DEVELOPMENT OF WELLBORE SIMULATOR AND HIGH TEMPERATURE PTS+FLUID SAMPLER LOGGING SYSTEM FOR A HIGHLY DEVIATED WELL

Masashi Kato[1], Takashi Okabe[1], Satoshi Ujyo[1], Russell Kunzman[2]

[1]Geothermal Energy Research & Development Co., Ltd., 1-22-4, Shinkawa, Chuo-ku, Tokyo 104-0033 Japan

[2]Thermochem, Inc., 3414 Regional Parkway, Santa Rosa, California 95403 USA

kato@gerd.co.jp

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ABSTRACT

An R&D project funded by the Japanese Ministry of the Environment on geothermal well drilling technology is under way. The purpose of the project is to develop an environmentally-friendly low-cost drilling technology for highly deviated wells (approximately 2,500m deviation and 70 degree inclination) in order to access high-temperature geothermal resources inside national parks in Japan, where they are often found, from well-pads outside the parks. In the course of the project, a wellbore simulator and PTS+fluid sampler system with roller centralizers were developed.

A wellbore simulator applicable for a highly deviated well (HDW) was developed to compare steam flow rates with drilling costs for different well deviations. The drift-flux correlation was identified as most suitable for these wells, and integrated into the existing GFLOW wellbore code to simulate the HDW. We compared this correlation with one developed for nearly vertical wells (Orkiszewski-correlation). We found that the Orkiszewski-correlation overestimated pressure losses and underestimated flowrates for the HDW. The wellbore simulator was used to estimate the optimal drilling direction that maximized the economic return from the well.

In order to evaluate productivity of the HDW, roller centralizers were added to a PTS/two-phase sampler logging tool. The tool can acquire simultaneously PTS data and collect fluid samples. The pressure and temperature specifications are maxima of 34.5MPa and 350 deg.C, respectively. The capacity of the sample chamber is 500 mL and the sampler can acquire brine, vapor and/or two-phase fluid. The tool was tested with the roller centralizers in a geothermal well in Japan. PTS data and fluid samples were successfully collected simultaneously. Because of the roller centralizer, we found that the tool up-and-down behavior was very smooth and the spinner data quality was excellent because the tool was properly centralized in the hole.

In this paper, the development of a combined wellbore simulator and the PTS+fluid sampler system are presented in detail.

1. INTRODUCTION

The R&D project of the Japanese Ministry of the Environment, “CONTROL SYSTEM FOR DRILLING GEOTHERMAL WELLS AT HIGH ANGLES OF DEVIATION IN NATIONAL PARKS”, is aiming to develop a low-cost control drilling technique for a highly deviated geothermal well whose inclination and deviation are approximately 70° and 2,500 m, respectively. As a part of the R&D, a wellbore simulator will be developed in order to understand the production characteristics in the highly deviated well and to help optimize the casing program. Also, in order to conduct formation evaluations of the highly deviated well, an economically feasible logging system, which can descend under its own weight even into the highly deviated well, is being developed.

There have been many wellbore simulators developed (ex. Freeston and Hadgu, 1988; Iwai and Furuya, 1995; Takahashi, 1999), and various methods (correlations) for calculating the relative flow rate between the vapour and liquid phases have been applied. We have developed the GFLOW wellbore simulator based on GWELL (Aunzo et al., 1991), whose source codes are available to the public (Kato et al., 2001). In GFLOW, the following equations, functions, etc. are added to the existing correlations of Orkiszewski: Miller's correlation (1980), CO_2 and NaCl simultaneous processing function, super-critical area calculation function, and a user interface (Kato et al., 2001). For a highly deviated well (HDW), the applicable correlation equation is not included in GFLOW, and this may create an error in the pressure loss calculation. Thus, in order to develop a wellbore simulator applicable to the HDW, the introduction of a Drift flux model has been studied. The Drift flux model has been adopted by Chevron Geothermal to eliminate the discontinuity that would otherwise be observed in calculation of the flow where the flow pattern varies (Peter and Acuna, 2010), but this model has not been studied in terms of its application to a HDW. An important application of such a wellbore simulator is help to optimize the casing program for the HDW in terms of cost and steam flow rate and to evaluate the economic efficiency of the HDW; however, few studies exist on such functionality.

Techniques or tools such as Logging while Drilling (LWD), coil-tubing, and tractors can be utilized in logging HDWs, but such techniques and tools are expensive. This R&D effort is aiming to develop a low-cost drilling technique for HDWs, low-cost formation evaluations, and an economical logging system, which can descend under its own weight into a well of 70-degree deviation by making use of a roller centralizer.

In this paper, the development status of the wellbore simulator and the performance of the production logging system for HDWs are presented. Note that the outline of this project is going to be given in another presentation in this workshop.

2. IMPROVEMENT OF WELLBORE SIMULATOR (GFLOW)

2.1 Investigation of Drift flux model

The configuration of a highly deviated well (HDW) is not sufficiently taken into account in the correlation equation adopted in the present GFLOW. Therefore, both the fluid velocity and pressure loss in the HDW may be calculated as being higher than the actual situation. In order to allow GFLOW to apply to HDWs, the correlation equation to be used in the Drift flux model is investigated. The Drift flux model is formulated by introducing the difference between the total volumetric rate of flow and vapor phase velocity, or between the total volumetric rate of flow and liquid phase velocity; or, in other words the model is formulated by introducing the drift velocity in each phase. The Drift flux model has the following features:

1. When the fluid phase velocity is low, the model can represent counter flow in which flow direction is opposite between vapor phase and fluid phase.
2. The model can support more precise analysis of the two-phase flow regime.
3. The model can handle non-steady flow in a production well. Since the equations in the model are continuous and differentiable it can be coupled with a geothermal reservoir simulator.
4. The experiment has been carried out at an angle as small as the horizontal with water/gas or oil/water, and the parameters to be used in the model have been precisely determined (Shi et al., 2005).

2.2 Evaluation of Drift flux model

The Drift flux model is compared with a model that does not support the HDW (a model supporting a well with small deviation). Figure 1 shows a cross sectional view of the well and calculation conditions used in the model, Figure 2 shows the comparison of calculation results, and Figure 3 shows the comparison of production output curves. This comparison of calculation results shows that the pressure loss is small in the Drift flux model but large in the model supporting the well with a small deviation, implying that the well capacity could be underestimated. This is because the highly deviated well is less influenced by buoyancy than are nearly vertical wells, and the velocity in the highly deviated well is relatively slow.

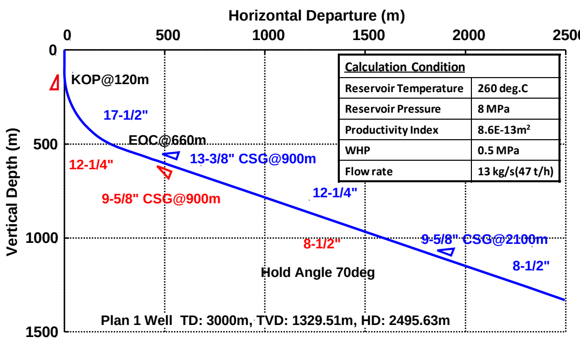

Figure 1: Cross sectional view of directional drilling path and calculation conditions used in model calculation

The model accuracy was evaluated for a well having a small deviation using -actual data. It was verified that in nearly vertical wells the Drift flux model has a calculation accuracy almost identical to that of a model of a well with a small deviation (Figure 4).

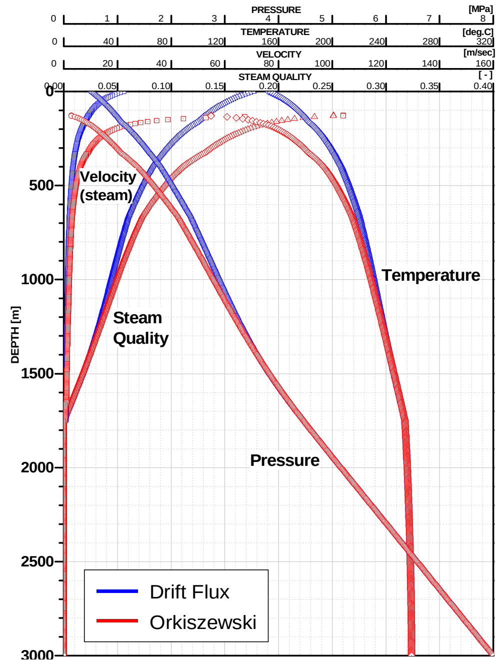

Figure 2: Comparison of calculation results

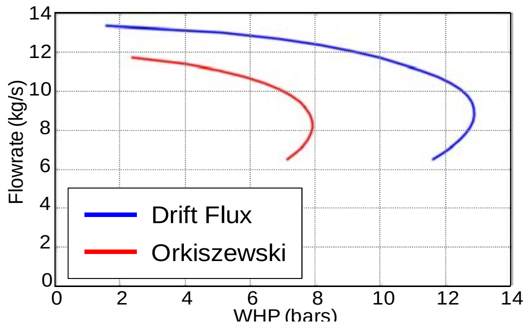

Figure 3: Comparison of production characteristic curves

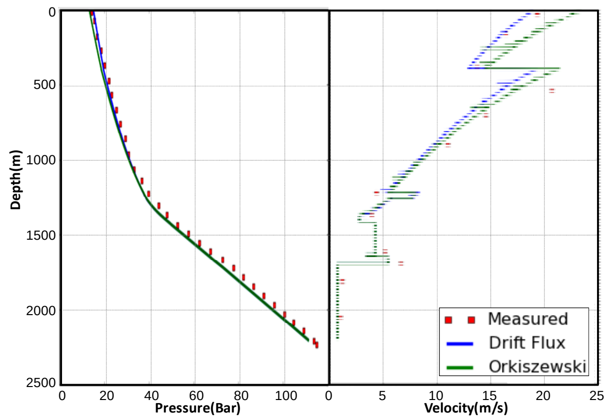

Figure 4: Comparison between the drift flux model and Orkisewski with using actual data

2.3 Casing program optimization

The cost effectiveness (drilling cost/production rate) of well drilling is not simply proportional to the hole diameter or well length, and there exists an optimal point in terms of both of production and drilling cost (NEDO, 1998).

In order to optimize the casing program for a possible new well, a study has been carried out with the new wellbore simulator. In the study, it is assumed that a well is drilled at high deviation into a national park. The well is drilled from the lower-temperature area outside of the park toward the high-temperature area inside the park (Figures 5 and 6). In the area used in this study, a geothermal deviated well (Well A; Measured depth = 1,750 m, Maximum inclination = 48.5°, and Deviation = 984 m) has already been drilled toward the inside of the park and the well is producing steam, which allows comparison between the simulation results and actual data (steam flow rate and other data).

The trajectory of the existing well (Well A) is slightly offset from the center of the heat source, but in the simulation the well is drilled toward the center. The well used in the simulation is assumed to have a 9-5/8" casing installed from the ground surface to 2,000 m deep and a 7" slotted liner installed below 2,000 m, and the well length is varied from 2,500 to 3,000 m (L). The maximum deviation of the well in the simulation is approximately 2,500 m. In addition 100% of the inflow is assumed to come from the bottom hole, and the bottom hole pressure in each simulation case is determined based on the vertical depth assuming that the water level is constant. The kick off depth is set to 200 m, and the final inclination is varied from 20° to 70°. In this case study, the PI (Productivity Index) is varied from 7.41E-14 to 1.39E-13 m^3, taking into account the finding that the permeability of the wells surrounding this area tends to be smaller with increasing depth (NEDO, 1990).

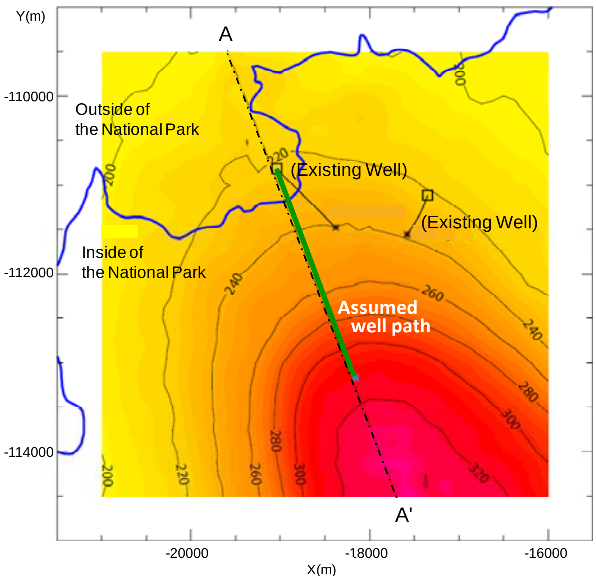

Figure 5: Temperature horizontal distribution at Japanese geothermal area and assumed directional drilling path

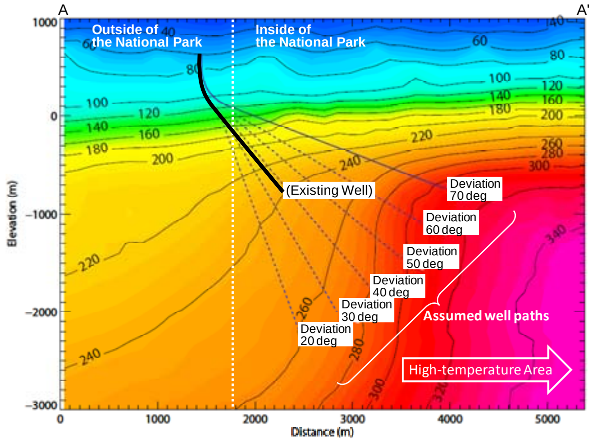

Figure 6: Temperature vertical distribution at Japanese geothermal area and assumed directional drilling path

Figure 7 shows the bottomhole temperature distribution used in the calculation. As shown in this figure, the temperature reaches its peak when the well inclination is 65° at the well length of 3,100 m. On the other hand, it is found that the best cost effectiveness in terms of steam flow rate and drilling cost is achieved when the well inclination is 60° at the well length of 3,100 m (Figure 8). The steam flow rate at this optimal point is about 1.7 times higher than that for the existing production well (Well A). Note that the steam flow rate in Well A, which is drilled from the outside toward the inside of the park, is also about 1.7 times higher than the average steam flow rate in the other production wells within this area. Based on these observations, the expected production steam flow rate at the optimal point will be about 2.9 times higher than the average steam flow rate in the other production wells within this area.

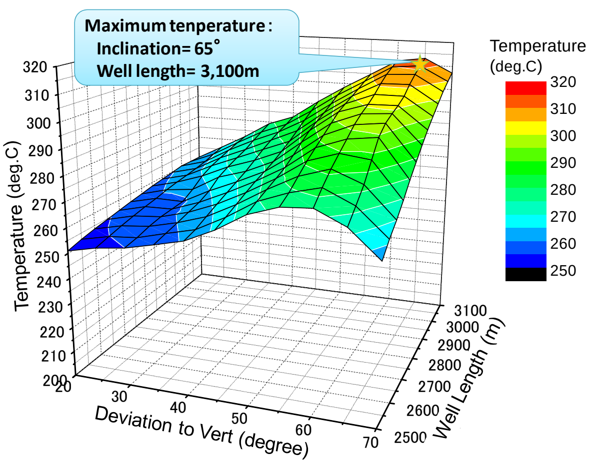

Figure 7: Bottomhole temperature distribution used in the calculation

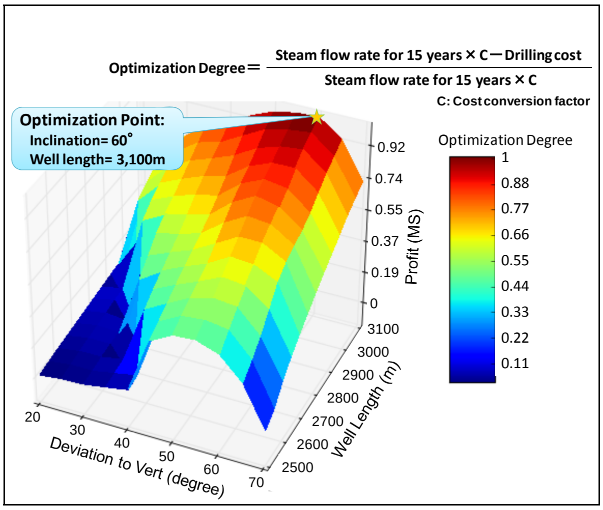

Figure 8: Optimal point in terms of steam flow rate and drilling cost

3. DEVELOPMENT OF THE LOGGING SYSTEM FOR HIGHLY DEVIATED WELLS

Logging by wireline is naturally restricted to well inclinations of up to 65° (Spreux, 1988). And also production conditions make it more difficult for a logging tool to descend. In this R&D effort, roller centralizers were added to a PTS/two-phase logging tool in order to conduct formation evaluations of the HDW.

3.1 Outline of the logging system

To evaluate the production performance of the HDW, a production logging tool capable of measuring pressure (P), temperature (T), flow rate (S) and fluid chemistry (by sample collection) will need to be used. We added roller centralizers to the PTS / two-phase sampling tool to allow the tool to descend smoothly into the HDW. The roller centralizer is designed such that 1) centering of the tool is secured even in the HDW (Optimization of the spring strength), 2) the tool does not get stuck in the slots of the liner (Adjustment of the roller thickness), and 3) the tool can smoothly descend through the liner hanger section (step section) of the casing (Drivability of roller section). In consideration of production phase operations, the strength of the section connecting the tool and centralizer is reinforced. The roller centralizer is composed of five arms, and the spring strength of the arms is adjustable. Two rollers are mounted on each arm, whose size can be modified.

Figure 9 illustrates the outline of the production logging system for the HDW.

The logging tool consists of PTS and sampler sections. The diameter of the PTS section is 59.4 mm, with a total length of 2,210 mm and a weight of 55 kg. The pressure sensor is a strain gauge sensor capable of measuring up to 34.5 MPa. The temperature sensor is a platinum resistance type sensor capable of measuring up to 350 deg.C. The spinner sensor is capable of detecting normal or positive rotation (+), or reverse or negative rotation (-) with its magnetic switch, and the impeller in the sensor can be exchanged with one suitable for the specific flow rate (flow velocity). Data are saved in the on-board computer memory, with a maximum sampling rate of 1 second (the rate is adjustable), and a maximum of 1,000,000 data sets can be recorded. The depth is measured with a dual digital encoder, which provides precise measurement. Pressure and temperature rating of the sampler section are up to 10.35 MPa and 350 deg.C respectively. The sampling is controlled with an electric solenoid valve controlled with a microprocessor timer. The titanium sample chamber has a capacity of 500 mL, and can accommodate a single phase of hydrothermal water or steam, or a multi-phase fluid (hydrothermal water + steam + gas).

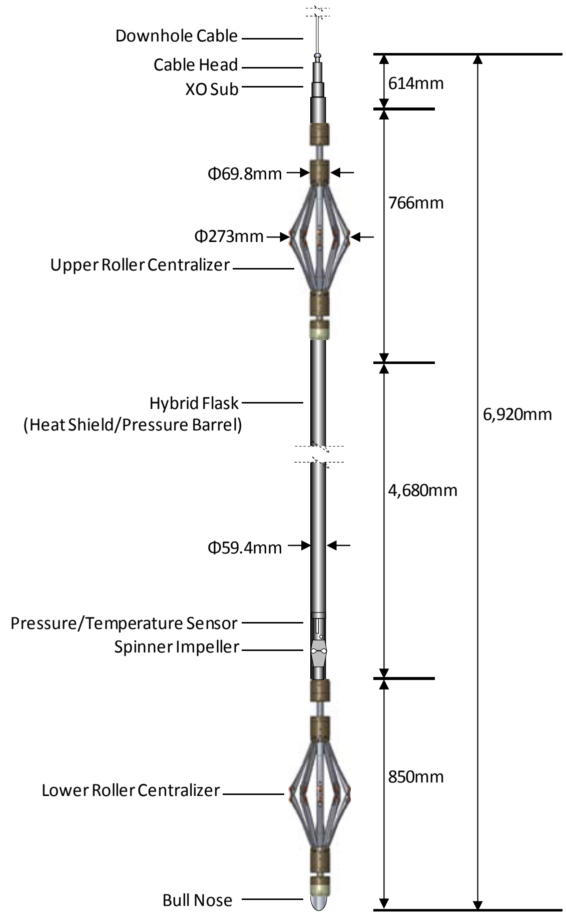

Figure 9: Outline of the logging system for a highly deviated well

3.2 Performance of the logging system

In order to verify the performance of the roller centralizer, a liner hanger simulated with a combination of the polyvinyl chloride (PVC) pipes was tested. Two types of PVC pipe, 4" and 8" pipes, were combined to simulate the pipe; the liner hanger section (step section) is formed at the connection section of these two types, and the entire pipe is set at 84° from the vertical (Figure 10). Transparent PVC pipes are used around the liner hanger section to allow observation of operation of the roller centralizer. Smooth operation of the roller centralizer when it passes through the liner hanger section (step section) has been verified through the tests (Figure 11).

The performance of the logging system in the actual well (Measured depth = 1,355.39 m, Maximum inclination = 48.25°, and Deviation = 742.33 m) was tested under a static condition. In order to evaluate the performance of the roller centralizer, the wireline tension was measured while the logging system was descending. The tension was measured with the bow-spring-type centralizer installed. Figure 12 shows the wireline tension while the logging system was descending. The total weight of the logging system for both the bow-spring type centralizer and the roller-type centralizer is almost the same, but the tension measured with the roller-type centralizer was found to be generally higher than the tension measured with the bow-spring-type centralizer while descending. The test well starts inclining at a depth of about 100 m, and from this depth on the logging equipment with the bow-spring-type centralizer keeps descending while the bow-spring blades are scraping on the borehole wall, which would cause the wireline tension to decrease. On the other hand, the roller centralizer reduces the friction between the logging tool and the borehole wall, which causes tension to be higher than that for the bow-spring type centralizer. It is also shown that the tension with the roller centralizer decreases below 400 m (relatively higher inclination section) while retrieving the logging system. From this observation it can be inferred that the friction with the roller centralizer is decreased more than with the bow-spring type centralizer while retrieving the logging system in the higher inclination section.

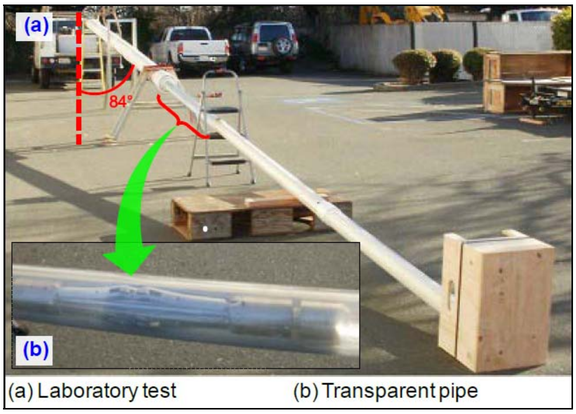

Figure 10: Laboratory test

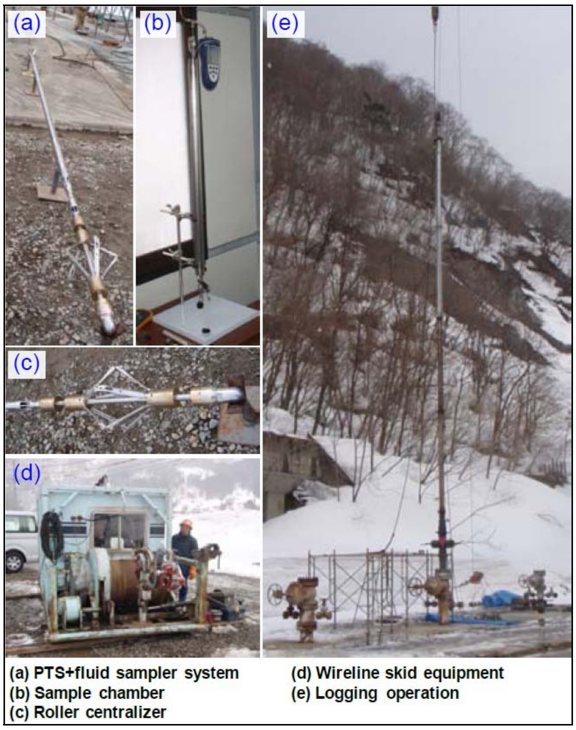

Figure 11: Situation of the logging test

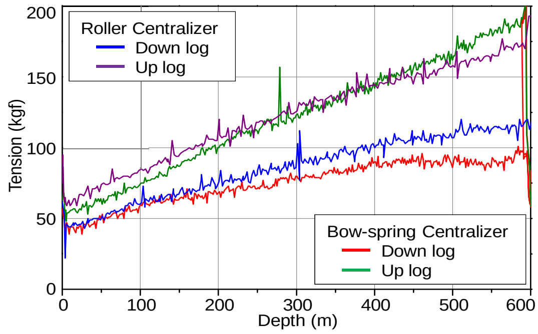

Figure 12: Comparison of wireline tension between the logging tool with the bow-spring centralizer and that with the roller centralizer

While verifying the operation of the roller centralizer at the liner hanger in the 7”CSG/4”CSG sections (region from 570 m to 610 m deep), it was found that the roller centralizer cannot go through the liner hanger of the well if the cable speed is 25 m/min or less. Since the centralizer can go through the liner hanger when the cable speed is 30 m/min or more, and since smooth operation of the centralizer was verified in the 4” casing slotted liner section, it can be concluded that a softer spring has to be used in the roller centralizer when the centralizer has to go through the liner hanger section with a 4” casing.

Figure 13 shows the logging results. Although a conventional PTS tool was used for comparison purpose, both logging results are coincident with each other.

A single-phase borehole sample was collected with a total weight of 442.1 g. The results of the water and gas sample analysis are listed in Table 1. The results of this analysis are compared with past sample analysis results, including a previous downhole sample (NEDO, 2008). The analysis data are generally consistent with the past data.

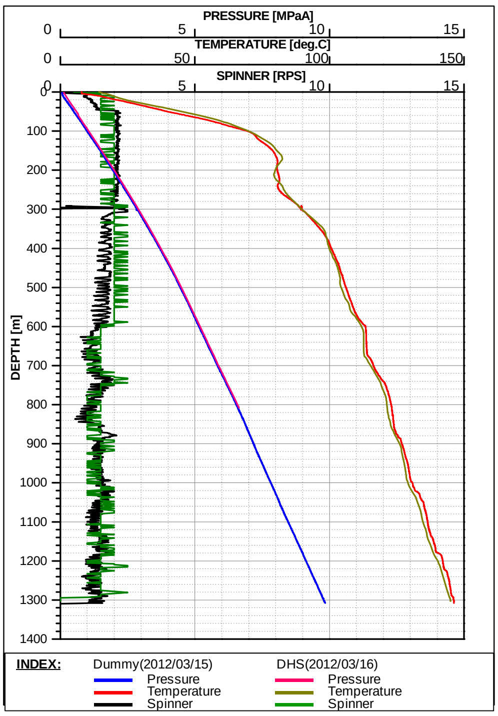

Figure 13: Logging results

Table 1: Results of the borehole sample analysis

Date			2012/12/1	2006/4/12	2007/11/22
Sampling method			PTS+fluid sampler for HDW (this paper)	Downhole sampler	Short-term production test (V-notch weir)
Sampling depth			700m	588m	surface
Brine	pH	–	6.86	6.4	8.5
	Na^+	mg/L	2,070	1,752	1,820
	K^+	mg/L	36.2	44	33.5
	Ca^{2+}	mg/L	38.3	49	51.9
	Mg^{2+}	mg/L	7.79	8.4	15.6
	Li	mg/L	1.52	–	1.2
	Sr	mg/L	3.29	–	–
	Ba	mg/L	0.137	–	–
	Fe	mg/L	3.79	–	–
	B	mg/L	32.2	–	–
	SiO_2	mg/L	119	120	116
	Al	mg/L	0.045	–	–
	Sb	mg/L	0.015	–	–
	As	mg/L	0.487	–	<0.01
	Mn	mg/L	0.069	–	–
	Cl^-	mg/L	1,070	1,048	1,800
	F	mg/L	2.06	–	0.9
	SO_4^{2-}	mg/L	825	550	506
	NH_4^+	mg/L	6.13	4.5	–
	$\delta^2H(H_2O)$	‰	−77.8	–	−81.2
	$\delta^{18}O(H_2O)$	‰	−7.9	–	−9.1
NCG	CO_2	Vol%	91	–	–
	H_2S	Vol%	<0.134	–	–
	NH_4	Vol%	0.737	–	–
	N_2	Vol%	6.52	–	–
	CH_4	Vol%	1.77	–	–

5. CONCLUSION

This paper presents the development status of a wellbore simulator and performance of a production logging system for a HDW. Results of the R&D are summarized as follows:

1. The Drift flux model was adopted in the wellbore simulator (GFLOW) for the HDW (well inclination = about 70°) and the model can provide enhanced calculation accuracy.

2. GFLOW was additionally used for an optimization study of the HDW casing program and a case study of an actual geothermal area was carried out. It was verified that the steam flow rate at the optimal point in terms of cost and efficiency increases to about 2.9 times higher than the average steam flow rate in the other production wells within the same area.

3. In order to evaluate productivity of the HDW, roller centralizers were added to the logging tool. It was verified in laboratory tests, where a well inclination of 84° was simulated, that the roller centralizer could smoothly go through the liner hanger section (step section).

4. Performance of the logging tool equipped with the roller centralizers was checked in an actual static well. It was verified with the test that, thanks to the roller centralizer, the friction between the logging tool and borehole wall was reduced based on the wireline tension measurement result. In the future, we are going to study performance of the roller centralizer in a producing HDW.

ACKNOWLEDGEMENTS

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