Proceedings World Geothermal Congress 2026, Calgary, Canada, June 8—11, 2026

Development of a Corrosion Prediction Model for Casing Materials in Acidic Geothermal Environments

Masatake Sato[1]*, Koji Sakura[1], Kaichiro Kasai[1], Norio Yanagisawa[2]
Geothermal Energy Research & Development (GERD)[1]*, National Institute of Advanced Industrial Science and Technology (AIST)[2]

INTRODUCTION

Geothermal fluids significantly impact the operation of geothermal power plants. Specifically, when the geothermal brine is acidic well casings, surface pipelines, and power generation equipment, typically constructed of carbon steel, often suffer from general corrosion and erosion. Corrosion progresses in carbon steel and low-alloy steels in high-temperature environments with a pH of 4 or less. Austenitic and duplex stainless steels are known to be susceptible to Chloride Stress Corrosion Cracking (Cl SCC) pitting, and crevice corrosion, when chloride and low pH under high temperature. Furthermore, in non-aerated, hydrogen sulfide-containing geothermal environments, Sulfide Stress Cracking (SSC) can occur in materials such as martensitic stainless steels, particularly during plant shutdowns (low temperature.). Therefore, when utilizing acidic geothermal brine, it is essential to select appropriate metallic materials based on the hydrothermal conditions, the composition of non-condensable gases, temperature, pH, and other contaminants.

According to a survey conducted in fiscal year 1992 for geothermal developers (NEDO, 1992), the proportion of wells with acidic hydrothermal water (pH 5 or less) in Japan was 13.3%, and the distribution of acidic hydrothermal resources is estimated to be about 30%.

In this R&D project, we focused on Cr13S, Cr13U, and 17Cr—materials that are more affordable compared to Duplex stainless steel—and evaluated their corrosion rates in acidic hydrothermal water through laboratory experiments (Fig.1). The aim is to develop a corrosion rate prediction model from the obtained results and make it easily accessible through software, thereby assisting developers in material selection.

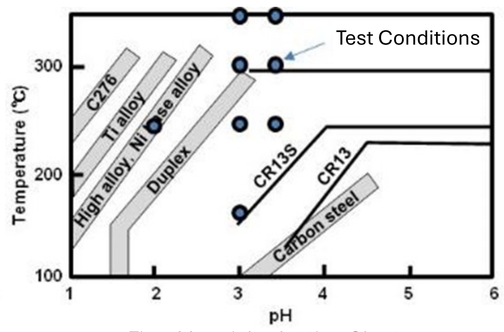


Fig.1 Material selection Chart

METHODS

Material Corrosion Test

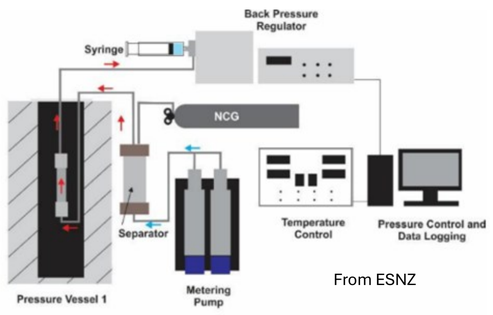
To acquire material corrosion test data in high-temperature, low-pH environments and develop a corrosion rate prediction formula based on this data. We also develop a materials selection

■ Conditions of Corrosion test
- Materials: 13Cr, Super13Cr, 17Cr
- Temperature: 150, 250, 300, 350°C
- pH: 2, 3, 3.5
- Cl- (Salinity) : 10,000ppm
- NCG in steam (Vol%): 3%
- CO2 in NCG (Vol%): 96 %
- H2S in NCG (Vol%): 4%

Test Method

Corrosion tests were conducted using a flow-type corrosion test device that continuously passes simulated hot water through the device (Fig.2). This method eliminates the effect of the rising pH of the hot water over the course of an exposure test, which is common in batch-type tests.

The National Institute of Advanced Industrial Science and Technology (AIST) performed removal of corrosion products from the corrosion test specimens, weight measurements, SEM-EDX, X-ray diffraction, and pitting analysis to obtain corrosion data at high temperatures and low pH levels.



From ESNZ

Fig.2 Corrosion Test equipment

Development of corrosion rate prediction formula

- A pH-corrected empirical formula was developed based on predicted pH at high temperatures (geochemical simulation). It was confirmed that this is possible for CO2-H2S mixed gases by weighting the effect so that CO2 is more prevalent at low temperatures and H2S is more prevalent at high temperatures (Fig.3).
- The Fig.4 below shows a comparison of experimental corrosion rate data and the calculation results of the corrosion rate prediction formula. All data plots fell within the Factor of 5 band for Super 13Cr steel, while an approximate Factor of 3 was obtained for 17Cr steel.
- This prediction formula was implemented in the "Geothermal Power Plant Risk Assessment System," making it available for detailed material selection studies for K55, CrMo, 13Cr, Super 13Cr, and 17Cr.

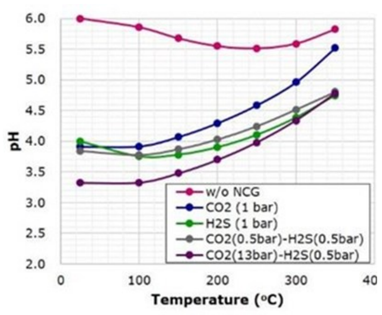


Fig.3 pH simulation

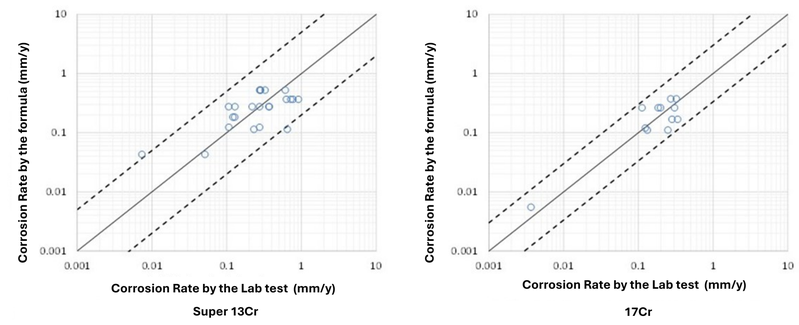


Fig.4 Comparison of corrosion rate

THE GEOTHERMAL POWER PLANT RISK ASSESSMENT SYSTEM

The Geothermal Power Plant Risk Assessment System is a software platform that integrates essential information required for the utilization of acidic geothermal fluids into a comprehensive risk assessment framework (Fig.5). The system is based on an extensive database of geothermal corrosion data originally obtained from the Sunshine Project conducted at the former Tohoku National Industrial Research Institute of AIST (National Institute of Advanced Industrial Science and Technology). To this foundation, newly acquired corrosion test data for novel materials—those with limited prior application in geothermal environments（no recommended materials between Carbon steel and Duplex)—have been added. The system was developed with the objective of providing geothermal developers considering the use of acidic geothermal resources with easy access to fundamental corrosion-related information.

The system comprises four main functions:
(1) a corrosion rate estimation tool based on empirical equations derived from corrosion test data.
(2) Material Selection chart based on these laboratory data for material corrosion.
(3) an economic evaluation tool.
(4) a database tool containing corrosion rate data and references to related scientific literature.

By combining these elements, the software integrates key information necessary for evaluating the risks associated with the utilization of acidic geothermal fluids.

Initially, the system was developed as a set of modules operating within Microsoft Excel. However, due to the increasing volume of data, resulting in slower database response times and heightened security concerns, the development policy was shifted toward creating a standalone software application.

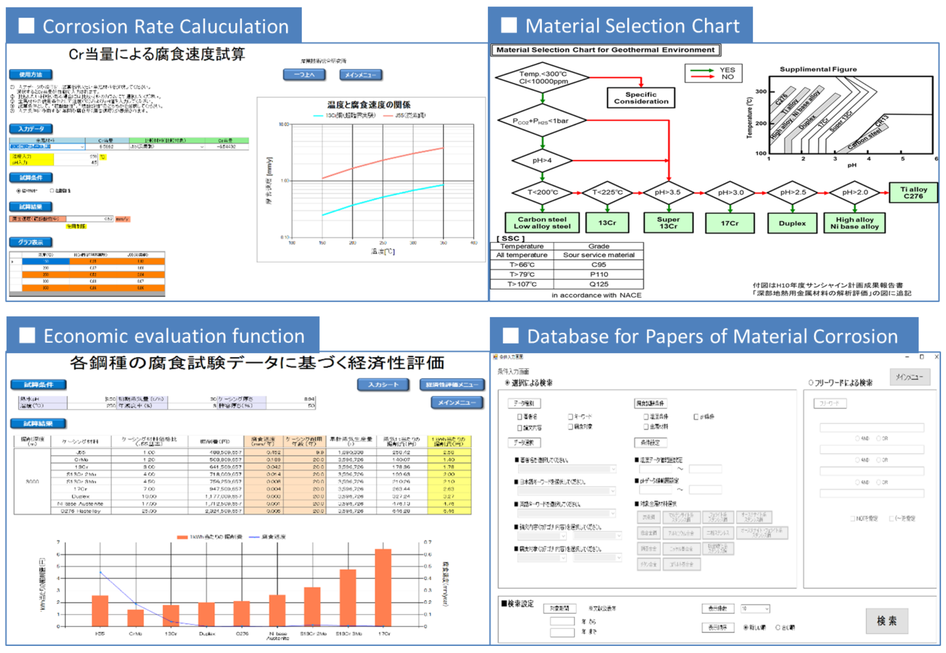
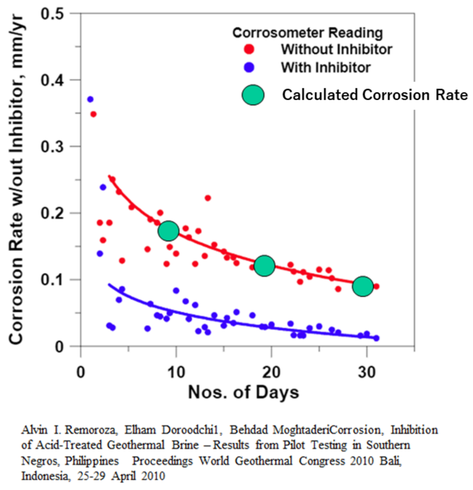


Fig.5 The Geothermal Power Plant Risk Assessment System

EXAMPLE OF APPLICATION

The corrosion inhibition test on carbon steel piping with / without corrosion inhibitor was conducted at the Nasuji-Sogongon area of the Southern Negros Geothermal Field in the Philippines. Hot brine at 160 deg.C was adjusted to a pH of 7 to 4.5 using sulfuric acid, and then cooled to 120 deg.C. This simulated the temperature drop caused by a double flash process. The adjustment to pH 4.5 was specifically to suppress the polymerization of silica and the objective was to evaluate the corrosion risk under these conditions. The mass loss method using metal coupons was employed to measure the corrosion rate, and the test was performed for over 30 days.

Regarding the empirical formula, in addition to the 24-hour value, estimates were calculated for 240 hours (10 days), 480 hours (20 days), and 720 hours (30 days), assuming a parabolic function (parabolic law). By overlaying the calculation results from the improved corrosion prediction equation onto the data from the long-term exposure test where no corrosion inhibitor was used, the predicted corrosion rates were consistent with the measured values (Fig.6). Therefore, we judged that the predicted results were consistent with the measured values, confirming the validity of the model.



Alvin I. Remoroza, Elham Doroodchi1, Behdad MoghtaderiCorrosion, Inhibition of Acid-Treated Geothermal Brine – Results from Pilot Testing in Southern Negros, Philippines Proceedings World Geothermal Congress 2010 Bali, Indonesia, 25-29 April 2010

Fig.6 Comparison with field test data

CONCLUSION

1. The risk assessment system for geothermal power plants dealing with acidic hydrothermal fluid was developed and completed with four functions implemented. Final development into software improved both response time and security.
2. Case studies confirmed that in a single-phase hydrothermal environment, which is close to the conditions of metal material corrosion tests, there was generally good agreement. For actual material selection, the preferred approach is to first use the risk assessment system for preliminary estimation, followed by on-site testing using equipment such as a loop-type corrosion test apparatus before making the final material choice.

FUTURE CHALLENGES

1. Improving the accuracy of the corrosion rate prediction formula by refining the regression equation to reflect specific case studies, as well as enhancing the prediction accuracy by collecting pH prediction data for two-phase conditions in addition to the single-phase hydrothermal conditions assumed in this project.
2. Continuous updates to the "Geothermal Power Plant Risk Assessment System" (including updated corrosion rate data, relevant literature, and case studies.) through the collection of case studies and additional data.
3. While there are few examples of corrosion tests conducted within production well bores, it is desirable that such tests be feasible in the future to improve the prediction accuracy of piping corrosion rates under two-phase conditions.

ACKNOWLEDGEMENTS

This R&D project was performed as part of research project “Research and Development of Geothermal Power Generation Technology”, funded by the New Energy and Industrial Technology Development Organization (NEDO). We also acknowledge the cooperation of Tohoku Sustainable & Renewable Energy Co. Inc. for conducting the field testing.

REFERENCES

Alvin I.Remoroza, Elham Doroodchil, Behdad Moghtaderi Corrosion, Inhibition of Acid-Treated Geothermal Brine—Results from Pilot Testing in Southern Negros, Philippines Proceedings World Geothermal Congress 2010 Bli, Indonesia, 25-29 April 2010
ASTM G1, 2017. Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.