MODELING OF THE DIFFERENT REINJECTION SCENARIOS DURING EXPLOITATION OF THE MUTNOVSKY GEOTHERMAL FIELD (DACHNY SITE)

(PART 1: MODEL SETUP)

ОЦЕНКА ВЛИЯНИЯ РЕИНЖЕКЦИИ НА ЭКСПЛУАТАЦИЮ МУТНОВСКОГО ГЕОТЕРМАЛЬНОГО МЕСТОРОЖДЕНИЯ (ДАЧНЫЙ УЧАСТОК)

(ЧАСТЬ 1: ОБОСНОВАНИЕ МОДЕЛИ)

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ABSTRACT

Fault-type geothermal fields are common in recent volcanism areas. The recent model of the Dachny site, Mutnovsky geothermal field (Kamchatka, Russia) represented a single fault production zone with the heat exchange to ambient rocks expressed in terms of “confining beds TOUGH2 option” (Kiryukhin, Stanford Workshop 2004) was improved by add of the 5-layer external grid connected to the production zone. 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

Продуктивность участка Дачный Мутновского геотермального месторождения приурочена к плоскости одиночной разломной зоны, которая является составляющей Северо-Мутновской вулкано-тектонической зоны. Последние модельные разработки учитывают наличие как этой зоны, так и вмещающих горных пород, которые представлены на модели в виде 5-ти слоев, сообщающихся с продуктивной зоной. Калибровка модели выполнена по данным эксплуатации месторождения 2002-2004 гг. Моделирование различных сценариев в связи с обеспечением устойчивой эксплуатации Мутновской ГеоЭС 50 МВт позволяет выявить оптимальные позиции размещения дополнительных эксплуатационных и реинжекционных скважин.

INTRODUCTION

The history of numerical models applications to Mutnovsky geothermal field started from large-scale 3D rectangular models (Kiryukhin, 1992, 1996) which were designed to understand heat and mass transfer processes in geothermal reservoir as a whole, and to forecast possible exploitation scenarios. This model (1996) consist of 500 elements 500 x 500 x 500 m^3 each with total volume of 5 x 5 x 2.5 km^3 used to forecast 20 year period of exploitation based on existing wells and it shown 44 MWe as a minimum yield of the field. Later this model was used by WestJec (Japan) company to do feasibility study of the Mutnovsky PP (1997).

Since the fault geometry of specific production zones distribution reveals (Kiryukhin et al, 1998), and central part of the Dachny Site proved to be a single-fault type geothermal field (the Main Production Zone in Dachny site strikes north-north-east and dip east-east-south at the angle 60^o), next development of numerical modeling applications to this field was targeted to description of specific geometry of the Main Production Zone (Kiryukhin et al, 2003, 2004, 2005).

MODEL SETUP

Grid generation

Geothermal reservoir is represented as association of the Main Production Zone (MPZ) reservoir and Host Rocks (HR) reservoir (Fig.1). Both reservoirs grids coincide with the Basic Grid (grid related to existing wells) in horizontal projection (Fig.2).

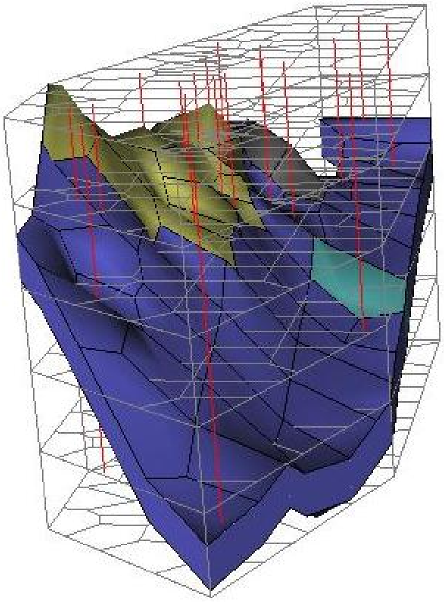


Figure. 1.Geometry of the 3-D numerical model of the Main Production Zone of the Dachny Site Mutnovsky geothermal field.

Basic Grid created on AMESH preprocessor (1999), which generated TOUGH2 mesh file in terms of horizontal connections parameters d1, d2, AREA.

Main Production Zone subdivided on two reservoirs: A-reservoir and B-reservoir. A-reservoir corresponds to the Main Production Zone itself with averaged vertical thickness 240 m (actual thickness 120 m), each element of which is located at the specified elevation corresponding to the roof of the Main Production Zone (Figs.1 and 2). B-reservoir correspond to diorite intrusion contact permeability zones, adjacent to Main production zone. Additional correction procedure was applied to mesh file to specify vertical component of grid connection, including more accurate BETAX presentation (format F20.14 instead of F10.4) to avoid “parasitic circulation” in the model (according to K. Pruess, pers. com., 1998) (Fig.3).

Host Rocks (HR) grid generated as a 5-layer system (at elevations +750, +250, -250, -750, -1250 m), each element of which connected to the Main Production Zone (MPZ) element, if such MPZ element center occur inside of HR element volume.

Basic Grid include 24 existing wells, 39 additional interior elements (F-elements and D-element) and 12 boundary (inactive) elements (B-elements). Total number of the elements of the model is 378 (Fig.1).

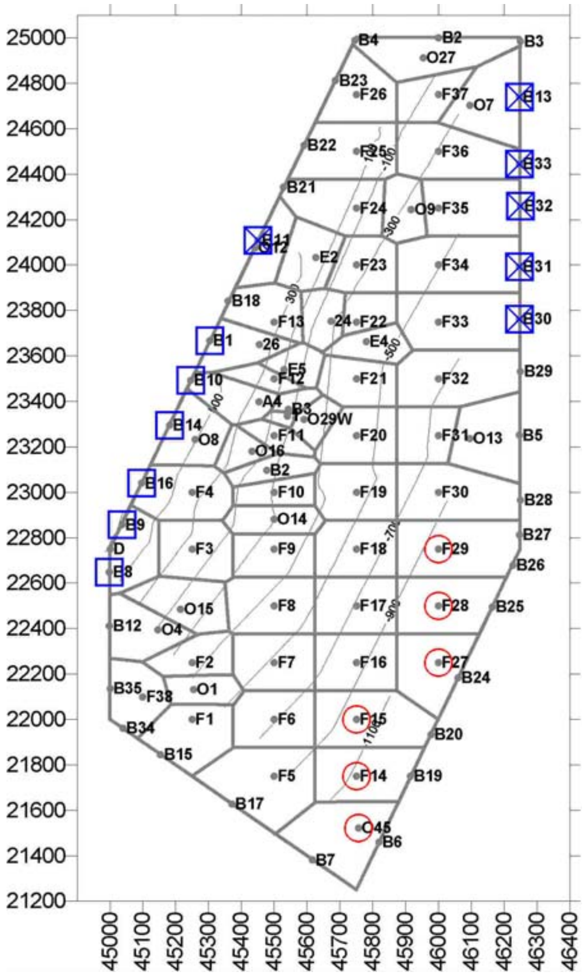


Figure. 2. Basic Grid of the reservoir. Counters elevations (m.a.s.l.) correspond to the top of the Main Production Zone. Open circles - sources assigned in the model, squares – inactive boundary elements valid for natural state stage (steam discharge), crossed squares- inactive boundary elements valid for natural state and exploitation (liquid discharge).

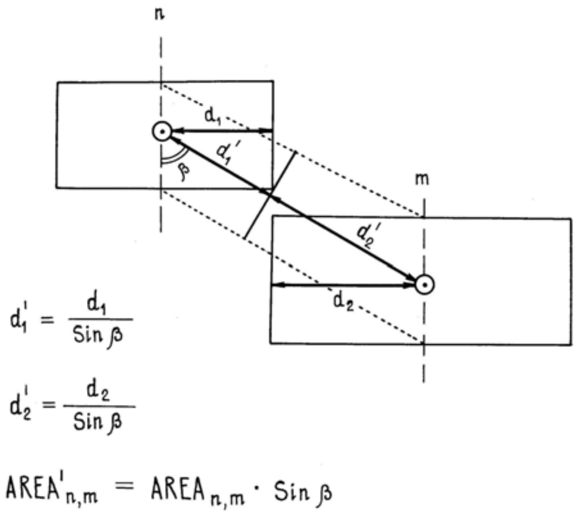


Figure. 3. Mesh parameters (d1, d2, AREA) corrections applied to A-MESH output.

Sinks/Sources, Permeability Distribution and Boundary Conditions

Figs. 2 and 4 demonstrates grid and permeability distributions assigned to the Main Production Zone reservoir of the model. «Sources» in the model are O45, F27, F28, F14, F15, F29 (9 kg/s, 1390 kJ/kg), permeability and rock properties assign based on the previous natural state modeling results (1996-2005).

Boundary conditions assign in B-elements (Fig.2). Liquid discharge elements assigned as P=const and T=const and are valid anytime in the model. These elements simulate liquid discharge from hydrothermal system to Verkhne-Zhirovsky natural discharge area and into ambient aquifers. Steam discharge elements assigned as P=const and S=const, and valid only for natural state modeling. Those elements correspond to unsaturated zone (Dachny steam discharge area), so they switch to "no flow" conditions after exploitation started. Host Rocks reservoir assigned with permeability 10^{-16} m^2.

Modeling of the well-reservoir interaction

The TOUGH2V2.0-based coupled wellbore flow option used (K.Pruess, 1999). For this purpose the total production indexes were split:

$$PI = (k_{rs}\rho_s / \mu_s + k_{rw}\rho_w / \mu_w) \, PI_0$$

,where $k_{r\beta}$ relative phase permeability, μ_β viscosity Pa*s, ρ_β density, kg/m^3, PI_0 productivity indexes (m^3) (liquid (β=w) or steam (β=s)). Productivity indexes PI_0 of five production wells were estimated according to wells rates (Q) at corresponding wellhead pressure (WHP) (referenced to initial exploitation data), flowing enthalpies h, reservoir P_r

and bottomhole P_b pressures, and relative permeabilities (k_{rs}, k_{rw}) derived from the natural state model and wellbore calculations (P_b) (Table 1). Grant type relative permeabilities used. Productivity indexes of the additional wells (F-wells, Table 2) (suggested to be drilled in the south-east portion of the Main Production Zone to maintain sustainability of steam production for Power Plant) assigned as 7.50 10^{-12} m^3 (average of wells 4E, O29W, 5E).

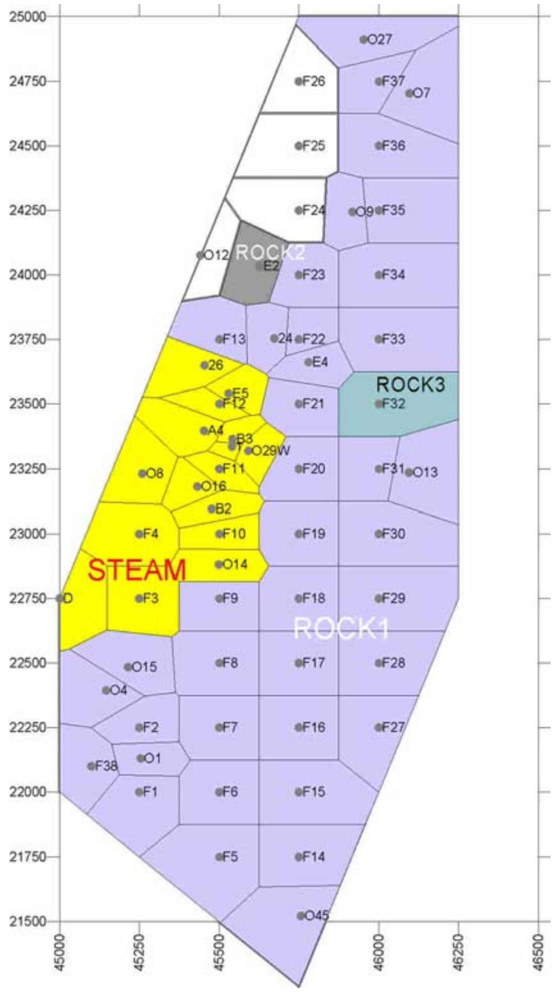
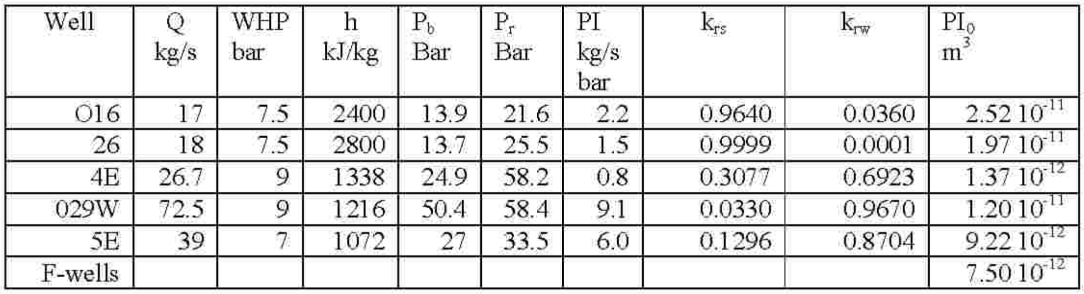


Figure. 4. Permeability distribution in the A-reservoir (Main Production Zone): STEAM, ROCK1, ROCK2 and ROCK3 domains with 100 mD, 100 mD, 1 mD and 0.01 mD, correspondingly.

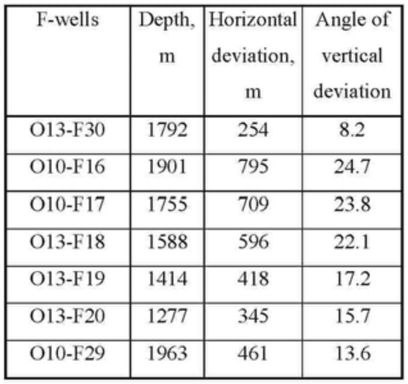
Bottom hole pressure P_b(WHP, Q, h, d) is calculated in the form of electronic tables based on HOLA code. Its worth to note, that liquid dominated reservoir wells sensitive to enthalpy variations: enthalpy decline below 1100 kJ/kg may turns off production wells, in contrary, enthalpy increase may cause quenching of wells in case of extensive boiling in reservoir. Steam wells production is less sensitive to reservoir enthalpy variations.

Table 1. Input data for exploitation wells (O16, 26, E4, O29W, E5 and F-wells) production indexes estimations.



Well	Q kg/s	WHP bar	h kJ/kg	P_b Bar	P_r Bar	PI kg/s bar	k_{rs}	k_{rw}	PI_0 m^3
O16	17	7.5	2400	13.9	21.6	2.2	0.9640	0.0360	$2.52\ 10^{-11}$
26	18	7.5	2800	13.7	25.5	1.5	0.9999	0.0001	$1.97\ 10^{-11}$
4E	26.7	9	1338	24.9	58.2	0.8	0.3077	0.6923	$1.37\ 10^{-12}$
029W	72.5	9	1216	50.4	58.4	9.1	0.0330	0.9670	$1.20\ 10^{-11}$
5E	39	7	1072	27	33.5	6.0	0.1296	0.8704	$9.22\ 10^{-12}$
F-wells									$7.50\ 10^{-12}$

Table 2. Assumed F-wells drilling parameters.



F-wells	Depth, m	Horizontal deviation, m	Angle of vertical deviation
O13-F30	1792	254	8.2
O10-F16	1901	795	24.7
O10-F17	1755	709	23.8
O13-F18	1588	596	22.1
O13-F19	1414	418	17.2
O13-F20	1277	345	15.7
O10-F29	1963	461	13.6

NATURAL STATE MODELING

Natural state modeling was run with the same boundary and sink/sources conditions as mentioned in the paper (Kiryukhin, 2005). In particularly, total upflow rate assign in the model is 54 kg/s, mass rates and enthalpies specified as 9 kg/s and 1390 кJ/кg (water 307°C) in each “source” element (Fig.2). Permeability distributions in the Main Production Zone A-reservoir domains STEAM, ROCK1, ROCK2 and ROCK3 assign as 100 mD, 100 mD, 1 mD and 0.01 mD correspondingly, in B-reservoir ROCK1 domain - 100 mD (Fig. 4). Host Rocks reservoir estimated permeability 10^{-16} m^2. It was found no satisfactory match in key calibration elements (modeling pressures lowering), if Host Rock permeability increases above 10^{-16} m^2 (that mean permeable production volume of the central part of the Dachny Site is basically limited to the Main Production Zone space).

CONCLUSIONS

1. The previous model of the fault type Main Production Zone of the Dachny Site Mutnovsky geothermal field (Kiryukhin, 2004) was up-dated based on TOUGH2V2.0 coupled wellbore flow option; and by introducing the Host Rocks as a 5-layers array, with the elements directly connected to corresponding elements of the Main Production Zone (which occurs along 60° dip fault zone).

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.

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