A Reservoir Simulation of the Oguni Field, Japan, Using MINC Type Fracture Model

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ABSTRACT

A quantitative reservoir model of present state has been developed through a natural-state simulation, in order to evaluate the geothermal potential of Oguni field in Japan. A series of calculation was carried out to forecast reservoir response to fluid production and injection using the natural-state model. The MINC type fracture model was introduced to this exploitation calculations, with equivalent steady properties. The thermal influence of low temperature reinjected water on the proposed production area was appraised. From this study, it was concluded that the projected productionheinjection scheme is appropriate for the future stable operation of power station.

1. INTRODUCTION

Electric Power Development Co. Ltd. (EPDC) has been carrying out an extensive exploration and reservoir assessment program in the Oguni area, Kyushu, Japan, since 1983, to develop a geothermal power station. Along with the EPDC's activity, New Energy and Industrial Technology Development Organization (NEDO) conducted "The Development of Geothermal Reservoir Evaluation Technology Project" (Kawano *et al.*,1989)in the same area in 1990-1993 to demonstrate a simulation study in an actual field development. In this project, EPDC developed a numerical model of Oguni reservoir using a multi-phase reservoir simulator (SING) which was developed by NEDO (1991).

This paper presents the result of the numerical modeling study. The quantitative reservoir model of present quasi-steady state was developed by a natural-state simulation. After the final model was derived by the trial-and-error matching of measured and calculated temperature and pressure distributions, a series of calculation was carried out to forecast reservoir response to fluid production and injection using the natural-state model. Multiple Interacting Continua(MINC) type fracture model (Pruess and Narasimhan, 1985) was introduced to this exploitation calculations, with equivalent steady properties. The results of calculations using MINC model were compared with those of porous type model and the thermal influence of low temperature reinjected water on the proposed production area was appraised.

2. OGUNI RESERVOIR SYSTEM

Abe *et al.*(1995) provide a detailed description of the conceptual modeling of the Oguni field. Oguni geothermal field is located in the central part of Kyushu, on the western flank of Mt.Waita, near the boundary separating Kumamoto and Oita prefectures (Figure 1). In the field, besides conducting several geological, geophysical and geochemical surveys, 12 small-diameter core holes(3 HH and 9 GH series) and 11 large-diameter wells (9 GH and 21H series; including future production and injection wells) have been drilled by EPDC. Figure 1 shows well locations and the inferred temperature distribution at -300m ASL based on measured data. The north-south section of the conceptual geothermal model is shown in Figure 2.

The granite basement of the Pre-Tertiary is found at about -1000m ASL in the area, and drops off steeply to the northeast. The stratigraphic sequence above the basement consists of the Taio Formation of the Pliocene , the Shishimuta Formation of the early Pleistocene, the Hohi Volcanic Rocks and the Kusu Formation of the lower to middle Pleistocene, and the Kuju Volcanic Rocks of the upper Pleistocene. The Nogami mudstones (Part of the Kusu group) and the altered Kuju Volcanic Rocks appear to function as a caprock for the geothermal system. Fractures are predominant in the Hohi Volcanic Rocks and the upper part of the Shishimuta Formation, and these formations constitute the principal aquifers.

It seems that the original heat source for the reservoir is the residual magma associated with the volcanism of Mt.Waita (0.3~0.4Ma). Based on the temperature distributions, the feedzone pressures and the geochemical analysis, it appears that hot fluid is upwelling from deep part at the flank of Mt.Waita, and flows horizontally to the north and northwest. The reservoir temperature is around 220 - 240 "C, and the maximum temperature (~240°C) in the area occurs near wells GH-4, GH-10, and GH-11.

The feedzone pressures imply that this area consists of two separate and distinct pressure zones (a high pressure zone in the area of southern wells HH-2, GH-6, GH-15, GH-19, N2-KW-3 and DY-2; a low pressure zone in the central and northern parts of the field) which are in poor communication with each other (Figure *6)*. At present, the reasons for the existence of two different pressure zones and the character of the impermeable barrier between them are poorly understood.

A state of fluid is single-phase liquid for the most part of the reservoir. However, based on the comparison of the measured temperature of wells with the saturated temperature profile corresponding to the measured reservoir pressure profile, geochemical data and the results of an analysis of pressure interference data, it appears that steam and water two-phase zone exists locally in the shallow part of the reservoir between +400m ASL and +600m ASL. The possible region of two-phase zone is in the area around well GH-8.

Based on the data of mud loss during drillings, temperature profiles of wells, well test data of individual wells and the pressure interference data, it appears that the permeability is fairly high in the Hohi Volcanic Rocks and the upper Shishimuta formation for the low pressure zone (kh=100~200 d-m), especially in the area of fractured zone associated with Takenoyu fault extending NW-SE. On the other hand, the reservoir permeability for the southern high pressure zone is moderate (kh=11 d-m).

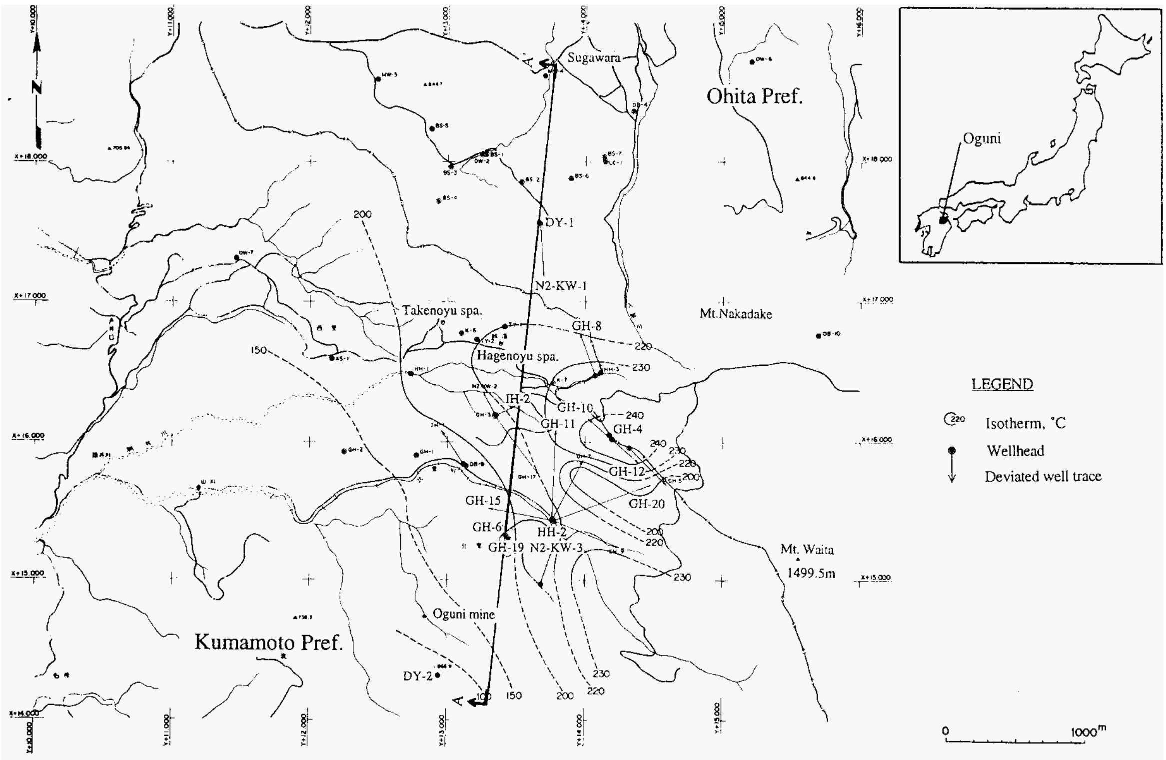


Figure 1 Well locations and temperature distribution at elevation -300m ASL of Oguni field

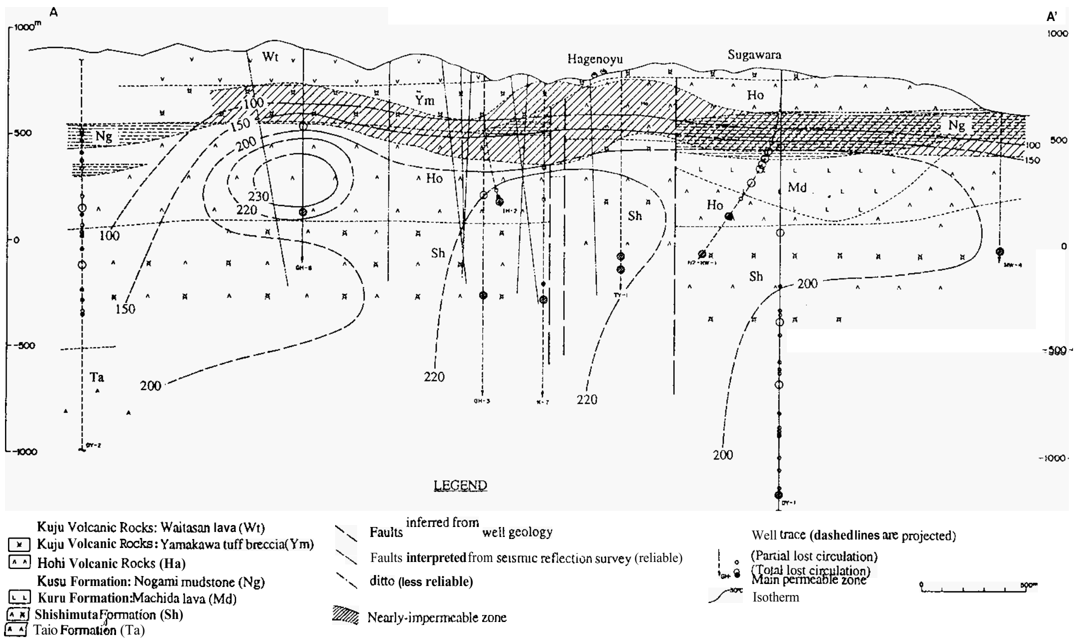


Figure 2 Geologic and temperature cross section of Oguni field along A-A‘

3. DESCRIPTION OF THE NUMERICAL MODEL

A three-dimensional, two-phase numerical simulation model of the Oguni field was developed using available geological, hydrological, geophysical, geochemical and reservoir engineering data. The model covers 49 km^2, extending 7 km in the E-W direction and 7 km N-S (Figure 3). Vertically the model extends from the top surface (ranging from +400m to +800m ASL) to -2500m ASL. The model consists of 1,287 gridblocks in 9 layers. 156 gridblocks of the top of the model (E-W direction (X) 12 x N-S direction **(Y)** 13) are used as boundary blocks, creating the one bar surface, based on water level data of shallow aquifer wells. The bottom boundary of the computational volume was treated as impermeable and constant heat flux boundary. The distribution of the mass sources for representing the upwelling flow at -2,000m ASL level near Mt.Waita were assigned in the bottom layer. The locations and extent of the mass sources, as well as permeability distribution, were used as the main fitting parameters in the natural-state simulation. For the lateral boundaries, the constant pressure boundary conditions were prescribed at the northern and the western sides. The southern and the eastern boundaries were, on the contrary, set as impermeable and insulated.

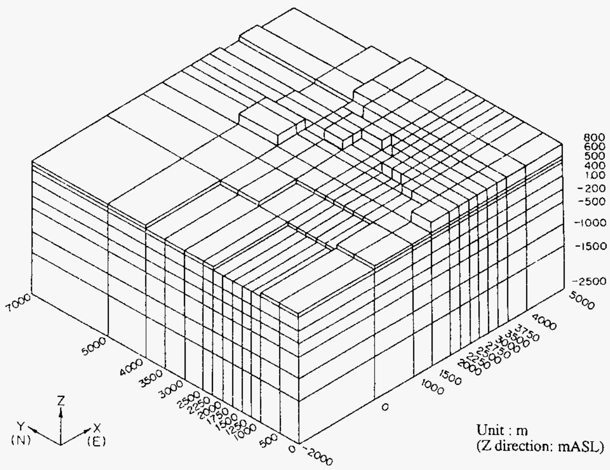


Figure 3 Three-dimensional view of the model

Rock properties (porosity, specific heat, thermal conductivity and density) except permeability in 3 mutually perpendicular directions, were input to the model based on measured data for each rock types. The permeability distribution was one of the most important free parameters in the simulation. The permeability-thickness products finally constructed in the model have fairly good agreement with the **kh** values obtained from pressure interference tests, for the region where these tests were performed. The fluid was treated as pure water in the model, because of the small quantity of non-condensable gas content(0.01 vol.% on the average).

4. NATURAL-STATE SIMULATION

The model was calibrated by a natural-state simulation. This procedure involved the matching by trial and error of the measured and calculated temperature and pressure distributions of natural state, using rock permeabilities and the locations and extent of mass sources as the main fitting parameter. This natural-state simulation was performed in the following two steps:

Step **1:** Calculation of quasi-steady state without any production or injection using SING-I code, which is restricted to single-phase liquid flow (usually 100,000 years). The reason is that the two-phase region is estimated quite small in the Oguni reservoir, so that its presence has little effect on the natural state except in the shallow small part of the computational volume.

Step 2 : Continuation of calculation using **SING-I1** simulator, which incorporate two-phase effects (usually 20,000 years). In this stage, besides the matching of temperature and pressure distribution and the discharge rates of hot springs, a further calibration of the model was tried by the matching of measured and calculated pressure transient data of the observation well points for several pressure interference tests performed in the field during April 1991 - July 1992.

Once the model was calibrated, it could be used for predicting the reservoir response to exploitation. After many (over a hundred times) natural-state calculation, reasonable matches were achieved between the observed and calculated subsurface temperature distributions and feedpoint pressures. Figure 4 is an example of the agreement between calculated and inferred temperature distribution along cross-section X=8. The distribution of calculated steam saturation on the same section is also shown in Figure 4. Figure 5 is an example of the comparison between the computed and measured temperature profiles in wells. Figure 6 compare the computed pressures to measured pressures at the feedpoints of the various wells. The general agreement of calculated and measured data in these figures implies that the model is reasonably calibrated.

5. FORECASTING OF RESERVOIR BEHAVIOR

Several possible productiodinjection schemes were considered in order to evaluate the reservoir response to electric power production. The cases considered were :

(A1):Power out-put ; 27MW(Double-flash)
Production ; central part 100%
Reinjection;western part 70% of total injection rate, southern (high pressure) part 30%

(A2):Power out-put ; 27MW(Double-flash)
Production ; central part 100%
Reinjection;northern part 70% , southern part 30%

(A3):Power out-put ; 27MW(Double-flash)
Production; central part 93%, southern part 7%
Reinjection ; northern part 93%, western part 7%(only blowing water of cooling tower)

and

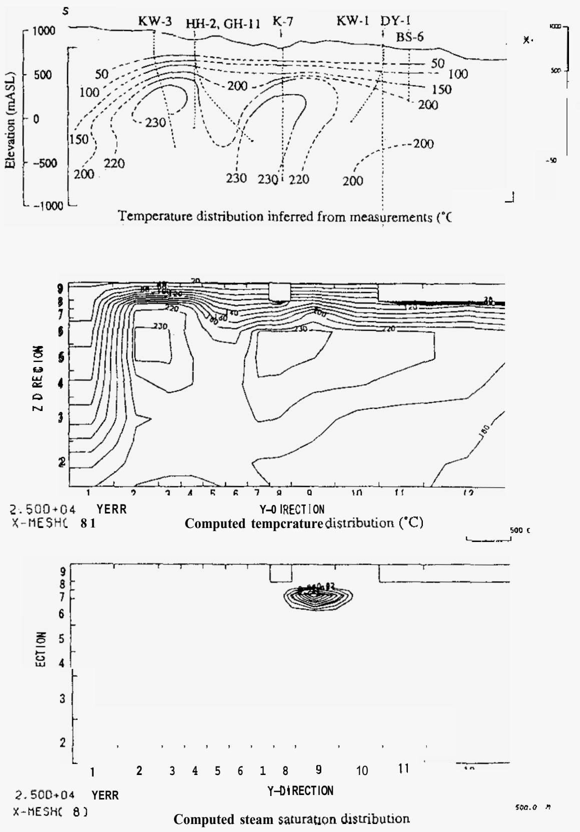


Figure 4 Temperature matching and calculated steam saturation along X=8 section

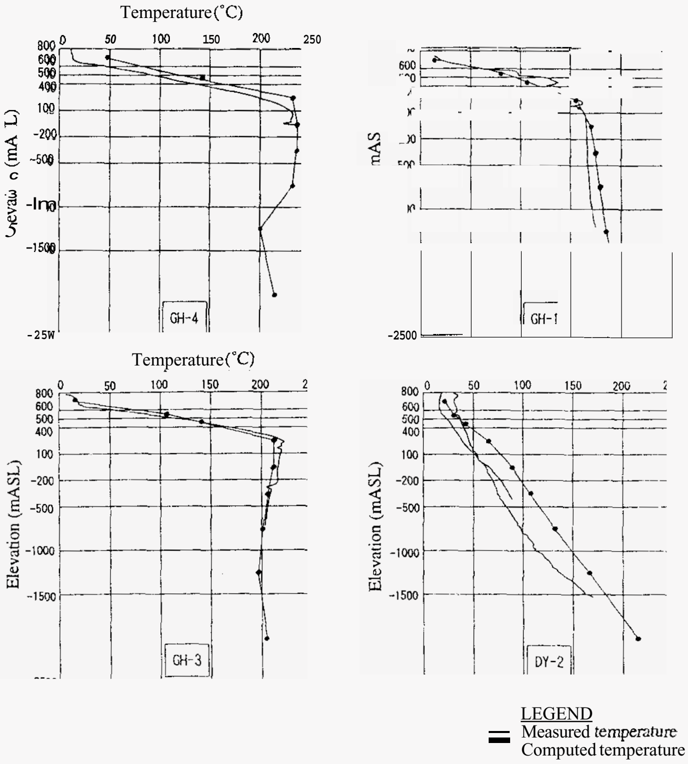


Figure 5 Comparison of computed temperature profiles with measured temperatures in wells

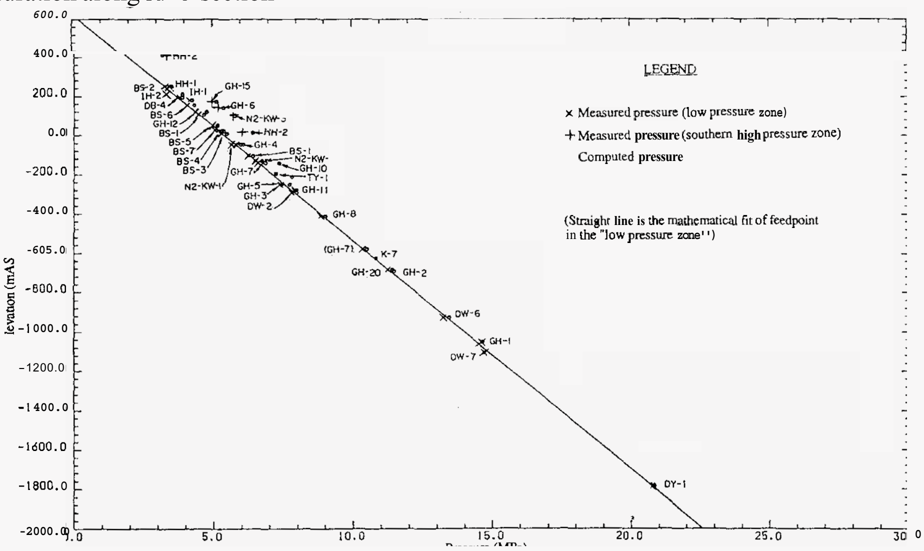


Figure 6 Comparison between measured and computed feedpoint pressures in wells

(B1):Power out-put ; 25MW(Double-flash)
Production/Reinjection scheme is the same as case (A3).

Production and reinjection areas mentioned above are shown in Figure 7. In case(A1), the possibility of reinjection nearby the production area was evaluated, within various confining conditions as national park boundaries, topography etc. The purpose of case(A2) is to assess the feasibility of reinjection to northern part (same aquifer as production zone) and southern part(high pressure zone). The purpose of case(A3) is to evaluate the practicality of reinjection mainly to northern part, including separated water from the southern production area which bears a small part of total necessary production rate.

The simulation was set to predict the reservoir behavior for **30** years. Results of exploitation simulation indicated that reinjection of plenty of water in western area and southern high pressure zone was not feasible. Reinjection to western area induced **a** radical cooling of the production zone for cold fluid flow eastward from western injection area in case(A1). The reinjection of significant rates of water in the southern area (Case(A1)and (A2)) causes substantial increases in underground pressure, because the southern high pressure zone of the reservoir is limited both in volume and fluid transmissivity by comparison with the reservoir of north. From results of the simulation, it is concluded that almost all fluid reinjection from the power station should take place in the northern part of the reservoir away from production zone, and if we take the strategy of production/reinjection like cases(A3), 27MW development, let alone 25MW, is completely feasible.

6. FRACTURE MODEL SIMULATION

The exploitation calculations mentioned above were carried out based on the natural-state model, which was porous type model. The actual condition of the Oguni reservoir is, however, naturally fractured reservoir consists of high permeable fracture zones and nearly-impermeable rock matrix regions. The thermal effect of a flow of cold injected water on the production zone is one of the key issues for exploitation of the field, and time-scales of the behavior in such a system may be short compared with the time required for equilibration between the rock matrix and the fracture system. Therefore, exploitation simulations involving MINC type double porosity model were carried out for the same productionheinjection condition as case(A3) of previous section.

Pritchett and Garg (1990) examined the influences of fracture separation and of country rock permeability for two-phase flow in fractured porous media. Fracture separation of the fractured porous media is an important parameter for the present study, although single-phase liquid flow is dominant in the field. An average fracture spacing representing the region involving productionlreinjection zones was estimated to be several tens of meter to lOOm (for maximum), based on lost circulation data of various wells in the area, and two values (50m and 100m) were chosen for the parametric study.

The region surrounded by thick line in Figure 7 shows an area of gridblocks using MINC formulation. 92 gridblocks of the steady model were changed to MINC model, which extends from **Z=3** to 6 layers. The rock properties assigned in these blocks were equivalent to those of steady model. For example, in the simulator, fracture permeability (kf) has an relationship with permeability of porous model (k) as :

$$k = k_f \cdot 2a / \lambda \qquad (1)$$

where λ is a fracture spacing (50m or 100m), and a is an aperture of fracture zone (0.1m or 0.67m was chosen for the study).

The exploitation simulations for MINC model were run for 16 years. Figure 8 shows an example of the influence of λ on temperature changes in production blocks. Figure 9 shows the same example in the blocks adjacent to the injection blocks. Figure 10 compares the temperature distribution along **X=8** section calculated by the fracture model (λ=100m) with that of porous model after 16 years of production. The deference of calculated temperature for various fracture spacings from that of porous model were acceptable at production zones, differing at the blocks nearby injection zone. From the fracture model simulation, it was concluded that the projected productionheinjection scheme is appropriate for the future stable operation of power station, even considering the characteristic of fracture system.

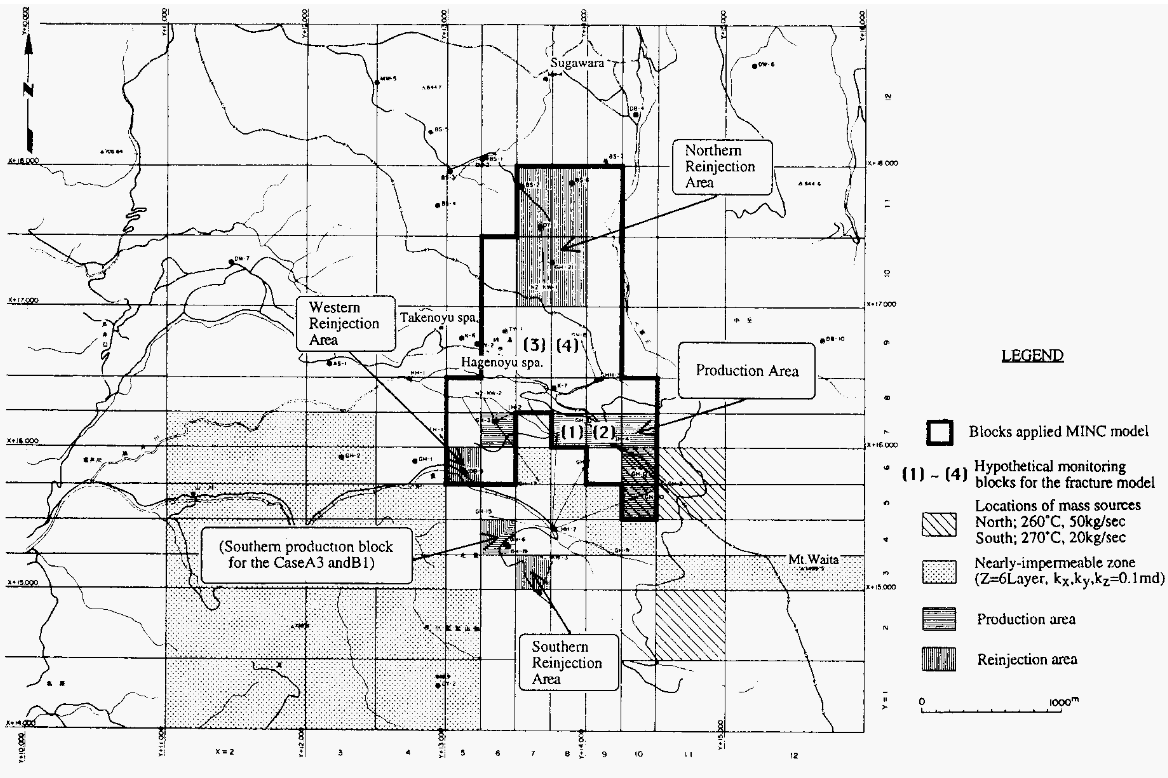
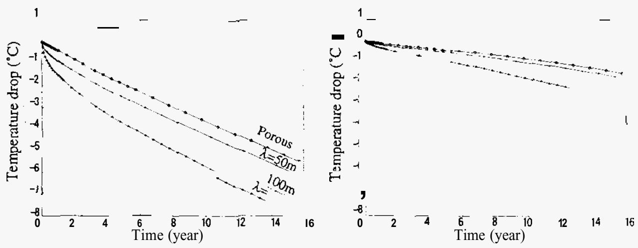


Figure 7 Location of hypothetical production and injection areas and MINC formulation blocks



[Block (8,7,4); Location(1) of Fig7)] [Block (9 7,5); Location(2) of Fig7)]

Figure 8 Change in temperature at production blocks

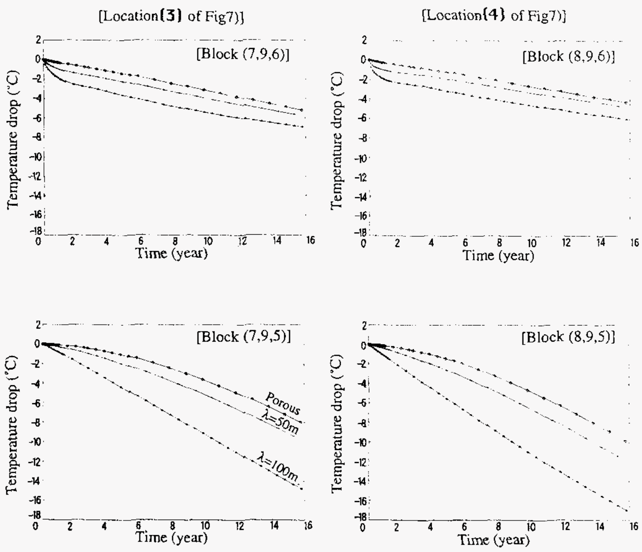


Figure 9 Change in temperature at the blocks nearby reinjection area

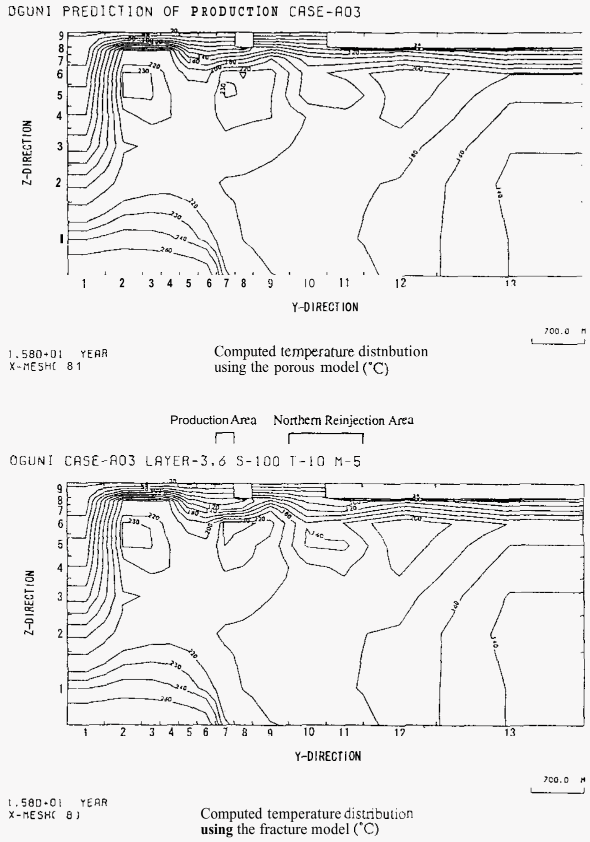


Figure 10 Computed temperature distributions for the porous and fracture tnodels after 16 years of production along X=8 section

7. CONCLUSION

- It was possible to match by simulation the quasi-steady state distribution of temperature and pressure within the field. The results of natural-state simulation validated most features of the conceptual model.
- Exploitation modeling confirmed that at least a 27MW development is completely feasible if almost all reinjection take place in northern appropriate area away from main production zone.
- The results of the simulation using the MINC type model with steady properties showed that the projected productionheinjection scheme is appropriate for the future stable operation **of** power station, even considering the effect of the fractured system.

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