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NEDO'S PROJECT ON GEOTHERMAL RESERVOIR ENGINEERING: A RESERVOIR ENGINEERING STUDY OF THE SUMIKAWA GEOTHERMAL FIELD, JAPAN

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INTRODUCTION

In order to promote the development of geothermal energy resources, it is important to understand how to estimate reservoir capacity and to minimize the risks associated with various development schemes prior to full-scale commitment so that power plant design may be formulated. The New Energy and Industrial Technology Development Organization (NEDO) has been developing technology suitable for the evaluation of geothermal reservoirs since FY 1984. Phase I of this program was completed during FY 1987; the results of these studies are being published during FY 1988. Then, beginning in FY 1988, NEDO undertook Phase II of the program, of which the major purpose is to devise techniques to deal with more complex reservoir behavior. This includes reservoirs in which the effects of fractures must be specifically treated and/or in which the fluid mixture contains important constituents in addition to H_2O (such as carbon dioxide gas).

STRUCTURE OF NEDO'S PROJECT

Figure 1 indicates the overall NEDO project schedule. The project has three major components: (1) the development of numerical reservoir simulators, (2) the acquisition of data from real geothermal fields, and (3) modeling and simulation studies.

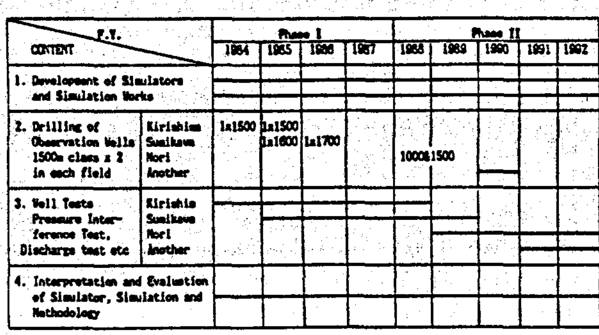


Figure 1. NEDO project schedule.

Simulator Development

So far, NEDO has developed three simulators suitable for geothermal reservoir engineering studies. The "SING-1" code is restricted to incompressible single-phase-liquid reservoirs using the Boussinesq approximation in either three-dimensional (Cartesian) or axisymmetric geometries. The more general "SING-2" simulator treats two-phase (water/steam) systems, including compressibility effects, and incorporates a representation for fracture/matrix phenomena. The generality of the SING-2 simulator is offset by computing cost; execution times are typically forty times greater for SING-2 than for SING-1. Hence, for preliminary studies SING-1 will be used wherever possible.

The "WENG" simulator is in a somewhat different category; it consists of an unsteady one-dimensional radial-flow single-phase-liquid heterothermal reservoir model coupled to a steady-state two-phase model of flow up a geothermal production well. Heat transfer through the casing is treated using a user-prescribed heat transfer coefficient in connection with a prescribed formation temperature profile. Frictional pressure drop and liquid-holdup effects are treated using empirical correlations.

The various NEDO simulators have been tested against analytical solutions and also against computed results obtained using older proven simulators. The results of the various test calculations have verified the reliability of the NEDO codes.

Field Studies

To apply the technology developed under this program to actual field situations, NEDO chose particular Japanese "model" geothermal fields for study: the Sumikawa and Kirishima fields (Phase I) and the Mori field (Phase II), as indicated in Figure 2. Several field surveys were conducted including long-term reservoir pressure observations, well logging, and discharge testing.

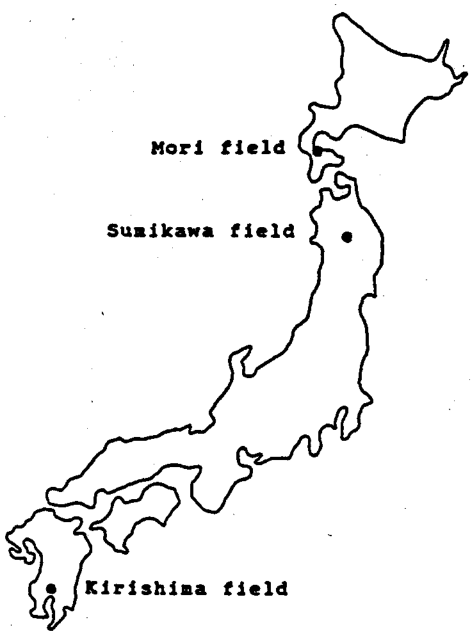


Figure 2. Locations of model geothermal fields.

The Kirishima study began in 1984 with the completion by NEDO of two deep observation wells in the field. Pressure observations have been made using these wells as well as six other preexisting wells drilled by the field developer. Results obtained from the Kirishima study have been summarized by Kitamura, *et al.* (1988) and Maki, *et al.* (1988a). The Sumikawa study started in 1985; as at Kirishima, two deep wells were first drilled for the purpose of pressure observations. Long-term pressure observations have been found to be very useful; at Kirishima, a total of eight observation wells have been instrumented and have recorded the response to a multi-year history of production and injection operations at the field on a year-round basis. The locations of the various Kirishima wells are shown in Figure 3 and the character of the discharge/injection/observation history is indicated in Figure 4. Results of pressure monitoring experiments at Sumikawa are discussed below.

Modeling and Simulation

Numerical reservoir simulation studies have been carried out to try to understand the reservoir mechanics in the selected geothermal fields (see, for example, Maki, *et al.*, 1988a; 1988b). These

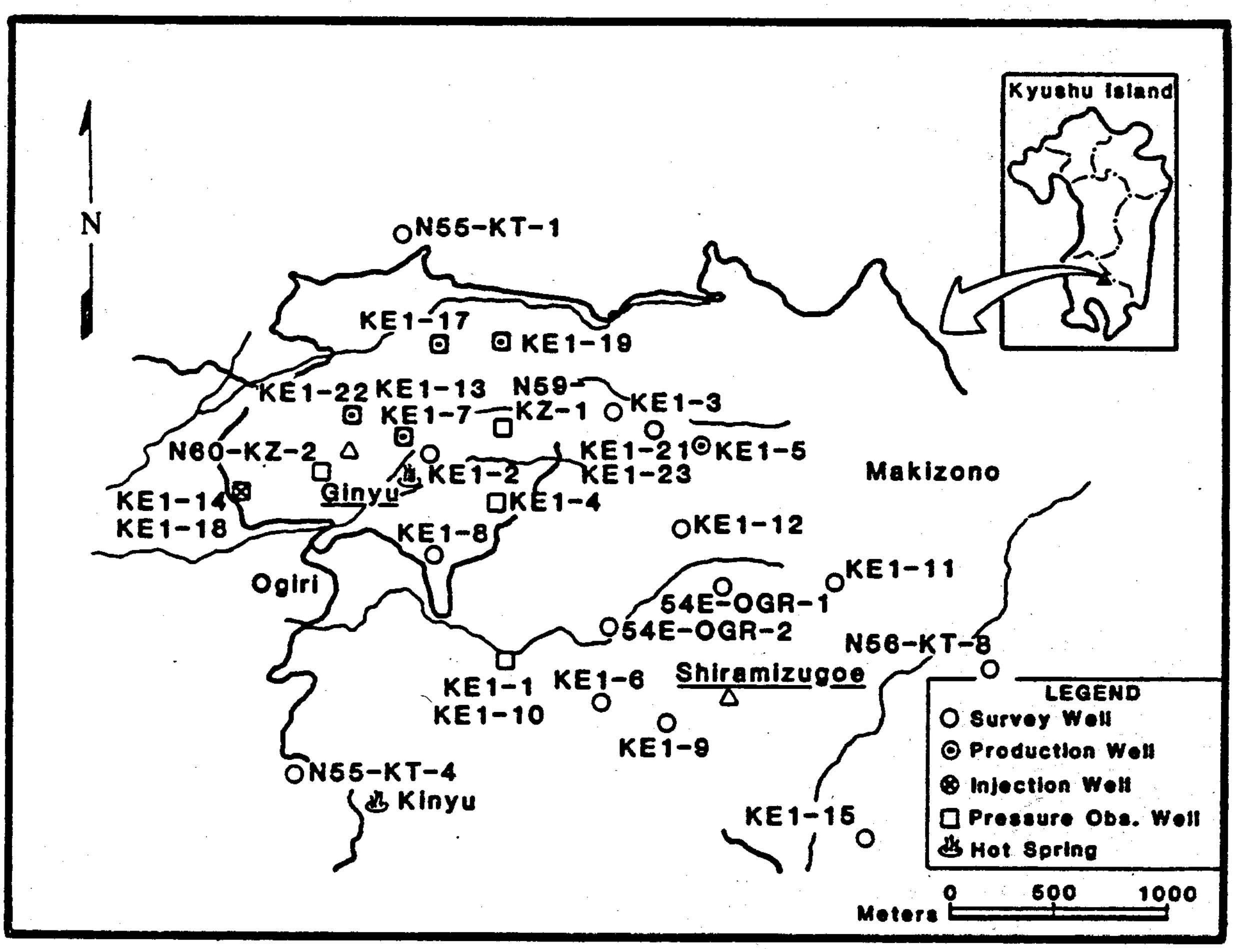


Figure 3. Map of the Kirishima geothermal field.

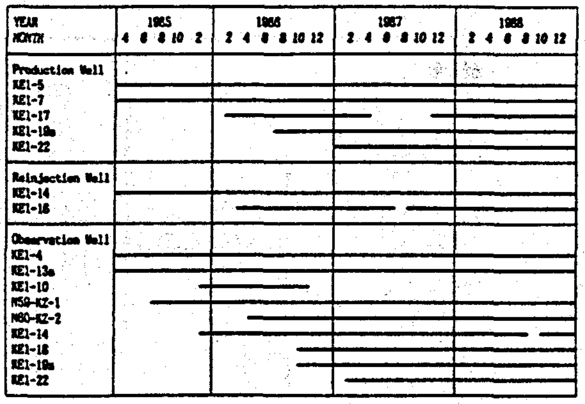


Figure 4. Kirishima pressure interference test schedule.

studies were based upon available analyses of well-test measurements, geological data, geophysical survey results and other pertinent information. Simulations of this type are carried out in an iterative manner, varying the values of the various unknown parameters in the mathematical model to maximize agreement between measurements and calculated results. These calculations are time-dependent in character but are carried forward for long periods of time so that a nearly steady natural-state representation is obtained. Adequate matches both for the (essentially steady) natural state of the system and for any documented transient behavior (such as long-term pressure transient testing and/or production history) are sought in this iterative procedure.

Once an internally consistent model of the reservoir in its natural state has been obtained which represents the known facts about the reservoir, a series of calculations may be performed to estimate the response of the reservoir to a variety of alternative development strategies. Sensitivity studies are also performed to evaluate the reliability of the resulting predictions, and an optimum reservoir development plan is devised.

THE SUMIKAWA GEOTHERMAL FIELD

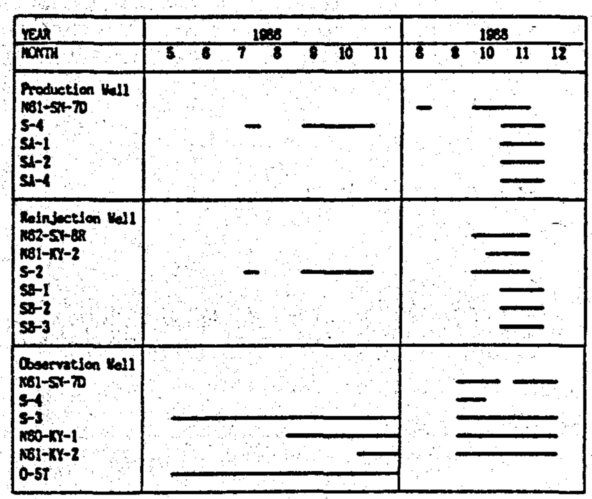
The Sumikawa field is located on the northern slope of Mount Yake in Akita prefecture in northeastern Japan. Mitsubishi Metal Corporation (MMC) has been carrying out field exploration studies in the general vicinity since 1965. This early exploration program involved drilling five wells and the performance of a variety of surveys (resistivity, gravity, geochemistry, etc.). In 1973, MMC commissioned the Ohnuma geothermal power station, located about two kilometers east of Sumikawa.

In 1974-75, the Japanese government carried out further investigations in the Sumikawa area, including the completion of five additional wells and a resistivity survey. The results of these surveys made it clear that Sumikawa was a promising field. At this point, MMC (in collaboration with MGC - Mitsubishi Gas Chemical Corporation) initiated a new exploration program which focused specifically on the Sumikawa field, and drilled the four deep "S-series" (S-1, S-2, S-3 and S-4) wells between 1980 and 1984. Results of this drilling program indicated the presence of a substantial underground two-phase flow region in the southern part of the field.

As discussed above, Sumikawa was selected by NEDO as one of its "model" fields in 1985. NEDO drilled two additional wells in the area in 1985-1986. Meanwhile, another related NEDO project was carried out at Sumikawa which involved the completion of the deepest well in the field (well SN-7D; 2486 meters) in 1987. As a consequence of these exploratory programs, a reasonably self-consistent picture of the geology and hydrology of the reservoir at Sumikawa is emerging. The present understanding of the system has been summarized by Kubota (1988) and also by Pritchett, *et al.* (1989) at this Workshop.

PRESSURE INTERFERENCE MEASUREMENTS AT SUMIKAWA

As Figure 5 shows, extensive discharge tests were performed at Sumikawa in 1986 and again in 1988. Although these tests were significantly shorter in duration than those at Kirishima, several interesting signals were recorded. Figure 6 indicates the locations of the wells involved. The first test entailed the three-month discharge of deep well S-4 in the autumn of 1986; the separated liquid component was reinjected into nearby (relatively shallow) well S-2. Four shut-in observation wells (KY-1, KY-2, S-3 and O-5T) were equipped with downhole capillary-tube pressure gauges. No signals attributable to the discharge test were observed in wells KY-2, S-3 or O-5T, but a substantial response was detected in deep well KY-1, which lies about one kilometer north of S-4 (see Figure 7). Analyses of this interference signal (Maki, *et al.*, 1988c; Pritchett, *et al.*, 1989) suggest the presence of a deep permeable channel oriented north-south at Sumikawa.



* No well test was carried out in 1987.

Figure 5. Sumikawa pressure interference test schedule.

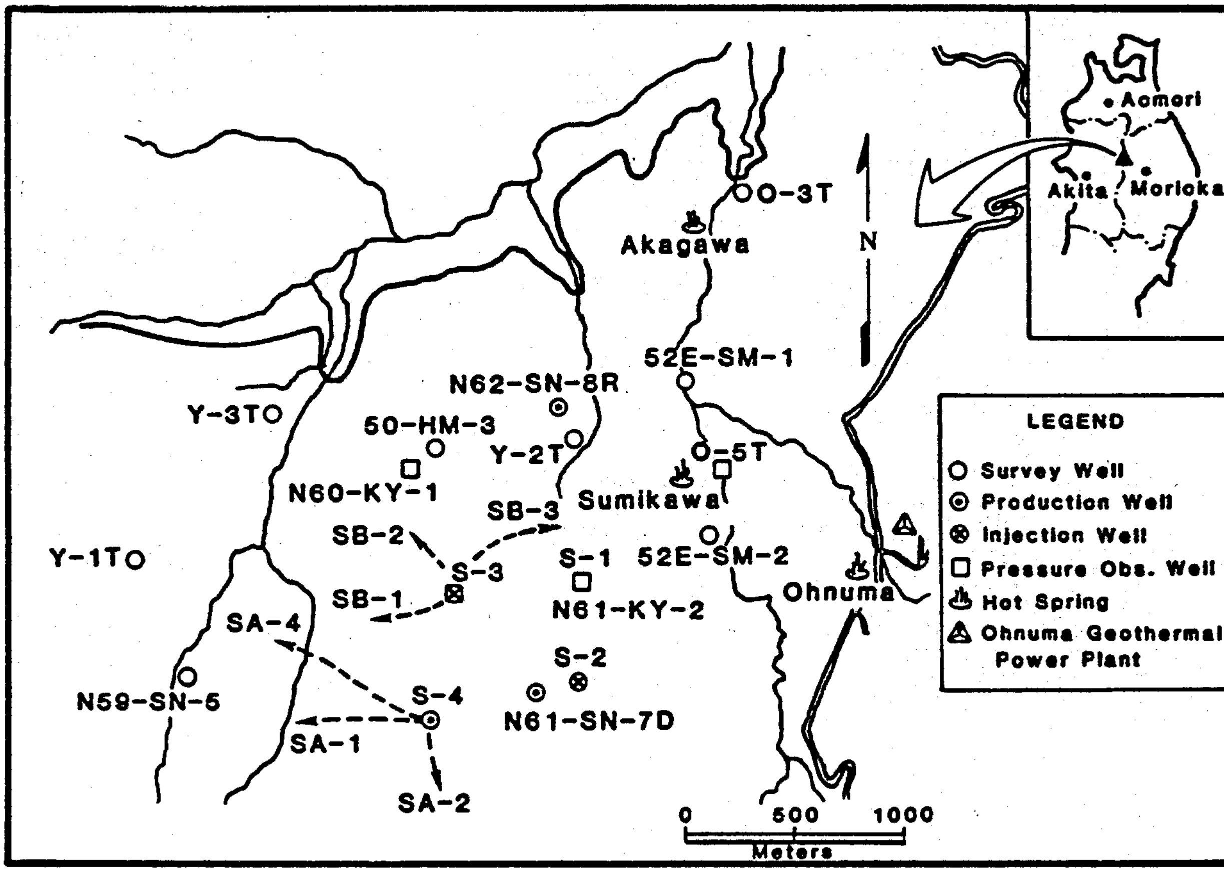


Figure 6. Map of the Sumikawa geothermal area.

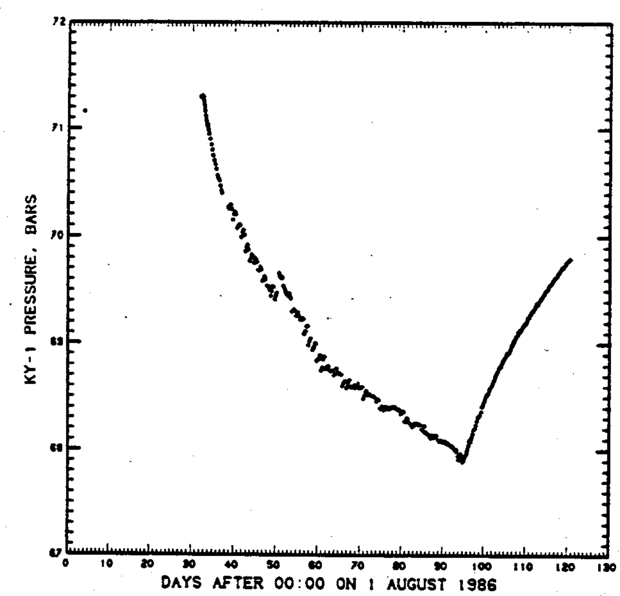


Figure 7. 1986 pressure interference signal in observation well KY-1.

Recently, additional pressure transient experiments have been performed. In autumn 1988, five wells (SA-1, SA-2, SA-4, S-4 and SN-7D) were discharged at various times and six wells (SB-1, SB-2, SB-3, S-2, SN-8R and KY-2) were used for reinjection at one time or another. Downhole pressure observations were made in wells SN-7D, S-4, S-3, KY-1 and KY-2. Analyses of the most recent tests are not yet complete; the results will be published in the near future.

MODELING STUDIES OF THE SUMIKAWA FIELD

An extensive computational effort using the "SING-2" numerical reservoir simulator is being carried out to try to understand the Sumikawa field in the natural state. Preliminary work was restricted to a two-dimensional vertical-section representation of the field to provide tentative estimates of the appropriate permeability distribution, boundary condition parameters, and so on. Then, the model was extended to three space dimensions and further refined. As new data is acquired, the model requires revision and upgrading. As discussed above, the development of each model involved an extensive series of calculations to attain adequate agreement between computational results and field measurements. Sensitivity studies have been carried out to try to estimate the reliability of the computational model. The best model developed so far reproduces observed temperatures and pressures reasonably well; Figure 8 compares computed and measured pressures in the central area of the field. The computational model will be further refined in the future as more field data become available.

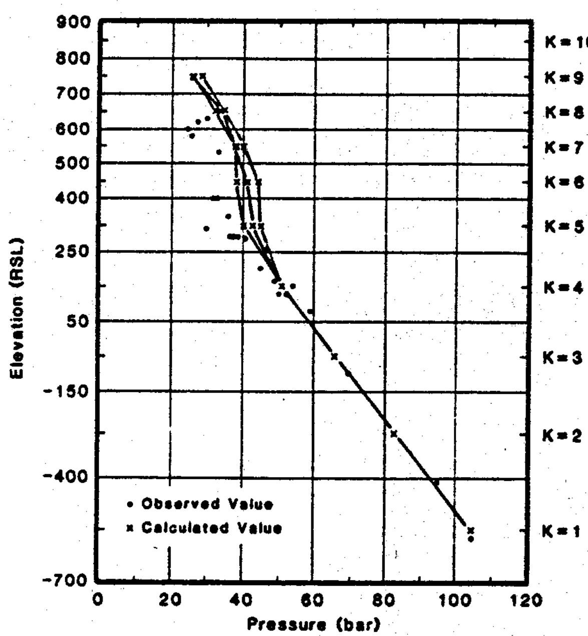


Figure 8. Observed and calculated pressure profiles in the Sumikawa field.

FUTURE PLANS

As discussed above, NEDO completed Phase I of the project in FY 1987 (ending March 1988) and initiated Phase II in FY 1988; the purpose of Phase II is to further examine a number of key issues raised during the Phase I effort. These include appropriate ways of dealing with fractured systems and the influence of incondensable gasses in the reservoir. Also, NEDO selected the Mori field in northern Japan as a new "model" field in 1988. The Mori system appears to be dominated by three major fault zones, and the fluid contains substantial amounts of CO_2 gas which has caused calcite scaling problems. Furthermore, a six-year production history is available for Mori, which permits reservoir studies to proceed beyond calculations of the natural state; history-matching calculations of the production phase will also be attempted. These calculations will incorporate representations for the effects of the fault zones and of the CO_2 gas in the system.

ACKNOWLEDGEMENTS

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