MODELING OF THE DIFFERENT REINJECTION SCENARIOS DURING EXPLOITATION OF THE MUTNOVSKY GEOTHERMAL FIELD (DACHNY SITE) (PART 2: MODEL APPLICATIONS)

ОЦЕНКА ВЛИЯНИЯ РЕИНЖЕКЦИИ НА ЭКСПЛУАТАЦИЮ МУТНОВСКОГО ГЕОТЕРМАЛЬНОГО МЕСТОРОЖДЕНИЯ (ДАЧНЫЙ УЧАСТОК) (ЧАСТЬ 2: ПРИЛОЖЕНИЯ МОДЕЛИ)

А.В. Кирюхин[1], Л.К. Москалев[2]

[1]- Институт вулканологии ДВО РАН
Пийпа- 9, Петропавловск-Камчатский, 683006
[2]- АО Геотерм
Королева- 60, Петропавловск-Камчатский, 683980
e-mail: *avk2@kcs.iks.ru*

ABSTRACT

Model calibration against 2002-2004 exploitation data and modeling of the possible future scenarios to maintain sustainability of the 50 MWe PP (Dachny) used to reveal optimal positions for additional exploitation and reinjection wells.

АННОТАЦИЯ

Моделирование различных сценариев в связи с обеспечением устойчивой эксплуатации Мутновской ГеоЭС 50 МВт позволяет выявить оптимальные позиции размещения дополнительных эксплуатационных и реинжекционных скважин.

INTRODUCTION

In this part of the paper reservoir modeling used as an instrument for optimal design of the exploitation load of the Dachny Site in Mutnovsky geothermal field, where SC “Geotherm” having put 50 MWe PP into operation in October 2002.

MODELING OF THE EXPLOITATION (MAIN PRODUCTION ZONE OF THE DACHNY SITE)

Data for Model Calibration

Exploitation model calibration is based mainly on the data received from initial production tests of wells 016, 26, 029W, 4E and 5E (used for PI estimations, Table 1, Part 1), operating wellhead pressure of the exploitation wells (Fig.5) and data of the total steam and total separate production from Mutnovsky PP separator (wells 016, 26, 029W, 4E, 5E, A2, O37 and 24) (Fig.6). There is no reliable data for individual exploitation wells production history. Pressure monitoring in well O12 (0.75 bar drop per year) rather characterized Host Rocks reservoir conditions, than production zone.

While production took place, individual wells wellhead pressures (Fig.5) and PP separator pressures (Fig. 6) gradually decline. From 5.4 bars to 5.0 bars (ati)) at PP separator during 1.5-year exploitation period) (Fig.6).

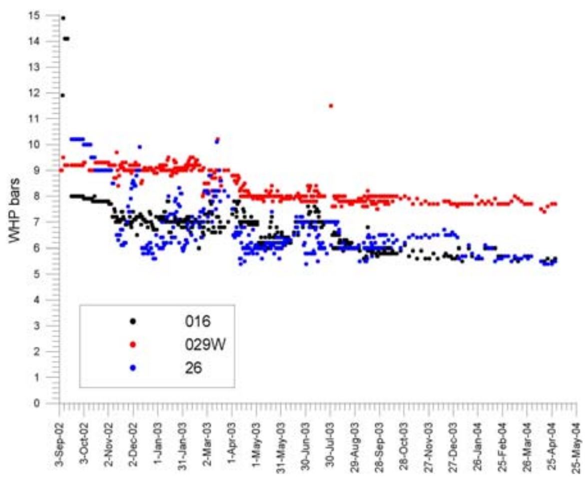

Figure. 5. Well Head Pressure (WHP, bars (ati)) variations) in exploitation wells of the Dachny site Mutnovsky geothermal field (SC “Geotherm”, 2004).

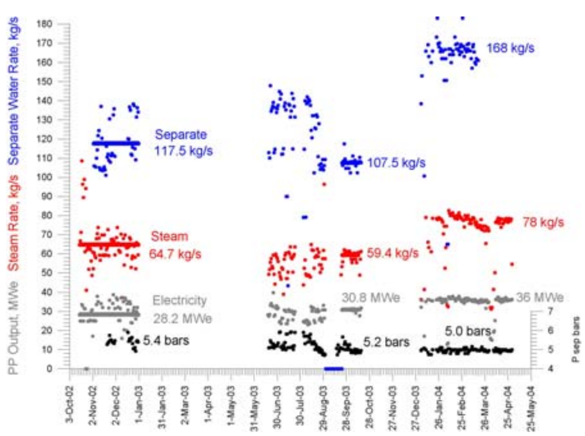

Figure. 6. Mutnovsky PP electricity output, total steam and separate water production, and separator pressure (bars, ati) (SC “Geotherm”, 2004).

Total steam production varies from 64.9 kg/s (2002) to 59.4 kg/s (2003) and to 78 kg/s (2004), the total separate production varies from 117.5 kg/s (2002) to 107.5 kg/s (2003) and to 168 kg/s (2004). Wells A2, 24 (Dachny) and O37 (Verkhne-Mutnovsky) contribution (steam – 3.5 kg/s (2003), 18.3 kg/s (2004), separate - 15 kg/s (2003), 77.7 kg/s (2004)). Hence, the total production of wells (wells 016, 26, 029W, 4E and 5E) estimated as 64.9 kg/s (2002), 55.9 kg/s (2003), and 59.7 kg/s (2004) (steam at PP separator at 5.0 – 5.4 bars (ati)), and 117.5 kg/s (2002), 104.0 kg/s (2003) and 90.3 kg/s (2004) (separate at PP).

Exploitation Model Calibration

Compressibility coefficient assign 5.0 10^{-7} Pa^{-1} in the Main Production Zone reservoir and 2.0 10^{-8} Pa^{-1} in the Host Rock reservoir. Well 027 (North Reinjection Site) assign as reinjection with 150 kg/s rate and enthalpy of 700 kJ/kg. The switch to "no flow" boundary conditions during exploitation implemented in B1, B10, B14, B16, B9, B8 boundary elements of the model. Production wells specified at wellhead pressure conditions corresponding to the PI_0 data from Table 1. Two-phase wells were switched off, if mass flowrate dropped less than 5 kg/s, steam wells were switched off, if mass flowrate dropped below 2 kg/s.

Model calibration targeted to match total steam (referenced to 5.2 separation pressure) and total separate production data against modeling (wells 016, 26, 029W, 4E and 5E) data. Actual production data estimated as 64.9 kg/s (2002), 55.9 kg/s (2003), and 59.7 kg/s (2004) (steam at PP separator at 5.0 – 5.4 bars (ati)), and 117.5 kg/s (2002), 104.0 kg/s (2003) and 90.3 kg/s (2004) (separate at PP).
Initial model scenario #1 show good steam production match (56.0 kg/s vs 59.7 kg/s), and not satisfactory separate production match by the end of 1.5-year exploitation period (Fig. 7). Separate production decline more rapidly (30 kg/s), compare to actual data with additional wells correction (90.3 kg/s) (Fig.7).

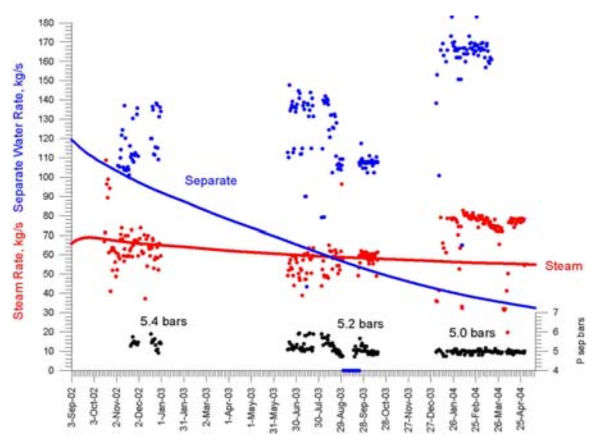

Figure. 7. Model match (Initial scenario #1): modeling steam and separate production from wells 016, 26, E4, 029W, E5 (referenced to 5.2 separation pressure, ati) against total PP production during exploitation of the Dachny site. Dots – PP exploitation data (Fig.6), solid line – modeling results.

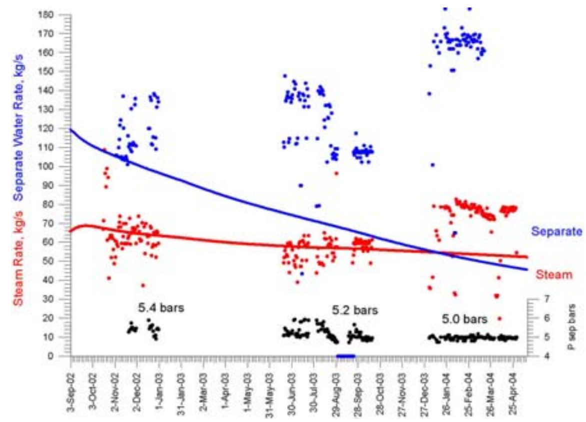

Figure. 8. Model match (scenario #2): modeling steam and separate production from wells 016, 26, E4, 029W, E5 (referenced to 5.2 separation pressure, ati) against total PP production during exploitation of the Dachny site. Dots – PP exploitation data (Fig.6), solid line – modeling results.

Scenario #2 assume possibility of the lateral cold water recharge to the Main Production Zone reservoir from Host Rock reservoir by assuming elimination production zone boundaries under exploitation conditions (Host Rock permeability assign 2 10^{-15} m^2). The explanation of the physical meaning of such boundary conditions switch under exploitation conditions explained in Geothermics Vol.25 #1 p.85 (Kiryukhin, 1996), when possibilities of different exploitation scenarios of the Mutnovsky field were discussed.

In case of such "lateral cold water recharge" (scenario #2) good steam production match (54.0 kg/s vs 59.7 kg/s), and more satisfactory separate production match (52 kg/s vs 90.3 kg/s) by the end of 1.5-year exploitation period obtained (Fig. 8).

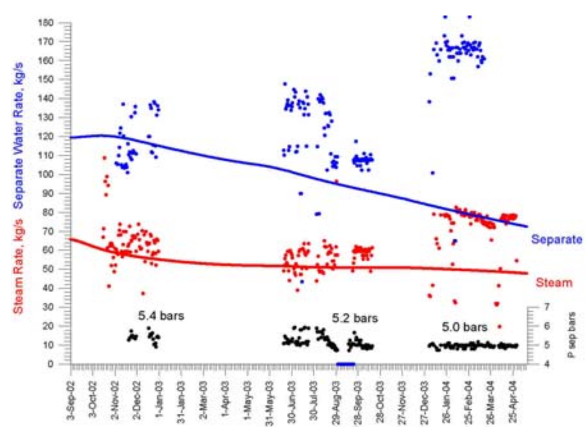

Figure. 9. Model matches (scenario #3): modeling steam and separate production from wells 016, 26, E4, 029W, E5 (referenced to 5.2 separation pressure, ati) against total PP production during exploitation of the Dachny site. Dots – PP exploitation data (Fig.6), solid line – modeling results.

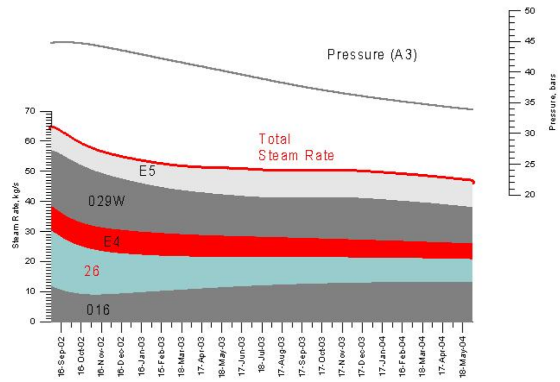

Figure. 10. Scenario #3: modeling of the steam production at 7 bars (wells 016, 26, E4, 029W, E5) and reservoir pressure (A3 model element) response in the Dachny site.

Scenario #3 assume possibility of vertical downflow of the cold water recharge to the Main Production Zone reservoir directly from abandoned wells of the Dachny Site Mutnovsky geothermal field. Those wells are basically characterized by poor casing cementing. Downflows from local cold groundwater aquifers with water levels near surface into geothermal reservoir with levels –600 m through abandoned wells casings is possible and really observed in some wells (O11, O42, etc). High possibility of such scenario un-directly confirmed by high fractions of meteoric gases observed in production wells during exploitation (Kiryukhin et al, 2005). To model such possibility additional cold water sources were assigned in the elements E4, E5, O29, O16, B2, where abandoned wells and significant pressure drop co-exist. Sources parameters assign: rates 12.0 kg/s (total downflow rate 60 kg/s), enthalpies 420 kJ/kg.

In case of “abandoned wells recharge” scenario #3 relatively good steam production match (50.0 kg/s vs 59.7 kg/s), and relatively satisfactory separate production match (82 kg/s vs 90.3 kg/s) by the end of 1.5-year exploitation period obtained (Figs. 9 and 10). Note some increase of actual production rates by 2004 may caused by wellhead pressures decline of production wells (Fig.5), which not accounted in the model.

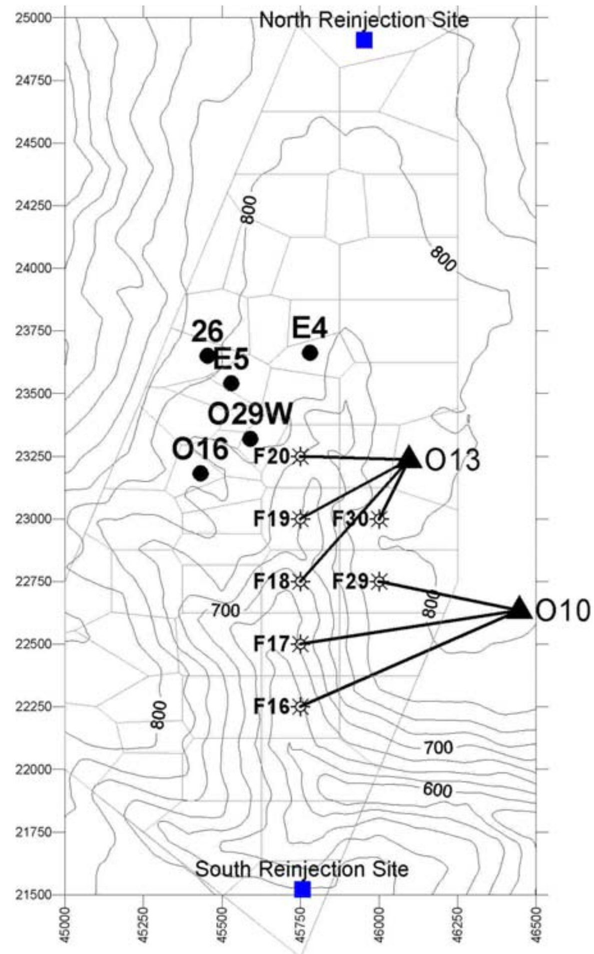

Figure. 11. Existing operating wells: solid circles. Additional F-wells: drilling targets (stars) and drilling rig positions (triangles). Reinjection Sites – squares.

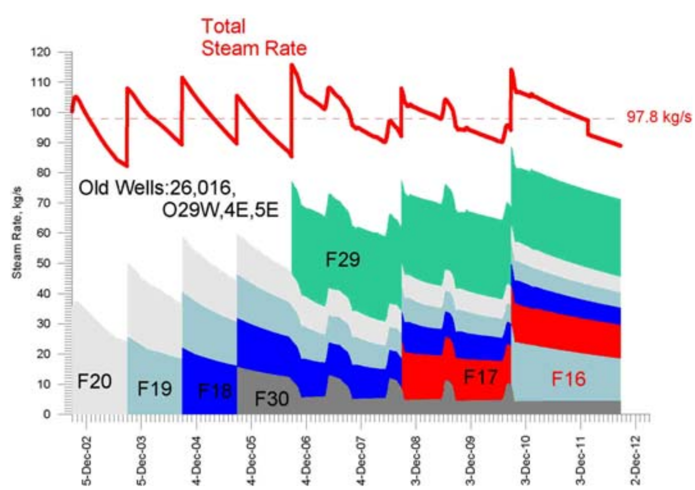

Figure. 12. Scenario #1. Modeling of the steam production (old wells: 016, 26, E4, 029W, E5 and additional F-wells) in the Main production fault zone Dachny Site. Reinjection 150 kg/s (South poligon) assign.

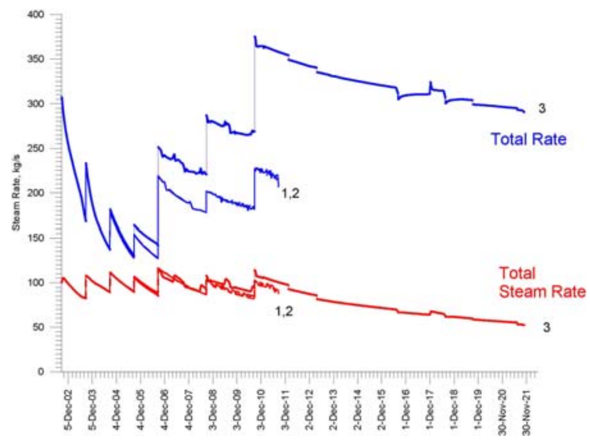

Figure. 13. Influence of reinjection on steam production sustainability of the Main Production Zone of the Dachny Site (based on model scenario #1): 1 - no reinjection, 2 - reinjection 150 kg/s in well O27 (North Reinjection Site), 3- reinjection 150 kg/s (South Reinjection Site). Upper graphs - total production rates, lower graphs - steam production at 7 bars.

F-wells Exploitation Scenarios

Mutnovsky 50 MWe PP needs 95 kg/s of 7 bars steam in stable terms during exploitation period. Previously obtained modeling results show existing wells (016, 26, 029W, E4 и E5) are not able to maintain steam supply for PP needs. So, additional production wells needed to maintain sustainable PP operations.

Study of the possibility of sustainable steam production (from model elements F16, F17, F18, F19, F20, F29 and F30) was performed. Corresponding F-wells locations and constructions are shown in Fig.11 and Table 2. F-wells targeted to the high temperature upflow zone in the south-eastern part of the Main Production Zone. All F-wells suggested deviated wells, drilled from positions of existing wells O13 and O10 correspondingly (Fig. 11). Wellbore diameter assumed to be 0.246 m until depth 900 m, and then 0.168 m. Time-schedule of the F-wells putting into operation is the following: F20 (immediately), F19 (1 year), F18 (2 years), F30 (3 years), F29 (4 years), F17 (6 years), F16 (8 years).

Modeling of the steam production from additional F-wells confirm possibility of the 97.8 kg/s steam production in average terms during 10-year exploitation period, which is sufficient for 50 MWe Power Plant production (Fig. 12) for scenario #1. In case of cold water recharge inflows scenarios #2 and #3 – 96.3 kg/s and 86.7 kg/s steam production available in average terms during 10-year exploitation period.

Although scenario #3 ("abandoned wells recharge") seems as the most probable of discussed above, there is possibility to switch to scenario #1, in case of isolation of the Main Production Zone reservoir from the leakage above by proper cementing of all abandoned wells.

Modeling of various reinjection regimes (based on scenario #1) show there is no important where reinjection took place (North or South Reinjection Sites) and whether reinject or not to reinject during first 10-years exploitation period (Fig.13). The situation is changes significantly by 10-year of exploitation. At this time reservoir boiling may induce significant pressure drop, with magnitude depending of reinjection regime. The optimal strategy was found in the model is - to reinject no less then 75 kg/s in the South Reinjection Site which maintain sustainable conditions for 50 MWe PP during 20-year exploitation period (Fig. 13).

CONCLUSIONS

1. Model calibration based on 1.5-year exploitation data reveals the most probable conditions during exploitation is downflow recharge (60 kg/s, 420 kJ/kg) into the Main Production Zone reservoir. This scenario explained change of the total steam and separate production from group of the wells (016, 26, E4, 029W, E5).

2. Modeling of the additional F-wells (wells to drill in the south-east portion of the MPZ) exploitation scenario confirmed possibility of the 97.8 kg/s steam production in average terms during 10-year exploitation period (which is sufficient for 50 MWe Power Plant production), if cold water inflows to production zone will be neutralized.

3. In terms of long-term exploitation (more than 10 years) the importance of reinjection strategy increase. Modeling shows that North Site reinjection has no effect on production characteristics of the field, and by 10-year of exploitation reservoir boiling may induce significant pressure drop, which quenches some of production wells. In opposite to this, reinjection into the South Site of the field (at least 75 kg/s, 700 kJ/kg) show positive influence on the total steam productivity, which may extend sustainable production for at least 20-year exploitation period.

5. In terms of stable conditions of steam supply to 50 MWe Mutnovsky Power Plant and future extension of PP's capacity - the possibility of use Verkhne-Mutnovsky site located 1.5-2.5 km north-east from Dachny site should be analyzed (Fig.13). This study is on-going.

ACKNOWLEDGEMENTS

The authors expresses gratitude to SC "Geoterm" staff: General Director V.E. Luzin, Chief Manager V.M. Morgun, chief hydrogeologist I.I. Chernev for helpful discussion and data support; Kamchatka EMSD GS RAS scientist D.V. Droznin for computer graphics support. This work has been supported by Russian Basic Sciences Foundation grant 03-05-65373, and Russia Ministry of Education Grant 02.01.023.

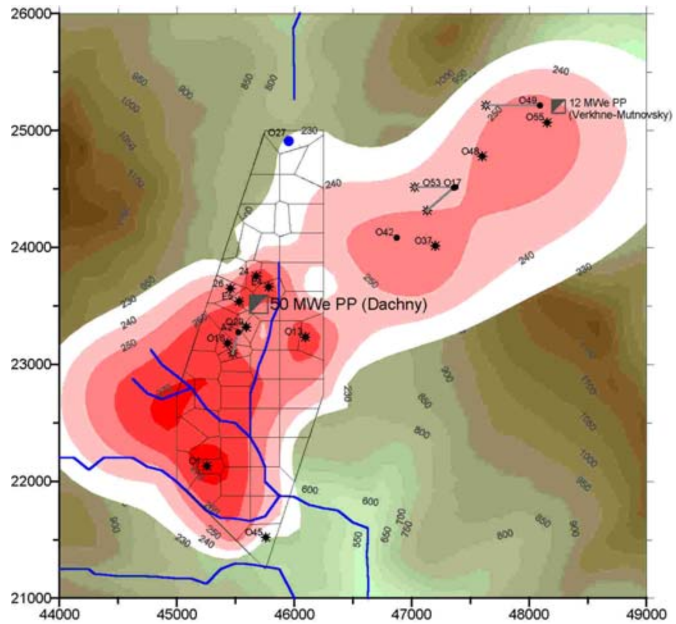

Figure. 14. Mutnovsky geothermal field in the limits of the model-1996, grid corresponding to Main Production Zone reservoir, topo counters, temperature distributions at –250 m.a.s.l., and Power Plants positions are shown too. Production wells – filled circles, feed zones projections – stars.

REFERENCES

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

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

C. Haukwa (1999) AMESH A mesh creating program for the Integral Finite Difference Method // LBNL Users Manual, 54 p.

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

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

A.V. Kiryukhin (2003) 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.

A.V. Kiryukhin (2004) Modeling of the Exploitation of the Mutnovsky Geothermal Field in Connection to 50 MWe PP steam supply // PROCEEDINGS, Twenty-Ninth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 26-28, 8p.

A.V. Kiryukhin (2004) MODELING OF THE MUTNOVSKY GEOTHERMAL FIELD (DACHNY) IN APPLICATION TO OPTIMAL EXPLOITATION LOAD DESIGN // Geothermal Resources Council, Palm Springs, CA, p.595-597.

A.V. Kiryukhin, V.L. Leonov, I.B. Slovtsov, I.F. Delemen, M.Y. Puzankov, A.Y. Polyakov, G.O. Ivanysko, O.P. Bataeva, M.E. Zelensky (2005) Modeling of the exploitation of the Dachny geothermal field in relation to steam supply to Mutnovsky PP// Volcanology and Seismology Journal , 50 p. (in Russian)

A.V. Kiryukhin (2005) Modeling of the Dachny Site Mutnovsky Geothermal Field (Kamchatka, Russia) in Connection with the Problem of Steam Supply for 50 MWe Power Plant // Proceedings World Geothermal Congress 2005, 12 p.

A.V. Kiryukhin, M.Y. Puzankov, I.B. Slovtsov, S.B. Bortnikova, M.E. Zelensky, A.Y. Polyakov (2005) THC-Modeling of the Secondary Mineral Deposition in Production Zones of Geothermal Fields // Volcanology and Seismology Journal, 30 p. (in Russian)

K. Pruess (1991) TOUGH2 - a general purpouse numerical simulator for multiphase fluid and heat flow, Lawerence Berkeley Lab. Report, LBL-29400, Berkeley, California, 102 p.

K. Pruess (1999) TOUGH2 Users Guide, Version 2.0 // LBL-43134.

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