GEOPHYSICAL MONITORING WITH RESERVOIR SIMULATION IN A GEOTHERMAL FIELD, JAPAN

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SUMMARY - Repeat and/or continuous geophysical measurements can be used to detect subsurface changes. However, the separation of signal from noise is often a difficult task. In geothermal reservoirs, it is very useful to predict changes in geophysical observables from changing reservoir conditions, computed by reservoir simulation. We calculated changes in self-potential based upon a three-dimensional reservoir model of the Ogiri field, which was constructed based upon various data and calibrated against the long-term gravity monitoring data. The calculated SP variation is qualitatively consistent both with a relatively long-term change obtained by repeated surveys and a short-term change detected by continuous measurements, which was associated with a field-wide shut-in of production and reinjection wells for a maintenance of the power station in spring 2003.

1. INTRODUCTION

Decline of geothermal steam is one of the most serious problems to be solved. There are various reasons behind the decline, such as reservoir pressure and/or temperature drop, change in steam to liquid ratio of produced fluid, scaling and so on. Proper reservoir management based upon a numerical reservoir model which is well calibrated against various data-sets is desirable. A technology to utilise geophysical monitoring data as well as well data was developed to reduce the inherent non-uniqueness of any mathematical reservoir models (e.g., Ishido et al., 2005); the so called geophysical postprocessors were developed, which calculate changes in observables such as gravity, self-potential (SP), etc. from changing underground condition computed by reservoir simulations. In this paper we will show the computed SP variation in the Ogiri field which is based upon a numerical reservoir model calibrated by the microgravity data (Sugihara and Ishido, 2008) and compare it to the measured data.

2. OGIRI GEOTHERMAL FIELD

2.1 Geothermal Power Plant

The Ogiri geothermal field is located on the western slope of the Kirishima-volcanoes in southern Kyushu, Japan (Figure 1) and a geothermal power plant has commenced operation with an installed capacity of 30 MW electricity generation in 1996. The main production wells are located in the middle of the field around the power plant; there are 12 production wells with two reserve wells in 2007. Six injection wells in the west of the field are in operation to reinject all waste water. The depth of the production and injection wells ranges 987 to 1992 m and 808 to 1598 m, respectively. An average production rate is 248 t/h of steam and 745 t/h of hot water in 2007. The all separated brine with a small amount of steam condensate is reinjected (Therm. Nuclear Power Eng. Soc., 2007).

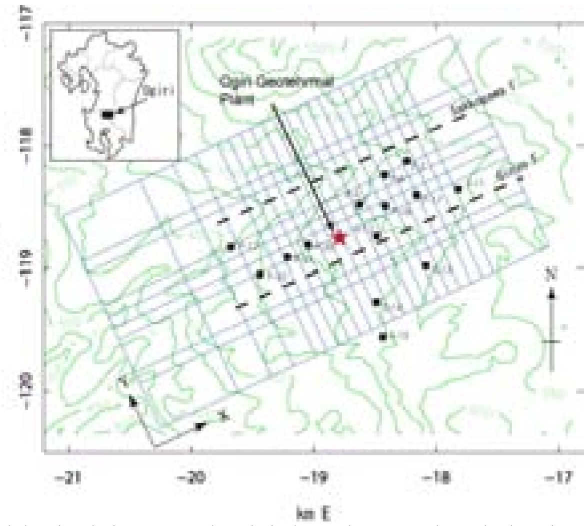

Figure 1: Location of the Ogiri field and the simulation area. Closed circles and squares show the locations of SP electrode in shallower (ca.1 m) and deeper (ca.8 m) holes, respectively. Surface traces of two major faults (Ginyu and Sakkogawa faults) are shown by broken lines. Also shown is computational grid spacing used for reservoir simulation.

2.2 Geological Setting

Kirishima volcanic zone is caused by the subduction of the Philippines' sea plate into the Eurasia plate. Fault systems and lineaments are dominant with trends of NW-SE and ENE-WSW. Hot springs, fumaroles, and a geothermally altered zone are aligned in this direction, especially along the ENE-WSW oriented faults named as Sakkogawa, Ginyu and Shiramizugoe faults (from north to south). The subsurface temperature reduces from southeast to northwest and steeply decreases beyond the Sakkogawa fault (Goko, 2004). Ginyu as well as Shiramizugoe are, therefore, the major target faults for geothermal development. The basement of the Ogiri field is the Cretaceous-Palaeogene Shimanto group found in a bore core below about 1300 m depth. A geothermal reservoir develops in the Pleistocene formations below about 500 m depth. Cap rocks consisting of alternated and crystallised minerals such as smectite are formed at the depths between 200 and 500m (Goko, 2004).

3. GEOPHYSICAL MONITORING

3.1 Microgravity monitoring

Microgravity observations were repeated between 2002 and 2007 at Ogiri, (Sugihara and Ishido, 2008). They succeeded in delineating the spatial distribution of a relatively small gravity change from the results of the so called hybrid measurements using an absolute gravimeter and conventional relative meters. Since the long-term gravity change was small, they concluded that a mass balance between the net production rate and fluid recharge rate from the reservoir boundary is almost established for the period between six and eleven years of fluid production. The reservoir model was modified so as to reproduce the observed gravity change. They also applied the same technique during the field-wide shut-in of production and reinjection wells for the maintenance of the power plant in April-May, 2003. Gravity changes of a few to several microGals were observed; positive and negative changes were detected in the production and reinjection areas, respectively.

3.2 SP monitoring

The New Energy and Industrial Technology Development Organization (NEDO) carried out SP survey at Ogiri in 1998. Comparing this result to that in 1987 (Ishido et al., 1990), decreases in SP were detected both in the production and reinjection areas. These changes are thought to be induced by the fluid production and injection operations at Ogiri. In addition to repeat surveys, continuous SP monitoring was carried out by NEDO from 1998 through 2001 (e.g., Horikoshi et al., 2001).
During the summer of 2002, various geophysical measurements (SP, gravity, GPS, tiltmeter and micro-earthquakes) were carried out at Ogiri and some of them resumed in early March 2003 to monitor the change during the shut-in. Silver-silver chloride electrodes for the continuous SP measurement were installed at the locations shown in Figure 1. At each of five locations where a 8 m-well was drilled, one electrode was set at the bottom of the well and another same-type one was set about 1 m deep near the wellhead in order to evaluate the rainfall effects.

4. NUMERICAL SIMULATION

4.1 Reservoir model

Sugihara et al. (2006) modified the 3D reservoir model developed by the Nittetsu Kagoshima Geothermal, Co. (NEDO, 2002) to explain their gravity data. They adopted finer block sizes for the upper part of the reservoir to reproduce the short-term variation during the 2003 shut-in. The model covers 3500 m x 1900 m area shown in Figure 1 and extends vertically to -1500m RSL. Block sizes vary from 100 to 1000 m and from 50 to 500 m in the horizontal and vertical directions, respectively. X-axis is selected along the direction of ENE-WSW strike of the major faults.

Seventeen rock types were selected based on the geological and drilling information (Figure 2). To simplify the simulation procedure, only the permeability was varied between different rock types (other rock properties are uniform). Rock properties for the final model are shown in Tables 1 & 2.

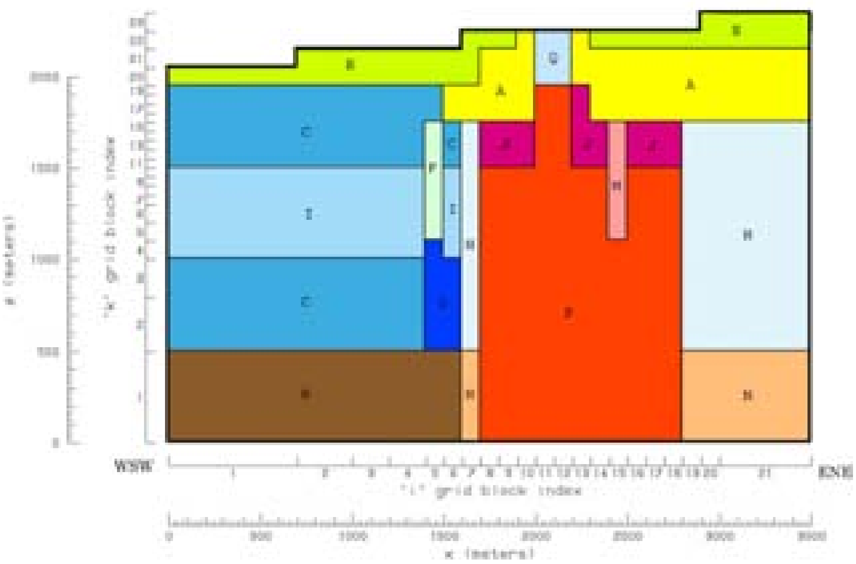

Figure 2: Vertical cross-section of the numerical model along the Ginyu fault. Alphabetic characters indicate rock types with different permeability.

Table 1: Physical parameters in the simulation

Parameter	Value	Unit
Porosity	10	%
density	2500	kg/m^3
Heat capacity	1050	J/kg-°C
Thermal conductivity	2	W/m-°C
Rate of hot water upflow	46	Kg/s
Temperature of hot water	243-260	°C
Heat flux at bottom surface	0.4	W/m^2

Table 2: Permeability of each rock type

Rock type	kx darcy	ky	kz	Rock type	kx darcy	ky	kz
A	10^{-5}	10^{-5}	10^{-5}	I	10^{-2}	10^{-2}	10^{-2}
B	10^{-4}	10^{-4}	10^{-4}	J	10^{-1}	10^{-2}	10^{-1}
C	10^{-3}	10^{-3}	10^{-3}	M	10^{-1}	10^{-3}	10^{-1}
E	10^{-3}	10^{-4}	10^{-3}	N	10^{-1}	10^{-2}	10^{-1}
F	10^{-2}	10^{-3}	10^{-2}	P	10^{0}	10^{-1}	10^{-1}
G	10^{-2}	10^{-3}	10^{-2}	Q	10^{-2}	10^{-2}	10^{-2}
H	10^{-2}	10^{-3}	10^{-2}				

Pressure and temperature along the upper surface were held at 0.1 MPa and 20°C, respectively. All vertical side surfaces except the WSW surface were closed at first. Most of the bottom surface was impermeable, but an upward conductive heat flux and hot water flows upward into the reservoir through a few central areas were imposed.

4.2 Postprocessor calculations

Sugihara and Ishido (2008) used the geothermal reservoir simulator STAR (Pritchett, 1995) and carried out reservoir simulation of the Ogiri field. The microgravity postprocessor (e.g. Pritchett, 1995) was used to calculate both the long- and short-term changes. To obtain a better match between the calculated and observed long-term gravity changes, they modified the boundary condition at the ENE side surface so as to allow the fluid recharge comparable to the net production rate between 2002 and 2007.

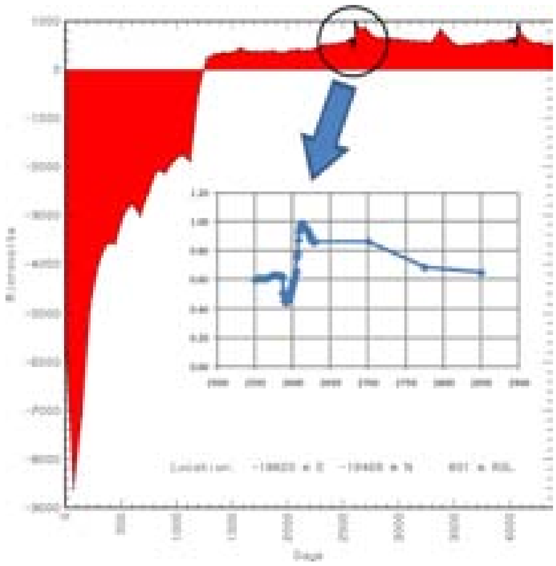

Figure 3: Temporal SP change near the power station calculated by the SP postprocessor. The horizontal axis denotes time in days after the start of the power generation in 2006. Short-term SP change associated with the shut-in in spring 2003 is magnified in the inserted figure (SP is in mV).

Using the updated 3D model, we calculated changes in SP. Figure 3 shows temporal SP change at an electrode in the central production area. The SP first decreases, soon turns to increase after about 100 days and becomes almost steady after 1300 days. (After 1300 days, the gravity change calculated by Sugihara and Ishido (2008) also becomes quite steady after the initial rapid decrease.) This calculated result qualitatively reproduces the observed SP change obtained by the repeated SP mapping in 1998 and 2001.

There are three short-term changes at about 2600, 3400, and 4000 days, which correspond to the assumed shut-ins of production and injection wells. The change around 2600 days is magnified in Figure 3; SP decreases for about 10 days, then rapidly increases and slowly returns near to the steady level by taking about 200 days. Such SP change was proposed by the calculation based upon a simple two dimensional model (Ishido et al., 2005).

We observed such SP increase in the production area by the continuous SP measurement in spring 2003 mentioned above. However, the SP changes were small in magnitude and disturbed by various noises. We need to clarify the noise sources and apply an appropriate noise reduction technique to get more definite conclusions.

5. CONCLUSIONS

The self-potential postprocessor was applied to the 3D reservoir model of the Ogiri geothermal field, which was calibrated against the observed changes in microgravity between 2002 and 2007 (Sugihara and Ishido, 2008). The calculated SP variation is qualitatively consistent both with the relatively long-term change obtained by the repeated surveys in 1998 and 2001 and the short-term change detected by the continuous measurement between March and May 2003.

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