High Temperature (400°C) Fluid-Density Logging Tool and Application in Resolving an Unstable Production Mechanism of the Well in Uenotai Geothermal Field in Japan

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Keywords

Fluid-density, memory tool, PTSD, unstable production, Uenotai geothermal field

ABSTRACT

The high temperature fluid-density tool has been developed by JAPEX Research Center under funding by the New Energy and Industrial Technology Development Organization (NEDO) of Japan. The tool is designed to work at temperatures up to 400°C. Since the tool contains a memory chip to store the measured data, it does not require conductor cables. Thus, it is easy to combine with other logging tools, such as PTF production logging tools.

The fluid-density tool was used to evaluate an unstable production mechanism in the well, which showed periodic fluctuations in the well head pressure and production rate. Integration of temperature, pressure, flow-velocity and fluid-density data obtained from stationary surveys conducted above and below the production zones showed that the mechanism of unstable production to be the periodic boiling of hot water inside the borehole below the feed zones. The identification of the mechanism allowed remedial action to be taken. The bottom-hole interval below the feed zone was plugged by sand and cement. The workover succeeded not only in restoring stable production but also served to increase the amount of steam production.

Introduction

New Energy and Industrial Development Organization (NEDO) started the research program "Development of Drilling and Production Technology for the Deep-seated Geothermal Resources" in 1992. The aim of this program is to evaluate the possibility of utilizing deep hydrothermal fluids and to develop various kinds of fundamental supporting technologies. Production logging of a well whose bottom hole temperature reaches 400°C was one of the important issues for this program.

Pressure, Temperature and Flow logging is widely used in geothermal wells (Davarzani. and Sloan, 1989; Miyairi and Sorimachi, 1996). These three parameters are generally recognized as the most important physical properties for evaluating the performance of production wells. However, an additional parameter, fluid-density, is also required for comprehensive evaluation in situations where two-phase flow is dominant in the reservoir. Fluid-density is necessary to calculate enthalpy of the fluid in two phase flow interval in a well. JAPEX Research Center succeeded in development of high temperature fluid-density logging tool through the NEDO research program.

In this paper, we first introduce the fluid-density tool developed, then report the successful use of this tool to resolve the mechanism behind an unstable production behavior of the well in Uenotai geothermal field, Akita, Japan.

High Temperature Fluid-Density Logging Tool

Method: The schematics and specification of the tool are shown in Figure 1, overleaf, and Table 1, respectively. The principle of the fluid-density measurement is the same as that of conventional γ-γ fluid-density tools used in oil wells (Verdier, 1986). Cs-137 with intensity of 3.7 MBq (100μCi) is used for the γ-ray source.

Table 1. Specification of memory type high temperature fluid-density tool.

Maximum Outer Diameter:	56 mm
Length	2,390 mm
Weight	30 kg
Maximum Operating Temperature:	400°C
Maximum Operating Pressure:	48 MPa
Operating Time at Max. Temperature:	6 Hours
Logging Cable:	Non-conductor Cable
Memory Capacity:	2 MB
Sampling interval:	0.1~60 sec
Measurement Range:	0 ~ 1.25 g/cm3
Sensor Type:	Gamma-ray detector with Cs-137 (3.7MBq) source
Seal mechanism:	Metal "O" ring

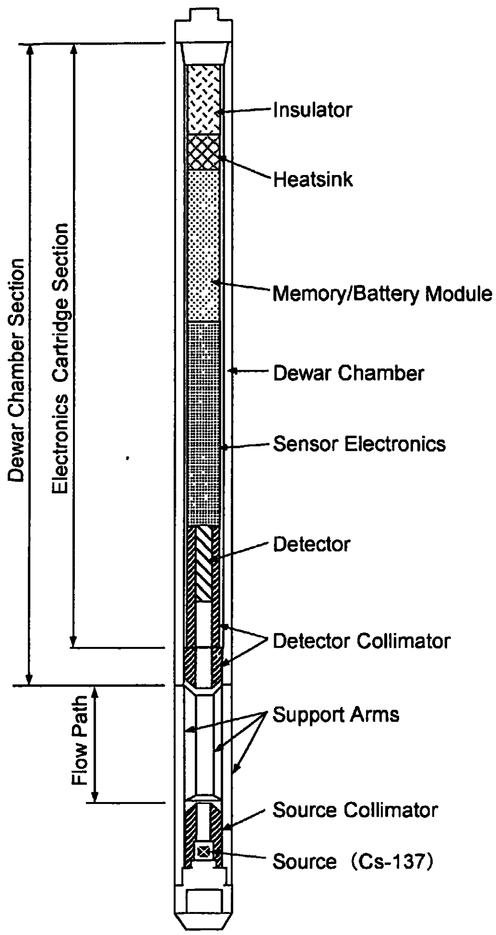

Figure 1. A schematics of high temperature (400°C) fluid-density logging tool.

The γ-rays radiated from the source are scattered and attenuated when they propagate through the flow path where borehole fluid can go through. The degree of attenuation is logarithmically proportional to the fluid-density in the flow path. Figure 2 shows a good linearity between fluid-density and count rate in logarithmic scale. The intensity of the source, which is approximately one hundredth of conventional γ-ray sources used in oil wells, is so small that handling of the source is not controlled by a regulation in Japan.

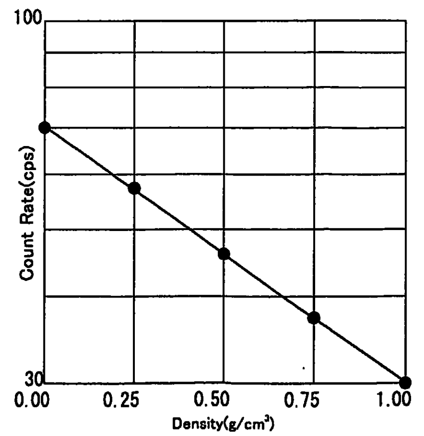

Figure 2. Relationship between fluid-density gamma-ray count rates in logarithmic scale. The relationship shows a good linearity.

Memory system: The fluid-density tool records count rate of transmitted γ-rays and temperature inside the heat insulation chamber. The data acquired are stored in a memory chip which has enough capacity for 10-hours of continuous recording with 1 second sampling of all channels. The tool also includes a battery module for power supply, thereby eliminating the need for electrical conductors in the logging cable. A personal computer (PC) at the surface records depth signal from a winch unit with time stamp. The memory tool records data with the same time stamp as well. After logging is completed, the data set is down loaded from the memory, and converted to a depth series by referring to the depth data set recorded by the surface PC.

Heat Protection System: The high temperature performance is realized by incorporating a specially designed heat protection system. The γ-ray detector, the memory chip, the electronics circuit, and the power supply battery are all protected by the double heat insulation chambers which are designed to keep the inner temperature below 120°C during 6 hours of operation in a 400°C environment. Figure 3 shows the heat insulation capability. The solid line is for outside temperature and the dotted line is for inner temperature. Inner temperature is maintained below 70°C for 3 hours after outer temperature reached 400°C.

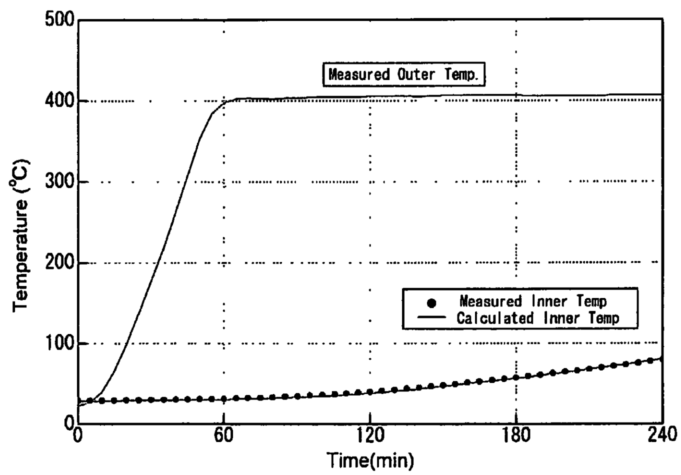

Figure 3. A capability of the double heat insulation chambers. Inner temperature is maintained below 70°C for 3 hours after outer temperature reached 400°C.

Combination with PTF tools: The fluid-density tool usually functions as a part of the high temperature PTFD system in combination with memory type Pressure-Temperature -Flowmeter probes, as shown in Figure 4. Since the memory tool does not need conductor cable, it is easy to combine with other logging tools. Each tool is only mechanically connected with each other. The fluid-density tool can also be combined with other logging tools, such as the conventional conductor cable type PTF tools through simple mechanical connections.

Performance: Figure 5 is typical profile of PTFD logging data. The flashing point is clearly seen by the flow-velocity profile. Temperature and pressure profiles also confirm the flashing depth. Fluid-density is relatively low in the two phase zone and high in liquid phase zone. The value of the density in the liquid zone is

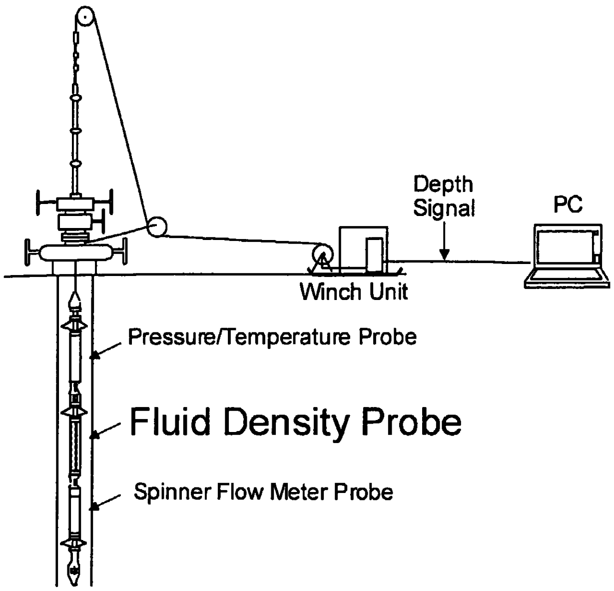

Figure 4. A schematics of fluid-density logging combined with memory type Pressure/ Temperature/ Flowmeter tools.

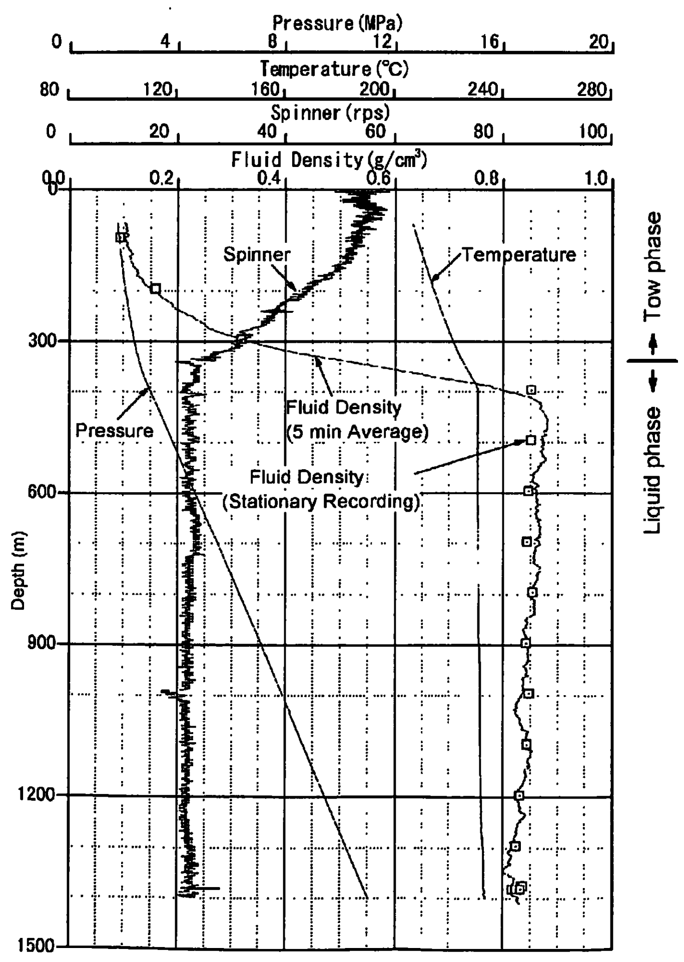

Figure 5. Pressure, temperature, spinner (flow-velocity) and fluid-density profiles measured in geothermal production well.

consistent with the theoretical values calculated from temperature and pressure data (square symbols). The phase change at the flashing point is also clear in the density profile. Through more than ten field tests, the performance of the tool, including mechanical strength, heat insulation capability and reliability of the measured data, has been verified.

Application in Uenotai Geothermal Field in Akita, Japan

Background: Well T-52 was drilled to a depth of 2,013 m and has been providing geothermal steam to the 25 MW Uenotai geothermal power plant in Akita Prefecture, Japan, since the plant was commissioned in 1993. However, the borehole had a problem of unstable production behavior, that is, the well head pressure and enthalpy drop periodically at intervals of around 70 minutes. Because of this behavior, wellhead pressures periodically fell below the production header pressure, so that the well was periodically unable to supply the power plant (Iwata, et al., 2002). This was recognized as a typical characteristics of a well intersecting multiple production zones with different production potential. However, it was difficult to evaluate the performance of each production zone quantitatively, because two phase flow dominated in the reservoir intervals. The fluid-density tool combined with a memory type PTF tool was used to investigate the mechanism of unstable production behavior.

Production Profile: Figure 6, overleaf, is a depth profile obtained during the first down survey. From the spinner data, the production zones are evaluated at 1460m (Zonel) and 1429m (Zone2) depth. These two zones are considered to contribute most of the production. Fluid-density data shows that the fluid is in two phase just above the lower production zone. That means the steam is coming out from the formation.

Cyclic Fluctuations: After identifying the production zones, we tried to monitor the changes in time at three different depths. The top depth (1400m) is above the upper production zone. The middle depth (1440m) is between the two major production zones. The bottom depth (1496m) is beneath the lower production zone. We monitored the changes in fluid condition by stationary survey at each depth for 3 hours, which covers approximately two cycles of the periodic fluctuation. Figure 7, overleaf, is a time series of the data measured at 1496m, which is beneath the lower production zone. At steady state the temperature, pressure and fluid-density are almost constant. The fluid-density indicates that the fluid is in liquid phase. Spinner flowmeter shows that there is no flow. During the fluctuated period, temperature and pressure rise up and the spinner starts to rotate. If it is assumed to be hot water, it is not clear how to explain this phenomena. However, if fluid-density data is introduced, it becomes very clear. During the fluctuated interval, the fluid-density decreases rapidly to around 0.05 g/cm^3, which means the fluid in liquid phase changes to two-phase.

Enthalpy Changes: Using temperature, pressure and fluid-density data, the enthalpies of the fluid were calculated. The calculated enthalpy curve in the Figure 7 indicates the fluid-enthalpy increases at the fluctuated period at 1496m depth. In the same way, fluid enthalpies at the other two depths are calculated. Figure 8 summarizes the changes in the enthalpies at three differ-

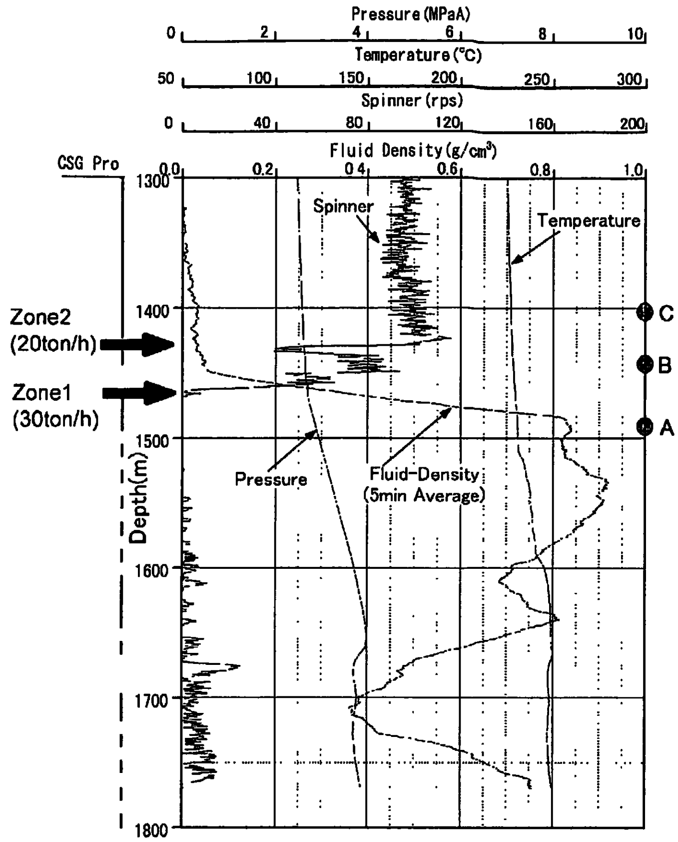

Figure 6. Pressure, temperature, spinner (flow-velocity) and fluid-density profiles measured in a well of unstable production behavior. Zoen1 and 2 are evaluated production zones. Points A, B and C denote depths for stationary recording.

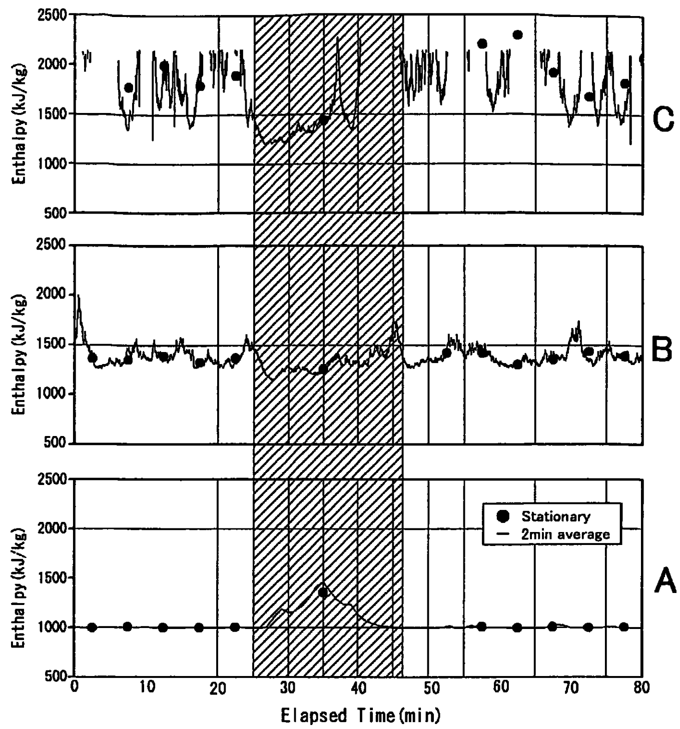

Figure 8. Enthalpy changes at three different depths. At the point A, below the production zones, the enthalpy increases significantly at the fluctuated period before. However, the enthalpies decrease at the point B and C, which are between and above the production zones.

ent depths. At the depth below the production zones (1496m), the enthalpy increases significantly as mentioned before. However, at the depth above the production zones (1400m) and between the production zones (1440m), the enthalpies decrease.

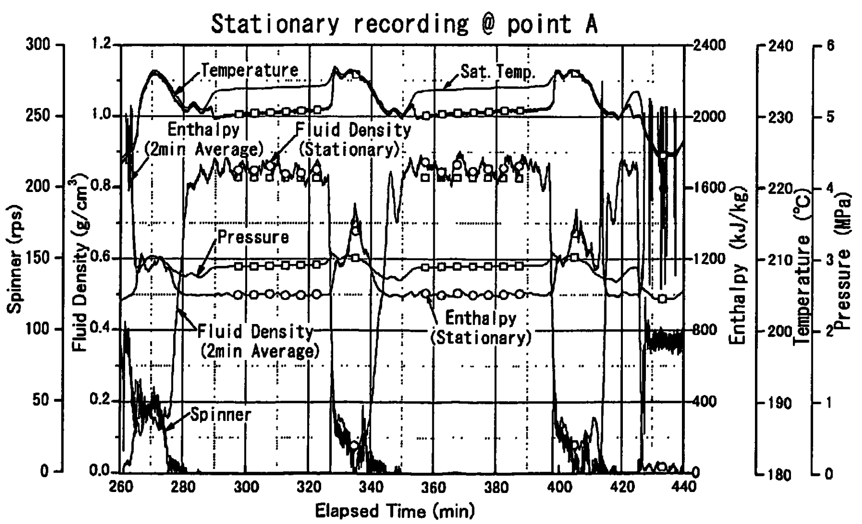

Figure 7. Pressure, temperature, flow-velocity and spinner (fluid-density) in time series measured at point A (1496m), which is beneath the lower production zone. Calculated enthalpy is over plotted.

Interpretation: We tried to explain this phenomenon by focusing on the enthalpy changes. Figure 9 illustrates interpreted profiles in the borehole. As the production rates at each production zone is known and the enthalpy at the three points are also known, we can calculate the enthalpy of the fluid flowing from each production zone. The calculated enthalpies of producing fluid at both steady state period and fluctuated period are listed in the Figure 8. The calculated enthalpy of the producing fluid from the upper production zone is 2730 kJ/kg and that of lower zone is 1430 kJ/kg. The fluid from the upper zone has much higher enthalpy than the fluid from the lower zone.

Then we estimated the flow rate at the fluctuated period, assuming that the enthalpy of producing fluid at each production zone does not change but the production rate changes. The results are illustrated in Figure 9. The production rate from upper zone decreased to 7 ton/h from 20 ton/h, while the production from lower zone does not change so much. A significant change is the production from the deeper part where no production zones are estimated. During the steady state period, there is no flow, but during the fluctuate period, 22 ton/h of fluid is coming up. The enthalpy of the fluid is estimated to be 1350kJ/kg, which is higher than the original condition but lower than that of production fluid from two production zones.

Discussion and Remedial Action: This phenomenon is like an eruption. The eruption of lower enthalpy fluid decreases the enthalpy of total produc-

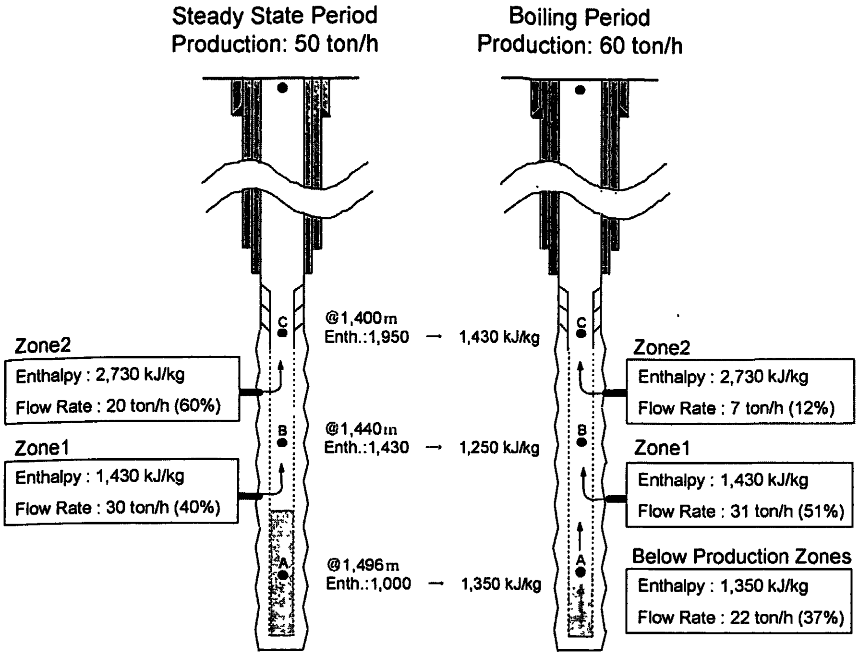

Figure 9. Interpreted profiles in the borehole. The production rate from the zone2 decreased to 7 ton/h from 20 ton/h, while the production from the zone1 does not change so much. A significant change is the production from the deeper part where no production zones are estimated. During the steady state period, there is no flow, but 22 ton/h of fluid comes up during the fluctuate period. The enthalpy of the fluid is estimated to be 1350, which is higher than the original condition but lower than that of production fluid from two production zones.

tion fluid. And this low enthalpy fluid increases the pressure in the borehole and eventually suppressed the production from the upper production zone. This might be the mechanism of unstable production behavior of this well. This mechanism may arise because a 500 m non-productive but high temperature interval below the feed zones acted as a natural boiler. Eruption of the low enthalpy boiling fluid from the boiler suppressed the steam production from the reservoir. Identification of the mechanism allowed remedial action to be taken. The bottom-hole interval below the feed zone was plugged using sand and cement and workover succeeded in restoring stable production. It also served to increase the amount of steam production.

Conclusions

A high temperature memory type fluid-density logging tool has been developed. The performance of the developed tool has been verified through field experiments. Fluid-density data was effectively used for evaluating the mechanism of unstable production behavior of a geothermal well. Identification of the mechanism allowed remedial action to be taken. Fluid-density is an indispensable parameter for comprehensive evaluation in situations where two-phase flow is dominant in the reservoir.

Acknowledgment

This study is a part of NEDO (New Energy and Industrial Development Organization) research program "Development of Drilling and Production Technology for Deep-seated Geothermal Resources". The authors would like to thank NEDO and Akita Geothermal Energy Co., Ltd. for permission to publish this paper.

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