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Corrosion and Scaling Deposits in the Berlín Geothermal Field

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ABSTRACT

A complete analysis of the solid materials found in the surface equipment in the Berlin Geothermal Field is undertaken during the shutdown of the power plant. Samples are collected from these equipment to evaluate the deposition process in order to minimize and prevent its deposition.

Results of analysis in September 2003 shutdown showed that a) cyclone separators contain mostly rock fragments from Unit IV formation, b) water tank with rock fragments and scaling deposits mostly amorphous silica, c) valves (ball and bypass valves) with scaling deposits (silica and halite) and few corrosion products d) steam pipeline with corrosion products (mostly magnetite, hematite and goethite) e) water pipeline with scaling deposits (amorphous silica and calcite) and corrosion products, f) two-phase pipeline with both corrosion and scaling products, g) water pump for the condenser with sulfur and h) turbine blades with few corrosion products mostly magnetite.

Corrosion in Berlín geothermal field is influenced mainly by the condensate, presence of abundant O_2 and H_2S, and solid particles.

An attempt to construct a Pourbaix diagram ($Fe/S/H_2O$ system with the pH and Eh values) was undertaken at a temperature of 170°C. Deposits in the separator system and pipelines are found in the area of magnetite, few hematite, pyrite and pyrrhotite.

1. INTRODUCTION

The Berlin geothermal field is located at the eastern part of El Salvador in Central America (Figure 1), 100 kms. East of San Salvador City, the capital of El Salvador. It lies at the northern slope of the Berlin-Tecapa volcanic complex and has an area of about 24 km^2 with an estimated geothermal power potential of 85MWe.

Interest in geothermal exploration in Berlín started in 1962 when the Geological Service of El Salvador conducted heat loss survey. Detailed geoscientific investigations were carried out from 1965 to 1970 by the United Nations and the Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL) with two exploratory wells drilled in 1968 at the Parras Lempa and one well (TR-1) in Berlín area. The last well intercepted the geothermal reservoir at 1400m depth with a reservoir temperature of 230ºC.

Drilling continued in 1978 with the aid of Interamerican Development Bank (IDB) and Electroconsult (ELC), feasibility studies were carried out for a possible exploration and development of the area.

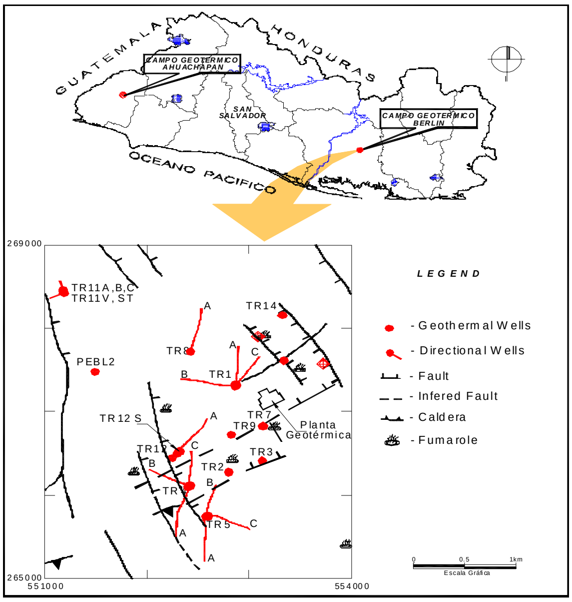

Figure 1: Location map of the Berlín Geothermal Field

In 1992, a back pressure unit was commissioned using well TR-2 as a production well and wells TR-1 and TR-9 as reinjection wells (Barrios, et al, 2001). Expansion of the geothermal field was a priority to address the growing demand of electrical energy of the country.

To date, 31 wells have been drilled in Berlín producing 56 MWe, two units of 28 MWe from a single flash condensing power plant.

Ongoing drilling activities are being undertaken by ENEL Greenpower SpA, the company's strategic partner, at the southern part of the geothermal field to confirm the existence of the field's geothermal resource, for the third condensing unit (Rodriguez & Herrera, 2003).

Maintenance of the Berlin geothermal power plant is undertaken yearly alternating the overhaul of the two units. In September 2003, overhaul was undertaken in the second unit. Samples were collected in different surface equipment to evaluate the deposition process in order to prevent and minimize the deposition. .

2. RESULTS OF ANALYSIS

A total of 53 samples were collected and analyzed using X-ray diffraction (XRD) and stereomicroscope. Results are presented as follows:

2.1 Turbine Blades

The turbine rotor contains a small amount of corrosion products. However, at the outer part of the blades, several corrosion products such as magnetite (Fe_3O_4) and pyrrhotite (FeS) and scaling deposits with 2 mm thickness (ericaite, $Fe_3B_7O_{13}Cl$ and ajoite, $(K,Na)Cu_7AlSi_9O_{24}(OH)_6.3H_20$)

were identified. The turbine ring contains scaling deposits such as halite (NaCl) and aphthitalite ($K_3Na(SO_4)_2$.

Ericaite belongs to the borate group while ajoite is a secondary silicate mineral produced by the oxidation of Cu minerals. Aphtitalite is a non-hydrous sulfate mineral with K + Na. All minerals were probably produced by the reaction of steam impurities (K, Na, B, Cl, O, SO_4 y Fe).

2.2 Condensers

Sulfur was found 100% in the condenser. In the impeller of the condensing pump, some deposits of pyrite were found together with sulfur. Pyrite is produced by the concentration of sulfur attacking the metal.

2.3 Cooling tower

The sprinkler in the cooling tower contains 100% sulfur. The blades of the fan contain scaling deposits such as quartz, (SiO_2), albite ($NaAlSi_3O_8$) and sanderite ($MgSO_4.2H_2O$).

Waste water was also collected and found to have 100% sulfur.

2.4 Separation system

The samples found in the cyclone separator and water tank contain subrounded silicified and chloritized rock fragments. In the water tank, amorphous silica is also present.

2.5 Valves

The ball valves in well TR-4 contain abundant corrosion products such as magnetite, hematite and goethite and some crystals of anhydrite cemented by quartz. In the gate valves, a hard layer of amorphous silica and clay minerals were found forming botroydal structure. In the bypass valves 20", some scaling deposits such as quartz, plagioclases, amorphous silica and clay minerals and few magnetite were identified. In the discharge valve, big white blocks of halite and sylvite were present. In the wierbox, some hard and porous deposits composed of clay minerals and plagioclases and some magnetite and hematite were found.

2.6 Steam traps well TR-4

The steam traps in the steam pipeline contain corrosion products mainly magnetite, hematite, goethite, pyrrhotite, pyrite, galena and crystals of quartz and chlorite. Almost all samples were laminated with a thickness of 1- 4 mm.

2.7 Drainpots two-phase pipeline wells TR-2 and TR-9

In most drainpots, corrosion products were mostly found such as magnetite, hematite, pyrite, pyrrhotite, sphalerite, clay minerals, calcite, halite and amorphous silica.

2.8 Drainpots reinjection line wells TR-8 and TR-14

In the reinjection line, amorphous silica was mostly identified together with calcite, some rounded silicified and chloritized rock fragments (max. size 1.5 cm), clay minerals and individual crystals of wairakite, albite, quartz and calcite

3. DISCUSSION

A summary of the minerals found in different surface equipment is given below:

3.1 Fe-oxides : magnetite and hematite

Magnetite is mostly observed in steam traps and occasionally in drainpots with a thickness of 1-4 mm. Usually, magnetite serves a passive layer or a protective layer in the pipelines. Once formed, the magnetite transforms to hematite with the presence of O_2 and pyrite and pyrrhotite with the presence of H_2S.

3.2 Fe-hydroxides: goethite

Goethite belongs to the group of iron hydroxide and usually occurs with hematite, pyrite, pyrrhotite and other sulfide minerals. It is mostly a product of surface oxidation of Fe oxide and sulfate and alteration of magnetite. It is not a protective layer due to the presence of H^+.

3.3 Fe-sulfides: pyrite and pyrrhotite

Pyrite is usually found in the impeller of the water pump on the condenser, steam traps and some drainpots of the two-phase pipeline. Iron sulfide minerals usually deposit through its affinity with H_2S. It is more aggressive usually producing pitting and perforating deeper in the metal.

In the steam pipeline, pyrite and pyrrhotite were observed together with magnetite and hematite. As mentioned earlier, pyrite in the steamline could also be a product of the reaction of magnetite with H_2S.

3.4 Sulfur

Sulfuric acid (H_2S) reacts with oxygen in the air, separating sulfur: This is shown in

$$2H_2S + O_2 \rightarrow 2H_2O + S$$

It forms a thin layer of 1-4 mm in the water pump and its accessories, which is advisable to clean up at least once a year to avoid the formation of pyrite. A thin layer was also observed in the sprinkler in the cooling tower and but was easy to remove.

3.5 Silica group

Amorphous silica is encountered in almost all drainpots of the two-phase pipeline, reinjection lines and some valves. It forms a protective layer against the corrosion products in the pipelines since few magnetite was observed.

However, the solubility of silica should be taken into account during the process of reinjection, due to its potential to form scaling deposits in reinjectoin wells.

Few amorphous silica was also observed in the cyclone separators and water tank.

3.6 Heavy metals: galena and sphalerite

Two of the heavy metals found in the last steam traps of the steam pipeline TR-4 and two- phase pipeline TR-2/TR-9 are galena (PbS) and sphalerite (ZnS).

Galena is present also in the cyclone separator as an accessory mineral while sphalerite was found in the system TR-2/TR-9.

Based on the studies of Gallup, et al, 1990, these minerals deposit in production wells, in the wellhead where fluid is supersaline. Usually, galena, bornite, sphalerite and troilite are found together. Galena predominate the scaling product followed by sphalerite and chalcopyrite.

The formation of these minerals maybe due to the presence of HS where upon the ascent of H_2S, sufficient HS react rapidly with the heavy metals and form scaling deposits. This could also be due to the increase in pH.

$$M^{(+2)} + HS^{(-)} = MS + H^{(+)}$$

Where M = Cu, Fe, Pb y Zn.

4. CONCLUSIONS

In summary, the deposits found were a) Steam line : corrosion products, b) Two-phase pipeline: corrosion products and scaling products, c) Reinjection line: corrosion and scaling products, d) Cyclone separator: rock fragments (Unit IV), e) Water tank: rock fragments and few scaling deposits, f) Valves: scaling deposits and few corrosion products and f) Weirbox: scaling deposits.

These deposits can be seen in Figure 2 (See page 4).

Electrochemical corrosion occurs in the Berlin geothermal field where there is a presence of liquid phase including condensates, responsible for the oxidation of the metals.

Other factors affecting corrosion are given below:

a) The pH has great influence on the rate of corrosion. At pH < 4.5, corrosion starts to form.

b) The presence of O_2 also affects the corrosion, where there is faster rate of corrosion (due to presence of $2e^-$).

c) The presence of H_2S also increases the corrosion process, which produces local attack in the metal (turbine blades and pipelines).

d) Solid particles also induce corrosion and erosion in metals (Datuin and Gazo, 1989).

e) In the steam line, corrosion products and few scaling deposits are due to the decrease in pressure or insufficient separation of vapor from water.

f) The presence of scaling deposits mostly amorphous silica in the reinjection line is due to the saturation of silica.

An attempt to construct Pourbaix diagram was undertaken using a theoretical value of Fe at a temperature of 170°C.

In general, in Berlin geothermal field, the deposits in the surface equipment are found in the area of magnetite, few hematite, pyrite and pyrrhotite with neutral pH (Figure 3).

The presence of these deposits is due to the heat loss along the pipeline and starts to form condensates which attack the metal (Giggenbach, 1979). This produces the dissolution of Fe and the deposition of magnetite and consequently of other oxide minerals. With the presence of H_2S, pyrite and pyrrhotite are formed until magnetite is formed again and other oxide minerals.

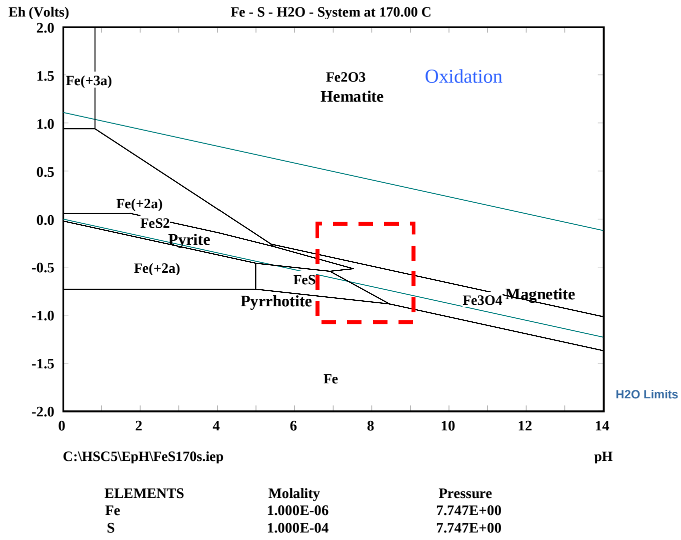

Figure 3: Pourbaix Diagram at 170°C in Berlín Geothermal Field.

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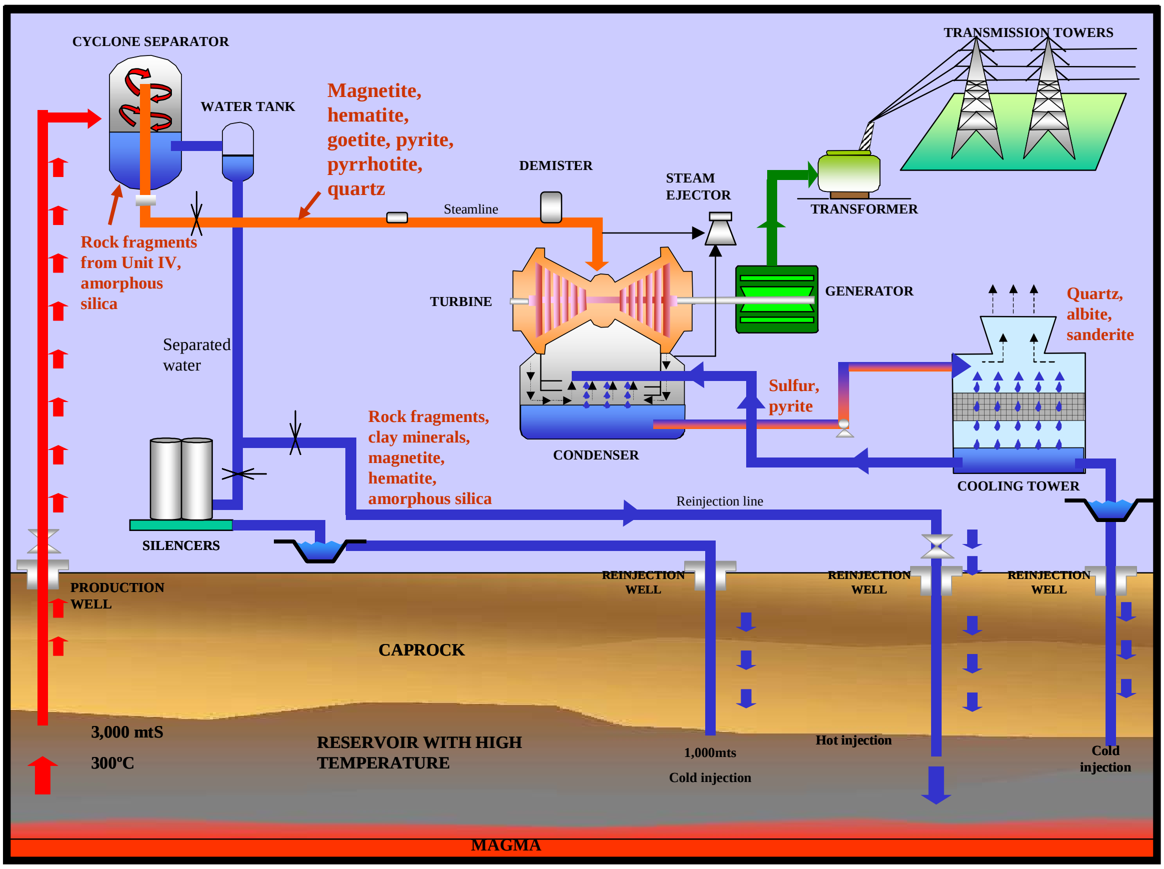

Figure 2: Process flow diagram and its deposits