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QRTZGEOTHERM: AN ACTIVEX COMPONENT FOR THE QUARTZ SOLUBILITY GEOTHERMOMETER

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SUMMARY – An ActiveX component to calculate temperature and vapour fraction in a geothermal reservoir using the quartz solubility geothermometry was written in Visual Basic. The approach is based on the conservation of mass and energy (enthalpy). Four representative types of regression equations for quartz solubility: *(i) a quadratic regression equation of 1/T and pressure P, (ii) a linear equation relating log* SiO_2 *to the inverse of absolute temperature T, (iii) a polynomial of T including logarithmic terms and (iv) temperature as a polynomial of* SiO_2 *including logarithmic terms* are programmed. The quadratic regression equation fits well all the experimental solubility data in pure water along the saturation curve and provides better agreement between the calculated and measured down-hole temperatures in the case of Cerro Prieto. The down-hole temperatures in the wells M-50 and M-90 were also calculated through a well simulator, WELLSIM. There is a significant consistency between the estimated temperatures using both the approaches.

1. INTRODUCTION

Quartz geothermometry is an integral part of geochemical studies of geothermal systems during the exploration and exploitation, which is based on the regression of experimental quartz solubility in pure water along the water-vapour saturation curve. It has been applied earlier considering only liquid phase in the reservoir. However, this approach does not fulfil the energy (enthalpy) balance condition.

Verma (2003) presented the preliminary results on the development of computer program, QrtzGeotherm for estimating temperature and vapour fraction in a geothermal reservoir considering the mass and enthalpy conservation. Four representative types of regression equations for quartz solubility (Figure 1): *(i) a quadratic regression equation of 1/T and pressure P (Verma, 2003), (ii) a linear equation relating log* SiO_2 *to the inverse of absolute temperature, T (Verma, 2002), (iii) a polynomial of T including logarithmic terms (Gunnarsson and Arnórsson, 2000) and (iv) temperature as a polynomial of* SiO_2 *including logarithmic terms (Fournier and Potter, 1982)* are programmed. The algorithm was written using the Newton-Raphson method. The fundamental problem with this algorithm is that the initial guess value of reservoir temperature should be close the real value. Verma (2003) justified the applicability of silica geothermometry only up to 370°C because all the thermodynamic properties of vapour and liquid water have similar values near to the critical point.

In this article the QrtzGeotherm is rewritten as an ActiveX component in Visual Basic 6.0 using the error and trail method for solving the equations. Its application is illustrated in the case of Cerro Prieto geothermal system. Similarly, the reservoir temperature and vapour fraction are calculated using a well simulator, WELLSIM.

2. GEOTHERMOMETER ALGORITHM

The distribution of fluid enthalpy between the liquid and vapour phases in a geothermal reservoir is expressed by

$$H_{res} = y\,H_v + (1-y)\,H_l \tag{1}$$

where H is enthalpy, y is the fraction of vapour by weight in the reservoir and sub-indices res, v and l stand for reservoir, vapour and liquid, respectively. According to the conservation of enthalpy, the reservoir enthalpy (H_{res}) is equal to the total discharge enthalpy (H_R).

Similarly, the equation for the conservation of silica is written as

$$SiO_{2,TD} = (1-y)\;SiO_{2,l} \tag{2}$$

where $SiO_{2,TD}$ is the total discharge concentration of silica and $SiO_{2,l}$ is the silica concentration in liquid phase in the reservoir. From equation 2, the fraction of vapour in the reservoir is

$$y = 1 - {}^{SiO_{2,TD}}\!\big/_{SiO_{2,l}} \tag{3}$$

Let the temperature in the reservoir be T. The value of T (and the corresponding saturated pressure (P) for the quadratic regression equation) is substituted in the regression equations to calculate the silica concentration of the liquid phase in the reservoir. This silica concentration ($SiO_{2,poly}$) is substituted for $SiO_{2,l}$ in equation 3 to calculate y. The value of y together with the values of H_l and H_v at T are used to calculate the reservoir enthalpy (H_{res}) from equation 1. H_{res} must be equal to the measured reservoir enthalpy (H_R), if T is equal to the reservoir temperature. Since we do not know the correct value of reservoir temperature, the values of H_{res}

calculated for each temperature and plotted in an enthalpy versus temperature plot to find the temperature for $H_{res} = H_R$.

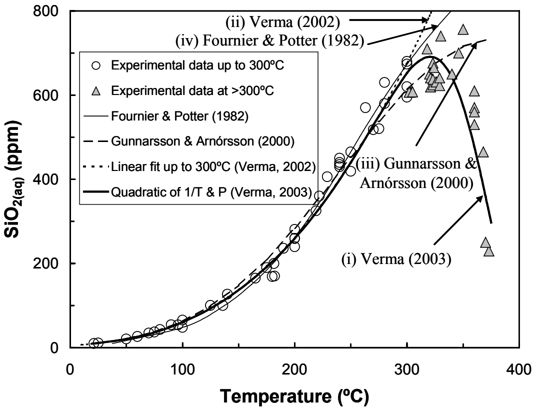

Figure 1: Representative quartz solubility regression equations along the saturation curve.

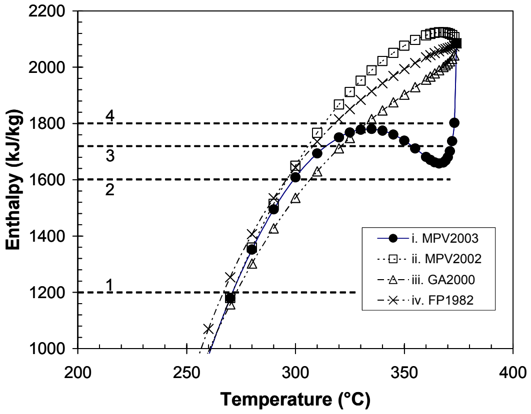

Figure 2: An illustration of four possible situations in the calculation of geothermal reservoir temperature

An alternative approach to solve the equations 1-3 is applying the error and trail method. There may be multiple solutions in the case of quadratic regression equation; therefore the initial guess value of the reservoir temperature is required.

The calculation procedure is further explained in Figure 2. Let the concentration of silica in the total discharge of a geothermal well be 530 ppm. For individual representative quartz solubility regression equation we can calculate the fraction of vapour and enthalpy at each temperature through the equations 1-3. The values of enthalpy and T for each solubility equation are plotted in Figure 2.

Consider four situations for the same total discharge concentration of SiO_2 (530 ppm) in which the total discharge enthalpy is 1200, 1600, 1720 and 1800 kJ/kg, respectively. The reservoir temperature will be at the intersection of enthalpy line and the polynomials in Figure 2. It can be observed that there is only one value of temperature for each enthalpy value for the quartz solubility regression equations in one variable (i.e. eqs. ii-iv). However, the quadratic equation may provide one or two values of temperature for each value of enthalpy in the temperature range for the validation of silica geothermometry.

In the case 1 (i.e. H=1200 kJ/kg) there is only one value even for the quadratic polynomial. In the case 2 (i.e. H=1600 kJ/kg) there is also only one intersection, however the enthalpy line is close to the minimum in the polynomial. It means if we consider all the errors in the measurement of different parameters, the reservoir temperature may be ~370°C. In the case 3 (i.e. H=1720 kJ/kg) there are two possible values of reservoir temperature. We have to use other criteria to decide the right value of the reservoir temperature. In the case 4 (i.e. H=1800 kJ/kg) the enthalpy line is higher than the maximum in the polynomial: If the enthalpy line is near to the maximum, we consider the reservoir temperature as the temperature corresponding to the polynomial maximum.

3. DESCRIPTION OF QRTZGEOTHERM

Using the algorithm presented above, an ActiveX component, QrtzGeotherm for the quartz solubility geothermometer is written in Visual Basic 6.0. The QrtzGeotherm is stored in the library "MyQrtzGeotherm". An ActiveX component preserves its integrity and flexibility in programming in any computer language. The input parameters are assigned through "let property" and the results are obtained through "get properties". The input parameters are total discharge enthalpy H_R, separator pressure (P_{sep}), atmospheric pressure (P_{atm}), silica (SiO_{2atm}) at weirbox and the total discharge silica (SiO_{2TD}) concentration.

If SiO_{2TD} is given, there is no need to provide the values of P_{sep}, P_{atm} and SiO_{2atm}. Actually, it calculates first SiO_{2TD}. For example, if one provides H_R=1362 J/g, P_{sep}=0.8 MPa, P_{atm}=0.1 MPa and SiO_{2atm}=1133 ppm, it calculates first the total discharge silica SiO_{2TD}=674 ppm. Then using the four regression equations it calculates temperature as 305, 301, 313 and 301ºC and vapour fraction as -0.009, 0.010, -0.42, 0.007 in the reservoir, respectively. From the total discharge silica concentration, the reservoir temperature and vapour fraction are calculated using the algorithm presented earlier. Thus the methodology works for liquid or liquid-vapour along the saturation in the geothermal reservoir.

4. A CASE STUDY: CERRO PRIETO

The silica concentration in total discharge, reservoir enthalpy and measured down-hole temperature for the wells of Cerro Prieto geothermal system are taken from Verma and Santoyo (1997). Recently, Verma et al. (2002) found that analytical error increases with increasing the concentration of silica in a water sample. The error in the calculated reservoir temperature is of the order of ±10ºC due to the errors in the coefficients of the regression equation.

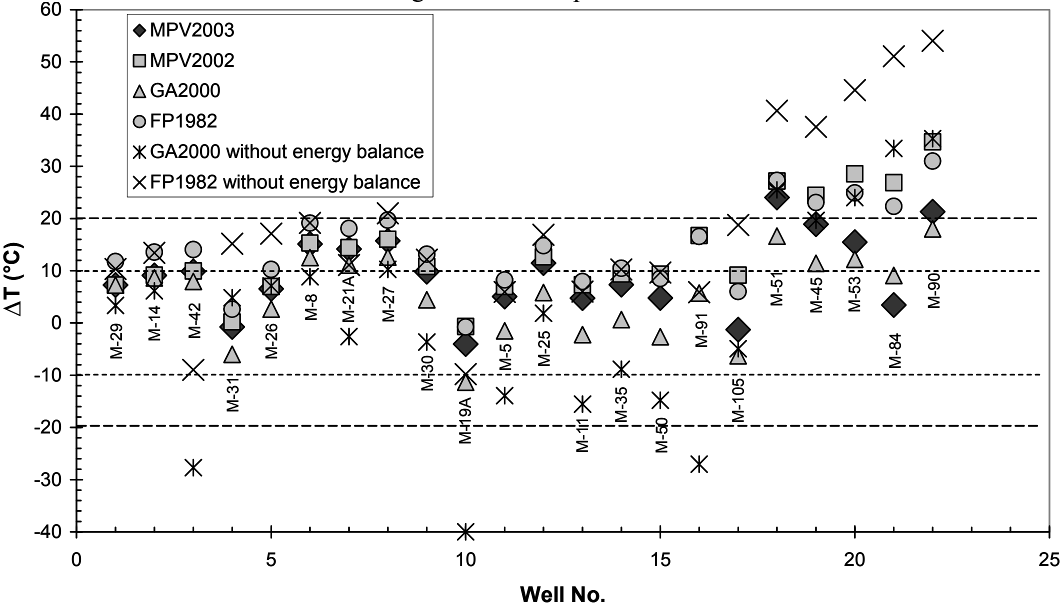

Figure 3: Difference between the measured and calculated reservoir temperature in the geothermal wells at Cerro Prieto. The dispersion of the polynomial equation is within analytical error ±20°C except for wells M-90 and M-51.

Similarly, there are some analytical errors in the measured down-hole temperature, silica concentration and reservoir enthalpy. Therefore, the total error in the calculated temperature is ±20ºC.

Figure 3 shows the difference between the measured and calculated reservoir temperature in the geothermal wells at Cerro Prieto. The wells are order according to the increasing value of measured temperature. It can be observed that there is higher dispersion if we apply the quartz solubility regression equations considering only liquid phase (i.e. without energy balance) in the reservoir as has been performed earlier. The dispersion for the polynomial equation is within analytical error ±20°C except for wells M-90 and M-51.

For well M-90, there is an intersect between the curves, $H=H_R$ and $H=H_{res}$ at 302ºC in the case of the quadratic equation, but the measure temperature is 345ºC. An error of 5% in the measurement of enthalpy and total discharge silica concentration may produce an intersect around 360ºC for the quadratic regression equation, which is closer to the measured temperature (See Verma, 2003). However, there is 52% lost of vapor within the reservoir in the second case which is quit unrealistic.

We analyzed the wells M-50 and M-90 using a well simulation, WELLSIM. The well M-50 has good agreement between the measured and calculated temperatures; therefore, it will serve as a calibration for the temperatures estimated by quartz geothermometer and WELLSIM.

A well simulator reconstructs the down-hole conditions of the thermodynamic properties with considering the conservation of mass, linear momentum and energy and two-phase flow.

Figures 4 and 5 present the variation of the calculated temperature and vapour fraction using the polynomial quartz solubility geothermometer and WELLSIM for well M-50 and M-90, respectively. The temperatures obtained by the quartz geothermometer are slightly higher than those of WELLSIM. The vapour fraction is higher for WELLSIM.

The quartz geothermometer calculates the temperature in the geothermal reservoir, whereas the temperature obtained from WELLSIM is at the bottom of the well. The movement of fluid from the reservoir to the bottom of a well reduces temperature as well as pressure. The pressure reduction produces some extra vapour. Therefore, the calculated temperature and vapour fraction by both the techniques are in good agreement. Thus it shows clearly that the measured down-hole temperature for M-90 reported by Verma and Sontoyo (1997) is inconsistent.

The approach implemented in the computer program, QrtzGeotherm to estimate the reservoir temperature through quartz solubility geothermometer provides a visualization of all the probable temperatures. In the case of Cerro Prieto the measured down-hole temperatures for each well were available; therefore, the results are compared to select the best choice of the two temperature values. This can also be done with other techniques like using other geothermometers and measuring pressure and temperature independently in each well.

Verma (2002) demonstrated that the cation-exchange geothermometers violate the basic laws of chemical thermodynamics. Similarly, there is even incorrect mathematics in dealing the gas geothermometry. For example, the methane breakdown geothermometer is based on the reaction

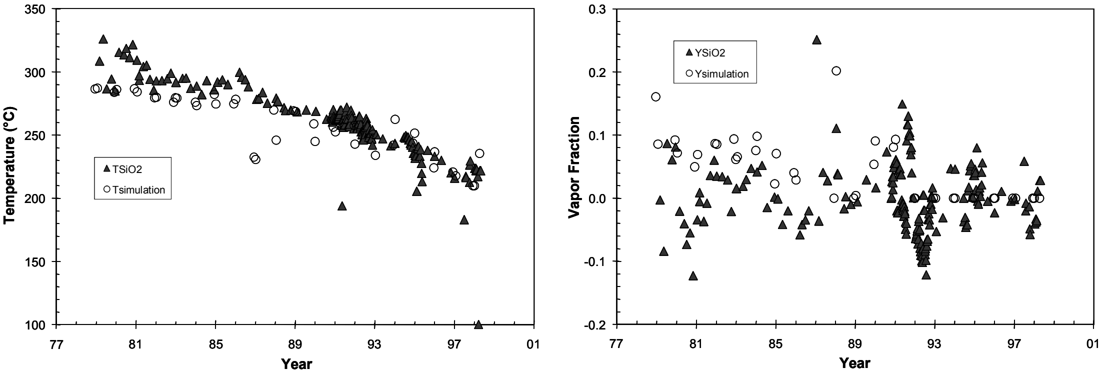

Figure 4: Variation of calculated temperature and vapour fraction in the well M-50 obtained from WELLSIM and polynomial quartz solubility geothermometer

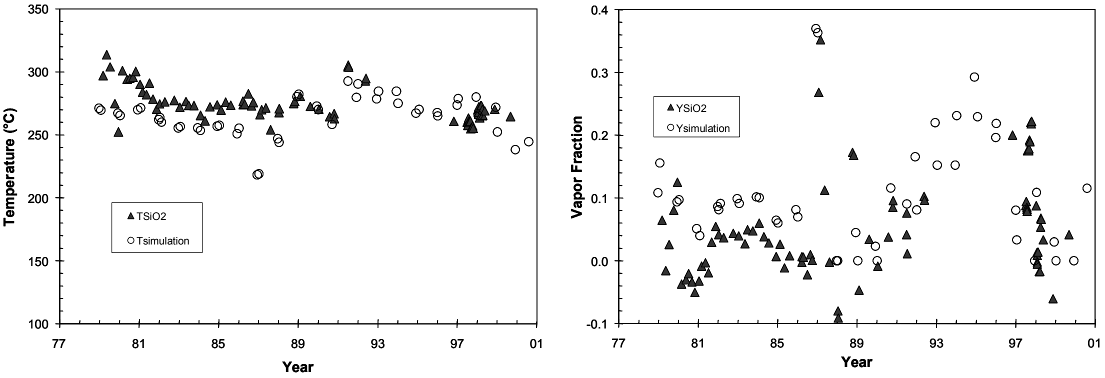

Figure 5: Variation of calculated temperature and vapour fraction in the well M-90 obtained from WELLSIM and polynomial quartz solubility geothermometer

$$CH_2 + 2H_2O = CO_2 + 4H_2$$

To estimate temperature using this reaction we have to know the temperature dependence of its equilibrium constant and the concentration of all the chemical species in vapour or liquid phase. Additionally, the amount of dissolved CO_2 and its species distribution ($CO_{2(g)}$, H_2CO_3, HCO_3^- and CO_3^{2-}) depends on the water alkalinity, buffering capacity, pH, total amount of CO_2, etc. (Verma, 2006). Thus the gas geothermometry is lacking a systematic understanding of its chemical thermodynamics.

5. CONCLUSIONS

It is demonstrated in the case of Cerro Prieto that an estimate of deep reservoir temperature from both the quadratic quartz solubility geothermometer and well simulator, WELLSIM is reliable. We are still working on geothermal systems which have compressed liquid away from the saturation curve in the reservoir like Los Azufres.

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