Corrosion and scaling at Cerro Prieto geothermal field

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Abstract

Purpose – The aim of this work is to study the corrosion and scaling factors, mechanisms and processes affecting the materials, equipment and installations of the Cerro Prieto geothermal field (GTF).

Design/methodology/approach – The physicochemical characteristics of the geothermal well and fluids were analysed, recorded and related to the corrosion and scaling phenomena.

Findings – The high temperature and salinity of the steam-brine mixture and the presence of hydrogen sulphide and carbon dioxide impart a severe level of corrosivity.

Originality/value – Corrosion and scaling control assure an efficient production regime, provide for the durability of the GTF engineering materials and equipment and contribute to environmental quality.

Keywords Geothermal power, Pollution, Corrosion

Paper type Research paper

Introduction

The geothermal (GT) energy facilities installed around the world generate more than 8,000 MW of electricity; conditions for the exploitation of GT resources vary depending on specific situations in each country.

Problems of scaling and corrosion have an important impact on the infrastructure used for production and conduction of GT steam, electric energy generation turbomachinery and facilities to cool and handle the condensates. Corrosion and scaling processes affect the operating efficiency and cause economic losses that diminish the opportunities to recover the capital investment. To a greater or lesser degree, energy production and plant life have been affected by corrosion failures or scaling which occur in the infrastructure of geothermoelectric installations.

The GT fluids contain dissolved minerals that put constraints on the design and operation of the GT resources. Minerals are deposited at different areas during the production and the operation stages and they affect adversely the power generation capability. Usually, calcite, silica, sulphides and sulphur are deposited from GT fluids.

Silica scaling is the main obstacle in the high temperature hydrothermal system.

The silica present in the hot GT fluid is very soluble, but after the flashing process the fluid cools off and the silica solubility decreases, inducing the formation of silica scale. Not all the scales are formed through precipitation reactions during the production of the GT fluid; many fine solid particles which previously existed in the rock matrix of the reservoirs migrate with the fluid and incorporate into the encrustation layer.

Control of scaling problems becomes a high priority activity in the maintenance and operation program of the GT fields (GTF). On the other hand, corrosion of metallic components of the GT infrastructure requires specialized engineering teams capable of performing detailed diagnostics of the deterioration of metals and making recommendations for appropriate methods of prevention and control.

The information provided in this paper is focused on experiences with scaling and corrosion processes occurring in the GTF of Mexico, mainly at Cerro Prieto (Figure 1), where the climate conditions and the physicochemical characteristics of the GT fluid (brines, water and steam) promote the occurrence of these phenomena.

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Figure 1 Geothermal field at Cerro Prieto

Geothermal fields

The central function of a GTF is to provide steam, at the appropriate temperature and pressure, to operate steam turbines for the generation of electrical energy. Some GTFs use the steam for district heating and to supply thermal energy for industrial plants. The fluids currently encountered in a GTF are steam, a mixture of steam and water, and salt-rich brine. The high temperature and salinity of this environment, and the presence of hydrogen sulphide and carbon dioxide, make them very corrosive.

Several GTFs are under exploitation to generate electricity in Mexico with an installed capacity of 953 MWe. Currently, there are four GTFs in production:

1. Los Azufres.
2. Los Humeros.
3. Las Tres Virgenes.
4. Cerro Prieto.

Mexico is one of the leading countries in GTF development for electricity production (Bertani, 2006).

The geothermal field in Cerro Prieto

This is the most important development in Mexico; it is located on the alluvial surface of the Mexicali valley, Baja California. The plain is a delta and the geological section is made up of unconsolidated clays, sand and gravel, which rest on sedimentary rocks of sandstone, lutites and limonites.

Cerro Prieto is the largest liquid-dominated reservoir in the world. Commercial electricity generation started in 1973 with the first power unit of 37.5 MW, operated by Comision Federal de Electricidad (CFE), which is the owner of the electricity industry in Mexico. Its capacity has been increased to reach 720 MW distributed in four power plants. About 350 wells have been drilled during the 35 years of development of this GTF, to depths ranging from 700 to 3450 m. Today, 160 wells are supplying about 5500 t/h of steam necessary for the power plants.

The soils at Cerro Prieto around the GTF are acidic with a pH 2-3, as H_2S is oxidized to H_2SO_4 and to sulphur (S), covering the land with yellow spots of sulphur (Galindo, 2006). Cerro Prieto operates a large network of pipelines that includes 120 km of carbon steel (CS) ducts for the transmission of steam and 40 km of CS pipes and 60 km of open reinforced concrete (RC) canals for the transportation of brines.

The production capacity of the wells is affected by boiling, corrosion and scaling problems. Cerro Prieto is studied continuously using the most advanced techniques and tools in order to understand its physicochemical changes. In addition, maintenance procedures are improved constantly to avoid the loss of steam production.

Materials, equipment and installations

The industrial equipment, structures and installations of GTFs are built of two engineering materials: CS and RC, the latter with a surface of low porosity to avoid the penetration of well water and dissolved brine minerals and future corrosion. Because of its useful properties, including high strength, ease of machining and welding, and low cost in comparison with other metallic or plastic materials, CS is the basic fabrication material used for well casings, pipelines, storage tanks, mechanical cables and machinery. However, due to its limited corrosion resistance to GT waters, it should be protected by paint, coatings and cathodic protection system, as necessary. Plastics and modern composite materials with higher corrosion resistance are replacing metallic materials where their performance is adequate. An abridged list of equipment for GT well (GTW) and brines is given in Table I. This equipment suffers from different forms of wear: erosion, abrasion, fatigue, disintegration, stress, aging and particularly wet corrosion.

Geothermal wells

The corrosion and scaling behaviour of fluids in the GTW, derived from their chemical composition, is related directly to the geological formations with which the fluids interact and percolate as they rise through the well. Two central, dominant parameters of a GTW are the heat and salt content of its fluids. Therefore, it is called a thermo-halide system. These parameters strongly influence corrosion and scaling when they react with the surface of the equipment and installations of the GTF. Corrosion behaviour is influenced by their high mineral content, including aggressive chloride (Cl^-) and sulphate (SO_4^{2-}) salts, which impart high electrical conductivity (about 3,000 μS/cm) and favours the electrochemical corrosion process. In addition, the GT fluids contain corrosive and toxic gases, e.g. H_2S, which enhance corrosion. The construction of a GTW involves the

Table I Industrial equipment and materials in geothermal fields

Equipment	Materials of construction
Pipes, tubes and ducts	Steel, reinforced concrete
Pumps, vertical and centrifugal	Steel, brass, bronze
Valves, diverse types	Steel
Fittings and flanges	Steel
Silencers	Reinforced concrete, steel
Brine canals	Reinforced concrete
Geotextiles, sedimentation ponds	Plastic, rubber
Monitoring and safety instrumentation	Metals, plastic

use of higher strength, erosion and abrasion resistant CS pipes through subterranean formations. The following American Petroleum Institute (API) steels are utilized: J-55, K-55, C-75, N-80 and L-80. Sometimes, due to high stresses, the steel tubes crack, fail and drop to the bottom of the hole, making special operations necessary to recover drilling tools and pipes (Valdez *et al.*, 1999). Larger diameter production casings made with special API steels and high-resistance pipe collars and threads have been implemented in the last decade. In some wells the pipes have been conventionally perforated with bullets and other have been completed with open hole designs. The wells have depths in the range 700-2,600 m and the down hole temperature ranges from 300 to 340°C.

The correct design, installation and maintenance of the well, its casing and other internal equipment are essential for an efficient, cost-effective, energy-saving production program. Unfortunately, some wells produce fluids impairing the tubular hardware in the well, the cement used to secure the casing in place, and sealing off extraneous and offensive zones.

The GTW generate naturally occurring corrosives such H_2S-containing brines. If these fluids are not controlled, they can corrode the internal well equipment, e.g. the tubular hardware. After the removal of some dissolved components through sedimentation, part of the remaining water is returned to the aquifer in reinjection wells. Injection tubing in disposal wells has the largest and most intimate contact with the corrosive effluents. It should be completely inert to the injected fluid and that is achieved by employing fibre reinforced plastic (FRP) tubing or tubing made from corrosion resistant alloys, but these alloys are expensive and therefore they are sometimes employed as liners on CS.

The cementing materials between the well bore and the steel casing must provide chemical resistance to the well fluids involved. The separation of the liquid brine from the steam is carried out in the steel surface equipment and installations mounted on the platform of each well. The basic wellhead equipment includes a valve assembly ("Christmas tree"), a high pressure and/or low pressure separator, a spherical valve, a flow line for separated brine, a silencer, and monitoring and safety tools.

Reinforced concrete (RC)

RC is considered a structural composite material formed by a ceramic matrix and reinforced by steel bars, rods, spiral or mesh. The matrix consists of a non-homogeneous mixture of Portland cement, aggregates of sand, gravel and water. The characteristics of the concrete are largely determined by the water/cement ratio; the lower the water content, all else being equal, the stronger the concrete. Concrete has a great propensity to change moisture content depending on its location and climate. The durability of the concrete structures is affected by the environmental factors, especially salinity and humidity. Low temperature during harsh winters in the desertic region of Cerro Prieto adversely affects its strength. Other external factors that cause deterioration in concrete in GTFs are sulphates, chlorides, carbonates and hydrogen sulphide. The salts $MgCl_2$ and $MgSO_4$ damage concrete surfaces during hydrolysis, reacting chemically with the calcium hydroxide [$Ca(OH)_2$] generated during the cement curing, producing calcium sulphate ($CaSO_4$). After that, calcium sulphate reacts with the aluminates present in concrete and increase the solid volume, causing expansion and cracking. The steel reinforcement exposed to infiltration of chemical species, such as chloride salts, is corroded and also is susceptible to failure (Rogers, 1999).

The susceptible concrete structures function as support bases of buildings, steam silencers, ditches and steam pipelines. All the concrete structures at Cerro Prieto are in various stages of degradation due to the GT aggressive environment. Figure 2 shows the deterioration by corrosion of brine conducting canals and the RC of the silencer house building.

Reinforced plastics

Reinforced plastics, e.g. fibre-glass reinforced polyester (FGRP) or epoxy, are composite, structural materials widely employed in GTF for the evaporative cooling towers, components for pumps, tubes, storage vessels, and as coating for GTW casings.

The degradation of FGRP usually starts at the outer surface; the rate depends on its properties, nature of surface finish and the environment aggressiveness. The glass-resin interface breaks down and mechanical properties are lost under the influence of the GT salts and H_2S, which cause gradual fractures and spalling during long-term exposure. By proper fabrication, inspection and maintenance, a long service life can be achieved by FGRP equipment.

Figure 2 Deterioration by corrosion of brine conducting canals and silencer house built with reinforced concrete

Corrosion: chemical, mechanical and thermal effects

Corrosion and scaling phenomena often appear simultaneously and act synergistically in equipment and installations of GTFs. Mineral scales and deposits, associated with GT water composition and circulation, have a marked effect on corrosion. They occur in these waters depending on their physicochemical interaction with the equipment surface, the operational conditions such as pH (4-8), dissolved oxygen (DO) content (4-6 mg/l) flow-regime and temperature (30-340°C). The dominant corrosion factors are salinity and the DO concentration. Salinity influences the brine electrical conductivity. The chloride ion also affects the oxide layer by penetrating the passive film. It can initiate pitting and crevices at localized sites. Localized attack results from differences in aeration, concentration, temperature, velocity and pH. It occurs as pits, crevices, cracks, grooves and eroded parts.

Two different domains and mechanisms of corrosion prevail:

1 Acidic corrosion under the preponderant influence of H_2S in the well casing, tubing and near the wellhead.
2 Neutral corrosion by the cathodic reduction of DO in the pipelines running from the wells to the GT plants and the evaporation ponds.

Various corrosion agents and processes which occur in GTFs are described below.

Acidity, gases and salinity

An acidic corrosion mechanism is established in the well casing, and pipelines, resulting in the overall reaction:

$$Fe + H_2S \rightarrow FeS + H_2. \qquad (1)$$

H_2S is a colourless gas with an offensive odour reminiscent of rotten eggs. It is a weak reductant, toxic and corrosive acid, which originates from the well hydrothermal pyrites by natural acidification. It bubbles into the atmosphere at the wellhead, corrodes steel and ductile iron, and forms a suspension and/or deposit of black iron sulphide (FeS), typical of sulphide attack (Schorr *et al.*, 2006). FeS can exist in a number of minerals such as FeS pyrrhotite (FeS), pyrite (FeS_2) and others, depending on the operating conditions of pipes, H_2S concentration, temperature and pH. Upon exposure to oxygen, the H_2S gas might oxidize to iron oxide and sulphur:

$$2FeS + 1.5O_2 \rightarrow Fe_2O_3 + 2S^0. \qquad (2)$$

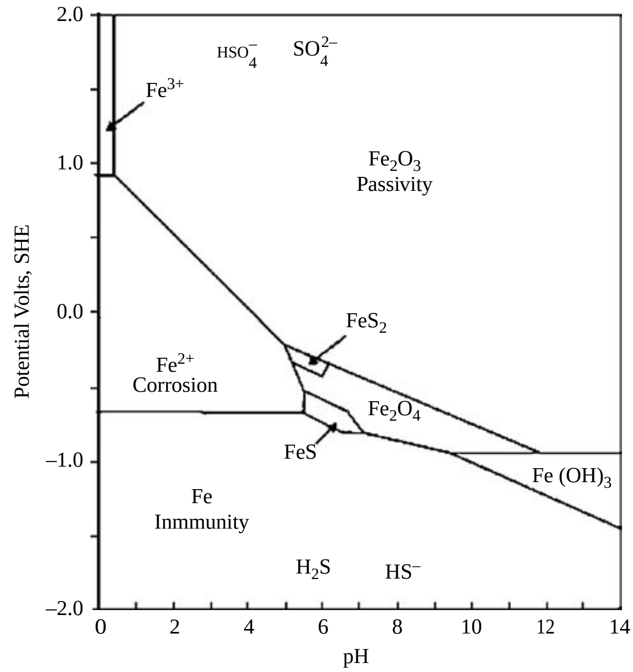
The initial FeS black film changes into a reddish-brown, hydrated iron oxide. Sometimes, under strongly oxidizing conditions, H_2S is converted into H_2SO_4, a strong acid corrosive toward CS and RC:

$$H_2S + 2O_2 \rightarrow H_2SO_4. \qquad (3)$$

The corrosion reactions and corrosion products for iron in a typical GT system containing H_2S are displayed in the Pourbaix corrosion diagram (Figure 3), which indicates (at equilibrium) domains of immunity, corrosion and passivity as a function of iron electrochemical potential and fluid pH.

Massive concrete structures such as canals, pipeline supports and steam noise silencers are degraded by H_2S gas trapped in condensed steam that permeates through the pores and cracks of the concrete wall, corroding the CS reinforcement.

Figure 3 Iron corrosion behaviour in a typical geothermal steam containing H_2S. pH vs electrode potential Pourbaix diagram



Apart from H_2S gas, GT fluids contain other corrosive gases: oxygen (O_2), carbon dioxide (CO_2) and ammonia (NH_3). Corrosion is affected by their solubility and chemical activity towards the equipment engineering materials.

GT waters carried by the canals at temperatures lower than 100°C and exposed to air are saturated with dissolved oxygen in the range 4-6 mg/l. As a result of the water-steel interactions, layers of ion oxides form: hematite, limonite and goethite ($Fe_2O_3 \cdot nH_2O$):

$$2Fe + 3H_2O + 1.5O_2 \rightarrow Fe_2O_3 \cdot 3H_2O. \qquad (4)$$

The interaction between H_2S and O_2 leads to sulphide oxidation and O_2 reduction, according to the equation:

$$H_2S + 0.5O_2 \rightarrow S^0 + H_2O. \qquad (5)$$

Carbon dioxide is generated by thermal and/or acidic decomposition of the formation carbonates and bicarbonates, reducing water pH value. A decrease in pH increases corrosion. Free CO_2 dissolves in water to form weak carbonic acid with the following chemical equilibrium:

$$CO_2 + H_2O \rightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-. \qquad (6)$$

Ammonia gas is generated by the chemical decomposition of compounds containing nitrogen such as kerogen. In contact with GT waters, slightly alkaline ammonium hydroxide is formed:

$$NH_3 + H_2O \rightarrow (NH_4)OH. \qquad (7)$$

Ammonia and its ammonium salts corrode copper (Cu) and copper alloys such as brass (Cu-Zn) and bronze (Cu-Sn), forming soluble ammonium metallic complexes that can result in uniform corrosion or stress corrosion cracking. In consequence, the brass and bronze components of pumps become damaged.

Salinity is usually determined by measuring the quantity of chlorides (called chlorinity) or the electrical conductivity of the brine. The main effect of salinity on corrosion results from the influence of Cl^- ion on the breakdown of passive films (Dexter, 2006).

GT brines contain a high concentration of dissolved, ionized salts, mainly chlorides and sulphates, which are aggressive ions in the context of corrosion. These elements and compounds are highly dissociated in the brines, contribute to their salinity, chlorinity and electrical conductivity, alter their pH and increase their corrosivity. Their amount relative to carbonates and bicarbonates, are of primary importance in any assessment of the corrosion characteristics of the brines. The chemical composition of typical GT brine is presented in Table II. The GT water becomes saltier by evaporation and ultimately reaches the evaporation ponds where the salts sediment out on the pond bottom.

Microbiologically induced corrosion

The role of microorganisms with thermophilic and halophilic capabilities in the deterioration and corrosion of materials used in the GTFs has supreme importance. Bacteria, fungi and algae, promote or influence the biodeterioration and biocorrosion of wood, glass fibre reinforced polyester (FRP), stainless steel, CS, aluminium and copper alloys (Valdez *et al.*, 2000).

Severe problems of biodeterioration were the cause of cooling tower failures at Cerro Prieto I GT power plant. The FRP screens were destroyed by colonies of anaerobic bacteria *Desulfobacter latus* and *Desulforomonas acetoxidans*; which use the polyester under the biofilms as a carbon source for their metabolism. After they consume the polyester, the screens lose their mechanical strength and the surface profile by which they deviate the cooling water. At the same time, algae and fungi consortia provide anaerobic conditions in wet media for bacterial biofilms that attack other components like wood, which is widely used in the construction of the large cooling towers of Cerro Prieto. Carbon and stainless steel bolts and nails underwent profuse pitting corrosion induced by the bacteria mentioned above (Figure 4).

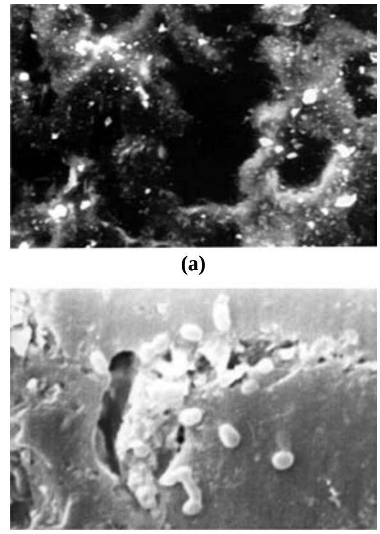
The thermophilic archaebacteria *Thermoproteus neutrophilus* present in the installations of the Tejamaniles GT power plant at Los Azufres GT, was responsible for localized corrosion on stainless steel UNS S31600. This microorganism came from the well and shows an amazing capability to colonize the SS surface and to promote selective corrosion at the grain boundaries of the metal, through the formation of non-uniform or non stable biofilms (Valdez *et al.*, 2000).

The biofilms and their participation in the deterioration and corrosion of materials have been characterized by means of electrochemical techniques and scanning electron microscopy analysis. Stainless and CSs immersed in GT brines, steam condensates or cooling water, inoculated with cultures of bacteria isolated from GT environments, underwent corrosion as soon as the microorganisms grew and colonized the metallic surfaces. The biological activity observed in these microorganisms is important because they show an ability to grow in adverse media at high salinity and temperature and low concentration of nutrients. These surprising survival limits are associated in all cases with corrosion and biodeterioration of materials in GTF and power plant installations.

Table II Chemical composition of typical Cerro Prieto geothermal brine

Component	Na	K	Mg	Ca	Cl	SO_4	SiO_2	HCO_3
Concentration ppm	6429	1176	18.6	347	11735	15	1133	303

Figure 4 Pitting corrosion induced by *Desulfobacter latus* and *Desulforomonas acetoxidans* on carbon steel surface at Cerro Prieto I cooling tower



(a)
(b)

Water facilities corrosion

A complex GTF displays numerous and diverse industrial water facilities for storage and supply to the field operations such as fire fighting, cooling water treatment, potable water, etc. The wide variety of equipment includes above storage tank (AST), pumps, pipelines and valves. They are generally fabricated from CS but to prevent and/or minimized corrosion they are internally and/or externally protected by paints and coatings. Some times, inhibitors are added to the water to avoid corrosion and for more efficient facility operation.

Local sources provide the water used in the plants, which is a hard, slightly salty with about 20 mg/l, acidic pH and low electrical conductivity: 1.5 mS/cm. The corrosivity of three different types of waters used in the Cerro Prieto facilities and their effects on CS and SS were determined by an electrochemical study applying in a three electrode cell using a Gamry CS-100 Potentiostat, following ASTM Standards G3 and G5. The waters tested were; irrigation canal water from the Colorado River (ICR), water from the municipal network (MWN) and geothermal separated cold brine (GCB). The results of corrosion rates are shown in Table III.

Table III Corrosion rates for carbon steel UNS G10180 and stainless steel UNS S31600 immersed in irrigation canal water from the Colorado River (ICR), water from the municipal network (MWN) and geothermal separated cold brine (GCB)

Water	Corrosion rate (mm/y) carbon steel UNS G10180	Corrosion rate (mm/y) stainless steel UNS S31600
IWC	0.432	0.0016
MWN	0.078	0.0002
GCB	0.535	0.050

Scaling

Two types of scales are usually encountered on equipment surfaces in GTFs: those formed at high temperatures combined with thick corrosion products or others deposited as water insoluble mineral constituents. Scaling is a typical problem in highly concentrated GT waters, in particular in hot GT brines. Generally, as the temperature decreases, the scaling problems become more serious along the production and distribution system (Figure 5). Scaling depends on the physicochemical characteristics of the GT fluids and brine composition: temperature, salinity, pH, density, dissolved gases, saturation, precipitations kinetics and thermodynamics, and flow regime.

In contact with the equipment surface, in particular metals, these sediments influence the corrosion behaviour by forming amorphous or crystalline deposits that promote localized corrosion beneath.

The deposits appear in the diverse sections of the GTF: production casings, distribution pipelines, brine canals and evaporation ponds. They are classified as scale, sludge, corrosion products and biological deposits; often they are mixed, multiphase materials.

The main minerals formed and deposited are iron oxides and sulphides as a result of corrosion, amorphous silica (SiO_2), carbonates ($CaCO_3$; calcite or dolomite $MgCO_3$), sulphates ($CaSO_4 \cdot H_2O$; gypsum) and silicates ($MgSiO_3$), dependent upon their respective solubility coefficients. Incrustation occurs when Ca^{2+} and HCO_3^- ions are present in excess of their equilibrium concentration and precipitation of $CaCO_3$ occurs:

Figure 5 Silica scaling sample removed from a steam pipeline at Cerro Prieto geothermal field

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O. \qquad (8)$$

As CO_2 is removed, more $CaCO_3$ incrusts the casing surface. These scales plug the casings and the pipelines and interfere with GT fluid flow. Silicate scales are very tenacious, dense and difficult to remove from the hot surfaces. A particular black incrustation, constituted by SiO_2 contaminated with black FeS, forms a hard adherent dense layer, which frequently obstructs the casing in Cerro Prieto GTW (Ocampo *et al.*, 2005). Sometimes the SiO_2 becomes light grey, reflecting a gradual decrease in the abundance of black FeS. In other cases, scales at the well head consist of black, sooty sulphides of Fe, Pb, Zn and Cu. They also appear as concentrated layers at the bottom of flow lines. An amorphous iron silicate becomes abundant too.

According to GT water classification, the Cerro Prieto reservoir brine is of subterranean origin and formed under stagnation (Mercado *et al.*, 1989). According to Lippmann *et al.* (1989), the Cerro Prieto brine originated from a mixture of sea water and Colorado River water. These studies have shown that the concentration of chloride, bromide and deuterium originated from a mixture of oceanic brine and river water was unaltered during passage through the GT system. The experience accumulated during 35 years of exploitation of Cerro Prieto field shows that scaling is a phenomenon that occurs along the major part of the GT system. Scaling by mineral deposition is a usual problem in most of production wells drilled in this high temperature hydrothermal reservoir. The scale occurs on all surfaces in contact with the produced brine, beginning in the reservoir, production casings, superficial installations (mufflers, separators, valves, pipes conduction of separated water, channels, power plant equipment, blades, turbines, etc.). Mainly, three types of scale occur at Cerro Prieto field:

1 Calcium carbonate (calcite).
2 Amorphous silica (SiO2).
3 Metallic sulphides (Ocampo *et al.*, 2005).

Corrosion and scaling control

The GT industry at Cerro Prieto manages aggressive thermal waters and steam, and brines at elevated temperature. These fluids and environments have a high level of corrosion risk. Therefore, corrosion control engineering and technology are applied. In analysing corrosion events there are three main steps:

1 Detection.
2 Characterization.
3 Control.

Practical methods that prevent and/or minimize corrosion include the use of corrosion information, selection of suitable corrosion-resistant materials (CRMs) and application of protection technology.

Materials selection

Use of corrosion-resistant construction materials is the most direct means of corrosion control in GTFs. The technical process of selection involves three main stages:

1 Analysis of the field requirements and operation conditions.
2 Selection and evaluation of candidate materials.
3 Selection of the most suitable material.

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Corrosion resistance is the main property to be considered in the choice of materials for equipments fabrication, but the final selection must be a compromise between technological and economic factors. It is sometimes more economical to use a more expensive CRM that will provide long and trouble-free service than to use a lower-cost material that may require frequent maintenance or replacement. The selected material should be able to perform the function safely for a reasonable period of time and at an acceptable cost.

Scaling inhibition

Scale formation and deposition in GT resource production facilities is controlled by brine acidification and the addition of organic inhibitors, as a general means of limiting scale, corrosion, flow risks and safety issues (Gallup *et al.*, 2005). The acid selected should be adequate to address the chemical nature of the scale: carbonate, sulphate or silicate. For instance, SiO_2 and silicates require hydrofluoric acid (HF) which reacts rapidly with siliceous scales:

$$SiO_2 + 4HF \rightarrow SiF_4 + 2H_2O. \quad (9)$$

Inhibitors are chemicals that modify the behaviour of the GT fluids and scaling reaction rates when added in relatively small amounts. The prevention of scale formation: silica, carbonates and sulphates has been studied in several GT waters around the world. Organic polymeric inhibitors produced by commercial vendors are used with positive results.

Knowledge on the formation, location and identification of the scales has a crucial impact on the GTF productivity. Therefore, novel methods and inhibitors for scale control and treatments are proposed frequently in the commercial literature. Economic considerations are of the utmost importance in anti-corrosion and anti-scaling methods involving inhibitors. The cost of an inhibitor under operating conditions is determined largely by both its chemical stability and its efficiency as a controlling agent.

Conclusions

Corrosion and scaling processes occurring at the Cerro Prieto GTF in Mexico, promoted by the physicochemical characteristics of the GT fluids and the climatic conditions, affect the production capacity of the GTWs. The prevention and control of corrosion and scaling in the GTF infrastructure will contribute to the preservation of the environmental quality and assure the durability of the GTF engineering materials. The industrial equipment, structures and installations of the GTFs are built of two basic engineering materials, CS and RC, which must be protected as necessary against corrosion by paints, coatings and cathodic protection.

The corrosion dominant factors are acidity (mainly by H_2S), salinity, and dissolved gases such as oxygen, carbon dioxide and ammonia. Different types of minerals form scales and sludge, with SiO_2 as the main mineral scale that must be removed by chemical and mechanical techniques. Application of corrosion control and scale inhibition technologies will prevent and/or minimize the appearance of events that lead to shutdown of production installations in the GTF.

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