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The Sulfide Minerals Deposit in the Geothermal Pipes of Dieng Geothermal Field, Indonesia

Agung Harijoko[1], Kinanti Hapsari[1], Yunarto Tri Wibowo[2], Randy Wijaya Atmaja[2], Muhammad Istiawan Nurpratama[2]

1. Department of Geological Engineering, Faculty of Engineering, Universitas Gadjah Mada. Jl. Grafika No.2 Yogyakarta Indonesia 2.PT. Geo Dipa Energy, Indonesia.

aharijoko@ugm.ac.id

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ABSTRACT

Dieng geothermal field is a high temperature liquid dominated geothermal field situated in a volcanic complex. The present production is 60 MWe supplied from the production zone of Sileri area. The geothermal fluid from Sileri is quite friendly having moderate salinity, neutral pH and sodium-chloride water. However, sulfide minerals deposit in the production wells of the Dieng geothermal field. This paper reports the paragenesis of sulfide minerals deposited in the geothermal well in order to understand the sulfide mineral deposition in response to boiling of hydrothermal fluid. Microscope observation of the polished section of the sulfides deposit revealed that the deposition occurred in four stages with a distinct mineral assemblage. In the first stage the mineral assemblage consists of dominantly chalcopyrite, while the second stage consists of chalcopyrite, galena and sphalerite. The next stage consists of a bit galena, sphalerite, chalcopyrite and pyrrhotite. During the third stage the pyrrhotite well developed with the grain size much bigger than other minerals. Finally in the last stage the assemblage consists of pyrrhotite with the smaller size. This implies that the chemical condition of the geothermal fluid in term of sulfidation state is getting lower that is possibly caused by further boiling, enabling more H_2S gas to escape.

1. INTRODUCTION

Sulfide minerals may deposits on the production wells and surface facilities of geothermal production. Several workers have reported the presence of sulfide mineral deposits in the installation of geothermal production, such as Fushime, Japan (Akaku, 1990); Kakkonda (Yanagisawa et al., 2000); Rekjanes, Iceland (Hardardóttir et al., 2005; Kristmannsdottir, 1989); Krafla, Iceland (Kristmannsdottir, 1989); Salton Sea and Imperial Valley in the USA (Skinner et al., 1967; McKibben and Williams, 1995; Gallup, 1998). The sulfide minerals scale can be precipitated directly from high- (Fushime, Japan) and low-salinity (Milos, Greece in Karabelas et al., 1989) geothermal waters.

Dieng geothermal field is one of the high temperature liquid dominated geothermal fields in Indonesia. Energy potential is about 250 MWe (Boedihardi et. al., 1991) with installed capacity of 60 MWe. One of the obstacles in the development of the Dieng geothermal field is the scale precipitation on the brine pipe (Fig. 1) as well as sulfide scale precipitation on the production well. PT. Geodipa as a developer conducts physical cleaning to tackle this problem. This paper is intended to report the sulfide minerals deposited on the well and understand the paragenesis of the sulfides to reveal the evolution of the geothermal fluid in term of its sulfur fugacity. In this study we identify the sulfides by means of x-ray diffractometer and thin section observation to understand the sulfides paragenesis. The deposition temperature of sulfides is inferred on the basis of saturated water temperature at wellhead pressure. As sulfide minerals formed on certain physico-chemical conditions, it implies the physico-chemical conditions of the geothermal fluid chemistry in Dieng geothermal field.

2. DIENG GEOTHERMAL FIELD

Dieng geothermal field is situated in the active Dieng volcanic complex, that is located in the northeastern tip of Dieng, Sindoro, and Sumbing volcanic line in Central Java, Indonesia. Based on the resistivity value result of MT surveys, the potential of Dieng geothermal field is defined into three areas of Sileri, Sikidang, and Pakuwaja.

On the surface, the potential areas are manifested by the fumarolic areas of Kawah Sileri, Kawah Sikidang, and Kawah Pakuwaja. Total potential energy is about 355 MWe calculated from those three areas. Some drilling has been conducted to confirm the resources. Two wells have been drilled in Pakuwaja area; so far this area is not developed yet due to low permeability, although the well intersects a high temperature zone. The drilling revealed that the Sileri and Sikidang sectors have good potential for the geothermal production zone. This production zone extends northwesterly from Sileri to Sikidang areas. The drilling intercepted the reservoir at the depth from about 2000 to 2300 m in Sileri area with the reservoir temperature ranging from 300°C to 335°C. In contrast, drilling at Sikidang area intercepted the reservoir at the depth from 1400 to 1500 m with the temperature ranging from about 240° to 300°C. However, the exploitation of Sikidang area is suspended due to high non-condensible gas concentrations in the geothermal fluid tapped from this zone. Right now, the geothermal production utilizes geothermal fluid collected from Sileri area (Layman et al., 2002; Boedihardi et al., 1991). The problems occur during the production due to scale deposition on the production well as sulfide scaling, such as well HCE 7B and 7C that collect geothermal fluid from Sileri area.

3. SAMPLES AND ANALYTICAL TOOLS

In this study, we got two sulfide scale samples collected from the production well of HCE 7B (1626 ft) and HCE 7C (4728 ft). These samples are used to characterize the sulfide minerals deposited from the geothermal water in conditions of boiling point. We conducted X-ray diffraction analysis in order to identify the sulfides minerals deposited in the scale and observed the thin section of those samples to understand the paragenesis of those sulfide minerals.

4. RESULTS AND DISCUSSION

4.1 Result of laboratory analyses

Sulfide scales collected from the well have a colloform-banding texture similar to the silica veins of epithermal deposit. The scale samples from production wells were collected after physical removal process so we could not measure the real thickness of the scale. The samples thickness is about 4 mm. XRD analysis carried out on two samples collected from the production well resulted in similar sulfide minerals composition of galena, chalcopyrite, sphalerite and pyrrhotite, while the non-metallic minerals that formed in the well is smectite.

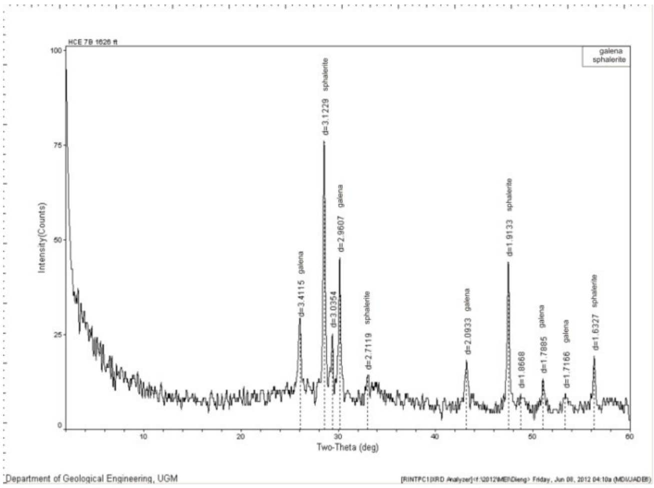

Figure 2: XRD analysis result of scales from well of HCE 7B at depth 1626 ft, using bulk sample powdered preparation.

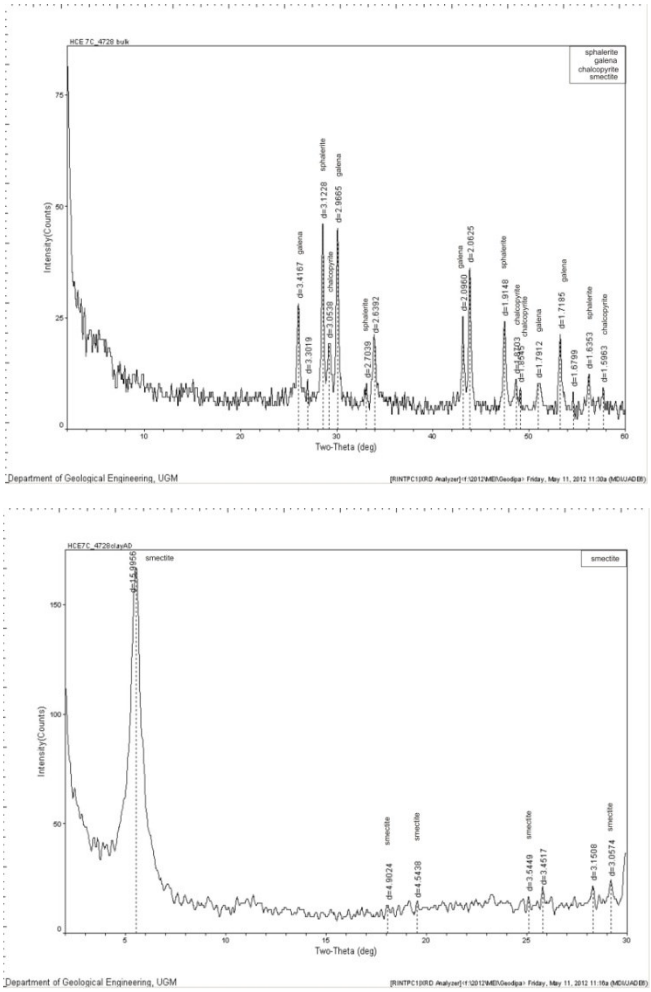

Figure 3: XRD analysis results of scales from well of HCE 7C at depth 4728 ft, using bulk sample preparation (top) and clay sample preparation (below).

Figure 4 shows the thin section photomicrograph of scale collected from well HCE 7B, while Figure 5 shows photomicrograph of thin section of scale collected from well HCE 7C. Microscopic observations showed a layered texture indicating different deposition time. In general, sulfide minerals formed consisting of galena, sphalerite, chalcopyrite and pyrrhotite.

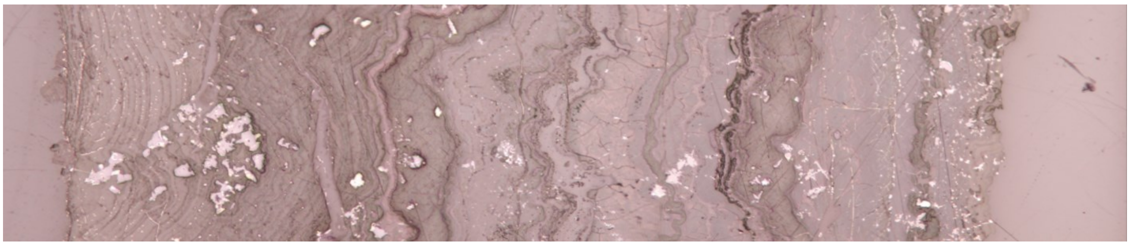

Figure 4: Photomicrograph of reflectance microscopy observations of scale sample collected from HCE 7B. Scaling thickness of approximately 2 mm.

Chalcopyrite galena sphalerite	pyrhhotite (finer grain) rare galena, sphalerite, chalcopyrite	pyrhhotite (coarser grain) rare galena, sphalerite, chalcopyrite

Figure 5: Photomicrograph of reflectance microscopy observations of scale sample collected from HCE 7C. The scaling thickness approximately 4 mm. Observation indicated there are three stages of sulfide deposition. In the beginning is dominantly chalcopyrite, sphalerite and galena change to predominantly fine grain pyrrhotite and rare galena, sphalerite and chalcopyrite. Finally in the lates stage is dominantly coarser grain of pyrhhotite and rare sphalerite, galena and chacopyrite.

4.2. DISCUSSION

4.2.1 Geothermal production

Both HCE 7B and 7C are production wells that collect geothermal fluid from Sileri area. The HCE 7B is installed with the wellhead pressure of 27.6 barg with the pressure and temperature of separator of 9.6 barg and 181.5ºC, respectively. While the wellhead pressure in HCE 7C is 62.05 barg and the separator is installed with pressure of 9.4 barg and temperature of 181ºC. The reservoir temperature is estimated by using water geothermometer. Slower-responding geothermometer of Na/K of Giggenbach (1987) indicates the temperature of 335ºC, while the SiO_2 adiabatic geothermometer indicates the temperature of 274ºC and 291ºC for wells DNG 7B and DNG 7C. Boiling temperature during production therefore is estimated on the basis of thermodynamic of saturated water at the pressure of the wellhead. The boiling temperature in HCE 7B is about 231ºC while HCE 7C is about 279ºC.

4.2.2 Sulfide mineral deposition

Metallic elements in the hydrothermal fluid (a high temperature of geothermal fluid) carry on the form of chloride complex ($MeCl_2$). Then, the metal complex reacts with dissolved sulfur in the solution to form sulfides. The type of sulfide produced by that reaction is controlled by the solubility of sulfide minerals that is affected by temperature, pH, and the concentration of the metal element. Moreover the fugacity of sulfur also controls the formation of sulfide mineral, so then Einaudi et al. (2003) classified the sulfidation state of the hydrothermal fluid into high-, intermediate- and low sulfidation hydrothermal fluid. Study of epithermal and porphyry types hydrothermal system shows that the sulfidation state at certain temperature will affect the type of sulfide minerals to be formed. Therefore, the sulfidation state is characterized by specific assemblages of sulfide minerals (Einaudi et al., 2003).

In the geothermal energy utilization, we tap high temperature geothermal fluid from reservoir through production wells. The fluid rises up to the surface driven by pressure difference between reservoir and wellhead. Consequently there will be a boiling or flashing that separate vapor from hot water. This process will increase the concentration of dissolved metals in the rest of hot water but decrease the dissolved sulfur in geothermal water due to release of H_2S in the vapor phase. Another effect of boiling to the physical and chemical condition of geothermal fluid is the pH value increase due to CO_2 and H_2S release from the hot water and the temperature decrease to reach the equilibrium phase after boiling (Barnes, 1979).

Boiling, therefore, is believed to be the triggering factor for sulfide mineral deposition in production well. As the sulfide mineral formed soon after the boiling, the formation temperature is approximately close to the boiling temperature that is inferred on the basis of temperature of saturated water at the pressure value of wellhead pressure. The deposition temperature in the well HCE 7B is inferred about 231ºC while HCE 7C is inferred about 279ºC.

The result of laboratory analysis showed that the scaling that formed in the wells has similar assemblages as that of sulfide minerals. Thin section analysis showed that the scaling formed gradually marked by the layered texture. There are differences content of sulfide mineral assemblages in the end and the beginning of scaling deposition, which is in the end of deposition marked by presence of abundant pyrhotite with the bigger grain size, whereas in the beginning of deposition commonly composed of chalcopyrite. The sulfide minerals assemblage difference indicates a change of sulfidation state from the medium sulfidation state in the beginning of deposition into low sulfidation state in the end. The deposition of sulfides and the change of sulfidation are interpreted due to boiling-induced changes in temperature, pH and Σ[S]. The changes of the sulfidation state is caused by boiling, where the hot water partially turns into vapor. This change triggers the precipitation of sulfide minerals in the well. In addition, the vapor formation cause partial sulfur content in the water vaporizes into the vapor so the content in the water is decreased. While, the dominant of pyrrhotite in the end of deposition is interpreted due to the addition of iron in the geothermal fluid possibly from the reaction of geothermal fluid with the production well pipe.

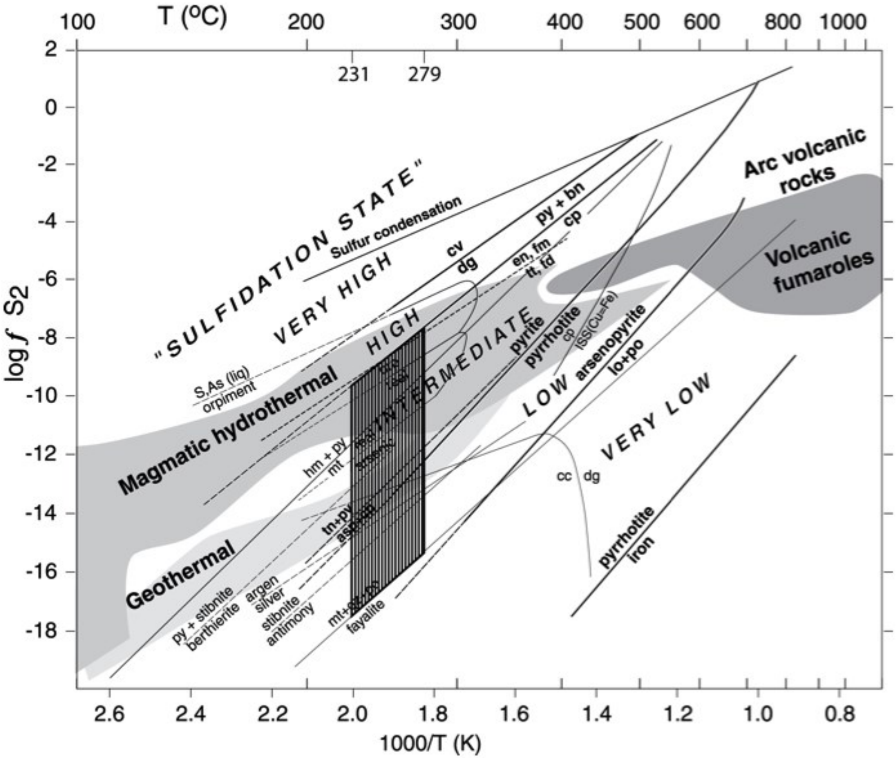

Figure 6: Vertical hatched area is the possibly environment of the Dieng geothermal fluid. Presence of pyrrhotite minerals indicate that the geothermal fluid from Sileri area has a low sulfidation state, while the occurrence of chalcopyrite indicates intermediate sulfidation, diagrams redrawn after Einaudi et al. (2003).

4. CONCLUSIONS

The scaling which forms in the separator pipe is rich of sulfide minerals content, consisting of galena, chalcopyrite, sphalerite, and pyrrhotite. This sulfide mineral content is similar to a typical sulfide mineral deposit of low sulfidation epithermal type. Thin section observation showed the differences of sulfide minerals assemblage, where the pyrrhotite is a low sulfidation stage indicator mineral deposit in the end of the deposition process. It is possibly influenced by the vapor phase separated process that releases dissolved H_2S so that the sulfur content in the geothermal fluid decreases. This sulfidation state inplies that the geothermal water from Sileri reservoir that is tapped by HCE 7B and 7C contains low enough sulfur, even though Dieng Geothermal System is situated in volcanic complex area.

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