

AN INTERPRETATION OF SMECTITE PRECIPITATION IN PRODUCTION WELLS CAUSED BY THE MIXING OF DIFFERENT GEOTHERMAL FLUIDS

Shuji Ajima * , Norifumi Todaka • and Hiroyuki Muratake **

* Electric Power Development Co. Ltd. (EPDC)

6-15-1, Ginza, Chuo-ku, Tokyo, Japan

** Kaihatsu Computing Service Center Co. Ltd.

2-2-18, Fukagawa, Kohto-ku, Tokyo, Japan

ABSTRACT

A trouble by smectite-amorphous silica precipitation happened at two production wells in the Onikobe Geothermal Power Station, northern part of Japan. It is considered that the reason of the down-hole scaling is caused by the mixing of two kinds of fluids in a production well, base on the facts as follows.

During the drilling, there were two lost circulation zones at shallow and deep. The precipitation occurred above the shallow feed zone. The pH of production fluid had changed radically from neutral to acid while the scaling trouble had occurred. According to the observation of cuttings and the analysis of alteration zoning of the vicinity wells, acidic altered minerals distribute at the shallow feed zone, whereas neutral alteration at the deeper. In addition to the facts above, our chemical modeling calculation, using SOLVEQ and CHILLER (Spycher and Reed, 1990), indicates that the mixing of the acid and the neutral fluids with some definite ratios would make a smectite supersaturated condition.

INTRODUCTION

EPDC's Onikobe Geothermal Power Station (GPS) started operation in March 1975 as the fourth geothermal power plant in Japan, and is now operating with a capacity of 12 500 kW. The location of the Onikobe GPS is shown in Fig.1. Unexpected troubles caused by clay mineral scaling happened in two production wells, well-128 and well-132. This paper reports our investigations on the production decline of well-128 using chemical modeling calculation, by that we estimate the cause of the trouble to be the mixing of different fluids in the well.

The geology around the power station consists, in descending order, of the Katayama lacustrine deposit, the Ofukazawa andesite member of the Akazawa Formation, the Sannozawa Formation of Pleistocene, the Kanisawa Formation, a local member

of "Green Tuff of Miocene, and Pre-tertiary granodiorite as the basement of the region. The granodiorite is confirmed at about 1 200 m in depth by some investigation wells. A two-phase geothermal reservoir is formed in the Ofukazawa andesite member made of andesite lava and tuff breccia shallower than 500 m in depth. The Sannozawa Formation made of altered dacitic tuff breccia has low permeability. The upper part of Kanisawa Formation is made mainly of andesite lava, and the lower part mainly of greenish andesitic tuff. This formation distributes in the depth from 700m to 1 200m and a water-dominated geothermal reservoir is formed in this formation, especially in vertical fractures caused by a local horst structure with a temperature of about 250°C. This is the main production zone of the Onikobe GPS at present.

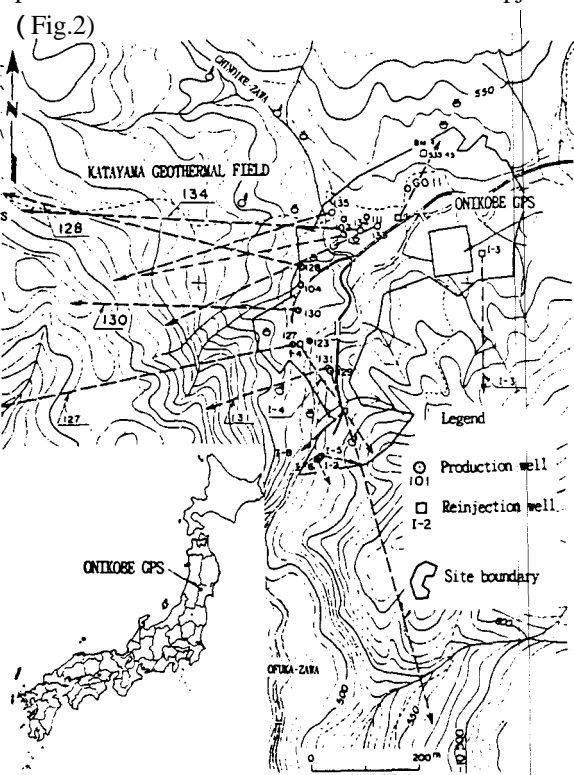


Fig.1 The location of the Onikobe geothermal field

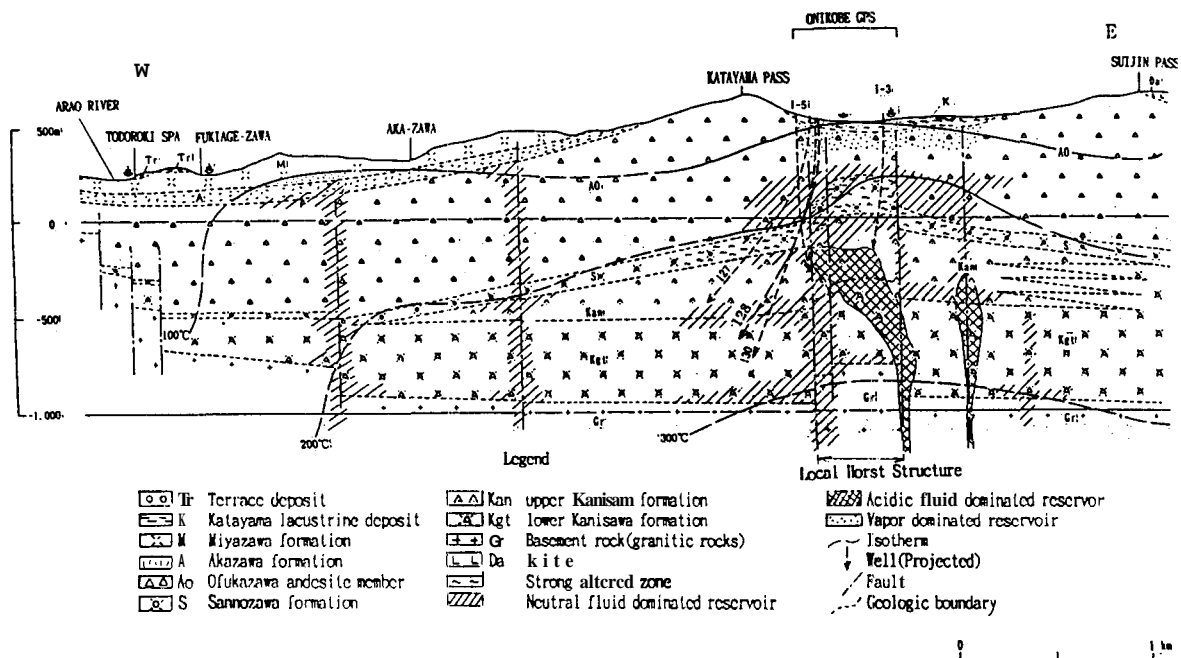


Fig.2 Geothermalsystem around the Onikobe GPS

The chemical compositions of separated waters are shown in Table 1. There are two types of production fluids in the Onikobe GPS, one is acid fluid with the pH of about 3, and the other is neutral to weak alkaline fluid with the pH between 7 and 8. Acid fluid is characterized by the higher concentration of Mg, Fe, Pb, Zn and Cl compared with the neutral to weak alkaline. These two types of fluids distribute in the the Onikobe geothermal reservoir.

These geothennal structure and chemistry are reported by Klein et al. (1990) and Abe (1995).

Table 1 Chemical compositions of separated water from production wells in the Onikobe GPS

Well No.	127	128	129	130	131	132	133	134	135
Length	1160m	125%	1461m	1500m	1000m	1303m	1260m	145%	1409m
pH	—	4.9	3.5	8.0	3.0	3.6	7.6	3.2	—
Cl	mg/l	4610	3350	3980	5030	4620	2600	4890	2270
SO ₄	mg/l	1.25	36.2	21.3	17.5	524	23	39.4	13.9
HCO ₃	mg/l	n.d.	n.d.	(83.1)	n.d.	n.d.	52	n.d.	n.d.
CO ₂	mg/l	n.d.	n.d.	(0.8)	n.d.	n.d.	6	n.d.	n.d.
Na	mg/l	2090	1530	1960	2050	2030	930	2030	1150
K	mg/l	380	300	307	415	370	130	370	215
Ca	mg/l	579	340	347	647	615	160	667	179
Mg	mg/l	6.28	22.9	1.96	39.8	22.6	0.22	46.1	0.21
T-Fe	mg/l	1.18	7.74	0.01	177	34.8	0.03	89.1	0.12
As	mg/l	0.75	2.02	1.02	0.81	0.66	1.3	0.72	1.17
Al	mg/l	0.38	0.37	0.02	0.37	0.15	<0.01	0.24	0.22
B	mg/l	56.5	43.1	58.0	56.5	56.3	47	58.1	31.1
Li	mg/l	4.27	3.22	2.77	3.80	3.12	3.1	3.06	2.79
I	mg/l	1.37	0.90	1.29	1.37	6.64	0.6	1.46	0.63
Pb	mg/l	0.03	0.26	0.18	1.75	0.11	<0.02	1.26	<0.01
Zn	mg/l	0.01	0.08	<0.01	3.16	0.23	—	1.94	0.01
Cu	mg/l	<0.01	<0.01	<0.01	0.02	<0.01	—	<0.01	<0.01
Br	mg/l	6.41	4.68	5.95	7.67	5.78	4.6	6.43	3.25
Mn	mg/l	1.95	3.4	1.56	4.55	2.06	0.20	3.95	0.19
SiO ₂	mg/l	702	736	672	725	571	690	548	736
									621

Remarks HCO₃, CO₂ value in parentheses were calculated from T-CO₂, pH

(Sampling date) 129: Jan. 13, 1993
 132: June, 18, 1990
 127, 128, 130, 131, 133, 134, 135: Jan. 31, 1997

HISTORY OF THE PRODUCTION WELL

Well-128 is a directional production well, drilled in 1982 with a length of 1255m. Production casing was set to the depth of 705m, and the rest 550 meters were drilled by 10 5/8 inch drilling bits in diameter, and 7 5/8 inch slotted pipes were inserted to the bottom.

At the first production test in July 1982, steam flow rate was recorded 48.5 t/h, with hot water of 144 t/h (WHP was 4.6 kg/cm² G). The separated water showed pH 8.5. As shown in Fig.3, the decline of the steam flow rate had been weak until the sudden decline occurred in 1988. In order to investigate the down-hole conditions, the well was shut-in in March 1989, when the steam flow rate was only 15 t/h.

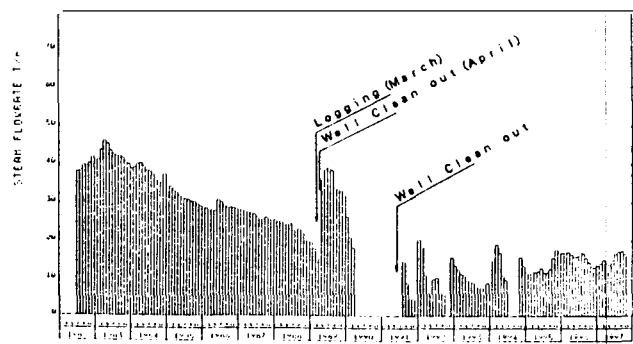


Fig.3 Well-128 long-term variations of the steam flow rate

PRESUMPTION ON THE CAUSE OF THE TROUBLE

By means of the following investigations, it was presumed that the production trouble was caused by the smectite-amorphous silica precipitation given rise to by the mixing of different kinds of geothermal fluids in the well.

Caliper logging

In order to understand the down-hole situation of the production well, X-Y caliper logging was executed in March, 1989.

The caliper probe could reach down only to the depth of 605 m in the production casing with an inner diameter of 279.4 mm. The maximum recorded reduction of the diameter reached to some 80 mm. The reduction of the diameter was observed from 605m to 200m in depth, decreasing upward, as shown in Fig.4 .

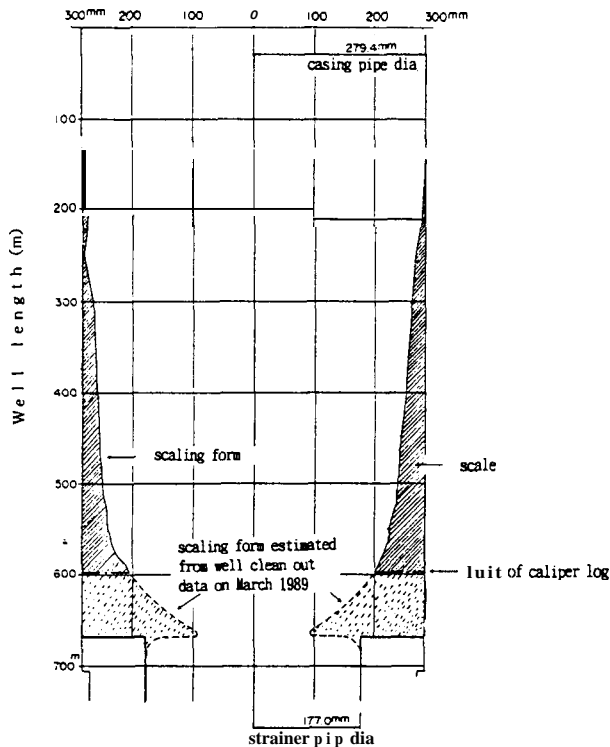


Fig.4 Caliper logging of well-128

Table 2 Chemical compositions of amorphous silica and smectite scales

depth	scale	SiO ₂	TiO ₂	Al ₂ O ₃	MgO	CaO	MnO	FeO	Na ₂ O	K ₂ O	Total
350	amorphous	57.75	0.12	7.18	4.74	3.80	15.49	0.00	0.59	0.56	90.22
350	smectitic	53.51	0.00	3.25	16.63	2.31	13.42	0.21	0.00	0.12	89.46
550	amorphous	52.97	0.00	5.34	6.53	2.93	20.12	0.00	0.39	0.32	88.59
550	smectitic	52.10	0.00	3.50	10.28	2.03	18.43	0.00	0.00	0.12	86.45

unit: wt%

Temperature loggings

Static temperature loggings were executed in September of 1989. The temperature profiles indicated a possible fluid flow between the 700 m and 1 200 m feed zones. On the contrary, the temperature profiles recorded before didn't show the downhole fluid flow.

Precipitation condition and analysis of the scale

Scale samples were collected from 250m to 650m in depths during the well clean-out in May, 1989. The scale were reddish brown in color and glassy with the naked eye. Under the microscope observation, the scale consists of the brown semitransparent part and the clear transparent part, and the latter had a tendency containing small opaque minerals scattered.

X-ray diffraction method with oriented specimen and EPMA analysis were carried out for the scale samples. According to Ishii and Todaka (1994), the X-ray diffraction results between non-treated and ethylene glycol treated specimens showed that the shift of the base lattice spacing was from 15 Å to 17 Å, and the reflection of (060) lattice was 1.53 Å, so that it was considered that the specimen was triakis-oktahedral smectite with poor crystallinity. EPMA analysis indicated that the main elements of the brown part were Si, Mn, Mg, Al and Ca, and there were little differences of the chemical components from depth to depth. Although main elements of the clear part were as same as those of the brown part, Si and Mn were richer than the brown part, and poorer in Mg. The EPMA qualitative analysis identified the opaque minerals to be Fe-S minerals, Cu-Fe-S minerals and Cu-Sb-S minerals. Typical EPMA results of the scale are shown in Table 2.

The scale was identified to be smectite, amorphous silica and a very small quantity of sulfides and sulfosalts, i.e. sphalerite and tetrahedrite etc. Ishii and Todaka (1994) classified the scale into two types as follows by precipitation conditions.

Type 1 : Boundary of smectite and amorphous silica is irregular.

Type 2 : Boundary of smectite and amorphous silica is sharp.

According to the microscopic texture, it was considered that Type 1 was the partial smectitization replacing amorphous silica, and that Type 2 was the docking of the perfectly replaced smectite and the amorphous silica, and/or the direct crystallization from geothermal fluids.

Chemical characteristics of geothermal fluids and distribution of altered minerals

The pH of the separated water had been stable at around 8 from the beginning of production in 1982 to 1989. In the period from 1990 to 1994, the pH changed radically between 8 and 6.5. After 1994, the quality has shifted gradually to the acid sphere with the pH of 3.5 at present in 1997. On the other hand, the Cl⁻ radical change between 2000 and 3000 mg/l started in 1989 and continued during the period of the pH's radical change, and it increased slowly to 3700 - 3800 mg/l at present while the pH decreased. The silica concentration has been stable at around 700 mg/l from the production start. The change of the quality is shown in Fig.5.

From the view point of the hydrothermal alteration, the main feed zone below 1100 m in depth is in the neutral altered zone characterized by wairakite and chlorite. This coincides with the pH value of the initial period of the production. On the contrary, acidic altered minerals i.e. kaolinite and pyrophyllite etc. are distributed in the shallow depth of about 700 m, where the acid fluid was probably reserved but there was little inflow at the beginning of the production. The rocks in the shallow feed zone had been strongly altered and weakened, and it was considered that the acid fluid started to feed in and increased its flow rate gradually after the operation, decreasing the pH. The pH of 3.5 at present is probably the value of the stage when there is little inflow of the neutral to alkaline fluid from the deep feed zone because of scale fragment settlement by the well clean-out.

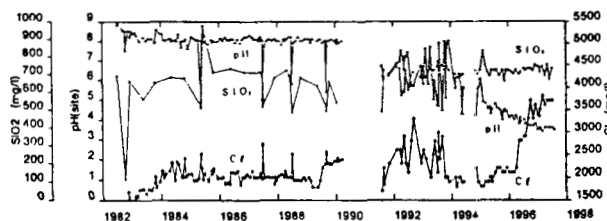


Fig.5 The chemical components history of separated water from the well-128

INVESTIGATION OF SMECTITE SCALING BY CHEMICAL MODELING CALCULATION

It was presumed that the mixing of different fluids had caused the smectite-amorphous silica precipitation. In addition to the above, we tried to examine saturation conditions of some minerals, using a chemical equilibrium simulator SOLVEQ and CHILLER (Spycher and Reed, 1990).

Application of a chemical modeling calculation to geothermal field

Chemical composition of geothermal fluid would change by flashing, temperature decline, and scaling while the fluid flows up in the production well. Chemical equilibrium simulator is possible to calculate speciations of aqueous species under reservoir conditions. Chiba (1985 and 1990) applied this method to geothermal fluids, using the data of Takinoue and Hatchobaru GPS. Takeno (1995) applied, using the data of Takinoue and Mori GPS. This method can simulate flashing, fluid mixing, and water-rock interaction, and can calculate mineral saturation conditions. Thus, the chemical modeling calculation is a useful method for analyzing scale precipitation.

Method of calculation

We calculated saturation conditions by mixing two types of different fluids; the acid fluid of pH 3.0 using the data of well-130 as a representative and the neutral fluid of pH 7.8 using the data of well-134 as a representative. These data are shown in Table 3.

Table 3 Input data for the fluid-fluid mixing calculation

Well No.	#130	#134
Sampling date	1995. 9. 21	1995. 9. 21
pH	3.00	7.80
Temperature of pH measurement (°C)	22.5	22.6
Cl ⁻ (mg/l)	4510	2550
SO ₄ ²⁻ (mg/l)	22.2	14.9
CO ₃ ²⁻ (mg/l)	0.00	234.5
HCO ₃ ⁻ (mg/l)	0.00	0.00
H ₂ S (mg/l)	0.00	0.00
SiO ₂ (mg/l)	718	707
Na ⁺ (mg/l)	1800	1330
K ⁺ (mg/l)	384	262
Ca ²⁺ (mg/l)	494	245
Mg ²⁺ (mg/l)	33.5	0.38
Fe ²⁺ (mg/l)	173	0.10
Al ³⁺ (mg/l)	0.21	0.12
Pb ²⁺ (mg/l)	2.00	0.31
Zn ²⁺ (mg/l)	3.72	0.00
Cu ²⁺ (mg/l)	0.01	0.00
Mn ²⁺ (mg/l)	8.92	0.98
Sb ³⁺ (mg/l)	0.038	0.083
CO ₂ (vol%)	59.50	63.00
H ₂ S (vol%)	26.90	21.40
N ₂ (vol%)	10.69	12.64
O ₂ (vol%)	0.39	0.14
H ₂ (vol%)	2.22	2.31
Non condensable gas concentration (vol%)	0.11	0.12
Steam flow rate (t/h)	17.7	31.4
Hot Water flow rate (t/h)	60	119
Separate pressure (kg/cm ² · G)	5.70	5.40
Temperature of SiO ₂ geothermometer (°C)	252.8	251.8
Enthalpy of discharge (kcal/kg)	262.6	261.2

Fig.6 shows the flow of the calculation. At first, the speciations of pre-flashed fluid are calculated from chemical compositions and flow rates of separated hot water, steam and non condensable gas. And next, both fluids are mixed and speciations are calculated in an equilibrium condition under the reservoir temperature (250°C). Consequently, possibility of scaling can be analyzed. We changed the mixing ratio of each fluid every 10%, to calculate saturation conditions of some minerals including smectite. The definition of saturation index is as follows.

$$S.I. = \log(Q/K)$$

S.I. : saturation index
 Q : activity product
 K : solubility product

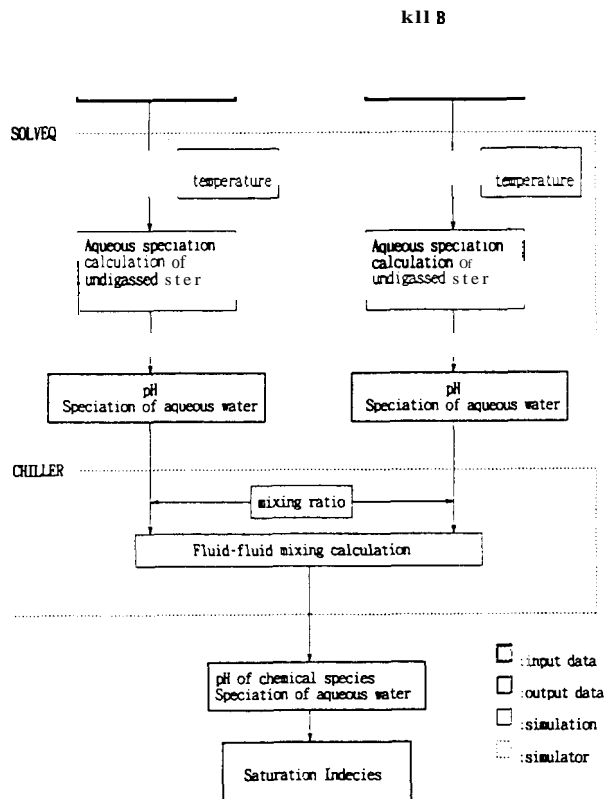


Fig.6 Flowchart of the fluid-fluid mixing calculation

Calculation results

Saturation indices of smectite, quartz, galena, sphalerite and tetrahedrite which are common scales at the Onikobe GPS and pH were calculated in each mixing ratio. The results are shown in Fig.7. The outline of the results is given as follows.

The case of 100% neutralfluid, no mixing

In this case, the fluid is supersaturated with respect to tetrahedrite, saturated with respect to quartz, but is undersaturated with respect to other minerals.

The case of the mixing ratios (acidfluid : neutral fluid) = (10%:90%) ~ (60%:40%)

Among these ratios, these fluids are supersaturated with respect to smectite. Smectite takes the maximum S.I. when the mixing ratio is 20%:80%. They are also supersaturated with respect to sphalerite, tetrahedrite and galena.

The case of the mixing ratios (acidfluid : neutral fluid) = (70%:30%) ~ (90%:10%)

Among these ratios, these fluids are undersaturated with respect to smectite. S.I. of galena, sphalerite, and tetrahedrite seem to decrease as acid fluid ratio increases.

The case of 100% acidfluid, no mixing

In this case, the fluid is still supersaturated with respect to galena, tetrahedrite, but is undersaturated with respect to the other minerals.

As there is no measured thermodynamic data of the smectite in the Onikobe geothermal field, we used the values referred to Tardy and Garrels (1974) and Kristmannsdottir (1983) in this calculation.

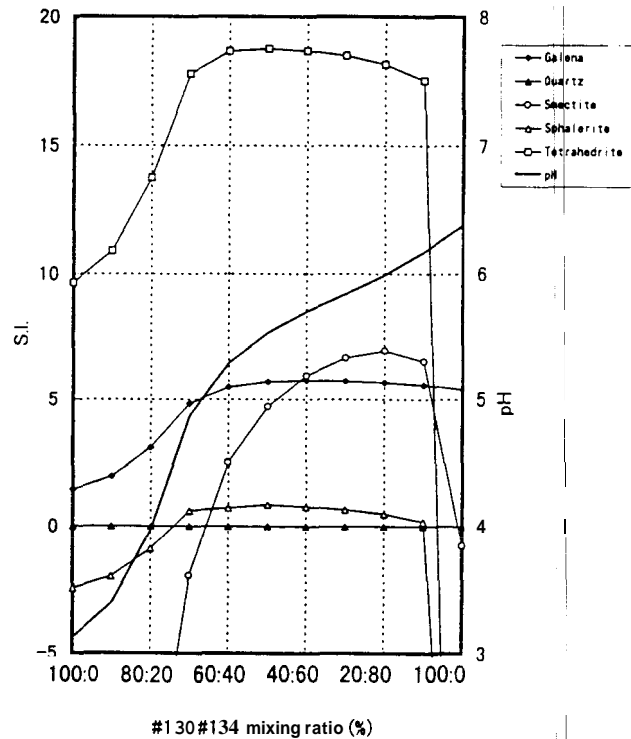


Fig.7 The relationship about S.I, pH and mixing ratio of acidfluid and neutralfluid at 250°C

Discussion

According to the chemical modeling calculation mentioned above, the fluids neither in acid nor neutral are undersaturated with respect to smectite. When the acid fluid mixing ratios are between 10% and 60% mixed fluids are supersaturated with respect to smectite, showing a peak of S.I. when the acid fluid mixing ratio is 20%. This calculation indicates that smectite has a possibility of scaling under pH conditions of 5 to 6 caused by the mixing of different fluids. In these pH conditions, mixed fluids are also supersaturated with respect to other minerals i.e. sphalerite and tetrahedrite etc., and this mineral assemblage coincides with the results of microscope observation and EPMA analysis.

When the acid fluid mixing ratio is over 70% and pH is less than 5, mixed fluids are undersaturated with respect to smectite, suggesting the possibility of scaling is low. This result coincides with the present situation, that the fluid is acid (pH is about 3.5) and there is no scaling trouble.

Although the chemical modeling calculation was executed under not a flow condition in a production well but an equilibrium condition in the reservoir, the calculation results on the saturation conditions of the smectite scale are concordant with the production history, the water characteristics history, and the scaling trouble period of well-128, respectively.

COUNTERMEASURE

The alteration zoning of the Onikobe geothermal field has been revealed with considerable precision, and it has become possible to predict chemical characteristics of the geothermal fluids. Based on the experiences of these production troubles, we have been applying revised casing designs to protect the mixing of different fluids in the recent make-up wells.

ACKNOWLEDGMENTS

We thank Dr. Hitoshi Chiba of Kyusyu University for his precious comments and recommendations on chemical modeling. We also thank Mamoru Yamada, Leader of Geothermal Engineering Group of EPDC, for giving us a chance of this presentation. Reviews of the original manuscript by Keiji Iguchi, Shigetaka Nakanishi, and Isao Shimizu helped to improve the paper.

REFERENCES

Abe, M. (1995), "Mixing of Acidic and Alkaline Geothermal Liquid," *Geothermal Energy*, Vol.20,

No.4, 364-380.

Chiba, H. (1985), "Aqueous Speciation of Geothermal Fluids and its Application to Geothermometry," *Geothermal Energy*, Vol.10, No.4, 30-43.

Chiba, H. (1990), "Aqueous Speciation Calculation of Geothermal Waters -Its Application to Geothermal Well Discharges and Limitations," *Journal of the Geothermal Research Society of Japan*, Vol.12, No.2, 113-128.

Ishii, H. and Todaka, N. (1994), "Smectite Scale in a Production Well of the Onikobe Geothermal Power Station," 1994 Annual Meeting Geothermal Research Society of Japan, Abstracts with Program, B32.

Klein, C. W., McNitt, J. R., Sanyal, S. K., Abe, M. and Nakanishi, S. (1990), "Corrosion vs. Temperature : Field Development Options at Onikobe Geothermal Field, Miyagi Prefecture, Japan," *Geothermal Resources Council Transactions*, Vol.14, Part2, 1493-1499.

Kristmannsdottir, H. (1983), "Chemical evidence from Icelandic geothermal systems as compared to submarine geothermal systems," *In Hydrothermal Processes at Seafloor Spreading Centers* (Edited by Rona, P.A. et al.), Plenum Press, New York.

Spycher, N. and Read, M. H.(1990), "Users Guide for SOLVEQ : A Computer Program for Computing Aqueous-Mineral-Gas Equilibria," Dept. of Geothermal Sciences, Univ. of Oregon

Spycher, N. and Read, M. H.(1990)"Users Guide for CHILLER: A Program for Computing Water-Rock Reaction, Boiling, Mixing and Other Reaction Processes in Aqueous-Mineral-Gas Systems," Dept. of Geothermal Sciences, Univ. of Oregon

Takeno, N. (1995), "A simulation study of alteration," *Journal of the Japan Geothermal Energy Association* , Vol.32, No.1, 64-77.

Tardy, Y. and Garrels, R. M.(1974), "A method of estimating the Gibbs energies of formation of layer silicates," *Geochimica et Cosmochimica Acta*, 1974, Vol.38, 1101- 1116.