## Computer Models, Used for Klaipeda Geothermal Plant Operation Failures Analyse

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*Abstract* – Klaipeda Geothermal Pilot Plant, operating since 2000, suffers from permanent decrease of injectivity of spent geothermal water. Among plenty and various causes of injectivity failures the most important ones are associated with scaling problem, because geothermal water is supersaturated by many minerals, salts and ions. A geochemical model PHREEQC has been used for scaling problems simulation, two other models (flow&transport) predicted scale of spread of injected geothermal water in the pumped aquifer.

*Keywords* – Geothermal water, geochemical model, flow and transport models

#### I. INTRODUCTION

Geothermal anomaly in West Lithuania is well known and studied [13], [14]. The Klaipeda geothermal project started in 1996. Since the end of 2000, Klaipeda Geothermal Pilot Plant is operated [2]. Geothermal water (GTW), which temperature is ca. +40°C, is pumped from two production wells, No 2p and 3p, which are approximately 1 km deep. Warm water, leaving part of heat in special heat-pump and cooled up to 12–15°C, is returned to the same aquifer via two other, injection wells No 1i and 4i (Fig. 1).

Start test of the plant pointed out, that pumping rates of production and injection wells are fairly good and varies from 140 up to 490 m<sup>3</sup>/h [5]. But the injection rates straight this time were significantly lower and have been deteriorated since now [12]. Plenty of applied countermeasures had only partial and temporary effect [6]. Among others causalities of this phenomenon, high salinity of GTW (ca. 100 g/l) seemed to be the key-one [7].



Fig. 1. Structure of Klaipeda Geothermal Plant (T1-T14 - sampling points)

 TABLE 1

 Potential causes of failures of injectivity at Klaipeda Geothermal

 Plant

Physical-chemical problems	Gaseous problems	Scaling problems
Injection wells installation and maintenance	$N_2$ – bubbling	Reduction of sulphates and Fe- sulphides production
Operation of filters in surface installations	O <sub>2</sub> access into surface equipment	Reduction of sulphates and sulphur S <sup>0</sup> production
Injection of inhibitors and bactericides	Production of H <sub>2</sub> S	Precipitation of gypsum and carbonates
Electric feed failures		Clay, sand particles
Drop of pressure and temperature in surface equipment		

Therefore from this water, lifted to land surface, precipitates many solids, which clogs filters of injection wells and pores of the aquifer and reduces its injectivity capacities. Sometimes in surface equipment of the plant was detected oxygen, which gives additional scales (e.g., Fe-oxides) damaging injectivity [12]. Furthermore, formation water is saturated by gaseous nitrogen, which bubbles in surface equipment when lifted to land surface and also reduces the injectivity. Those and some other problems, complicating injection, are shown in Table 1.

Despite numerous efforts (filtration of spent geothermal water, application of scaling inhibitors and anti-bacteria preparations, soft acidification of injected water), injectivity of the wells No 1i and 4i systematically dropped down and total injection in 2010 did not exceeded 100 m<sup>3</sup>/h. Among the various methods of investigation and explanation of those injectivity failures some computer models were successfully employed [7, 8].

#### II. GEOCHEMICAL MODEL PHREEQC

PHREEQC is a computer program designed to perform a wide variety of aqueous geochemical calculations [10]. For us is important, that PHREEQC can show not only an aqueous species, present in geothermal water, but also calculate saturation indices (SI) for the individual mineral phases. As it is known SI>0 means that the fluid is supersaturated for the mineral phase concerned and this mineral can precipitate. On the contrary, SI<0 means, that the corresponding mineral is

dissolved. It is evident, that SI=0 means, that the fluid and the mineral phase are in equilibrium.

PHREEQC starts to work after the input of actual data and parameters of geothermal water. Input data are temperature, density, pH and Eh values, concentrations of ions, present in geothermal water. All those concentrations are inputted in mg/l form, and PHREEQC re-calculates them into modalities and activities of aqueous species and show them in descending order. Later on this computer program calculates SI from the following equation [1]:

$$SI = \log (IAP / K), \qquad (1)$$

where IAP is ion activity product,  $\boldsymbol{K}-equilibrium$  constant,

$$IAP = [A] [B],$$
 (2)

$$\mathbf{K} = [\mathbf{A}'] [\mathbf{B}' \tag{3}$$

where A, B are activities of species A, B in the water sample, A', B' activities at equilibrium.

Output of data of PHREEQC shows familiar facts: most of the main cations and anions in geothermal water exist as freeions. As we shall see later, most important result of geochemical simulation is presence of great variety of iron species in formation, spent in heat pump and injected geothermal water.

#### A. Simulated versions

Three principal versions have been simulated: 1) physicalchemical status of geothermal water and its transformation in surface equipment and injection wells; 2) role of soft acidification in those transformations and improvement of injectivity; 3) possibilities of injection of fresh groundwater into geothermal water reservoir aiming rise of injectivity.

<u>First version</u> imitates traditional operation of geothermal plant: formation water from production wells is pumped into heat-pump, where it leaves certain part of its heat and later on is injected into injection wells. *En route* into this water sometimes and somehow enter small amounts of oxygen. PHREEQC model show that most interesting is proportions of Fe-species in formation, spent and injected geothermal water (Table 2).

From Table 2 follows, that the main Fe-specie in geothermal water always is  $Fe^{2+}$ -ion (65–81 %). Relative quantity of  $Fe^{2+}$  in geothermal water decreases, when concentration of H<sub>2</sub>S in it increases. In such case geothermal water is enriched by Fe-sulphides. Besides, trivial calculations show, that 10 mg/l of H<sub>2</sub>S is that concentration, which can sustain all  $Fe^{2+}$  amount (ca. 20 mg/l), present in formation water. But the model also show, that it never happens and content of Fe-sulphides in geothermal water never exceed 20 %. Besides, in all the cases geothermal water contains about 14–19 % of FeCl<sup>+</sup>, because Cl-species of Fe never precipitates [1].

PHREEQC simulation results also show, that formation water, pumped from the production wells, is saturated by Fesulphides (pyrite FeS2, mackinawite FeS, FeSppt), oxides (hematite Fe<sub>2</sub>O<sub>3</sub>) and hydroxides, e.g., goethite FeOOH (Table 3). Table 3 demonstrates, that the formation water from the production well No 3p (3, 4 variants) is supersaturated by Feoxides, hydroxides and sulphides (S>0). Highest values of positive SI are typical for pyrite FeS<sub>2</sub>, mackinawite FeS, FeS<sub>npt</sub> and hematite FeOOH. Besides, SI of Fe-sulphides is always positive and high, even in the cases, when input concentration of H-sulphides is small (e.g., 0,51 mg/l). But those SI values are especially high, when input concentration of H-sulphides is also high, e.g., 10 mg/l, which are in equilibrium with actual concentration of Fe, 20 mg/l. Spent geothermal water before injection is even more supersaturated by Fe-sulphides (6, 7 variants). From this point of view injected geothermal water (7, 8 variants) did not differ from the formation water (3, 4 variants).

TABLE 2		
PERCENT OF AQUEOUS FE-SPECIES IN GEOTHERMAL WATER, P	PHREEC	C DATA

Groups of	Parameters,	Formation water	from well No 3p	Spent water fr	com well No 3p	Water, pumped No	out from well 4i		
parameters	elements, species		Simulated variants						
	species	3	4	6	7	8	9		
Input	рН	6,32	6,32	6,52	6,52	6,71	6,71		
data	Eh, mV	-108	-108	-20	-20	-120	-120		
	H <sub>2</sub> S, mg/l	0,51	10	0,28	10	0,08	10		
	O <sub>2</sub> , mg/l	0	0	0,01	0,01	0	0		
% of Fe- aqueous species	Fe <sup>2+</sup>	81,10	67,17	80,18	68,22	81,30	65,83		
	FeCl <sup>+</sup>	17,53	14,62	19,00	15,92	18,45	14,14		
in geo-	FeSO <sub>4</sub>	1,23	1,03	0,98	0,84	1,11	0,96		
thermal water	Fe(HCO <sub>3</sub> ) <sup>+</sup>	-	-	0,09	0,07	0,11	0,08		
	Fe(HS) <sub>2</sub>	0,14	16,42	0,04	14,83	0,02	20,35		
	Fe(HS) <sup>3-</sup>	-	0,26	-	0,12	-	0,20		
	Total %	100	100	100	100	100	100		

SATURATION INDICES OF VARIOUS STECES IN GEOTIERMIRE WATER, I TINLE QC DATA								
Groups of Parame	Parameters.	Formation water from well No 3p		Spent water in surface equipment		Injected and pumped out water (well No 4i)		
parameters	elements, species	Simulated variants						
		3	4	6	7	8	9	
Input data	t, °C	38	38	11,6	11,6	25	25	
	pH	6,32	6,32	6,52	6,52	6,71	6,71	
	Eh, mV	-108	-108	-20	-20	-115	-115	
	H <sub>2</sub> S, mg/l	0,51	10	0,28	10	0,08	10	
	HCO3 <sup>-</sup> ,mg/l	14,68	14,88	15,70	14,68	19,88	19,88	
	O <sub>2</sub> , mg/l	-	-	0,01	0,01	-	-	
SI of S <sup>0</sup> , Fe-		Saturation indices						
oxides, Fe- sulphides	S <sup>0</sup>	-0,36	+0,73	+2,05	+3,42	-1,19	+0,77	
supmees	Fe <sub>2</sub> O <sub>3</sub>	+5,29	+5,13	+6,03	+5,89	+5,73	+6,93	
	FeOOH	+1,60	+1,52	+2,03	+1,96	+1,85	+2,45	
	FeS <sub>ppt</sub>	+0,57	+1,59	+0,46	+1,76	+0,30	+2,03	
	FeS	+1,30	+2,32	+1,19	+2,50	+1,03	+1,76	
	FeS <sub>2</sub>	+12,22	+14,34	+15,53	+18,21	+11,61	+14,85	
SI of	CaSO <sub>4</sub>	0,00	0,00	+0,03	+0,03	0,00	+0,01	
sulphates	CaSO <sub>4</sub> .2H <sub>2</sub> O	+0,10	+0,10	+0,24	+0,24	+0,16	+0,12	
	SrSO <sub>4</sub>	+0,05	+0,05	+0,13	+0,13	+0,02	0,00	
SI of	CaCO <sub>3</sub>	-0,99	-0,99	-1,07	-1,10	-0,59	-0,44	
carbonates	CaMg(CO <sub>3</sub> ) <sub>2</sub>	-1,62	-1,62	-2,06	-2,12	-0,89	-0,52	

 TABLE 3

 Saturation indices of various species in geothermal water, PHREEOC data

Interesting and somehow different is behaviour of molecular sulphur in geothermal water – flakes of  $S^0$  always appear (SI>0), if concentration of H-sulphides is increased up to 10 mg/l (variants 4, 7, 9 in Table 3). But emergence of those white flakes seems also to be stimulated by other factors (e.g., fluctuations of Eh, pH, input of O<sub>2</sub>).

Actually, SI>0 show only potential possibility of scaling [1]: high positive value of SI did not mean, that those species would be first and abundant scaling species. For example, from Table 3 follows that SI of pyrite (FeS<sub>2</sub>) is always 10–20 times greater neither SI of mackinawite FeS. Nevertheless black flakes of mackinawite always appear first and are very abundant. Explanation follows from the ratio IAP/K (see eq. 1–3).

Results of simulation confirm, that SI of gypsum and anhydrite are always positive, but very close to zero (see Table 3). Almost the same value of SI is typical for strontium sulphate, celestite ( $SrSO_4$ ). Therefore scaling of all those sulphates seems to be theoretically probable, but insignificant.

All SI of Ca and Mg carbonates are negative, what means, that scaling of those minerals is not reliable. Nevertheless, former findings of such scales in the surface equipment filters enables us to suspect, that precipitation of carbonates sometimes was/is possible.

<u>Versions two and three</u> (simulated injection of softly acidificated or fresh water) examine possibilities to increase injectivity into wells No 1i and 4i. For this purpose spent GTW was regularly and softly acidified by HCl. But nowadays this operation gives miserable effect and spent GTW injection rate further decreases. Looking for explanation of this phenomenon, we have simulated a case, when softly acidified spent GTW in injection wells is mixing with formation water in proportion 50%–50%. Also another, purely hypothetical variant – substitution of spent GTW by almost fresh groundwater, pumped from shallow aquifer – was simulated. Mixing proportion of this water and formation GTW was the same as already mentioned (50%–50%).

Agreeable to Table 4, formation water is always supersaturated by Fe-sulphides, oxides (SI>0), which can always precipitate. Similar possibility (but week) also exists for Ca, Sr- sulphates. However, scales of carbonates or crystals of molecular sulphur (S<sup>0</sup>) are not reliable (SI<0). Even less probable is precipitation of Fe-compounds, molecular sulphur and all carbonates from softly acidified (by HCl) formation water, where all of them are dissolved (SI<0). Only Ca, Mg sulphates did not dissolve in acidified water (SI>0). Almost the same picture demonstrates mixture of formation water and softly acidified GTW: only pyrites (FeS<sub>2</sub>) SI is slightly positive (see column 5 in Table 4).

Also was simulated another, hypothetical case of almost fresh water injection into GTW reservoir, expecting essential improvement of injectivity. Modelled almost fresh water was supposed to take from ca. 300 m deep  $P_2$  aquifer, hoping that from this water will not precipitate scales, and, perhaps, this water will dissolve former scales, already clogging pores of GTW reservoir. Mixing proportions of fresh/formation water was the same as in previous cases (50 %–50 %).

Injection of soid CTW Ersch water injection						•	
Groups of parameters	Parameters, elements,	injection of actu. G1 w		F resh water injection			
	species	Formation water	Acid.GTW	Mixture	Formation water	Fresh water	Mixture
Input data	t, °C	20	11,6	15,8	11,6	14,4	18,3
	pH	6,34	3,0	3,17	6,34	7,6	7,02
	Eh, mV	-128	-89	-101	-89	-75	-1,71
	H <sub>2</sub> S, mg/l	1,86	0,28	0,000	1,12	1,12	0,102
	HCO3 <sup>-</sup> ,mg/l	79,8	79,8	63,3	79,8	329	140
	O <sub>2</sub> , mg/l	0	0	0	0	0	0
			Saturation	indices		· · · · ·	
SI of S <sup>0</sup> , Fe-	S <sup>0</sup>	-1,01	-7,17	-1,85	-0,11	+2,88	-3,95
oxides, Fe-	Fe <sub>2</sub> O <sub>3</sub>	+2,33	-17,66	-9,33	+2,49	+7,92	+3,63
supmues	FeOOH	+0,16	-9,82	+5,66	+0,26	+2,98	+0,83
	FeS <sub>ppt</sub>	+1,01	-6,34	-7,70	+0,75	+1,04	-0,05
	FeS	+1,75	-5,61	-6,97	+1,48	+1,77	+0,24
	FeS <sub>2</sub>	+12,70	-0,59	+3,31	+13,66	+16,23	+8,62
SI of	CaSO <sub>4</sub>	0	+0,03	+0,01	+0,03	-1,39	-0,35
sulphates	CaSO <sub>4</sub> .2H <sub>2</sub> O	+0,19	+0,21	+0,20	+0,24	-1,14	-0,12
	SrSO <sub>4</sub>	+0,07	+0,12	+0,09	+0,12	-0,85	-0,22
SI of	CaCO <sub>3</sub>	-0,24	-3,34	-3,19	-0,33	+0,24	+0,57
carbonates	CaMg(CO <sub>3</sub> ) <sub>2</sub>	-0,58	-6,91	-6,55	-0,90	+0,56	+0,89

TABLE 4 SATURATION INDICES OF VARIOUS SPECIES IN GTW/ACIDIFIED AND FRESH WATER MIXTURES. PHREEOC DATA

Nevertheless, from Table 4 follows, that the use of almost fresh water only slightly reduces Fe-compounds scaling. Much better fresh water reduces possibilities of formation of  $S^0$  and Ca, Mg-sulphates scales. However, the model show, that abundance of bicarbonates (HCO<sub>3</sub><sup>-</sup>) in almost fresh water will stimulate Ca, Mg-carbonates scaling and also complicate injection.

# where $k_f$ is in cm/s, $k_s$ in D (Darcy), $\gamma$ – specific density, kg/cm<sup>3</sup>, $\mu$ – dynamic viscosity of GTW, cP (centipuases). Some data on those and other parameters are given in Table 5.

There are certain problems with GTW heads. As it is well known, GTW head depends upon its specific density, i.e.:

 $P = \gamma H/10$ ,

#### III. FLOW AND TRANSPORT MODELS

Another computer model was used for (1) evaluation of possible drawdowns in productive aquifer ( $D_1$ km sandstones) without GTW withdrawals restoration and (2) evaluation of spent GTW flow distances in a case of standard procedure of GTW pumping/injection. For this purpose a regional model of GTW flow in named productive aquifer, occupying territory with a 50 km radius around Klaipeda (Fig. 2), was developed. The Groundwater Vistas Enterprise V5 [11] and computer codes MODFLOW2002, MODFLOW2005 and MODPATH 3.0 [3, 4, 11] were used for model creation and GTW flow simulation.

Information, necessary for model development, was collected from various sources [5], [9], [12]. From this data follows that average parameters of the productive aquifer (D<sub>1</sub>km) in West Lithuania are: *net-to-gross* (thickness) 65 %, porosity 26 %, permeability 2000 mD. Between the permeability ( $k_s$ ) and hydraulic conductivity ( $k_f$ ) exists ratio:

$$k_{\rm f} = k_{\rm s} \gamma/\mu$$
,



Fig. 2. Potentiometric surface of productive formation  $\left(D_2 p r + D_1 k m\right)$  and location of simulated area

3 – simulated area.

<sup>1 -</sup> well: above - its No, below - actual altitude of relative head, m a.s.l.;

<sup>2 -</sup> equipotential line, m a.s.l.;

PARAMETERS, USED FOR MODEL DEVELOPMENT					
Parameter	Dimension	Values from–to	Average value		
Sandstones:					
porosity, n <sub>0</sub>	%	23–27	26		
permeability, k <sub>s</sub>	mD	2200-4950	-		
hydraulic conductivity, k <sub>f</sub>	cm/s	3–4,4	-		
transmissivity, T	m²/d	170-200	-		
GTW:					
specific density, $\gamma$	kg/cm <sup>3</sup>	-	0,0001067		
dynamic viscosity, µ	cP	-	0,76		

 TABLE 5

 Parameters, used for model development

where P is pressure in aquifer, kg/cm<sup>2</sup>, H – measured pressure head of GTW in the well, m,  $\gamma$  – specific density, kg/cm<sup>3</sup>, 10 is pressure head of fresh groundwater (density 1 kg/cm<sup>3</sup>).

Salinity of GTW in West Lithuania significantly varies: in Klaipeda it amounts up to 90–100 g/l, but only 20 km northward, in Palanga it is only 25–28 g/l. Therefore heads of saline water should be re-calculated. Fig. 2 shows those heads in productive  $D_1$ km aquifer. As we can see, in Central Lithuania GTW flow direction is NW, but in Klaipeda region GTW moves from SW, from the deepest part of Baltic syneclise toward the Riga Bay, regional area of deep groundwater discharge [9]. But this flow is very slow, because groundwater flow gradient in Klaipeda region is only 0,00015–0,0002.

Model grid in simulated area is 500x500 m, near Klaipeda – 50x50 m. D<sub>1</sub>km aquifer plane boundaries of 2nd type (Q=0) coincide with groundwater flow lines, boundaries of 3rd type Q(x, y, F,  $\Delta$ H) or general head boundary conditions simulate groundwater inflow or outflow from the model area. Vertical boundaries are confining D<sub>1</sub>km aquifer beds – impermeable formations (boundary conditions of Q=0 type). Inside boundaries are production and injection wells of Klaipeda Geothermal Plant. Simulated groundwater heads were beforehand re-calculated into fresh water heads.

Procedure of model calibration started with simulation of undisturbed piezometric heads of D<sub>1</sub>km aquifer, i.e., heads, measured before the start of operation of Klaipeda Geothermal Plant (Fig. 3). This calibration enabled us to specify hydraulic conductivities of productive formation. Later on this parameter was specified for Klaipeda Geothermal Plant area. For this purpose a 7 day long pumping from the production well No 3p, accompanied by groundwater heads drawdown in the injection well No 1i, which was 3,4 m (the distance between wells 3p and 1i is 1,5 km), was used. Specified values of hydraulic conductivity and net-to-gross thickness of D1km aquifer in simulated area are shown in Fig. 4 and 5. Net-togross thickness of D<sub>1</sub>km aquifer in simulated area is 65 % of its total thickness; in Klaipeda Geothermal Plant area its value is 56 m (see Fig. 5). Model calibration specified value of another parameter of D<sub>1</sub>km aquifer – piezoconductivity, which is  $1,3 \cdot 10^7$  m<sup>2</sup>/d in average.



Fig. 3. Simulated static potentiometric surface of D<sub>1</sub>km aquifer

1 – well: above – its No, below – actual altitude of relative head, m a.s.l.;

2 - simulated equipotential line, m a.s.l.

First task of the simulation was to assess possible drawdowns in productive aquifer ( $D_1$ km sandstones) without GTW withdrawals restoration.



Fig. 4. Net-to-gross thickness of D1km aquifer in simulated area



Fig. 5. Specified values of hydraulic conductivity of  $D_{1}km$  aquifer

Results of this simulation we can see from the Fig. 6 and Table 6, which show the depression cone of ca. 90 m depth (in the centre), originating in a case, when total pumping rate from two production wells is 700 m<sup>3</sup>/h.



Fig. 6. Predicted cone of depression of  $D_1 km$  aquifer, adequate to ultimate GTW withdrawals by Klaipeda geothermal plant



2 - simulated drawdown izolines.

TABLE 6
PREDICTED DRAWDOWNS FOR ULTIMATE GTW WITHDRAWALS BY KLAIPEDA
GEOTHERMAL PLANT

<b>T1</b>	Predicted drawdown in a model cell, m			
Time, years	Well No 2p	Well No 3p		
0,1	65,58	67,17		
0,25	73,28	74,86		
0,5	78,57	80,14		
1	83,49	85,06		
2	87,67	89,24		
3	89,67	91,24		
4	90,67	92,23		
5	91,18	92,74		
6	91,44	92,99		
7	91,57	93,13		
8	91,63	93,19		
9	91,67	93,23		
10	91,68	93,24		
15	91,7	93,26		
20	91,7	93,26		

 TABLE 7

 Simulated process of operation of Klaipeda Geothermal Plant in 2001–2010

Year	Month	GTW withdrawals, m <sup>3</sup> /d		Injection vol	umes, m <sup>3</sup> /d
		Well No 2p	Well No 3p	Well No 1i	Well No 4i
2001	IV	3840	3840	840	6840
	V-VIII	3600	3600	720	6480
	IX-XII	3600	3600	1440	5760
2002	I-XII	3240	3240	1200	5280
2003	I-VII	2400	2400	960	3840
	stop	0	0	0	0
2004	VI- VIII	3240	3240	1200	5280
	IX-X	1560	1560	1200	1920
	stop	0	0	0	0
2005	I-XII	2040	2040	960	3120
2006	I-VI	1800	1800	960	2640
	VII	1320	1320	1200	1440
	stop	0	0	0	0
2007	I-V	1620	1620	1320	1920
	stop	0	0	0	0
2008	XII	2040	2040	0	4080
2009	I-V	1800	1800	0	3600
	VI-XI	1560	1560	960	2160
	XII	1800	1800	1800	1800
2010	I-III	1800	1800	1200	2400

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Fig. 7. Simulated present potentiometric surface of  $D_1 km$  aquifer in geothermal plant vicinity

- 1 production well and its No;
- 2 injection well and its No;
- 3 simulated altitude of relative head, m a.s.l.

Results of simulation show, that geothermal plant can be operated without GTW withdrawals restoration. In this case, of course, deep and large depression cone will be formed: even 50 km from Klaipeda GTW drawdown can be 1,5-2 m. In the centre of depression cone drawdown stabilization will last 9–10 years (see Table 6). Re-calculations of fresh water heads into salt ones show that the head of GTW in Klaipeda will be found at the depth 125–127 m from the land surface. In pumped wells it will be even greater, at the depth ca. 200 m.

In Table 7 are given results of simulation of GTW withdrawals from production wells No 2p, 3p and spread of spent GTW, injected into wells No 1i and 4i during the period 2001–2010.

Fig. 7 demonstrates present (2010, March) piezometric heads of  $D_1$ km aquifer in Klaipeda Geothermal Plant area. From this figure follows, that GTW drawdown in pumped wells is at 42,8–43 m a.s.l, in injected wells – at 61–64 m a.s.l. It means, that GTW depression in production wells is 10–11 m, controversially; dome height of GTW at injection wells is 6–9 m.

Fig. 8 show simulated scale of spread of injected GTW during the period 2001–2010. We can see, that flow of GTW, injected into well No 4i, is radial, but in well No 1i area it is



Fig. 8. Simulated area of spread of GTW, injected into productive aquifer  $(D_1 km)$ , period 2001–2010

- 1 production well and its No;
- 2-injection well and its No;
- 3 present flow lines of GTW in D1km aquifer;
- 4 areal of injected GTW spread, formed in 2001 -010.

slightly distorted by GTW pumping from production wells. The model also show, that injected GTW travel distance around the well No 4i is 340-360 m, around the well 1i - 180-320 m. Because pumped aquifer is fairly thick and productive (effective porosity 26%), GTW travel distance from injection wells is not high, therefore travel time of injected GTW up to pumping ones will take not one ten of years.

#### IV. CONCLUSIONS

Geochemical model PHREEQC demonstrates, that spent GTW injectivity is essentially governed by precipitation of Fesulphides, oxides and hydroxides. Fe-sulphides scaling can be restricted by stopping activity of SRB (sulphate reducing bacteria's) in injection wells. But bactericide Bactron, used for this purpose, seems to be not effective, because it not only kills bacteria: Bactron, likewise gypsum-scaling inhibitor Labuxan, adds some extra-organic matter into GTW, indispensable for SRB existence, thus activating extra-scaling.

Stopping any entry of oxygen into the geothermal plant system can eliminate scales of Fe-oxides, hydroxides and crystals of S0. Model also show, that an attempt to inject not spent GTW, but almost fresh groundwater from shallow aquifers will be not very effective. Only soft acidification of spent GTW reduces abundance of almost all scales, deteriorating injectivity. Finally we must state, that used geochemical model did not simulate emission of gases from GTW ("bubbling") and did not imitate drastically drop of pressure of GTW in surface equipment and its role in scaling processes.

Groundwater flow and transport models show, that it is possible to take 700 m<sup>3</sup>/h (16800 m<sup>3</sup>/d) of GTW from D<sub>1</sub>km aquifer without any restoration of GTW resources. But it will result in formation of the depression cone with the depth of 200 m and radius of 50 km, drawdown stabilization will last 9–10 years. Though parameters of productive aquifer allow to take named volume of GTW from this formation, another problem arises: how and where to utilize this large amount of salt water?

Simulation data also demonstrate, that travel distance of GTW, injected into well No 4i during the period 2001–2010, is not great due to the fairly large thickness of productive aquifer and significant effective porosity of GTW-containing sandstones. It guarantees safe operation of geothermal plant not one decade, if decrease of injectivity will be stopped and successfully managed.

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### Antanas Algirdas Klimas, Marius Gregorauskas, Algirdas Mališauskas. Datormodeļu izmantošana Klaipēdas ģeotermālās stacijas ekspluatācijas problēmu analīzei

Klaipēdas ģeotermālā stacija darbojas kopš 2000. gada. Stacijas ekspluatāciju apgrūtina nepieciešamība ievadīt izmantoto termālo ūdeni atpakaļ pazemē aptuveni viena kilometra dziļumā. No daudzajām problēmām, kuras rodas ievadot izmantoto termālo ūdeni produktīvajā slānī, kā galvenā problēma ir dažādu nogulšņu rašanās, jo termālais ūdens satur daudzus minerālus un sāļus. Nolūkā noskaidrot slāņa kolmatācijas iemeslus un apjomus, un lai pārbaudītu dekolmatācijas iespējas, izmantots termodinamiskais modelis PHREEQC. Lai prognozētu iesūknētā termālā ūdens izplatību produktīvajā slānī, izmantoti filtrācijas un migrācijas modeļi MODFLOW2000, MODFLOW2005, MODPATH3.0.

Modelēšana parādīja, ka iegūstot termālo ūdeni līdz 16800m<sup>3</sup>/dienn, to var neatgriezt atpakaļ produktīvajā slānī. Taču tas var novest pie depresijas konusa veidošanās, kura dziļums var sasniegt 200m un rādiuss 50km. Šī pazeminājuma stabilizācija var notikt pēc 9-10 gadiem. Kaut arī ūdens nesošā slāņa hidroģeoloģiskie parametri pieļauj tik ievērojamu ūdens atdevi, rodas cita problēma: kā lai utilizē izlietoto ūdeni?

Modelēšana arī parādīja, ka produktīvajā slānī atgrieztā izlietotā ūdens migrācija ir neliela, slāņa ievērojamā biezuma un porainības dēļ. Ja tiks atrisināta ūdens nesošā slāņa kolmatācijas problēma, var garantēt ilgstošu stacijas ekspluatāciju.

#### Антанас Альгирдас Климас, Мариус Грегораускас, Альгирдас Малишаускас. Компьютерные модели, использованные для анализа проблем эксплуатации Клайпедской геотермальной станции

Клайпедская геотермальная станция эксплуатируется с 2000 года. Эксплуатация осложняется проблемами возвращения использованной термальной воды в продуктивный пласт, залегающий на глубине около 1 км. Среди множества причин компликаций с возвращением использованной термальной воды в продуктивный пласт важнейшими являются проблемы выпадения различных осадков, так как термальная вода насыщена многими солями и минералами. С целью выявления причин и масштабов кольматации продуктивного водоносного пласта этими осадками, а также для модельных проверок возможностей декольматации этих пор использована термодинамическая модель PHREEQC. Для анализа и прогноза масштабов растекания возвращенной термальной воды в продуктивный пласт использованы фильтрационная и миграционная модели MODFLOW2000, MODFLOW2005, MODPATH3.0.

Моделирование показало, что возможен водоотбор термальной воды до 16800 m<sup>3</sup>/сут без её возврата обратно в продуктивный водоносный пласт. Однако это может привести к образованию депрессионной воронки глубиной до 200 м и радиусом до 50 км, а стабилизация понижения произойдет после 9-10 лет. Хотя гидрогеологические параметры водоносного пласта и позволяют столь значительный водоотбор, возникает другая проблема: как и где утилизировать такое количество рассола?

Моделирование также показало, что расстояние миграции возвращенной в продуктивный пласт использованной термальной воды является небольшим из-за значительной мощности и пористости пласта. Это гарантирует многолетнюю эксплуатацию станции, если проблема кольматации водоносного пласта будет решена.