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The Material Corrosion Test Using Small Loop System at Geothermal Power Plant in Japan

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ABSTRACT

We carried out the material corrosion test in acidic fluid at Kakkonda and Yanaizu-Nishiyama geothermal power plant using small loop test system. The loop-test system is about 2 meter depth and 3 meter wide and has three corrosion test place using corrosometer, LPR plobe and coupon test. The test coupon is approxi.30 mm length and 8mm diameter and we can insert 8 test coupon to loop system. Then the carbon steel, low alloy steel and stainless steel are set in the loop system about 1 day. The corrosion rate is calculated from weight loss of coupon. And we made estimation system of corrosion rate using previous data and temperature, pH and metal chemical composition. At Kakkonda test under pH 3.6 and 145 degree C, the corrosion rate of carbon steel (K55) is about 1.61 mm/year and closed to estimated corrosion rate about 1.5mm/year based on previous corrosion test by AIST Tohoku, from 1974 to 2002. On the other hand, the corrosion rate of carbon steel at Yanaizu-Nishiyama under pH 4.9 and 168 degree C is about 0.13 mm/year and less than estimated rate estimated rate about 0.8 mm/year. And other examined material show the difference between estimated corrosion rate and on-site rate.

1. INTRODUCTION

The scale and corrosion at the surface facilities and borehole are the major problem for development and maintain of geothermal power plant. In the case of corrosive condition, the operator have to exchange surface facilities many times or use expensive materials for the surface facilities and borehole. And in the case of many scaling field, the operator have to use the scale inhibitor. These are including cost and safety problem for operating plant. Then, we need the solution for the problem of scaling and corrosion at surface facilities and borehole to reduce the plant risk of geothermal development.

Then, New Energy and Industrial Technology Development Organization (NEDO) started the project "Research and Development of Geothermal Power Generation Technology" at FY2013. And we (GERD, AIST and TenarisNKKTubes) proposed the project of "Development of Geothermal Power Plant Risk Assessment System (Prediction, Measure and Management for Scale and Corrosion)". The proposal is accepted at FY2014 for 4 years project. The concept of the project is shown in Figure 1 (Yanagisawa et al., 2016).

The project apply geochemical and flow simulation to estimate erosion and corrosion of material and scaling at surface facilities and borehole. And the result of simulation will be checked using the database of material corrosion and scaling by previous research.

To check the result of simulation, not only the database but also the field test and monitoring is important. Then, the first feasibility study of field test is carried out at Kakkonda and Yanaizu-Nishiyama geothermal power plant in FY 2015. In this paper, we show the estimation of corrosion rate using previous test data and compare with the field test.

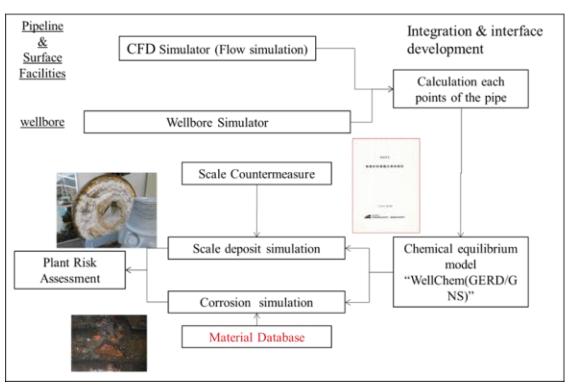

Figure 1: The concept of the project of Plant risk assessment

2. ESTIMATION OF CORROSION RATE BASED ON PREVIOUS DATA

From 1974 to 2002, the Sunshine project to develop the geothermal energy was carried out in Japan supported METI and NEDO. In this project, AIST-Tohoku branch carried out the survey of erosion and corrosion in geothermal power plant pipelines. The on-site survey was carried out at several geothermal field using production and survey well and the test needs long term over 100 days. And the several laboratory tests were carried out, for example, the stress corrosion, galvanic corrosion, acidic corrosion using autoclave and flow pipe test simulated production well. From these test, the relationship between corrosion rate and corrosion environment for different alloy elements has been summarized (Kurata et al., 1995, Sanada et al., 1995, Sanada et al., 1997, Sanada et al., 2000).

From the results of test data, the corrosion rate depends on temperature, pH and the chemical composition of material. For index of corrosion rate by material chemical composition, the idea of Cr equivalent was introduced (Kurata et al., 1992). The ratio of the contribution to corrosion resistance of Cr and elements other than Cr was deduced from the experimental data.

The Cr equivalent is calculated two type acid fluid. One is for HCl solution and the other is for H2SO4 solution. And in the case of HCl solution, the Cr equivalent is calculated as follows;

$$Creq = Cr - 13.73\ C + 1.598\ Si - 0.433\ Mn + 27.28\ P - 51.12\ S + 0.237\ Ni + 0.712\ Mo - 1.060\ Cu\ (wt\%). \quad (1)$$

And the material corrosion rate (C.R, mm/year) is calculated using temperature, pH and Cr equivalent

$$\log (C.R) = 6.696 - 1930\ (1/T) - 0.622\ (pH) - 0.085\ (Creq) \quad (2)$$

The list of calculation results of Creq is shown in Table 1. The carbon steel shows the negative value and the stainless steel shows about 20. And this value shows that the carbon steel is corrosive material.

Table 1: The list of the Cr equivalent of several materials using on-site test

	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Creq
K55(Carbon Steel)	0.45	0.24	0.96	0.022	0.025				0.01	-6.8779
TN80SS(Low Metal Alloy)	0.26	0.25	0.5	0.015	0.003	0.05	1.03	0.5		-1.73311
TN80Cr13(Stainless steel)	0.25	0.25	0.5	0.015	0.002	0.15	12.9	0		9.99301
TN110Cr13S(Stainless steel)	0.015	0.2	0.2	0.015	0.001	6	12.3	2	0.01	15.54173

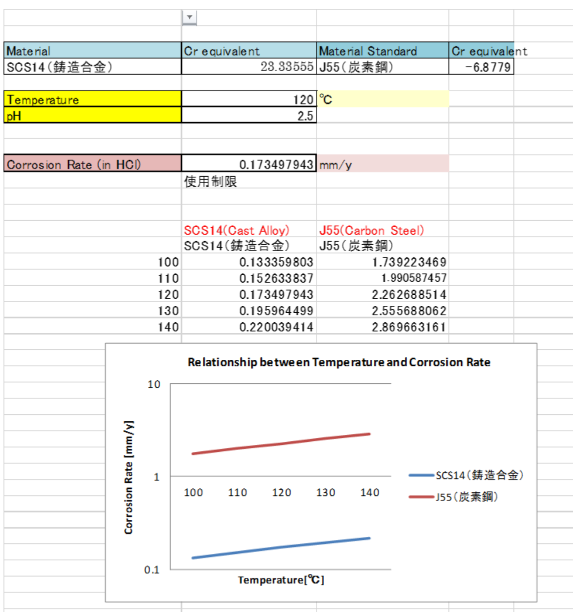

Figure 2: sample of the corrosion rate calculation system using Microsoft excel file

Based on above equation, we make the calculation system using Microsoft excel. The sample of this system is shown as Figure 2. The corrosion rate is calculated in excel system, firstly select material and indicate Cr equivalent and secondly input the temperature and pH. And in this system, the estimated corrosion rate at from 100 to 140 degree C and compare the rate between selected material and carbon steel.

3. ON SITE CORROSION TEST AT KAKKONDA GEOTHERMAL FIELD

Corrosion and materials selection for casing, wellhead and downstream equipment has been identified as a major concern. Then, in this project, Quest Integrity NZL Ltd (Quest Integrity) assisted in the design and demonstration testing of a corrosion test loop at geothermal field. Then, GERD constructed the test loop as shown in Figure 3. The loop system has three test point, the corrosometer was set at TEST1, the LPR(Linear Polarisation Resistance) probe was set at TEST2 and the several coupons were set at TEST3 in Figure 3.

In this test system, we try to measure the corrosion rate using the corroso-meter, LPR probe and cylinder coupon samples. And for cylinder coupon samples, we prepared four materials, K-55 (carbon steel), TN80SS (low alloy steel), TN80Cr13 and TN110Cr13S (Stainless steel) and the several chemical composition of materials and Cr equivalent are shown in Table 1.

The size of cylinder coupon sample is about 30mm length with 8mm outer diameter and 5.2mm inner diameter and the set of nine samples and flow direction of hot fluid as shown in figure 4 in test loop system of Test 4 and Test 5. After on-site test, we measured the weight change of the cylinder coupon samples and calculated average corrosion rate. And the temperature of test loop is controlled by the open ratio of valve at entrance of the test loop.

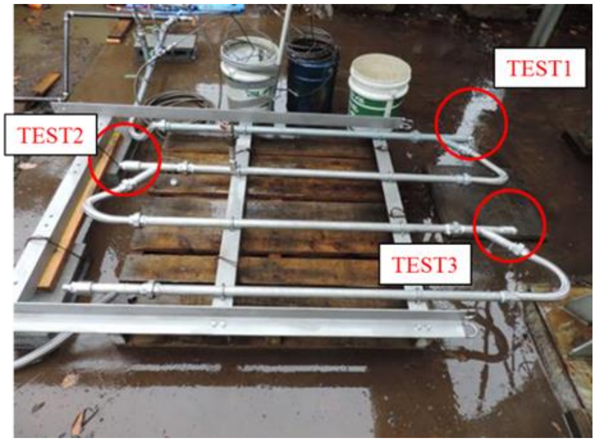

Figure 3: Corrosion test loop system at Kakkonda geothermal field

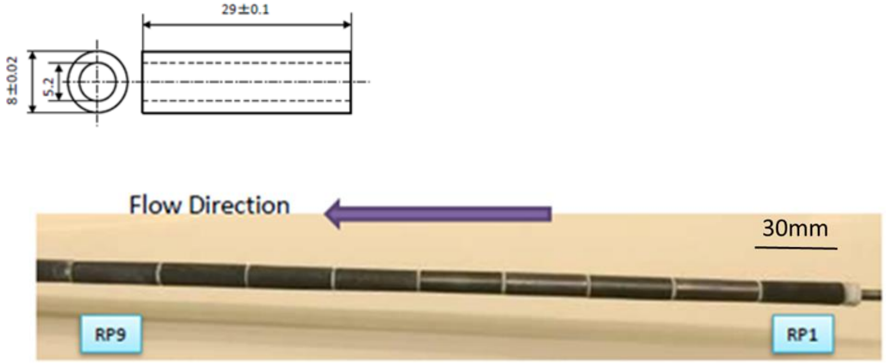

Figure 4: The size and shape of Cylinder coupon samples and flow direction of the corrosion test loop system.

And our test carried out at two geothermal field, Kakkonda and Yanaizu-Nishiyama geothermal field.

Kakkonda geothermal field is near Iwate volcano in Iwate Prefecture, north of Japan. The main geothermal reservoir exist about 1,500 meter depth and 3,000 meter depth. Deeper reservoir exist near boundary sedimentary rock and granitic rock and the fluid from this reservoir shows low pH. The geothermal power plant of Kakkonda has 80MW capacity and the 1st turbine started 1978. And the deep-seated geothermal resource survey project carried out by NEDO from 1992 to 2000 and WD-1a drilled until 3,726 meter depth, 500 degreeC.

At Kakkonda geothermal field, the test loop system is connected the hot water line separated from the production well K6-5. The geochemistry of fluid from this well as follows; pH is about 3.5, T-SiO_2 is 1,010mg/l, Na is 1,300mg/l, Cl is 2,330mg/l, Ca is 74mg/l, K is 232mg/l, SO_4 is 44mg/l and T-Fe is 25mg/l.

Yanaizu-Nishiyama geothermal field is western area of Fukushima Prefecture, north part of Japan. The main geothermal reservoir exist from 1,500 to 3,000 meter depth. The geothermal power plant of Yanaizu-Nishiyama has 65MW capacity started 1995. And the EGS field test for water injection superheated region carried out by JOGMEC from 2013.

At Yanaizu-Nishiyama geothermal field, the test loop system is connected the two-phase line separated from the production well 33P. The geochemistry of fluid from this well as follows; pH is about 4.6, T-SiO_2 is 570mg/l, Na is 5,060mg/l, Cl is 9,650mg/l, Ca is 493mg/l, K is 1,030mg/l, SO_4 is 40mg/l and T-Fe is 4.6mg/l.

In both field, we carried out several corrosion test. And to compare with corrosion estimation formula (2) in previous section, we use the data of one day coupon test as shown in figure 4. The detail of coupon test as shown in Table 2.

Table 2: The list of corrosion test at Kakkonda and Yanaizu-Nishiyama geothermal field.

	Time start	Time End	Duration (min)	Temperature (℃)	Pressure (MPa)	Flow Rate (L/min)	pH
Kakkonda-TEST4	2015/11/4 9:20	2015/11/5 8:31	1380	145	0.32	8.3	3.6
Kakkonda-TEST5	2015/11/5 9:40	2015/11/6 9:05	1410	135	0.22	8.3	3.6
Yanaizu-TEST4	2016/1/27 15:15	2016/1/28 9:15	1075	169	0.68	4	4.9
Yanaizu-TEST5	2016/1/28 13:20	2016/1/29 9:00	1030	164	0.66	7.3	4.9

The list of samples and results are shown in Table 3 and Table 4. Firstly, we measured the weight difference by flow test. But several scales such as amorphous silica and metal minerals precipitated on samples, we remove the scale by washing using several acid and NaOH and we measured the weight after DHACP and calculate the corrosion thickness and corrosion rate for each test. And we estimate the average corrosion rate as follows; K-55 is 1.61 mm/year, TN80SS is 1.61 mm/year, TN80Cr13 is 0.17mm/year and TN110Cr13S is 0.03mm/year under 145 ºC and pH 3.6 at Kakkonda geothermal field. In the case of Yanaizu-Nishiyama, we estimate the average corrosion rate as follows; K-55 is 0.14 mm/year, TN80SS is 0.1 mm/year, TN80Cr13 is 0.05mm/year and TN110Cr13S is 0.07mm/year under 164 ºC and pH 4.9

Table 3: The list of corrosion rate of test materials at K6-5 at Kakkonda geothermal field.

Material	TEST-ID	Intial weight(g)	After Exposure(g)	Difference (g)	Difference after DHACP (g)	Exposuer time(hr)	Corrosion Thickness (mm)	C.R (mm/y)	C.R. Average (mm/y)
K-55	TEST-4RP1	6.4453	6.4482	-0.0071	0.0216	23.833	0.0038	1.4	1.61
	TEST-4RP9	6.4349	6.4296	-0.0053	0.0186	23.833	0.0033	1.2	
	TEST-5RP1	6.3351	6.3387	0.0036	0.0314	23.417	0.0055	2.07	
	TEST-5RP9	6.4121	6.4181	0.006	0.0268	23.417	0.0047	1.76	
TN80SS	TEST-4RP8	6.4884	6.4805	-0.0079	0.0224	23.833	0.0039	1.45	1.61
	TEST-5RP8	6.3786	6.3698	-0.0088	0.0268	23.417	0.0047	1.76	
TN80Cr13	TEST-4RP4	6.3255	6.3241	-0.0014	0.0023	23.833	0.0004	0.15	0.17
	TEST-5RP4	6.2929	6.2909	-0.002	0.0028	23.417	0.0005	0.18	
TN110Cr13S	TEST-4RP3	6.2194	6.2196	0.0002	0.0004	23.833	0.0001	0.03	0.03
	TEST-5RP3	6.2714	6.2717	0.0003	0.0006	23.417	0.0001	0.04	

Table 4: The list of corrosion rate of test materials at 33P at Yanaizu-Nishiyama geothermal field.

Material	TEST-ID	Intial weight(g)	After Exposure(g)	Difference (g)	Difference after DHACP (g)	Exposuer time(hr)	Corrosion Thickness (mm)	C.R (mm/y)	C.R. Average (mm/y)
K-55	TEST-4RP1	6.4577	6.4605	0.0028	0.0036	18	0.0006	0.31	0.14
	TEST-4RP11	7.0621	7.064	0.0019	0.0012	18	0.0002	0.1	
	TEST-5RP1	7.113	7.1157	0.0013	0.0013	19.65	0.0002	0.1	
	TEST-5RP11	6.855	6.857	0.002	0.0007	19.65	0.0001	0.05	
TN80SS	TEST-4RP2	6.9262	6.9284	0.0022	0.0014	18	0.0002	0.12	0.1
	TEST-5RP2	6.9556	6.958	0.0024	0.0011	19.65	0.0002	0.09	
TN80Cr13	TEST-4RP4	6.9172	6.9183	0.0011	0.0004	18	0.0001	0.03	0.05
	TEST-5RP4	6.8482	6.8494	0.0012	0.0008	19.65	0.0001	0.06	
TN110Cr13S	TEST-4RP3	6.9736	6.9736	0	0.0009	18	0.0002	0.08	0.07
	TEST-5RP3	7.0637	7.0643	0.0006	0.0009	19.65	0.0002	0.07	

4. COMPARE THE CORROSION RATE BETWEEN ESTIMATION USING DATA BASE AND ON-SITE TEST

Using corrosion rate calculator of excel file shown in Figure 2, we estimated the corrosion rate of K-55 carbon steel, TN80SS, TN80Cr13 and TN110Cr13S under pH 3.6 at 135 and 145 ºC in Table 5 with Kakkonda test results and under pH 4.9 at 160 and 170 ºC in Table 6 with Yanaizu-Nishiyama test results.

At Kakkonda test, in the case of carbon steel K-55, the calculated corrosion rate is almost same as the average corrosion rate of on-site. And the TN80SS, the calculated corrosion rate is about half as the corrosion rate of on-site. On the other hand, TN80Cr13 and TN110Cr13S, the calculated corrosion rate is higher than the on-site corrosion rate.

At Yanaizu-Nishiyama test, all material shows the calculated corrosion rate is higher than the on-site corrosion rate.

Then, the equation of corrosion rate using Cr equivalent is useful for the estimation of the corrosion rate of carbon steel, K-55 in the case of one-day flow test at Kakkonda geothermal field. But in other materials, we have to check the relationship between estimation and on-site test, for example, by longer term test, in other filed or revise of Cr equivalent.

Table 5: The list of corrosion rate of test materials at K6-5 at Kakkonda geothermal field.

Material	Calculation		Field test
	135℃	145℃	On-site
K55	1.36	1.53	1.61
TN80SS	0.88	0.99	1.61
TN80SSCr13	0.32	0.36	0.17
TN110Cr13S	0.21	0.23	0.03
			(mm/y)

Table 6: The list of corrosion rate of test materials at 33P at Yanaizu-Nishiyama geothermal field.

Material	Calculation		Field test
	160℃	170℃	On-site
K55	0.8	0.88	0.14
TN80SS	0.52	0.57	0.1
TN80SSCr13	0.19	0.21	0.05
TN110Cr13S	0.12	0.13	0.07
			(mm/y)

5. SAMMARY

Several research about corrosion in the geothermal field was carried out by AIST-Tohoku from 1974 to 2002 and we have to review the activity. Especially, using pH, temperature and Cr equivalent material, the estimation of the corrosion rate was carried out. As the basis for this, the idea of Cr equivalent was introduced, and the ratio of the contribution to corrosion resistance of Cr and elements other than Cr was deduced from the experimental data.

And we compare the estimated corrosion rate using Cr equivalent with the on-site corrosion test at Kakkonda geothermal field at FY2015. The corrosion rate of carbon steel at Kakkonda is about 1.6mm/year at on-site examination and match to the result of calculation based on previous data-base.

But figures to observe one digit difference in others, in particular in the case of Yanaize-Nishiyama, shall be scrutinized furthermore in not only field test results but also calculation formula itself.

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