Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Survey of the Casing Material Corrosion Problem for Supercritical Geothermal Development

Norio Yanagisawa[1], Yoshio Masuda[2], Hiroshi Asanuma[3]

[1] Advanced Industrial Science and Technology (AIST), Central 7, 1-1-1, Higashi,Tsukuba, Ibaraki 305-8567 Japan

[2]Tohoku-Center, AIST,4-2-1, Nigatake, Sendai, Miyagi 983-8551 Japan

[3] Renewable Energy Research Center, AIST, 2-2-9, Machiikedai, Koriyama, Fukushima 963-0298, Japan

Keywords: material corrosion rate, super critical, pH, Cr equivalent, geochemistry

ABSTRACT

The material corrosion is one of issue for the development of super-critical geothermal resources. To solve the problems, we tried to estimate the behavior of corrosive fluid of the several developing stage including drilling, production using Slveq-Chim by Reed (2014) and the material corrosion rate based on estimation formula using material Cr equivalent by Kurata et al.(1992). The highest material corrosion rate shows at sub-critical temperature zone from 300 to 350 degree C and higher pressure than saturation curve. This estimation results are one of important information for casing program.

1. INTRODUCTION

Recently, the survey of the possibility of super-critical geothermal system is carried in several countries (Robson et al., 2017). Supercritical geothermal systems are located at depths near or below the brittle-ductile transition zone in the crust where the reservoir fluid is assumed to be in the supercritical state. These systems have garnered attention in recent years as a possible type of unconventional geothermal resource that could yield much higher well productivities due to their very high enthalpy fluids. Supercritical conditions are often found at the roots of volcanic-hosted hydrothermal systems. Deep wells drilled in geothermal fields such as The Geysers and Salton Sea, USA, Kakkonda, Japan, Larderello, Italy, Krafla, Iceland and Los Humeros, Mexico, have encountered temperatures in excess of 374°C, and in some cases have encountered fluid entries.

In Japan, the WD-1a well drilled to a depth of 3729 m into a high temperature granitic pluton and a bottom-hole temperature of 500°C (Muraoka et al.,1998). And the super-critical geothermal survey project, IDDP project, is carried out at Iceland. From 2010 to 2012, the production test is carried out and the fluid is acidic condition (Armansson et al., 2014).

For super-critical geothermal development, the material corrosion problem became serious due to higher temperature and pressure, especially acidic condition based on HCl, H_2S, CO_2. On the other hand, many laboratory and field test were carried out by AIST-Tohoku from 1974 to 2003 supported by NEDO and METI. In this project, the survey of erosion and corrosion of material in geothermal power plant at several geothermal field and the several laboratory tests, for example, the stress corrosion, galvanic corrosion, acidic corrosion using autoclave and flow pipe test simulated production well were carried out. From these tests, 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).

In this paper, we try to estimate the pH condition and the material corrosion rate at higher temperature condition including super critical condition.

2. METHODS OF ESTIMATION

2.1 Geochemical simulation

One of the geochemical simulators, SOLVEQ-XPT and CHIM-XPT, uses a thermodynamic database (SOLTHERM-2011.XPT) up to 500 ° C and 100 MPa, and uses the extended Debye-Hückel model. Then, using SOLVEQ-XPT and CHIM-XPT, the initial state of the supercritical fluid was determined as follows.

1) The process of adding volcanic gas and 3% NaCl before mineral equilibrium was assumed.

2) The initial condition was set at 500 ° C. and 60 MPa

3) The equilibrium mineral used was made to be Na> K with quartz (Si), anorthite (Al), albite (Na), muscovite (K) etc. The chemical equilibrium system is a Na-K-Al-Si-O-H-Cl-C-S-Ca-Mg-Fe system.

4) NaCl contained in supercritical geothermal fluid may affect the pH of the fluid by becoming HCl by reaction with rocks and water. The following reaction equation was established among quartz, plagioclase NaCl, HCl, andalusite, and hot water, which constitute granite.

$1/2\ Al_2SiO_5 + 5/2SiO_2 + 1/2H_2O + NaCl = NaAl_3Si_3O_8 + HCl$

5) The gas composition to be added, the similar conditions as Kakkonda was used. Based on the analysis results of Kasai et al. (1998), the similar condition as Kakkonda was that the gas ratio was CO2: 70 vol%, H2S: 30 vol%, and the amount 0.008 mol / kg.

From the initial state at 500 ° C. and 60 MPa determined by the above process, the pH change accompanying the temperature and pressure change of the fluid was determined. The calculation range is a temperature / pressure range of fluid density 0.35g/cm3 or more at 374 ° C. or higher, and a pressure range higher than the saturated water vapor pressure at 374 ° C. or lower.

2.2 Estimation of material corrosion rate

From the results of material corrosion survey at geothermal production conditions, the corrosion rate depends on temperature, pH and the chemical composition of the exposed material. To estimate the 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 was 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%). (1)

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

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

3. RESULT

3.1 pH distribution

Fig. 1 shows the result of calculation of the range from 500 ° C. to room temperature by Solveq-Chim under the similar Kakkonda condition. At lower temperature than 320 ° C., a value near pH 4 is shown. At higher temperature than 320 ° C, the pH rises as the temperature rises, and for example, at 22 MPa, the pH shows a value of 7 or more near the critical temperature.

This rise in pH tends to be gradual as the pressure rises, but in the supercritical temperature / pressure region, the pH tends to rise as the fluid density approaches a line of 0.35g/cm^3. Also, the line at which the pH is equal is almost parallel to the line with a fluid density of 0.35g/cm^3. It suggests that fluid density corresponds with pH.

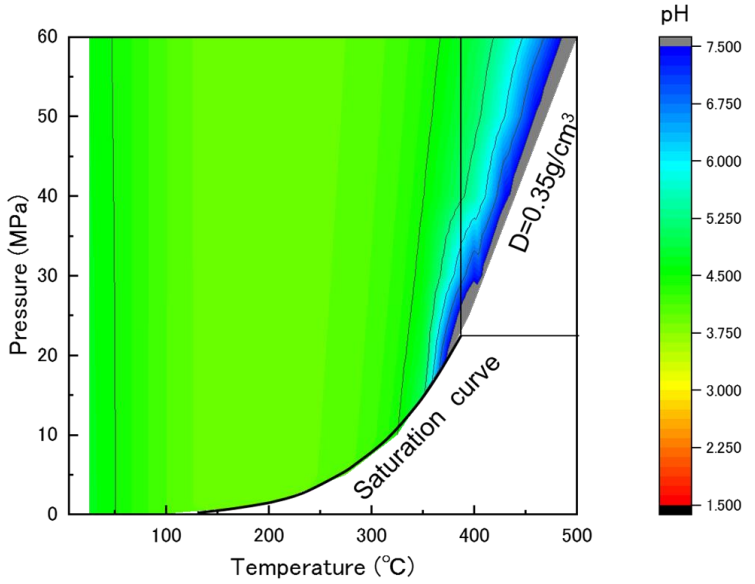


Figure 1: The pH distribution at higher pressure region than the saturation line and the 0.35 g/cm3 line under Kakkonda like condition

3.2 Material corrosion rate distribution

Fig. 2 shows the result of calculating the corrosion rate of low alloy steel (Cr equivalent, -1.7) from the material corrosion prediction equation using Cr equivalent and the result of pH and temperature. In addition, low alloy steel is assumed to be used in a well for which there is no problem in short-term use.

As a result of the calculation of the corrosion rate, in the subcritical temperature region, there is no pressure dependence and the material corrosion rate increased with the temperature rise. However, when the temperature exceeds 300 ° C., the temperature dependency rapidly becomes strong and the corrosion rate shows a peak value, and the saturated water vapor pressure shows about 2.3 mm/year at about 300 ° C. and about 3.0mm/year at about 350 ° C in the case of 60 MPa.

In the supercritical temperature region, the pressure dependency further increased, and the corrosion rate tended to decrease as the density approached 0.35g/cm^3.

Then, the corrosion rate of the material shows the peak value from 300 to 350 ° C in the subcritical temperature region, and under the similar Kakkanda condition, the maximum corrosion rate of low alloy steel is 3.0 mm

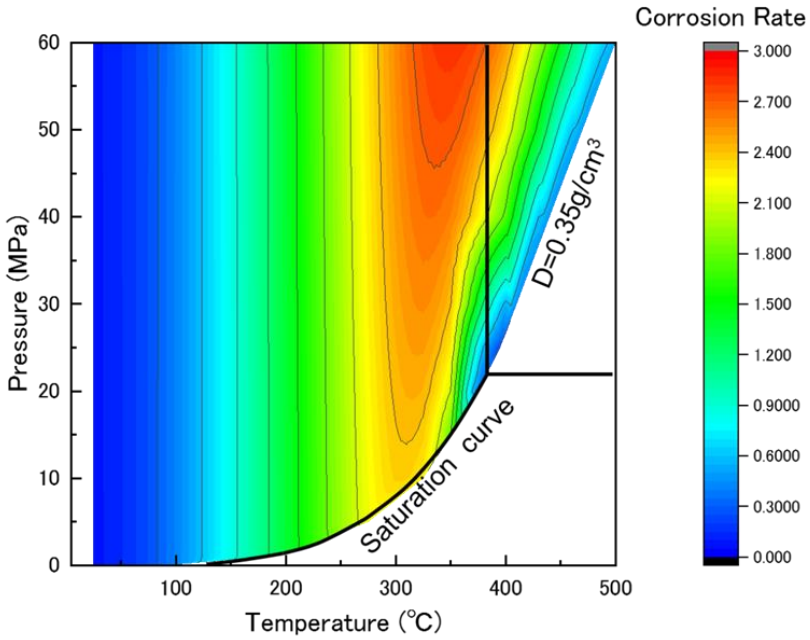


Figure 2: The corrosion rate of low metal alloy distribution at higher pressure region than the saturation line and the 0.35 g/cm^3 line under Kakkonda like condition

4. SUMMARY

(1) The pH of the liquid phase in the supercritical rock increases as the temperature rises.

(2) The temperature-pressure distribution map of material corrosion rate was prepared from the existing material corrosion prediction equation, and it was shown that the material corrosion rate is maximized in the subcritical region of 300 to 350 ° C. It has been shown that the corrosion risk is high at a depth of 300 to 350 ° C. in the well.

ACKNOWLEDGEMENTS

This paper is based on results obtained from a project subsidized by the New Energy and Industrial Technology Development Organization (NEDO).

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