FORECAST OF INJECTIVITY FOR A WELL WITH A CONSTANT BOTTOMHOLE PRESSURE

I.M. KUTASOV & M. KAGAN

School of Petroleum Engineering, University of New South Wales, Sydney, Australia

SUMMARY - A semi-theoretical equation is used to approximate the dimensionless flow rate. This equation is utilized to forecast the injection fluid rate for a well with a constant bottomhole pressure (BHP). The advantage of fluid injection at BHP is that fluid injection can be easily controlled (at constant flow rate injection the BHP and wellhead pressure are changing with time). It was observed that during long term reinjection of water into geothermal reservoirs the well injectivity decreases as result of formation damage. To evaluate the skin factor in these cases a new method is proposed. It is assumed that the instantaneous injection flow rate and time data are available for a test at a constant bottomhole pressure. A simulated example of forecasting the injection flow rate for four values of the skin factor is presented.

1. INTRODUCTION

A loss of formation permeability associated with injection of fresh water into sandstone was observed by many investigators. Experiments have shown that clay swelling is not the most important factor. The dislodging of particles from the surface and subsequent pore blocking are the essential mechanisms of formation damage (Schechter, 1992). Interesting results were obtained by numerical simulation of chemically induced permeability changes involving injection of a high salinity brine into sandstone containing the mineral anhydrite (Kühn, et. al., 1999). The authors have shown that temperature conditions during the injection process control the chemical reaction in the vicinity of the well. Anhydrite ($CaSO_4$) is more soluble in cold water than in hot water. Thus anhydrite has to precipitate because of the increased temperature and this will result in the reduction of permeability (Kühn, et. al., 1999). For long term fluid injection, we need methods of forecasting the well injectivity and estimating damage to the formation. A semi-theoretical equation is used to approximate the dimensionless flow rate (Kutasov, 1987; Kutasov, 1999). This formula is used to obtain a quadratic equation for determining the skin factor. The accuracy of the basic equation is shown below.

2. DIMENSIONLESS FLOW RATE

Let us assume that a fluid is injected into an infinite-acting reservoir at a constant pressure and the effective wellbore radius concept can be used (Uraiet and Raghavan, 1980). In this case the relationship between well flow rate and time for a well with a constant BHP in oilfield units is (Lee, 1982):

$$q = \frac{kh(p_i - p_{wf})}{141.2B\mu} q_D \qquad (1)$$

$$t_D = \frac{0.0002637kt}{\phi c_t \mu r_{wa}^2} \qquad (2)$$

$$r_{wa} = r_w e^{-s} \qquad (3)$$

where q_D is dimensionless flow rate, and t_D is the dimensionless time based on the apparent well bore radius, B is the fluid formation volume factor, c_t is total compressibility, h is reservoir thickness, r_w is well radius, r_{wa} is the apparent well radius, p_i is initial reservoir pressure, p_{wf} is bottomhole injection pressure, μ is fluid viscosity, ϕ is porosity, s is skin factor, t is time, and k is permeability Note that by convention injection flow rate has a negative sign. We should also note that Equation (1) is widely used in the petroleum industry to forecast oil flow rates. Analytical expressions for the function $q_D = f(t_D)$ are available only for asymptotic cases or for large values of t_D. The dimensionless flow rate was first calculated and presented in a tabulated form by Jacob and Lohman (1952). Sengul (1983) computed values of q_D for a wider range of t_D and with more table entries. We have found (Kutasov, 1987; Kutasov, 1999) that for any values of dimensionless production time a semi theoretical Equation 4 can be used to forecast the flow rate

$$q_D = \frac{1}{\ln(1 + D\sqrt{t_D})} \qquad (4)$$

$$D = d + \frac{1}{\sqrt{t_D} + b};$$

$$d = \frac{\pi}{2}, \quad b = \frac{2}{2\sqrt{\pi} - \pi}$$

In Table 1 values of q_D calculated after Equation 4 and the results of a numerical solution (q_D^*) are compared. The agreement between values of q_D and q_D^* calculated by these two methods is seen to be good.

Table 1 Comparison of values of dimensionless flow rate for a well with constant BHP: q_D^* - numerical solution (Sengul, 1983); q_D - Equation 4.

t_D	q_D^*	q_D	$\Delta q/q^* \cdot 100$,%
0.0001	56.918	56.930	0.02
0.0002	40.392	40.405	0.03
0.0005	25.728	25.741	0.05
0.001	18.337	18.350	0.07
0.002	13.110	13.122	0.09
0.005	8.4694	8.4818	0.15
0.01	6.1289	6.1410	0.20
0.02	4.4716	4.4835	0.27
0.05	2.9966	3.0079	0.38
0.1	2.2488	2.2596	0.48
0.2	1.7152	1.7255	0.60
0.5	1.2336	1.2430	0.77
1	0.98377	0.99260	0.90
2	0.80058	0.80877	1.02
5	0.62818	0.63555	1.17
10	0.53392	0.54068	1.27
20	0.46114	0.46730	1.34
50	0.38818	0.39351	1.37
100	0.34556	0.35025	1.36
200	0.31080	0.31484	1.30
500	0.27381	0.27706	1.19
1,000	0.25096	0.25366	1.08
2,000	0.23151	0.23372	0.95
5,000	0.20986	0.21153	0.80
10,000	0.19593	0.19727	0.69
20,000	0.18370	0.18477	0.58
50,000	0.16966	0.17044	0.46
100,000	0.16037	0.16098	0.38

3. SKIN FACTOR

Let us assume that after some period of fluid injection the wellbore damage resulted in a significant reduction of the fluid injection rate and the bottomhole pressure cannot be increased. To make a decision about the expedience of well stimulation by acidizing or hydraulic fracturing, the well's skin factor should be determined. Below we suggest a new method which allows calculation of the skin factor for damaged and stimulated oil wells. To utilize the proposed technique the well, as in all buildup or drawdown pressure tests, should be shut-in for some time to allow reestablishment of the practically uniform pressure distribution around the wellbore. When the pressure distribution around the wellbore is not constant before testing the Slider's method for analysing transient tests should be used (Earlougher, 1977). In this case the corrected value of initial reservoir pressure is used. Let us now assume that the fluid injection rate and flowing time data were recorded during a test at a constant BHP. Introducing new variables

$$c = \exp\left(\frac{1}{q_D}\right) - 1, \quad x = \sqrt{t_D}$$

and after simple transformations we obtain from Equation 4

$$x^2 + a_1 x + a_2 = 0 \qquad (5)$$

$$x = \sqrt{t_D} = -\frac{a_1}{2} + \sqrt{\frac{a_1^2}{4} - a_2}$$

$$a_1 = \frac{db - c + 1}{d}, \qquad a_2 = -\frac{bc}{d}$$

The apparent (effective) well radius is calculated from Equation 2

$$r_{wa} = \sqrt{\frac{0.0002637kt}{t_D \phi c_t \mu}}$$

and, finally

$$s = -\frac{r_{wa}}{r_w}$$

Thus, we obtained a simple quadratic equation for estimating the skin factor. The test data are used to estimate the values of q_D from Equation 1.

4. EXAMPLE.

For an example, we use a modified version of a water injection well in an infinite-acting reservoir fiom Earlougher (1977; example 7.1). The reservoir, well, and fluid data are presented in Table 2. An injectivity test in a waterflooded reservoir has shown the well is damaged and the skin factor is 2.4. What will be the predicted flow injection rates after acidizing? It is assumed that after well stimulation the skin factor can be reduced to -4.8. The results of calculations after Formula 1 are presented in Table 3.

Table **2.** Input parameters

h = **4.88,** m	k = **41.3,** md
ϕ = 0.15	p_i = 13.38, bar
c_t = 9.67·10^{-5}, 1/bar	p_{wf} = 57.57, bar
B = 1.00	μ = **0.001.** Pa·s
r_w = **0.0762,** m	

Table **3.** Predicted (-q) injection flow rate **(m^3/D)** at various values of **skin** factor

time	Skin factor			
hrs	2.4	0	-2.4	-4.8
10	47.4	62.7	91.4	163.7
20	45.8	60.0	85.8	147.5
50	43.9	56.8	79.4	130.1
100	42.9	54.6	75.0	119.2
150	42.1	53.3	72.6	113.8
200	41.6	52.5	71.2	110.1
300	40.8	51.4	69.1	105.3
400	40.3	50.6	67.7	102.1
500	40.0	49.9	66.6	99.7
600	39.7	49.4	65.8	97.9
800	39.2	48.8	64.5	95.2
1000	38.9	48.2	63.5	93.1

5. CONCLUSIONS

A new technique has been developed for forecasting the injection flow rate and analysing the constant bottomhole pressure test data. The suggested method allows one to calculate the **skin** factor) for damaged wells or stimulated wells.

6. REFERENCES

Earlougher, R.C., Jr. **(1977).** ***Advances in Well TestAnalysis,*** **SPE,** New York, Dallas.

Jacob, C.E. and Lohman, S.W. **(1952). Non-**steady flow to a well of constant drawdown in an extensive aquifer, ***Trans. Amer. Geophys. Union,***pp. **559-564**

Kühn, M., Schneider, W., Bartels, J., **and** Clauser, C. **(1999).** Numerical simulation **of** chemically induced permeability changes during heat mining in hot aquifers. ***Proc. 21st NZ Geothermal Workshop 1999,*** University of Auckland, pp. **223-228.**

Kutasov, I.M. **(1987)** Dimensionless temperature, cumulative heat flow and heat flow rate for a well with a constant bore-face temperature. ***Geothermics,*** Vol. **16,** No. **2,** pp. 467-472.

Kutasov, I.M. **(1999).** ***Applied Geothermicsfor Petroleum Engineers,*** Elsevier

Lee, J. **(1982).** ***Well Testing,*** **SPE** Monograph Series, **1982.**

Schechter, R.S. **(1992).** ***Oil Well Stimulation,*** Prentice Hall, Englewood Cliffs, NJ, USA

Sengul, M.M. **(1983).** Analysis of step-pressure tests, **SPE** Paper No. **12175,** ***58th Annual Technical Conference and Exhibition,*** San Francisco, October **5-8, 1983**

Uraiet, A.A. and Raghavan, R. **(1980).** Unsteady flow to a well producing at constant pressure, *J. Pet. Techn.* October, pp. **1803-1812.**