

Integrated Coating System for Corrosion Protection of Carbon Steel in Artificial Geothermal Brine

Gabriela Aristia, Le Quynh Hoa, Ralph Bäßler
BAM - Federal Institute for Materials Research and Testing
Unter den Eichen 87
Berlin 12205
Germany

ABSTRACT

Corrosive geothermal brines are a major challenge to geothermal power-plants. For cost reasons, plant designers prefer to use carbon and low alloyed steels, which are susceptible to uniform and localized corrosion when exposed to geothermal brines having acidic and saline properties. To solve such problem, coatings or inhibitors would be a protective solution as an alternative to the use of high alloyed materials.

This study investigated a coating system consisting of polyaniline/silicon dioxide based on resources locally available in Indonesia. Protection against corrosion of carbon steel was shown by long-term (28 day) exposure and electrochemical tests of coated carbon steels, performed in an artificial acidic and saline geothermal brine, comparable to the conditions encountered at a site in Indonesia.

Therefore, an integrated coating system is proposed for corrosion protection, combining the electrochemical functionality of polyaniline and the physical advantages of silica.

Key words: geothermal, coating, polyaniline, silicon dioxide, corrosion

INTRODUCTION

Geothermal energy is a promising choice for alternative energy resources due to its reliability and low CO₂ emissions¹. One way to harness this energy, is to extract hot fluid from a geothermal well. Geothermal fluids are a complex medium with different physical and chemical properties depending on the location and depth of a geothermal well. Thus, these fluids can be corrosive to the geothermal power plant depending on the corrosivity class^{2, 3}. The geothermal power plant consists of various parts, such as pipelines and heat exchangers. For continuous power generation, this power plant should be safe and durable. Therefore, it is important to protect the infrastructure in this environment from corrosion.

In terms of geothermal potential, Indonesia tops the list with nearly 29 GW_e of energy savings⁴. Indonesia is located in the Ring of Fire and has unique geothermal resources, some of which are located in volcanic environments. This study focuses on the corrosion and corrosion protection of carbon steel in artificial geothermal water comparable to conditions in Sibayak, Indonesia. The Sibayak geothermal resource has a temperature range of 36 - 310 °C, and the geothermal water is saline and acidic with pH 4⁵. The combination of chemical composition and temperature-pressure condition can lead to corrosion on carbon steel⁶.

The corrosion protection of a geothermal power plant encountering acid fluids can be achieved by choosing high-alloy materials, such as titanium and nickel-chromium alloys^{7, 8}. Although these materials offer improves performance, they also have higher cost-performance ratio. Therefore, corrosion protection on carbon steel becomes an alternative to provide more options at a lower price. Corrosion protection can be provided by a coating or an inhibitor. Coatings, having several advantages over other protection methods, are effective at low costs⁹. However, protective coatings require proper application, surface preparation and corrosion analysis.

Polyaniline (PANI) is an electroactive polymer that is cost effective and can be incorporated into a coating system to improve corrosion resistance. Several methods have been developed to use polyaniline in corrosion testing¹⁰. Mixing and drop-casting scheme for corrosion protection requires chemical oxidative polymerization to produce polyaniline powder, which is dispersed in the polymer matrix, dissolved in an appropriate solvent and applied to a substrate. These methods are the simplest among all possible applications for mass production, but they are complex systems that are not so easy to understand.

Polyaniline has been used to increase the corrosion resistance of a coating¹⁰. However, for a geothermal application, the thermal stability of the coating must be improved. Therefore, a coating system was developed by combining the corrosion resistant properties of polyaniline and the temperature stability of SiO₂. Here, SiO₂ was chosen because it is one of the available materials near the geothermal site that can help reduce the production cost of such a coating system. To understand the role of polyaniline/SiO₂ addition in corrosion protection of the coating system, this study includes exposure tests, surface analysis and electrochemical tests. The results of polyaniline/SiO₂ coating were compared with bare carbon steel surface and solely alkyd coated carbon steel.

EXPERIMENTAL PROCEDURE

Specimens Preparation

Carbon Steel

Specimens used as base material to investigate the coating system were made of carbon steel (S235JR+CR, equivalent to UNS G10080), which was characterized using spark optical emission spectroscopy to determine the elemental composition as shown in table 1. Specimens for the exposure test were prepared having a dimension of 50 mm × 20 mm × 4 mm, and a hole was drilled with the diameter of 5 mm to arrange the specimens in an autoclave. Specimens for electrochemical measurements were prepared with the dimension of 20 mm × 15 mm × 4 mm and spot welded to a Ni/Cr based rod with the diameter of 2 mm. Both types of specimens were ground using SiC paper up to the grade of 320 grit and rinsed using acetone.

Table 1: Elemental composition of carbon steel based on spark emission spectroscopy

Element	Fe	Mn	Cu	C	Cr	Si	Ni
Composition (%)	99.28	0.3085	0.0789	0.0697	0.0564	0.049	0.0448

Element	Al	S	P	Sn	Ti	V	Ca
Composition (%)	0.0325	0.0229	0.0115	0.0023	0.0013	0.0012	0.0005

Element	B	N	Mo	Co	W	Nb	Ta	Pb
Composition (%)	0.0002	>0.0240	<0.01	<0.01	<0.01	<0.005	<0.002	<0.001

Coating System

Polyaniline was prepared by chemical polymerization by dissolving 0.2 M aniline in 1.2 M phosphoric acid with the total volume of 200 mL and preserved for 2 hours at 5 °C in a climate chamber. The oxidizing agent, ammonium peroxodisulfate (APS), with the concentration of 0.25 M (100 mL) was added dropwise while stirring the solution to obtain a homogeneous solution. Then, the solution was kept undisturbed in the climatic chamber with the temperature of 5 °C for 12 hours to carry out the polymerization. Polyaniline was filtered and purified with bi-distilled water and acetone to avoid the presence of oligomers until the pH of the filtrate reached 7. Polyaniline was then dried at room temperature for 24 hours.

Polyaniline powder was characterized by Fourier-Transform-Infrared (FTIR) spectrometer to confirm its functional group. In addition, UV-VIS spectrometry was also performed to indicate the electronic state of polyaniline. SiO₂ was tested in combination with an alkyd coating using Thermo gravimetric analysis (TGA) to identify the thermal stability properties of the coating system, which are affected by the thermal resistance emanating from SiO₂.

In this experiment, commercial marine coatings from PT Bintang Energi[†] in Indonesia were used, which are alkyd-based marine coatings, containing CaCO₃. The formulation of the investigated coatings was 10 g of the total mixture of binder and pigments which then dissolved in 5 mL methyl iso butyl ketone (MIBK), using an orbital shaker with 225 rpm for 30 minutes. Pigments of PANI and SiO₂ were added to the binder and solvent as described in our previous paper⁹.

Coatings were applied on the surface of carbon steel that were previously mechanically ground up to 320-grit SiC paper by gravity feed double action air brush BELKITS[†], with the standard needle and nozzle diameter of 0.25 - 0.3 mm. The air brush was used with the air pressure of 2.5 bar. The specimens were then left in the dust free area until they became dry.

Conditions

Electrolyte used in the experiments was artificial geothermal water based on a geothermal brine found in Sibayak, Indonesia^{5, 6} shown in table 2.

Table 2: Chemical Composition of Artificial Geothermal Water.

Cont.	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	Ca ²⁺	K ⁺	Na ⁺	pH _{25°C}
mg/l	1,500	20	15	200	250	600	4

Experiments were performed at room temperature with argon purged throughout the experiments to avoid oxygen in the solution. At 150 °C, the experiment was performed in an autoclave and an initial partial pressure of 500 kPa argon was specified to achieve a total pressure of 1 MPa during the measurement. For both experiments, a three-electrode system was used with carbon steel and coated carbon steel as the working electrode, Ti/TiO₂ mesh as the counter electrode, and a KCl saturated Ag/AgCl electrode as the reference electrode (figure 1).

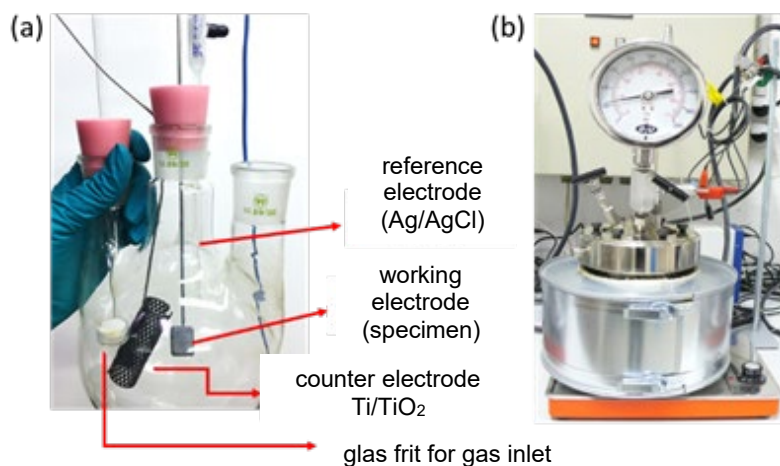


Figure 1: Test setup for electrochemical experiments at (a) room temperature and (b) at 150 °C

After the exposure test, the specimens were analyzed with an optical microscope to observe the change in the surface. FTIR was also performed to identify the change of the functional group in the coating system, which was affected by the exposure time.

[†] Trade Name