A MODELING STUDY OF THE NATURAL STATE OF THE KIRISHIMA FIELD

MAKI, H., New Energy Development Organization, Sunshine 60, 29F, Higashi-Ikebukuro, Toshima-ku, Tokyo 170, Japan
ISHIDO, T. (Speaker), Geological Survey of Japan
ABE, I., Nippon Steel Corporation
NOBUMOTO, R., Nittetsu Mining Company
OIKAWA, Y., Information and Mathematical Science Laboratory, Inc.

Introduction

The New Energy Development Organization (NEDO) is conducting a program entitled Development of Geothermal Reservoir Evaluation Technology. The purpose of the program is to develop methods, including well-testing and computer-assisted numerical modeling, to aid in quantitative understanding of geothermal reservoirs in both the natural state and under conditions of exploitation. NEDO has selected the Kirishima geothermal prospect in southern Kyushu as one of the fields to be investigated under this program.

Since 1972, the Nippon Steel Corporation and the Nittetsu Mining Company have been jointly engaged in survey work in the area with the ultimate objective of constructing a geothermal power plant. These companies have carried out a variety of geological and geophysical surveys in the Kirishima area, and have also drilled a number of exploratory wells (the 400 m to 2000 m "KE" series wells).

The development of the present mathematical model for the Kirishima (Ginyu) reservoir was accomplished in an iterative fashion. Given a set of assumptions concerning the reservoir parameters, a 'natural state' was calculated using numerical simulators. Adjustments to unknown parameters were based on comparisons between computed results and measured field data. The natural-state calculation was then repeated; this continued until satisfactory results were obtained.

Kirishima Field

The Kirishima field is situated in a volcano-tectonic depression (the "Kagoshima graben") which trends north-south and relates to the block-faulting after deposition of the Shimanto group. The volcanic activity began in the Pliocene and continued during the Quaternary, so andesitic lava flows and pyroclastics accumulated in enormous thickness (more than 2000 meters in the depression area [Nakagawa, et al., 1985]). Figure 1 is a general map of the Kirishima field showing many of the wells in the area. The field lies at an elevation between 800 meters and 1000 meters above sea level, and several fumaroles and hot springs are present (notably Ginyu and Kinyu, as indicated in Figure 1). The Kirishima volcanoes are located about five kilometers to the northeast of the explored geothermal area. The trends of faults and surface lineaments are mainly ENE-WSW and NW-SE. The most important faults in the area are the "Ginyu fault" and the "Shiramizugoe fault"; many wells were drilled along these faults in an attempt to find permeable horizons.

In most of the Kirishima wells, repetitive surveys of downhole temperature and standing water level were carried out for at least several days after cold-water circulation was terminated. These heat-up surveys permit the estimation of reservoir pressure and temperature. Two major features are evident in the natural-state temperature distribution in the field. First, there is a general tendency for temperatures to decrease from east to west; this implies that the thermal anomaly is associated with the volcanos located northeast of the field. Second, a local high-temperature feature is found in the center of the study area. Based on these thermal features, we conclude that the Ginyu fault is responsible for the local geothermal feature located in this part of the Kirishima field.

As discussed above, simultaneous downhole temperature surveys and measurements of standing shut-in water level were carried out during heat-up for most of the wells in the area. These measurements permit the determination of the stable feedpoint pressures for the various wells. These results indicate that underground pressures are significantly different between the Ginyu part of the Kirishima field (to the north) and the Shiramizugoe area (farther south). This suggests, in turn, that an impermeable boundary is present separating these two parts of the field, and that little communication between these two areas should be expected.

The major vertical fault has been mapped by encounters during drilling at Ginyu; the well feedpoints tend to align along the fault in the Makizono lavas, Ebino formation and Iino lavas(below sea level). Most of the wells have no feedpoints in the upper and middle Makizono lavas which have undergone extensive hydrothermal alteration, however. This relatively impermeable region acts as a caprock for the Ginyu reservoir.

Pressure transient tests, including monitoring of shut-in observation wells using capillary-tube type downhole pressure gages, have been carried out for the Ginyu reservoir. Permeability-thickness values ranging from 11 to 185 darcy-meters were obtained from the analyses of these tests [Yokoi, et al., 1987; Kitamura, et al., 1988] .

Modeling of the Natural State

To make time-dependent calculations of the effects of fluid production and reinjection upon the reservoir, it is necessary to first establish the natural (or pre-production) state of the system. It is not sufficient in this connection to merely prescribe a "natural state" based, for example, upon interpolation between measured (or inferred) pressures and temperatures. It is essential that the natural state itself represents a quasi-steady solution of the partial differential equations which govern flow in the reservoir. Since transient processes associated with initiation of convection occur over time scales of the order of 10^4 years, the natural state can be regarded as stationary over the 10-50 year period required to exploit a geothermal reservoir. Thus, the requirement that the natural state be itself a nearly steady solution of the governing equations is an essential test of the model of the reservoir. In the present work, numerical techniques are employed to estimate the natural heat and mass flows through the reservoir, using measured values of temperature and pressure at different depths as a basis for comparison. The present methodology is similar to that adopted in a previous study of the Hohi area [Ishido et al., 1984] . In the present study, three-dimensional unsteady geothermal reservoir simulators ("SING-I", restricted to single-phase flow; and "SING-II", also capable of treating two-phase water/steam systems) were used. These programs were developed by NEDO under the current project.

In Figure 1 also shown is a top view of the three-dimensional computational grid used for the Ginyu natural-state simulations. In the vertical direction, the study volume extends from -1400 m ASL(above sea level) to +400 m ASL. Thirteen subdivisions were used in the x-direction; in the y-direction, seven subdivision were employed; and the volume was divided vertically into nine layers. Not all of the grid subdivisions were of the same size. Maximum resolution was reserved for the central region of the Ginyu well field, in which the grid blocks measured 250 meters by 250 meters (horizontally) by 100 meters (vertically).

The most important parameters which were systematically varied during the matching process were the permeabilities of the rocks in the computational grid, and the parameters designating the boundary conditions. No mass or heat transfer was permitted across the southern and eastern vertical faces of the study volume. Upon the upper grid surface (400 m ASL), a pressure distribution reflecting the local elevation of the groundwater table was imposed. On the lower grid surface, prescribed upward mass fluxes of hot water were imposed in areas where the Ginyu fault penetrates the boundary.

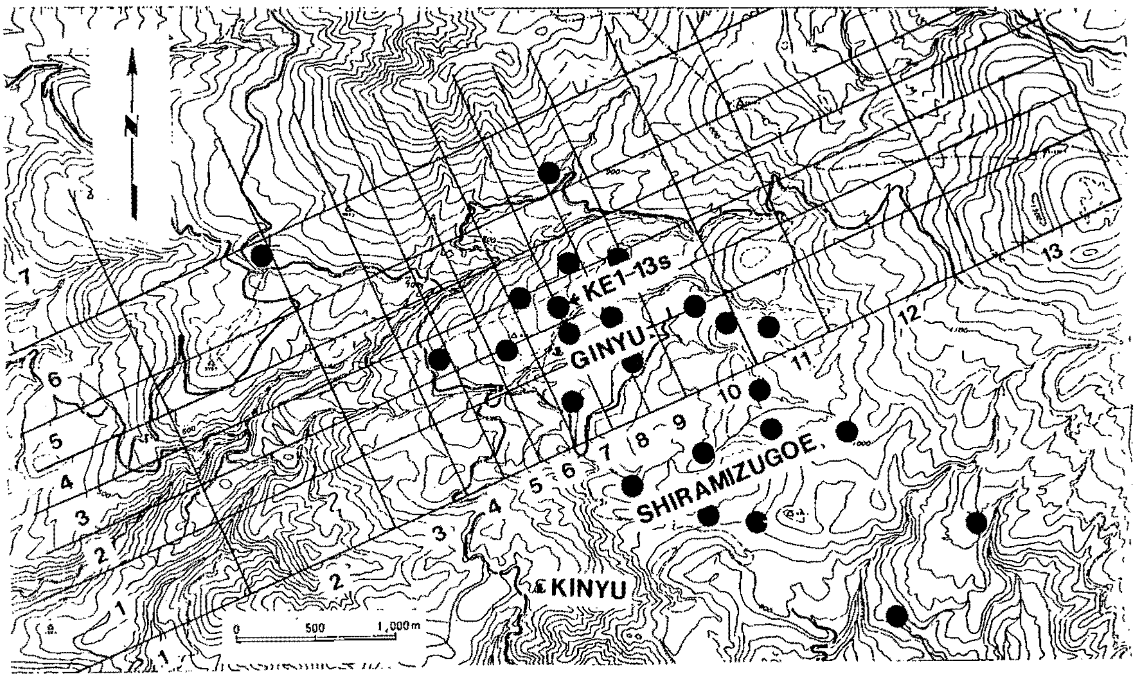

Fig. 1. Topographic map of the Kirishima field. Locations of wells are shown by solid circles.

The Ginyu reservoir in its natural state is single-phase liquid except for a relatively small two-phase zone extending from about sea level toward the surface. Although the SING-I (single-phase) simulator has been used successfully to carry out preliminary natural state calculations, SING-II (two-phase) is now being used to take into account more complicated phenomena related to two-phase flow. (The results obtained with SING-II are discussed hereafter.) The iterative computation process had to be repeated more than 50 times before a satisfactory model of the Ginyu system was obtained. Starting from an essentially arbitrary initial state, the final calculation was carried out for a total computed history 20,000 years long. By about 10,000 years, most of the changes had taken place; thereafter the system evolved only very slowly.

The computed natural-state temperature distribution is shown in Figure 2. The observed temperature distribution is well reproduced in Figure 2. The computed natural-state vapor saturation distribution is plotted in Figure 3. The computed pressures along a vertical axis passing through the two-phase zone shown in Figure 3 is plotted in Figure 4. The pressure distribution observed in the Ginyu reservoir is fairly well reproduced in the final model.

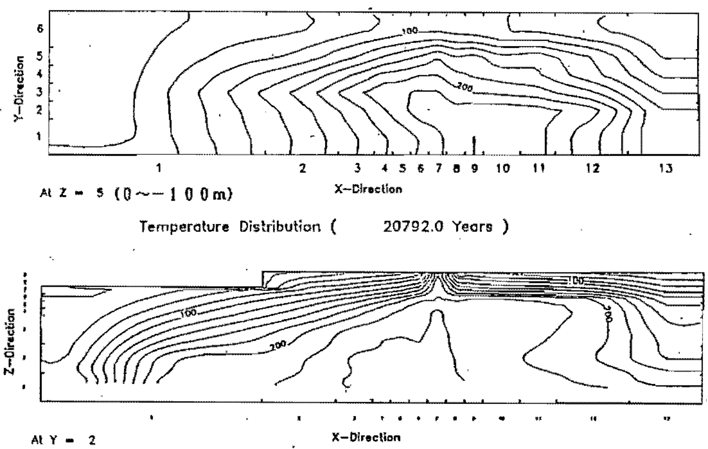

Fig. 2. Computed temperature distribution in a horizontal plane (upper diagram) and in a ENE-WSW vertical plane (lower diagram). Contour interval is 20 °C.

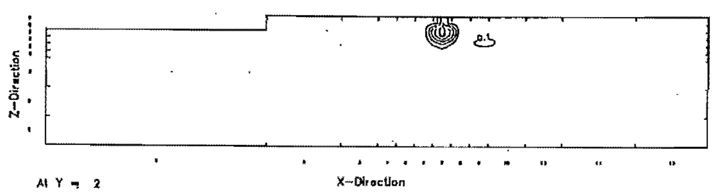

Fig. 3. Computed vapor saturation distribution in the same vertical plane shown in Fig. 2. Contour interval is 0.1.

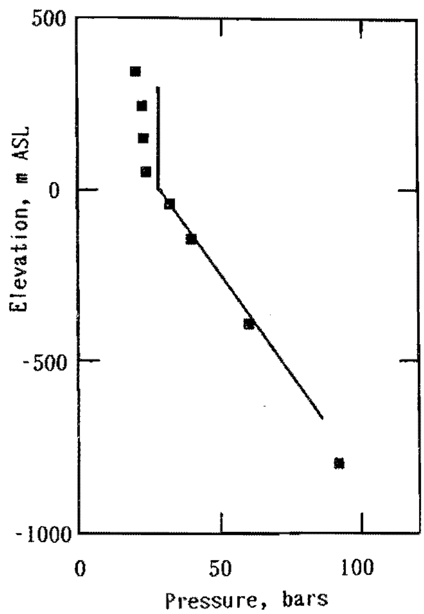

Fig. 4. Computed and observed pressures as a function of elevation for Ginyu reservoir. Solid squares show computed grid-block values. Profile estimated from measured feedpoint pressures is shown by solid line.

Calibration of the Model against Interference Test Data

An interference testing program has been in progress at the Ginyu area since January 1985. A total of five production wells, two reinjection wells, and five shut-in observation wells have been involved in the tests. Figure 5 shows the pressure history recorded in observation well KE1-13s from January 1985 to December 1987. The signal recorded in well KE1-13s shows a very clear response to the changes in discharge from the various flowing wells.

The natural-state model described above was used as initial conditions to calculate the response of the system to the 3-year fluid discharge history. The computed pressure history for the grid block which contains the primary feedpoint for well KE1-13s is shown in Figure 5. The agreement between calculated results and observations is fairly good. This simulation of the interference test, despite the limitations imposed by spatial resolution, supports the present mathematical model for the Ginyu reservoir.

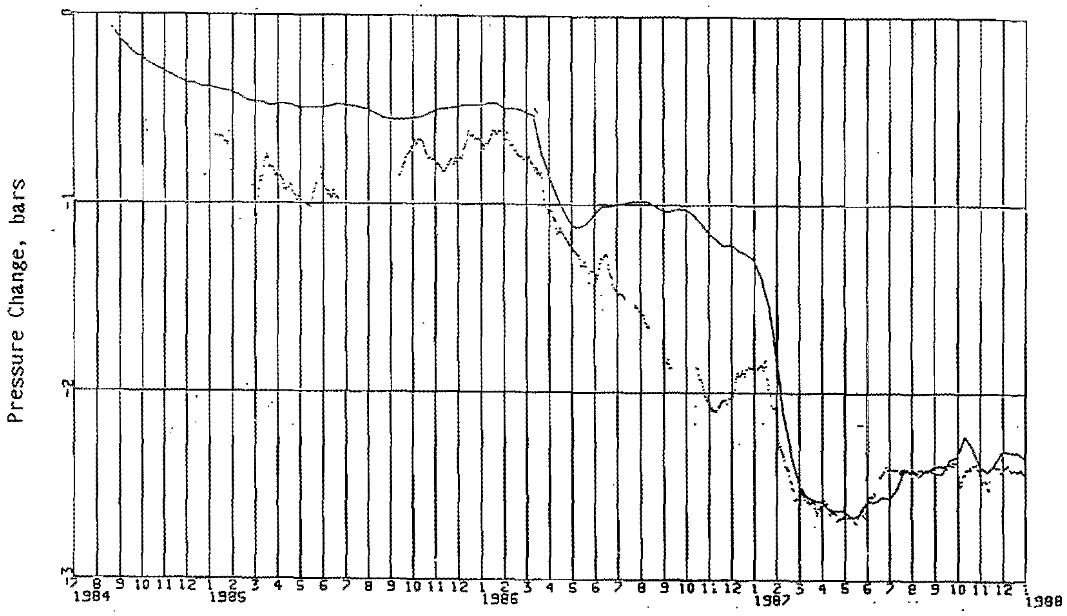

Fig. 5. Measured pressure change in well KE1-13s at feedpoint depth. Solid line shows KE1-13s response calculated by natural-state model.

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