail. When pumping starts (pumping rate Q = const.) the first liquid produced will be that stored in the wellbore, and the initial flow rate from the formation to the well Q_{IN} will be zero. With increasing flow time, at constant surface producing rate Q the down-hole flow rate will approach a constant value.

$$Q_{IN} = Q - C\frac{dh_V}{dt} \tag{10}$$

where: Q_{IN} – flow rate from the formation to a well
Q – constant surface producing rate
C – unit wellbore storage factor (Ramey, 1970)

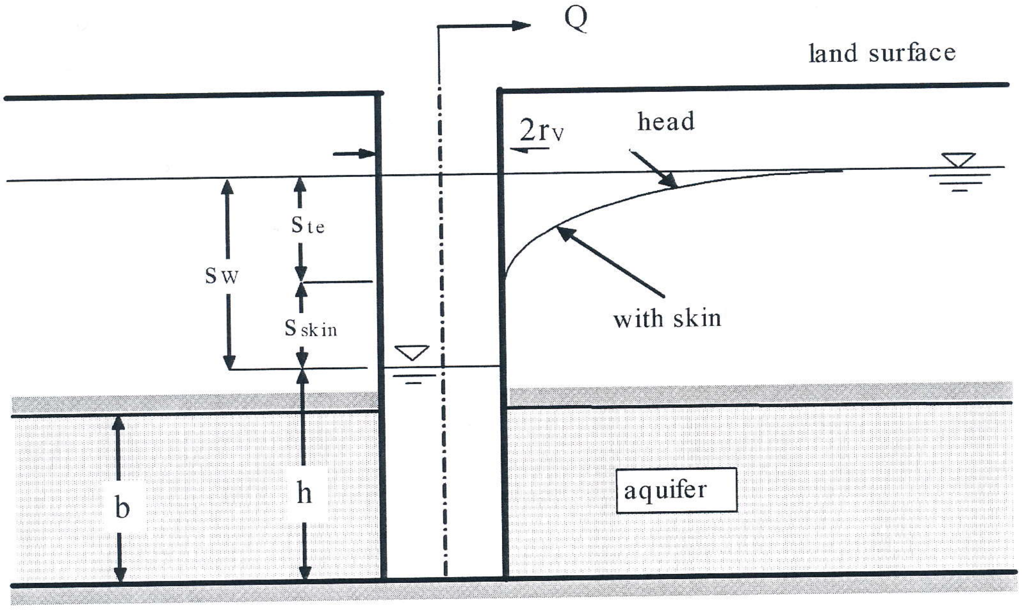

Fig. 1. Drawdown around a production well with skin effect

RESULTS AND DISCUSSION

Solution

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

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial s}{\partial r}\right)=\frac{S}{T}\frac{\partial s}{\partial t} \qquad (11)$$

Expressed in terms of the dimensionless variables equation may be written in the form:

$$\frac{\partial^2 s_D}{\partial r_D^2}+\frac{1}{r_D}\frac{\partial s_D}{\partial r_D}=\frac{\partial s_D}{\partial t_D} \qquad (12)$$

where: s_D – dimensionless drawdown
t_D – dimensionless time
r_D – dimensionless radius

The initial and boundary conditions for assume problems are

$$s_D(r_D, 0) = 0 \qquad (13)$$

$$s_D(r_D, t_D) = 0 \text{ for } r_D \to \infty \qquad (14)$$

$$s_{VD} = s_D + \left(r_D\frac{\partial s_D}{\partial r_D}\right)_{r_V} W \qquad (15)$$

$$C_D\frac{d s_D}{d t_D} - \left(r_D\frac{\partial s_D}{\partial r_D}\right) = 1 \qquad (16)$$

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). Wei Chun Chu (1980) proved that this algorithm may be used to numerically invert for skin factor $W > 0$ and dimensionless wellbore storage $C_D > 100$.

As can be seen in Fig. 2, two semilogarithmic straight lines are obtained. They agree with the results obtained by Garcia-Rivera and Raghavan (1980). The second straight line represents part of the pumping test which can be evaluated by means of the Jacob semilogarithmic method.

The dimensionless intersection times t'_D (dimensionless time where the first straight line in the semilog graph s_{WD} vs. log t_D) intersects the axis log t_D were determined by means of the computer program. It was found that the dimensionless intersection time t'_D is a unique function of the dimensionless wellbore storage constant C_D and the skin factor W.

$$t'_D = a_T W + b_T \qquad (17)$$

where: a_T and b_T – coefficients

The coefficients a_T and b_T for all straight lines were evaluated by the least squares method. The dimensionless intersection time was derived in the following form

$$t'_D = 10^{(1{,}0036 \log C_D - 0{,}7553)}\ W + 10^{1{,}0852 \log C_D - 0{,}2821} \qquad (18)$$

By means of equation (18), skin factor W for the cleaned well before and after well rehabilitation was determined.

CONCLUSIONS

In this contribution a correlation of the dimensionless intersection time t'_D as a function of the dimensionless wellbore storage C_D and skin factor W is shown.

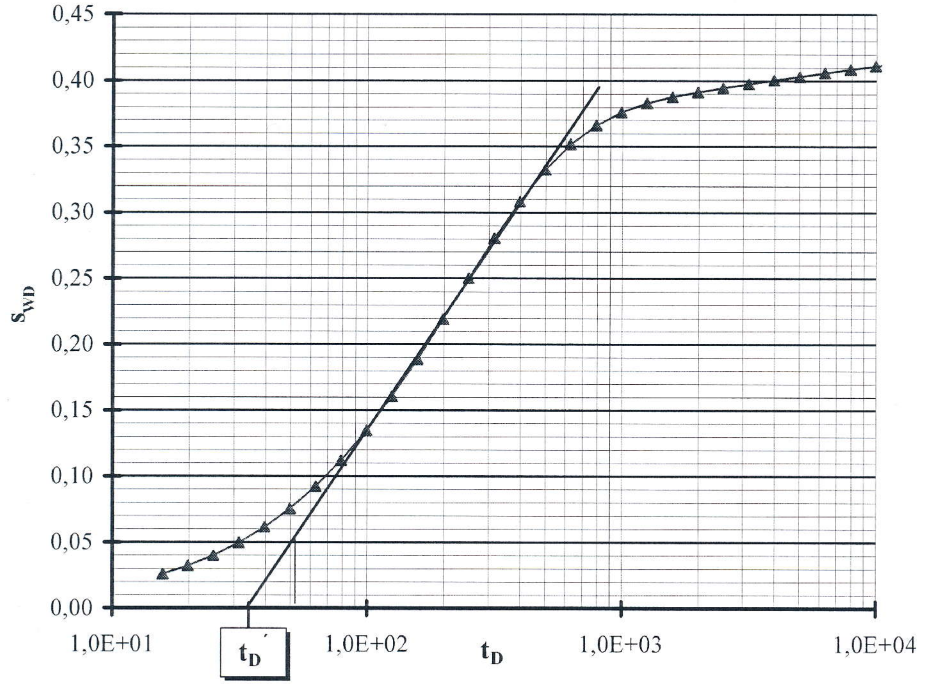

Fig. 2. Graph of s_{WD} vs. log t_D for a wellbore and skin factor (for C_D = 100, W = 10)

The derivation was done with utilization of an approximate solution of the general partial differential equation for the problem of radial flow in an extensive confined aquifer of uniform thickness to a single fully penetrating well pumped at a steady rate of flow. The solution was obtained by applying the Laplace transform and the Agarwal (1970) method, in conjunction with the algorithm 368 of Stehfest (Stehfest, 1970) approximate method of inversion. Skin factor W is estimated from short-time transient test data by means of equation (14). To apply this method, it is necessary that formation transmissivity, storativity, and wellbore radius be known or evaluated. The test must must be conducted at a known constant flow rate.

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Vyhodnocení poškození nebo regenerace vrtu.

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V článku je uvažován případ nestacionárního radiálního proudění vody zvodnělou porézní vrstvou k úplnému „reálnému“ vrtu. Předpokládá se, že vrt se nachází v neomezené zvodnělé vrstvě, tzn., že se neprojevuje vliv hraničních podmínek ve vlastním vrtu. Oproti řešení ideálního vrtu (Theis, 1935) jsou brány v úvahu dodatečné odpory, které vznikají ve vlastním vrtu, na jeho stěnách a nejbližším okolí a konečný objem vrtu. Pod pojmem dodatečné odpory rozumíme souhrn jevů, jejichž vlivem dochází k odchýlení naměřených hodnot snížení na odběrném vrtu oproti teoretickému snížení získanému za předpokladu ideálního vrtu. Některé druhy dodatečných odporů mohou vzniknout již při zhotovení vrtu a jejich zdrojem jsou nedostatky a nedokonalosti techniky a technologie hloubení, zejména vystrojení jímacích vrtů (např. snížení propustnosti v bezprostředním okolí vrtu vlivem vniknutí výplachu do porézního prostředí nasyceného vodou při rotačním způsobu vrtání, důsledkem čehož vzniká tzv. „kalová“ kůra, nebo při nárazovém vrtání, kdy dochází ke zhutnění porézního prostředí v blízkosti vrtu a tím ke snížení propustnosti). Dalšími příčinami vzniku dodatečných odporů jsou různé hydromechanické, chemické, biologické a jiné jevy, které se mohou vyskytnout na vrtu a jeho nejbližším okolí v průběhu exploatace vrtu. Separace jednotlivých složek dodatečných odporů je velmi problematická, a proto je k charakteristice dodatečných odporů užito sumárního bezrozměrného koeficientu dodatečných odporů W (tzv. skin faktoru). V případě, že jsou brány v úvahu dodatečné odpory a vliv vlastního objemu vrtu na počáteční úsek hydrodynamické zkoušky a zkouška je vedena dostatečně dlouho, pak můžeme v grafu hydrodynamické zkoušky nalézt dva přímkové úseky. První přímkový úsek je ovlivněn dodatečnými odpory a objemem vrtu, druhý přímkový úsek charakterizuje zvodnělé prostředí a je vyhodnotitelný klasickou Jacobovou semilogaritmickou aproximací.

V příspěvku je odvozena metoda určení sumárního koeficientu dodatečných odporů, tzv. skinového faktoru W z prvního přímkového úseku hydrodynamické zkoušky. Základní rovnice nestacionárního radiálního proudění vody zvodnělou porézní vrstvou byla řešena v bezrozměrném tvaru pomocí Laplaceovy transformace. K inverzi byl použit Stehfestův algoritmus 368 (Stehfest, 1970). Při zpracování řešení pro různé parametry W a C_D byla odvozena závislost bezrozměrného času průsečíku prvního přímkového úseku (obr. 2) a bezrozměrné zásobnosti vrtu C_D a skinového faktoru (koeficientu dodatečných odporů) W. Výsledný vztah je dán rovnicí (18).

Odvozená metoda může být použita k vyhodnocení účinku regenerace vrtu, popř. ke sledování stavu vrtu v určitých časových etapách, kdy na základě vyhodnocení sumárního koeficientu dodatečných odporů můžeme sledovat „stárnutí" vrtu a lze určit vhodný okamžik pro jeho regeneraci. Zároveň při sledování stavu vrtu, pokud jsou na základě počáteční hydrodynamické zkoušky vyhodnoceny parametry zvodnělého prostředí, můžeme podstatně zkrátit hydrodynamickou zkoušku, protože stačí pro vyhodnocení koeficientu dodatečných odporů vyhodnotit v grafu hydrodynamické zkoušky pouze první přímkový úsek.

vrt; hydrodynamická zkouška; dodatečné odpory; regenerace vrtů

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