MODELING OF THE MUTNOVSKY GEOTHERMAL FIELD EXPLOITATION IN CONNECTION WITH THE PROBLEM OF STEAM SUPPLY FOR 50 MWe PP

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KEY WORDS

Geothermal fields, Mutnovsky, Dachny site, PP, exploitation, production zone, modeling, numerical, thermal, hydrodynamic.

ABSTRACT

The Mutnovsky geothermal field modeling study (TOUGH2) previously made by the author (Kiryukhin, 1992, 1996, 2002) has shown that total steam production of the wells existing in 1991 will yield not less than 44 MWe. In October 2002 Mutnovsky 50 MWe PP was put into operation in Dachny site. The so-called Main production zone in Dachny site strikes north-north-east and dip east-east-south at the angle 60° (Kiryukhin et al.,1998). The problem of steam supply to Mutnovsky 50 MWe PP (Dachny) triggered the new reservoir model demand. Due to above, the old model (1992, 1996, 2002) has been revised and the new one based on "well-by-well" generated mesh (A-Mesh grid generator) strongly related to the particular wells and production zone has been used. The following data are used for the new model calibration: (1) flowtests from wells E4, 016, 26, 029W and 24 (the data of 1999-2002), (2) additional wells A1 – A4 drilling data, (3) pressure monitoring data (well 012) and (4) exploitation wells E4, 016, 26, 029W, A2, E5 (2002-2003 year) data. Modeling results show that total steam production of the wells (E4, 016, 26, 029W, A2, E5) will decline from 60-70 kg/s to 30 kg/s during the period of 10 year exploitation due to overload of the north part of the Main production zone. The study of steam production from the south-east part of the Main production zone is going on now.

1. INTRODUCTION

The previous numerical model of the Mutnovsky geothermal field (1992, 1996) was designed to understand heat and mass transfer processes in geothermal reservoir as a whole, and to forecast possible exploitation scenarios. This model consisting of 500 elements 500 x 500 x 500 m^3 each with total volume of 5 x 5 x 2.5 km^3 was used to forecast 20 year period of exploitation based on existing wells and it shown 44 MWe as a minimum yield of the field. Next time this model was used by WestJec (Japan) company to do feasibility study of the Mutnovsky PP put into operation in October 2002. After having put this PP into operation 30-35% steam supply shortage was found. Since that reservoir modeling demand was regarded as an instrument for steam production increase the mean optimal design of the exploitation load in relation to the particular production zones was revealed in the field. The revised numerical model of the field was based on the appropriate grid generation (Fig.1).

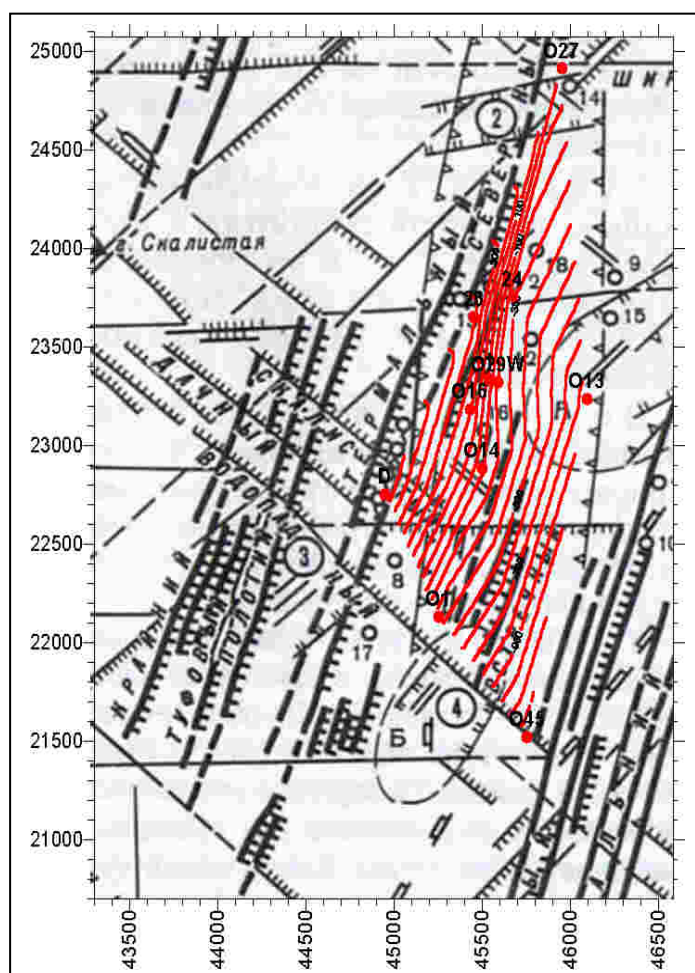## 2. PRODUCTION ZONES OF DACHNY SITE IN THE MUTNOVSKY GEOTHERMAL FIELD

The Main production zone in Dachny site is penetrated by wells 045, 01, 014, 016, 1, 029W, 26, 24, 4Э. This production zone strikes north-north-east with east-east-south dip 60°. The strike of production zone is subparallel to the system of faults (the so-called Vstrechny, Thermal, Pologiy, Tuffaceous and Krainiy), the south-west boundary is the so-called Vodopadny fault and the east fault is the sub-meridional zone of the magnetic anomaly (V.L. Leonov, 1986) (Fig. 2). Roof and bottom elevations of the production zone are estimated based on KGGE data (1991) in which the roof elevation is estimated from the minimum depth of the production zone penetrated by slotted line while the bottom elevation is estimated from the maximum depth of the production zone penetrated by the slotted line (Table 1).

The Main production zone penetrated by high well head pressure (WHP) wells is characterized by chlorite-wairakite secondary mineral association, Cl/SO4>1, high values of the Na-K geothermometer (compare to direct temperature measurements) and submeridional tracer interaction (1991). Four additional wells (A1-A4) recently drilled or equipped with slotted liners outside of the Main production zone has demonstrated zero or low productivity (Fig.3).

It is worth to note that similar "single fault" type geothermal fields have been found in Japan (Ogiri) where 30 MWe comes from single fault of 20 m thick and 232^oC liquid phase circulates in andesite host rock (Goko, 2000). Additional examples are Okuaizu (Japan) and Dixie Valley (USA).
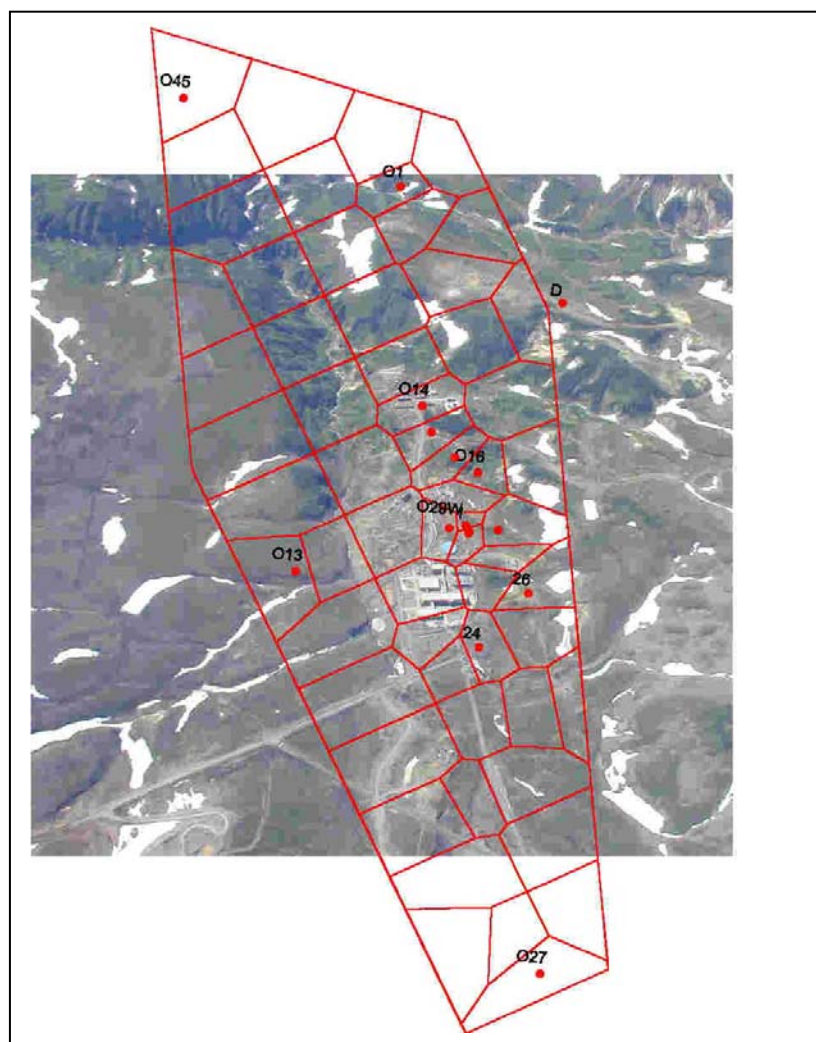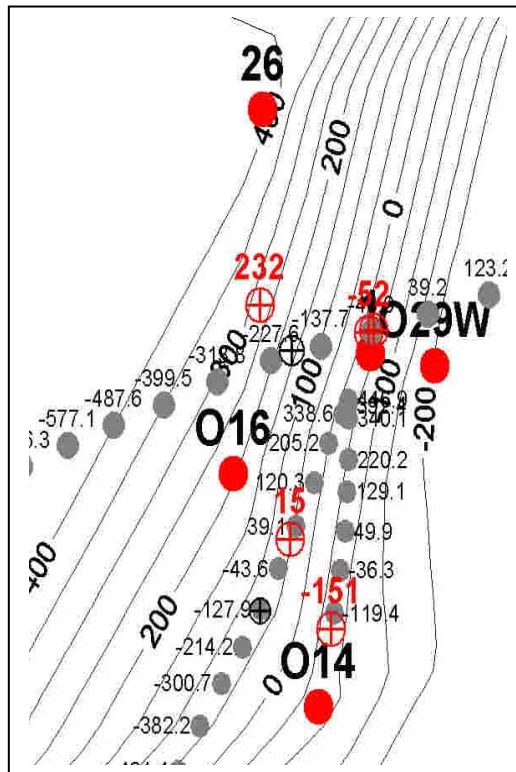

Fig.1 Air photo of Dachny site in the Mutnovsky geothermal field (view from the north, N.I. Seliverstov, 2003). Numerical grid used in the new model is overlaid.

Fig. 2. Structural map of the Mutnovsky geothermal field (V.L. Leonov, 1986) and roof elevations (m.a.s.l.) of the Main production zone of Dachny site.

Table 1. Input data for mapping the Main production zone of Dachny site in the Mutnovsky geothermal field.

№ скв. Well#	X	Y	Z	кровля, глубина,м top,m	подошва, глубина,м bottom,m	Кровля, м абс Top, masl	подошва, м абс bottom, masl	вертикальная мощность, м vertical thickness ,m	T, oC
1	45540	23336	786	820	1100	-34	-314	280	280
26	45455	23650	816	388	466	428	350	78	226
O16	45432	23181	788	577	832	211	-44	255	244
O27	45953	24912	813	830	1021	-17	-208	191	230
O29W	45591	23320	791	1010	1057	-219	-266	47	268
O1	45254	22131	803	1156	1195	-353	-392	39	304
O14	45499	22881	775	851	993	-76	-218	142	274
O13	46095	23236	802	1660	1951	-858	-1149	291	303
O45	45756	21522	710	1979	2080	-1269	-1370	101	291
24	45673	23754	793	1081	1300	-288	-507	219	275
D	44950	22750	775	0		775			96
							Среднее Average	164.3	

Fig.3. Roof elevations of the Main production zone - isolines, wells A2-A4 drilling tracers (•) and mud losses zones (⊕).

## 3. MODELING OF THE NATURAL STATE CONDITIONS AND EXPLOITATION OF DACHNY SITE IN THE MUTNOVSKY GEOTHERMAL FIELD.

3.1 The numerical model description.

The numerical model geometry is shown in Fig.4. Geothermal reservoir is represented as one layer with variable thickness each element of which is located at the specified elevation corresponding to the Main production zone. Grid generation is based on A-MESH and MINC preprocessors. 24 existing wells, 39 additional interior elements (F-elements and D-element) and 12 boundary (inactive) elements (B-elements) are specified in the model (Fig. 4).

«Sources» in the model are O45, F27, F28, F14, F15, F29. Mass rate and enthalpy are specified as 9 kg/s and 1390 кJ/кg (water 307 ^{o}C) in each "source" element.

Permeability and rock properties are assigned based on the previous modeling (1996, 2002) and then they are corrected taking into account the natural state condition modeling results. Boundary conditions are assigned in B-elements as P=const and T=const. Heat exchange between the elements and host rock are specified through QLOSS subroutine where heat exchange coefficient is assigned as 0.0042 W/m^2 ^{o}C. Pressure boundary conditions are estimated based on the data received from well O12.
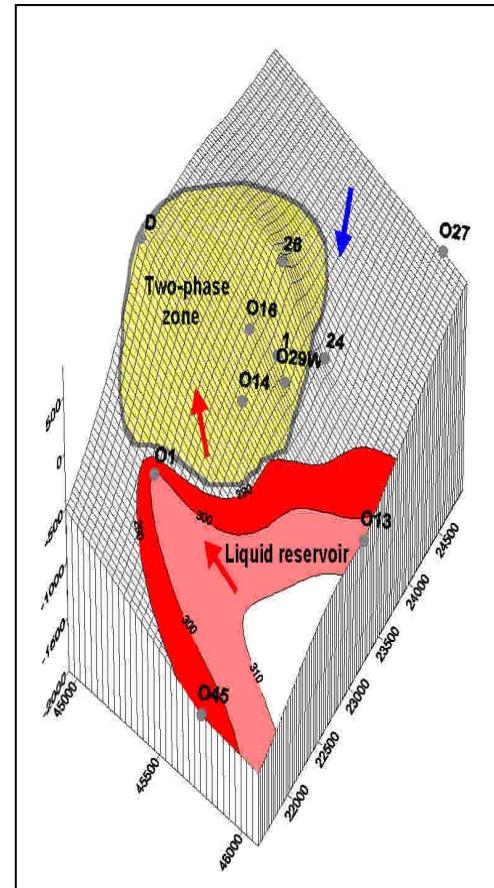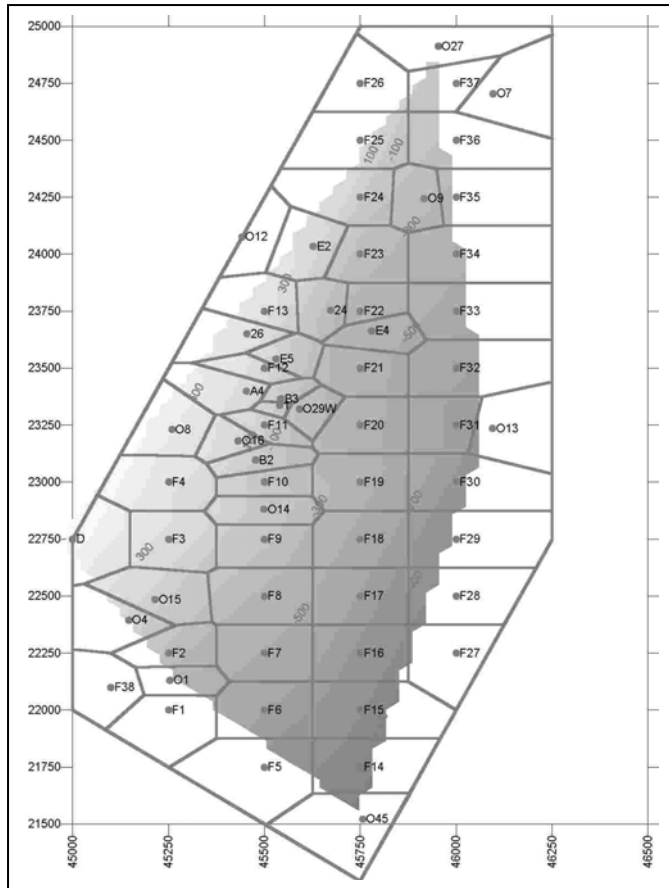
Fig.4 On the left – geometry of the numerical model of Dachny site in the Mutnovsky geothermal field: elements and its elevations (m.a.s.l.). On the right – 3-D image of the Main production zone with temperature, phase distributions along and production wells.

3.2 Natural State Modeling.

Modeling is targeted to temperature, pressure and phase condition match based on model sources and sink parameters. Total upflow rate estimated in this model is 54 kg/s and permeability distribution is shown in Fig.5. Permeability coefficients in domains STEAM, ROCK1 (ROCK3) and ROCK2 are estimated as 100 mD, 50 mD and 10 mD correspondingly. Fig.6 shows temperature, steam saturation and flows distribution along the Main production zone (liquid flows are greater than 1 kg/s and steam flows are greater than 0.1 kg/s between the elements). Upflows are directed from south-east part to north-north-east part (liquid discharge) and west part (steam discharge, element D – the so-called Kotel) of the production zone (element D – Kotel).

3.3 Modeling of the exploitation up to 2012 year.

3.3.1 Input data for the model calibration.

Model calibration is based on the data received from production wells 016, 26, 029W, 4Э, A2 and 5Э (Table 2), pressure monitoring data (well 012 where capillary tubing system is installed) and geothermometer data. The following parameters are found necessary to calibrate the model: (1) compressibility coefficient $5.0 \cdot 10^{-7}$ Pa^{-1} in STEAM domain and $5.0 \cdot 10^{-8}$ Pa^{-1} in the rest domains; (2) double porosity approach in well O16 element (THRED model with fracture/matrix ratio 0.01 and fracture distance 1 m is used.

3.3.2 Modeling of well-reservoir interaction.

Special subroutine DEBIT is used for well-reservoir interaction representation in the model. Mass flowrate is determined from the following equation: $Q = PI * (P_r - P_b(WHP, Q, h, d))$ where Q – mass flowrate of the well; PI – production index of the well; P_r - reservoir pressure, $P_b(WHP, Q, h, d)$ – bottom hole pressure that is a function of Q, fluid enthalpy h, well head pressure WHP and well construction features d (well diameter vs depth).
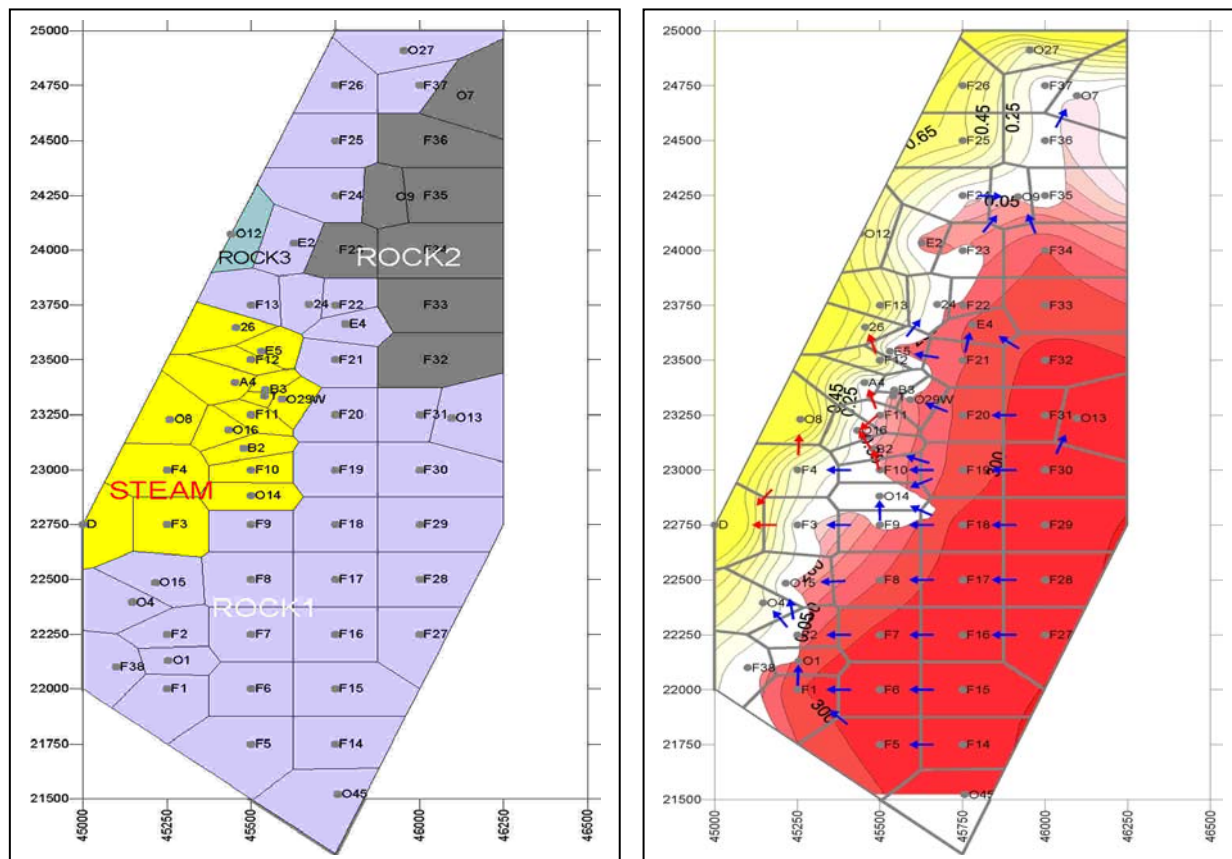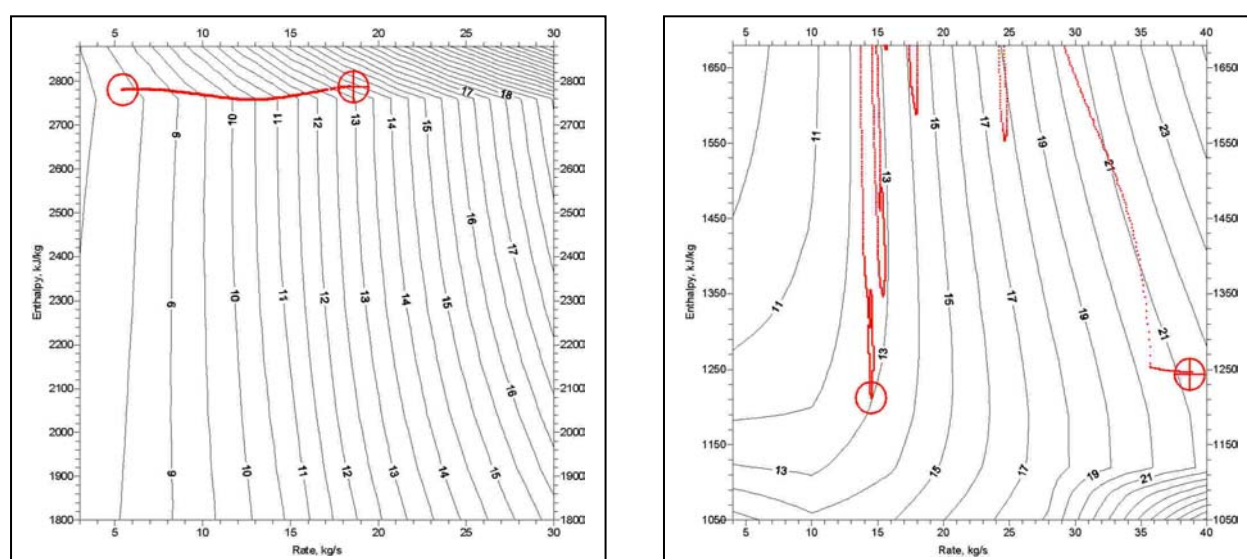

Fig.5 (Left) Permeability distribution in the model along the Main production zone. Fig.6 (Right) Modeling of natural state conditions: temperature, pressures and flow distributions.

Table 2. Parameters of the Mutnovsky production wells before exploitation (September 2002) and ½ year after the beginning of exploitation (March 2003) (I.I. Chernev, pers. com.). Steam rate is converted to 7 bars.

№ скважины	Расход, кг/с	Расход пара, кг/с	Устьевое давление, бар	Энтальпия кДж/кг
До начала эксплуатации				
O16	19.1	18.5	8.4	2690
26	28.2	28.5	10.1	2780
4E	32.8	6.5	7.6	1104
029W	71.1	15.6	7.3	1150
A2	34.4	7.2	8.4	1131
5E	36.9	7.1	8.7	1097
Март 2003 г				
O16	16.9	16.5	7.7	2709
26	17.6	17.6	7.4	2759
4E	26.8	1.6	9	819
029W	72.5	17.0	9.2	1181
A2	14.9	6.8	6.9	1644
5E	39.1	8.9	7.1	1166

Table 3. Modeling estimated production indexes of the wells 016, 26, 029W, 4Э, A2 and 5Э and enthalpy and pressure values in corresponding model elements.

Скважина	Энтальпия, модель кДж/кг	Расход, измер. кг/с	Устьевое давление, бар	Расчетное. Забойное давление, бар	Давление в резервуаре, модель бар	Коэффициент продуктивности, кг/с бар
016	2800	17	7.5	12.5	27.8	1.11
26	2800	18	7.5	14.0	25.2	1.61
4E	1200	26.7	9.0	24.5	88.6	0.42
029W	1150	72.5	9.0	50.7	72.5	6.78
A2	1650	15	7.0	10.8	47.2	0.41
5E	1175	39	7.0	21.0	72.5	0.76

Fig.7 Bottom hole pressures in wells 26 (left) and 5E (right) vs mass flowrate and enthalpy under WHP 7.5 and 7.0 bars correspondingly. Symbol ⊕ means initial well parameters (Table.3), while symbol «o» means final well parameters, also transient traces are shown (#1 scenario of the exploitation).

Bottom hole pressure P_b(WHP, Q, h, d) is calculated in the form of electronic tables based on HOLA code (Fig. 7). Productivity indexes of six production wells are shown in Table 3, estimations based on initial well parameters before the beginning of exploitation, reservoir pressures derived from modeling of the natural state conditions. Fig.7 (right) shows that enthalpy decline below 1100 kJ/kg turns off a two-phase production well (well 5E, for example). Enthalpy increase above 1350 kJ/kg has also negative effect on mass flowrate of two-phase production wells (Fig.7, right). Steam well flowrates (Fig. 7, left) are more sensitive to reservoir pressure variations.

3.3.2 Modeling of Dachny site exploitation in the Mutnovsky geothermal field up to 2012 year.

Exploitation wells are assigned under well head pressure conditions corresponding to the data from Table 3, well 027 is specified as reinjection with mass rate 84 kg/s and enthalpy 700 kJ/kg. Two scenarios of exploitation up to 2012 year are studied: (1) Six wells 016, 26, 029W, E4, A2 and E5 exploitation, (2) Two times (x2) exploitation load increase in the model elements 016, 26, 029W, E4, A2 and E5.

Neither changes in boundary conditions are assumed. Two-phase wells were switched off if mass flowrate dropped less than 10 kg/s, steam wells were switched off if mass flowrate dropped below 5 kg/s. Modeling results are represented in Figs. 8 and 9.

Scenario #1 (Fig. 8) shows 60-70 kg/s steam production during the first two years of the exploitation, then steam production drops to 45 kg/s by 3-rd year, and then drops to 30 kg/s. Well flowrate-enthalpy traces during exploitation (Fig. 7, right) show two-phase well (029W, E4, A2 and E5) increase enthalpy due to reservoir boiling and then decrease due to cold water inflow. There are no significant enthalpy variations of steam wells during exploitation (Fig.7, left) based on modeling results.

Scenario #2 (Fig. 9) shows sharp steam production drop from 160 to 65 kg/s during the first 1.5 years of the exploitation, then another drop to 45 kg/s by 2.5 year of the exploitation, and gradual decline from 45 to 25 kg/s during next 4 years and then all the wells turn off by the 9-th year of the exploitation.
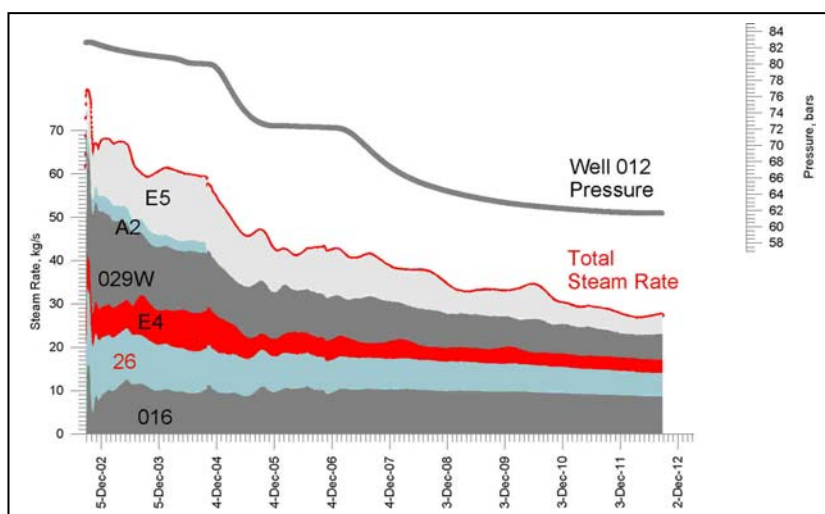
Fig.8 Scenario #1: modeling of the steam production (wells 016, 26, E4, 029W, A2, E5) and reservoir pressure (well 012) change in Dachny site of the Mutnovsky geothermal field up to 2012 year.
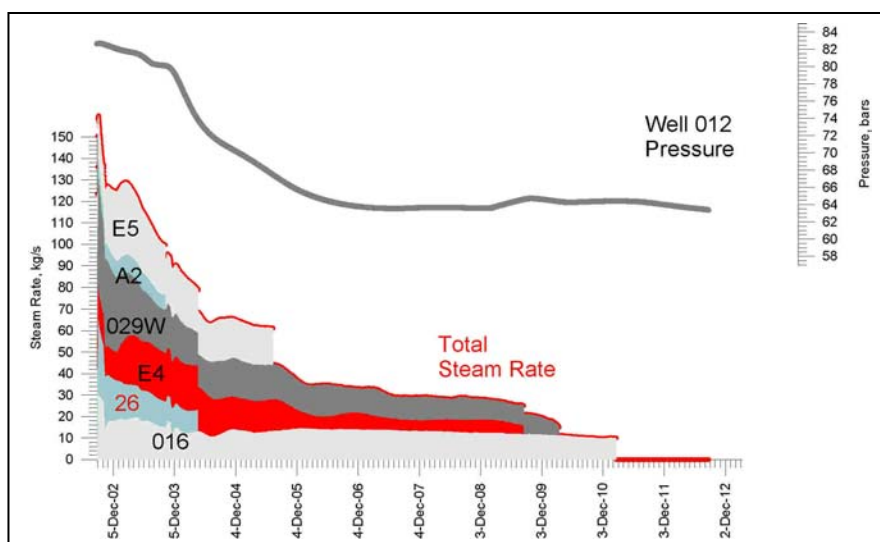
Fig.9 Scenario #2: modeling of the steam production (doubling load of the wells 016, 26, E4, 029W, A2, E5) and reservoir pressure (well 012) change in Dachny site of the Mutnovsky geothermal field up to 2012 year.

4. CONCLUSIONS

1. Steam production from the existing production wells of the Dachny site in the Mutnovsky geothermal field (016, 26, E4, 029W, A2, E5) is limited by 60-70 kg/s with possibility of decline down to 30 kg/s during the first 10 years of the exploitation. Significant exploitation load in central part of the Dachny site will not yield adequate steam production increase in stable terms, moreover, it may have negative effect for steam productivity.

2. Mutnovsky 50 MWe PP needs 100 kg/s of 7 bars steam in stable terms of 20–30 years exploitation period. Additional study of the steam productivity increase from south-east portion of the Main production zone of the Dachny site (model elements F5-F9, F14-F20, F27-F31) is going on.

3. The modeling results show necessity of reliable and regular (per month) enthalpy-flowrate data receipt from production wells under exploitation conditions. Chemistry and gas monitoring data obtained during exploitation may be useful to detect the boundary conditions. Reservoir pressure data in the central part of geothermal reservoir is desired too. All the above data are necessary for proper calibration of the numerical model and accurate forecast of steam production scenarios.

ACKNOWLEDGEMENTS

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