

Coatings to Regulate Scaling in Geothermal Applications

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ABSTRACT

This paper explores the possibility of using thermal spray coatings to engineer the substrate surfaces and modify the scaling behaviour in simulated geothermal environments. The coatings were pre-selected based on the performance data in literature, ease of application, availability and cost. The philosophy was to select coating types that facilitate and/or retard the formation of surface scales, by investigating modifying the coating properties through a matrix

of process parameters. Gas pressure was selected as a variable to modify the topography and surface roughness of the deposits. Carbon steel substrates were coated with different coating materials and water contact angle measurements were carried out. These measurements provided an indication of possible wettability of the coatings, and allowed further down-selection in conjunction with optical profilometry. The down-selected coatings were tested in simulated scale-forming conditions for 96 h followed by detailed post-test characterisation (photography, light and electron microscopy).

Keywords: Surface area, Scaling, Thermal spray, Geothermal brine

INTRODUCTION

Geothermal Energy is currently engineered as an “always on” baseload supply, due to the limited flexibility to throttle the well without scaling and fatigue issues, and it is engineered for maximal efficiency at this output level.^{1,2} Scaling is a major problem in geothermal plants, particularly in cases where the geothermal fluid composition and plant operation make it difficult to control scaling.³⁻⁵ In such areas, particularly where scale inhibitors cannot be employed,⁶ the formation of scales can make the process less efficient and in extreme cases can lead to unexpected shutdown.

Scaling is not only dependent on the geothermal fluid chemistry and operational conditions,³ it also depends on the surface properties of the materials⁷ in contact with the geothermal fluid. Geothermal fluids containing high silicate⁸ and carbonate⁹ content have shown propensity to scale due to changes in pressure and temperature during unit operations and processes associated with geothermal plants. Carbonate scaling, particularly in the form of calcium carbonate is well known in geothermal plants working with limestone or dolomite aquifers.¹⁰ These are more common in low to medium enthalpy geothermal facilities.¹¹ In contrast, silicates (or silica) is widespread in high enthalpy geothermal fields.¹² Sulfates, sulfides, oxides and hydrated oxides can also form scales.^{13,14} Some chlorides can also form scales (silver chloride, lead chloride etc), but nitrates do not as metal nitrates are soluble in water.

To ensure maximum benefits and smooth running of geothermal plants, one needs to modify the design in order to influence the scaling. For example, if scaling is unavoidable due to the physics of the process, then controlling the region where scales form might be beneficial in terms of both maintenance and repair.⁵ To explore this idea, work was undertaken to engineer the substrate surfaces and modify the scaling behaviour using thermal spray coatings.

As one of the most reliable and economical of all thermal spray coating processes, the twin-wire arc spray (TWAS) process was selected to coat specimens. The coated specimens were tested for the scaling behaviour. Unlike other thermal spray processes, the droplet size of the consumable formed in TWAS is determined by the process parameters rather than the feedstock material. The heating of the wire tips, and the drag and magnetic forces can influence the particle distribution, hence modifying the resulting coating microstructure and properties. The effect of gas pressure, type, but also voltage on coating properties and droplets were thoroughly investigated^{15,16,17} and it was shown that a large increase in droplet sizes was measured when reducing the gas pressure, but also when changing parameters such as voltage and current. These parameters, potentially altering the surface profile of the coatings and their wettability, were investigated in this study.

This paper presents the scaling behavior of TWAS coatings when tested in simulated geothermal environments.

EXPERIMENTAL PROCEDURE

Materials

Carbon steel (50x20x5 mm) was used as the substrate in this study. Prior to the thermal spray process, angular alumina (type NK36) at 100 psi was used to grit blast the substrates to Sa 2.5. Coatings were deposited from three different wires whose composition is detailed in Table 1.

Table 1 Chemical composition of alloys used for the deposition of thermal spray coatings

Alloy	Al (wt.%)	Zn (wt.%)	Mg (wt.%)	Cu (wt.%)
Al 1100	99.5 min	0.1	-	0.2 max
ZnAl	15.0	85.0	-	-
Zn	99.99	-	-	-

Thermal spray coatings

TWAS coatings were prepared using a Metallisation 528 arc-spray system with 2.3mm diameter wires drawn continuously from two separate spools using a gun wire pull system. The drive unit for this system includes a constant mesh gear system powered by an electronically-controlled electric motor giving variable speed control. Table 2 Twin-wire arc spray process parameters summarises the process parameters maintained throughout the coating deposition. A thickness of 300 μm was selected as a target for all samples.

Table 2 Twin-wire arc spray process parameters

Alloy	Wire diameter (mm)	Wire Feed rate (m.min^{-1})	Spray Distance (mm)	Increment step (mm)	Traverse speed (m.s^{-1})	Voltage (V)	Current (A)
Al 1100 ZnAl Zn	2.3	5.0	95.0	10.0	0.45	33.0	200

In order to modify the droplet formation mechanism gas pressure was varied for each deposited material. The spraying air pressure and sample labels are detailed in Table 3.

Table 3 Sample labels and process parameters

Material	Al 1100			ZnAl 85/15			Zn		
Pressure (bar)	6	4.5	2.8	6	4.5	2.8	6	4.5	2.8
Label	Al-P1	Al-P2	Al-P3	ZnAl-P1	ZnAl-P2	ZnAl-P3	Zn-P1	Zn-P2	Zn-P3

Contact angle measurements

The wettability of the deposited coatings was examined via the measurement of contact angles between a liquid droplet and the coated sample surface. Contact angles with water were measured using a Kruss drop sample analyser (DSA). A total of nine measurements (three measurements at each of three different locations) were taken per coating. Droplets were deposited on the surface using an automated syringe, and contact angle was measured on photograph taken by a camera.

Surface characterization

Chemical composition of the samples was evaluated after exposure using scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). For imaging, backscattered electron images (BSE) were presented in the document to highlight the difference in composition of the elements on the samples' surfaces.

Optical profilometry

A non-contact 3D optical profilometer (Alicona InfiniteFocus SL) was used to characterise the surface topography of the deposited specimens using a 5x objective lens. The analysed area was 15 mm x 15 mm for each coating, located in the centre of the sample.

Sample preparation for scaling tests

Prior to the scaling tests, a protective paint was applied to the back, side and edges of all samples, leaving one face exposed. The paint, Belzona 1593*, was applied in two layers, applied less than 24 hours apart.

Simulated brine

The solution chemistry used in the simulated environment was based on the field conditions measured in a geothermal power plant after a low pressure separator. The solution composition for the tests was chosen to include elements that would be corrosive to the metals

*Trade name

and alloys, control the pH and would be involved in the scaling process (e.g. SiO_2 , Ca, Mg, Cl). In order to make the solution, the SiO_2 was dissolved into 0.1M NaOH before being mixed with a solution of $\text{NaHCO}_3/\text{Na}_2\text{CO}_3$. Chloride was then added as $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ to reach pH 8. The exact composition of the brine prior to testing was measured and is presented in Table 4. CO_3^{2-} analysis was conducted by acid titration, while other elements were measured by Inductively Coupled Plasma-mass spectrometry (ICP-MS).

Table 4 Elements of the simulated geothermal brine

Element/species	Cl	Na	Si	Ca	Mg	CO_3^{2-}	HCO_3^-
Concentration (mg/L)	1003	2544	67.5	7.2	14.9	0	4297

Scaling tests

Scaling tests were conducted on the coated samples. Samples were each placed in individual glass baskets in a 2L vessel. Two separate tests were conducted, the first one contained 4 coated samples and a reference sample (bare carbon steel), while the second one contained 5 coated specimens and a reference sample. In both vessels, simulated geothermal brine was poured under air and the temperature of the solution was raised to 100°C , maintained for an hour, then cooled to 50°C , and held for 96 hours. The tests conditions were selected to ensure the completion of the scaling process based on the species present in the brine. The temperature was raised by a heating jacket. Figure 1 shows the photographs of the set-up used for the two tests, with two type K thermocouples per reactor (one being connected to the heating jacket, the other to the inside of the vessel), as well as the samples placed in their glass baskets.

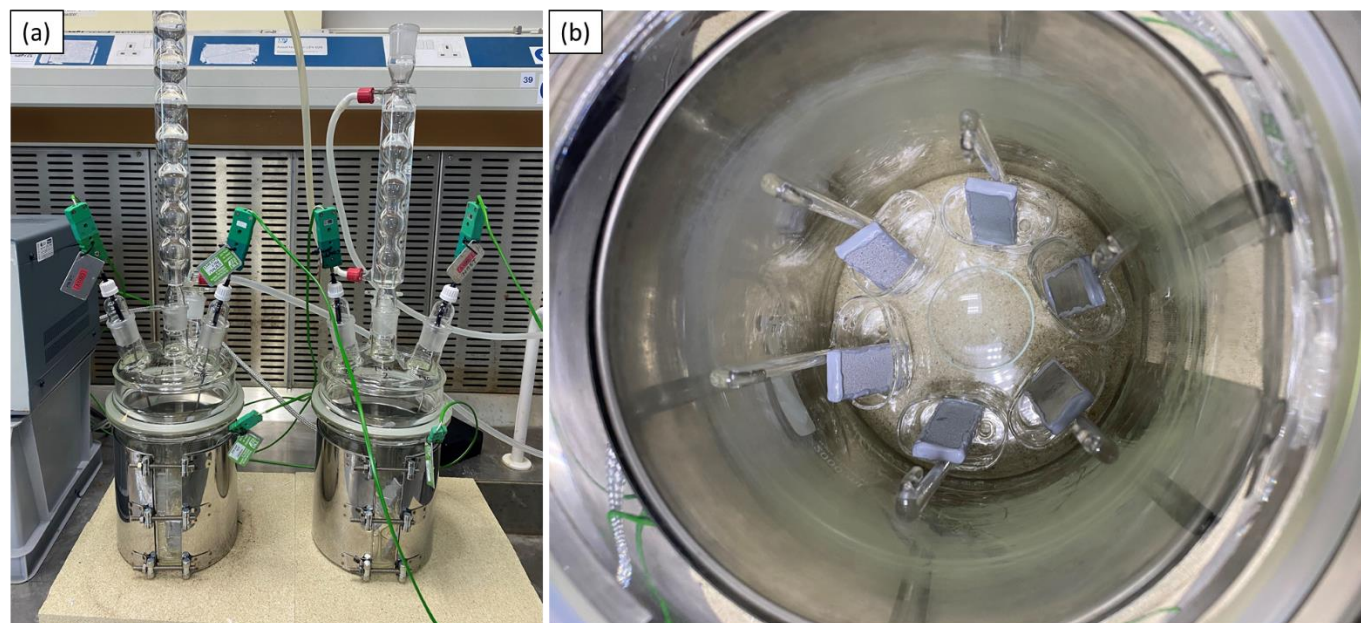


Figure 1 Photographs of (a) set-up showing both reactors tested in parallel, with their heating jackets, condensers and type K thermocouples, and (b) samples in their baskets positioned in the reactor prior to testing