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THE DEVELOPMENT OF A COMPUTERIZED PRESSURE TRANSIENT TEST SYSTEM (PART 1)

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ABSTRACT

Since 1997, New Energy and Industrial Technology Development Organization (NEDO) has been conducting research to develop the technology to characterize and to forecast mass and heat flows useful not only for exploration but also for the characterization and management of geothermal reservoirs.

As part of this project, a computerized pressure transient testing system has been developed to improve well-testing techniques in order to characterize the fracture permeability within geothermal reservoirs. A software package for inversion analysis of pressure transient data, which would have been of help the interpretation of pressure data with a higher accuracy than traditional method have been developing.

A prototype pressure transient testing system in a completely pre-programmed manner was constructed and sinusoidal injection tests were carried out to check the operation of our system at the Hijiori geothermal field in 1998 and 1999. As a result of the field tests, it was confirmed that the system could successfully control injection rate and pressure in a prescribed manner. The problems to improve the prototype system for practical application were clearly recognized.

This paper will present recent results of the development of our pressure transient test system and related field tests in the Hijiori geothermal field, northeastern Japan.

INTRODUCTION

The pressure transient test is one of the more important methods for evaluating geothermal reservoirs. In many cases, geothermal reservoirs were managed according to the data based on pressure transient tests. However, it has often been pointed out that the data obtained by pressure transient tests could not be analyzed due to poor data quality and because field engineer were not often familiar with pressure data analysis and could not fix the problem during the test. The quality of information obtained from a pressure transient test depends, among other things, on the quality of the pressure and flow data. Inaccurate pressure and flow measurements will, in general, lead to inaccurate estimates of formation properties.

At present, conventional pressure transient testing methods of the petroleum industry have been adapted for characterizing fractured geothermal reservoirs. These methods provide useful general indicators of permeability, but inherent ambiguities in observed responses limit their ability to estimate fracture distribution, orientation and reservoir permeability. To solve these problems, computerized pressure transient testing system and a software package for the automated well test analysis with a high accuracy have been developed.

This system consists of a pressure-control tools with a feedback control system, downhole pressure and well temperature profile monitoring tools, numerous surface sensors (pressure, flow, temperature) and a computerized package which can interface with a test assisting software and a data interpretation software. We also plan to develop a computer support system, which can manage, guide and diagnose the well tests in order to obtain high quality data.

REVIEW OF EXISTING PRESSURE TRANSIENT TESTS

Through reviewing the existing data of pressure transient tests conducted in geothermal fields in Japan, the following problems were identified.

In many cases, conventional well tests have been carried out at a constant rate of injection for a short term usually by staff unfamiliar with theoretical aspects of well-test interpretation. The obtained data have been analyzed only by using type curve matching techniques or the Horner method, which often yield rather poor estimates of reservoir parameters.

By reviewing the pressure testing data, it became clear that pressure data were often contaminated with noise and spurious signals. The sources of noises were numerous and include the following:
(1) Undetected intermittent recording system failures,
(2) Incorrect settings of measurement system,
(3) Errors in instrument calibration,
(4) Insufficient thermal insulation / protection of the transducer,
(5) Water in capillary tubing (failure to purge),
(6) Poor choice of downhole sensor depth,
(7) Insufficient test duration
(8) Unexpected interference from nearby field operations.
These problems should be detected and corrected while the test is underway. Therefore what would appear to be needed is a computerized test system, which can control all the measurement apparatus.

Moreover it is advisable that a test system which uses the change of wellhead pressure causing rise and fall (vertical movement) of the water table in the well should also be improved so that a pressure transient test can be performed without damaging the production well due to cooling effect by cold water injection, and also it can be conducted in places where acquisition of water is difficult.

COMPUTERIZED PRESSURE TRANSIENT TESTING SYSTEM

Development of control system

After reviewing the existing data on pressure transient tests in the geothermal field in 1997, a fundamental computerized pressure transient test system was designed. The conceptual diagram of the pressure transient test system is shown in figure 1.

This system consists of two large components: one is on-site hardware called the data acquisition control system for pressure transient tests, and the other is data analysis software for pressure transient tests.

The main device is a personal computer (PC), called the pressure transient test controller (Figure 1-(2)). This PC controls all the equipment of this system. Peripheral measurement equipment consists mainly of a capillary tube type downhole pressure sensor (Figure 1-(6)), fiber optic temperature sensors (Figure 1-(7)), numerous kinds of surface sensors (Figures 1-(8), (9), (10), (12), (13)), a borehole sparker water level meter (Figure 1-(11)), pressurized devices (pumping-system, air compressor; Figure 1-(5)), and surface injection lines.

Pressure source generator

Most of the features of this system are computer-controlled pressurizing devices (Figure 1-(5)). These devices are driven with an inverter controlled electric AC (alternating current) motor. The rotating speed of the AC motor is determined by the inverter frequency, which is established through compliance with the completely pre-programmed manner.

The first step in developing this system was to develop the injection test system that controls the injection rate of water. The range of inverter frequency available is between 10 and 60Hz, though the actual injection rate is determined by pumping ability. One problem encountered was the difficulty in stable injection of water at a very low rate because the inverter controlled AC motor could not drive at an inverter frequency of less than 10 Hz. To control a very low rate of injection, a bypass line control system was introduced. Electric flow rate control valves (Figure 1-(4)) were located in the main and the bypass lines. The flow rate adjustment range of the injection pump of this prototype system was set from 50 to 500 l/min.

Borehole water level meter (Figure 1-(11))

In air pressure test, wellhead pressure is first increased gradually over several hours to 40bars. The increase in wellhead pressure results in lowering of the water table in the well and injection of a volume of water into the surrounding formation. Subsequently, the wellhead pressure is lowered to the ambient atmospheric pressure. The lowering of wellhead pressure results in an influx of water into the well, and a rise in the water level. In order to measure the water level precisely, a borehole water level meter has been developed. Comparing the performance of some kinds of water level meters, the water level meter using acoustic wave generated by a sparker showed the deepest measurable depth of 500 meters and the high resolution of 0.1meter. This method was chosen to develop.

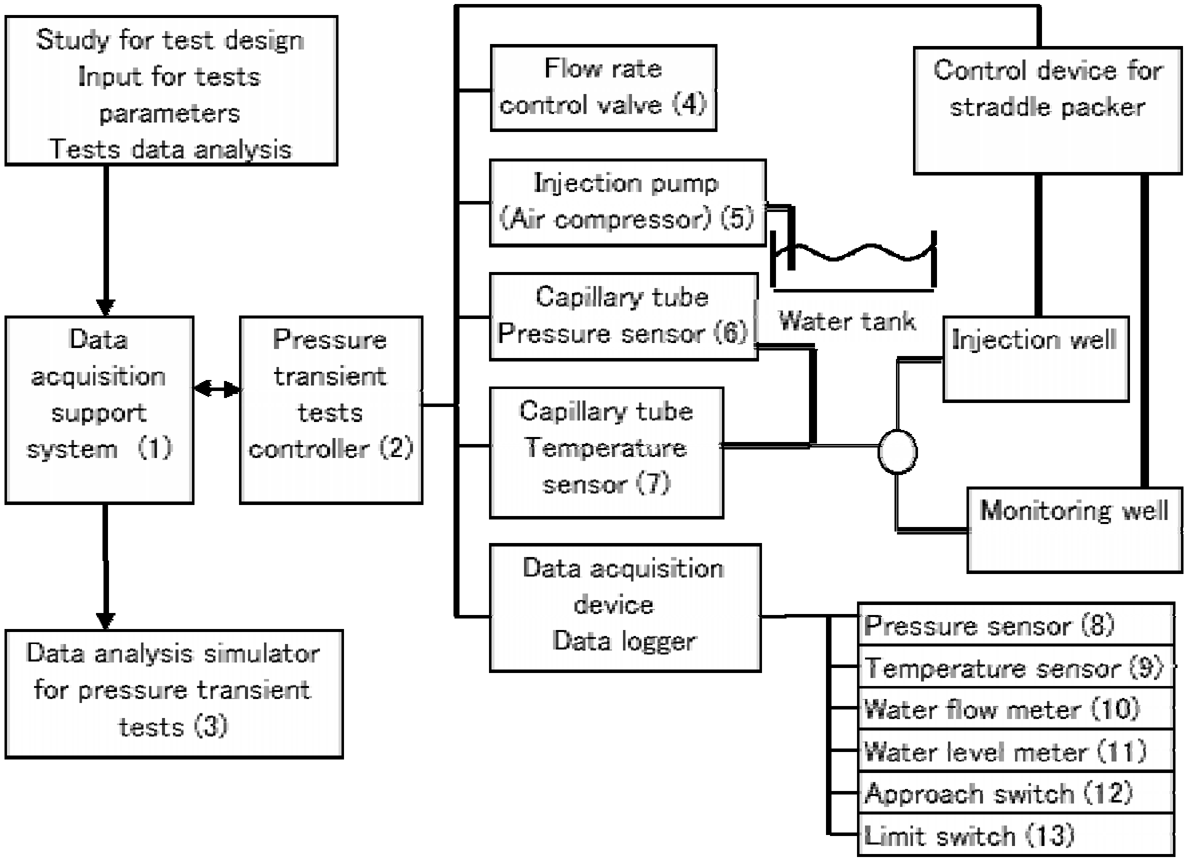

Figure 1. Concept of pressure transient tests controller unit

Temperature sensor / capillary type pressure sensor (Figures 1-(6), (7))

Downhole temperature and pressure were measured with the fiber optic temperature sensor and capillary tube type pressure.

Pressure transient tests control software

In the development of the injection pumping control, the main task involved creating the software package software that smoothly controls the flow rate.

In order to increase efficiency and safety of examination work, software with a dialog interface was chosen, and a learning function was added. MS Windows NT Workstation TM was adapted for the operational system of the well-testing control system.

Moreover, two PCs, which evaluate the hydrological properties of reservoir, were used for backup of measurement control, i.e. well-test controller PC and PC, which constitute a well-test supporting system. They were connected in a network and share hydrological parameters and measurement data.

Data analysis software

In general, the hydrological properties of fractures of the reservoir are evaluated based on the analysis solution method. To evaluate the hydrological properties in a geothermal reservoir, which can be non-isothermal and in a two-phase condition, inversion-analyzing methods using the numerical simulation and model fitting method were also investigated.

FIELD TESTS FOR THE PROTOTYPE OF THE PRESSURE TRANSIENT TEST SYSTEM

In 1998, a prototype of the above-mentioned computerized pressure transient test system was fabricated. An air-pressure test system is also being developed along with a water pumping system so that a pressure transient test can be performed without damaging or cooling the production well, and can be conducted in places where water acquisition is troublesome.

In 1999, the prototype system was constructed and the field operation test was carried out to estimate the performance of the various equipment, specifically the performance of the inverter-controlled pump. Three types of pressure transient tests - a sinusoidal test (injection water is controlled in sinusoidal pattern), stepped constant rates test and triangle air pressure pattern test - were conducted.

Experimental field

The Hijiori geothermal field is located in western Yamagata Prefecture, northeastern Japan (Figure 2). The field is known as the test site for the Hot Dry Rock (HDR) power generation system project conducted by NEDO (Tenma et al. 1997). Two fracture zones with high water permeability were created in the granodiorite zone, which underlies the Hijiori caldera at a depth of 1,500m or more. (Kitani et al., 1998).

Two wells, HDR-1 and HDR-2a were used for the field tests at the southern edge of the Hijiori caldera. HDR-1 was used as an active well and HDR-2a was used as an observation well. HDR-1 and HDR-2a were completed at depths of over 2km. The main fracture zone of HDR-1 is at a depth of 2,151m and those of HDR-2a are at depths of 1,802m and 2,205m. The injection test conditions are shown in Tables 1 and 2. The prefixed depths of the pressure sensors were 1,850m in HDR-1 and 2,000m in HDR-2a. During the injection tests, temperature and pressure were measured at intervals of five minutes and ten seconds, respectively. The air pressure test conditions are shown in Table 3

Table 1 Summary of injection tests in the Hijiori geothermal field (1998)

Stage	Injection Time (hour)	Total Injection (ton)	Max. Wellhead Pressure (bar)
Stage 1	**0.5**	**13.5**	**41.0**
Stage 2	**2.0**	**48.0**	**40.0**
Stage 3	**1.0**	**21.0**	**39.0**
Stage 4a	**1.0**	**21.0**	**22.0**
Stage 4b	**5.0**	**105.0**	**34.0**

Table 2 Summary of injection tests in the Hijiori geothermal field (1999)

Stage	Injection Time (hour)	Total Injection (ton)	Max. Wellhead Pressure (bar)
Stage 1	**3.0**	**30.0**	**30.0**
Stage 2	**5.0**	**66.0**	**30.0**
Stage 3	**7.5**	**51.0**	**30.0**
Stage 4	**7.5**	**97.0**	**30.0**
Stage 5	**5.5**	**98.0**	**30.0**
Stage 6	**7.0**	**133.0**	**30.0**

Table 3 Summary of air pressure tests in the Hijiori geothermal field (1999)

Stage	Max. Wellhead Pressure (MPa)	Max. Differential of Water Levels (m)
Stage A	**2**	**233**
Stage B	**3**	**367**
Stage C	**1**	**97**
Stage D	**3**	**352**
Stage E	**4**	**483**

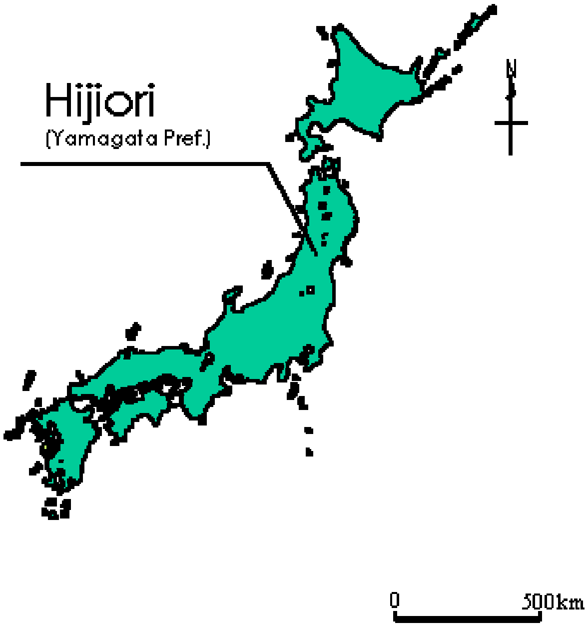

Figure 2 Location of the Hijiori geothermal field

RESULT

In sinusoidal injection tests (cycles of 1 - 4 hours) and stepped constant rate tests, sufficient injection patterns were obtained, which proves the feedback control system of the water flow rate was adequate (Figure 3). However, injection control was sometimes unstable as a result of a control valve switching.

The triangle pressure pattern test, using a controlled air compressor, also provided good performance and a maximum water level change of about 480m could be produced (Figure 4).

Since the pressure data in the HDR-2a observation well contained excessive noise, it is difficult to pinpoint the exact pressure.

Since condenser capacity is quite low for detecting water level signals, a fiber optic sensor was adopted to measure the water level. Moreover, it became clear that multi-reflection filtering processing is required in areas where the water is greater than 20m deep.

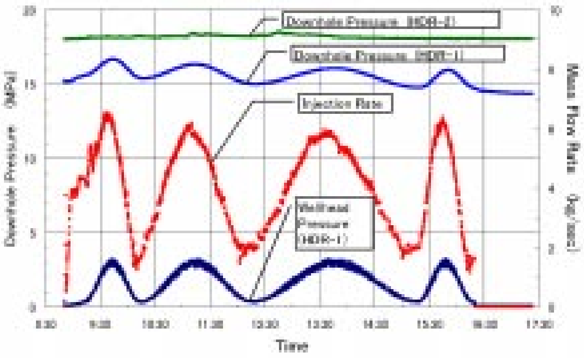

Figure 3 Record of water injection tests in the Hijiori geothermal field.

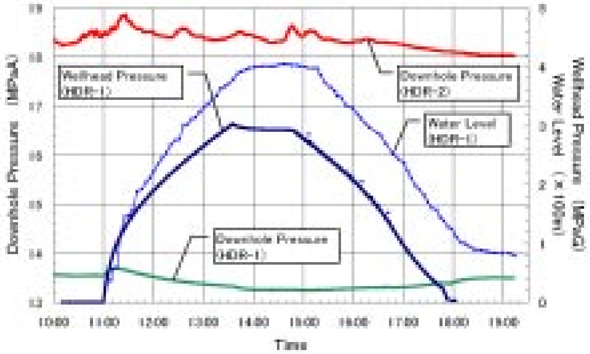

Figure 4 Record of air pressure tests in the Hijiori geothermal field.

CONCLUDING REMARKS

The purpose of this research task was the development and performance testing of a computerized pressure transient test system. A prototype of a computerized pressure transient test system was verified to approximate the desired specifications. Our system was further confirmed to be capable of controlling a large amount of injection fluid within a prescribed flow pattern. The development of simplified, accelerated reservoir simulators, suitable for modeling geothermal reservoirs in real time, has proceeded satisfactorily.

There remain, however, issues to be resolved;

In order to conduct pressure transient tests safely and efficiently, it is necessary to construct a database on geology and well information that will be a useful tool to support data analysis of wells.

In order to stabilize flow rates, the inverter circuit in the injection control system must be revised.

In order to measure water level precisely in a wellbore, the sparker water level meter necessitates modification. In particular, it must be waterproof, temperature resistant, and easily handled, while a noise-filtering function must be added.

The air pressure system must be revised through field operation tests in various geothermal fields in order to obtain more accurate data.

In order to analyze pressure data faster and more efficiently, an efficient hybrid inversion method combining the full Newton and annealing methods must be developed.

As geothermal fluid contains many chemical elements, functions to treat fluid including NaCl and CO_2 must be added in the developed numerical simulator.

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REFERENCES

Kitani, S., Miyairi, M., Tezuka, K. and Yagi, M. (1998), Geological structure in and around Hijiori HDR test site, *Proceedings of 4th International Hot Dry Rock Forum*, Strasbourg, Sept., 28-30.

NEDO, (1997) Development of Technology for Reservoir Mass and Heat Flow Characterization Theme 1: Characterization of Hydrological Properties of Fractures, New Energy and Industrial Technology Development Organization, Tokyo, Japan (in Japanese with English abstract).

NEDO, (1998) Development of Technology for Reservoir Mass and Heat Flow Characterization Theme 1: Characterization of Hydrological Properties of Fractures, New Energy and Industrial Technology Development Organization, Tokyo, Japan (in Japanese with English abstract).

Tenma N., Ikawa T., Nagai M., (1997), Productivity of a Recent Three-well System at Hijiori HDR Test Site, *Proceedings of 23rd Stanford Workshop on Geothermal Reservoir Engineering*, 191-194.