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Sustainable Development of Geothermal Energy -A Case Study of Hatchobaru Geothermal Field, Central Kyushu, Japan-

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ABSTRACT

Geothermal energy is renewable but its sustainability is not self-evident. Therefore it is very important to manage geothermal reservoir in order to realize sustainable production of geothermal energy. We estimated the mass balance in the geothermal reservoir during exploitation at Hatchobaru geothermal field, central Kyushu, Japan, based on the changes in gravity and Gauss's theorem. Combining the estimated mass change and the rates of produced and re-injected geothermal fluids, we calculated the rate of natural recharge to the geothermal reservoir from outside. As a result, we estimated that the rate of natural recharge is nearly same as the rate of steam discharged to the atmosphere from the cooling towers. The above result is consistent with the mass balance estimated from numerical modeling. Therefore we conclude that the sustainable production of geothermal energy is realized at Hatchobaru Geothermal Power Station.

1. INTRODUCTION

Geothermal energy is one of renewable energies and its contribution to power generation in Japan is larger than that of solar energy or wind energy, although the installed capacity of geothermal power generation is smaller than that of solar or wind energy. The above fact shows that geothermal power generation is much more stable than that of other renewable energies. However, geothermal energy has a specific problem, that is, geothermal energy is renewable but its sustainability is not self-evident. Rybach and Mongillo (2006) mentioned that there is still a clear need for significantly more research to sustainability.

2. HATCHOBARU GEOTHERMAL FIELD

Hatchobaru geothermal field in central Kyushu, Japan is 5km northwest of Kuju volcano and its shows a liquid dominated fracture type geothermal reservoir. No.1 Unit (55MW) was completed in June, 1977 and No.2 Unit (55MW) was completed in June, 1990. We have started repeat gravity measurements just before the commencement of operation of the No.2 Unit in order to verify the sustainable development of geothermal energy.

The production zone is in the southeastern part of the field and the re-injection zone is in the northwestern part as shown in Figure 1. Most production wells are from about 1000m to 2500m depth and most re-injection wells are from 1000m to 1500m depth. The deep geothermal fluids rise along fractures in the southeastern part of the field and flow laterally towards northwest.

3. REPEAT GRAVITY MEASUREMENT

The stations for repeat gravity measurement are also shown in Figure 1. Representative examples of gravity change in the production and re-injection zones are shown in Figure. 2(a) and (b). The gravity in the production zone changed as follows; the gravity in the production zone increased a little in a limited area of the production zone just after the commencement of deep fluid production and after that, it decreased rapidly up to about 200 microgal in the whole production zone. After that, the gravity in the production zone became stable. The pattern of gravity change in the production zone is very similar to the change in reservoir pressure (Tagomori ert al., 1996). The leveling surveys clarified that the ground movements ranged from -15mm to +35mm from August 1990 to March 1996 in the field, which corresponds to about -10 to +5 microgal in gravity change. These values show that the effect of vertical ground movements is negligible on the observed gravity changes.

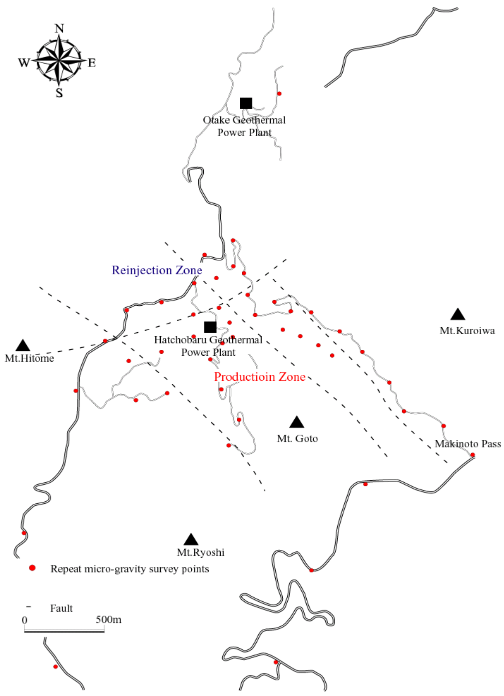

Figure 1. Location map of repeat gravity measurement at Hatchobaru geothermal field. Small red solid circles show gravity stations. The solid square shows the location of geothermal power plant. Broken lines show main fracture zones. Solid triangles show Quaternary (not active) volcanoes of the Kuju volcanic group.

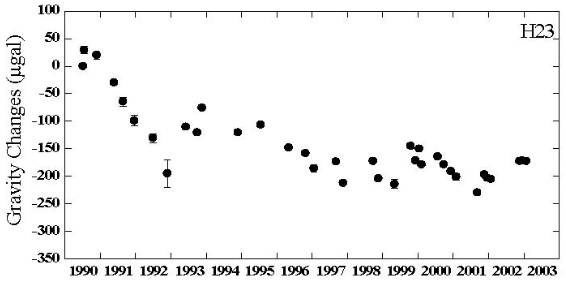

Figure 2(a). Example of gravity change after the commencement of power generation in Hatchobaru geothermal field. Gravity change at the station H23 in the production zone.

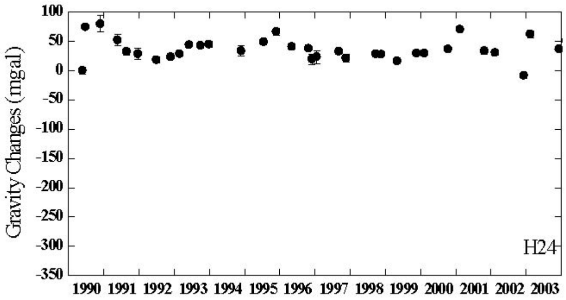

Figure 2(b). Example of gravity change after the commencement of power generation in Hatchobaru geothermal field. Gravity change at the station H24 in the re-injection zone.

On the other hand, gravity change at the re-injection zone shows different pattern from that in the production zone. The gravity increased up to several tens of microgal after the commencement of re-injection. After that, it decreased and became stable gradually. The temporal change in the re-injected mass is also very similar to the pattern of gravity change in the re-injection zone (Tagomori et al., 1996).

Contour maps of gravity change from June 1990 to June 1992 and from October 2000 to October 2001 are shown in Figure 3(a) and (b). The gravity change from June 1990 to June 1992 is much more rapid than that from October 2000 to October 2001, that is, the gravity change was becoming gradually stable. The gravity change in the later stage of exploitation is limited in the narrow area.

We estimated the mass balance in the geothermal reservoir based on the change in gravity and Gauss's theorem (La Fehr, 1965). Combining the estimated mass change and the rates of produced and re-injected geothermal fluids, we estimated the mass balance as shown in Figure 4(a) and (b) for different periods. The values in Figure 4 are estimated assuming that all the re-injected fluids were supplied to the reservoir. However, if we assume that 75% of the re-injected fluids returned to the reservoir, we have a good correspondence between the observed and calculated mass balance (Tokita et al., 2006).

4. DISCUSSIONS

We showed the mass balance in the geothermal reservoir at Hatchobaru geothermal field based on the gravity measurements and Gauss's theorem and also compared the results with those by numerical simulation (Tokita et al., 2006). The numerical simulation also showed that the inflows from the lateral boundaries and the reinjection flow rate are 46% and 48% of the produced mass flow rates, respectively. Therefore, totally, 94% of the produced mass has been supplied, that is, almost sustainable. These values are comparable to mass balance obtained from repeat gravity measurements. Therefore we can conclude that the sustainable production of geothermal energy is realized at Hatchobaru Geothermal Power Station.

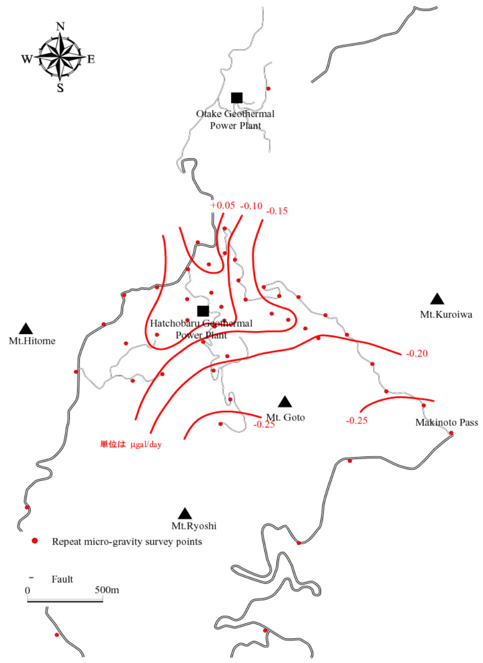

Figure 3(a). Gravity change from June 1990 to June 1992 at Hatchobaru geothermal field.

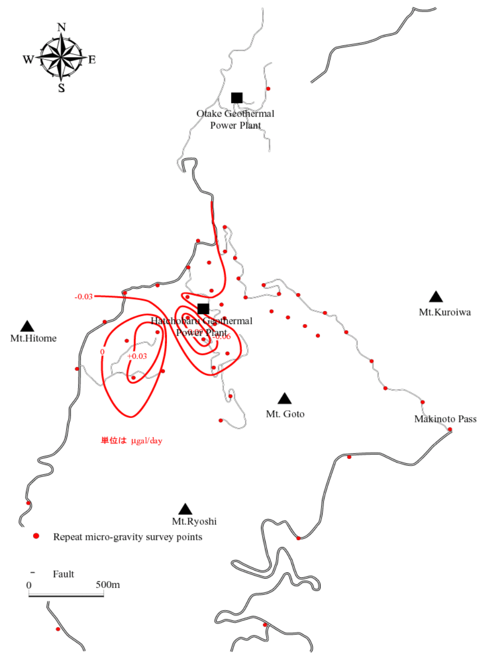

Figure 3(b). Gravity change from October 2000 to October 2001 at Hatchobaru geothermal field.

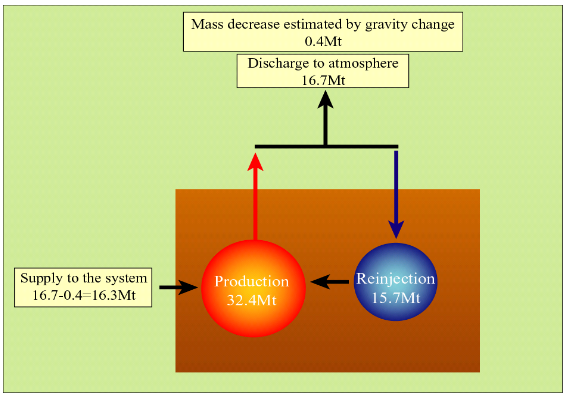

Figure 4(a). Mass balance at Hatchobaru geothermal field from August 1991 to May 1993 estimated from rates of produced and re-injected fluids and gravity measurements. It is assumed that all the re-injected fluids are supplied to the reservoir.

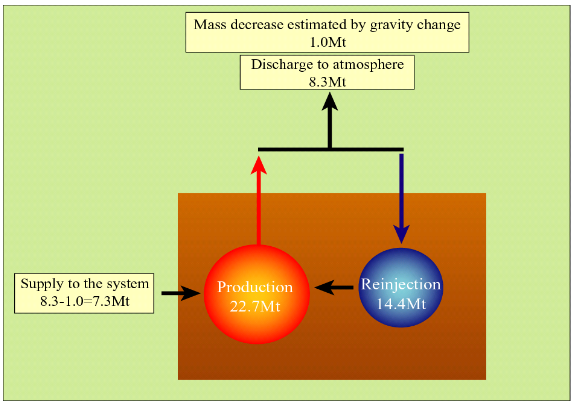

Figure 4(b). Mass balance from October 2000 to October 2001.

Here we propose a method to realize sustainable production of geothermal energy based on the results obtained at Hatchobaru geothermal field. At Hatchobaru geothermal field, No.1 Unit (55MW) was installed in June 1977 but at this time, the commissioned capacity was 23MW. Three years after, the commissioned capacity was increased to 55MW, that is, the installed capacity. No.2 Unit (55MW) was installed in 1990 and the total installed (=commissioned) capacity became 110MW. After the commencement of No.2 Unit, the output decreased to about 80MW. Main reason of such decreased output is quick return of re-injected fluids to the geothermal reservoir. Therefore the locations of production and re-injection wells were re-examined and was established the optimum arrangement of well locations. In addition, a new production zone was found and also the power generation system was improved. Various kinds of effort recovered the output to the installed capacity of 110MW. At present, Hatachobaru geothermal power station is continuing the stable operation of which output is between 100MW and 110MW. Total mass in the reservoir is almost balanced but each production well decreases about 5 % yearly. So we must drill make-up production wells. However, numerical simulation shows that in any case we will have power output of 120MW (Tokita et al., 2006), that is, the 120MW is sustainable production rate which is larger than the installed capacity. Therefore we think that the sustainable production of geothermal energy will be maintained also in the future. Figure 5 shows a scenario of sustainable power generation at Hatchobaru geothermal field.

The following processes are recommended to realize sustainable production of geothermal energy based on experiences at Hatchobaru geothermal field.

1) **Start at the moderate installed capacity(about 50% of the predicted value)**
2) **Do gravity monitoring and prediction by numerical modeling (This process is repeated.)**
3) **Find the sustainable installed capacity**
4) **Continue sustainable production**

The important thing is to do conservative assessment of geothermal resource at the initial stage of exploitation, because it is very difficult to estimate the sustainable production rate before exploitation. Figure 6 shows the experiences in the resource assessment in Japan. The maximum output of geothermal power stations in 2007 is -25% to -50% smaller than that of the installed capacity at about half of geothermal power stations in Japan. Therefore it is strongly recommended to start at the moderate installed capacity.

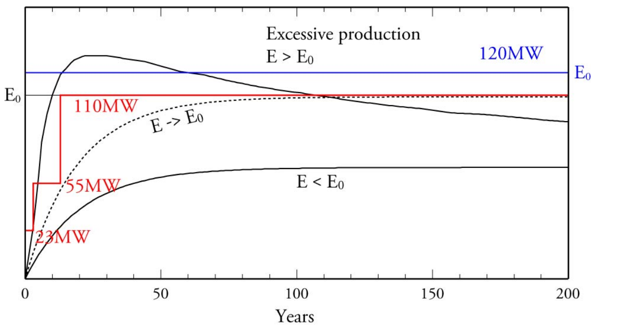

Figure 5. A scenario of sustainable production of geothermal energy at Hatchobaru geothermal field on the Axelsson's diagram (Axelsson et al., 2003). E_0 is sustainable production rate.

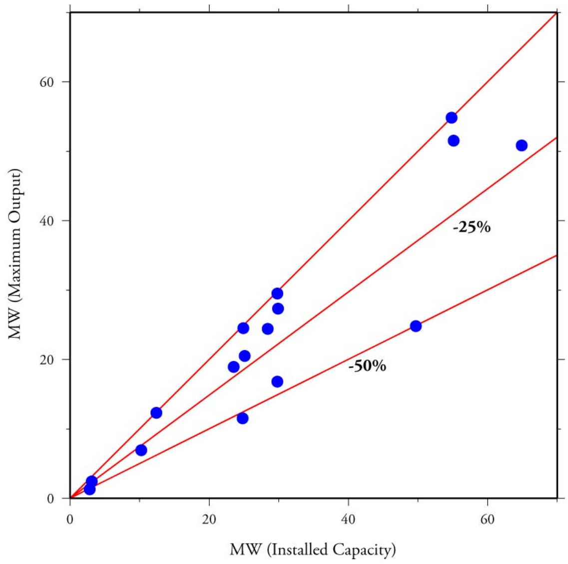

Figure 6. Relation between the maximum output and the installed capacity at geothermal power stations in Japan.

5. CONCLUSIONS

We estimated the mass balance in the geothermal reservoir at Hatchobaru geothermal field based on the changes in gravity and Gauss's theorem. Combining the estimated mass change and the rates of produced and re-injected geothermal fluids, we calculated the rate of natural recharge to the geothermal reservoir from outside. As a result, we estimated that the rate of natural recharge is nearly same as that of steam discharged to the atmosphere from the cooling towers. Therefore we conclude that the sustainable production of geothermal energy is realized at Hatchobaru Geothermal Power Station. Based on the results obtained at Hatchobaru geothermal field, a scenario of sustainable production of geothermal energy was proposed.

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