PROCEEDINGS, Twenty-Ninth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 26-28, 2004
SGP-TR-175

MODELING STUDY OF THE MUTNOVSKY GEOTHERMAL FIELD (DACHNY) IN CONNECTION WITH THE PROBLEM OF STEAM SUPPLY FOR 50 MWe PP

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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 problem of steam supply to Mutnovsky 50 MWe PP (Dachny) trigged 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 zones has been used (the so-called Main production zone in Dachny site strikes north-north-east and dip east-east-south at the angle 60^o (Kiryukhin et al.,1998)). 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) output data. Modeling results show that total steam production of the wells (E4, 016, 26, 029W, 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. Modeling of additional exploitation load in the south-eastern part of the Dachny site to maintain 50 MWe PP is on-going.

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.

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, 4E (Fig.1). This production zone strikes north-north-east with east-east-south dip 60^o. 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 S.G. Assaulov data (1996) in which the roof elevation is estimated from the minimum depth of the production zone penetrated by slotted line. The Main production zone penetrated by high well head pressure (WHP) wells (Table 1) 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. 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 shows space deviation of the points of the full circulation loss from the Main production zone plane. 75% of all full circulation loss zones and 100% of all production wells are occurring to ±150m thick interval of the Main production zone plane. Another minor permeability zone may be refer to the lower full circulation loss zones of the wells 04, 2E, 012, 4E and 011 related to diorite intrusion contact, penetrated by wells above mentioned below the Main production zone (Fig.3).

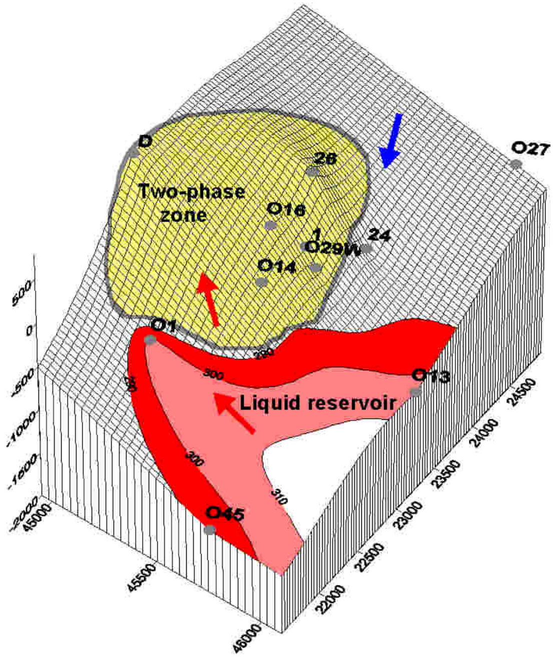

Figure. 1. *3-D conceptual model of the Main production zone with temperature, phase distributions along and production wells.*

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

Well#	X	Y	Z	top,m	bottom,m	Top, masl	bottom, masl	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

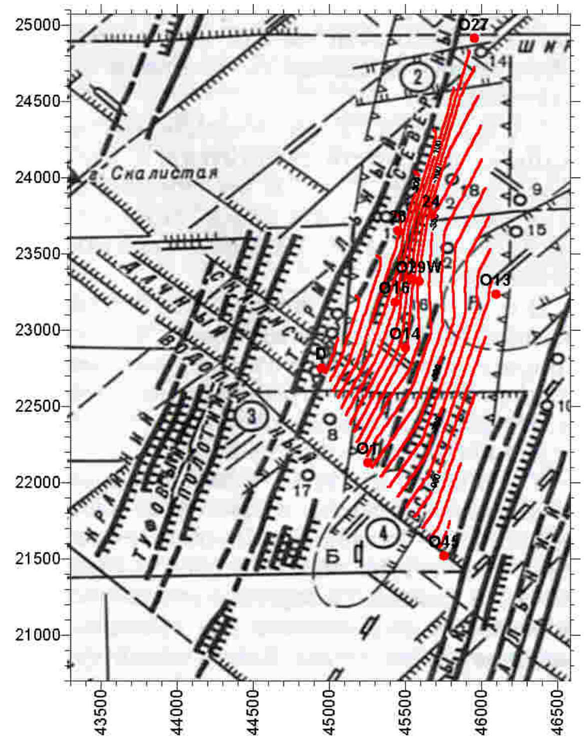

Figure. 2. *Structural map of the Mutnovsky geothermal field (V.L. Leonov, 1986) and roof elevations (m.a.s.l.) of the Main production zone of Dachny site.*

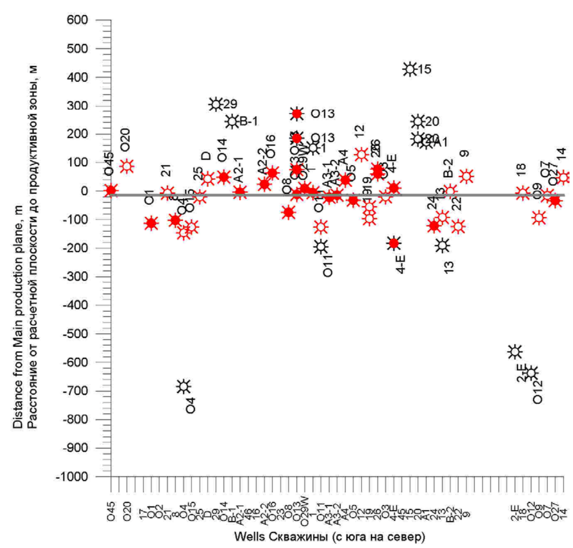

Figure. 3. *Deviation from Main production zone plane ($dz*\cos(60.4^o)$): $Z = -1.691076246561*X +0.48880109651512*Y +65583.1$ to the points of the full circulation loss. Filled symbols correspond to production wells.*

Note the 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°C liquid phase circulates in andesite host rock (Goko, 2000). Similar examples are Okuaizu (Japan) and Dixie Valley (USA).

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

The numerical model description

Grid generation based on A-MESH preprocessor (1998), which yield TOUGH2 input parameters in terms of horizontal connections parameters d1, d2, AREA. Then additional correction procedure was implemented to specify vertical component in grid connection (Fig.4). In addition to this, the more accurate BETAX presentation (format F20.14 instead of F10.4) used to avoid “parasitic circulation” in the model (K. Pruess, pers. com., 1998).

Geothermal reservoir is represented as a combination of two layer-type reservoirs: A-reservoir and B-reservoir. A-reservoir numerical grid correspond to the Main production zone with averaged vertical thickness 240 m, each element of which is located at the specified elevation corresponding to the Main production zone (Fig.5). B-reservoir numerical grid includes three elements corresponding to wells 2E, 5E and O12 diorite intrusion contact permeability zones.

In total 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.6 demonstrate grid and permeability distributions assigned in the A-reservoir and B-reservoir of the model. «Sources» in the model are O45, F27, F28, F14, F15, F29, 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 (Fig.6).

Boundary conditions are assigned in B-elements as P=const and T=const (natural state modeling). Heat exchange between the elements and host rock with average temperature 100 °C are specified through QLOSS subroutine where heat exchange coefficient is assigned as 0.0042 $W/m^2\,{}^oC$.

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, mass rate and enthalpy are specified as 9 kg/s and 1390 кJ/кg (water 307 °C) in each “source” element (Fig.6). Permeability distributions in A-reservoir domains STEAM, ROCK1, ROCK2 and ROCK3 are estimated as 100 mD, 100 mD, 1 mD and 0.01 mD correspondingly, in B-reservoir ROCK1 domain - 100 mD. Fig.7 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.

Modeling of the exploitation up to 2012 year

Input data for the model calibration

Model calibration is based mainly on the data received from initial production tests of wells 016, 26, 029W, 4Э, A2 and 5E, and data of the total steam and total separate production from Mutnovsky PP separator. The total steam production (at 6 bars abs) of the wells above mentioned declined from 64.9 kg/s to 59.4 kg/s (8.5%), the total separate production declined from 117.5 kg/s to 107.5 kg/s (8.5%) during one year exploitation period.

Pressure monitoring well O12 shows 0.75 bar pressure drop during one year exploitation period, but this data are not characterize production zone where exploitation took place.

At this stage of calibration the compressibility coefficient was found necessary to implement in the model: 5.0 10^{-7} Pa^{-1} in STEAM domain and 5.0 10^{-8} Pa^{-1} in the rest domains.

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).Bottom hole pressure $P_b(WHP, Q, h, d)$ is calculated in the form of electronic tables based on HOLA code (Fig. 8,9). Productivity indexes of five production wells are shown in Table 2, estimations based on initial well parameters before the beginning of exploitation, reservoir pressures derived from modeling of the natural state conditions. Fig.9 shows that enthalpy decline below 1100 kJ/kg may turns off a two-phase production well (well O29W, for example). Steam well production (Fig. 8) is less sensitive to reservoir enthalpy variations.

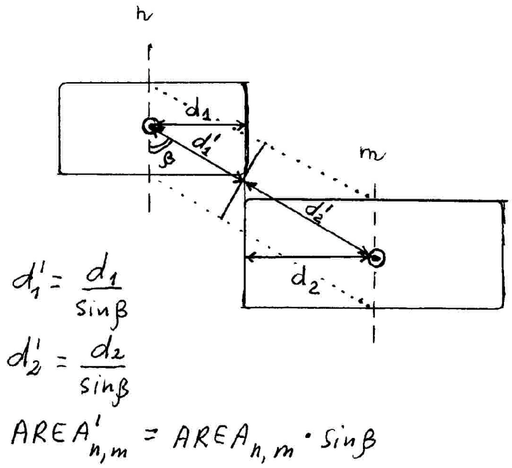

Figure. 4. *Mesh parameters (d1, d2, AREA) corrections applied to A-MESH output.*

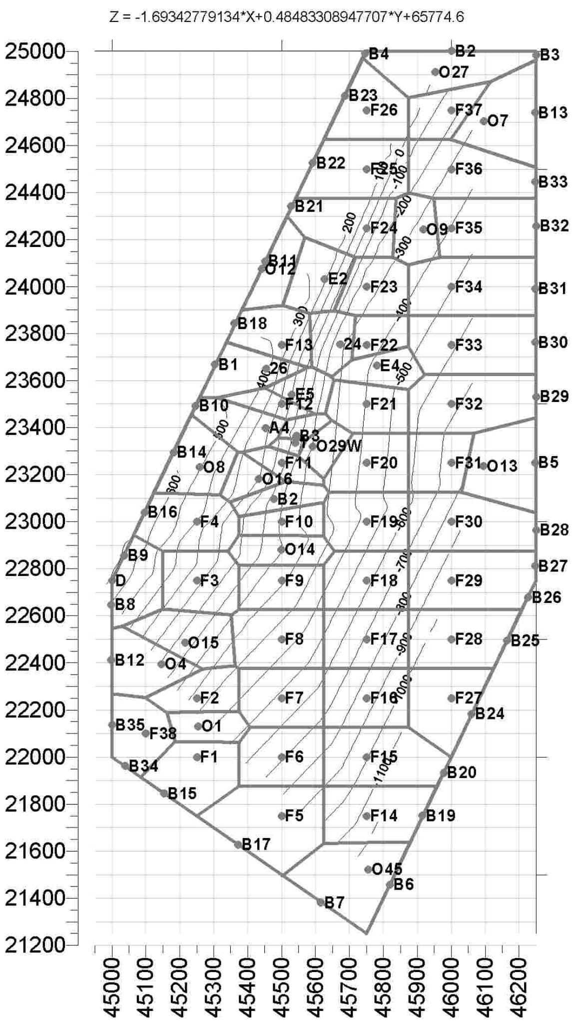

Figure. 5. *Dachny site in the Mutnovsky geothermal field. Numerical grid of the A-reservoir elements and its elevations (m.a.s.l.).*

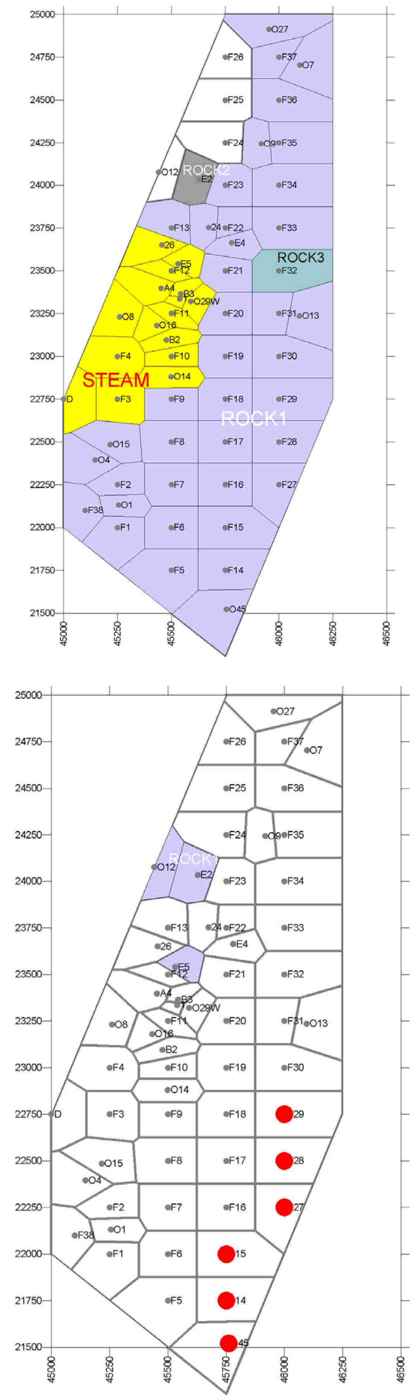

Figure. 6. *Permeability distribution in the model. Upper chart: A-reservoir (Main production zone) STEAM, ROCK1, ROCK2 and ROCK3 domains with 100 mD, 100 mD, 1 mD and 0.01 mD, correspondingly. Lower chart: B-reservoir (diorite contact zone) ROCK1 domain with 100 mD permeability. Sources are shown as a thick circles.*

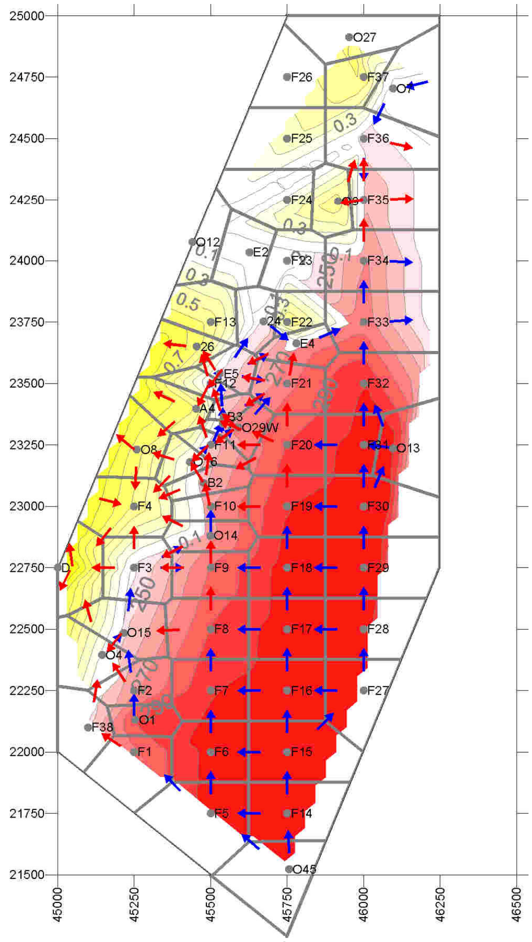

Figure. 7. *Modeling of natural state conditions: temperature, pressures and flow distributions.*

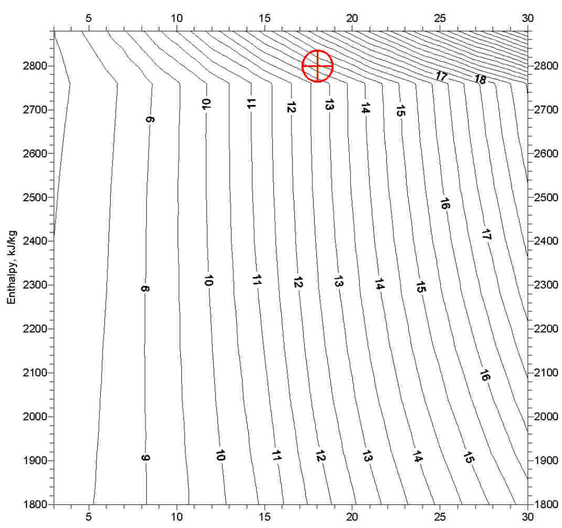

Figure. 8. *Bottom hole pressures in well 26 vs mass flowrate and enthalpy under WHP 7.5 bars. Symbol ⊕ means initial well parameters.*

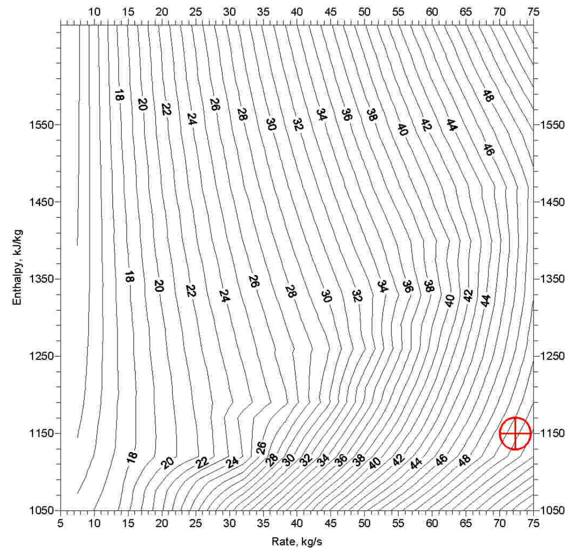

Figure. 9. *Bottom hole pressures in well O29W vs mass flowrate and enthalpy under WHP 7.5 and 9.0 bars correspondingly. Symbol ⊕ means initial well parameters.*

Table 2. *Exploitation wells initial parameters used for production indexes estimation in the model.*

Well	Enthalpy, kJ/kg	Rate, kg/s	WHP, bars abs	BHP, bars abs	Reservoir Pressure, bars	Production Indexes, kg/s bar
016	2800	17	7.5	12.5	26.7	1.2
26	2800	18	7.5	14.0	25.5	1.6
4E	1200	26.7	9.0	24.5	58.2	0.8
029W	1150	72.5	9.0	50.7	58.5	9.3
5E	1175	39	7.0	21.5	33.5	3.3

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 2, well 027 is specified at reinjection with mass rate 84 kg/s and enthalpy 700 kJ/kg. Two scenarios of exploitation up to 2012 year are studied: (1) Five wells 016, 26, 029W, E4 and E5 exploitation, (2) Two times (x2) exploitation load increase in the model elements 016, 26, 029W, E4 and E5.

The switch to "no flow" boundary conditions during exploitation are assumed in B1, B10, B14, B16, B9, B8 boundary elements in the model.

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 for two scenarios are represented in Figs. 10 and 11.

Scenario #1 (Fig. 10) shows total steam production drop of the wells 016, 26, 029W, E4 и E5 from 64 to 33 kg/s during the 10 year exploitation period, and 13 bars pressure drop in reservoir (A3 element). Well 26 may abandoned by 5-th year of exploitation.

Scenario #2 (Fig. 11) shows total steam production drop of the wells from 130 to 40 kg/s during the 10 year exploitation period, and 18 bars pressure drop in reservoir (A3 element). Wells 26 and 5E may abandoned by 2-nd and 5-th year of exploitation, correspondingly.

CONCLUSIONS

1. Steam production from the existing production wells of the Dachny site in the Mutnovsky geothermal field (016, 26, E4, 029W, E5) is limited by 60-70 kg/s with possibility of decline down to 33 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 F16, F17, F18, F19, F20, F29 and F8 is going on (Fig.12).

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

The author expresses gratitude to AO “Geoterm” staff: General Director V.E. Luzin, Chief Manager V.M. Morgun, hydrogeologists I.I. Chernev and L.K. Moskalev for helpful discussion and data support. This work has been supported by AO “Geoterm” contract №30 of 16.04.2003, Russian Basic Sciences Foundation grant 03-05-65373, Far East Division of Russian AS grant 03-3-A-08-069 and Russia Ministry of Education Grant 02.01.023.

REFERENCES

Z.P.Aunzo, G.Bjornson, G.S.Bodvarsson (1991), Wellbore models GWELL, GWNACL, and HOLA.Users Guide // *Draft,1991,81 p.*

S.G. Assaulov, N.P. Assaulova Mutnovsky geothermal field, DATABASE 1996 (Copy presented to WestJEC for implementation of the Kamchatka Feasibility Study).

Feasibility Study of the Integrated Power and Heating Plant System Sustained by the Mutnovsky Geothermal Field in Kamchatka // *West JEC, 1997 // Report for EBRD.*

Geothermal and Geochemical Studies of High-Temperature Hydrothermal (Using the Pattern of the Mutnovsky Geothermal Field*). Moscow, Science, 1986 , p. 305.*

Goko, K., 2000. Structure and hydrology of the Ogiri field, West Kirishima geothermal area, Kyushu, Japan. *Geothermics 29 (2), 127-149.*

A. Kiryukhin, I. Delemen and D. Gusev. High-Temperature Hydrothermal Reservoirs, *M. Science, 1991, p. 160.*

A Kiryukhin, M. Takahashi, A. Polyakov, M. Lesnykh and O. Bataeva (1998) Studies of the Mutnovsky Geothermal Field Water Recharge Conditions with the Use of Data on Oxygen (O^{18}) and Hydrogen (D) Isotopy // *Volcanology and Seismology, № 4-5, pp.54-62.*

A.Kiryukhin, 1992. Progress Report on Modeling Studies … *LBL-32729, p. 21.*

A. Kiryukhin. High-Temperature Fluid Flows in the Mutnovsky Hydrothermal System, Kamchatka // *Geothermics, v.23, No. 1, 1993, pp.49-64.*

A. Kiryukhin. Modeling Studies: Dachny Geothermal Reservoir, Kamchatka, Russia // *Geothermics, v.26, No.1, 1996, pp.63-90.*

A. Kiryukhin. Modeling of Exploitation of Geothermal Fields // *Vladivostok, Dalnauka, 2002, p. 216.*

A.V. Kiryukhin Modeling of the Exploitation of the Mutnovsky Geothermal Field in Relation to 50 MWe PP steam supply // *International Geothermal Workshop, Russia, Sochi, 6-10 Oct. 2003, 91 p.*

LAHEY Fortran90 v. 4.5// Lahey Computer Systems , Inc. // *P.O. Box 6091 Incline Village, NV 89450*

K.Pruess “TOUGH2 Users Guide, Version 2.0” // *LBL-43134, Nov.,1999*

Rosly G.A., 2003. Main Results of Exploitation Drilling // Report on AO Geoterm Worksho, June, 2003, Petropavlovsk-Kamchatsky, 35 p.

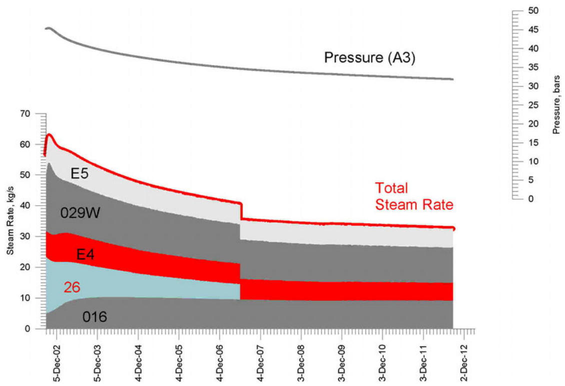

Figure. 10. *Scenario #1: modeling of the steam production (wells 016, 26, E4, 029W, E5) and reservoir pressure (well 012) change in Dachny site of the Mutnovsky geothermal field up to 2012 year.*

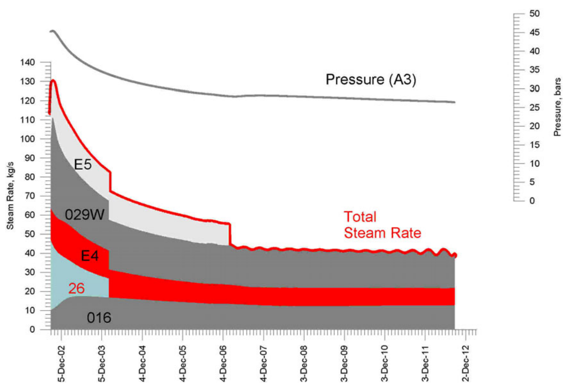

Figure. 11. *Scenario #2: modeling of the steam production (doubling load of the wells 016, 26, E4, 029W, E5) and reservoir pressure (A3 element) change in Dachny site of the Mutnovsky geothermal field up to 2012 year.*

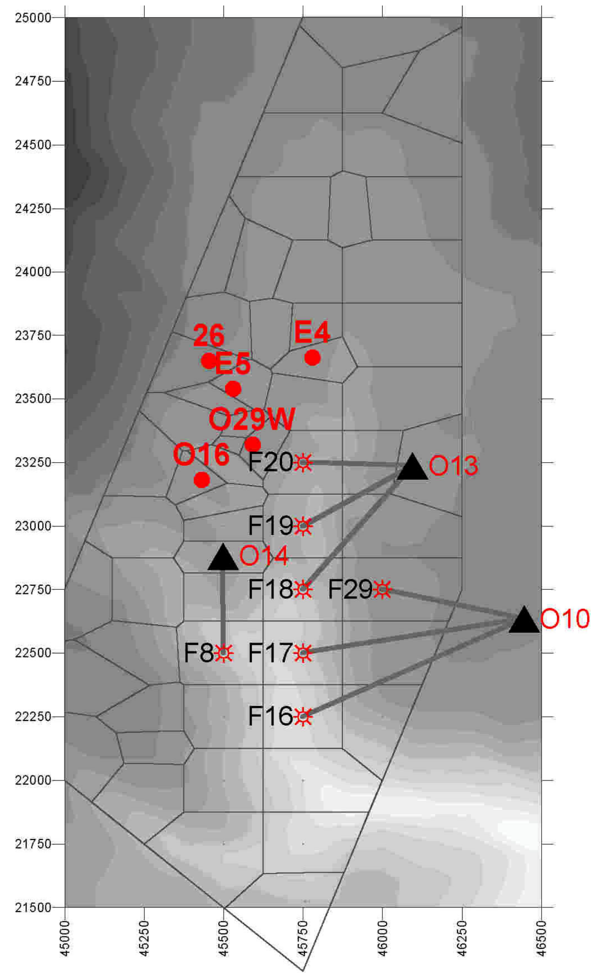

Figure. 12. *Possible well locations corresponding to on-going modeling scenario in connection to 50 MWe PP steam supply. Existing exploitation wells (26, O16, O29W, 4E, 5E) – filled circles, new drilling targets projections for additional exploitation wells (F16, F17, F18, F19, F20, F29 and F8) – open stars, and possible sites for directional drilling rigs (wells O13, O10 and O14 sites). Shaded areas shows topo surface elevations (from +500 to + 1000 m.a.s.l.)*