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THE SIMPLIEFIED ESTIMATION OF WELLHEAD PRESSURE IN REINJECTION GEOTHERMAL PROCESSES

1. INTRODUCTION

Simple use of common know formulas for pressure drop during production from petroleum/gas/geothermal reservoir with reverse sign, only accidentally show correct value of repression. The estimation of injection pressure in more complicated procedure because of variation of viscosity and density of injected fluid, as well as, interaction of injected fluid with the formation rock. The chemical interaction may in some cases totally mask true hydrodynamic effect due to "cake effect" which is effect of clogging of pore throat in injection path. This paper is restricted to normal work of production/injection system – when high quality of reinjected water is pumped into the geothermal reservoir.

2. CLASSICAL ESTIMATION OF INJECTIVITY INDEX AND WELLHEAD PRESSURE DURING INJECTION OF GEOTHERMAL WATER

When field injectivity test is not performed because of technical problems with source of water, usually the designing the injection process must be evaluated. Based upon existing production data following estimation were done using classical rules, as described below.

2.1. Estimation of injectivity-productivity ratio

A relation, which is valid for typical changing of injection/production parameters, is following

$$\mathrm{II} = \mathrm{PI}\frac{\mu_p \, q_i}{\mu_i \, q_p} \tag{1}$$

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where:

- II – injectivity index,
- PI – productivity index,
- ρ_i – density of injected water,
- ρ_p – density of produced water,
- μ_i – viscosity of injected water,
- μ_p – viscosity of produced water.

This relation is restricted only to Darcy conditions of flow in porous media. Example of variation of injectivity index with pure water is presented in the Table 1. This injectivity/productivity ratio was evaluated for 30, 45, 55°C (@ 259 bar) for typical Polish water from Podhale geothermal reservoir [4].

Table 1

Properties of water and injectivity/productivity ration during injection

T [°C]	ρ [kg/m^3]	μ [mPas]	II/PI
30	1002	0.800	0.378
45	996	0.592	0.509
55	992	0.492	0.609

This estimated injectivity/productivity ratio may be corrected for damaged/stimulated injection well and with rate dependent skin – for high rate injection processes.

The term "skin-effect" defined by van Everdingen (1953) is equivalent in hydrogeology as "pressure drop to the filter" is described as

$$S' = \left(\frac{k}{k_s} - 1\right) \ln\left(\frac{r_s}{r_w}\right) \tag{2}$$

where:

- r_s – radius of unchanged zone of permeability,
- r_w – radius of wellbore,
- k – permeability of reservoir layer,
- k_s – damaged/stimulated permeability of reservoir layer.

This allow to define appeerent mechanical skin effect

$$r_{weff} = r_w \cdot \exp(-S) \tag{3}$$

The pressure drop/repression inside well – for the doublet – with distance between wells described as d is calculated as

$$p_{wb} - p_i = \frac{q\mu}{2\pi k h} \ln\left(\frac{d}{r_{wb}}\right) \tag{4}$$

Using including of skin-effect into eq. (4) and introducing of rate depended skin – following modified “Forchhaimer type” equation may be written

$$\Delta p = \frac{q\mu}{2\pi k h}\left(\ln\left(\frac{r}{r_e}\right) + S\right) \tag{5}$$

where:

$$S = S' + Dq \tag{6}$$

where

S' – mechanical skin,
Dq – rate dependent skin.

Other type of skin-effect one may find in [11] and in other sources [2, 3, 6].

Using equations (5) and (6) one may written following formulas for repression in the geothermal doublet

$$\Delta p = \frac{q\mu}{2\pi k h}\left(\ln\left(\frac{r}{r_e}\right) + S' + Dq\right) \tag{7}$$

or

$$\Delta p = \frac{q\mu}{2\pi k h}\left(\ln\left(\frac{r}{r_e}\right) + s\right) + D\frac{\mu}{2\pi k h}q^2 \tag{8}$$

The equation (8) may be written using simplified formula

$$\Delta p = a(T,S)q + b(T)q^2 \tag{9}$$

where $a(T, S)$, $b(T)$ – coefficients related to equation (8).

The production/injection rate is usually expessed in the reference conditions – eg. 20°C. Assuming different injection condition of fluid – the new formula equivalent to eq. (9) may be written

$$\Delta p(T,\ q_{20}) = a(T,S)\,q_{20} + b(T)q_{20}^2 \tag{10}$$

where

$$a(T,S) = \frac{\mu(T)}{2\pi k h\,(\rho(T)/\rho_{20})}\left(\ln\left(\frac{d}{r_w}\right) + S'\right) \tag{11}$$

$$b(T) = \frac{\mu(T)}{2\pi k h\,(\rho(T)/\rho_{20})} \tag{12}$$

Using set of equation (10)–(12) it is possible to calculate of repression of pressure in the well based data from production tests with different temperatures

$$\Delta p(T,\ q_{20}) = a_2(T,S)\, q_{20} + b_2(T) q_{20}^2 \tag{13}$$

where:

$$a_2(T,S) = a_1(T,S)\frac{\mu_2(T)\rho_1(T)}{\mu_1(T)\rho_2(T)} \tag{14}$$

$$b_2(T) = b_1(T)\frac{\mu_2(T)\rho_1(T)}{\mu_1(T)\rho_2(T)} \tag{15}$$

The additional terms related to wellbore friction during vertical flow were calculated using classical hydrodynamic formulas using Wood approximation of friction coefficient and Darcy–Weisbach formula. Examples of injectivity pressures in the Bały Dunajec PGP-2 well [8] were calculated for varying temperature and rate. This is presented in Table 2.

Table 2

Wellhead pressure estimated for injection with varying temperature in the Biały Dunajec PGP-2 well

Flow rate [m³/h]	Break. press [bar]	Wellhead pressure [bar]		
		Temp. 30°C	Temp. 45°C	Temp. 55°C
10	128.3	25.7	25.2	24.9
20	128.3	27.9	26.8	26.3
50	128.4	35.8	32.7	31.2
100	128.4	53.1	45.6	42.0
150	129.1	75.6	62.4	56.1
200	130.2	103.5	83.2	73.4

A plot of wellhead pressures versus flow rate for different injection temperatures for Biały Dunajec PGP-2 well (after stimulation by nitrogen/hydrochloric acid matrix treatment) is presented in Figure 1. Analyses of injectivity index in the Biały Dunajec PGP-2 well shows lower (in comparison to Bańska PGP-1 well) injectivity order 4.37 m^3/h/bar (0.437 m^3/h/m), 6.39 m^3/h/bar (0.63 m^3/h/m) for 20 m^3/h rate at temperature 30° and 45°C and 2.48 m^3/h/bar (0.243 m^3/h/b), 3.33 m^3/h/bar (0.33 m^3/h/m) for 200 m^3/h rate at temperature 30° and 45°C. The necessary wellhead pressure needed for injection 200 m^3/h varies from 73.4 bar at temperature water equal 55°C – to 104 bar at temperature 30°C (83.2 bar @45°C). Results of calculations are presented in the Tables 3 and 4.

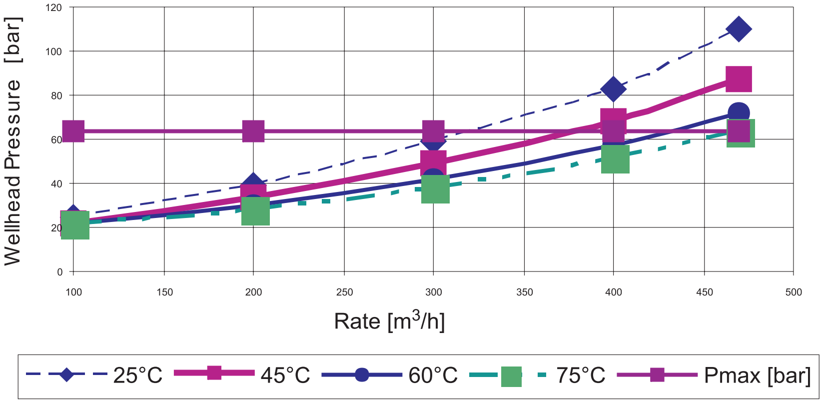

Fig. 1. Forecasting of wellhead pressures for various conditions of water injection

Table 3

Estimated of wellhead pressures in the function of rate and temperatures in the Biały Dunajec PGP-2 well

Q [m^3/h]	P_{wh} [bar]			
	25°C	45°C	60°C	75°C
100	24.3	22.1	22.1	22.1
200	39.2	33.8	29.8	28.0
300	58.8	49.0	42.0	38.4
400	82.8	68.0	57.0	51.5
450	96.6	78.8	65.6	58.9
400	–	–	–	64.0

Table 4

Comparison of wellhead pressures before and after acid stimulation of Biały Dunajec PGP-2 well for the rate of 200 m^3/h

	25°C	45°C	60°C	75°C
Present wellhead pressure [bar]	39.2	33.8	29.8	28.0
Wellhead pressure before stimulation [bar]	105.0	84.0	70.0	60.0
Change of pressure [bar]	–65.8	–50.2	–40.2	–32.0

3. CONCLUSIONS

1) A simplified estimation of injection pressures in steady state may be very efficient for stable no-reacting reservoir. This is very accurate in carbonate/fissure reservoirs (vide Podhale reservoir), where quality of injection water in unimportant.
2) The calculation of injection pressures in sandstone/clay reservoir with average permeability below 100 md [5] may be risked because of possible plugging effects – which is caused by precipitation various minerals, corrosion products – etc. [7, 10, 12–14].

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