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Estimated Effect of the Exploitation Induced Infiltration in the Pauzhetsky and Mutnovsky Geothermal Fields, Kamchatka, Russia

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ABSTRACT

A three-dimensional numerical model of the Pauzhetsky geothermal field has been developed based on a conceptual hydrogeological model of the system (Kiryukhin et al, 2008). The model is calibrated, combining natural-state and 1960–2006 exploitation data. Heat and mass balances derived from the calibrated model helped identify the sources of the geothermal reserves in the field. With the addition of five makeup wells, simulation forecasts for the the period 2007–2032 a sustainable average steam production of 29 kg/s, which is sufficient to maintain the generation of 6.8 MWe at the Pauzhetsky power plant. Nevertheless, significant inflow of the meteoric waters in Pauzhetsky accounted for 30% of the total withdrawal of the fluids and was found to be occuring not only in areas of the former hot springs discharge, but mostly in areas of the abandoned wells, where no natural discharge was observed before exploitation started. This leads to the conclusion that some of these poorly cemented abandoned wells may conduct infiltrated meteoric water into the reservoir, cooling production zones and negatively impacting production parameters. Re-modeling scenarios were conducted under the assumption that the artificially created infiltration zones could be isolated.

Extremely low water levels in Mutnovsky geothermal field (500-600 m below surface) induce vertical infiltration of meteoric waters in production zones too, especially if poorly cemented abandoned wells conduct downflows. Integrated analysis of the production data from 2000-2006 combined with numerical simulation shows the possibility of such phenomena.

1. INTRODUCTION. PAUZHETSKY CASE

A three-dimensional numerical model of the Pauzhetsky geothermal field has been developed based on a conceptual hydrogeological model of the system. The model is calibrated, combining natural-state and 1960–2006 exploitation data (Kiryukhin et al, 2008). Modeling predictions of total two-phase and steam production rates for the 2007–2032 period shows, that the total discharge and steam production rates may be maintained at 266.1–317.7 kg/s (288.3 kg/s on average), and 26.8–31.9 kg/s (28.9 kg/s on average), respectively, provided that five additional make-up wells are put into operation, and that the steam transmission lines from wells 122 and 131 are improved to allow a reduction in wellhead pressures. The minimum production from the existing wells (103, 106, 108, 120, 121, 122, 123, 131, and GK3) is predicted as 159.2 kg/s (including 12.8 kg/s of steam) (Fig.1).

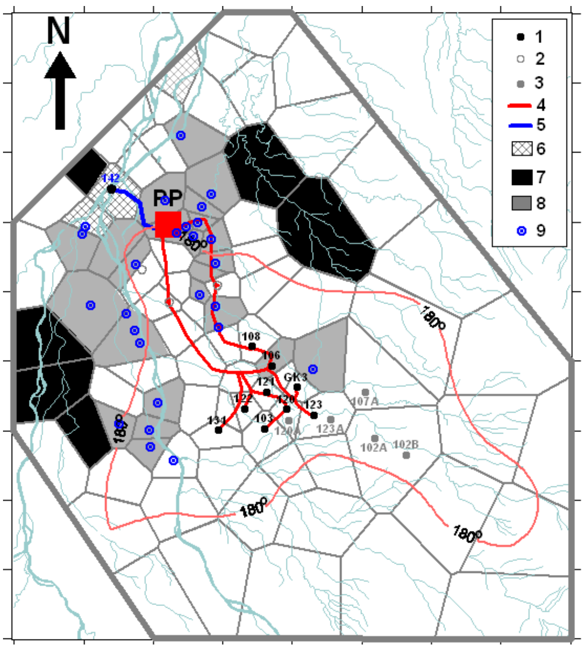

Figure 1: Top view of the numerical grid used to model the Pauzhetsky geothermal field. 180°C isotherm corresponds to the initial temperature at -250 m asl. Well 142: injection well; PP: Power plant. Legend: 1- existing production wells, 2- old production wells, 3- additionally needed wells, 4- steam transmission lines, 5- separate water pipeline, 6- hot spring, areas, 7 - low permeability domains, 8 – infiltration areas, 9 – potential infiltrators - abandoned or monitoring wells inside of the infiltration areas. Grid size 500 m

Based on the modeling results combined with water isotope (T, D, O18) data and chloride balances analysis, significant inflow of the meteoric waters in Pauzhetsky accounted for 30% of the total withdrawal of the fluids. It was found to be occuring not only in areas of the former hot springs discharge, but mostly in areas of the abandoned wells, where no natural discharge was observed before exploitation start (Fig. 1). This leads to the conclusion that some of these poorly cemented abandoned wells may conduct infiltration meteoric water into reservoir, cooling production zones and negatively impacting production parameters.

When infiltration areas were disabled in the model (Fig. 1), the following predictions of total two-phase and steam production rates for the 2007–2032 period were obtained. The total discharge and steam production rates are maintained at 267.0–370.0 kg/s (322.4 kg/s on average), and 28.9–41.2 kg/s (35.6 kg/s on average), respectively. The minimum production from the existing wells (103, 106, 108, 120, 121, 122, 123, 131, and GK3) is 274.7 kg/s (including 24.0 kg/s of steam) (Figs. 2 and 3).

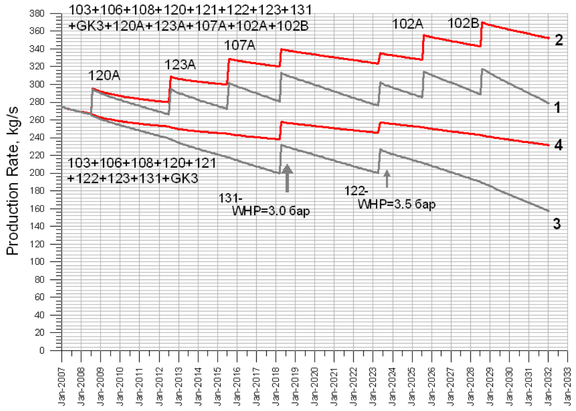

Figure 2: Predicted total two-phase production rate for Pauzhetsky: 1 - Wells 103, 106, 108, 120, 121, 122, 123, 131, GK3, 120A, 123A, 107A, 102A, and 102B for the 2007–2032 period (Kiryukhin et al, 2008); 2 – the same, as 1, but with disabled infiltration areas; 3 - steam rates using only wells existing on December 2006 (Kiryukhin et al, 2008); 4 - the same, as 1, but with disabled infiltration areas

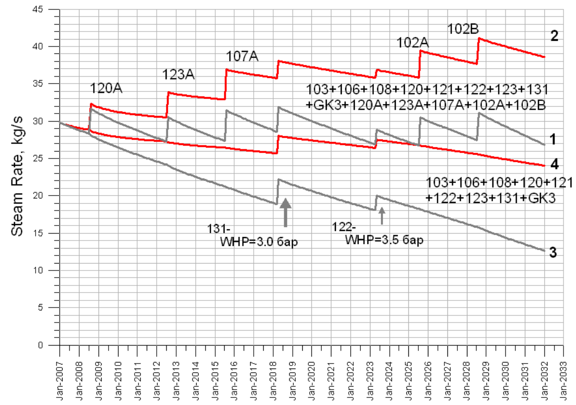

Figure 3: Predicted total steam production rate for Pauzhetsky: 1 - Wells 103, 106, 108, 120, 121, 122, 123, 131, GK3, 120A, 123A, 107A, 102A, and 102B for the 2007–2032 period (Kiryukhin et al, 2008); 2 – the same, as 1, but with disabled infiltration areas; 3 - steam rates using only wells existing on December 2006 (Kiryukhin et al, 2008); 4 - the same, as 1, but with disabled infiltration areas. The steam rate is calculated at the separation pressures of corresponding wells

That mean production output may be significantly improved if infiltration from abandoned wells is stopped. In average terms, total steam production may increase by 23.2% according to modeling. Moreover, minimum steam production from the existing wells (103, 106, 108, 120, 121, 122, 123, 131, and GK3) may increase by 87.5%. That may increase power generation from 7 to 8.6 MWe and avoid drilling unnecessary additional wells.

Lets look to Mutnovsky geothermal field from this point of view since this is a largest high temperature geothermal field close to Petropavlovsk-Kamchatsky with 62 MWe installed capacity (25% of Kamchatka's needs at this time) and still with remaining reserves for production increases and optimization.

2. ESTIMATING RE-INJECTION AND INFILTRATION EFFECT ON EXPLOITATION OF MUTNOVSKY GEOTHERMAL FIELD

2.1. Modelling of Conditions for Providing the Mutnovsky GeoPP of 50 MW Power with Heat Carrier During 15 Years of Exploitation

Analysis of possible variants for exploitation of the Dachny site, Mutnovsky geothermal field, were started in (Kiryukhin, 1996, Kiryukhin et al, 2005; Kiryukhin, Vereina, 2005). The most recent modeling efforts were focused on central part of Dachny site, where Main production zone was intensively drilled and studied in 2001-2003 years (Fig. 4).

As the first model variant (EX3), the exploitation of five main existing production wells (016, 26, E4, 029W, E5) during 15 years is considered. Heat exchange, "production zone–host rocks," as well as dependence of productivity indexes of productive wells on steam saturation, varying during exploitation, and phase mobilities are taking into account. According to modeling results, the total steam output from considered production wells will decrease from 64.4 kg/s to 31 kg/s and the pressure in central observational well will decrease from 44.7 bar to 32 bar, during 15 years of exploitation. As a whole these results appears to be similar to those obtained before (Kiryukhin etc. (2005), Kiryukhin, Vereina, 2005).

Further the model variants including the additional model wells (F-wells) (fig. 4) are considered. The locations of the wells were specified the same as those in (Kiryukhin etc. (2005), Kiryukhin, Vereina, 2005). The productivity ,indexes of F-wells are given as 3.0×10^{-12} м^3.

Model variant EX3A considers the following time-schedule of putting into operation the additional productive wells: F19 and F20 immediately, F18 in 2 years, F30 in 5 years, F29 in 9 years, F17 in 12 years, F16 in 14 years (Fig. AAA). According to modeling results such time-schedule can provide average steam output of 105.4 kg/s and average total output of steam-water fluid amount to 272.7 kg/s during 15 years of exploitation, which corresponds to 52.7 MW electric power (2 kg/s of steam at pressure of 7 bar-a is accounted for 1 MW electric power). Thus, taking into account heat exchange, production zone–host rocks and more precise description of dependences of productivity factors of productive wells on thermodynamical parameters of hydrothermal reservoir varying during exploitation allows more optimistic forecasting results (fig. 5).

2.2 Modeling Taking Re-Injection Into Account.

Model variant EX3B considers the same conditions, as the previous one, but now re-injection is specified in the well O27 at Northern re-injection site (Fig. BBB). Re-injection flow rate and enthalpy are given as 150 kg/s and 700 kJ/kg, respectively. Forecasting results don't differ from those in previous variants too much: the average total steam output and average total output of steam-water fluid amount to 105.5 kg/s and 273.0 kg/s, respectively. This is because the model re-injection site is spatially close to inactive boundary elements in model (describing the outline of discharge into adjacent hydro-geological formations: namely, into Zhirovaya river basin). Indirectly, the absence of considerable effect of re-injection on productive wells at the Dachny site is shown by absence of significant returns of chloride-ion to exploitation wells (Kiryukhin et al., 2006).

The model variant EX3C considers the same conditions as the variant EX3A, but re-injection is now specified in Southern site in the well O45. Re-injection flow rate and enthalpy are given as 150 kg/s and 700 kJ/kg, respectively. According to modeling results, average total steam output increases up to 115.6 kg/s during 12.5 years of exploitation which corresponds to 57.8 MW electric power. However, the effect of re-injection at the Suthern site is mixed: on the one hand, re-injection into zone of deep feeding of the hydrothermal reservoir promotes the increase of productivity of deep wells (F-wells), but, on the other hand it results in temperature (and pressure) decrease in near-surface steam-condensate zone and putting out of operation shallow productive wells (26, E5).

2.3 Modelling Taking Infiltration Into Account

The model variant EX3F **(Fig 6)** includes the same conditions as the base variant EX3A, but it also considers possible infiltration in the central part of Dachny site at a total flow rate 60 kg/s and enthalpy 420 kJ/kg. The vertical infiltration of waters of meteoric origin at Dachny site may be due to water entering through poorly cemented wells (the total number of wells at Dachny site is 64), which can also be promoted by anomalously low level in hydrothermal reservoir (500-600 m below the ground surface). As modeling results show, the average total steam output and average total output of steam-water fluid amount to 96.8 kg/s and 308.6 kg/s, respectively, which corresponds to 48.4 MW electric power.

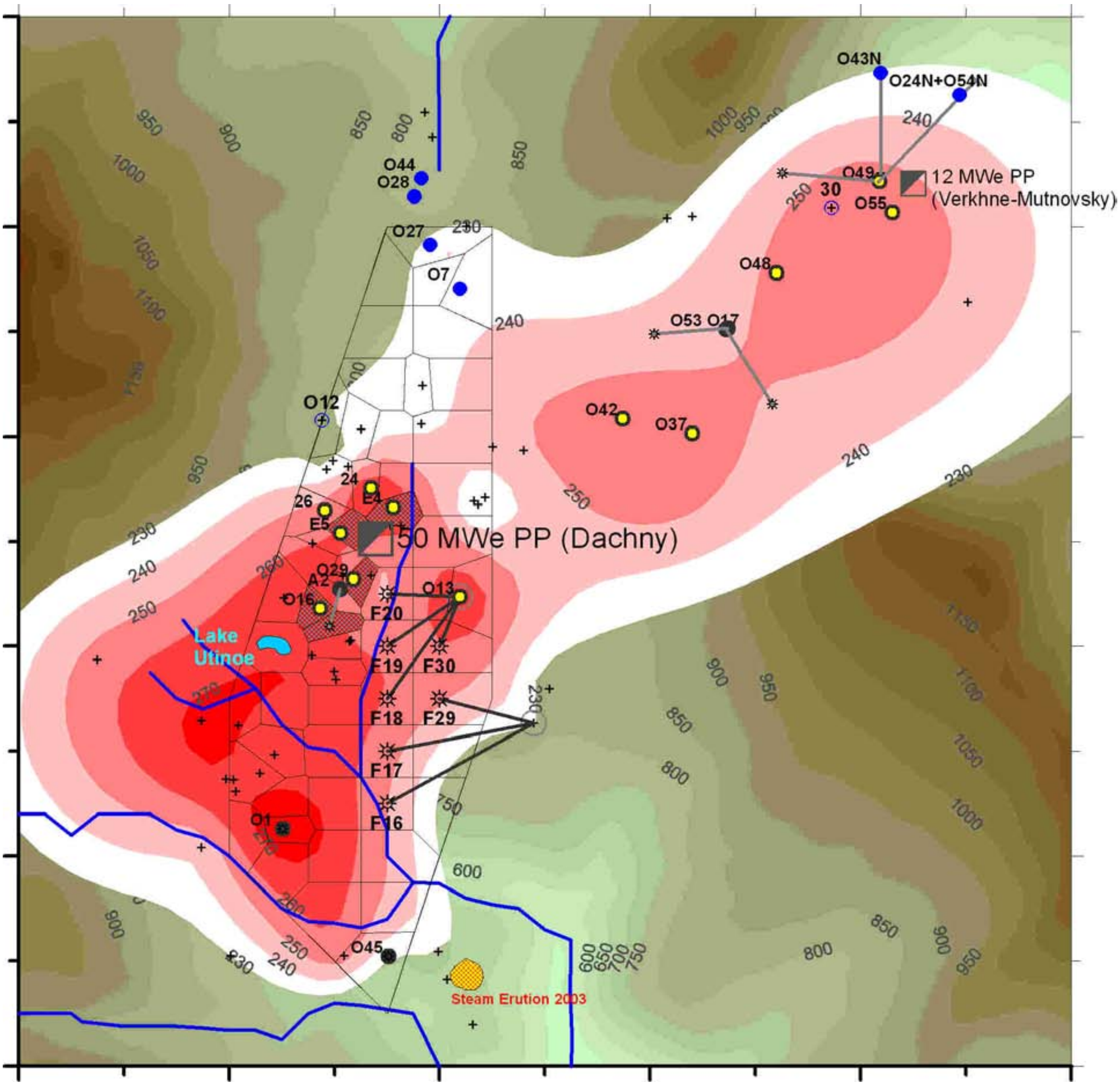

Figure 4: Schematic map of Mutnovsky geothermal field. Background contours are topography and temperature distribution at -250 m.a.s.l. Limits of this map correspond to limits numerical model (Kiryukhin, 1996); internal grid correspond to detailed model of the Main production zone (Kiryukhin et al, 2005, Kiryukhin and Vereina, 2005). Main exploitation wells - circles with yellow marks inside; reinjection wells - blue filled circles; monitoring wells - empty blue circles (30 and O12); directional wells - lines terminated at bottom positions (stars); small crosses - drillholes; hatched area – infiltration zone, assumed in modeling scenario EX3F; F-wells - additional production wells (F16, F17, F29, F18, F19, F20, F30) considered in the modeling scenario to provide Mutnovsky GeoPP 50 MW power with steam from the central block of Dachny site. Grid – 500 m

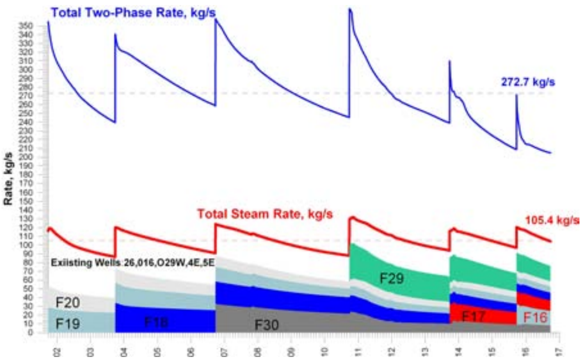

Figure 5: Forecasting modeling (scenario EX3A) of total two-phase, total steam production of wells (existing wells 016, 26, E4, 029W, E5 and additional F-wells) at Dachny site, Mutnovsky geothermal field

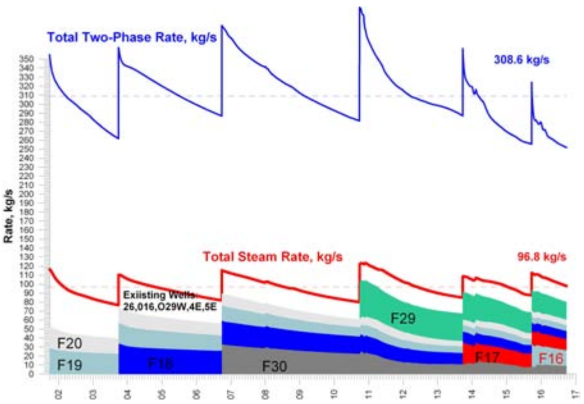

Figure 6: Forecasting modeling (scenario EX3F) of total two-phase, total steam production of wells (existing wells 016, 26, E4, 029W, E5 and additional F-wells) at Dachny site, Mutnovsky geothermal field

2.4 Actual Exploitation Scenario and Indications of Infiltration

In reality, the decision was taken to use existing wells from Verkhne-Mutnovsky site to support steam for Mutnovsky 50 MWe PP (Dachny) rather than drill additional F-wells according to modeling scenarios above. Wells O37, O53N, O17N and O42 were used for exploitation. Wells O13 and 24 from Dachny were used too. Fig. 7 shows total two-phase production, steam production and steam fraction transient data. It can be clearly seen that steam fraction gradually declines from 0.46 in year 2002 when Mutnovsky PP started to 0.27 by the end of 2006.

The inflow of infiltration waters from above into the hydrothermal reservoir is indirectly confirmed by data on gas composition of productive wells, where meteoric-gas components increased when exploitation started and dilution in chlorine-ion is marked (Kiryukhin et al, 2006). Thus, the scenario of infiltration waters inflow into hydrothermal reservoir is very probable.

In addition to potential infiltrators (abandoned wells, indicated by crosses in Fig. 4), artificially dammed Utinoe Lake may also serve as recharge area for production reservoir 500 m below. The lake is located at the site of the former thermal discharge, hydraulically connected to underlying reservoir.

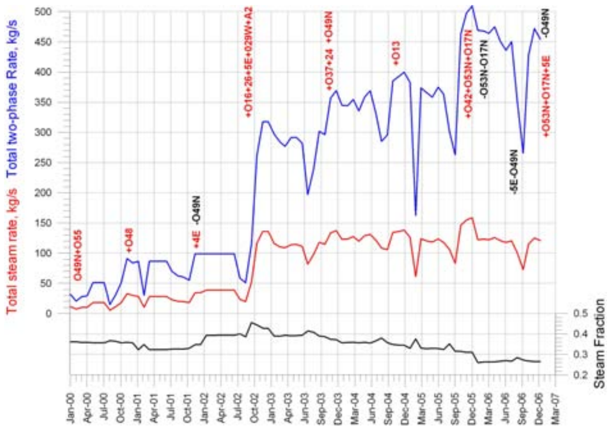

Figure 7: Mutnovsky geothermal field: observed total two-phase production rate (upper graph), observed total steam production rate (middle graph) and corresponding steam fraction (lower graph). Data from Maltseva et al, 2007

Nevertheless, it is not clear now for the Mutnovsky case whether or not it is a benefit that water may recharge into the production reservoir from above. Positive consequences from this are that water recharge into the production reservoir may delay water level drop in the high temperature zone and mitigate underground boiling processes, which triggered severe steam explosion in June 2003 close to well O45. Such reservoir boiling processes occurring in some parts of reservoir are reflected also by significant well head pressure increases observed in some wells: 30 (up to 34.5 bars) and O1 (up to 50 bars) last year. A negative consequence is a reduction of the produced steam fraction, as shown from actual production curves (Fig.7) and comparison of modeling scenario EX3A and EX3F on Figs. 5 and 6 respectively.

CONCLUSIONS

Significant inflow of the meteoric waters in Pauzhetsky amounting to 30% of the total withdrawal of the fluids, found to be occuring not only in areas of the former hot springs discharge, but mostly in areas of the abandoned wells where no natural discharge observed before exploitation started. This leads to the conclusion that some of these poorly cemented abandoned wells may conduct infiltration meteoric water into the reservoir, cooling production zones and negatively impacting production parameters. Re-modeling scenarios were conducted using the assumption that artificially created infiltration zones can be isolated and show total steam production may increase by 23.2% and minimize the number of additional wells drilling to maintain existing PP output capacity.

Multi-variant modeling of exploitation Dachny site, Mutnovsky geothermal field allows specification of the conditions to provide steam for Mutnovsky GeoPP of 50 MWe during 15 years using seven make-up wells in Dachny site. The most probable modeling scenario is that exploitation of the field is accompanied with inflow of infiltration waters of meteoric origin into hydrothermal reservoir from above (model estimated flowrate is 60 kg/s). This qualitatively corresponds to the steam fraction decline observed during first four years of exploitation.

It will be worthwhile to integrate modeling efforts using inverse modeling capabilities and the experience of previously performed modeling studies (the coarse rectangular Dachny+Verkhne Mutnovsky model

(Kiryukhin, 1996), the more detailed model of Dachny (Kiryukhin, 2005)) with comprehensive fluid gas and geochemistry production analysis in order to constrain the full scale Mutnovsky reservoir model in order to understand reservoir processes under exploitation and optimize geothermal energy recovery. This work is on going.

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