

The Review of the Material Corrosion under Geothermal Condition in Japan

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ABSTRACT

Recently, geothermal projects (including hot spring binary) are progressing in various places in Japan. The selection of plant material related risk management of plant (prevention scale and corrosion problem) will be important. Especially, in acidic condition with high temperature and potential region, the material corrosion problem become more serious. Then, from 1974 to 2002, the researchers of AIST Tohoku branch (in Sendai) carried out the research the material corrosion in geothermal field. But this research ended at 2003 due to budget. In 2014, we started the project of the Development of Geothermal Power Plant Risk Assessment System supported by NEDO. In this project, the data of material corrosion is important to estimate the lifetime of plant material. In this presentation, we review the research of material corrosion in Japan and show the future plan of risk assessment.

1. INTRODUCTION

In the development of geothermal power plant system, several risks are included related resource and plant operation. These risks directly related with cost and safety of operation. The resource risks are about reservoir management and environmental impact (H2S, earthquake, subsidence etc.)

And the plant risk is mainly the scale and corrosion at the surface facilities and borehole. In the case of corrosive condition (low pH etc.), 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 t surface facilities and borehole to reduce the plant risk of geothermal development.

By the way, NEDO started the project “Research and Development of Geothermal Power Generation Technology” at FY2013. The project consist four major purpose and the one of them is “Innovative Technology Development for Promotion of Introduction of Geothermal Power Plant”.

We (GERD, AIST and NKKTubes) 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. In this paper, we introduced the concept of the project and the review of the study of material corrosion and scaling.

2. THE OUTLINE OF A PROJECT

The project “Development of Geothermal Power Plant Risk Assessment System (Prediction, Measure and Management for Scale and Corrosion)” started at middle of FY2014 by GERD, AIST and NKKTubes. The concept of the project is shown in Figure 1.

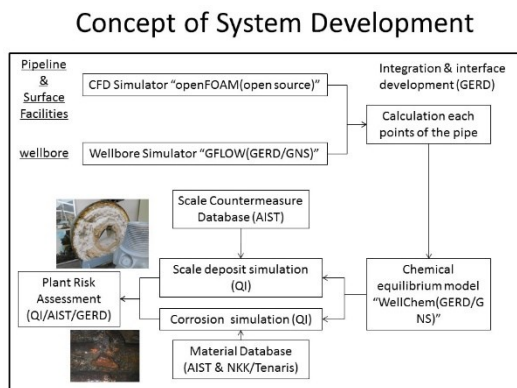


Figure 1: The concept of the project of Plant risk assessment.

The project contain the 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. In this project six small theme are carried out as follows;

- (1) Integration of Geothermal Power Plant Risk Assessment System by GERD.
- (2) Development of Corrosion, Erosion and Scale Prediction Technology by GERD.
- (3) Development of Corrosion and Scale Database by AIST.
- (4) Development of Material Selection by NKKT
- (5) Development of Field Monitoring Technology for Geothermal Power Plant Risk Assessment by GERD and AIST
- (6) Development of Site Test Technology for Geothermal Power Plant Risk Assessment by GERD, AIST and NKKT

To check the result of simulation, not only the database but also the field test and monitoring is important. The field test will be carried out the operating or developing geothermal power plant in Japan. The feasibility study of field test is carried out at Kakkonda and Yanaizu-Nishiyama geothermal power plant in FY 2015.

The concept of field test is shown in Figure 2 and the project schedule in figure 3.

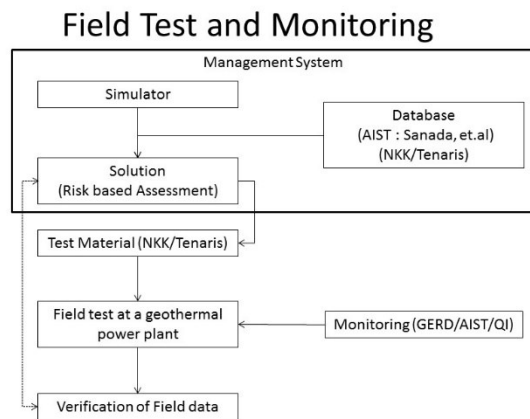


Figure 2: The concept of the field test and monitoring.

Project Schedule

	2014 August 2014-March 2015	2015 April 2015-March 2016	2016 April 2016-March 2017	2017 April 2017-March 2018
Design & Planning (GERD)	Invitation for Public Participation by NEDO (end of May to end(?) of June)			
Maintenance of Database (AIST/NKKT)	→			
System Development (GERD/GNS & QJ)	Prototype		Practical-use system	
Field Test	→			
Demonstration Test	→			

Figure 3: The schedule of the project

3. MATERIAL CORROSION SURVEY AT AIST-TOHOKU UNTIL FY2002

3.1 History of survey

The first geothermal power plant in Japan started at Matsukawa in 1966. After that, Japanese geothermal power plant faced to the problem of scale and corrosion. And after the oil shock in 1974, Japan started the New Sunshine project to accelerate the research and NEDO established in 1980.

In the New Sunshine project, AIST-Tohoku (Sendai) branch started the survey about erosion and corrosion at pipeline of geothermal power plant. The on-site survey were carried out at existing power plant (Onikobe, Matsukawa, Hachobaru) and at developing field (Yamagawa, Sumikawa). And the several laboratory test were carried out, for example, the stress corrosion, galvanic corrosion, acidic corrosion using autoclave and flow test.

In 1986, AIST-Tohoku started to make database of these survey of on-site and laboratory test. The database contains the information about material, for example, chemical composition, mechanical properties, heat treatment, size and shape and the information about fluid condition, for example, pH, chemical composition, temperature, pressure (Sanada et al., 2000).

In 1991, AIST-Tohoku started the experiment of corrosion under super-critical condition for future geothermal development using deep-seated resources. NEDO started the project of "Deep-seated geothermal resources survey" in 1992 at Kakkonda geothermal field. NEDO drilled WD-1a until 3,726 meter and the bottom temperature was about 500 degree C with high salinity brine (Kasai et al., 1998). Unfortunately, WD-1a did not reach the reservoir, NEDO tried to the sidetrack drilling until 2,600 meter as WD-1b and the material test was carried out using the fluid from WD-1b (NEDO, 1998). After this test, the material corrosion was assessed by AIST-Tohoku.

In 1997, IEA (International Energy Agency) Geothermal was established and NEDO and AIST joined several Annex of IEA-GIA. AIST-Tohoku joined the Annex -IV "Deep Geothermal Resources" and mainly survey the material based on Subtask C with Keith Lichti, New Zealand. The aim of Subtask C is the Material Evaluation Programme and exchange of information and establishment of a database on fluid chemistries, materials properties and corrosion issues, together with field testing. This activity is from 1997 to 2001 and the result of activity as follows (Sanada et al., 1997, Sanada et al., 2000);

- (1) Compile references: Over 200 papers have been listed from Geothermics, GRC Transactions et al.
- (2) Corrosion model: Corrosion models have been developed for downhole and wellhead environments under flowing conditions. These models include the corrosion chemistry and phase stability of mineral corrosion products as well as the effect of fluid velocity on erosion corrosion.
- (3) Guidelines of materials selection: A guideline has been proposed for corrosion control and materials selection for deep and acidic geothermal wells with pH values as low as 3.
- (4) Information exchanges at WGC 2000: The Japan and New Zealand participants in the subtask C attended the WGC 2000 to exchange information on the materials corrosion controls. Information exchanges of relevant research results were done with those of Italy, Turkey, USA, The Philippines, et al., as well as Japan and New Zealand.

And in 2002, AIST-Tohoku conclude 25-years survey about material corrosion and erosion. But due to main researcher retirement and budget from government ended, the material survey activity ended in 2003.

3.2 Resistivity of materials to erosion- corrosion and effect of pH

Geothermal environments vary greatly in their acidity, temperature, pressure and ion and gas concentrations. In such conditions, it is well-known that even in the same geothermal environment, similar kinds of material exhibit different corrosion behavior. Therefore, from the viewpoint of selecting a suitable material for use in geothermal energy extraction, it is very important to be able to forecast the nature of the corrosion that might be expected to occur in a given environment and to predict the extent of corrosion for a given material.

As a representative example of a simulation, the autoclave test carried out under various corrosion conditions in which the concentration of Cl⁻ was varied from 0 ppm to 1.2 x 10⁵ ppm by adding NaCl to the solutions of hydrochloric acid used. From the tests, it was found that the level of corrosion increases with decreasing pH very much so that it becomes increasingly difficult to use carbon and low alloy steels in such environments.

As one of the examples, experimental results of J55, obtained from autoclave and field tests performed in two-phase flow at a velocity of 100m/s, temperature 110 degree C and with pH between 2 and 4.5, are shown in Figure 4. Both of the corrosion and the erosion-corrosion rates for J55, and for various materials, were found to depend linearly on pH. While the corrosion rate generally increased by a factor of between 5 to 10 per unit pH, the erosion-corrosion rates were found to increase by a factor of between 10 and 50. This means that pH has a greater effect on erosion - corrosion than on corrosion.

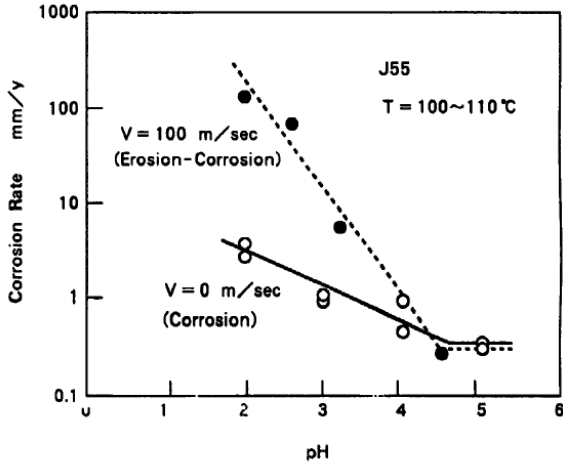


Figure 4: Effect of flow on corrosion rate (Kurata et al., 1995)

3.3 Prediction of corrosion rates

To make the above data applicable to material selection in more general environments, a relationship between corrosion rate and corrosion environment for different alloy elements has been derived (Kurata et al., 1995, Sanada et al., 1995). 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. The method of analysis is outlined briefly as follows.

$$\text{Log (C.R.)} = A_0 + A_1 \{Cr\}_{eq} \quad (1)$$

$$\{Cr\}_{eq} = Cr + B_0C + B_1Si + B_2Mn + B_3P + B_4S + B_5Ni + B_6Mo + B_7Cu \quad (2)$$

where C.R. , $\{Cr\}_{eq}$ are the corrosion rate (mm/y), Cr equivalent (mass %), respectively.

In equation (1) , alloy elements of the material are formulated by first converting to Cr equivalent, defined by (2) ; that is to say, since Cr is the element which serves as the fundamental component of corrosion resistant materials, the contributions of other elements to corrosion resistance were expressed in terms of Cr.

The pH, temperature and corrosion satisfy the following equation:

$$\text{C.R.} = K \exp\{-En/RT\} [H^+]^{-n} \quad (3)$$

where K, En, $[H^+]^{-n}$, R, are constant, activated energy, concentration of hydrogen ion, reaction degree of hydrogen ion, gas constant

Taking logarithms of equation (3), we obtain as follows:

$$\log (\text{C.R.}) = \log K + 0.4343En/ (RT) + n \log [H^+] \quad (4)$$

In equation (4), $\log [H^+]$ denotes the pH and $\log K$ is a constant based on factors, other than pH or temperature, which affect corrosion rate. Then, the corrosion rate can be related linearly to Cr equivalent and corrosion factors by

$$\log (\text{C.R.}) = C_0 + C_1 \{Cr\}_{eq} + C_2 (\text{pH}) + C_3 (1/ T) \quad (5)$$

Using the results of corrosion tests for various materials and the corresponding corrosion factors, the regression method was used to obtain the coefficients. The experimental data from other fields; comparison between the calculated and experimental data shown in Figure 5 gives reasonable agreement.

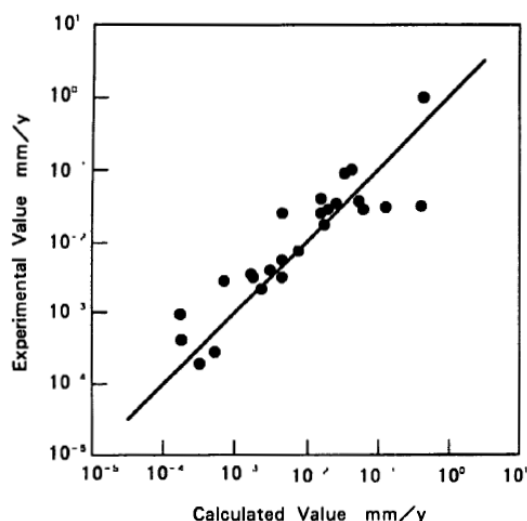


Figure 5: Correlation between calculated value and on-site experimental value at several geothermal field (Kurata et al., 1995).

4. FUTURE PROBLEM

The review of several result of corrosion test in laboratory and on-site is important to future geothermal development. The future applications are follows;

Apply to geothermal development temperature range expansion including hot spring generation of electricity and EGS and to acid fluid condition.

The corrosion and scaling condition at every location of the surface facilities (such as separator and turbine).

The estimation of the rate of corrosion and scale precipitation using initial fluid chemistry

The selection of the method of preventing scale and corrosion with the cost and the effect

The estimation of change about scale and corrosion rate with the geochemical condition

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 of 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 this method is one of part of ongoing project of “Development of Geothermal Power Plant Risk Assessment System (Prediction, Measure and Management for Scale and Corrosion)” by AIST, GERD and NKKT for future geothermal development.

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