Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Development of a High Temperature Borehole Sampler and Scale Build Up Analysis Using a Wellbore Geochemistry Simulator

Sato, M$^+$., Okabe, T$^+$., Nakata, H$^+$., White,S.P^{++}., and Yanagisawa, N^{+++}.

+ Geothermal Energy Research & Development Co., Ltd., Shinkawa Nittei Annex Bldg. 22-4, Shinkawa 1-Chome Chuo-ku, Tokyo 104-0033, Japan. msato@gerd.co.jp, okabe@gerd.co.jp, nakata@gerd.co.jp

++ Industrial Research Limited, Gracefield Road PO Box 31-310 Lower Hutt New Zealand. S.White@irl.cri.nz

+++ National Institute of Advanced Industrial Science and Technology, AIST Tsukuba West, 16-1, Onogawa Tsukuba, Ibaraki 305-8569, Japan. n-yanagisawa@aist.go.jp

Keywords: Geochemical, Sampler, Simulation, Hot Dry Rock

ABSTRACT

A high temperature borehole sampler has been developed capable of capturing a high quality, representative sample of wellbore fluid and delivering this to the surface for subsequent analysis. We conducted fluid sampling in a production well of Hot Dry Rock project (HDR) in Hijiori, Japan where severe Anhydrite scale was observed in the well by borehole camera and caliper logs. We collected wellbore fluid samples from the well, which has several feed-zones, and clarified the chemical difference in each feedzone. We then simulated equilibrium conditions of Anhydrite using a wellbore geochemistry simulator 'WellChem'. Based on this simulation, we understood that one of the reasons for Anhydrite scaling was the mixing of fluids from different feedpoints. Furthermore, we obtained 6.5×10^{-6}(mol/s/m^2) as a precipitation rate of Anhydrite from the scale buildup calculation using the caliper log.

1. INTRODUCTION

Scaling in production and injection wells is a problem which cannot be disregarded in reservoir management. Production well scales such as calcite scale, anhydrite scale, and smectite scale, etc. have been reported (Akaku, 1988 □ Ajima et al. 1998 □ Kato etc., 2001). These are often caused by the mixing of two or more fluids with different characters, such as temperature, chemical composition, and pH, etc. Caliper logging and Down Hole Video Logging are used to evaluate the scaling situation in a well. The Down Hole Sampler tool is used for collecting fluid from the well and this makes it possible to determine the geochemical difference between feed zones in the well. The results give important information for reservoir analysis and management of wells.

NEDO (New Energy and Industrial Technology Development Organization) had carried out development of production technology for deep-seated geothermal resources project under a New Sunshine project administrated by the Ministry of Economy, Trade and Industry (METI) from 1992 to 2001. Deep-seated geothermal resources located below already developed shallow reservoirs, if made exploitable, have the potential to supply a considerable amount of geothermal energy for power generation. Development of these resources, however, is time consuming and costly with present drilling and production technologies. This is mainly due to the high pressure and formation temperature of deep-seated reservoirs. NEDO is working to overcome these obstacles through the development of new drilling and production technologies. The high temperature downhole fluid sampler is one of the products in this project. This tool can collect in-situ wellbore fluid at temperatures of up to 300deg.C. The chemical composition of fluid from each fracture intersecting the wellbore may be determined adding to the understanding of the reservoir characteristics.

We applied this tool to a production well which was used in the Hot Dry Rock Project (HDR) carried out at Hijiori in Yamagata prefecture, Japan. A circulation test was conducted from November 27, 2000 to August 29, 2002 during which an Anhydrite scaling problem was observed in the production wells. We tried to understand the scaling mechanism using the sampler tool. This paper presents the results of the field test and the analysis results of the scaling mechanism.

2. HIGH TEMPERATURE DOWN HOLE SAMPLER TOOL

In the prototype Controlled Displacement Sampler (CDS) described below, there are two coaxial chambers inside a heat insulated pressure body (Figure 1). The inner chamber is divided into two sections by a movable piston. Before deployment, during the set-up procedure this piston is positioned at the fluid sample entry end of the chamber. The small quantity of air left between the sample inlet valve and the face of the movable piston is purged and replaced with pure water. The cavity on the other side of the piston is also filled with water before deployment and this is referred to as the working fluid. The working fluid cannot contaminate the sample fluid as it is separated from it by the movable piston. The outer coaxial chamber is connected to the working fluid chamber by an adjustable throttling valve and check valve. When a sample is collected, the working fluid is transferred to the outer chamber under the control of the throttling valve. A sample is collected by perforating a thin rupture disk with a timer-controlled piercing needle. The time delay before piercing is pre-set at the surface so no communication with the tool is required. This obviates the use of non-standard, specialist, very high temperature logging cables. The needle mechanism is controlled by a battery powered motor.

When the rupture disk is pierced, the high pressure fluid enters the sampler causing the non-return valve to open. The sample fluid applies pressure to the face of the movable piston and so the working fluid is forced to transfer to the outer chamber at a controlled rate via the throttling valve. This reduces the flow of the incoming sample therefore preventing the sample from boiling. The transfer of the working fluid into the outer coaxial chamber also acts as a cooling medium for the sample. The seals on the moving piston are passing over metal which has not been exposed to the hot borehole fluid and is being cooled by the displaced working fluid. When the sample chamber is full and the pressure has equalized, the sampler can be brought to the surface; the increasing differential pressure closes the inlet valve.

3. HOT DRY ROCK PROJECT IN HIJIORI

Under the New Sunshine project administrated by the Ministry of Economy, Trade and Industry (METI), various field tests have been conducted to develop a heat extraction system in the HDR at Hijiori caldera in Yamagata Prefecture since 1984. The HDR test site is located on the southern edge in the 2km diameter Hijiori caldera, which was formed about 10,000 years ago. Topographic effects extend underground, and the predominant fracture orientation is E-W, with a high dip angle to the N. The Hijiori HDR system has two reservoirs (the shallow reservoir and the deep reservoir) and four wells (SKG-2, HDR-1, HDR-2a and HDR-3: Figure 2). The history of the Hijiori HDR geothermal energy R&D project is divided into two phases. The first phase was during 1985 to 1991, when the shallow reservoir was created and various technological developments were carried out. During a 90-day circulation test in 1991, the recovery rate of hot water and steam was about 78% and extracted heat energy was about 8.5 MW thermal (Yamaguchi et al., 1992, Kruger and Yamaguchi, 1993). Based on the results obtained from the shallow reservoir and with the aim of constructing a larger scale and higher temperature reservoir, the second phase started in 1992. The deep reservoir was created by hydraulic fracturing at a depth of about 2,200m. Two wells were deepened to about 2,300m to penetrate the deep reservoir, and the present Hijiori multi-reservoir HDR system was established in 1994. In 1995 and 1996, two short-term circulation tests were conducted to determine the deep reservoir characteristics for a long-term circulation test (LTCT). The LTCT was the final stage of the second phase, and consisted of three tests; the first test was conducted from November 27, 2000 to November 15, 2001, utilizing the deep injection well HDR-1 and production wells HDR-2a and HDR-3 (Oikawa et al., 2001). From December 23, 2001 to April 28, 2002, the second circulation test (dual circulation test) was carried out; this used both HDR-1 and SKG-2 as injection wells; and HDR-2a and HDR-3 as production wells. The third test was a demonstration for electric power generation using the HDR system from June 1, 2002 to August 31, 2002. In the LTCT, we faced a scaling problem which had not affected earlier tests/The mainly Anhydrite scale was produced with well bore fluid of the production wells.

3.1 Scaling situation in HDR-3

We conducted some investigations in order to know the scaling situation. We carried out PTS logging periodically in the LTCT. In the early period (February 2001) of the LTCT, the PTS tool could run down to 2,303m which is the bottom of the well. By May 2001 the logging depth had reduced to 2000m. The scale which adhered to the PTS tool was mainly Anhydrite, this was verified by X-ray analysis. There is a known feed zone near 2000m. Figure 3 shows the PTS data on August 2002. We conducted Down Hole Video logging (DHV) in order observe the situation visually. The tool, which can log under high pressure and high temperature (69MPa, 177deg.C 4hr) was used to log to a depth of 1969.4m. We could see some scaling situation in the well, his most remarkable scale was discovered at a depth of 1750m, the main feed zone of the well. We could not acquire clear images near the bottom because of muddy water. A typical view of the wellbore is shown in Figure 4. Figure 5 shows the results of X-Y caliper logging run in order to determine the thickness of the scale. We found three scaling depths which corresponded with feed zones (A, B, C in Figure 5). A is at 1,649m, B at 1,754 – 1,759m and C at 1,930m. Since the scale occurs near the feed zones, we postulated that the scale was caused by the mixing of different fluids.

4. SAMPLER LOGGING

Sampler logging was carried out in order to characterize the feed point's geochemistry. Samples were collected at 1,740m and 1,900m in order to clarify the cause of scale generation with a depth of 1,760m. We also collected steam and brine samples from the surface two-phase line for comparison. The amounts of the samples were about 1 liter, and we could extract gas samples compressed in the sample chamber using the Surface Extraction System which is a special system for the down hole sampler tool. Table 1 shows the chemical analysis results. The Hijiori reservoir is separated into shallow and deep reservoir at 1,800m. The results show that the difference of chemistry was observed between 1,740m and 1,900m samples. Cl^- concentration in the deep reservoir is 630ppm at 1,900m, and the concentration in the shallow reservoir is 224ppm at 1,740m. It showed that the shallow sample was diluted by in coming fluid from a feed zone at 1,760m. On the second half of the LTCT, the influence of the injection fluid to the shallow reservoir is becoming remarkable.

5. DISCUSSION

5.1 Analysis of Saturation Index

Generally it is reported that generation of Anhydrite scale is related to fluid mixture and a rising of temperature (Kato et al, 2001). We conducted geochemical simulation using the sample analysis results in order to consider the Anhydrite scale. We used the geochemical simulator "WellChem" (White et al., 2000, Osawa et al., 2002). WellChem can calculate chemical conditions in a flowing well by combining with the well bore simulator "GFLOW" (Kato et al., 2001). Figure 6 shows the results of a simulation of Anhydrite deposition. Anhydrite is saturated for the 1,740m sample at about 205deg.C, and for the 1,900m sample about 265deg.C. The temperatures at these depths are 201.1deg.C at 1,740m and 261.8deg.C at 1,900m. So these samples were almost at saturation condition with Anhydrite at both depths. The solubility of Anhydrite increases with decreasing temperature (retrograde solubility). If we ignore fluid mixing at the feed zone of 1,760m, fluid from the 1,900m feed zone becomes under saturated at 1,760m. However we observe Anhydrite scale at 1,760m and believe this is caused by mixing with low temperature fluid from the 1,760m feed zone.

5.2 Fluid mixing simulation

We calculated saturation index of Anhydrite in the well bore setting a low enthalpy fluid inflow from 1,750m. PTS logging shows that mixing ratio of 1,760m is about 30%. Simulation conditions are as follows.

1) Chemistry of deep fluid: Analysis results of the sample at 1,900m.

2) Chemistry of inflow fluid: Analysis results of Injection fluid.

3) Mixing ratio : 30% by PTS logging

4) Enthalpy of inflow fluid : 530kJ/kg which simulated by GFLOW

We calculated two cases with the results shown in Figure 7. One is considered only deep fluid (Case1) with no mixing with inflow fluid. In this case, Anhydrite was under saturated through the well. The second case considered fluid mixing at 1,760m (Case2). In this case, Anhydrite is super saturated from 50m to 1,760m. These results supported that the low enthalpy fluid from 1,760m was strongly affected to Anhydrite scaling.

The drilling report said that Anhydrite mineral was found in core sample of granite. In mineral composition of the core sample, anhydrite occupies about 5%. It could consider that these Anhydrites were dissolved in injected water, and the fluid was important source of Anhydrite scale in Hijiori.

5.3 Scale build up simulation

The modeling of Anhydrite scaling based on kinetics has progressed in recent years. Kato et al. (2001) applied a kinetic model in order to analyze the deposition rate of Anhydrite scale in a production well. In order to calculate scaling with time, they assumed that Anhydrite precipitates from well fluid deposits inside a uniform thickness casing. With this assumption, a mathematical model was developed using isothermal non-steady plug-flow model. The analyses were made using scaling calculations coupled with well bore simulations. We applied this method to the analysis of the anhydrite scale of HDR-3. In this analysis, we considered the kinetic deposition and mass transport in the well. The saturation index was modified by precipitation rate, fluid velocity and distance from the feed zone (equation (1)).

$$S=(S_0-1)\exp\left(-\frac{Ak}{\rho u C_{eq}}z\right)+1\text{□@¥¥¥¥¥}(1)$$

(S0 : saturation index (Q/K) calculated by geochemical simulator, A : Surface area/capacity (m^{-1}), k : deposition rate ($mol/s/m^2$), u : velocity (m/s), z : distance from the feed zone, ρ :density of fluid (kg/m^3), C_{eq} : equilibrium concentration (mol/kg))

$$\frac{\partial\xi}{\partial t}=k\frac{2\sqrt{\xi}}{\rho_s}(1-S)\frac{G}{1-\phi}\text{□@¥¥¥¥¥¥¥}\quad(2)$$

Equation (2) represents a governed equation on temporal change in wellbore diameter with precipitation.

(ξ: 2nd power of scale thickness, k : deposition rate ($mol/s/m^2$), t : time, ρs : density of scale (kg/m^3), S : modified saturation index, G : Molecular weight of Anhydrite (kg/mol), φ : porosity of scale)

We use a geochemical simulator called WellChem (Osawa et al., 2002) to calculate saturation index and output from the wellbore simulator GFLOW to provide fluid velocity, pressure, temperature required as input for WellChem. The period of simulation was about 2 years from November 2000 to September 2002 and the results are shown in Figure 8. Scale thickness became thinner upwards regardless of the value of log k. Scale thickness at greater depth increased as log k increased, while that at shallower depths drastically decreased. Deposition rate (log k) used in the simulations ranged from -6.00 to -4.00. The best match to caliper log data was provided by log k = -5.00 (6.5×10^{-6}($mol/s/m^2$)), this approximately agreed with the partial maximum reduction section of diameter. Kato et al. (2001) reported a slightly higher value for log k of Anhydrite of -4.50. We also calculated future scale build up at 1,750m for the future. In the case of log k=-5.00, the maximum scale thickness increases linearly with time, and becomes 60mm after four years (Figure 9). This is equivalent to the half of cross section of well bore.

6. CONCLUSION

A high temperature borehole sampler was developed for capturing a high quality, representative sample from well bore. We conducted fluid sampling from a high temperature production well of the HDR project in Hijiori, Japan. The purpose was to understand the scaling mechanism of Anhydrite in the well bore. Sampler logging was successful and we collected two samples at 1,740m and at 1,900m. These depths are at shallow and deep position from a feed zone at 1,760m which had severe Anhydrite scale. Geochemical simulation by WellChem was carried out using analysis results of these well bore samples. The results show that mixing with low enthalpy fluid at 1,760m is probably the reason for scale built up on the well bore. We tried to apply the modeling method of Anhydrite scaling based on kinetics reported by Kato et al. (2001). The period of scale built up simulation was about 2 years from November 2000 to September 2002. As a result of history matching to a caliper log, log k = -5.00 which is 6.5×10^{-6}($mol/s/m^2$) is approximately agreed with the partial maximum reduction section of diameter.

7. ACKNOWLEDGEMENT

The authors thank New Energy and Industrial Technology Development Organization for permission to publish this paper.

8. REFERENCES

Ajima, S. Todaka, N. and Muratake, H.: An interpretation of smectite precipitation in production wells caused by the mixing of different geothermal fluids, 1998, Proceedings, Twenty-third Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 26-28, 264-269.

Akaku, K.: Geochemistry of mineral deposition from geothermal waters: Deposition processes of common minerals found in various geothermal fields and case study in the Fushime geothermal field, 1988, Chinetsu, 25, 44-61 (in Japanese with English abstract).

Kato, H., Kamei, J., Kitao, K., and Muramatsu, Y.: Numerical simulation of Anhydrite scaling in production well at the Sumikawa geothermal field, Japan, 2001, Geothermal Resources Council Transactions, Vol. 25, August 26-29.

Kato, M., Okabe, T., Nakata, H., Kissling, W. and White, S.: Development of a wellbore flow simulator GFLOW, 2001, Proc. Geother. Res. Soc. Japan, A19 (in Japanese).

Kruger P., and Yamaguchi, T.: Thermal drawdown analysis of the Hijiori HDR 90-day circulation test, 1993, Proceedings, 18th Stanford Workshop on Geothermal Reservoir Engineering, 111-118.

Oikawa, Y., Tenma, N., Yamaguchi, T., Karasawa, H., Egawa, Y. and Yamauchi, T.: Heat extraction experiment at Hijiori test site, 2000, Proceedings, 26th Stanford Workshop on Geothermal Reservoir Engineering

Osawa, K., Sato, M., Okabe, T., Nakata, H. and White, S. P.: Development of a Wellbore Mineral Saturation

Index Calculating Program WellChem, 2002, Proc. Geother. Res. Soc. Japan, B44 (in Japanese).

Sato, M., Okabe, T., Nakata, H., Sleet, P., Twose, C., Hirtz, P., Kasagi, T., Goko, K. and Kondo, T.: Development of a high temperature borehole fluid sampler and its field experiment in the Ogiri geothermal field, Japan, 2002, Geothermal Resources Council Bulletin, Vol 26, 357-360.

Twose, C., Parker, R., Okabe, T., Kirihara, K., Nakata, H., Kondo, T., Karasawa, H. and Cappetti, G.: Development of a high temperature borehole fluid sampler and its field experiments in the Larderello Geothermal Field, Italy, 2000, Proceedings World Geothermal Congress 2000, 1889-1892.

Ujyo, S., Kato, M. and Okabe, T.: Introduction to the high temperature-high pressure borehole video logging to solve geothermal downhole problems, 2002, The journal of geothermal energy, Vol.27, 85-90.

White, S.P., Lichiti, K. and Bacon, L.: Application of chemical and wellbore modeling to the corrosion and scaling properties of Ohaaki deep wells, 2000, Proceedings World Geothermal Congress 2000, 3963-3968.

Yamaguchi, T., Hiwaki, N., Abe, T., and Oikawa, Y.: 90-day circulation test at Hijiori HDR test site, 1992, Transactions, Geothermal Resources Council, 16, 417-422.

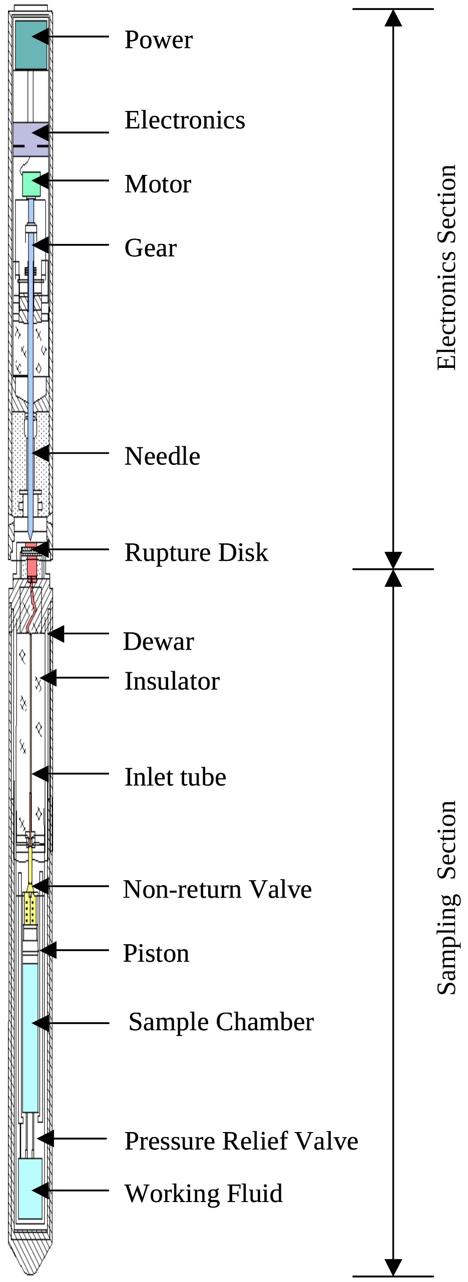

Figure 1: High Temperature Borehole Sampler Tool

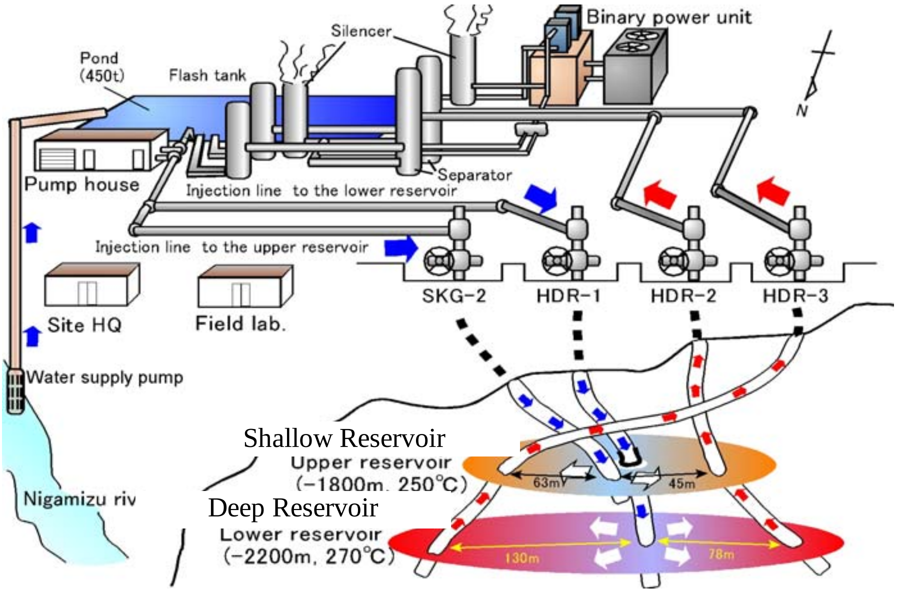

Figure 2: Concept of the recently Hijiori HDR System

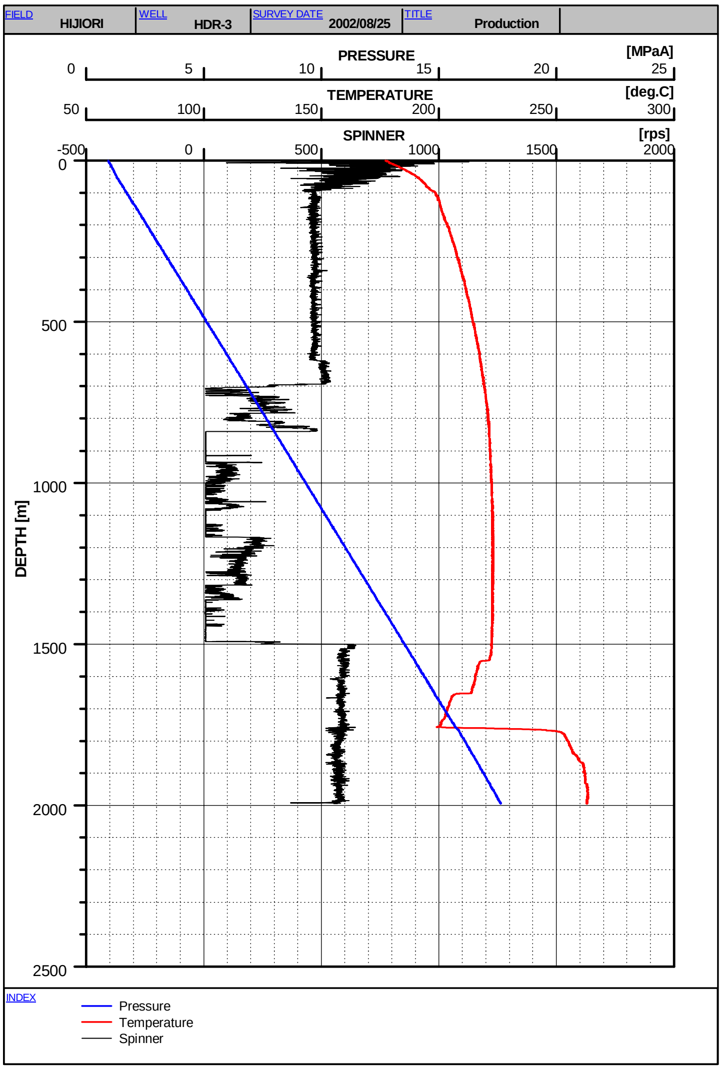

Figure 3: PTS logging results in HDR-3

Figure 4: Anhydrite scale at 1,750m pictured by Down Hole Video tool

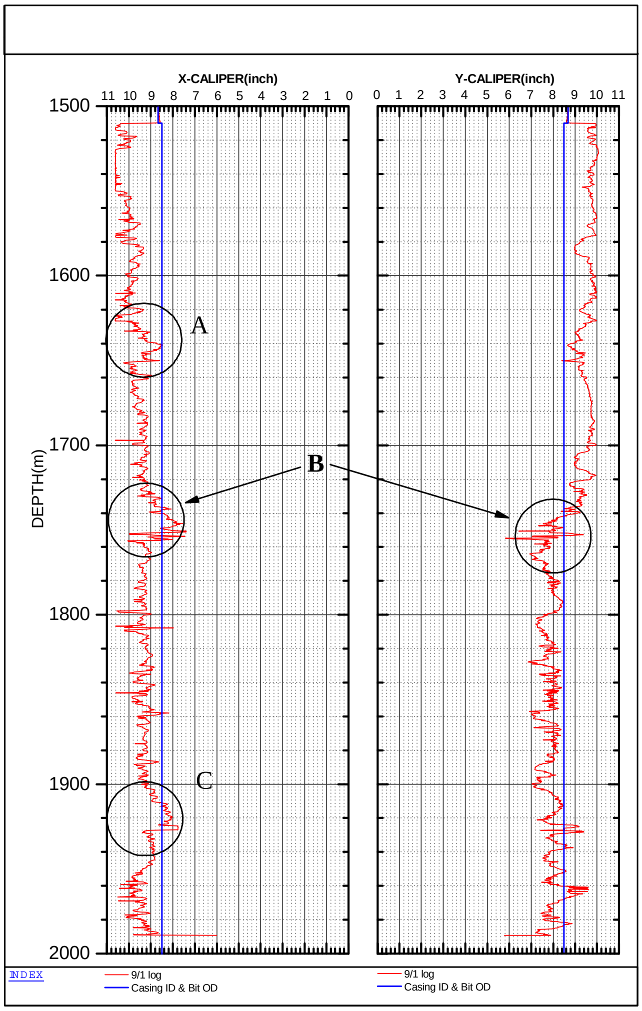

Figure 5: Caliper logging result in HDR-3

Table 1: Analysis results of Well bore samples

Concentration	Sampling Depth			Injection Water
	1740m	1900m	Surface	
Na (mg/kg)	155	534	354	130
K (mg/kg)	20.3	78.4	48.6	16.9
Ca (mg/kg)	96.7	9.1	12.1	47.7
Mg (mg/kg)	0.485	0.288	0.053	5.8
Fe (mg/kg)	1.45	3.52	0.13	0.29
B (mg/kg)	1.4	7.4	3.7	1.09
SiO_2 (mg/kg)	209	547	374	127
Cl (mg/kg)	224	630	313	95.1
F (mg/kg)	2.76	8.12	5.73	1.54
SO_4 (mg/kg)	166	241	239	200
pH at 25deg.C	7.03	6.72	8.78	8.38
Conductivity(mS/cm)	1.31	1.76	1.74	0.90
CO_2 (ppm)	196	1480	682	－
H_2S (ppm)	0.39	0.24	1.7	－
NH_4 (ppm)	1.28	0.62	0.61	－
Ar (ppm)	0.081	0.362	0.255	－
N_2 (ppm)	<2.77	26.7	9.53	－
CH_4 (ppm)	0.055	0.235	0.051	－
H_2 (ppm)	0.006	0.048	0.008	－

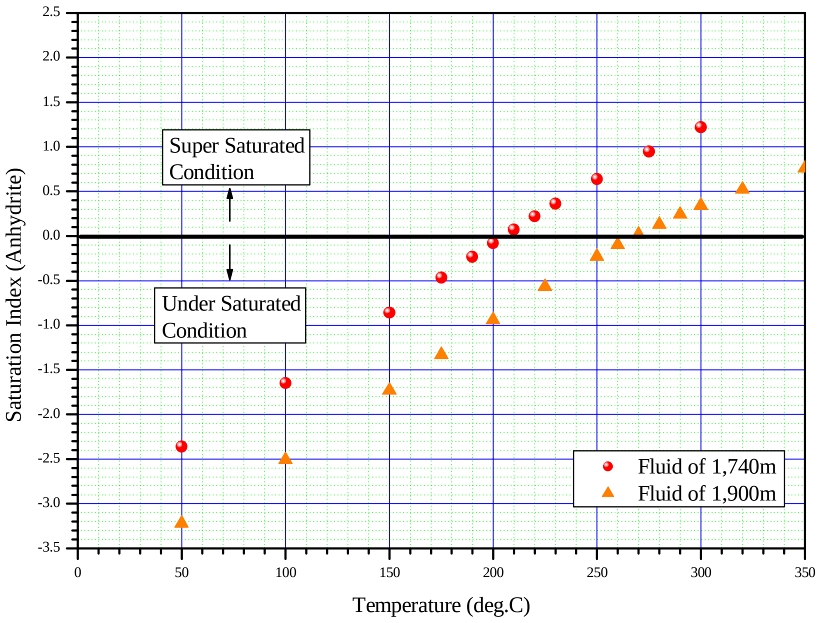

Figure 6: Calculation results of Saturation Index using Wellbore samples (1,740m, 1,900m).

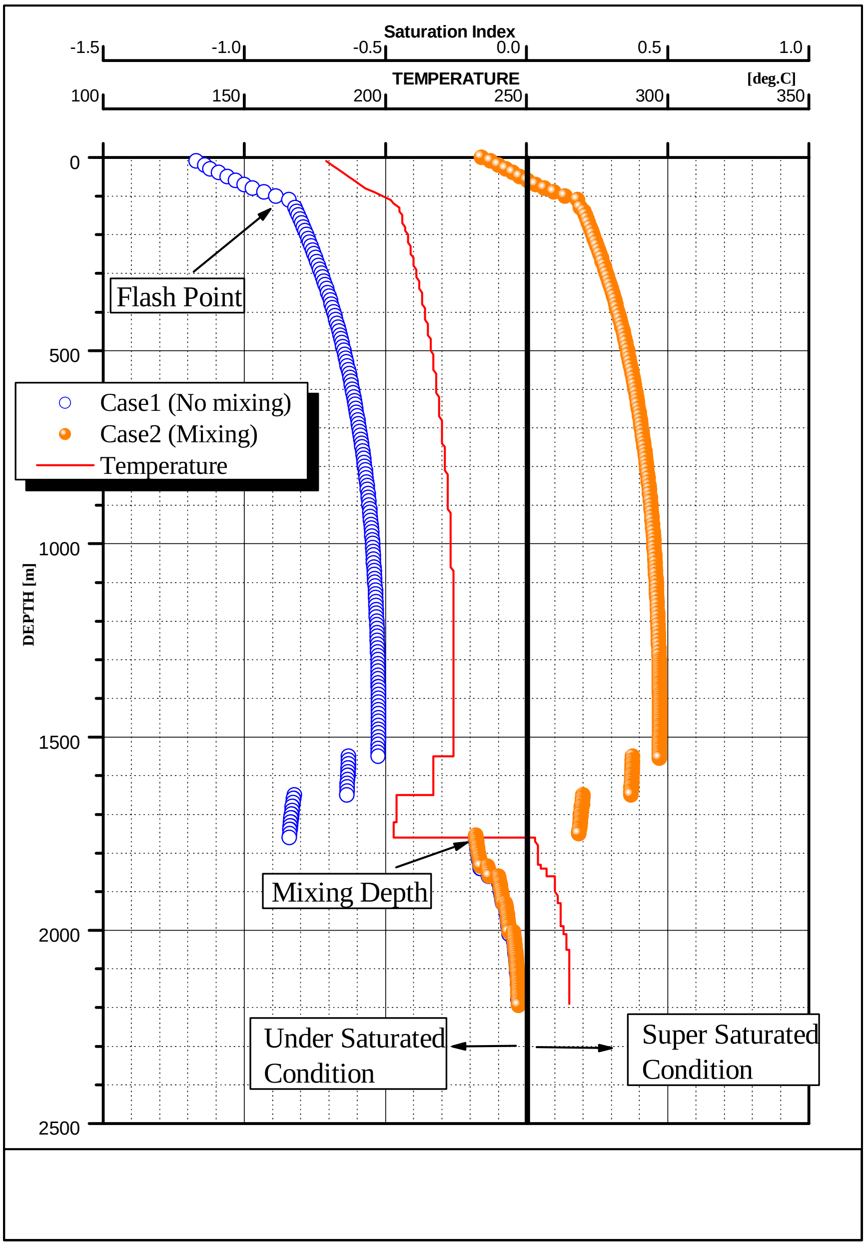

Figure 7: Saturation Index in case of mixing with low enthalpy fluid (Blue : Case 1, Yellow : Case 2, Red : Temperature)

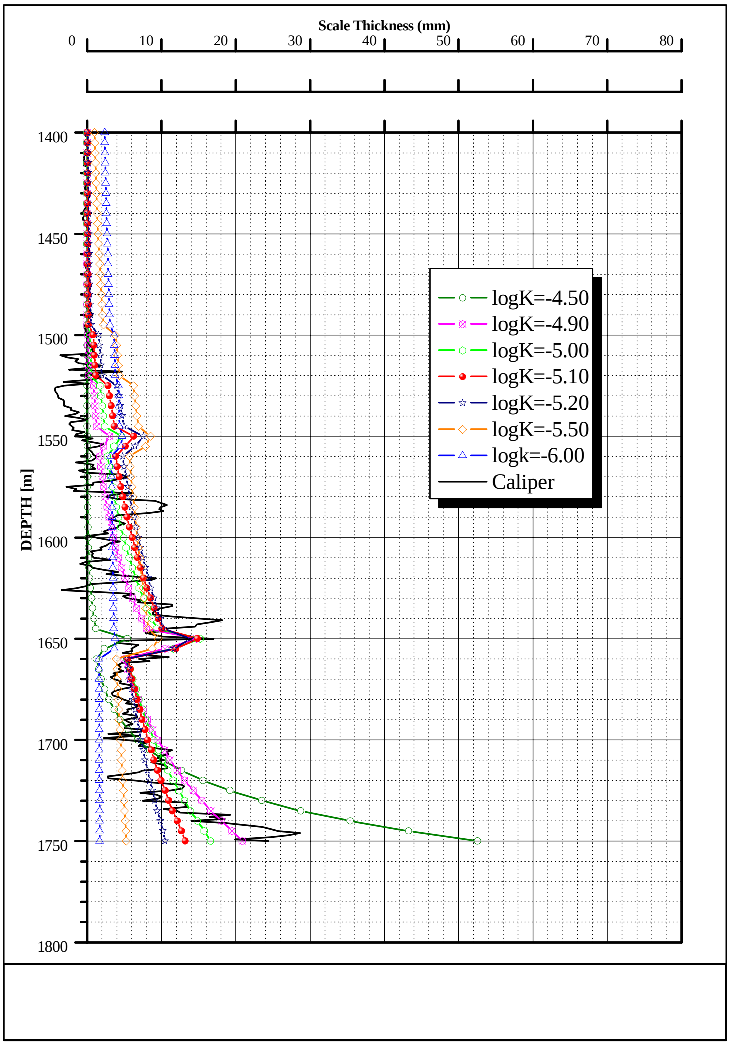

Figure 8: Results of Anhydrite Scale build up Simulation

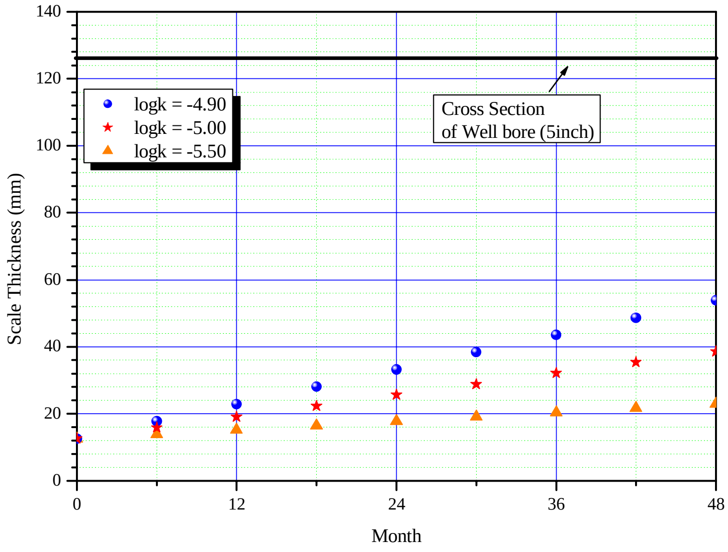

Figure 9: Simulation results of Scale Thickness in future