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Enhancement of Silica-Enthalpy Mixing Model to Predict Enthalpy of Geothermal Reservoir

Jodhi P. GIRIARSO, M. Husni THAMRIN, Eben Ezer SIAHAAN

jodhi.pramuji@pertamina.com

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ABSTRACT

Silica has been using as one of geothermometer in the geothermal exploration. Its solubility is very sensitive due to temperature changes. When fluids rise and appear as thermal manifestation, the temperature tend to decrease. This occurs due to mixing with surface water. This mixing process use as basis to build silica-enthalpy mixing model. This paper discussed condition and assumption of fluids that can be using in the mixing model. Basic assumptions that in high-temperature water, solubility of silica controlled by its quartz species, no silica deposition occurred before or after mixing, no conductive cooling occurred after mixing, and any steam that formed adiabatically did not separate from residual liquid water before mixing with the cold-water. In its application, this model be able to characterize reservoir condition validated by using measured silica and enthalpy from well. Chemically, the validation also sort water type of thermal manifestation that can be used are chloride and bicarbonate type. Chloride type represents reservoir fluids, whilst bicarbonate type point out the fluids which affected by surface water. Meantime, sulfate type cannot be used because of the tendency of formation is due to the condensation of geothermal gasses. Due to its solubility, silica mixing model is well suited to describe their process in water domination geothermal system. Interestingly, the model is also very effective to identify steam entry in geothermal well because the prediction of enthalpy from this model covers the saturation enthalpy from water. The higher measured enthalpy than the maximum enthalpy prediction indicated excess enthalpy which beneficial for power generation.

INTRODUCTION

Silica is one of the component that influence the most by temperature changes rapidly affects the solubility. Many experiments had done to investigate it and its correlation with deep water temperature. White et al. (1956) found that the silica concentration in hot springs at Steamboat, Nevada was very close to the experimental solubility of amorphous silica and led to its function as geochemical indicator of geothermal reservoir temperature. Another field evidences found by so many scientists led to a significant approach to understand the geothermal reservoir characteristic by its geochemistry characterization, especially silica content. Likewise, shown by Mahon (1966) about silica concentration of hot water discharged from Wairakei's well that had positive correlation with solubility of quartz after adiabatic steam loss correction. Fournier (1977) presented the first geothermometer in equation from the experimental quartz solubility data. Henley et al. (1984) compiled all the existing silica geothermometer for many silica phases, including the effects of adiabatic and conductive cooling processes. Fournier and Potter (1982) derived a polynomial equation for the quartz geothermometer using the revised quartz solubility data, which is applicable up to 330°C. Verma and Santoyo (1997) applied a statistical data treatment method and theory of error propagation in improving this silica geothermometer equation. They had to eliminate the data points for temperature higher than 300°C as those points were outlier according to their statistical analysis. Rimstidt (1997) compiled all the quartz solubility data along the water-vapor saturation curve and derived a regression expression that is valid up to 300°C. In many geothermal fields the reservoir temperatures have been measured above than 300°C. Therefore, it is necessary to know the quartz solubility data at temperatures higher than 300°C in order to deal the geochemistry of high temperature hydrothermal systems. Verma (1999) presented the chemical thermodynamic calculations for quartz solubility for a wide range of temperature and amount of water in the reaction vessel. It was observed a wide difference between calculated and experimental solubility. With a critical evaluation of this discrepancy he concluded a need of creating internal consistent thermodynamic data for aqueous silicic species and reevaluation of quartz solubility data at higher temperatures along the water-vapor saturation curve. Also, Verma (2000) suggested the new formula for silica solubility that can handle high temperature until critical point of water.

At high temperature, solubility of quartz reach maximum value at about 770 mg/kg at temperature close to 338°C, and the solubility of quartz at the critical temperature is only 300 mg/kg (Figure 1). Therefore, for the conductively cooled liquids, there are two possible initial reservoir temperatures when dissolved silica concentrations are above 300 mg/kg, below and above 338°C. For practical implication silica geothermometry applied to hot spring waters is not likely to give temperature greater than 230°C to 250°C because quartz dissolved and precipitates very quickly in response to changing temperature above about 230°C (Fournier, 1973; Rimstidt and Barnes, 1980). In the temperature range 250°C to 330°C the silica geothermometer is useful when applied to waters produced from geothermal wells where movement from the reservoir to the surface is rapid. Reservoir waters in natural hydrothermal system having temperatures in excess of 330°C are very likely to be highly saline, so the curves and equations for dilute solutions would not be applicable.

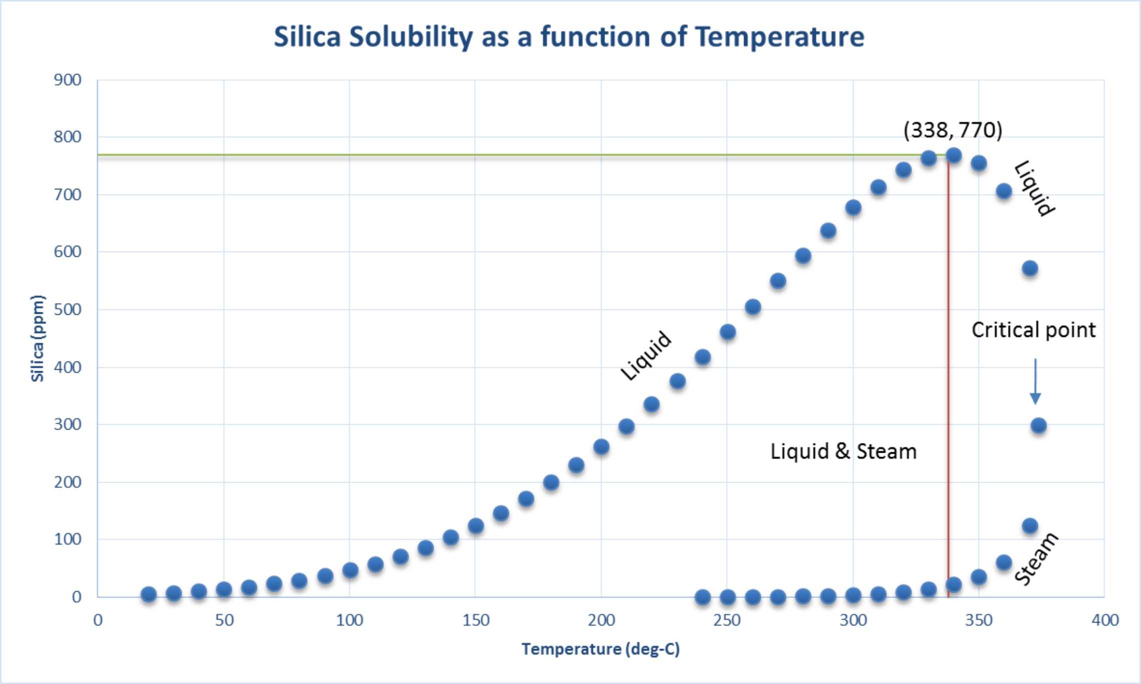

Figure 1 Silica solubility as a function of temperature

In contrast to temperature, enthalpy is a derived property that can be obtained from steam tables, provided that the temperature, pressure, and salinity are known. It is useful to use enthalpy as a coordinate rather than temperature because the combined heat contents (enthalpies) of two waters at different temperatures are conserved when those waters are mixed (neglecting small heat of dilutions effects), but the combined temperatures are not. Figure 2 shows the solubility of quartz in the pure water at the vapor pressure of the solution, plotted as a function of the enthalpy of the solution. In contrast to the silica temperature plot (Fig 1) in which there are two values for dissolved silica at a given temperature (in liquid and steam), in the silica enthalpy plot there is only one value for dissolved silica at a given enthalpy. The solubility of quartz in steam is part of a bell-shaped, symmetrical distribution of dissolved silica values that first increase to a maximum value at an enthalpy of about 1596 kJ/kg, and then decrease with a further increase in enthalpy. For practical application most reservoir fluids are sufficiently dilute so that enthalpies of pure water can be used to construct enthalpy-composition diagrams.

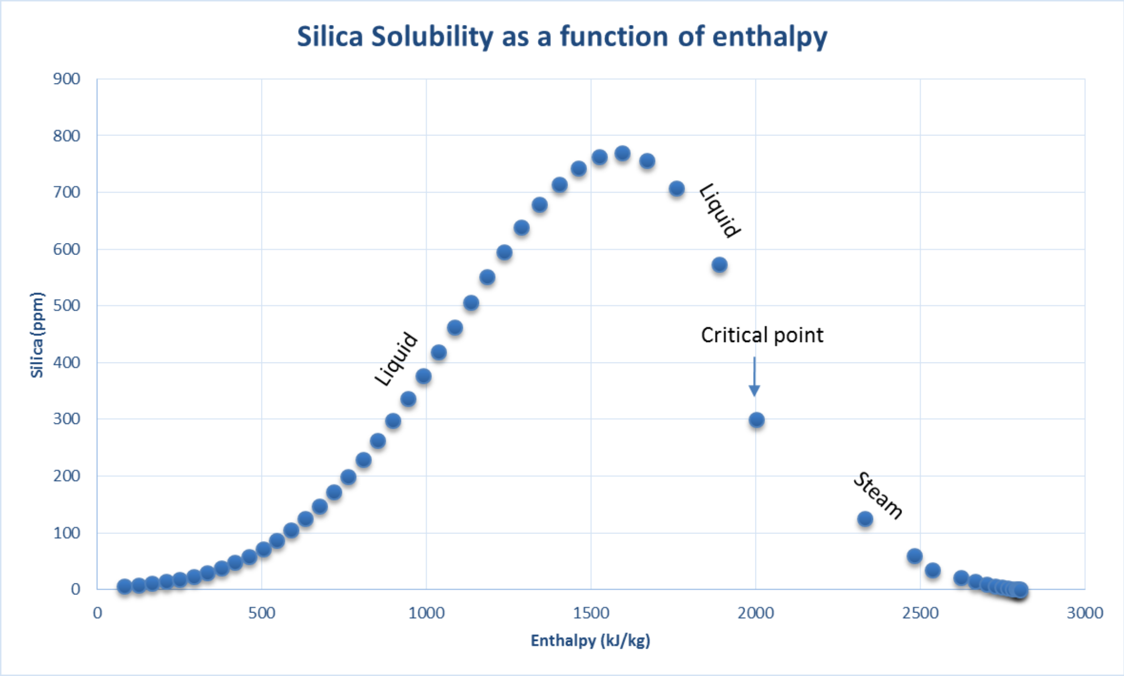

Figure 2 Silica solubility as a function of enthalpy

THE SILICA MIXING MODEL

Under some circumstances the dissolved silica concentration of a mixed water and a silica-enthalpy diagram may be used to determine the temperature of the hot water component (Fig. 3). This procedure assumes that any steam that formed adiabatically (as the hot water moved up to a shallower environment) did not separate from the residual liquid water before mixing with the cold water component. Also, to give accurate results, it is vital that no conductive cooling measured occurred after mixing. It is also necessary that no silica deposition occurred before and after mixing and that quartz controlled the solubility of silica in the high temperature water. Even with these restrictions the silica mixing model has been found to give good results in many places. In special circumstances, a silica mixing model could be used in which chalcedony or another silica phase is assumed to control the dissolved silica in the high temperature component (Fournier, 1989).

A straight line drawn from a point representing the non-thermal component of the mixed water (point A, Fig. 3) through the mixed-water warm spring (point B) to the intersection with the quartz solubility curve gives the initial silica concentration and enthalpy of the hot water component (point C). The following procedure can be used to determine the enthalpy and temperature of the hot water component when steam was lost before mixing took place. For the situation in which steam was lost at atmospheric pressure prior to mixing (point D, Fig. 3), a horizontal line drawn from point D to the intersection with the maximum steam loss curve gives the initial enthalpy of the hot water component (point E). The initial dissolved silica is shown by the point F. If steam had been lost at higher pressure before mixing, point D would lie above 419 kJ/kg on the extension of line AB, and point E lie would lie between the maximum steam loss and quartz solubility curves.

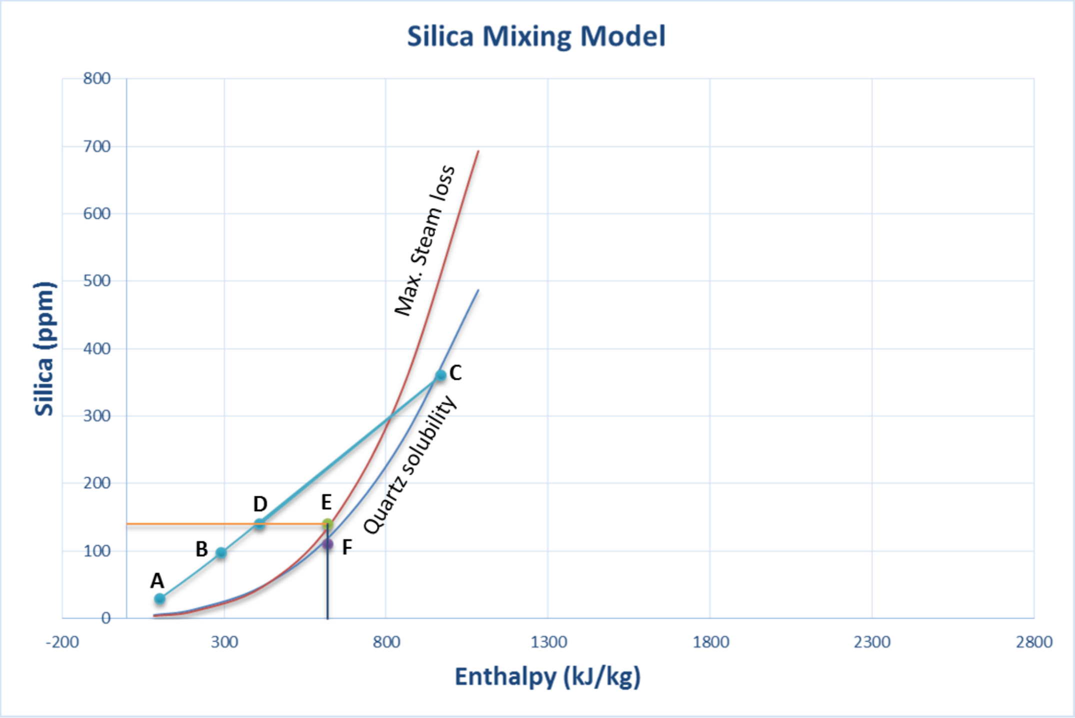

Figure 3 Silica mixing model

The silica mixing model used by Sebesan et. al (2015) in their study of silica content in geothermal waters function of temperature to estimate the temperatures of depth in geothermal reservoirs in Oradea. Shaoping et. Al (1997) also applied it in Yangyi geothermal system with silica solubility controlled by chalcedony species. Burgos (1999) applied it to make mixing model from cold water and warm spring in Berlin geothermal field, El Salvador. Filiz et. Al (2000) used it to evaluate the reservoir temperature and mixing ratios of thermal waters with cold groundwater in Germencik geothermal field, Turkey. Stănăşel et. al (2005) used it to evaluate fluids of Well 4058 from Săcuieni.

DISCUSSION

Most of them used quartz and chalcedony solubility as solubility control which have limitation until 250°C only to make their silica mixing model. Silica solubility from Fournier and Potter (1982b) and Verma (2000) offer us its application until high temperature or enthalpy, so it is encourage to examine this solubility curve into silica mixing model (Fig. 4). Silica from manifestation fluids plotted versus its enthalpy saturation of temperature manifestation then use trend line to make intersection line with solubility curves. Not all fluids of thermal manifestation can apply, but only the chloride and/or bicarbonate type. Chloride type have correlation with reservoir fluid, and bicarbonate type when the thermal manifestation exposed with surface water. Before apply it to silica mixing model, it needs to see in the Cl-HCO_3-SO_4 ternary diagram to make sure of it. For the example we took silica of thermal manifestation from Ulubelu geothermal field. The scatterplot diagram has positive correlation which means very strong correlation of those two variables.

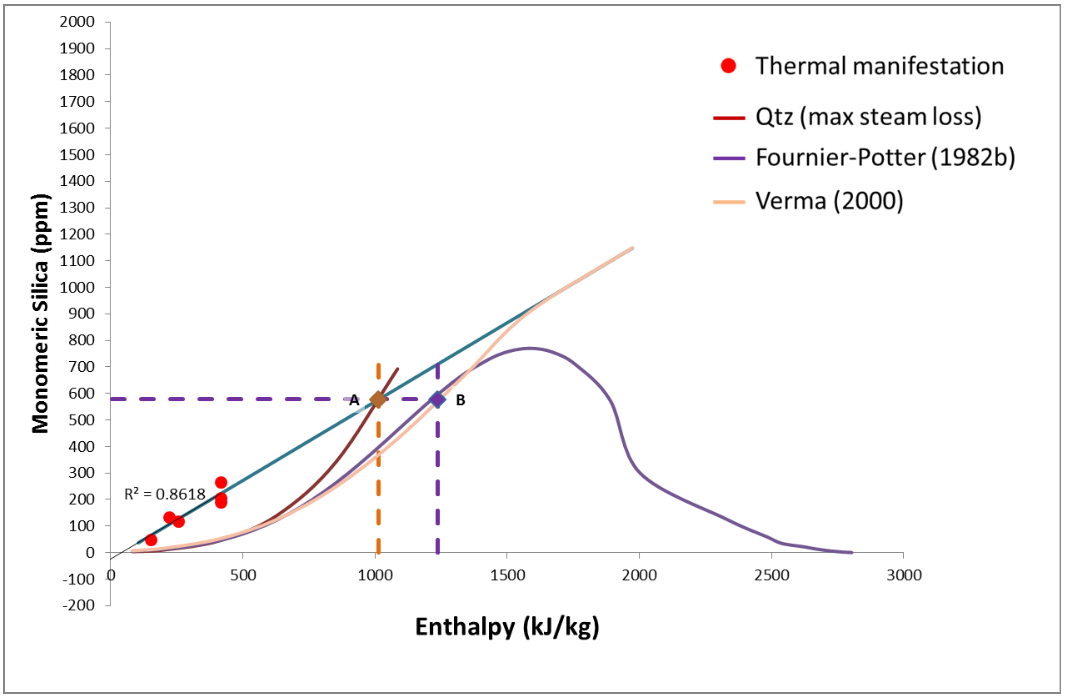

Figure 4 Silica solubility curve in high enthalpy

Point A is intersection trend line with quartz solubility (max steam loss). A horizontal line drawn from point A to the intersection with Fournier-Potter (1982b) and Verma (2000) solubility curve gives the initial enthalpy of reservoir fluids (point B). In this case the lowest predicted enthalpy is 1013 kJ/kg or equal to 235°C, and the highest predicted enthalpy is 1236 kJ/kg or equal to 280°C. We assume that silica solubility in thermal manifestation fluids controlled by quartz solubility with maximum steam loss because its evaporation at atmospheric pressure. The area under both intersection gives us prediction of our saturated enthalpy of this field which is between 1014 – 1211 kJ/kg. To validate this method, measured enthalpy and total discharged of silica from the monitoring wells of Ulubelu geothermal field apply to the same model gives us the new diagram (Fig. 5).

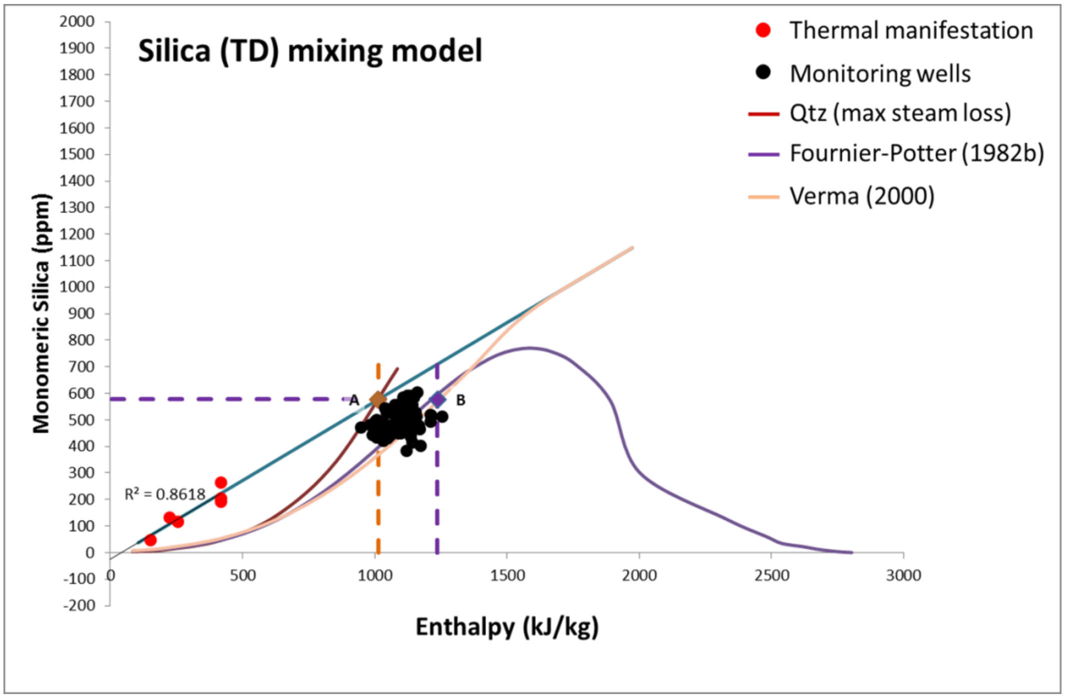

Figure 5 Silica mixing model of Ulubelu geothermal field

Scatterplot of monitoring wells fits the area under two intersection give us strong confidence to use the new diagram to predict enthalpy of reservoir by using silica-enthalpy of thermal manifestation fluids follow several assumption by Fournier (1989) and use the chloride and bicarbonate type of fluids. Chloride type will likely the most confidence type that we can use in this diagram. But bicarbonate type also convenient to use because we can assume it mixed between reservoir fluid and surface water. The mixing process will decrease temperature, also will reduce silica concentration by mass balance. We cannot consider it deposited because the first assumption no deposited after mixing.

This mixing model is very suitable to estimate reservoir temperature in the field that have thermal manifestation such as hot spring and/or warm spring which have chloride and/or bicarbonate type. Also, it is useful if we can acquire the cold water. Indonesia have many that kind of geothermal field.

CONCLUSION

The silica mixing model can be improved using the silica solubility by Verma (2000) and Fournier-Potter (1982b). Both silica solubility curve can be applied until high temperature reservoir. This method can be one of alternative to predict enthalpy and temperature reservoir along with some assumptions. Several requirements that must be met such as any steam that formed adiabatically (as the hot water moved up to a shallower environment) did not separate from the residual liquid water before mixing with the cold water component. No conductive cooling measured occurred after mixing. No silica deposition occurred before and after mixing and that quartz controlled the solubility of silica in the high temperature water. Moreover fluid type of thermal manifestation must be chloride and/or bicarbonate water. We can get rid of chloride water if it’s believed there was silica deposition around the thermal manifestation to meet the requirement above.

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